Fargo, ND | HEI No. 7382_0012
March 30th, 2021

*Renwick Dam in Pembina County, ND – May 2013. Photo Courtesy of Civil Air Patrol*

# TONGUE RIVE WATERSHED PLAN

## Appendix D-2: Existing Conditions Hydrology and Hydraulics Report

# TONGUE RIVER WATERSHED PLAN

## APPENDIX D-2: EXISTING CONDITIONS HYDROLOGY AND HYDRAULICS REPORT

March 30th, 2021

Pembina County Water Resource District

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision, and that I am a Registered Professional Engineer under the laws of the State of North Dakota.

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# 1 INTRODUCTION

The Pembina County Water Resource District (PCWRD) entered into a Cooperative Agreement with the Natural Resource Conservation Service (NRCS) in 2016 to complete a Watershed Plan through the Regional Cooperation Partnership Program (RCPP) for the Tongue River Watershed. Prior to entering into the Cooperative Agreement, locally led planning was already underway by the PCWRD. Data developed from this previous planning that is applicable to the NRCS Watershed Planning effort will be completed through the Cooperative Agreement.

The Tongue River Watershed is a 469 square mile subwatershed of the Pembina River Watershed. The Tongue River Watershed Plan is focused on the Tongue River Watershed above Renwick Dam and below Senator Young Dam. The area associated with the Tongue River Watershed Plan is shown on **Figure 1**. The Tongue River Watershed above Renwick Dam and below Senator Young Dam is approximately 104 square miles. As part of the watershed planning effort, the existing conditions hydrology and hydraulics as it relates to flooding is evaluated. This report provides documentation on the development of hydrologic and hydraulic models used for the Tongue River Watershed Planning effort. This includes previously developed base data and models, and the development of existing conditions models used for the Tongue River Watershed Plan.

# 2 PREVIOUSLY DEVELOPED MODELS AND BASE DATA

Prior to 2011 several hydrology models existed for the tributary rivers of the Red River of the North, however these models were developed independently and resulted in little uniformity between each model. In 2010 the City of Fargo, ND, partnered with the United States Army Corps of Engineers (USACE) to develop a uniform set of tributary hydrology models that could be used to analyze the hydrology of the southern half of the Red River Basin (Phase I). Phase I consisted of developing a set of base input data and model development standards, development of HEC-HMS (v.3.5) models for tributaries upstream of Halstad, MN, and routing HEC-HMS outflows into an existing HEC-RAS unsteady model for the Red River. The study results were presented in the *Fargo-Moorhead Metro Basin-Wide Modeling Approach Hydrologic Modeling* report. (USACE & City of Fargo, 2011).

In 2011, the USACE along with local sponsors began work on Phase II of the Red River HEC-HMS modeling effort, which included development of standardized HEC-HMS (v.3.5) hydrology models between Halstad, MN, and the international border. The Phase II study used base input data and modeling standards developed in the Phase I study. At the completion of the Phase II study, uniform HEC-HMS models existed for the tributary subwatersheds for the United States portion of the Red River Basin (excluding the Devils Lake Basin). The study results were presented in the *Red River of the North Hydrologic Modeling – Phase 2* Report (USACE, 2013). Methods developed in Phase I, and further implemented in Phase II, were aimed at developing a consistent method to analyze hydrology within the Red River Basin while still accounting for unique characteristics within each subwatershed that may influence flooding.

## 2.1 HEC-HMS PHASE II MODEL DEVELOPMENT

Development of the HEC-HMS model for the Pembina River Watershed was completed through the *Red River of the North Hydrologic Modeling – Phase 2* effort (USACE, 2013). The Tongue River Watershed is a subwatershed of the Pembina River Watershed. Section 2.1 provides a brief overview of the development of the Pembina River HEC-HMS model. This model was initially used and subsequently modified as part of the Tongue River RCPP Watershed Planning effort. More information on the summary information provided in this section is available in the *Red River of the North Hydrologic Modeling – Phase 2* Report (USACE, 2013) and the USACE Final Report specific to the Pembina River Watershed (USACE, 2014).

### 2.1.1 LIDAR RECONDITIONING

LiDAR topographic data made available through the International Water Institute (IWI) (IWI, 2008-2009) was used throughout the study. The bare earth LiDAR data does not account for any subsurface drainage (i.e. culverts). The bare earth LiDAR was reconditioned in order to hydrologically represent how flows move across the landscape. The reconditioning includes a technique within GIS to burn in culverts to the LiDAR, which artificially lowers LiDAR elevation at roadways allowing water to flow through. The hydrologically reconditioned LiDAR is then used to create derivative GIS datasets (slope, flow direction, flow accumulation, etc.).

### 2.1.2 DRAINAGE AREA DELINEATION

Hydrologically reconditioned LiDAR topographic data was used to delineate subbasin boundaries. During initial model development, subbasins were defined at an approximate HUC 12 size. Additional subbasin splits were added during model development based on existing project locations, locally critical areas as determined by County Water Resource Boards, critical hydrologic flood routing locations (flow splits, break-outs, etc.) and other sensitive areas (towns, known flood issues, etc.). Non-contributing drainage areas were identified through a “fill-and-spill” methodology using LiDAR data to evaluate potential for hydrologically closed basins to contain the 100-year 10-day runoff volume as defined by *TR-60: Earth Dams and Reservoirs* (NRCS, 2005).

### 2.1.3 TIME OF CONCENTRATION

Travel time grids were created for each tributary subwatershed using a Travel Time Routine developed by the Minnesota Department of Natural Resources (MnDNR). The routine is implemented within a GIS environment using LiDAR topographic data, National Land Cover Data (NLCD) (Homer, et al., 2015), and derivative GIS datasets from hydrologic reconditioning. The routine assigns a Manning’s N-value based on the accumulated flow and land use. Slope is then used to estimate velocity and, subsequently, travel time using Manning’s equation. Longest travel time per subbasin can then be derived in a consistent method across the modeling extents. The longest travel time derived from the MnDNR Travel Time Routine served as an initial time of concentration (Tc) estimate for each subbasin, with further refinements through calibration to historic flood events.

### 2.1.4 CLARK’S UNIT HYDROGRAPH PARAMETERS

A regional regression analysis was conducted during the Phase II model development to develop a consistent method for the initial estimate of the Clark’s Storage Coefficient (R). The analysis considered parameters for the watersheds above gaging locations such as stream length, drainage area, percent slope, NWI wetlands and lakes, and watershed slope. This analysis resulted in a relationship between the time of concentration and the Clark’s Storage Coefficient that was spatially dependent. The relationship was applied in GIS to allow the relationship to be applied to each subbasin used in the HEC-HMS model. Similar to the time of concentration, Clark’s Storage Coefficients derived with this analysis served as an initial estimate for each subbasin with further refinements through calibration to historic flood events.

### 2.1.5 RUNOFF CURVE NUMBER DEVELOPMENT

The NLCD (Homer, et al., 2015) data and Hydrologic Soil classifications from the Soil Survey Geographic Database (SSURGO) (NRCS, 2001) were combined to develop Red River Basin-wide 24-hour AMC II Curve Number (CN) data. Guidance from *TR-55 Urban Hydrology for Small Watersheds* (NRCS, 1986) and Minnesota Hydrology Guide (USDA, SCS, 1976) was used to develop a conversion table to determine an appropriate 24-hour CN for a given hydrologic soil group and an NLCD land use combination. *TR-55* lists the 24-hour CN values for a range of agricultural land cover types, such as row crops and small grains. NLCD land cover data does not differentiate cropland based on row crops or small grains, instead all cultivated cropland is grouped into one category. A Technical Advisory Committee (TAC) was established during Phase I of the hydrologic model development. Through development of the Red River Basin-wide CN data, the TAC vetted synthetic CN values for the Red River Basin. The TAC determined that cultivated cropland should consist of 80% row crop and 20% small grains in good condition. Due to the relatively flat slopes predominant in the majority of the Red River Basin, a treatment type of contoured and terraced was assumed for selection of CN values from *TR-55* (NRCS, 1986). The CN conversion table used for the Red River Basin is shown in **Appendix A**. This information was applied in GIS to create a Red River Basin 24-hour AMC II CN gridded dataset.

### 2.1.6 REACH ROUTING

Model reaches were derived using reconditioned LiDAR data. The HEC-HMS models used two types of reach routing based on the location within the watershed.

- Muskingum Cunge routing was used along the beach ridge and upper portions of the watershed where attenuation is not as critical. Cross sections and slopes were estimated from LiDAR data.
- Modified Puls routing was used in the Lake Agassiz lake plain using the best available HEC-RAS models. If no HEC-RAS model was available, simplified HEC-RAS models were developed using LiDAR data to estimate an anticipated floodplain storage vs flow relationship.

### 2.1.7 CALIBRATION

A combination of Next-Generation Radar (NEXRAD) (NOAA, 1995) and existing rainfall gage data was used to compile a set of rainfall driven runoff events for calibration. Since NEXRAD isn't available prior to 1995, historical rainfall events were limited to events after 1995. Each of the Red River tributary subwatersheds were calibrated to at least two historic rainfall events. The Pembina River Watershed was calibrated to three historic rainfall events. These events occurred in June of 2002, June/July of 2005, and May of 2013. The calibration was completed by primarily adjusting the following parameters; initial abstraction, Curve Number, Clark's Storage Coefficient, time of concentration, and baseflow. The subwatershed conditions prior to the calibration events were reviewed to determine the approximate antecedent moisture condition (AMC). The goal of model calibration was to meet the following criteria:

- Simulated total runoff volume within 10% of the observed volume.
- Simulated peak flow within 10% of the observed peak flow.
- Simulated time to peak flow within ½ day of observed time to peak flow.

### 2.1.8 SYNTHETIC MODEL DEVELOPMENT

Synthetic modeling parameters for the calibrated Clark's Storage Coefficients and time of concentration were averaged from the calibrated events. During calibration, Curve Number parameters were adjusted to reflect the moisture conditions within the Tongue River Watershed preceding the historic rainfall events. For the synthetic events, Curve Number parameters were set to the original values determined based on soil types and land use to reflect average (AMC II) conditions within the watershed. Several synthetic modeling scenarios were developed, including 2-year through 100-year events for both the 24-hour (Hershfield, 1961) and 10-day (Miller, 1964) duration rainfall events, and a 100-year, 10-day runoff event (NRCS, 2005). For more specific information on calibration for the Pembina River Watershed, refer to the USACE Final Report for the Pembina River Watershed (USACE, 2014).

# 3 TONGUE RIVER WATERSHED PLAN EXISTING CONDITIONS

The Tongue River Watershed Plan is focused on the Tongue River Watershed below Senator Young Dam and above Renwick Dam. Due to the planning area location, the modeling extent for the watershed plan is the Tongue River Watershed above Renwick Dam as shown on **Figure 3**. The Tongue River Watershed above Renwick Dam is an approximate 152 square mile subwatershed of the 469 square mile Tongue River Watershed, which is a subwatershed of the Pembina River Watershed. The Pembina River Watershed HEC-HMS model previously developed as part of the Phase II study (USACE, 2013), discussed in Section 2 of this report, was used as a base model and modified to meet requirements for the Tongue River Watershed Planning effort.

This section provides additional information on modifications that were made to the HEC-HMS hydrologic model, development of a HEC-RAS unsteady hydraulic model, calibration of the hydrologic and hydraulic models, and development of synthetic rainfall event simulations.

## 3.1 HYDROLOGIC (HEC-HMS) MODEL

The Tongue River Watershed was separated from the Pembina River Watershed HEC-HMS base model into an independent HEC-HMS model. Modifications were made to the Tongue River HEC-HMS model to add detail within the Tongue River Watershed. Most of the modifications were made to the Tongue River Watershed above Renwick Dam. The hydrologic model was completed as necessary to generate inflow hydrographs for the HEC-RAS hydraulic model that was developed for the Tongue River Watershed upstream of Renwick Dam. These hydrologic model modifications are discussed in the following subsections.

### 3.1.1 SUBBASIN BOUNDARY MODIFICATIONS

The HEC-HMS model used in the Tongue River Watershed Planning effort is primarily used to generate inflow hydrographs for the HEC-RAS unsteady state flow model that is discussed in Section 3.2. Subbasins were split and re-delineated to add detail in areas such as hydraulic routing storage locations, road crossings, and other critical hydraulic locations. A comparison of the initially developed subbasins and the re-delineated subbasins for the Tongue River Watershed Plan is shown on **Figure 3.1.1**. These modifications resulted in 77 subbasins above Renwick Dam compared to 18 subbasins from the Phase II study. The re-delineated subbasins were reduced in size from an average of 8.4 square miles from the Phase II study to an average of 2 square miles for the Tongue River Watershed Plan.

### 3.1.2 RUNOFF CURVE NUMBER

Initial runoff Curve Numbers for the re-delineated subbasins were estimated by overlaying the Curve Number gridded GIS datasets described in Section 2.1.5 with the modified subbasins. 24-hour AMC II

Curve Number values for the modified subbasin are displayed in **Figure 3.1.2**. The values range from 57 to 82 throughout the watershed.

### 3.1.3 INITIAL UNIT HYDROGRAPH PARAMETERS

Initial unit hydrograph parameters were estimated for the time of concentration (Tc) and Clark's Storage Coefficient (R) using the same methodology used for the Phase II study discussed in Sections 2.1.3 and 2.1.4 of this report, respectively. R/Tc ratios provide a method to normalize unit hydrograph parameters that has been used previously within the Red River Basin. Generally, the more available subbasin flood storage (for example, lakes and wetlands) for runoff originating in a subbasin, the higher the R/Tc ratio. As illustrated in **Figure 3.1.3**, R/Tc values generally increase in the western portion of the Tongue River Watershed, where more depressional areas in the landscape provide flood storage. Further downstream, where most landscape is flat and drained for agricultural production, the R/Tc ratio reduces.

### 3.1.4 REACH ROUTING MODIFICATIONS

With additional subbasin delineations in the Tongue River Watershed, additional reaches were required in the model. For the Tongue River Watershed Plan, routing of the Tongue River mainstem from 127$^{th}$ Ave NE to the outflow from Renwick Dam is modeled using HEC-RAS (see Section 3.2). Modified Puls routing was used for the Tongue River mainstem from Senator Young Dam to North Dakota State Highway 89 which is downstream of where the HEC-RAS model begins. Muskingum Cunge routing was used in the upper portions of the watershed, and for all tributary streams contributing to the Tongue River. The existing conditions HEC-HMS model schematic and reach routing methods are shown on **Figure 3.1.4**. While reach routing is critical for portions of the HEC-HMS model upstream of the HEC-RAS hydraulic model extent, it should be noted that reach routing generally does not affect inflows into the HEC-RAS model where the models overlap. This is because HEC-HMS subbasin outflows (not combined or routed outflows) are directly applied to the HEC-RAS model in areas where the two models overlap.

### 3.1.5 EXISTING DAMS

There are 10 existing dams in the Tongue River Watershed as shown on **Figure 3.1.5**. All existing dams are within the planning area between Senator Young Dam and Renwick Dam. The purpose of the dams is typically flood control with secondary purposes of water supply, fish and wildlife, and recreation. Characteristics for the existing dams are shown in **Table 1**. The dam characteristics within the HEC-HMS model were developed based on as-built survey data and LiDAR.

**Table 1:** Existing Dams in the Tongue River Watershed

| Existing Dam | Purpose(s) | Hazard Classification | Year Constructed | Contributing Area (square miles) | Storage at Auxiliary Spillway[1] (acre-feet) |
|---|---|---|---|---|---|
| Senator Young | Flood Control / Water Supply | High | 1961 | 48.1 | 4,459 |
| Olson | Flood Control | High | 1957 | 6.3 | 586 |
| Olga | Flood Control | Low | 1955 | 2.1 | 510 |
| Bourbanis | Flood Control / Fish and Wildlife | High | 1957 | 8.6 | 978 |
| Hanks Corner | Flood Control | Significant | 1955 | 1.1 | 154 |
| Herzog | Flood Control | Significant | 1957 | 17.5 | 971 |
| Goschke | Flood Control | Significant | 1958 | 10.0 | 1,048 |
| Weiler | Flood Control | Significant | 1957 | 11.6 | 1,652 |
| Morrison | Flood Control | Low | 1956 | 7.7 | 545 |
| Renwick | Flood Control / Recreation | High | 1962 / 2014[2] | 152.5 | 4,072 |

[1]Storage volumes reported are effective flood storage above the Normal Pool Elevation

[2]A rehabilitation project on Renwick Dam was completed in 2014 (NRCS, 2012)

## 3.2 HYDRAULIC (HEC-RAS) MODEL

An unsteady HEC-RAS (v.5.0.7) model was developed and used to generate water surface profiles by hydraulically routing runoff hydrographs generated by the HEC-HMS model. Development of the HEC-RAS unsteady state hydraulic model began in 2016. The HEC-RAS model consists of channel cross sections, 1-dimensional storage areas, and 2-dimensional storage areas. The channel cross sections route flows in the Tongue River and span from 127$^{th}$ Ave NE in Beaulieu Township, Pembina County, to the inlet of the Renwick Dam reservoir. Channel cross sections are included downstream of Renwick Dam to obtain an appropriate tailwater condition for the model, and to extend the model through the USGS Streamgage 05101000 at Akra, ND. A 1-dimensional storage area was used to represent the elevation-storage relationship in the Renwick Dam reservoir. 2-dimensional storage areas are located adjacent to the Tongue River mainstem to route overland or breakout flows. Additionally, 1-dimensional storage area elements were added upstream of 2-dimensional storage areas to apply runoff hydrographs from the HEC-HMS model. Channel cross sections, 1-dimensional storage areas, and 2-dimensional storage areas in the HEC-RAS model schematic are shown on **Figure 3.2**.

### 3.2.1 STORAGE ROUTING

Storage routing is used to account for floodplain storage adjacent to the Tongue River mainstem. Due to the complex routing in overland flooding, 2-dimensional storage areas are used for the Tongue River Watershed. 2-dimensional storage areas allow the model to account for floodplain storage available for out of bank flows and are used to convey flows through the floodplain. Storage areas are connected to cross sections and other storage areas to hydraulically route flows through the floodplain.

Storage areas were initially delineated based on subbasin boundaries used in the HEC-HMS model. Storage area boundaries were adjusted so that connections would be located on section lines and natural drainage divides within the modeling extent. Internal storage connections were added for township roads that contain culverts or bridges to simulate flow through roads that were not on storage area boundaries.

Small 1-dimensional storage areas were added within the 2-dimensional storage areas in order to add inflows from HEC-HMS to the 2-dimensional storage areas. Larger 1-dimensional storage areas upstream of 2-dimensional areas were also used as inflow locations. A 1-dimensional storage area was used to represent the elevation-storage relationship in the reservoir at Renwick Dam.

### 3.2.2 CHANNEL BATHYMETRY AND HYDRAULIC STRUCTURES

Survey data spanning from 129$^{th}$ Avenue NE in Beaulieu Township, Pembina County, to the inlet of the Renwick Dam reservoir was collected by Houston Engineering, Inc. (HEI) in the spring of 2017. Field survey that was collected for this portion of the river consisted of river channel hydraulic structures, river channel cross sections near hydraulic structures, river channel cross sections approximately every 1,500 feet, and other culverts and bridges in the floodplain that convey breakout flows during large events. Survey data collected from 129$^{th}$ Avenue NE to the reservoir at Renwick Dam is shown on **Figure 3.2.2**.

Additional survey data spanning from 127$^{th}$ Avenue NE to 129$^{th}$ Avenue NE in Beaulieu Township, Pembina County, was collected by NRCS staff starting in 2015 and continuing through 2019. The survey collected by NRCS staff was incorporated into HEC-RAS cross sections. The HEC-RAS cross sections supplied by NRCS staff were then included in the overall HEC-RAS model being described here.

### 3.2.3 MANNING'S N-VALUES

Manning's N-values are set within the HEC-RAS cross sections to account for channel roughness. NLCD land use GIS grids were used to generate a Manning's N-value grid. Nearly all NLCD land cover categories were aggregated into four land use types; channels, agricultural or cropland, wetlands, and forested. Due to the cell size of the NLCD GIS grids (30 meters x 30 meters), portions of the river channels can be omitted from the NLCD grids. The NLCD grid was modified by generating a channel boundary and merging the channel with the NLCD grid. The NLCD grid was also used for flow routing computations in 2-dimensional areas. Manning's N-values were set through calibration and verification of the Tongue River Watershed Plan HEC-RAS and HEC-HMS models as described in Section 3.3. Manning's N-values in the existing conditions hydraulic model are shown in **Table 2**.

**Table 2:** Manning's N-Values by Land Use

| Land Use | Manning's N-Value |
|---|---|
| Channel | 0.035 |
| Agricultural / Cropland | 0.06 |
| Wetlands | 0.05 |
| Forested | 0.11 |

### 3.2.4 INFLOWS

Hydrographs generated from the HEC-HMS model were applied to the HEC-RAS model. HEC-HMS junction hydrographs were applied at the upstream extents to cross sections within the HEC-RAS model. Further downstream, HEC-HMS subbasin hydrographs were applied to the cross sections and 1-dimensional storage areas within the HEC-RAS model.

### 3.2.5 TAILWATER

The tailwater boundary condition for the Tongue River was estimated by entering a friction slope downstream of Renwick Dam. The slope was estimated from LiDAR data in the Tongue River channel. The outflow from Renwick Dam is simulated with a stage-discharge rating curve.

## 3.3 CALIBRATION AND VERIFICATION

Two historic rainfall events were used for calibration and verification of the HEC-RAS model for the Tongue River Watershed Plan. A rainfall event in mid-June of 2002 was used to estimate model parameters in the Tongue River hydrologic and hydraulic models. An event in May of 2013 was used to verify the parameters used in the models.

### 3.3.1 JUNE 2002 CALIBRATION EVENT

The hydrologic and hydraulic models were calibrated based on a rainfall event that occurred in the summer of 2002. Rainfall depths in the Tongue River Watershed upstream of Renwick Dam during the event ranged from 2.5 to 5.0 inches. The average total rainfall depth upstream of Renwick Dam was approximately 3.6 inches. The rainfall depths used for the simulation spanned from June 9$^{th}$ to the early hours of June 11$^{th}$. Total rainfall depths during the event are shown on **Figure 3.3.1a**.

Documented historic data that was used for calibration of the model included: observed rainfall depths, NEXRAD rainfall data, and discharge measurements at the Tongue River USGS Streamgage 05101000 at Akra, ND. The observed discharge hydrograph was used to derive daily flow volumes at the stream gage.

Runoff Curve Numbers for a 24-hour storm duration were initially applied for the calibration event (see **Appendix A**). Due to the lack of rainfall before the June 2002 event, a dry antecedent moisture condition was adopted, and runoff Curve Numbers were adjusted. The final Curve Numbers used in the simulation were between an AMC I and AMC II condition. This antecedent moisture condition was reviewed based on guidance from the *National Engineering Handbook (NEH)* (NRCS, 2004), and is valid based on minimal rainfall occurring in the days prior to the event.

Pool elevations in the dams upstream of Renwick Dam were set to the normal pool elevation because of the lack of precipitation leading up to the event. Measured discharge at the USGS Streamgage at Akra, ND, downstream of Renwick Dam prior to the rainfall was below 6 cubic feet per second. Based on the as-built rating curve for Renwick Dam, this is indicative of a pool elevation at, or near the normal pool elevation. Therefore, an assumption was made that the dams contributing to Renwick were also at normal pool elevation. The rating curve from the as-built plans was used to route flows through Renwick Dam.

Initial unit hydrograph parameters that were estimated in previous modeling efforts (Section 2) were further adjusted with the June 2002 rainfall event. Reasonable modifications were made to both R and Tc during calibration, and the final R/Tc ratios from calibration are shown on **Figure 3.3.1b**.

Hydrographs in the hydraulic model were compared to the recorded discharge at the Tongue River USGS Streamgage at Akra, ND. The observed discharge hydrograph and the simulated HEC-RAS model discharge hydrograph are shown on **Figure 3.3.1c**. The simulated HEC-RAS peak flow rate and volume are consistent with observed flow rates and volumes at the gage during the event. **Table 3** summarizes the peak flow rates and timing, as well as the 1-day through 5-day volumes centered on the peak flow rate (i.e. the 1 through 5-day volumes were computed by finding the area under the hydrograph centered on the peak ±0.5 days, ±1.0 days, etc.).

**Table 3:** Peak Flow and Volume Comparison at USGS Gage 05101000 at Akra, ND in June 2002

| Source | Peak Flow (cfs) | Peak Flow Time | Volume (Ac-Ft) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1-Day | 2-Day | 3-Day | 4-Day | 5-Day |
| USGS Gage 05090000 at Akra, ND | 554 | 6/11/02 23:30 | 1,085 | 2,113 | 2,936 | 3,477 | 3,972 |
| HEC RAS Model | 551 | 6/12/02 5:00 | 1,084 | 2,099 | 2,907 | 3,514 | 4,035 |
| %Difference | -0.57% | - | -0.09% | -0.68% | -1.00% | 1.08% | 1.59% |

Parameters in the HEC-RAS model were also established during calibration. These parameters include Manning's N-values, overbank reach lengths, and storage area connection coefficients. Initial values were set based on guidance from the HEC-RAS User's Manual (USACE, 2016) and HEC-RAS Technical Reference Manual (USACE, 2016). Manning's N-values were set based on the values presented in **Table 2**. A sensitivity analysis on Manning's N-values is discussed in **Appendix C**. Overbank reach lengths were digitized utilizing GIS and the resultant HEC-RAS model floodplain. Storage area connection coefficients were generally set based on Table 3-1 from the HEC-RAS 2D Modeling User Manual (USACE, 2016).

### 3.3.2 MAY 2013 VERIFICATION EVENT

After the hydrologic and hydraulic models were calibrated, a second historic event was simulated to verify the parameters in the calibration event. The May of 2013 rainfall event spanned from the beginning of May 19th through the end of May 20th. Rainfall depths in the Tongue River Watershed upstream of Renwick Dam during the event ranged from 2.9 to 7.3 inches. The average total rainfall depth for the planning area was approximately 5.1 inches. Total rainfall depths from May 19th to May 21st are shown on **Figure 3.3.2a**.

Documented historic data that was used for verification of the model included: observed rainfall depths, NEXRAD rainfall data, discharge measurements at the Tongue River USGS Streamgage 05101000 at Akra, ND, water surface elevation measurements in the reservoir upstream of Renwick Dam during the event, and aerial photography taken by the Civil Air Patrol on May 22, 2013. These independent sources of historic data provide verification benchmarks for the Tongue River Watershed upstream of Renwick Dam.

Renwick Dam was constructed in 1962. A rehabilitation project on the auxiliary spillway of the dam had begun in May of 2013. During the May rainfall event, the reservoir upstream of Renwick Dam began rising rapidly. Due to the on-going rehabilitation project in May of 2013 and the rising elevations in the reservoir, there was a fear that flow over the existing auxiliary spillway may result in failure of the dam. In order to avoid activation of the auxiliary spillway, a berm was constructed across the spillway. These emergency measures altered the outlet rating curve for Renwick Dam.

A new outlet rating curve was developed for the May 2013 rainfall event based on the reservoir elevation measurements and measured discharge at the gage immediately downstream of Renwick Dam. The new rating curve is shown in **Figure 3.3.2b**. The observed elevation and discharge during the event are shown as black points on the figure. The principal spillway consists of a two-stage riser. The first stage includes two 8' x 3' orifices (blue line). The second stage is a 14' 2" x 6' concrete riser structure (orange line). The outlet pipe of the riser structure is a 6' x 6' concrete box culvert (grey line). When combining the outlet works for the principal spillway of Renwick Dam, the yellow line in **Figure 3.3.2b** is produced, which matches closely with the observed data for the calibration event. For reference, the green line in **Figure 3.3.2b** shows the as-built rating curve for Renwick Dam including auxiliary spillway discharge.

The upstream dams' pool elevations were set above the normal pool elevations for the simulation due to the above average snowmelt runoff that occurred in the weeks preceding the rainfall. While the majority of the upstream dams aren't in the HEC-RAS model, they are included in the HEC-HMS model. Images of various upstream dams were captured by Civil Air Patrol and activation of the auxiliary spillway was observed. The aerial photos are shown in **Figure 3.3.2h** through **Figure 3.3.2o**. **Figure 3.3.2c** shows the modeled peak water surface elevation in the dams compared to spillway activation during the event based on aerial photos. The water surface elevation is shown relative to the auxiliary spillway crest elevation. The blue bars in **Figure 3.3.2c** represent the dams that had auxiliary spillway flow during the event, and the orange bars represent dams that did *not* have auxiliary spillway flow.

Another element involved in the verification of the models using the May 2013 event was the operation of Senator Young Dam. Local authorities indicated that the principal spillway outlet gate for Senator Young Dam was closed during the event in order to save Renwick Dam. Exact timing of the closing and subsequent opening of the outlet gate was not known. Local authorities indicated that the gate was closed when the reservoir at Renwick Dam started rising rapidly and was opened once the reservoir at Renwick started to recede. To simulate the operation of Senator Young Dam in the HEC-HMS model, no flow was released from the dam beginning on May 19$^{th}$. The reservoir upstream of Senator Young Dam raised to a level that approached the auxiliary spillway elevation. In the model simulation, the dam was opened on May 21$^{st}$ at noon, at which point the as-built rating curve for Senator Young Dam was utilized.

Runoff Curve Numbers were adjusted to produce the quantity of runoff volume recorded at the USGS gaging station at Akra, ND. 24-hour Curve Numbers were used with a wet antecedent moisture condition (between AMC II and AMC III). This antecedent moisture condition was reviewed based on guidance from the *National Engineering Handbook (NEH)* (NRCS, 2004), and is valid because of the large snowmelt that occurred prior to the event.

The observed discharge hydrograph and the simulated HEC-RAS model discharge hydrograph at the USGS Gage near Akra, ND are shown in **Figure 3.3.2d**. The peak flow rate from the measured data at the stream gage and the HEC-RAS modeled results differ by less than 1%. In addition to a peak flow comparison, volume of runoff through Renwick Dam was compared for several durations centered on the peak discharge. **Table 4** summarizes the peak flow rates and timing, as well as the 1 through 5-day volumes centered on the peak flow rate.

**Table 4:** Peak Flow and Volume Comparison at USGS Gage 05101000 at Akra, ND in May 2013

| Source | Peak Flow (cfs) | Peak Flow Time | Volume (Ac-Ft) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1-Day | 2-Day | 3-Day | 4-Day | 5-Day |
| USGS Gage 05090000 at Akra, ND | 1,546 | 5/22/13 9:00 | 3,060 | 6,086 | 9,004 | 11,078 | 12,798 |
| HEC RAS Model | 1,550 | 5/22/13 11:30 | 3,032 | 5,993 | 8,818 | 10,979 | 12,692 |
| %Difference | -0.25% | - | 0.93% | 1.56% | 2.11% | 0.90% | 0.84% |

Inundation mapping was used to compare the HEC-RAS model floodplain against the aerial photography captured by the Civil Air Patrol on May 22, 2013 around 6:00 PM local time. The Civil Air Patrol captured photos of several dams in the Tongue River Watershed shortly after the event. Modeled inundation and areal imagery of Renwick Dam are shown in **Figure 3.3.2e** and **Figure 3.3.2f**, respectively. Modeled inundation and areal imagery of Morrison Dam are shown in **Figure 3.3.2g** and **Figure 3.3.2h**, respectively. In addition to these two dams, several other upstream dams were photographed, but are not in the HEC-RAS model. **Figure 3.3.2i** through **Figure 3.3.2o** show areal imagery of Weiler, Goschke, Herzog, Bourbanis, Olga, Olson, and Senator Young Dam. While inundation extents cannot be compared in these locations, the activation of auxiliary spillways of each of the dams can be compared to what was modeled using HEC-HMS (i.e. compared to **Figure 3.3.2c**).

## 3.4 SYNTHETIC MODEL DEVELOPMENT

The HEC-HMS hydrologic model used to analyze synthetic rainfall events utilized the R and Tc parameters developed through calibration described in Section 3.3. Runoff Curve Numbers were set to initial values described in Section 3.1.2. The calibrated HEC-RAS hydraulic model used to analyze synthetic rainfall events is described in Section 3.2.

Synthetic rainfall events for 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals were developed based on NOAA Atlas 14 rainfall depths with a 4-day duration. A 500-year rainfall event was not simulated for this analysis due to the lack of critical structures within the planning extents (critical structures consist of schools, hospitals, nursing homes, etc.). Rainfall depths were calculated for each subbasin using GIS gridded data. The gridded rainfall depths were then reduced based on areal reduction factors and guidance from *TP-49 Two- to Ten-Day Precipitation for Return Periods of 2 to 100 Years in the Contiguous United States* (Miller, 1964). The 4-day duration average rainfall depths for the synthetic events are shown in **Table 5**.

The 4-day duration storm was used for this analysis because it produces the greatest peak outflow from Renwick Dam compared to the 24-hour and 10-day duration storms. Additionally, the inundation associated with the 4-day rainfall events causes prolonged flooding of agricultural lands adjacent to the Tongue River. While there are some locations along the Tongue River upstream of Renwick Dam that have higher peak flows for the 24-hour duration rainfall events, the increase in the duration associated with the 4-day rainfall events causes an increase in damages to agricultural lands. A sensitivity analysis was completed on the 24-hour, 4-day, and 10-day duration events and is discussed in **Appendix C**.

**Table 5:** 4-Day Rainfall Depths

| Return Period | NOAA Atlas 14 4-Day Rainfall Depth (inches) | HEC-HMS 4-Day Rainfall Depth* (inches) |
|---|---|---|
| 2-year | 2.84 | 2.70 |
| 5-year | 3.53 | 3.35 |
| 10-year | 4.13 | 3.93 |
| 25-year | 5.02 | 4.77 |
| 50-year | 5.75 | 5.46 |
| 100-year | 6.52 | 6.19 |

* Average rainfall depth adjusted for areal reduction based on watershed size of 152 square miles

The rainfall distribution used for the synthetic events was developed using a “nesting” technique described in the *NEH, Part 630, Chapter 4* (NRCS, 2015). Individual distributions were developed for the 2-, 5-, 10-, 25-, 50-, and 100-year events. “Nesting” the distribution means that all shorter duration storms are contained, or “nested”, within longer duration storms. That is, the 4-day storm contains the 5-minute storm, 10-minute storm, and so on.

Runoff Curve Numbers were adjusted to the appropriate 4-day duration to match the corresponding synthetic rainfall duration. Table 2.3b in *TR-60 Earth Dams and Reservoirs* (NRCS, 2005) provides a relationship between 24-hour and 10-day Curve Numbers. Interpolation of this data was used to generate 4-day Curve Numbers for the synthetic HEC-HMS hydrologic model.

# 4 TONGUE RIVER WATERSHED PLAN MODELING RESULTS

## 4.1 SYNTHETIC MODEL RESULTS

Multiple reporting locations were selected to evaluate modeling results throughout the watershed at geographically significant locations. These locations include North Dakota State Highways, township roads, and at the outlet of Renwick Dam. The reporting locations are shown on **Figure B.1** in **Appendix B** and are further summarized below.

- Tongue River at ND Highway 32 – First stream crossing near the upstream extent of the hydraulic model
- Tongue River at ND Highway 5 – Downstream of a known breakout location
- Tongue River at 133rd Avenue NE – Downstream of the confluence with Busse/Smith Coulee
- Renwick Dam Outflow – Combined outflow from Renwick Dam including principal spillway and auxiliary spillway

- Busse/Smith Coulee at 132nd Avenue NE – Busse/Smith Coulee is a tributary to the Tongue River. The confluence with the Tongue River is approximately one-half mile downstream of 132nd Avenue NE.

Hydrographs for the 2-year through 100-year events at the reporting locations are shown in **Appendix B** on **Figure B.2** through **Figure B.6**. The peak discharges for the analyzed events are shown in **Table 6**.

**Table 6:** 4-Day Rainfall Peak Discharges (cfs)

| Return Period | Tongue River at ND Highway 32 | Tongue River at ND Highway 5 | Tongue River at 133rd Ave NE | Renwick Dam Outflow | Busse/Smith Coulee at 132nd Ave NE |
|---|---|---|---|---|---|
| 2-year | 415 | 397 | 483 | 308 | 84 |
| 5-year | 603 | 612 | 700 | 425 | 231 |
| 10-year | 845 | 816 | 993 | 520 | 462 |
| 25-year | 1,225 | 1,031 | 1,454 | 753 | 846 |
| 50-year | 1,494 | 1,130 | 1,786 | 1,169 | 1,150 |
| 100-year | 1,812 | 1,153 | 2,302 | 2,119 | 1,442 |

The inundation extents for the 2-year through 100-year events are shown in **Appendix B** on **Figure B.7** through **Figure B.12**. Flood damages, especially damages to agricultural lands, are caused both by the extent of the inundation and, almost equally as important, the duration of inundation. The total inundated acres and cropland inundated acres for the analyzed events based on duration is shown in **Table 7**. Cropland acres were estimated using the National Agricultural Statistics Service (NASS) (USDA, 2017).

**Table 7:** 4-Day Rainfall Inundation (acres)

| Duration (hours) | 2-year Event | | 5-year Event | | 10-year Event | | 25-year Event | | 50-year Event | | 100-year Event | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total Inundated | Cropland Inundated | Total Inundated | Cropland Inundated | Total Inundated | Cropland Inundated | Total Inundated | Cropland Inundated | Total Inundated | Cropland Inundated | Total Inundated | Cropland Inundated |
| 0-24 | 61 | 19 | 235 | 95 | 399 | 197 | 700 | 390 | 799 | 475 | 834 | 491 |
| 24-48 | 59 | 19 | 103 | 43 | 154 | 68 | 227 | 116 | 494 | 276 | 555 | 344 |
| 48-72 | 61 | 16 | 84 | 36 | 102 | 45 | 138 | 61 | 232 | 102 | 601 | 299 |
| 72-96 | 79 | 13 | 43 | 17 | 33 | 15 | 35 | 17 | 42 | 18 | 69 | 29 |
| 96-120 | 46 | 5 | 37 | 9 | 33 | 14 | 27 | 12 | 30 | 13 | 34 | 14 |
| >120 | 414 | 40 | 583 | 62 | 673 | 88 | 747 | 116 | 778 | 129 | 794 | 135 |
| **Totals** | 721 | 113 | 1,084 | 261 | 1,394 | 428 | 1,875 | 712 | 2,374 | 1,012 | 2,887 | 1,312 |

Economic damages associated with cropland flooding were evaluated in the *Economics Evaluation Technical Memorandum* which can be found in Appendix D-5 within the *Tongue River Watershed Plan and Environmental Assessment*. In addition to agricultural land damages, structural damages also occur when buildings are inundated during a flood event. Buildings affected by each of the different flood events were quantified, and economic damages associated with the structures were evaluated in the *Economics Evaluation Technical Memorandum* located in Appendix D-5 of the *Tongue River Watershed Plan and Environmental Assessment*.

## 4.2 WATERSHED INUNDATION CHARACTERISTICS

The Tongue River Watershed above Renwick Dam has 9 dams that control much of the runoff in the watershed. Senator Young Dam is the largest of all of the upstream dams and is the only other dam in the watershed that is located on the Tongue River mainstem.

In the western region of the watershed, upstream of Senator Young Dam, the Tongue River has a well-defined floodplain. The well-defined floodplain continues downstream of Senator Young Dam until the Tongue River crossing at North Dakota State Highway 32. At North Dakota State Highway 32, the Tongue River transitions to a perched channel, meaning that the channel banks are higher than the adjacent floodplain. When flood waters exceed the capacity of the perched river system, they breakout of the channel and travel overland in the floodplain. These overland flows cause significant damage to cropland during large runoff events. The Tongue River transitions back to a well-defined floodplain upstream of Renwick Dam, near 133$^{rd}$ Avenue NE. Significant flooding also occurs in intermediate tributaries to the Tongue River south of 96$^{th}$ Street NE and east of North Dakota State Highway 32 due to the flatter slopes present in the region. This portion of the watershed is partially controlled by Goschke and Weiler Dams, which cause additional attenuation for floodwaters entering the lower region.

In summary, runoff accumulates rapidly in the upper portion of the watershed where it is controlled by various retention structures. The added attenuation from upstream dams causes prolonged inundation durations in the lower region of the watershed where the slopes flatten. Consequently, significant crop damages occur in the lower Tongue River Watershed above Renwick Dam.

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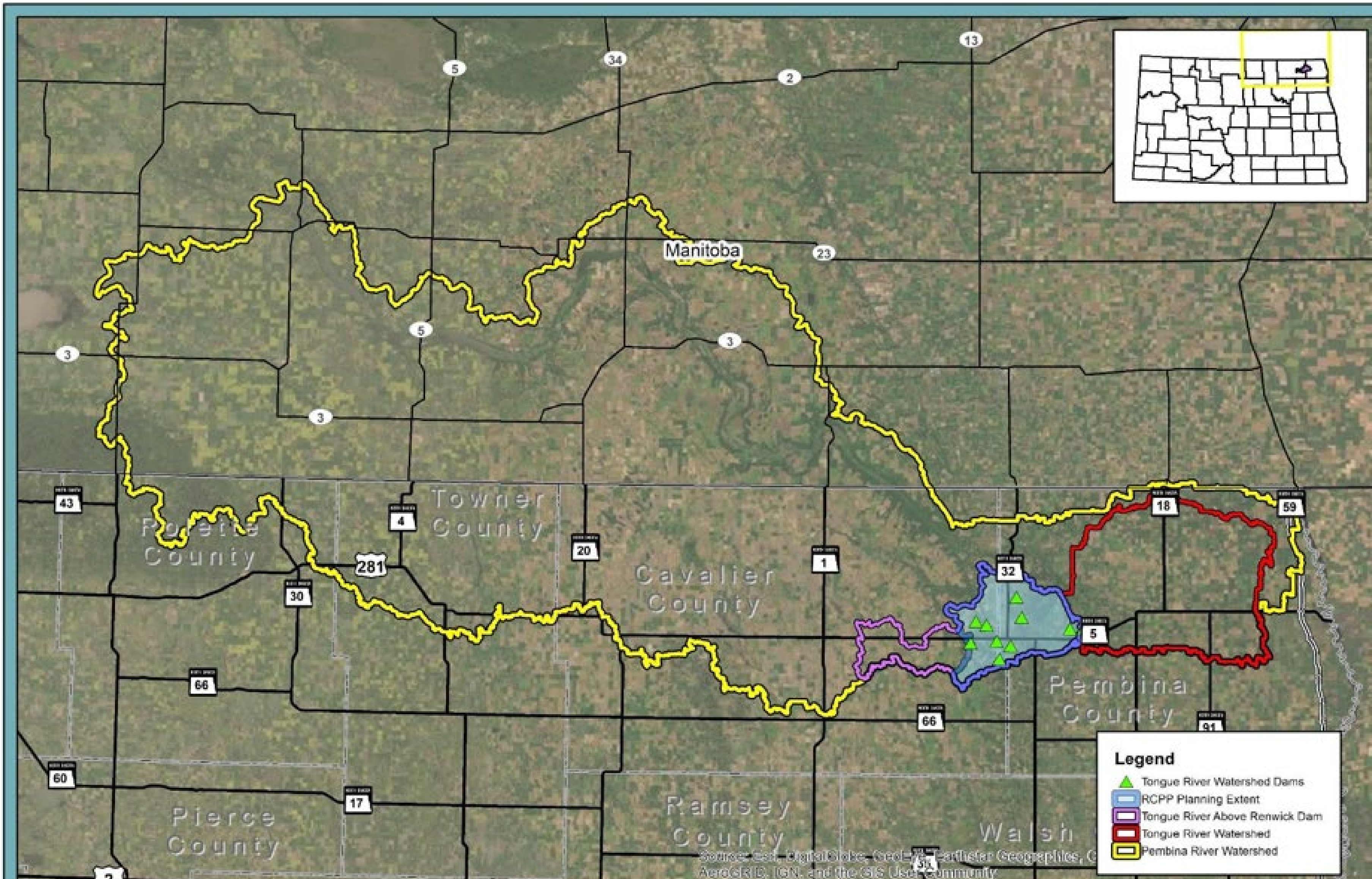
# FIGURES




F-1

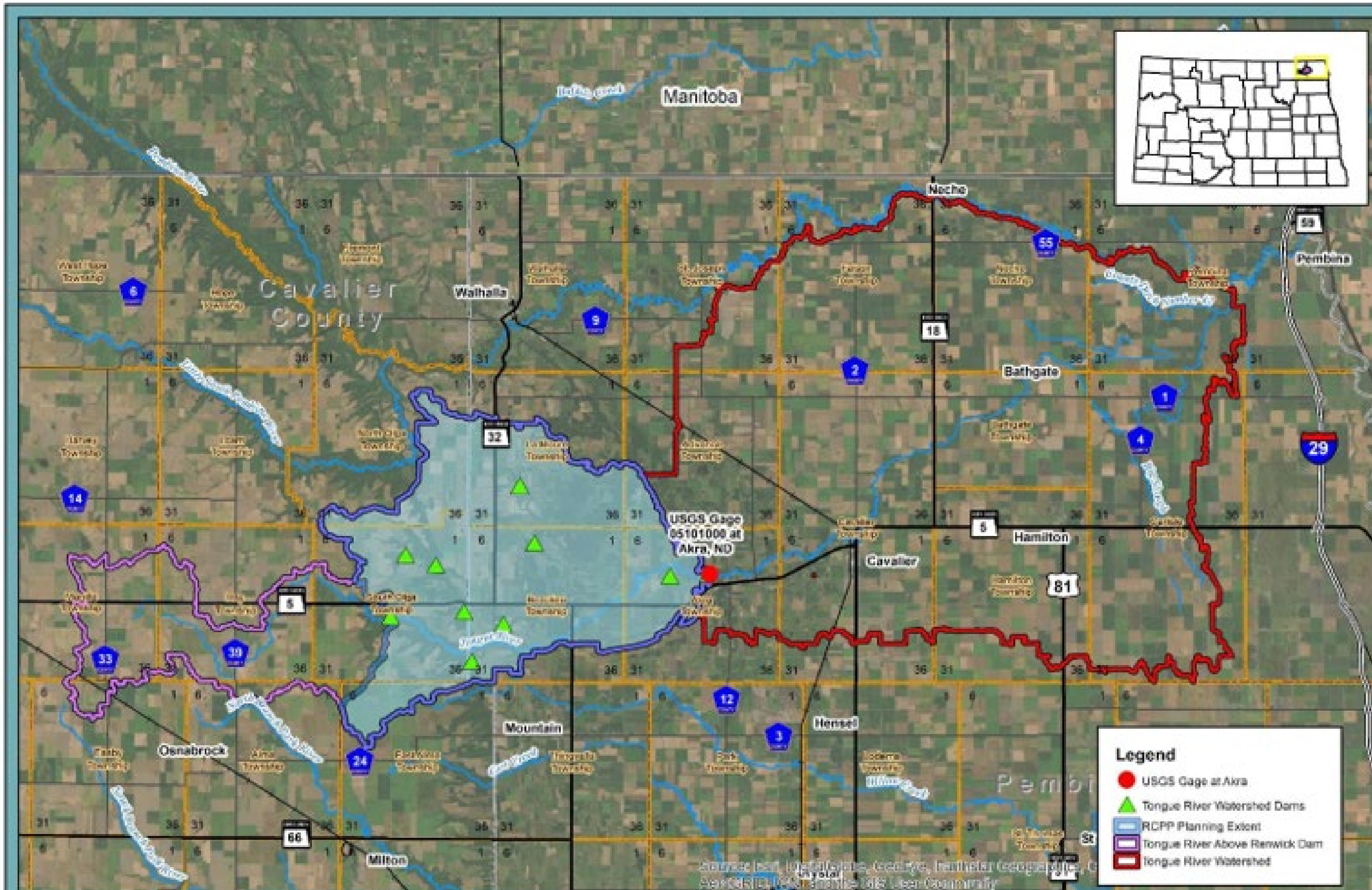
**Figure 1: Pembina River Watershed**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

N W E S

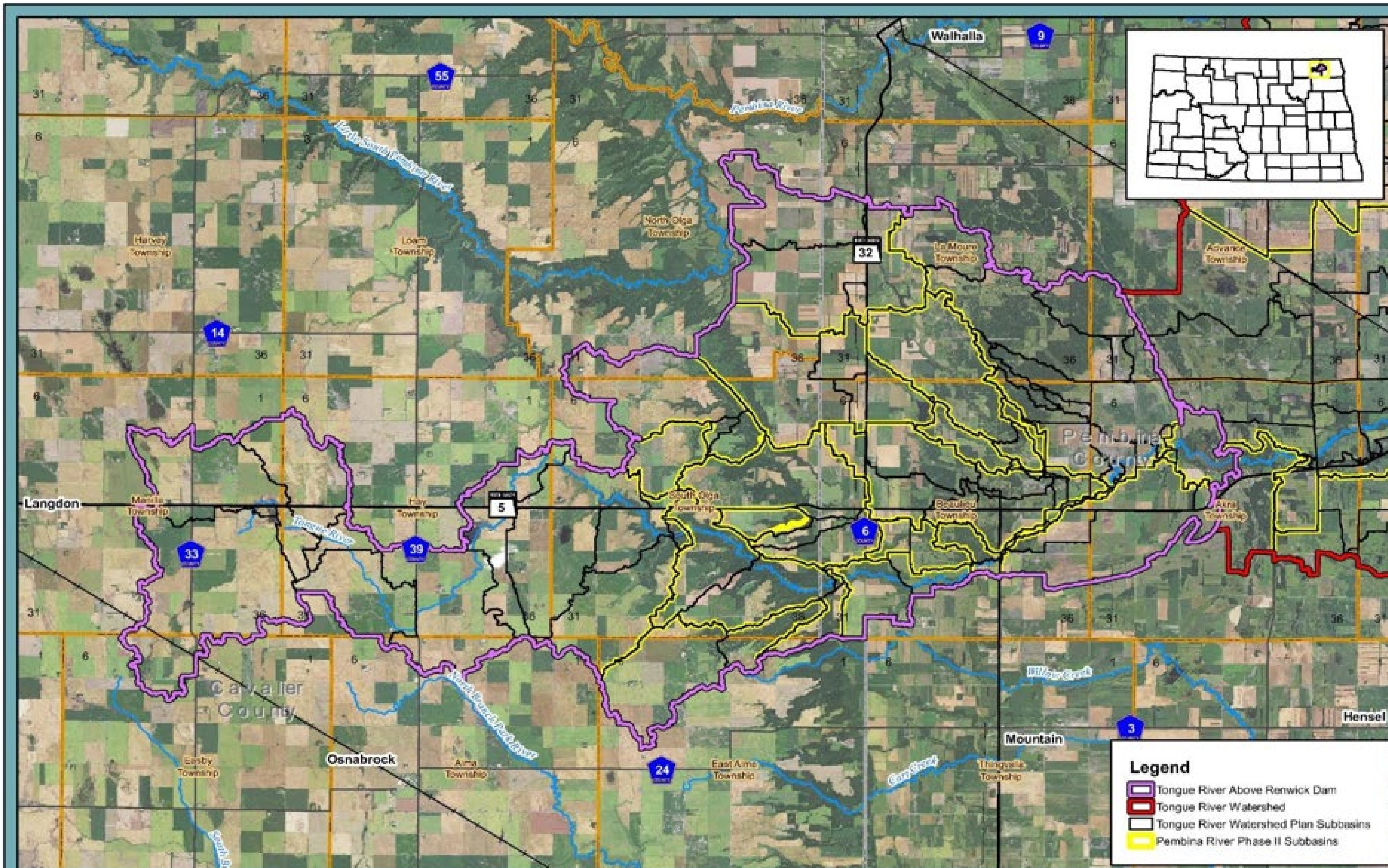
0 5 10 20 Miles

Houston Engineering Inc.




F-3

**Figure 3: Tongue River Watershed Above Renwick Dam**
Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District



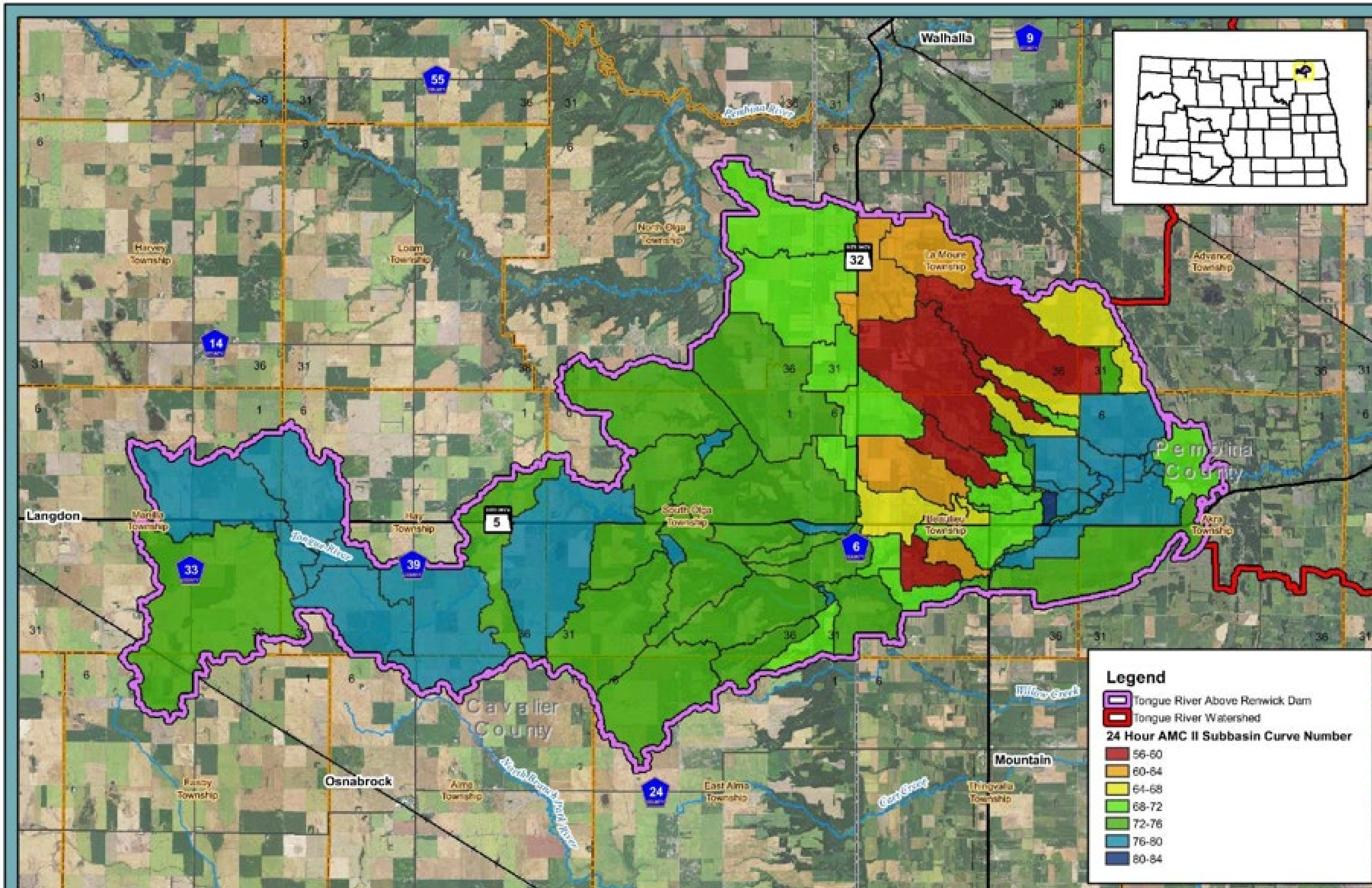

F-3.1.1

**Figure 3.1.1: HEC-HMS Subbasins**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

0 1 2 4 Miles

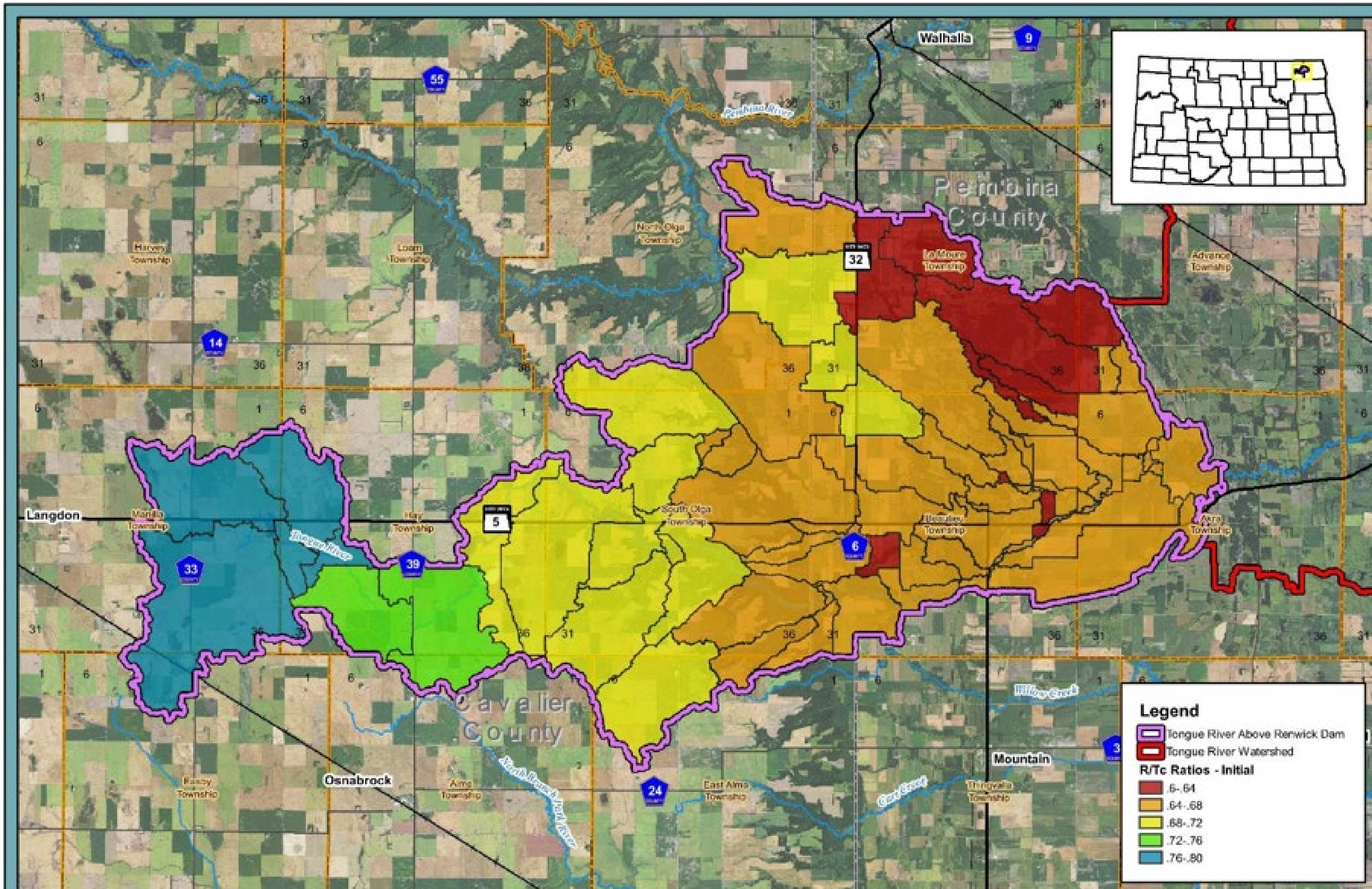
Houston Engineering Inc.




F-3.1.2

**Figure 3.1.2: 24-Hour AMC II CN Values**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District



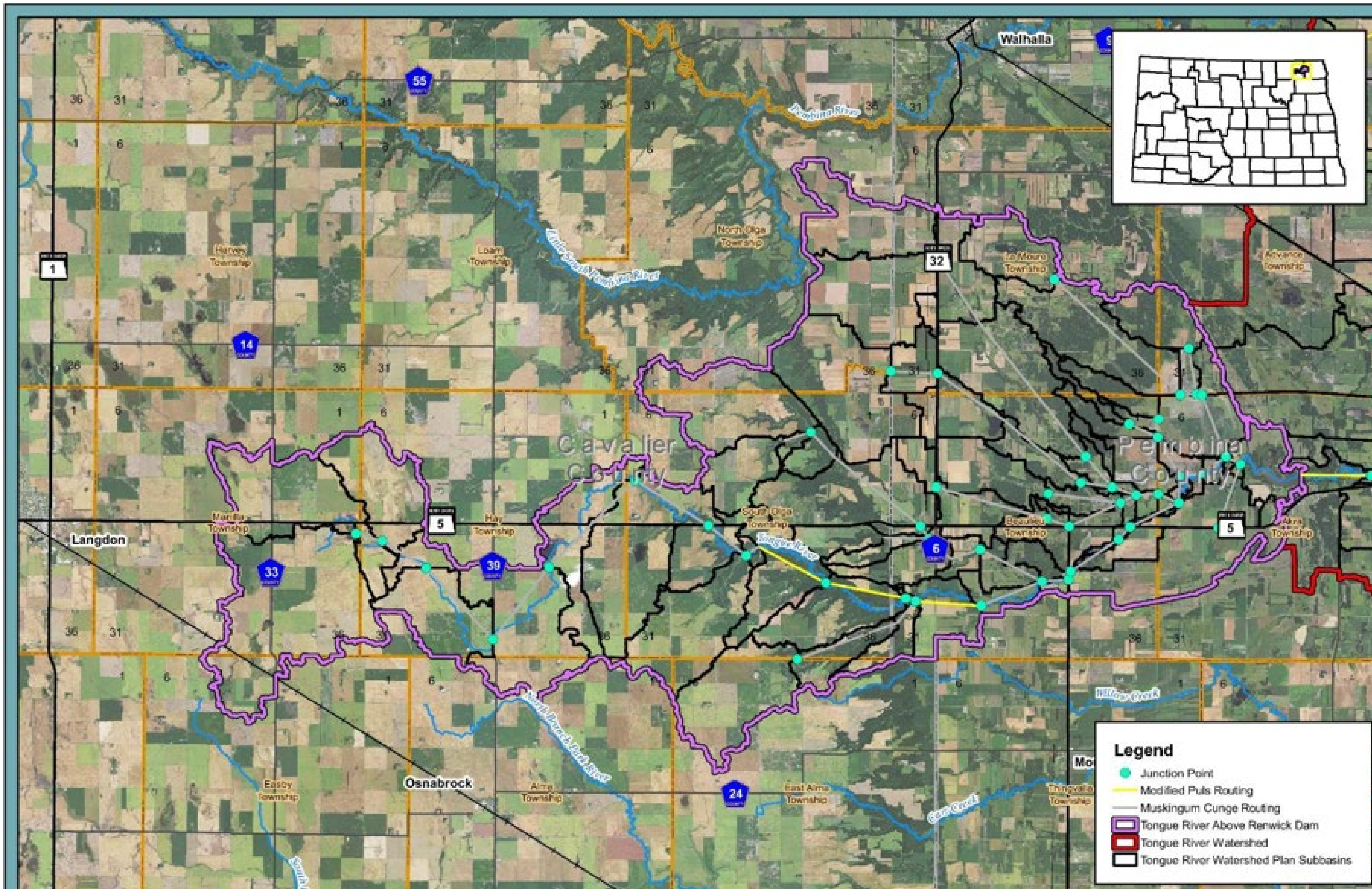

F-3.1.3

**Figure 3.1.3: R/Tc Ratios - Initial**

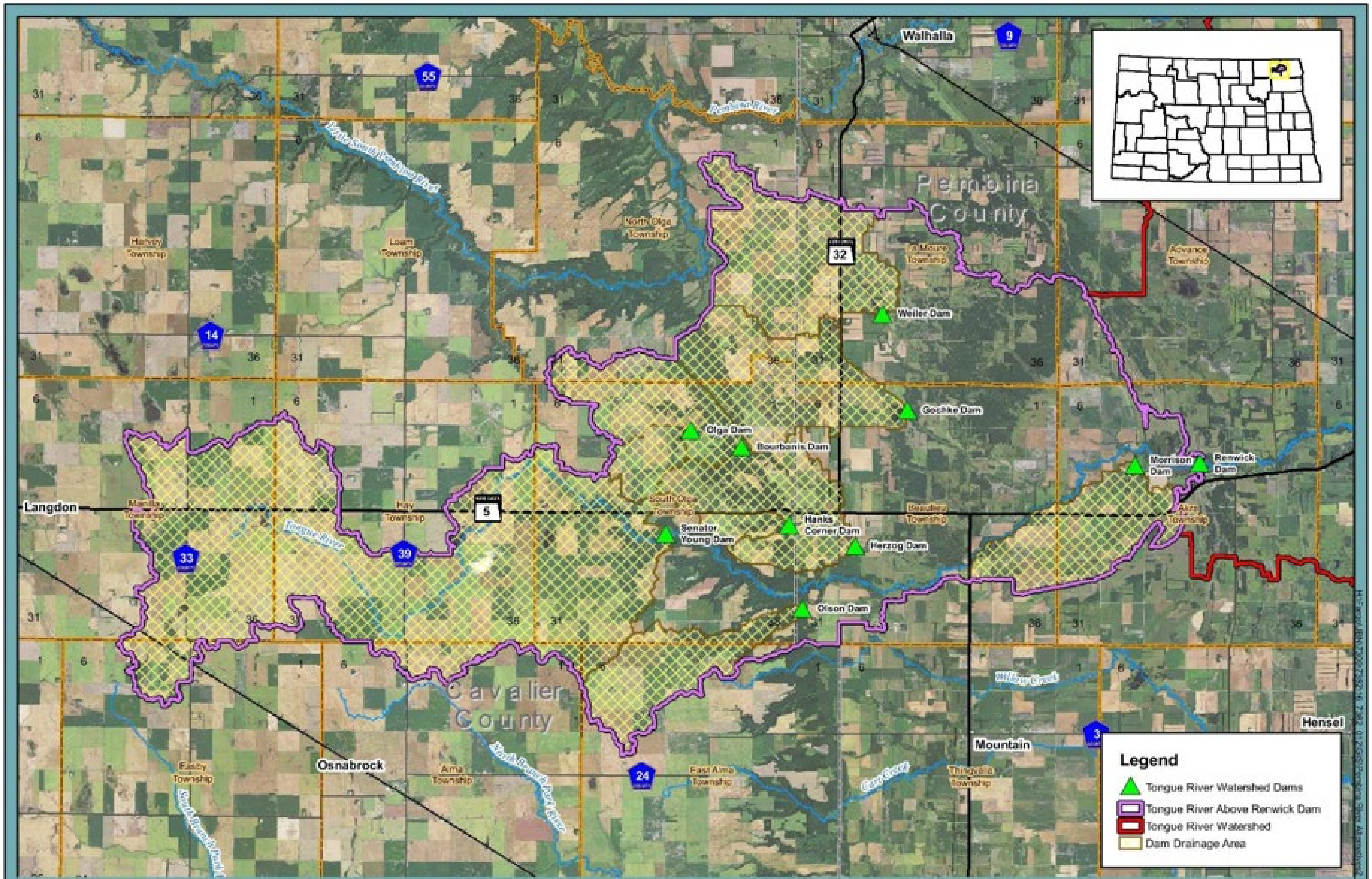
Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

0 1 2 4 Miles

Houston Engineering Inc.




| F-3.1.4 | **Figure 3.1.4: HEC-HMS Routing**<br>Tongue River Watershed Plan - Appendix D-2<br>Existing Conditions Hydrology and Hydraulics Report<br>Pembina County Water Resource District | N / W / E / S | 0 1 2 4 Miles | Houston Engineering Inc. |
|---|---|---|---|---|

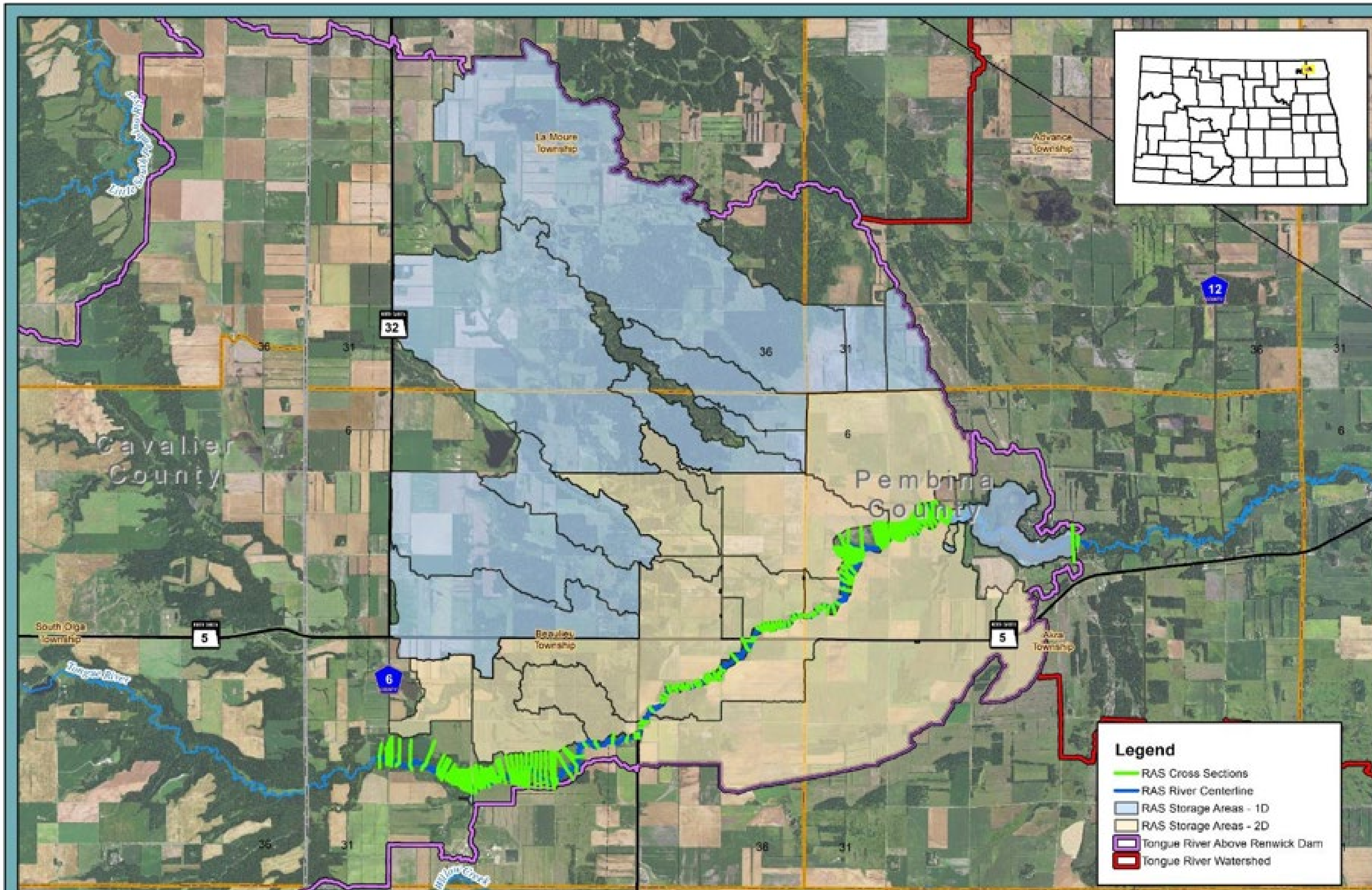



F-3.1.5

**Figure 3.1.5: Existing Dams**
Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

0 1 2 4 Miles

Houston Engineering Inc.



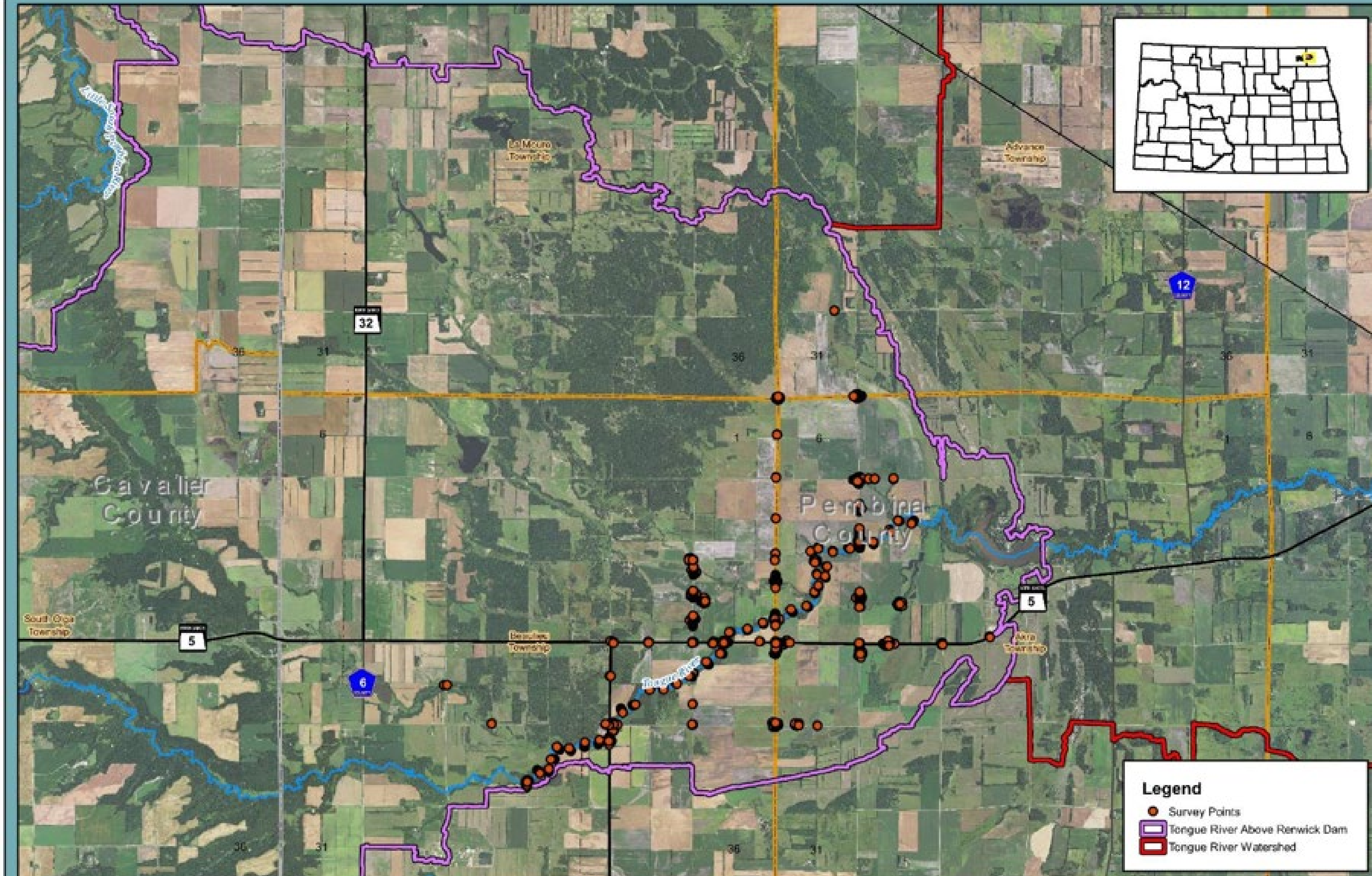

F-3.2

**Figure 3.2: HEC-RAS Model Schematic**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

0 0.5 1 2 Miles

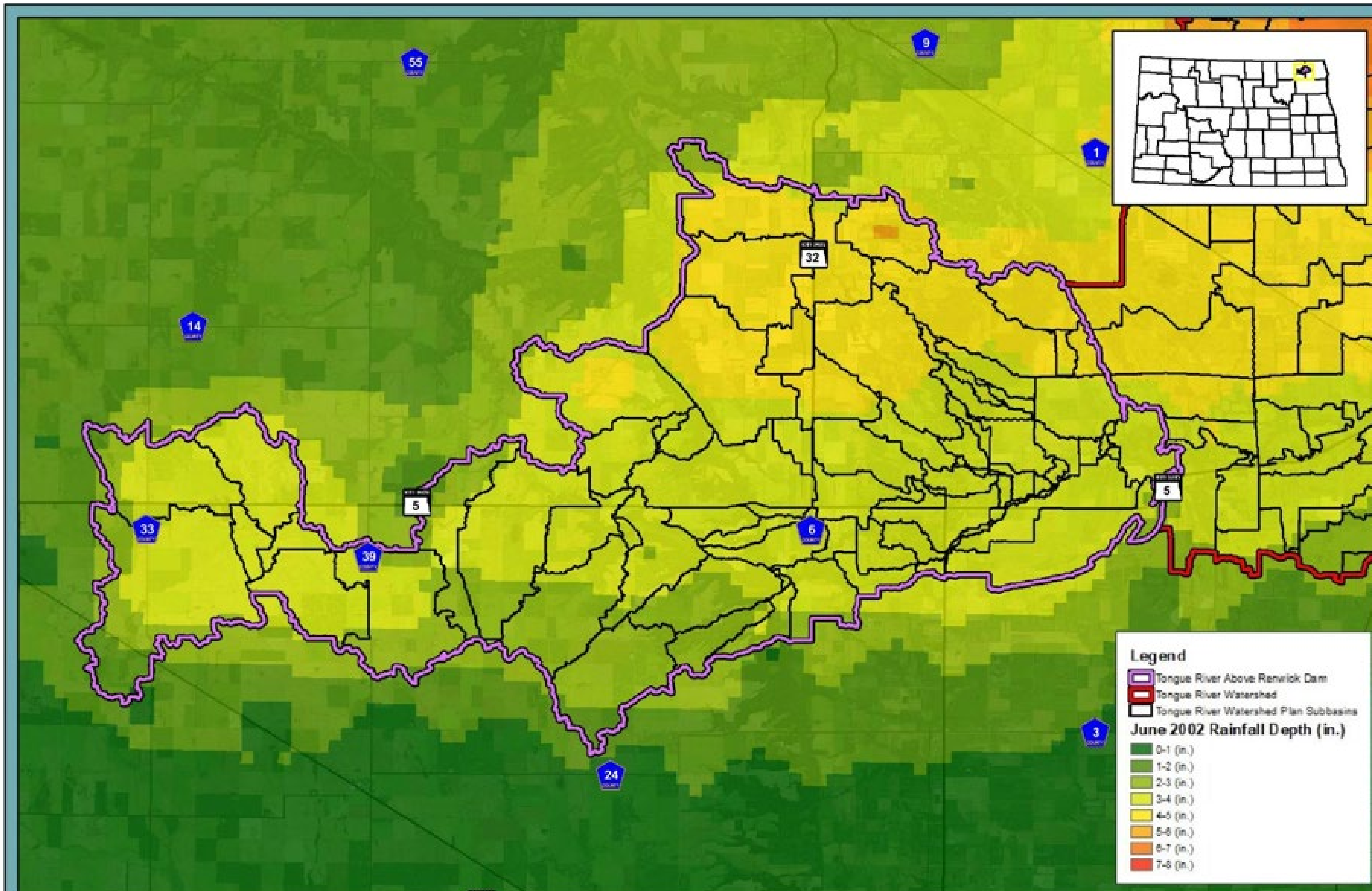
Houston Engineering Inc.




F-3.2.2

**Figure 3.2.2: Field Survey Data**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District




F-3.3.1a

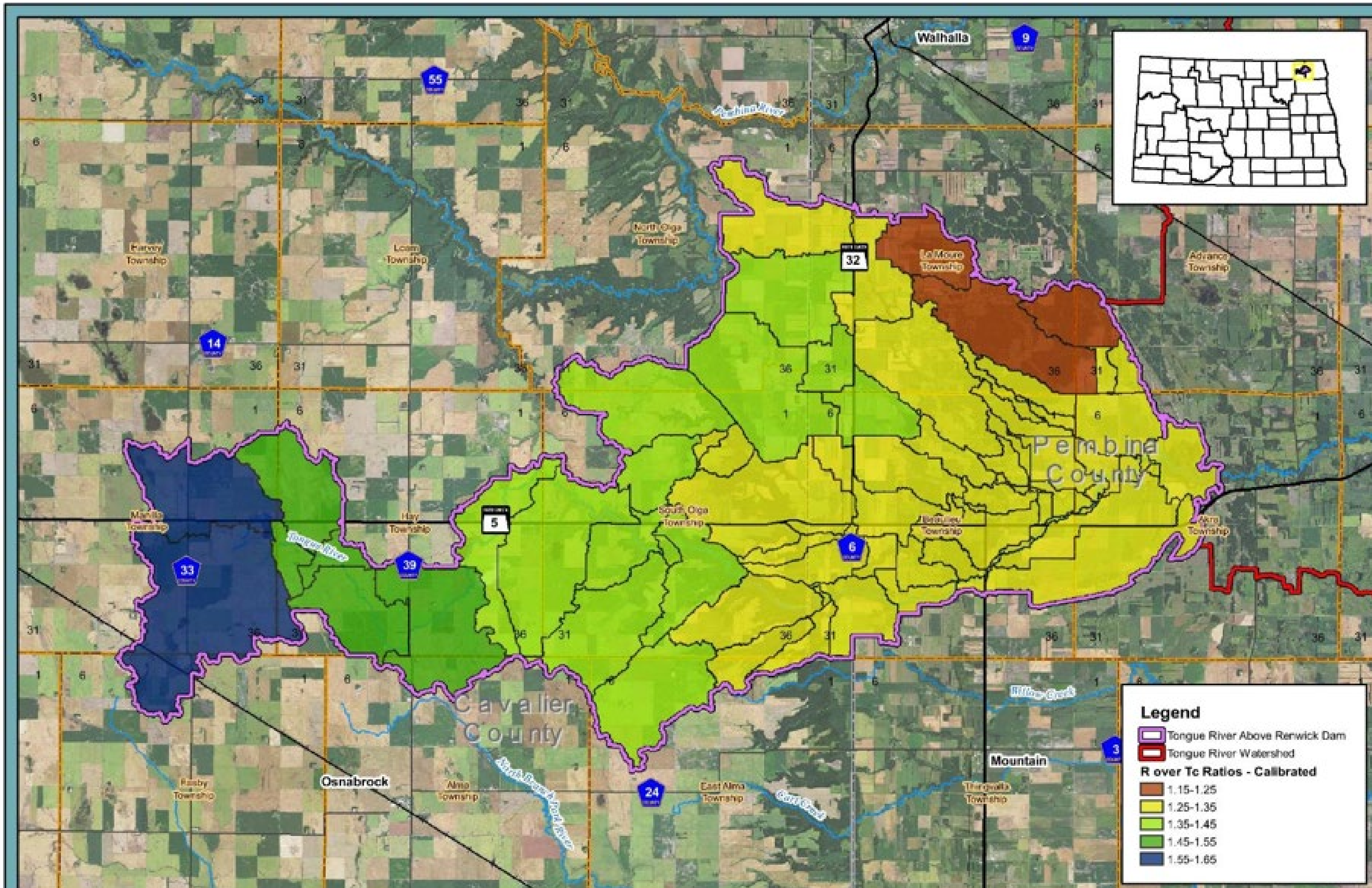
**Figure 3.3.1a: 2002 Historic Event Rainfall**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

N W E S

0 1 2 4 Miles

Houston Engineering Inc.




F-3.3.1b

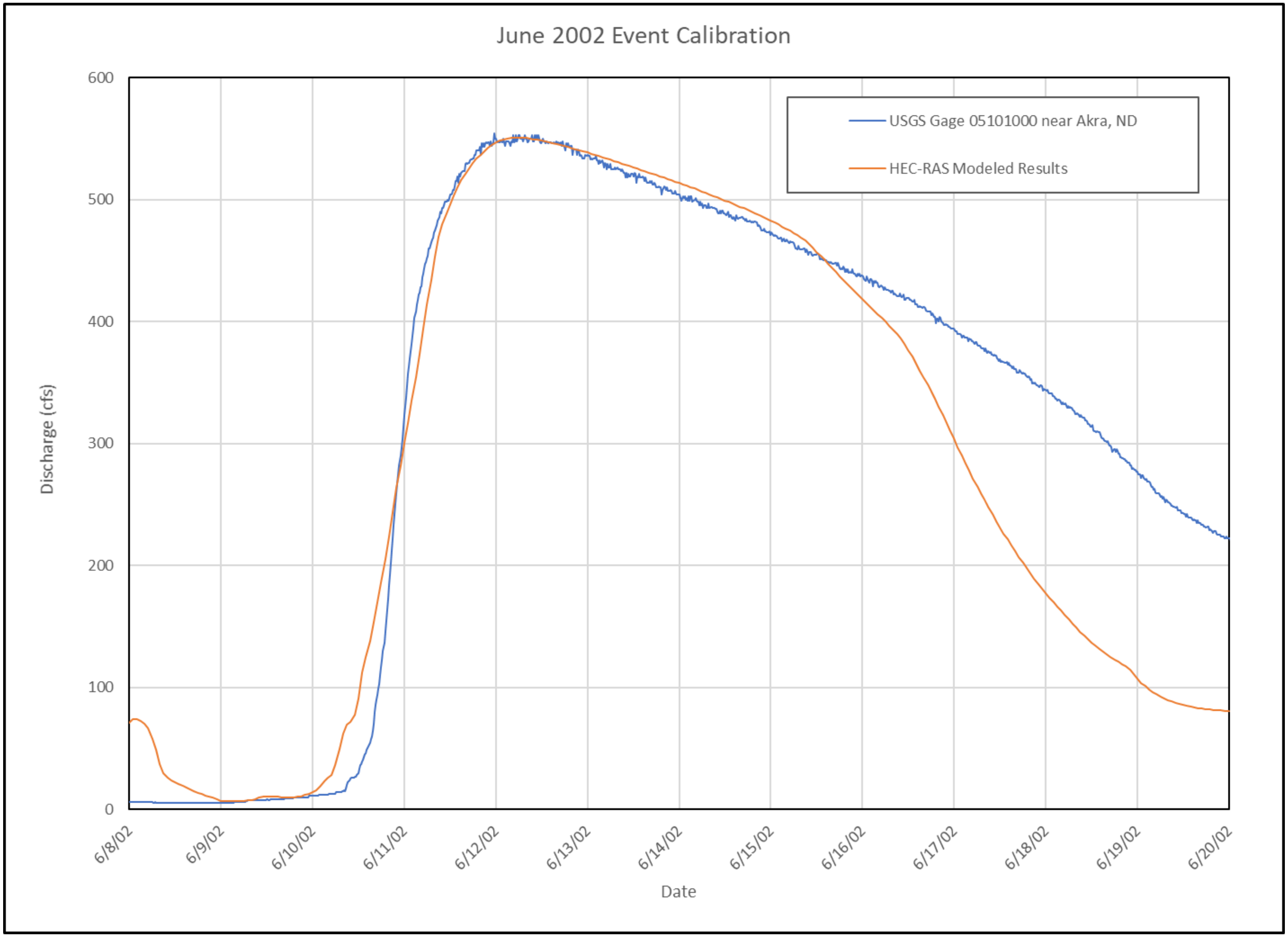
**Figure 3.3.1b: R/Tc Ratios - Calibrated**

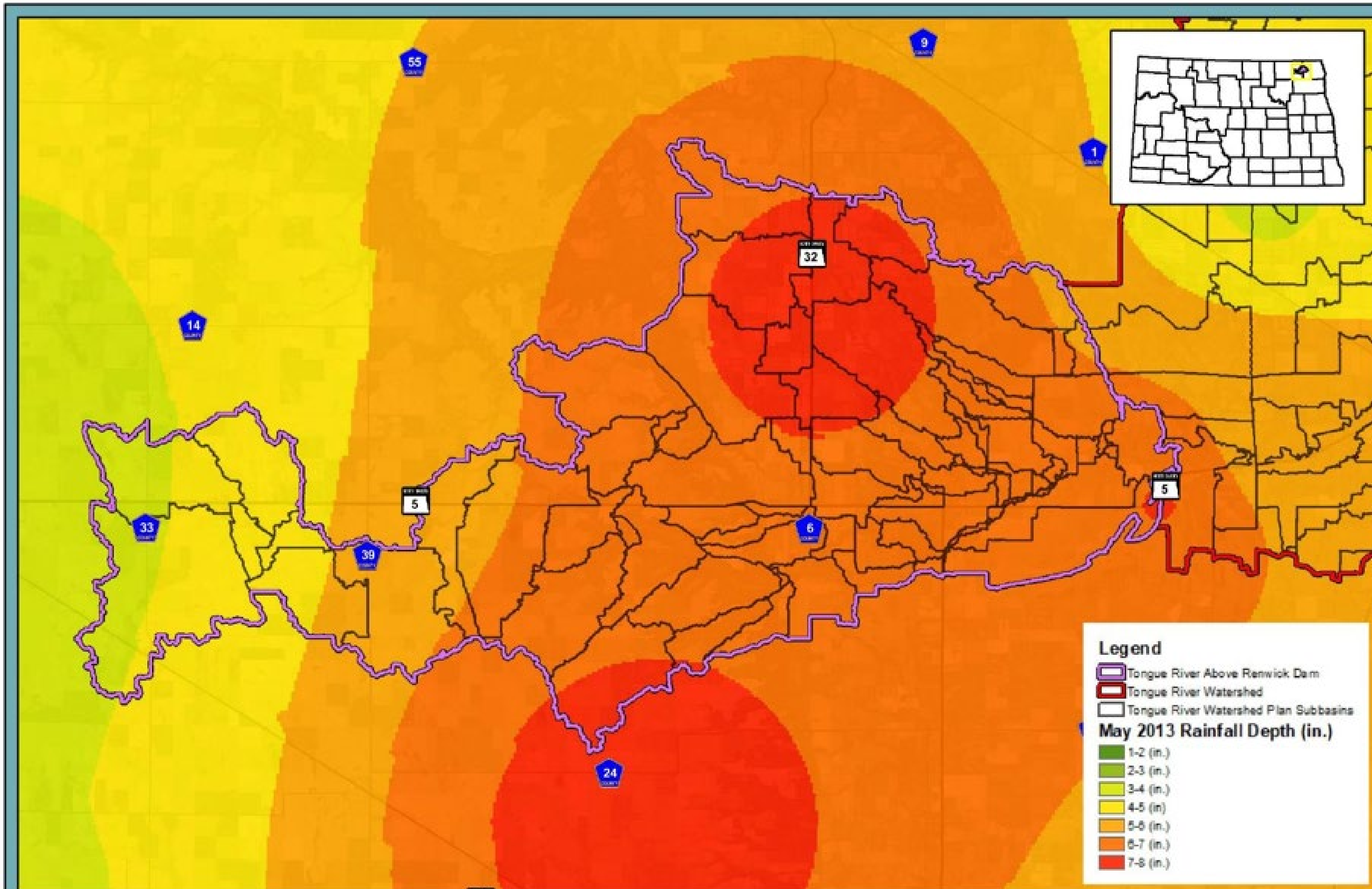
Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

0 1 2 4 Miles

Houston Engineering Inc.

***Figure 3.3.1c:*** *2002 Historic Event – Peak Discharge at Akra, ND (USGS Gage 05101000)*






F-3.3.2a

**Figure 3.3.2a: 2013 Historic Event Rainfall**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

N W E S

0 1 2 4 Miles

Houston Engineering Inc.

***Figure 3.3.2b**: Renwick Dam Rating Curve During May 2013 Rain Event*

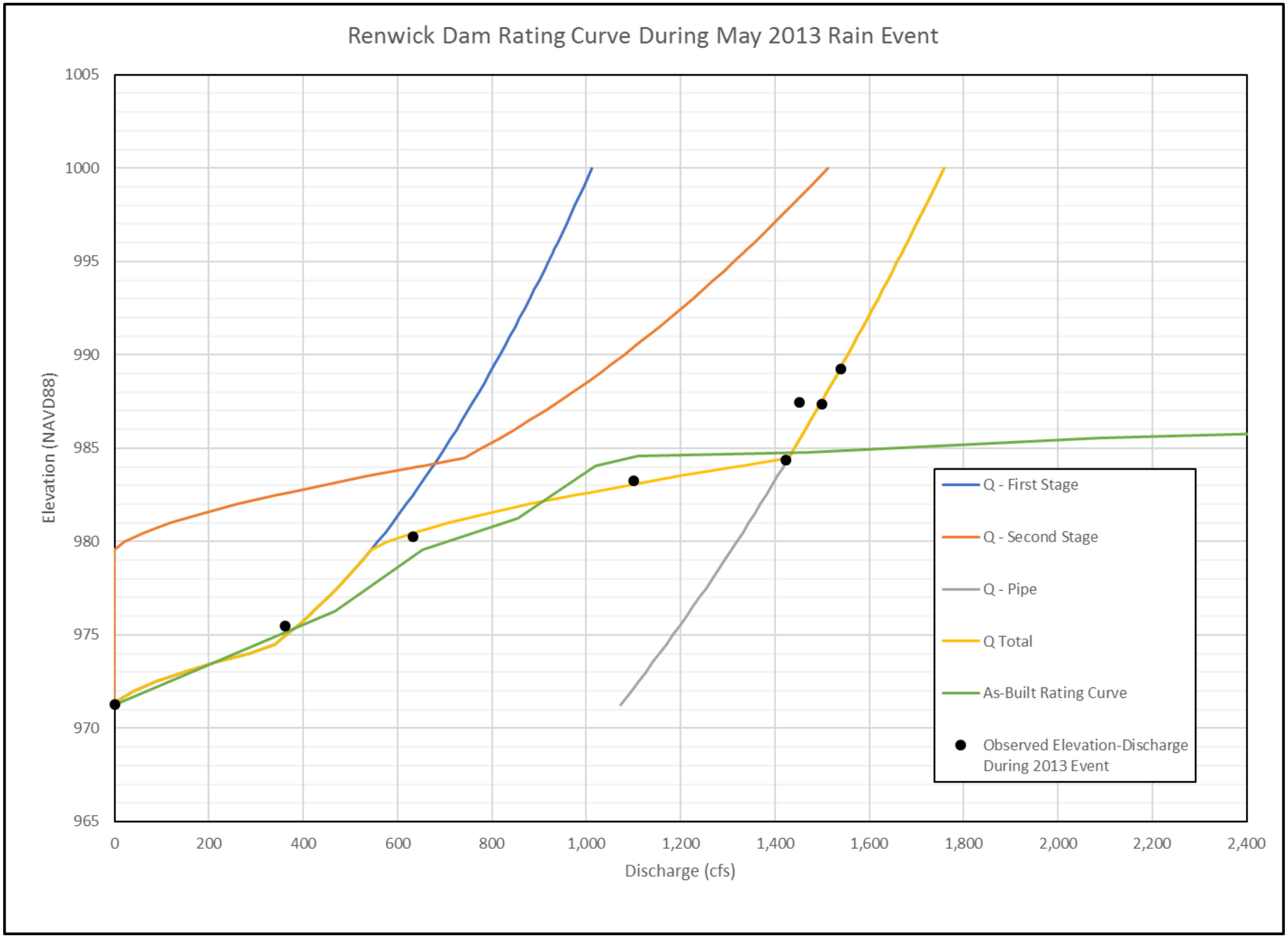


***Figure 3.3.2c:*** *2013 Historic Event – Upstream Dams Auxiliary Spillway Activation*

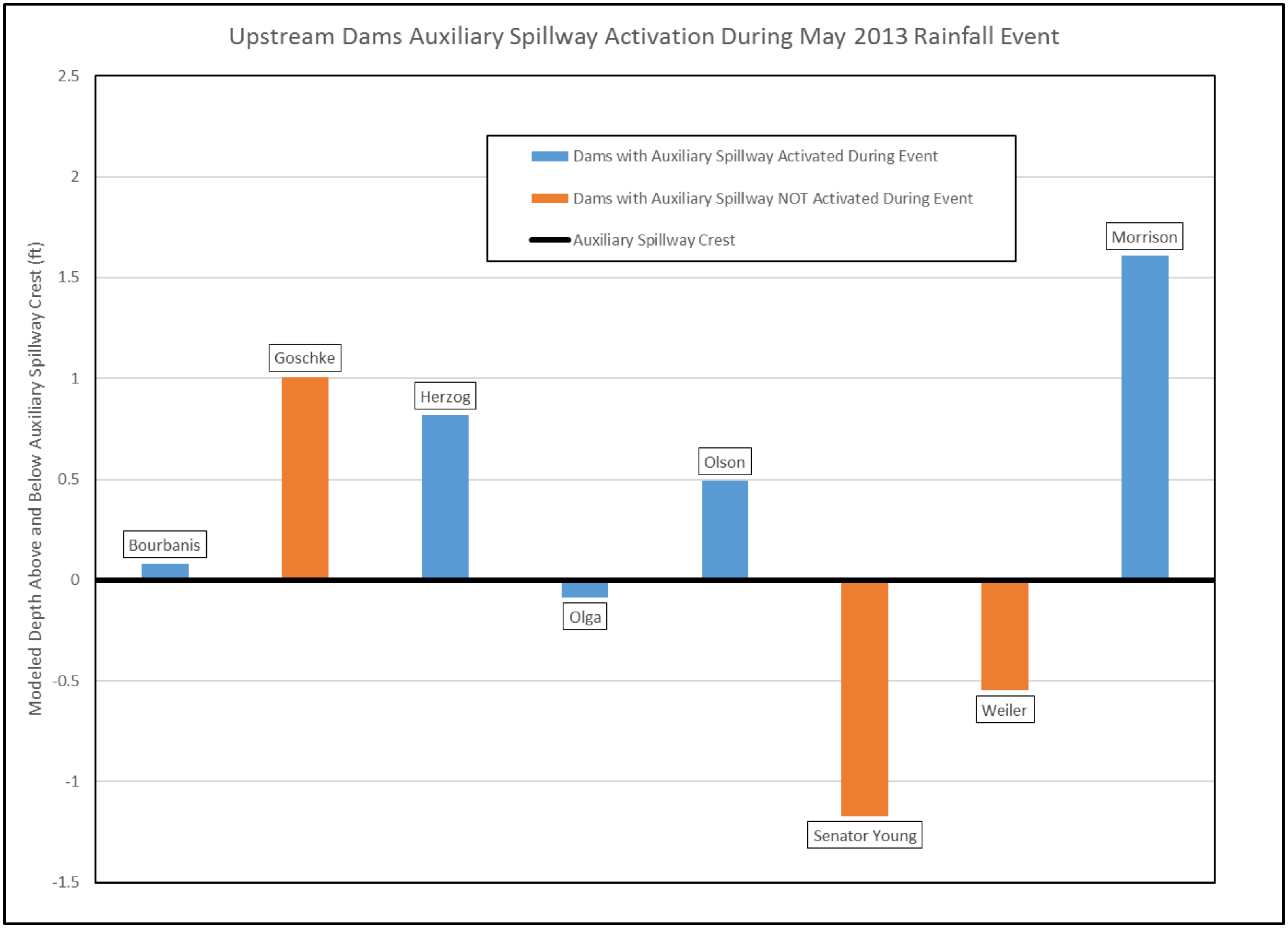
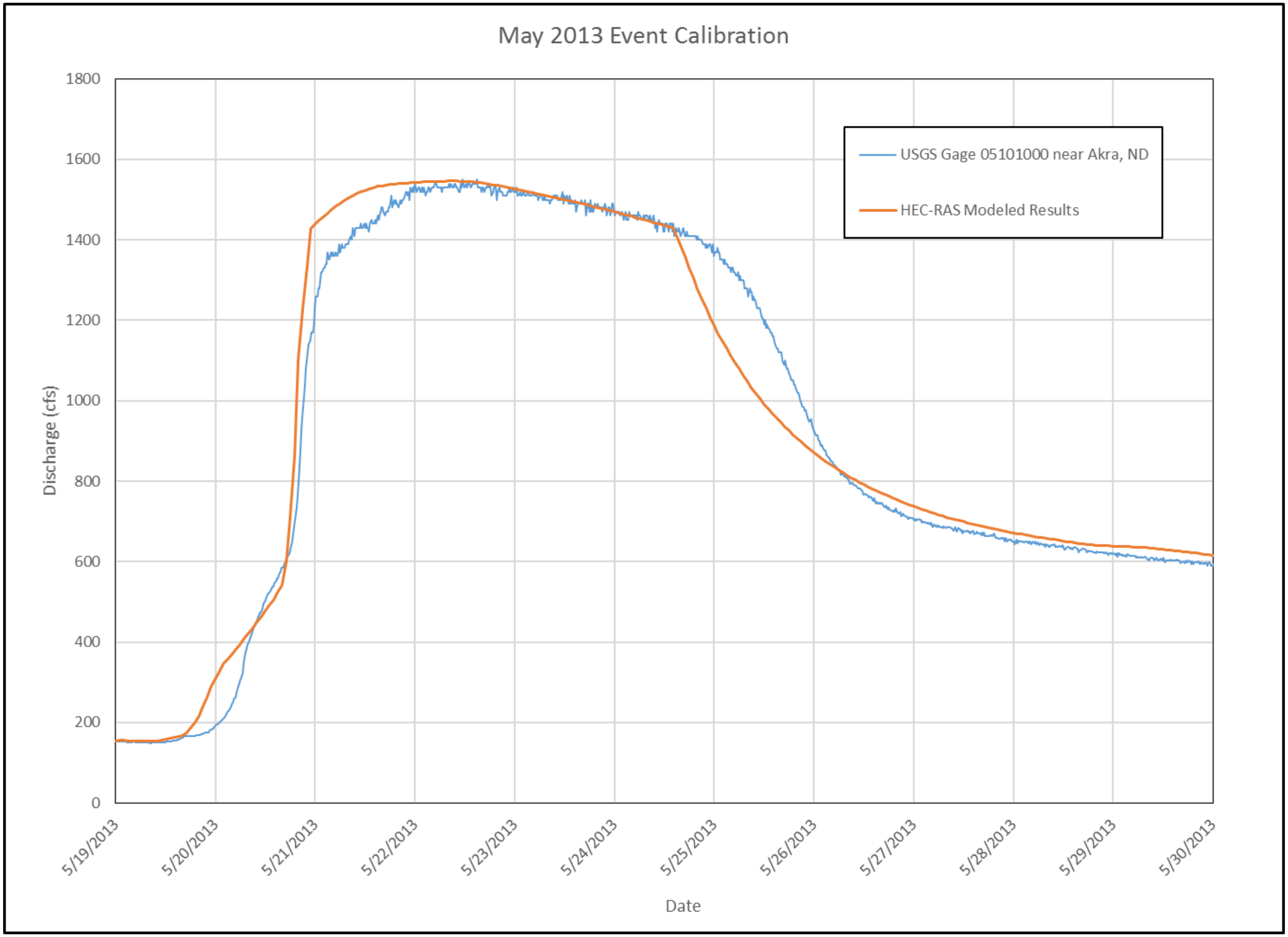
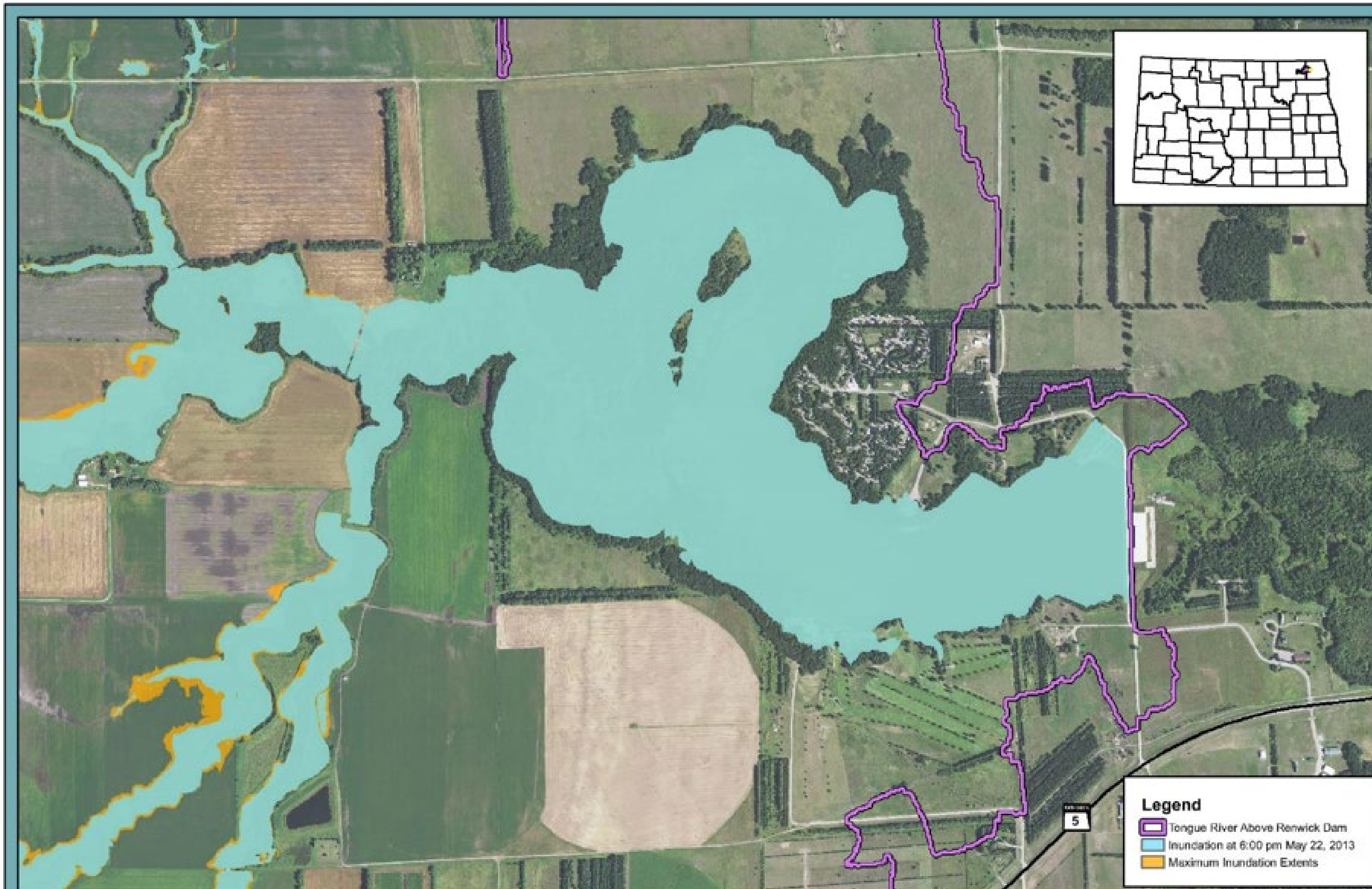


***Figure 3.3.2d:*** *2013 Historic Event – Peak Discharge at Akra, ND (USGS Gage 05101000)*






F-3.3.2e

**Figure 3.3.2e: 2013 Historic Event Inundation for Renwick Dam**

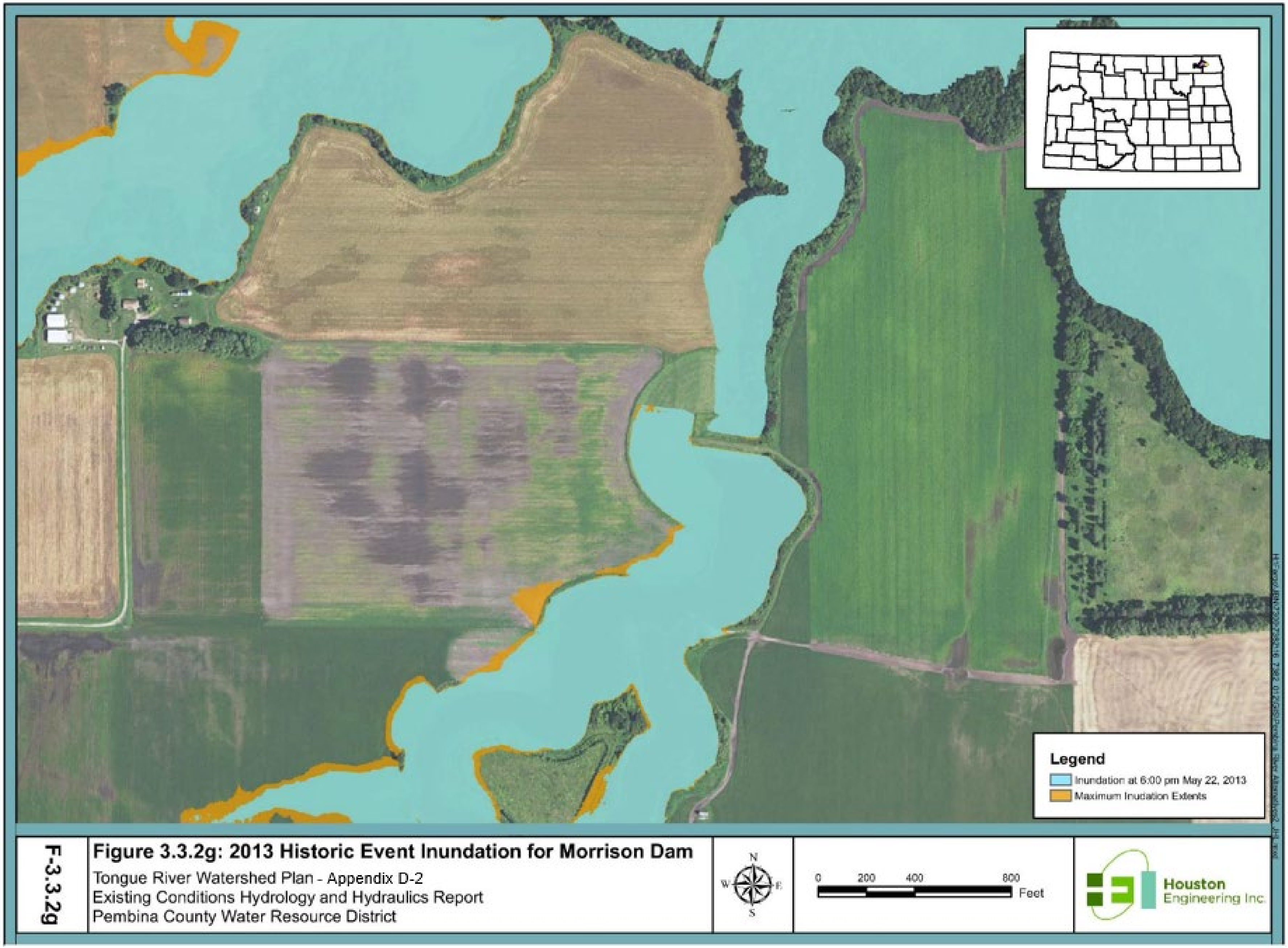
Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

N W E S

0 500 1,000 2,000 Feet

Houston Engineering Inc.

***Figure 3.3.2f:*** *2013 Historic Event Areal Imagery for Renwick Dam Looking West*




F-3.3.2g

**Figure 3.3.2g: 2013 Historic Event Inundation for Morrison Dam**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

***Figure 3.3.2h:*** *2013 Historic Event Areal Imagery for Morrison Dam Looking Southwest*

***Figure 3.3.2i:*** *2013 Historic Event Areal Imagery for Weiler Dam Looking Northwest*

***Figure 3.3.2j:*** *2013 Historic Event Areal Imagery for Goschke Dam Looking Northwest*

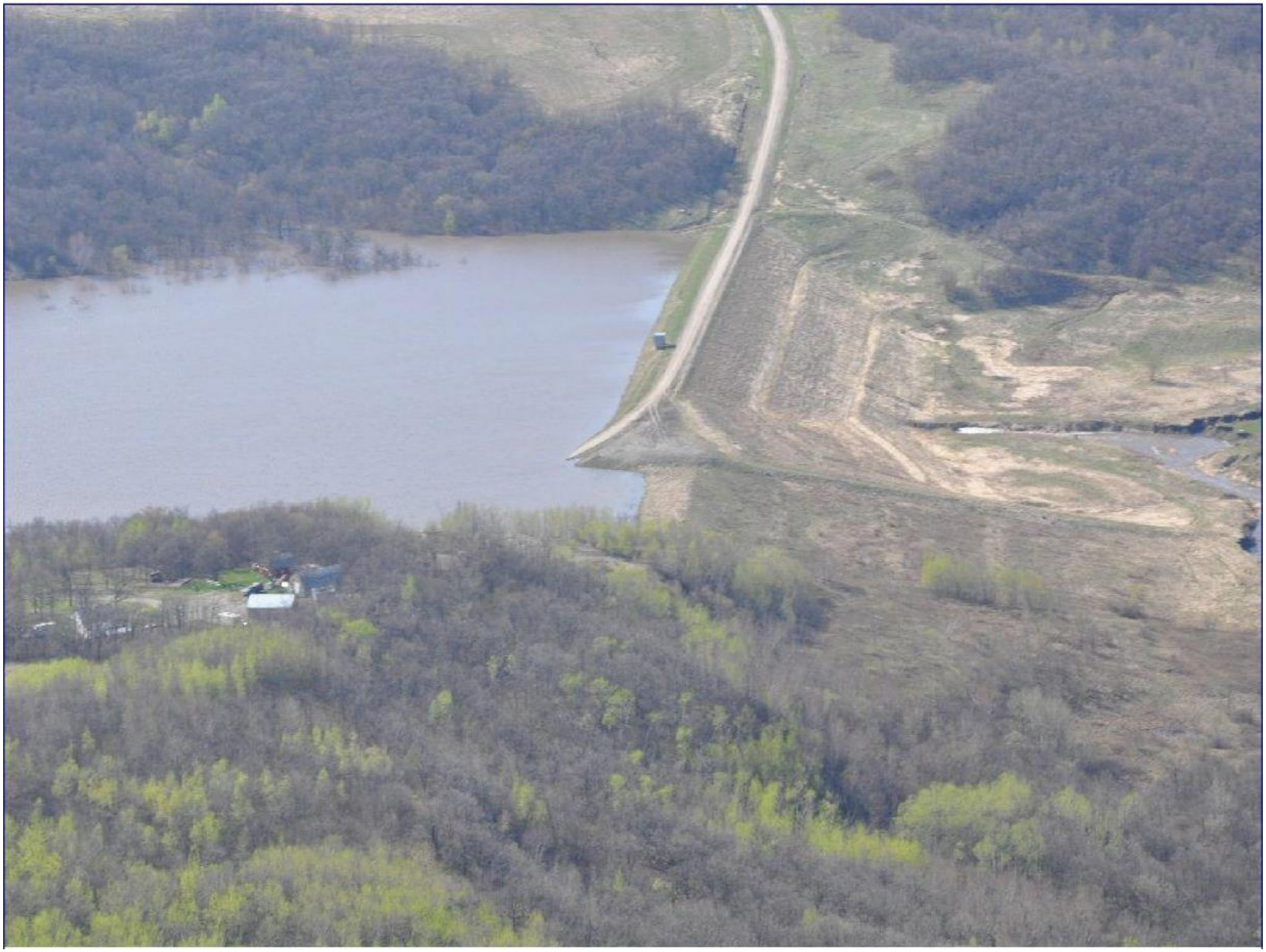
***Figure 3.3.2k:*** *2013 Historic Event Areal Imagery for Herzog Dam Looking Southwest*

***Figure 3.3.2I:*** *2013 Historic Event Areal Imagery for Bourbanis Dam Looking South*

***Figure 3.3.2m:*** *2013 Historic Event Areal Imagery for Olga Dam Looking West*

***Figure 3.3.2n:** 2013 Historic Event Areal Imagery for Olson Dam Looking South*

***Figure 3.3.2o:*** *2013 Historic Event Areal Imagery for Senator Young Dam Looking Northwest*



# APPENDIX D-2-A

## Red River Basin 24-Hour Runoff Curve Number Conversion Table

# APPENDIX D-2-A:

## *Red River Basin 24-Hour Runoff Curve Number Conversion Table*

**FM Metro Basin-Wide Modeling Approach**
**Runoff Curve Number (2001 NLCD/SSURGO)**
**11/11/2010**

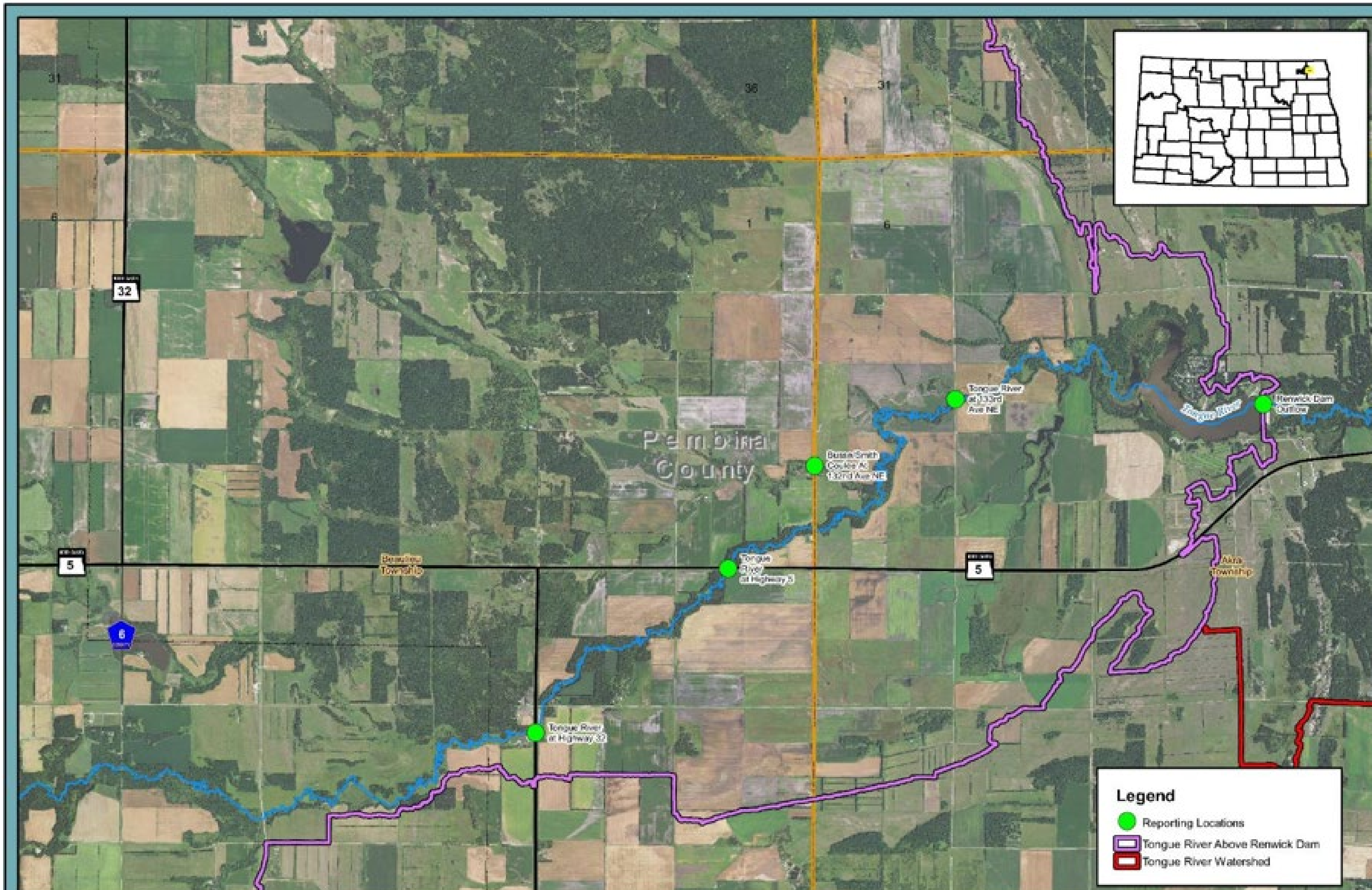
| NLCD 2001 Info | | | | | Pervious CN by Hydrologic Soil Group | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Value/ Code | Land Cover Code | Detailed Land Cover Class Definition | TR55 or MN Hydrology Guide Designation (MNHG) | % Impervious | A | B | C | D | A/D | B/D | C/D |
| 11 | Open water | 11. Open Water - All areas of open water, generally with less than 25% cover of vegetation or soil. | MNHG- Water Surfaces (lakes, ponds,...) | | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 12 | Perennial Ice/Snow | 12. Perennial Ice/Snow - All areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover. | MNHG- Water Surfaces (lakes, ponds,...) | | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 21 | Developed, Open Space | 21. Developed, Open Space - Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes. | TR55-Residential Districts (98 for impervious areas and Open Space in Good condition for pervious areas) based on Percent Impervious Listed. | 10 | 45 | 65 | 76 | 82 | 45 | 65 | 76 |
| 22 | Developed, Low Intensity | 22. Developed, Low Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units. | TR55-Residential Districts (98 for impervious areas and Open Space in Good condition for pervious areas) based on Percent Impervious Listed. | 35 | 60 | 74 | 82 | 86 | 60 | 74 | 82 |
| 23 | Developed, Medium Intensity | 23. Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units. | TR55-Residential Districts (98 for impervious areas and Open Space in Good condition for pervious areas) based on Percent Impervious Listed. | 65 | 77 | 85 | 90 | 92 | 77 | 85 | 90 |
| 24 | Developed, High Intensity | 24. Developed, High Intensity - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover. | TR55-Residential Districts (98 for impervious areas and Open Space in Good condition for pervious areas) based on Percent Impervious Listed. | 90 | 92 | 94 | 96 | 96 | 92 | 94 | 96 |
| 31 | Barren Land | 31. Barren Land (Rock/Sand/Clay) - Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover. | TR55-Developing Urban Areas (Newly graded areas (pervious areas only, no vegetation)) | | 77 | 86 | 91 | 94 | 94 | 94 | 94 |
| 41 | Deciduous Forest | 41. Deciduous Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change. | TR55-Woods (Fair Condition) | | 36 | 60 | 73 | 79 | 79 | 79 | 79 |
| 42 | Evergreen Forest | 42. Evergreen Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage. | TR55-Woods (Good Condition) | | 30 | 55 | 70 | 77 | 77 | 77 | 77 |
| 43 | Mixed Forest | 43. Mixed Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover. | TR55-Woods (Good Condition) | | 30 | 55 | 70 | 77 | 77 | 77 | 77 |
| 52 | Scrub/Shrub | 52. Shrub/Scrub - Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions. | TR55-Brush (brush-weed-grass mixture with brush major element)(Fair Condition) | | 35 | 56 | 70 | 77 | 77 | 77 | 77 |
| 71 | Grassland/Herbaceous | 71. Grassland/Herbaceous - Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing. | TR55-Meadow (continuous grass, protected from grazing and generally mowed for hay)(Fair Condition) | | 30 | 58 | 71 | 78 | 78 | 78 | 78 |
| 81 | Pasture/Hay | 81. Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation. | TR55-Pasture, grassland, or range - continuous forage for grazing (Fair Condition) | | 49 | 69 | 79 | 84 | 84 | 84 | 84 |
| 82 | Cultivated Crops | 82. Cultivated Crops - Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled. | TR55-Assume 80% Row Crop and 20% Small Grains in Good Condition - Contoured and Terraced (since most of are is less than 2% slope) | | 61 | 71 | 78 | 81 | 61 | 71 | 78 |
| 90 | Woody Wetlands | 90. Woody Wetlands - Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water. | MNHG-Swamp(Vegetated) | | 78 | 78 | 78 | 78 | 78 | 78 | 78 |
| 95 | Emergent Herbaceous Wetland | 95. Emergent Herbaceous Wetlands - Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water. | MNHG-Swamp(open water) | | 85 | 85 | 85 | 85 | 85 | 85 | 85 |

# APPENDIX D-2-B

## Existing Conditions
## Hydrographs and Inundation

# APPENDIX D-2-B

## *Existing Conditions Hydrographs and Inundation*




F-B.1

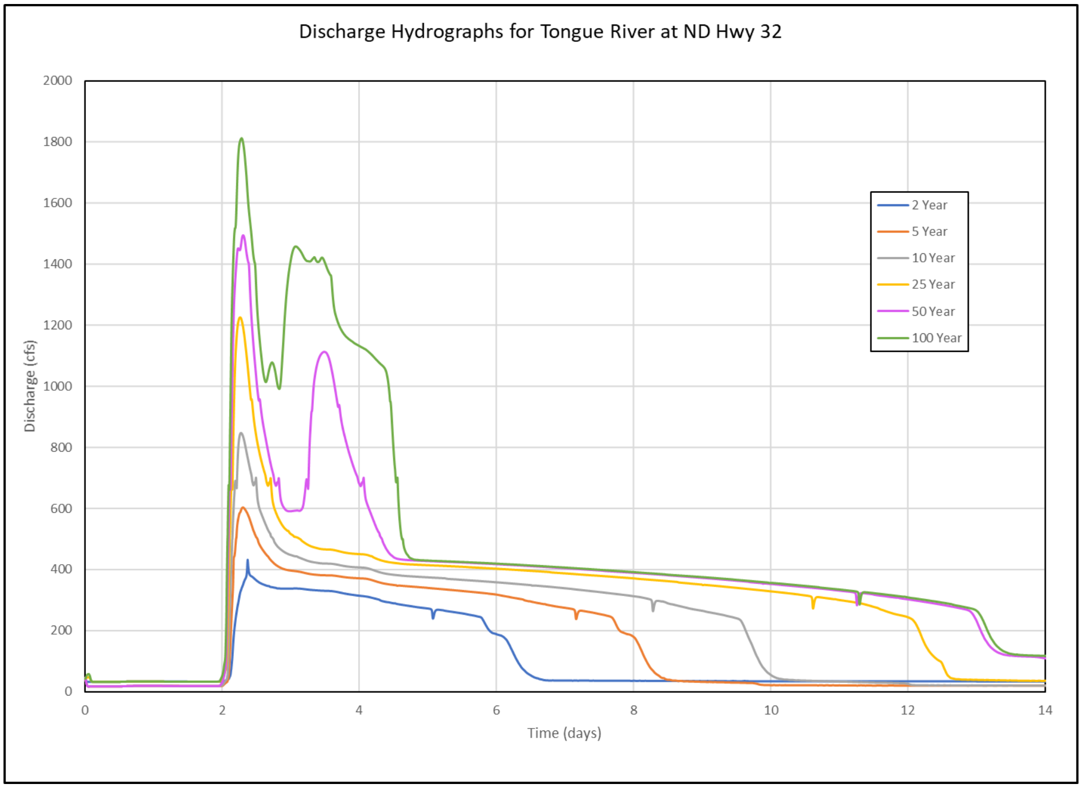
**Figure B.1: Synthetic Model Results Reporting Locations**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

0 0.25 0.5 1 Miles

Houston Engineering Inc.

### ***Figure B.2:*** *Tongue River at ND Highway 32*




### ***Figure B.3:*** *Tongue River at ND Highway 5*

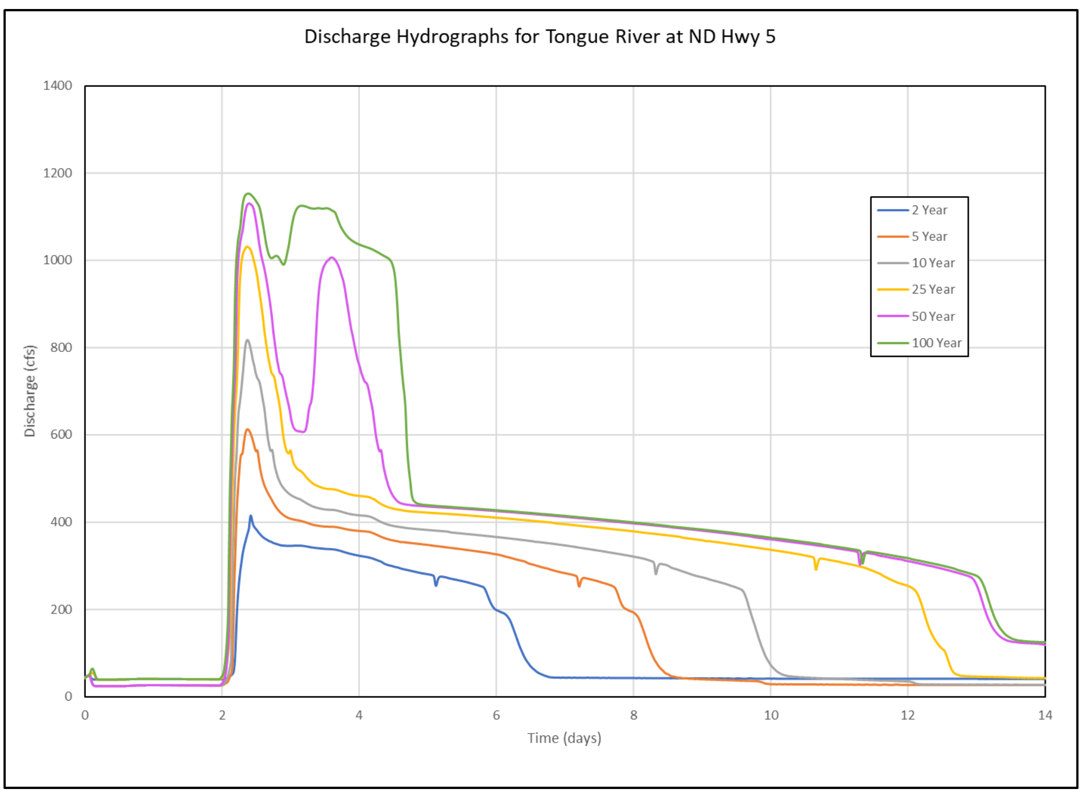


***Figure B.4:*** *Tongue River at 133rd Avenue NE*

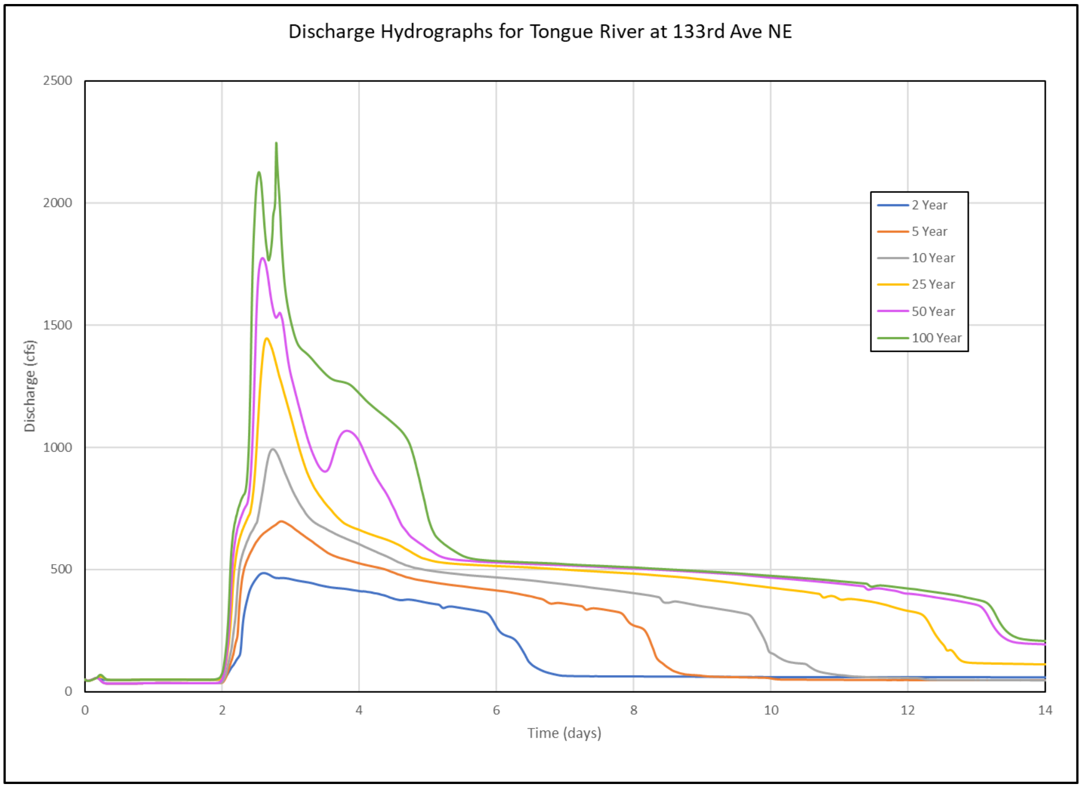



***Figure B.5:*** *Renwick Dam Outflow*

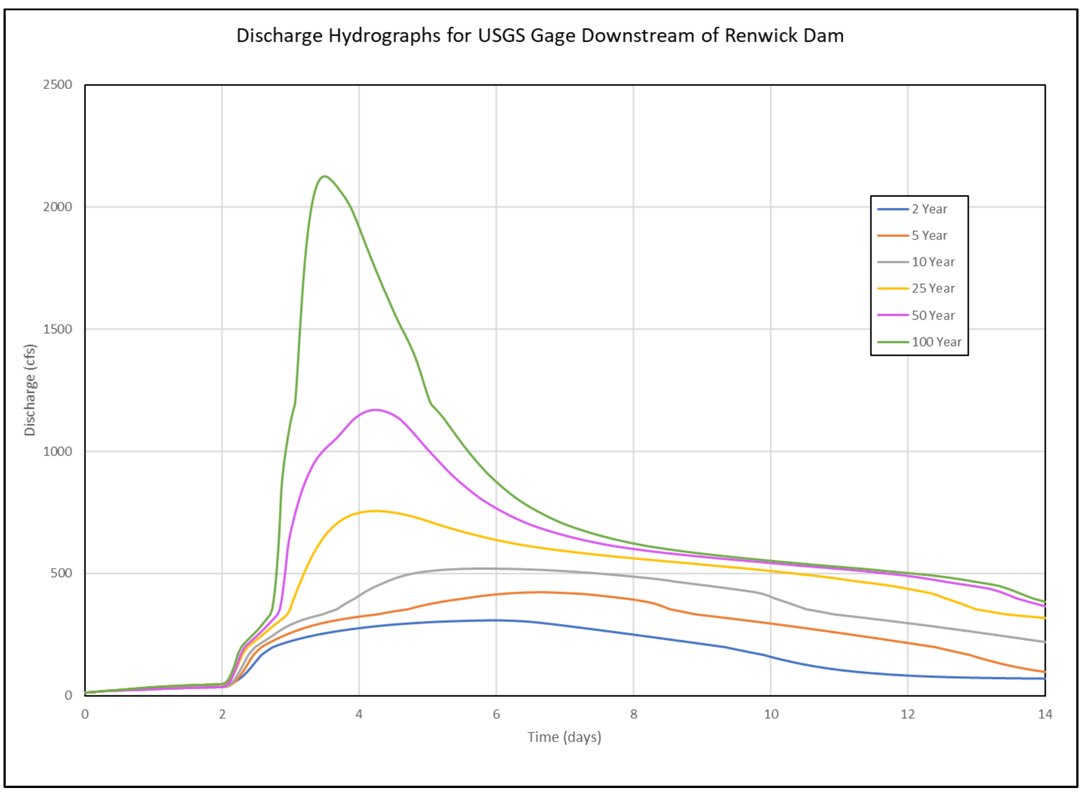
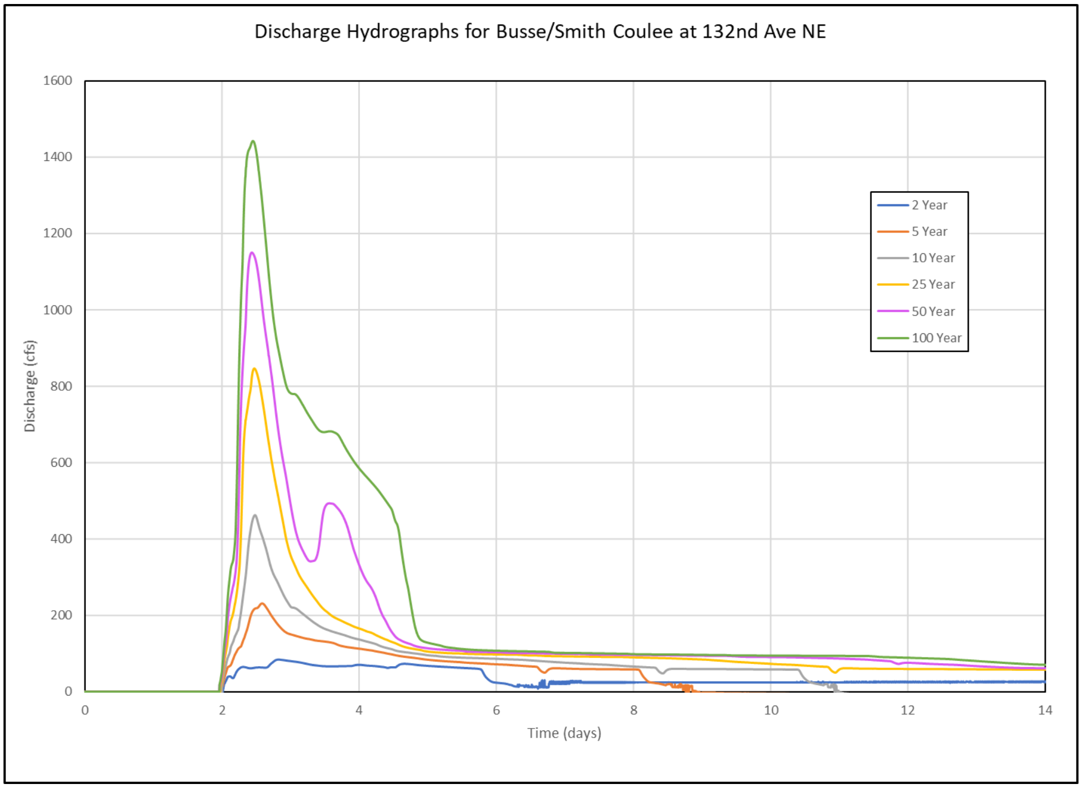
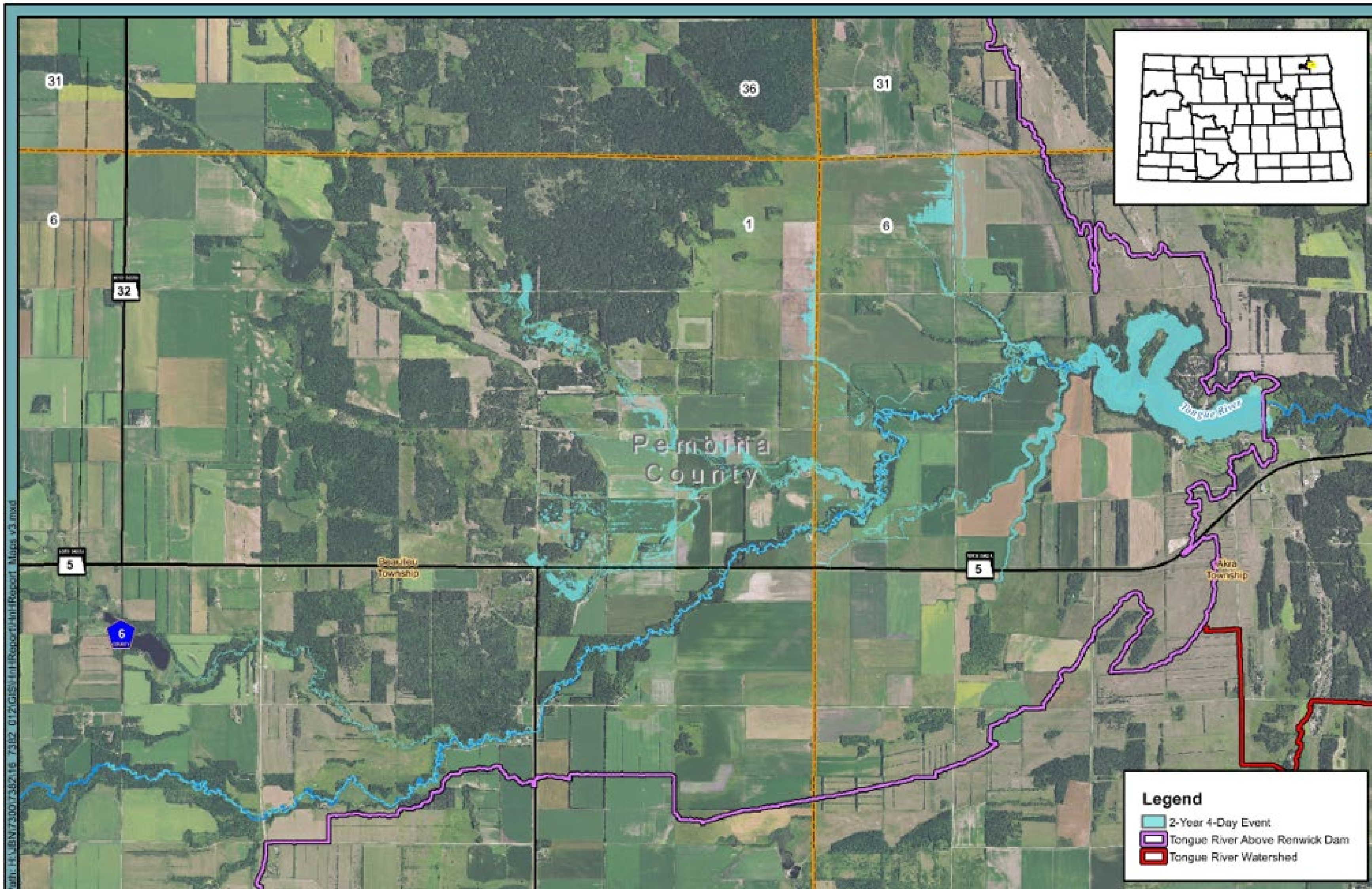


*Figure B.6: Busse/Smith Coulee at 132nd Avenue NE*





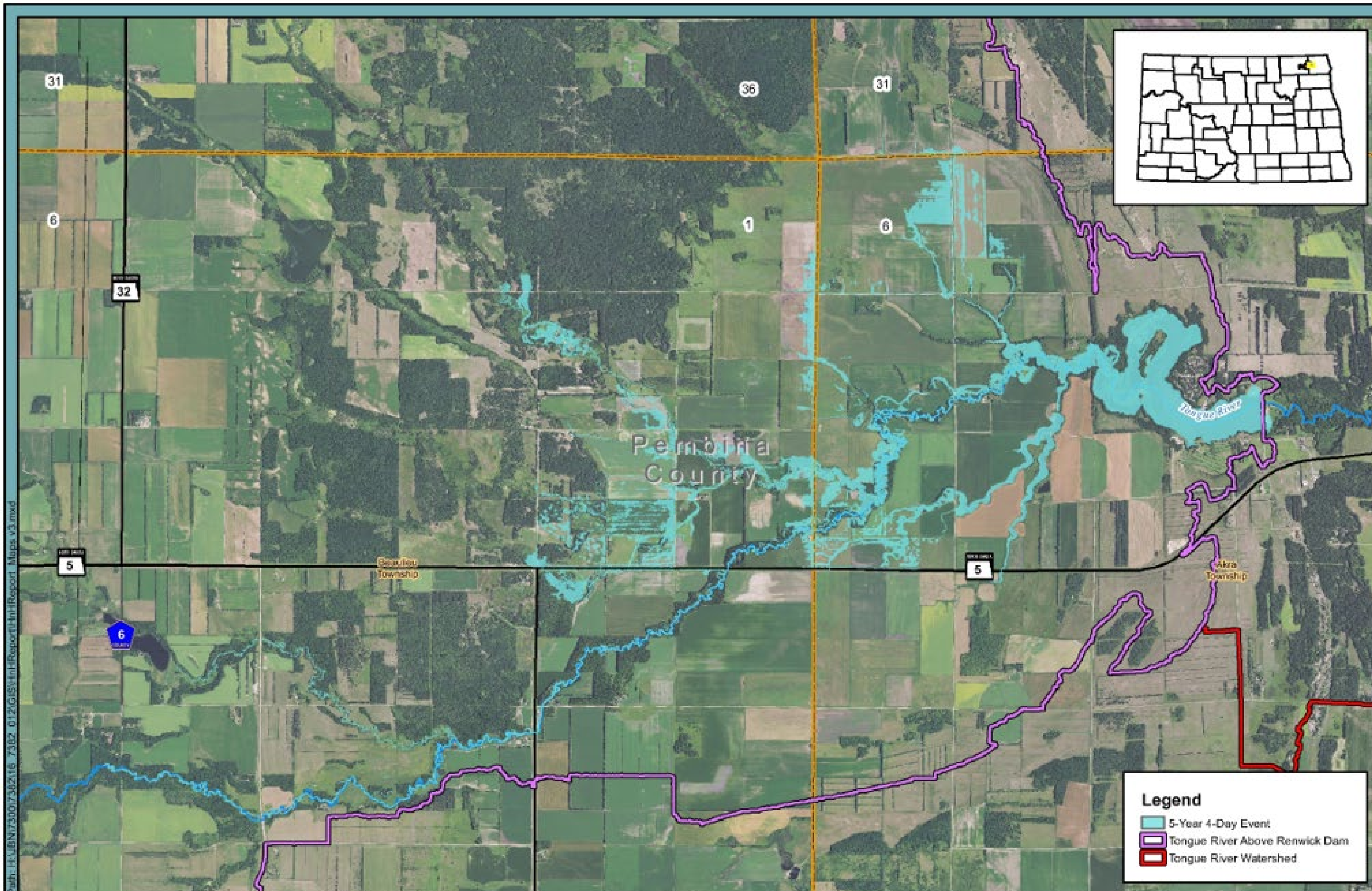

F-B.7

**Figure B.7: 2-Year 4-Day Rainfall Inundation**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

0 0.25 0.5 1 Miles

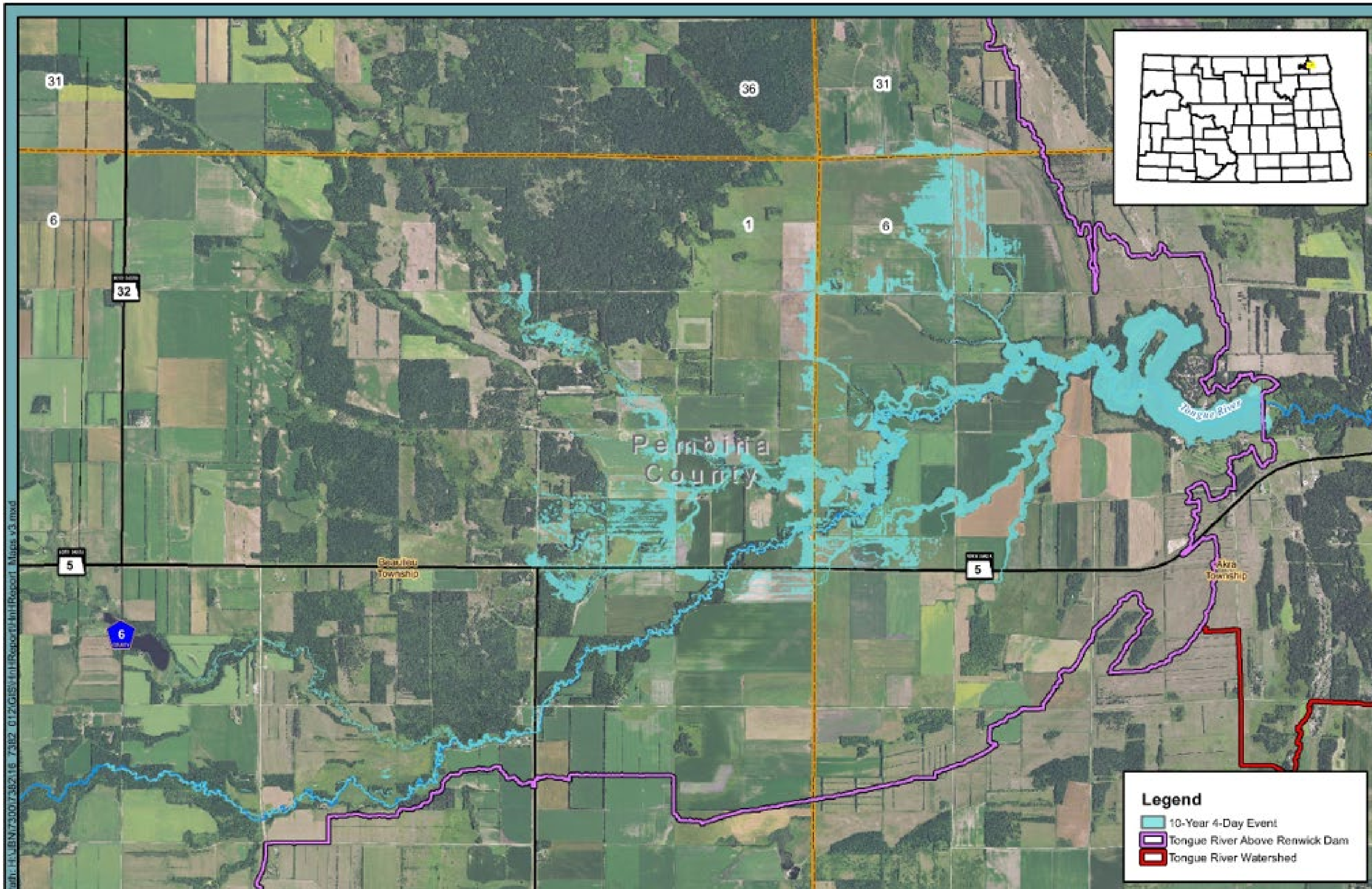
Houston Engineering Inc.




F-B.8

**Figure B.8: 5-Year 4-Day Rainfall Inundation**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District




F-B.9

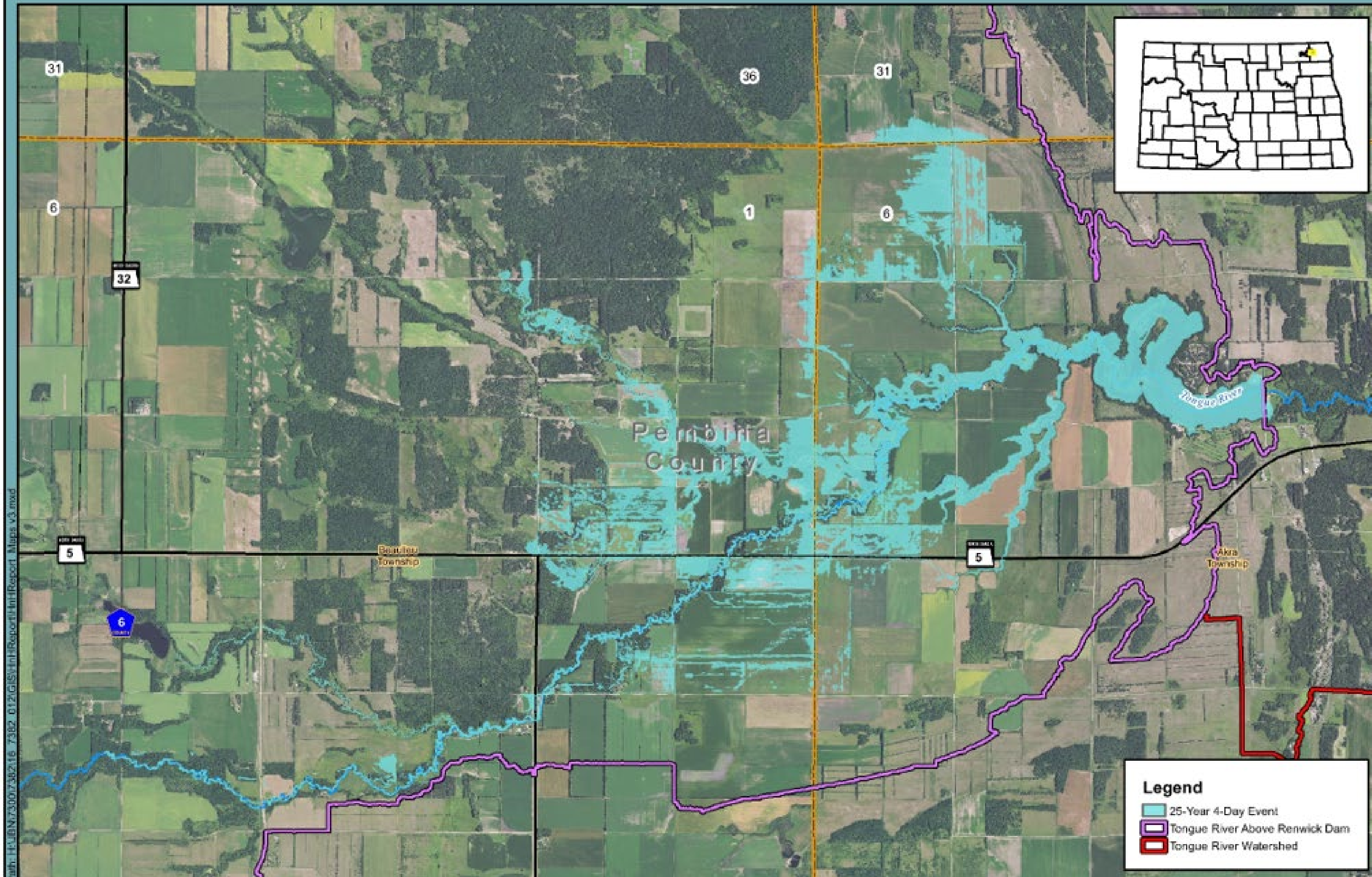
**Figure B.9: 10-Year 4-Day Rainfall Inundation**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

N W E S

0 0.25 0.5 1 Miles

Houston Engineering Inc.




F-B.10

**Figure B.10: 25-Year 4-Day Rainfall Inundation**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

0 0.25 0.5 1 Miles

Houston Engineering Inc.

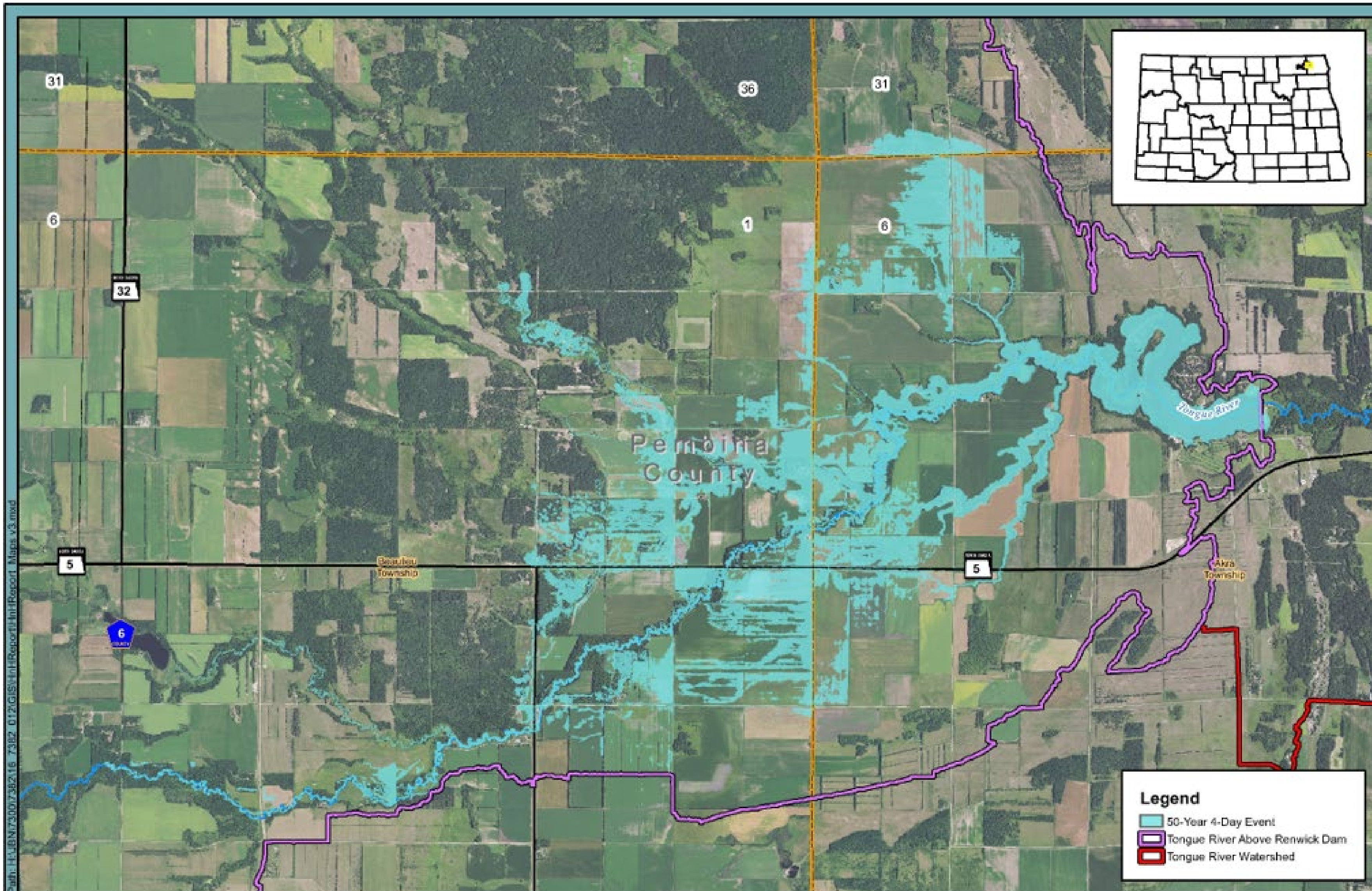
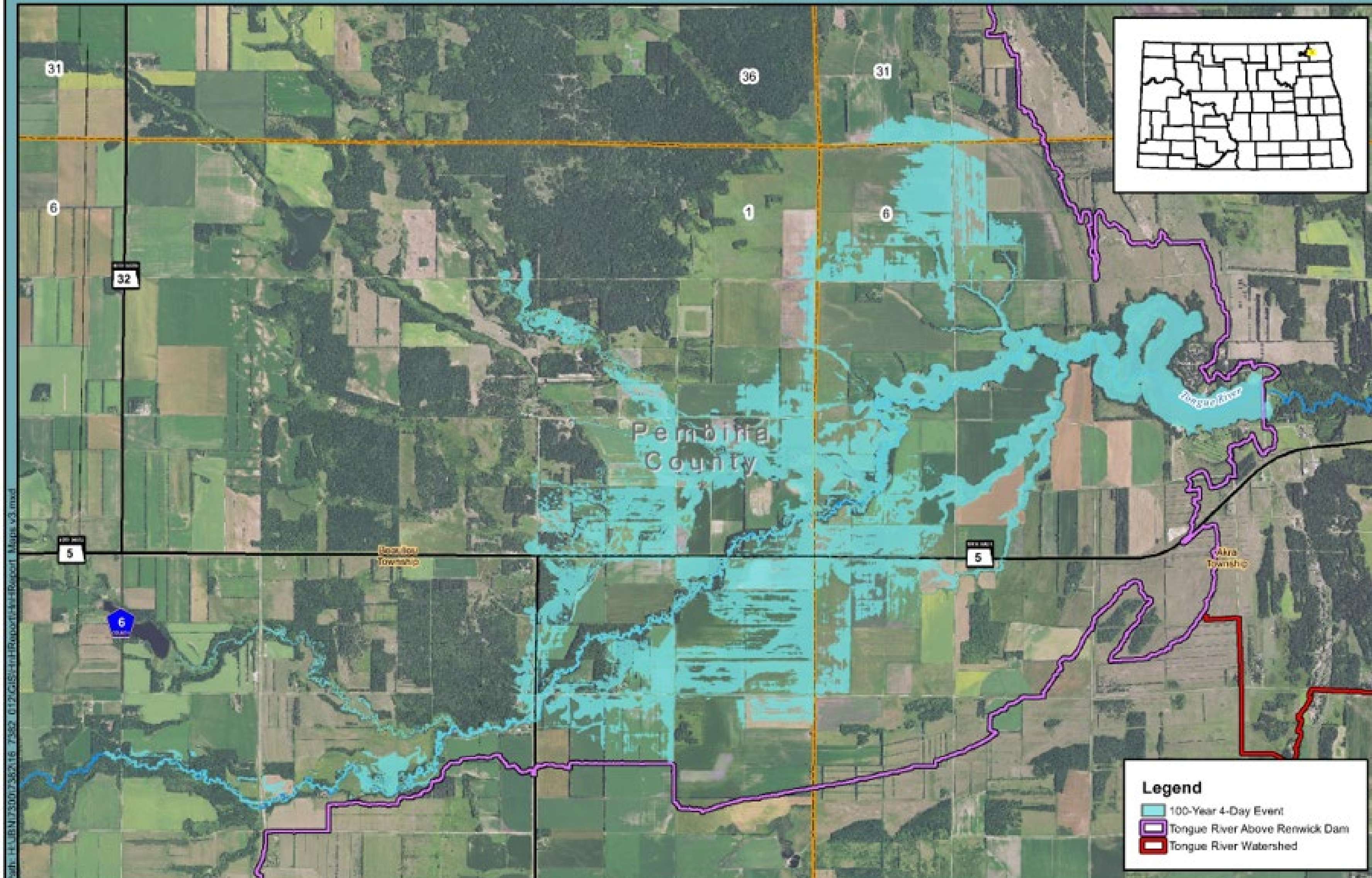



**Figure B.11: 50-Year 4-Day Rainfall Inundation**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District




F-B.12

**Figure B.12: 100-Year 4-Day Rainfall Inundation**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District

N W E S

0 0.25 0.5 1 Miles

Houston Engineering Inc.

# APPENDIX D-2-C

## SYNTHETIC MODEL SENSITIVITY ANALYSIS

# C.1 SYNTHETIC MODEL SENSITIVITY ANALYSIS

After the hydrologic and hydraulic models were calibrated, a sensitivity analysis was completed to assess the applicability of model parameters for floods occurring at different times of the year and for different rainfall event durations. The existing conditions results shown in the sensitivity analyses will not be an exact match with the results shown in the main body of the report due to a change to the version of the hydraulic model that occurred during the study. However, the differences between the results shown in this appendix and what is in the main body of the report are minor (less than 2%). Differences between results for the existing conditions and the sensitivity condition are relative. Changes to the existing conditions hydraulic model would also be made to the hydraulic models that contain parameters changed to quantify the sensitivity analyses. Therefore, the results presented in this appendix are valid even though the existing conditions results shown are not identical to the existing conditions results in the main body of the report.

## C.1.1 MANNING'S N-VALUES

The Manning's N-values in the hydraulic model were established through calibration of the June 2002 event, described in Section 3.3.1. During an early to mid-summer flood event, such as the calibration event, crops are growing, and considerable vegetative cover is provided. To evaluate a minimal vegetative cover condition (crop residue cover), which would be representative of a spring or fall condition, Manning's N-values were adjusted. For a constant flow rate, it's expected that crop residue cover will decrease the channel retardance, thus increasing velocities, decreasing the water surface elevation, and decreasing inundation. A sensitivity analysis was completed by decreasing the Manning's N-value of cropland areas from 0.06 to 0.045 based on guidance from the HEC-RAS Hydraulic Reference Manual (USACE, 2016). The N-values used in the sensitivity analysis are shown in **Table 8.**

**Table 8:** Manning's N-Value Sensitivity – N-Value by Land Use

| Land Use | Existing Conditions / Calibrated Manning's N-Value | Crop Residue Cover Manning's N-Value |
|---|---|---|
| Channel | 0.035 | 0.035 |
| Agricultural / Cropland | 0.06 | 0.045 |
| Wetlands | 0.05 | 0.05 |
| Forested | 0.11 | 0.11 |

To evaluate the sensitivity analysis, discharge hydrographs for the 25-year and 100-year rainfall events were compared for the two conditions. Discharge hydrographs were calculated at the five reporting locations described in Section 4.1. **Figure C.1** shows the reporting locations, and the hydrographs are shown on **Figure C.2** through **Figure C.6**. The peak discharges for the 25-year and 100-year events at these locations are shown in **Table 9.**

**Table 9:** Manning's N-Value Sensitivity – Peak Discharges (cfs)

| Return Period | Manning's N-Value | Tongue River at ND Highway 32 | Tongue River at ND Highway 5 | Tongue River at 133rd Ave NE | Renwick Dam Outflow | Busse/Smith Coulee at 132nd Ave NE |
|---|---|---|---|---|---|---|
| 25-year | Existing Conditions | 1,210 | 1,026 | 1,473 | 752 | 870 |
| | Crop Residue Cover | 1,214 | 1,027 | 1,491 | 752 | 848 |
| | *Difference (%)* | 0.3% | 0.2% | 1.2% | 0.0% | -2.5% |
| 100-year | Existing Conditions | 1,773 | 1,138 | 2,190 | 2,104 | 1,477 |
| | Crop Residue Cover | 1,814 | 1,147 | 2,413 | 2,123 | 1,447 |
| | *Difference (%)* | 2.3% | 0.7% | 10.2% | 0.9% | -2.1% |

The total inundation area was also evaluated for the two Manning's N-value conditions. The total inundation for the 25-year and 100-year rainfall events are shown in **Table 10**.

**Table 10:** Manning's N-Value Sensitivity – Total Inundation (acres)

| Land Use | Existing Conditions / Calibrated Manning's N-Value | Crop Residue Cover Manning's N-Value Sensitivity | *Difference (%)* |
|---|---|---|---|
| 25-year | 1,877 | 1,765 | *-6.0%* |
| 100-year | 2,876 | 2,728 | *-5.1%* |

Due to the minor changes to both peak discharge and total inundation based on the Manning's N-value sensitivity analysis, the original calibrated Manning's N-values were used for the synthetic rainfall analysis. The calibrated Manning's N-value was determined to be ideal because it was developed based on calibration to observed data rather than literature guidance. Also, the primary focus of the planning effort is to reduce agricultural damages occurring as a result of rainfall events. Therefore, the growing season Manning's N-values were deemed appropriate for use in synthetic rainfall analysis

## C.1.2 SYNTHETIC EVENT DURATIONS – 24-HOUR, 4-DAY, 10-DAY

Three synthetic event durations were simulated; 24-hour, 4-day, and 10-day, to determine which duration storm event produces highest peak flow and greatest impacts. The 24-hour and 10-day storms were developed in the same way as the 4-day duration event described in Section 3.4. NOAA Atlas 14 rainfall depths were calculated based on GIS gridded data, the rainfall depths were adjusted based on areal reduction factors in *TP-49* (Miller, 1964). The nested distribution for each duration and return period was calculated based on *NEH, Part 630, Chapter 4* (NRCS, 2015). Runoff Curve Numbers were adjusted to the appropriate duration to match the corresponding synthetic rainfall duration based on guidance from *TR-60* (NRCS, 2005). The average rainfall depths for each duration storm event are shown in **Table 11.**

**Table 11:** Rainfall Duration Sensitivity – Rainfall Depths

| Return Period | NOAA Atlas 14 Rainfall Depth (inches) | | | HEC-HMS Rainfall Depth* (inches) | | |
|---|---|---|---|---|---|---|
| | 24-hour | 4-day | 10-day | 24-hour | 4-day | 10-day |
| 25-year | 4.21 | 5.02 | 5.96 | 4.00 | 4.77 | 6.36 |
| 100-year | 5.57 | 6.52 | 7.47 | 5.29 | 6.19 | 7.09 |

* Average rainfall depth adjusted for areal reduction based on watershed size of 152 square miles

Peak discharges were calculated at the outlet of Renwick Dam for the three storm durations for the 25-year and 100-year events and are shown in **Table 12**. Discharge hydrographs at the outlet of Renwick Dam for the three storm durations are shown on **Figure C.7**. Evaluation of the results indicates that the 4-day duration rainfall event produces the highest discharge at the outlet of Renwick Dam. Additionally, the inundation associated with the 4-day rainfall events causes prolonged flooding of agricultural lands adjacent to the Tongue River. While there are some locations along the Tongue River upstream of Renwick Dam that have higher peak flows for the 24-hour duration rainfall events, the increase in the duration associated with the 4-day rainfall events causes an increase in damages to agricultural lands. Therefore, the 4-day duration event was selected to be analyzed for the synthetic rainfall events for this study.

**Table 12:** Rainfall Duration Sensitivity – Peak Discharges (cfs)

| Return Period | Renwick Dam Outflow | | |
|---|---|---|---|
| | 24-hour | 4-day | 10-day |
| 25-year | 677 | 752 | 603 |
| 100-year | 1,898 | 2,104 | 1,137 |

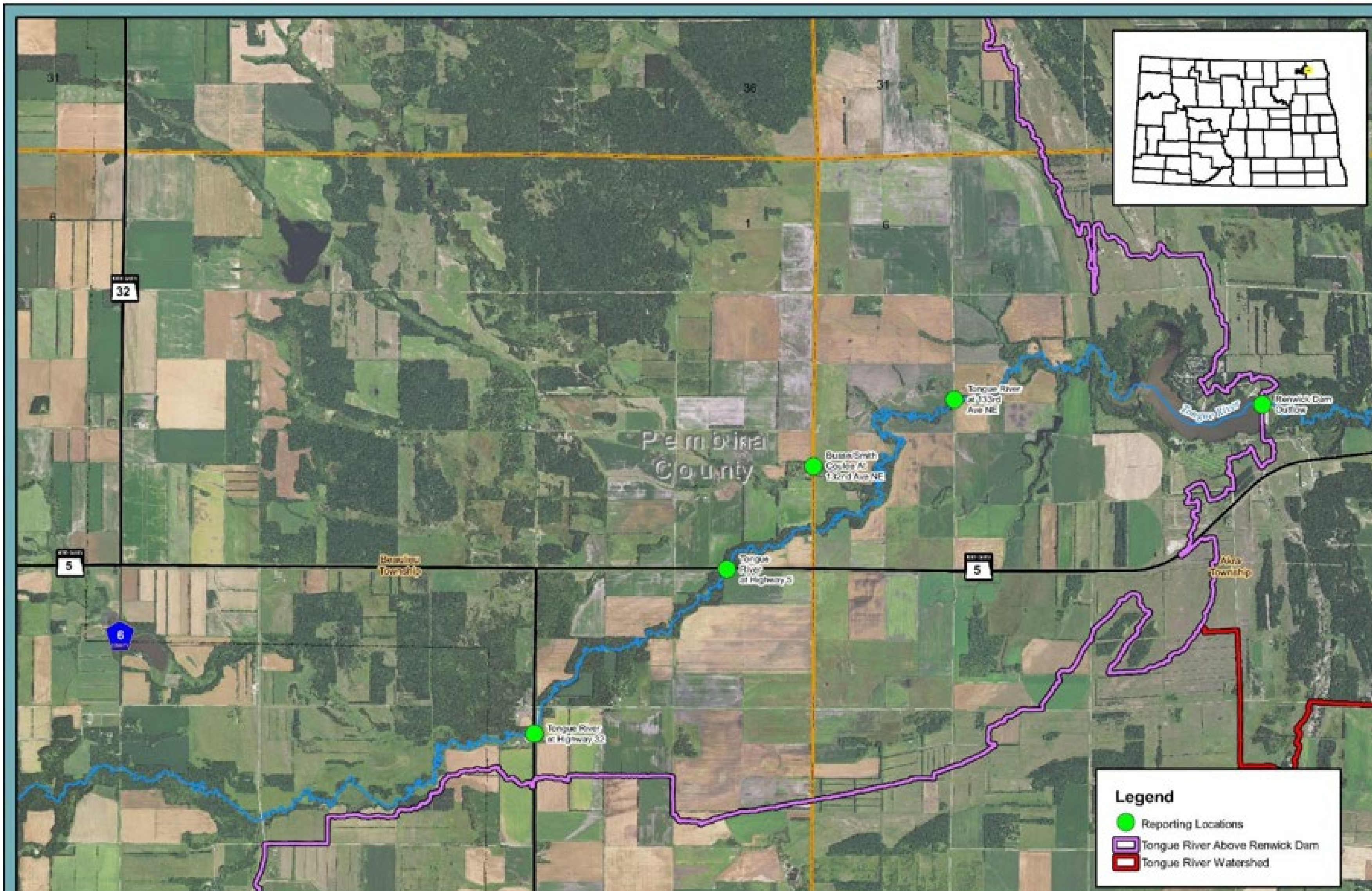
## C.1.3 CURVE NUMBER – SEASONAL VARIATION

Runoff volumes can vary based on multiple factors including the time of year, vegetative cover, and water content within the soil. During the spring, most cropland is covered by a certain degree of crop residue cover depending on individual management practices by producers. During the spring, these types of soil conditions can often result in increased runoff due to decreased infiltration. During the growing season, these same lands consist of vegetative cover from growing crops. The vegetative cover results in decreased runoff due to increased infiltration. However, runoff during any time of the year is also influenced by the water content within the soil. In the Tongue River Watershed, this is primarily driven by the amount of precipitation occurring prior to the rainfall event, and weather patterns allowing for drying of topsoil.

Due to the numerous factors that occur during a specific rainfall event, such as time of the year, vegetative land cover, water content of the soil, etc., synthetic rainfall scenarios are developed to simulate a typical event that would occur within a watershed. A primary focus of the planning effort is to reduce agricultural damages occurring as a result of rainfall events. Therefore, the growing season runoff Curve Number values were deemed appropriate for use in synthetic rainfall analysis. Growing season Curve Numbers used for synthetic rainfall scenarios are described in **Appendix A** of this report.

# APPENDIX D-2-C

## *Synthetic Model Sensitivity Analysis*




F-C.1

**Figure C.1: Sensitivity Analysis Reporting Locations**

Tongue River Watershed Plan - Appendix D-2
Existing Conditions Hydrology and Hydraulics Report
Pembina County Water Resource District



Houston Engineering Inc.

***Figure C.2:*** *Manning's N-Value Hydrographs – Tongue River at ND Highway 32*

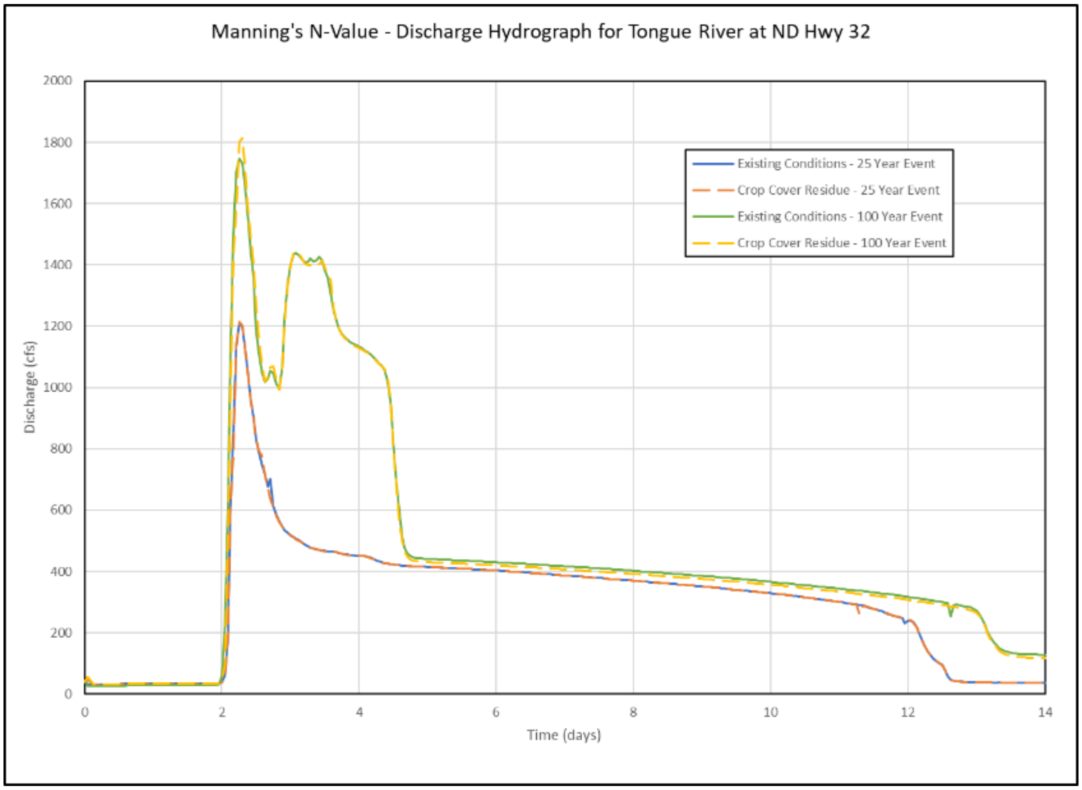



***Figure C.3:*** *Manning's N-Value Hydrographs – Tongue River at ND Highway 5*

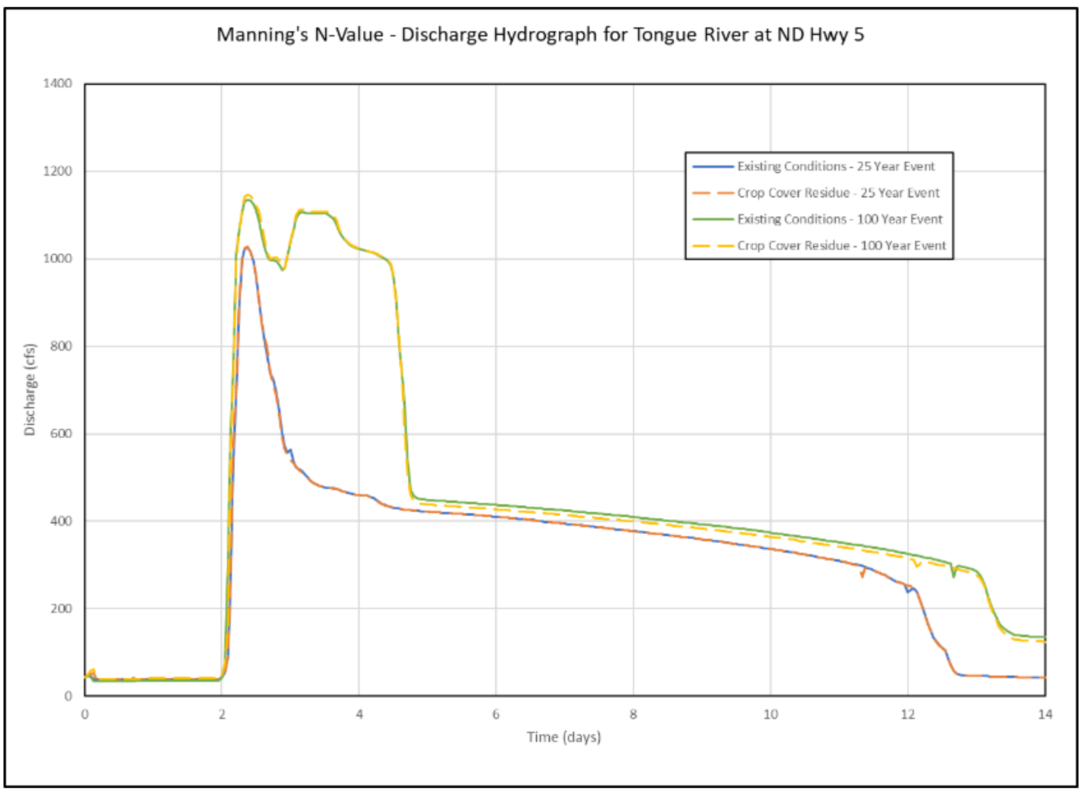


***Figure C.4:*** *Manning's N-Value Hydrographs – Tongue River at 133rd Avenue NE*

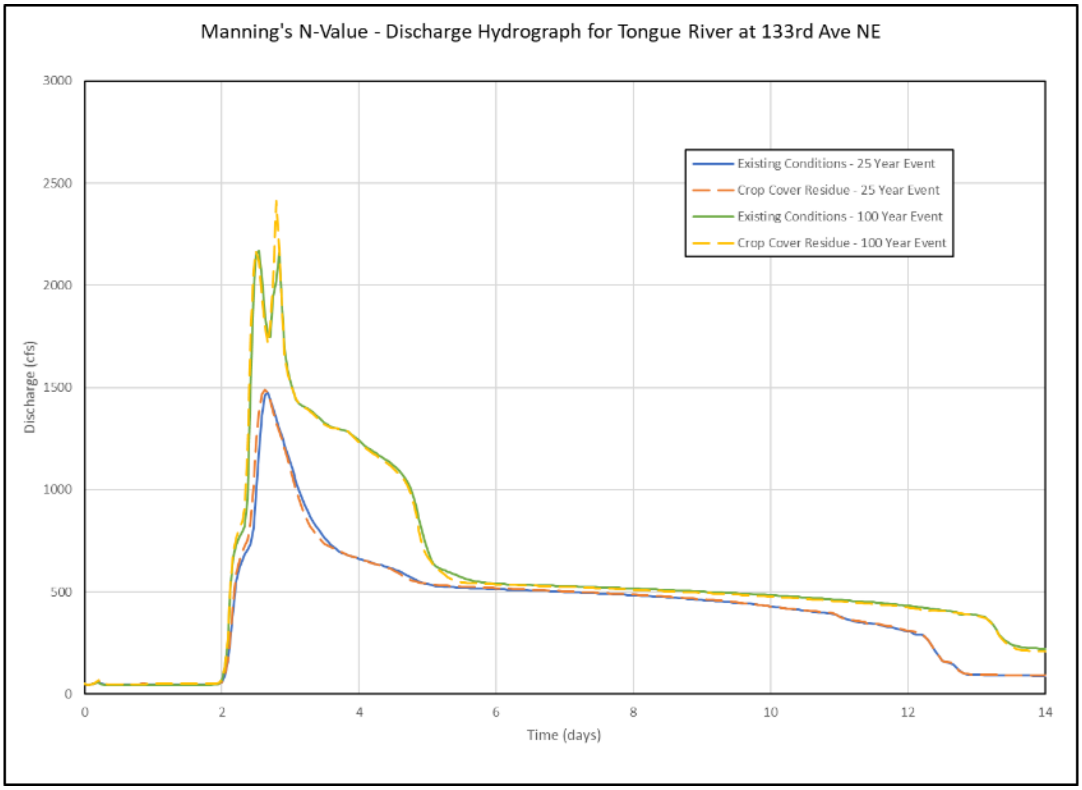



***Figure C.5:*** *Manning's N-Value Hydrographs – Outflow from Renwick Dam*

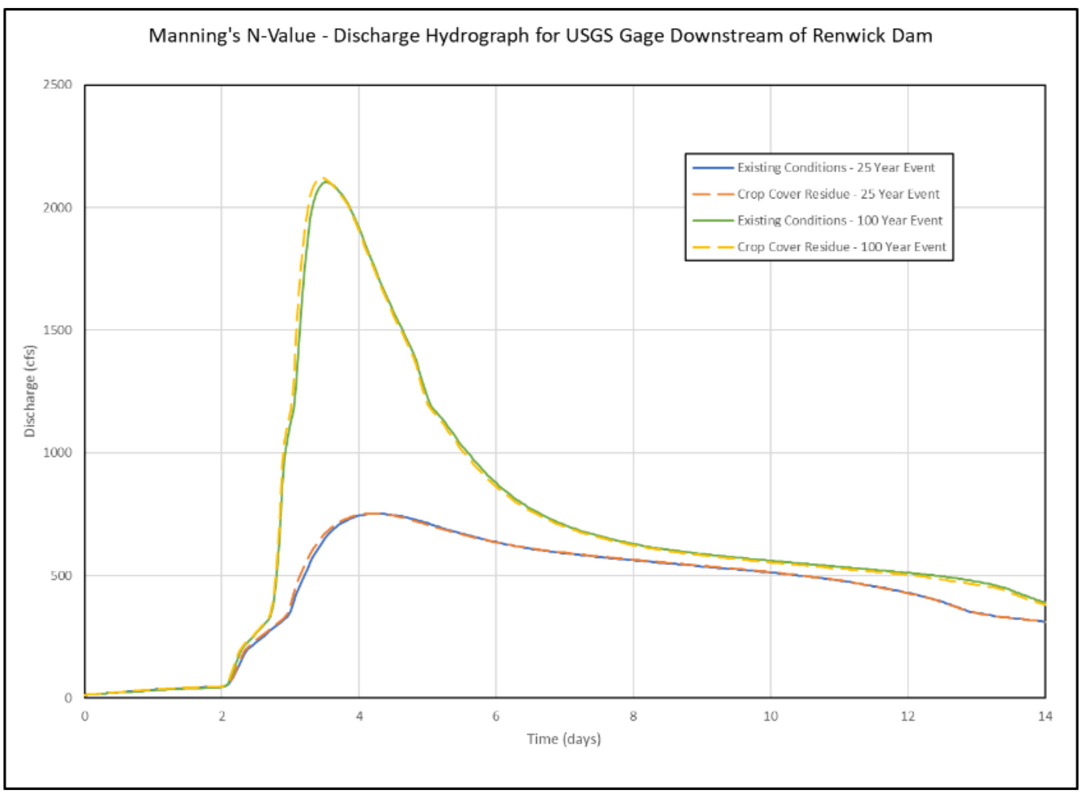


***Figure C.6:*** *Manning's N-Value Hydrographs – Busse/Smith Coulee at 132nd Avenue NE*

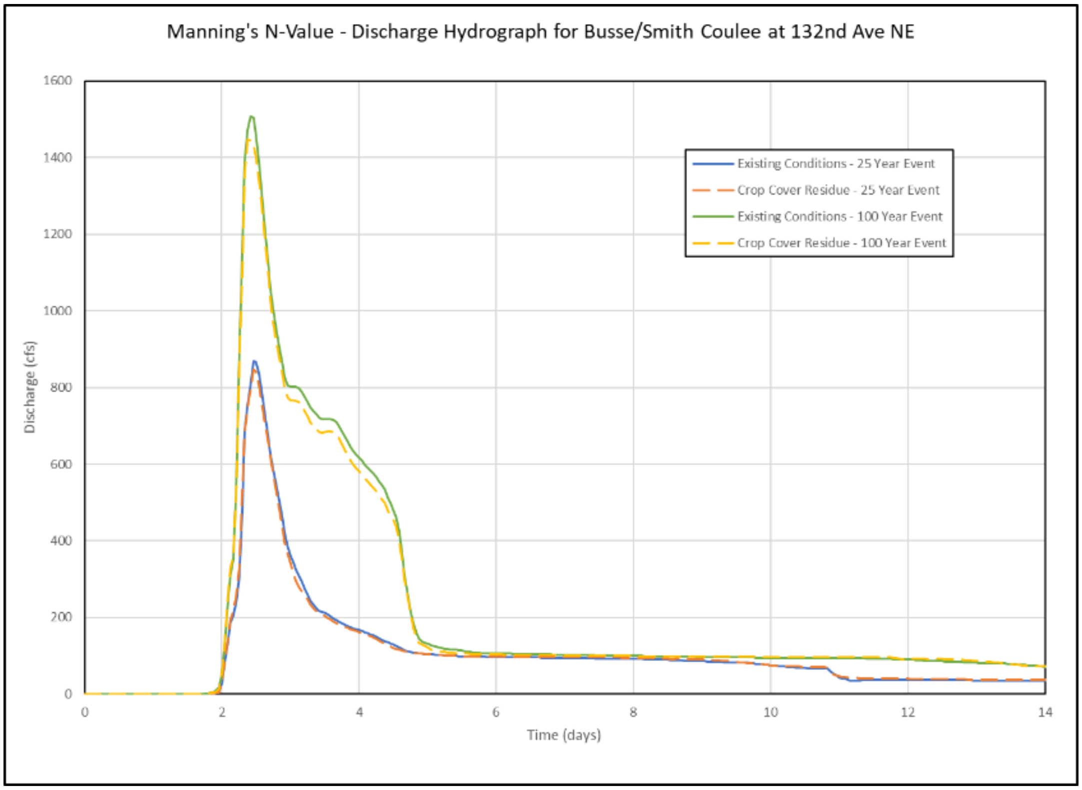



***Figure C.7:*** *Duration Hydrographs – Outflow from Renwick Dam*