APPENDIX D

INVESTIGATIONS AND ANALYSES

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Fargo, ND | HEI No. 8150-0002
June 26, 2020

May 22, 2013 – Cart Creek at Crystal, ND Looking Southeast

NORTH BRANCH PARK RIVER WATERSHED PLAN: APPENDIX D-1

Existing Conditions Hydrology and Hydraulics Report

NORTH BRANCH PARK RIVER WATERSHED PLAN

EXISTING CONDITIONS HYDROLOGY AND HYDRAULICS REPORT

June 26, 2020

Park River Joint Water Resource District

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

Bret T. Zimmerman, PE PE-10646	Paul D. LeClaire, PE PE-28012
Date	Date

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1 INTRODUCTION

The Park River Joint Water Resource District (PRJWRD) is a joint powers agreement between the Walsh and Pembina County Water Resource Boards formed in response to major flood damages after the May 2013 spring rainfall event. The PRJWRD entered into a Cooperative Agreement with the Natural Resource Conservation Service (NRCS) in 2015 to complete a Watershed Plan through the Regional Cooperation Partnership Program (RCPP) for the North Branch Park River Watershed. Prior to entering into the Cooperative Agreement, locally led planning was already underway by the PRJWRD. Data developed from this previous planning that is applicable to the NRCS Watershed Planning effort will be completed through the Cooperative Agreement.

The North Branch Park River Watershed is a subwatershed of the Park River Watershed and is shown on **Figure D-1-1**. 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 North Branch Park River Watershed Planning effort. This includes previously developed base data and models and development of existing conditions models used for the North Branch Park 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* (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 taking into account unique characteristics within each subwatershed that may influence flooding.

2.1 HEC-HMS MODEL DEVELOPMENT

Development of the HEC-HMS model for the Park River Watershed was completed through the *Red River of the North Hydrologic Modeling – Phase 2* effort (USACE, 2013). This section provides a brief overview of the development of the HEC-HMS model that was initially used and subsequently modified as part of the North Branch Park 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 Park River Watershed (USACE, 2014).

2.1.1 DRAINAGE AREA DELINEATION

LiDAR topographic data made available through the International Water Institute (IWI) (IWI, 2008-2009) 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).

2.1.2 TIME OF CONCENTRATION

Travel time grids were created for each 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 (slope, flow direction, flow accumulation, etc.). The reconditioning process involves manipulating LiDAR data so that drainage paths are not obstructed by roads or other embankments. Reconditioning is most often used in instances where bridges or culverts take flows under roadways where raw LiDAR data shows an obstruction. The Travel Time Routine assigns a Manning’s N-value based on the accumulated flow developed from LiDAR reconditioning 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 Routine served as an initial time of concentration (Tc) estimate for each subbasin, with further refinements through calibration to historic flood events. Time of concentration values for the 51 subbasins in the HEC-HMS model ranged from 4.5 hours to 45 hours.

2.1.3 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.

2.1.4 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 values for various crop cover types and land uses that were applied in the *Red River of the North Hydrologic Modeling – Phase 2* study are identical to CN values with the same crop cover and land use that are available in the latest NRCS guidance (NRCS, 2004). The CN conversion table used for the Red River Basin is shown in **Attachment D-1-A**. This information was applied to create a Red River Basin 24-hour AMC II CN gridded GIS dataset.

2.1.5 REACH ROUTING

Model reaches were derived using reconditioned LiDAR data (reconditioning LiDAR data is described in more detail in Section 2.1.2). 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.

2.1.6 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 subwatersheds were calibrated to two historic rainfall events. The two historic rainfall events used for calibration of the Park River Watershed were in May of 2010 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.

2.1.7 SYNTHETIC MODEL DEVELOPMENT

Synthetic modeling parameters for the calibrated Clark's Storage Coefficients and time of concentration were averaged from the calibrated events. Curve Number parameters were reset 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 and 10-day duration rainfall events, and a 100-year, 10-day runoff event. For more specific information on calibration for the Park River Watershed, refer to the USACE Final Report for the Park River Watershed (USACE, 2014).

3 NORTH BRANCH WATERSHED PLAN EXISTING CONDITIONS

The North Branch of the Park River Watershed (North Branch Watershed) is an approximate 257 square mile subwatershed of the 986 square mile Park River Watershed. The Park 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 baseline model and modified to meet requirements for the North Branch 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 model, and development of synthetic rainfall event simulations.

3.1 HEC-HMS MODEL MODIFICATIONS

Modifications were made to the Park River Watershed HEC-HMS base model to add additional detail within the North Branch Watershed. The hydrologic model was completed as necessary for inflow locations to the HEC-RAS hydraulic model that was developed for a portion of the North Branch Watershed. These modifications are discussed in the following subsections.

3.1.1 SUBBASIN BOUNDARY MODIFICATIONS

The HEC-HMS model used in the North Branch Watershed Planning effort is primarily used to develop inflow hydrographs for the HEC-RAS unsteady state flow model that is discussed in Section 3.2. Subbasins were delineated to match HEC-RAS model geometry components, such as hydraulic routing storage locations, road crossings, and other critical hydraulic locations. A comparison of the initially developed subbasins and subbasins modified for the North Branch Watershed Plan is shown on **Figure D-1-3.1.1.** These modifications resulted in 232 subbasins compared to 51 subbasins from the Phase II study. The modified subbasins were reduced in size from an average of 19 square miles from the Phase II study to an average of 4 square miles.

3.1.2 RUNOFF CURVE NUMBER

Initial runoff Curve Numbers for the modified subbasins were estimated by overlaying the Curve Number grids described in Section 2.1.4 with the modified subbasins. 24-hour AMC II Curve Numbers values for the modified subbasin are displayed in **Figure D-1-3.1.2.** The values range from 61 to 81 throughout the watershed.

3.1.3 INITIAL UNIT HYDROGRAPH PARAMETERS

Initial unit hydrograph parameters were estimated for the Clark’s Storage Coefficient (R) and time of concentration (Tc) using the same methodology used for the Phase II study discussed in Section 2 of this report. 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 in **Figure D-1-3.1.3**, R/Tc values generally increase in the western portion of the North Branch 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. While flood storage is available in the downstream portion of the Park River Watershed, most of this storage is more pertinent to reach routing parameters within the HEC-HMS model.

3.1.4 REACH ROUTING MODIFICATIONS

With additional subbasins in the North Branch Watershed, additional reaches were required in the model. The same general methodology from the initial model development for reach routing was used in the modified HEC-HMS model. Muskingum Cunge was used along the beach ridge and upper portions of the watershed, and Modified Puls routing was used in the lake plain. In the North Branch Watershed, the Pembina County and Cavalier County line is approximately where the transition occurs from beach ridge to lake plain. The existing conditions HEC-HMS model schematic and reach routing methods are shown on **Figure D-1-3.1.4.** While reach routing is critical for portions of the HEC-HMS model that do not overlap the HEC-RAS hydraulic model, it should be noted that reach routing general does not affect inflows into the HEC-RAS model where the models overlap. This is because HEC-HMS subbasin outflows are directly applied to the HEC-RAS model in areas where the two models overlapped.

3.2 HYDRAULIC (HEC-RAS) MODEL

An unsteady HEC-RAS (v.5.0.3) 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 2014 through the previous planning effort that was underway at the beginning of the North Branch Watershed Planning effort. This initially developed HEC-RAS model was adopted and further modified for the NRCS Watershed Planning effort. The HEC-RAS model consists of channel cross sections to route the channel flows and the HEC-RAS 1-dimensional storage area elements to route the overland or breakout flows. The extent of the channel cross sections is described below, and the HEC-RAS model schematic shown on **Figure D-1-3.2**:

- The North Branch of the Park River from upstream of North Dakota State Highway No. 66 near Milton, ND, to the confluence with the Middle Branch Park River approximately 4 miles northwest of Grafton, ND.
- Cart Creek from upstream of North Dakota State Highway No. 32 near Mountain, ND, to the confluence with the North Branch of the Park River.
- Four unnamed tributaries to Cark Creek. The unnamed tributaries were modeled with channel cross sections because they were identified as areas with high flows during storm events. Modeling these locations with storage areas would not provide enough detail to analyze the flows.

3.2.1 STORAGE ROUTING

Storage routing is used to account for floodplain storage that is available where landscape slopes flatten as the beach ridge transitions to the lake plain. Storage areas allow the model to account for floodplain storage available to out of bank flows. Storage areas are connected to cross sections and other storage areas to hydraulically route flows through floodplain areas.

Due to the flat topography in the lake plain, 1-dimensional storage areas are used for the North Branch Watershed. Storage areas were initially delineated along section lines resulting in 1 square mile storage areas. The 1 square mile storage areas were then subdivided along natural drainage divides. Calibration of the hydraulic model, with 1-dimensional storage areas, verified floodplain flow rates and timing based on the modeled versus observed hydrograph. The inundation extents and the timing of the simulated historic event was compared to aerial photography captured during the event and to USGS Streamgage data. Model calibration is further discussed in Section 3.3.

During large flood events, overland flows leave the North Branch Watershed and breakout into the larger Park River Watershed. To account for these out of system breakout flows, 1-dimesional storage areas were added along the outside edges of the North Branch Watershed boundary. These boundary storage areas act like “sinks” and allow the overland flows to breakout of the watershed. Input parameters and model background data is described in the following sections.

3.2.2 CHANNEL BATHYMETRY AND HYDRAULIC STRUCTURES

Survey data for the North Branch Watershed was previously collected as part of the planning effort that was underway when the North Branch Watershed Planning effort began. Survey data was collected by Houston Engineering, Inc. (HEI) in the spring of 2014. Data that was collected consisted of river channel hydraulic structures, river channel cross sections near hydraulic structures, and other culverts and bridges in the floodplain that convey breakout waters during large events. The survey data that was collected is shown on **Figure D-1-3.2.2**.

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, 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. Manning’s N-values were set through calibration of the HEC-RAS and HEC-HMS models. Manning’s N-values in the existing conditions hydraulic model are shown in Table 1.

Table 1: Manning's N-Values by Land Use

Land Use	Manning’s N-Value	Normal Range
Channel	0.039	0.033 – 0.045
Agricultural / Cropland	0.041	0.025 – 0.045
Wetlands	0.04	0.035 – 0.07
Forested	0.09	0.08 – 0.12

3.2.4 INFLOWS

Hydrographs generated from the HEC-HMS model were applied to the HEC-RAS model to simulate storm events. Hydrographs from junctions within the HEC-HMS model 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

As part of the Grafton Area Flood Risk Reduction (GFRR) Project, the City of Grafton created an unsteady HEC-RAS model for the Park River including the lower reaches of the North, Middle, and South Branches of the Park River. The GFRR model consists of channel cross sections and 1-dimensional storage areas. The GFRR model was linked to the North Branch model to verify that the tailwater condition near the North Branch Park River outlet is accurate, verify overland breakout flow locations, and to extend the model to the USGS Streamgage in Grafton for calibration purposes. The expanded HEC-RAS model schematic is shown on **Figure D-1-3.2.5a**.

After calibration of the model (discussed in Section 3.3), the expanded HEC-RAS model was truncated to the model extents described in Section 3.2 and shown on **Figure D-1-3.2**. A stage-discharge rating curve developed from the larger HEC-RAS model is applied as the tailwater boundary condition to the downstream cross section in the truncated model. This truncated model extent, as compared to the expanded model extent from calibration, was used to allow for faster computation run times and to improve model stability for future model development. The truncated model covers the entire study area and produces identical results to the expanded model. Hydrographs comparing the results of the two model geometries at the outlet of the North Branch Park River (including breakout flows) is shown in **Figure D-1-3.2.5b**.

3.3 CALIBRATION

The hydrologic and hydraulic models were calibrated based on a rainfall event that occurred in late May of 2013. The 2013 event produced between 3 to 8 inches of rain in the Park River Watershed over a 4-day period from May 18th through May 21st. There was only a trace amount of rainfall (± 0.2") 10 days prior to the event. The rainfall depths used for the simulation spans from May 16th to May 23rd, which includes minimal rainfall before and after the 4-day period described. Total rainfall depths from May 16th to May 23rd are shown on **Figure D-1-3.3a**.

Documented historic data that was used for calibration of the model included: observed rainfall depths, NEXRAD rainfall data, discharge measurements at the Park River USGS Streamgage 05090000 at Grafton, ND, aerial photography in the North Branch Park River Watershed taken by the Civil Air Patrol on May 22, 2013 around 5:00 PM local time, and Homme Reservoir average daily discharge data derived from the outlet rating curve based on stage measurements. These independent sources of historic data provide calibration benchmarks within three separate regions of the Park River Watershed.

Hydrographs in the hydraulic model were compared to the recorded discharge at the Park River USGS Streamgage 05090000 at Grafton, ND. The observed discharge hydrograph and the simulated HEC-RAS model discharge hydrograph are shown on **Figure D-1-3.3b.** The simulated HEC-RAS peak flow rate and volume are consistent with observed flow rates and volumes at the gage during the event. Table 2 summarizes the peak flow rates and timing, as well as the 3-day and 5-day volumes centered on the peak flow rate (i.e. the 3-day and 5-day volumes were computed by finding the area under the hydrograph centered on the peak ±1.5 days and ±2.5 days respectively).

Table 2: Peak Flow and Volume Comparison at USGS Gage 05090000 near Grafton, ND

Location	Peak Flow (cfs)	Peak Flow Time	Volume (Ac-Ft) 3-Day	5-Day
USGS Gage 05090000 at Grafton	6,010	5/23/13 0:00	27,527	37,575
HEC RAS Model	5,943	5/23/13 0:00	27,464	37,467
% Difference	1.1%	-	0.2%	0.3%

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 5:00 PM local time. The Civil Air Patrol captured three photographs along Cart Creek near Crystal, ND, two photographs along the North Branch Park River north of the confluence with the Middle Branch Park River, and one photograph along the Park River near the confluence with the South Branch Park River. The photograph locations, HEC-RAS model floodplain inundation, and photographs are shown in **Figure D-1-3.3c** through **Figure D-1-3.3m**. There are two inundation extents shown for modeled inundation. One represents the maximum inundation that occurred during the event, and one shows the modeled inundation on May 22 at 5:00 PM (approximate time that the Civil Air Patrol photos were taken). The HEC-RAS inundation extent at the approximate time the photographs were taken was compared to the photographs to validate that the modeled floodplain extents generally matched the actual floodplain extents indicated in the photographs. The aerial photographs also show high-water indicators, such as darker soils where the floodplain has receded. The HEC-RAS maximum inundation extents were also compared to these high-water indicators to validate the modeled floodplain. The validation of the floodplain extents both at the time of the photographs and the maximum inundation provide a qualitative verification of the calibration event.

Daily average discharges recorded at USGS Streamgage 05088500 at Homme Reservoir on the South Branch Park River near the city of Park River, ND were also used during calibration. The gage is operated in cooperation between the USACE and the USGS. The gage only records average daily stages. A known stage-discharge rating curve for the outlet structure of the reservoir is used to derive an average daily discharge. Average daily data does not typically record enough information for a detailed calibration of a historic event. However, this historic information can be useful for verification of the timing and volume of runoff in the South Branch Park River. A hydrograph showing the recorded daily average discharge and the HEC-HMS model simulated discharge is shown on **Figure D-1-3.3n**.

Runoff Curve Numbers were adjusted to produce the quantity of runoff volume recorded at the USGS gaging station in Grafton, ND. Due to the majority of the rainfall occurring over a 4-day period, 4-day Curve Numbers were used with a dry antecedent moisture condition (AMC I). This antecedent moisture condition was reviewed based on guidance from the *National Engineering Handbook (NEH)* (NRCS, 2004), and is valid based on recording only trace amounts of rainfall (± 0.2”) in the days prior to the event.

Cultivated crop Curve Numbers are indicative of a growing season condition where crop maturity would result in increased demand on the water budget, thus reducing excess runoff. In the North Branch Watershed, the growing season condition would be the expected conditions in mid to late summer when crop growth rate is peaking, and crops are nearing maturity. Based on guidance from *TR-55* (NRCS, 1986), a fallow cover type with crop residue cover is indicative of conditions prior to any seasonal agricultural operations occurring and fall tillage conditions are still present. In the North Branch Watershed, these conditions would be expected during spring runoff. Due to the early stages of seeded crop development conditions in the watershed at the time of the calibration event, the land cover condition for the North Branch Watershed was somewhere between the cultivated crop cover condition and fallow with a crop residue cover condition.

During calibration, adjustments were made to the Curve Numbers to reflect anticipated land cover and antecedent moisture conditions. These adjustments resulted in similar modeled runoff volumes as compared to observed data at the Grafton gaging station. The calibrated Curve Numbers were then compared to the Curve Numbers for cultivated crops and fallow cover type with crop residue cover, as defined in *TR-55* (NRCS, 1986). The 4-day Curve Numbers, for the proper antecedent moisture condition (AMC I), for cultivated crops, fallow cover type with crop residue cover, and the calibrated Curve Numbers are shown in **Table 3**. The calibrated Curve Numbers are between the anticipated peak crop development conditions and the anticipated spring cover conditions. Therefore, the calibrated Curve Numbers are valid for the land cover condition that was present in the North Branch Watershed at the time of the event. Section 4.2.3 contains additional discussion on the seasonal variation of Curve Numbers

Table 3: 4-Day Calibration Curve Number Comparison

Land Cover Type	CN for Hydrologic Soil Group			
	A	B	C	D
Anticipated Peak Crop Development Conditions (Cultivated Crops**,** Attachment D-1-A)	35	45	54	58
Anticipated Early Crop Development (Calibration Event)	43	53	61	65
Anticipated Spring Cover Conditions (*TR-55* Fallow Cover Type with Crop Residue Cover)	49	61	69	73

* Cultivated crops consist of 80% row crop and 20% small grains in good condition – contoured and terraced (*TR-55*)

Unit hydrograph parameters in the HEC-HMS hydrologic model were adjusted during calibration. The R and Tc parameters were adjusted to alter the shape and timing of the runoff hydrographs. The parameters were adjusted spatially based on the subbasins. Reasonable modifications were made to both R and Tc during calibration, and the final R/Tc ratios from calibration are shown on **Figure D-1-3.3o.**

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 generally assumed to be lower than normal based on the event occurring in May. A sensitivity analysis on Manning's N-values is discussed in Section 4.2.1. Overbank reach lengths were digitized utilizing GIS and the resultant HEC-RAS model floodplain. Storage area connection coefficients were generally set to the default value of 2.0.

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 back to initial values described in Section 2.1.4. The calibrated HEC-RAS hydraulic model used to analyze synthetic rainfall events is described in Section 3.2.

Synthetic rainfall events were developed based on NOAA Atlas 14 rainfall depths with a 4-day duration. 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). Areal reduction factors were developed for the 24-hour, 4-day, and 10-day duration storms. Runoff Curve Numbers were adjusted to the appropriate duration to match the corresponding synthetic rainfall duration based on guidance from *TR-60 Earth Dams and Reservoirs* (NRCS, 2005). The 4-day duration NOAA Atlas 14 average rainfall for the synthetic events are shown in Table 4 along with the values used in the hydrologic model which had an areal reduction factor of 0.948 applied to them (based on guidance in *TP-49 Two- to Ten-Day Precipitation for Return Periods of 2 to 100 Years in the Contiguous United States*). The 4-day duration storm was used for this analysis because it produces the greatest peak flow compared to the 24-hour and 10-day duration storms. A sensitivity analysis was completed on the 24-hour, 4-day, and 10-day duration events and is discussed in Section 4.2.2.

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-, 100-, and 500-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.

Table 4: 4-Day Rainfall Depths

Return Period	NOAA Atlas 14 4-Day Rainfall Depth (inches)	HEC-HMS 4-Day Rainfall Depth* (inches)
2-year	2.85	2.70
5-year	3.55	3.37
10-year	4.17	3.95
25-year	5.09	4.83
50-year	5.85	5.55
100-year	6.66	6.31
500-year	8.76	8.30

* Average rainfall depth adjusted for areal reduction based on watershed size of 257 square miles

4 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, cities, and at the outlet of the watershed. The reporting locations are shown on **Figure D-1-B.1** in **Attachment D-1-B** and further summarized below.

- Cart Creek at ND Highway 32 – East of the community of Mountain, ND. Upper region of Cart Creek downstream of the beach ridge where overland flows occur with higher frequency.
- Cart Creek at 86th Street NE – Downstream of the confluence of Cart Creek and an unnamed tributary.
- Cart Creek at 138th Avenue NE near Crystal, ND – Downstream of a railroad crossing and at the downstream end of where the Cart Creek flows through the community of Crystal.
- North Branch Park River at ND Highway 32 – Upper region of North Branch Park River downstream of the beach ridge where overland flows occur with higher frequency.
- North Branch Park River at ND Highway 18 near Hoople, ND – Upstream of the confluence with Cart Creek and approximately half of a mile downstream of the community of Hoople.
- North Branch Park River Outlet (Channel Only) – This reporting location only accounts for the flow within the North Branch Park River channel near the confluence with the Middle Branch Park River. The reporting location is located at the Burlington Northern Santa Fe (BNSF) Railroad crossing.
- North Branch Park River Outlet (Including Breakouts) – This reporting location accounts for both the channel flows measured at the BNSF Railroad crossing and all breakout/overland flows near the outlet of the North Branch Park River. Flows measured at this reporting location span an approximate 9 mile long transect.

Hydrographs for the 2-year through 500-year events at the reporting locations are shown in **Attachment D-1-B** on **Figure D-1-B.2** through **Figure D-1-B.8**. The peak discharges for the analyzed events are shown in Table 5.

Table 5: 4-Day Rainfall Peak Discharges (cfs)

Return Period	Cart Creek at ND Highway 32	Cart Creek at 86th Street NE	Cart Creek at Crystal, ND	North Branch at ND Highway 32	North Branch at ND Highway 18	North Branch Outlet (Channel Only)	North Branch Outlet (Including Breakouts)
2-year	185	493	960	415	574	602	1,162
5-year	346	866	1,695	688	962	741	1,988
10-year	525	1,200	2,466	973	1,410	809	2,833
25-year	832	1,680	3,705	1,440	1,991	892	4,195
50-year	1,107	2,142	4,454	1,849	2,418	931	5,103
100-year	1,426	2,840	6,277	2,304	2,821	967	6,593
500-year	2,492	5,080	11,335	3,833	4,227	1,060	11,464

The inundation for the 2-year through 500-year events is shown in **Appendix C-1**. 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 6. Cropland acres were estimated using the National Agricultural Statistics Service (NASS) (USDA, 2017).

Table 6: 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		500-year Event	
	Total	Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total	Cropland	Total	Cropland
0-24	1,613	1,081	2,210	1,614	2,793	2,204	3,836	3,208	4,433	3,785	5,075	4,265	5,939	5,180
24-48	1,085	748	1,689	1,184	2,206	1,630	2,697	2,110	3,371	2,786	3,833	3,266	5,149	4,522
48-72	744	521	1,259	878	1,617	1,140	1,965	1,438	2,409	1,862	2,949	2,415	3,427	2,864
72-96	367	246	730	523	1,144	847	1,441	1,061	1,611	1,207	1,748	1,368	2,551	2,102
96-120	228	155	473	346	628	461	1,131	884	1,202	877	1,391	1,045	2,060	1,667
>120	1,834	1,154	2,109	1,375	2,480	1,688	3,183	2,273	4,048	3,026	4,663	3,546	6,342	4,968
Totals	5,871	3,905	8,470	5,920	10,867	7,970	14,254	10,974	17,074	13,543	19,660	15,905	25,468	21,303

4.2 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.

4.2.1 MANNING’S N-VALUES

The Manning’s N-values in the hydraulic model were established through calibration of the May 2013 event, described in Section 3.3. During a late spring to early summer flood event such as the calibration event, there is minimal vegetative cover on cropland when compared to the vegetative cover of a mid to late summer flood event during the growing season. For a constant flow rate, it’s expected that vegetative cover will increase the channel retardance, thus decreasing velocities, increasing the water surface elevation, and increasing inundation. A sensitivity analysis was completed by increasing the Manning’s N-value of cropland areas from 0.041 to 0.05 based on guidance from the HEC-RAS Hydraulic Reference Manual (USACE, 2016). The N-values in the sensitivity analysis are shown in Table 7.

Table 7: Manning's N-Value Sensitivity – N-Value by Land Use

Land Use	Existing Conditions / Calibrated Manning's N-Value	Vegetative Cover Manning's N-Value Sensitivity
Channel	0.039	0.039
Agricultural / Cropland	0.041	0.05
Wetlands	0.04	0.04
Forested	0.09	0.09

To evaluate the sensitivity analysis, discharge hydrographs for the 10-year and 100-year rainfall events were compared for the two conditions. Discharge hydrographs at four locations; Cart Creek at Crystal, ND, North Branch at ND Highway 18, North Branch Outlet (Channel Only), and North Branch Outlet (Including Breakouts) are shown in **Attachment D-1-C**. **Figure D-1-C.1** shows the reporting locations, and the hydrographs are shown on **Figure D-1-C.2** through **Figure D-1-C.5**. The peak discharges for the 10-year and 100-year events at these locations are shown in Table 8**.**

Table 8: Manning's N-Value Sensitivity – Peak Discharges (cfs)

Return Period	Manning's N-Value	Cart Creek at Crystal, ND	North Branch at ND Highway 18	North Branch Outlet (Channel Only)	North Branch Outlet (Including Breakouts)
10-year	Existing Conditions	2,466	1,410	809	2,833
	Vegetative Cover	2,414	1,397	803	2,817
	Change (%)	*-2.1%*	*-0.9%*	*-0.7%*	*-0.6%*
100-year	Existing Conditions	6,277	2,821	967	6,593
	Vegetative Cover	6,282	2,791	950	6,505
	Change (%)	*0.1%*	*-1.1%*	*-1.8%*	*-1.3%*

The total inundation area was also evaluated for the two Manning's N-value conditions. The total inundation for the 10-year and 100-year rainfall events are shown in Table 9.

Table 9: Manning's N-Value Sensitivity – Total Inundation (acres)

Land Use	Existing Conditions / Calibrated Manning's N-Value	Vegetative Cover Manning's N-Value Sensitivity	*Change (%)*
10-year	10,867	10,889	*0.2%*
100-year	19,660	19,713	*0.3%*

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.

4.2.2 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), and the nested distribution for each return period was calculated. 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 10**.**

Table 10: 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
10-year	3.39	4.17	5.11	3.11	3.95	4.89
100-year	5.66	6.66	7.64	5.19	6.31	7.31

* Average rainfall depth adjusted for areal reduction based on watershed size of 257 square miles

Peak discharges were calculated at the outlet of the North Branch Watershed for the three storm durations for the 10-year and 100-year events and are shown in Table 11. Discharge hydrographs at the outlet of the North Branch Watershed for the three storm durations are shown on **Figure D-1-C.6** and **Figure D-1-C.7** in **Attachment D-1-C**. Evaluation of the results indicates that the 4-day duration rainfall event produces the highest discharge at the outlet of the watershed. Therefore, the 4-day duration event was selected to be analyzed for the synthetic rainfall events for this study.

Table 11: Rainfall Duration Sensitivity – Peak Discharges (cfs)

Return Period	North Branch Outlet (Channel Only)			North Branch Outlet (Including Breakouts)		
	24-hour	4-day	10-day	24-hour	4-day	10-day
10-year	785	809	743	2,517	2,833	2,011
100-year	951	967	924	5,960	6,593	4,932

4.2.3 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 North Branch Watershed, this is primarily driven by the amount of precipitation occurring prior to the rainfall event, and weather patterns allowing for drying of topsoil.

As discussed in Section 2.1.4, Curve Numbers for cultivated cropland during the growing season consists of 80% row crops and 20% small grains in good condition from *TR-55* (NRCS, 1986). The cultivated cropland Curve Numbers for the hydrologic soil groups are shown in **Attachment D-1-A**. During a spring rainfall event, prior to any seasonal agricultural operations occurring, cropland would not have vegetative cover and would be anticipated to function as a fallow cover type with crop residue cover, resulting in higher Curve Numbers and increased runoff. The moisture condition in the spring also varies. Soils needs to dry before the land can be tilled in preparation for planting. It is anticipated that a typical spring rainfall event, prior to agricultural operations, would have an average to dry moisture condition. The 4-day Curve Numbers for cultivated crops and for a fallow cover type with crop residue cover with an average and dry moisture condition are shown in Table 12. A growing season cover condition (cultivated crops) is within the range of a spring cover condition with an average to dry antecedent moisture conditions.

Table 12: 4-Day Cultivated Crops and Crop Residue Cover Curve Numbers – Seasonality

Land Cover Type and Moisture Condition	Land Condition	CN for Hydrologic Soil Group			
		A	B	C	D
Cultivated Crop – Average (AMC II)	Growing Season	55	65	73	76
Fallow: Crop Residue Cover – Average (AMC II)	Spring Condition	68	78	84	87
Fallow: Crop Residue Cover – Dry (AMC I)	Spring Condition	49	61	69	73

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 **Attachment D-1-A** of this report.

4.2.4 FLOW RECURRENCE VS RAINFALL RECURRENCE

Peak flow recurrence was compared to the resultant peak flows from rainfall recurrences to determine the applicability of the analyzed synthetic rainfall events to determining structural (non-cropland) impacts. Peak flow rates at Crystal, ND were estimated using Regional Regression Equations defined in USGS *Scientific Investigations Report 2015-5096* (Williams-Sether, 2015). Peak flow rates generated from USGS Regional Regression Equations account for flows throughout the entire year, including spring runoff. The Regional Regression Equations are developed using data recorded at gaging stations. Most gaged watersheds in the Red River Basin are located on the lower end of larger tributary rivers, such as the Park River. The location of the gaging station results in a large contributing drainage area. Gaging stations in the Red River Basin are skewed towards spring floods, because snowmelt events occur from built up snowfall from a season of hydrologic events as compared to one rainfall event. With a large contributing area to the gaging stations, the likelihood of severe rainfall over an expansive area that results in high runoff is much less than the likelihood over a smaller contributing area. An example of this is the calibration event (rainfall in late May of 2013). This event produced severe flooding in Crystal, ND, however this event recorded a relatively minor flood at the USGS Streamgage in Grafton, ND.

The community of Crystal, ND was selected because most of the structural inundation within the study area occurs there. This comparison indicated that the peak flow rates that are a result of synthetic rainfall analysis are greater than peak flow rates derived from USGS Regional Regression Equations for equivalent recurrences. This would indicate that flood damages in the North Branch Watershed are more at risk from severe rainfall events as compared to spring runoff. For purposes of estimating structural damages within the North Branch Watershed, synthetic rainfall events will be utilized. Table 13 below summarizes the peak flow rates from the USGS Regression Equations and the resultant peak flows from the analyzed synthetic rainfall events.

Table 13: Flow vs Rainfall Recurrence Comparison at Crystal, ND

Recurrence	USGS Regression Flow Rates	4-Day Atlas 14 Rainfall Resultant Flow Rates
2-year	460	960
5-year	1,230	1,695
10-year	1,960	2,466
25-year	3,090	3,705
50-year	4,050	4,454
100-year	5,110	6,277
500-year	7,850	11,335

4.3 WATERSHED INUNDATION CHARACTERISTICS

The western portion of the North Branch Watershed is located above the Lake Agassiz flood plain along the beach ridge. Topography in this region has steep slopes, with the steepest slopes occurring near the Pembina County and Cavalier County line. Several coulees along the beach ridge rapidly deliver runoff from the upper portion of the watershed into the lake plain region of the watershed. Typically flood inundation in the western portion of the watershed only occurs within the coulees.

Downstream of the beach ridge, Cart Creek is characterized as 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. Further downstream, Cart Creek transforms to a more traditional river system with a defined floodplain. Crystal, ND is located adjacent to Cart Creek and has experienced damages due to large runoff events. Significant flooding occurs at the confluence of Cart Creek and the North Branch Park River. Damages to adjacent cropland in this region have been indicated as a concern in recent years. While some flooding occurs along the North Branch Park River upstream of the confluence with Cart Creek, this area has not been considered as crucial for flood mitigation by local authorities.

In summary, runoff accumulates rapidly in the upper portion of the watershed, and as the floodwaters transition to the lower portion of the watershed, flows breakout of the channels. Flooding along Cart Creek and near the confluence of Cart Creek and North Branch Park River cause significant damages to adjacent cropland. The community of Crystal, ND routinely deals with the threat of flooding.

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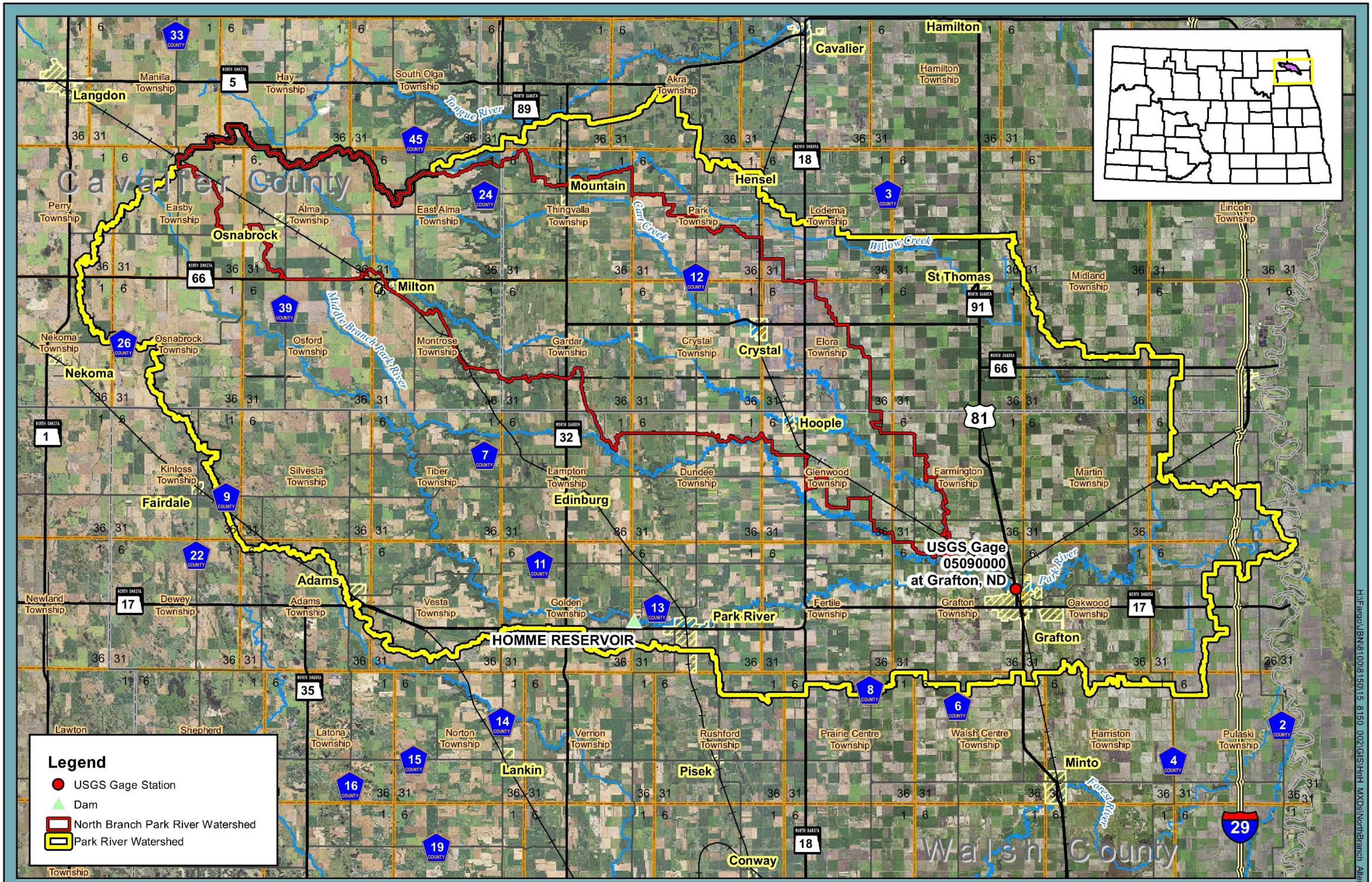
FIGURES



F-1

Figure 1: North Branch Park River Watershed

North Branch Park River Watershed
Existing Conditions Hydrology and Hydraulics Report
Park River Joint Water Resource District

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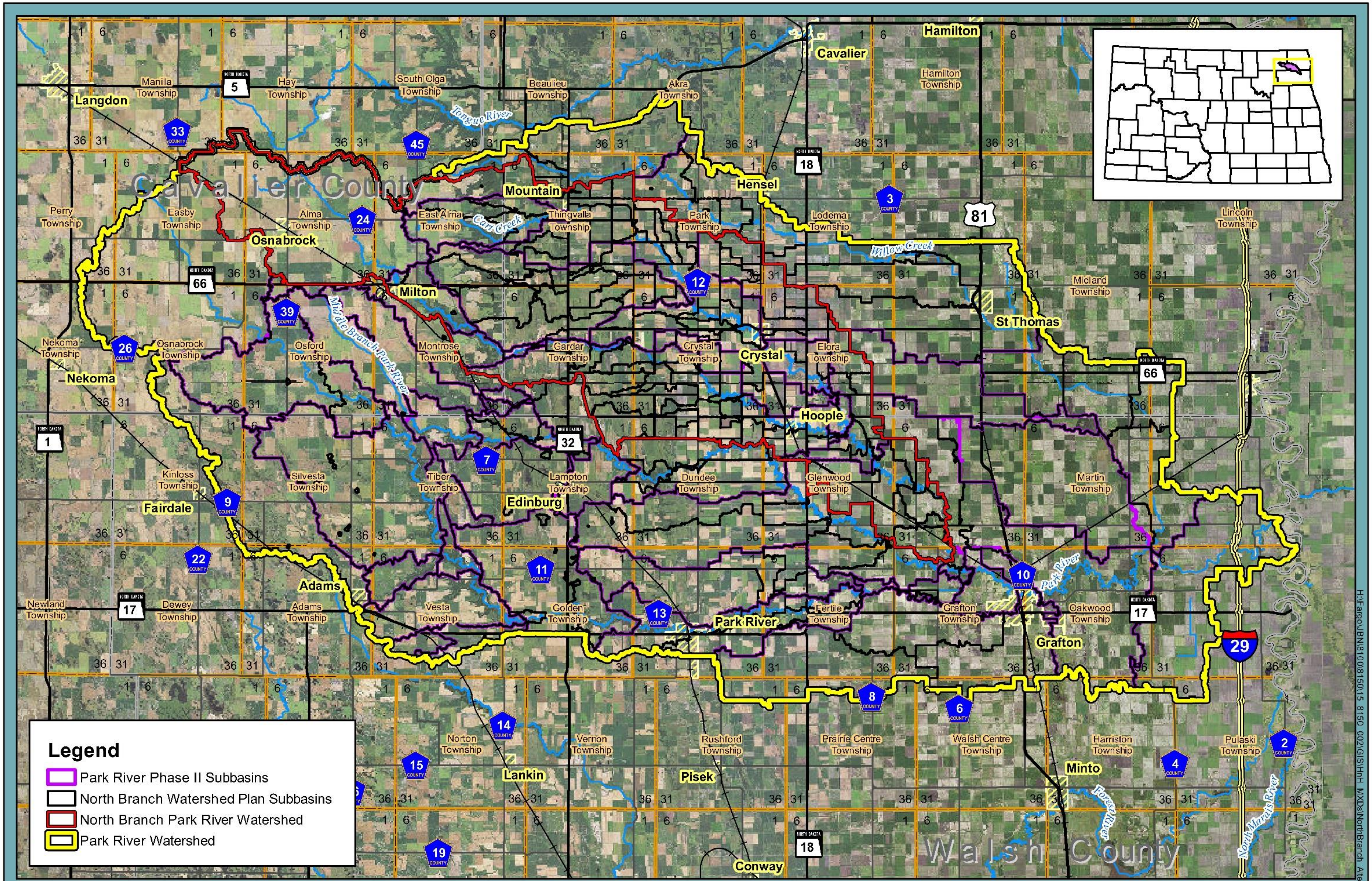

F-3.1.1

Figure 3.1.1: HEC-HMS Subbasins

North Branch Park River Watershed
Existing Conditions Hydrology and Hydraulics Report
Park River Joint Water Resource District

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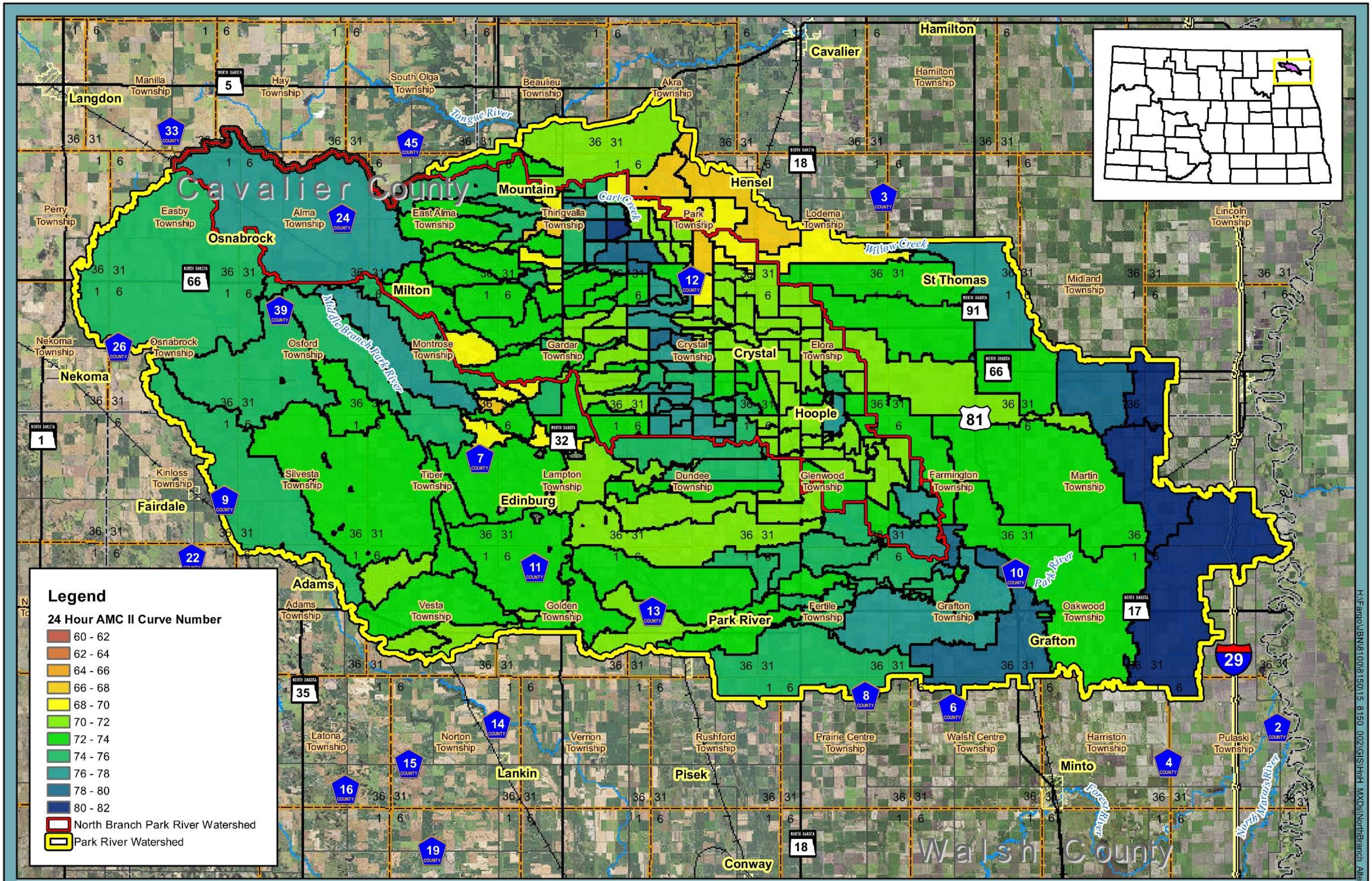

Figure 3.1.2: 24-hour AMC II CN Values

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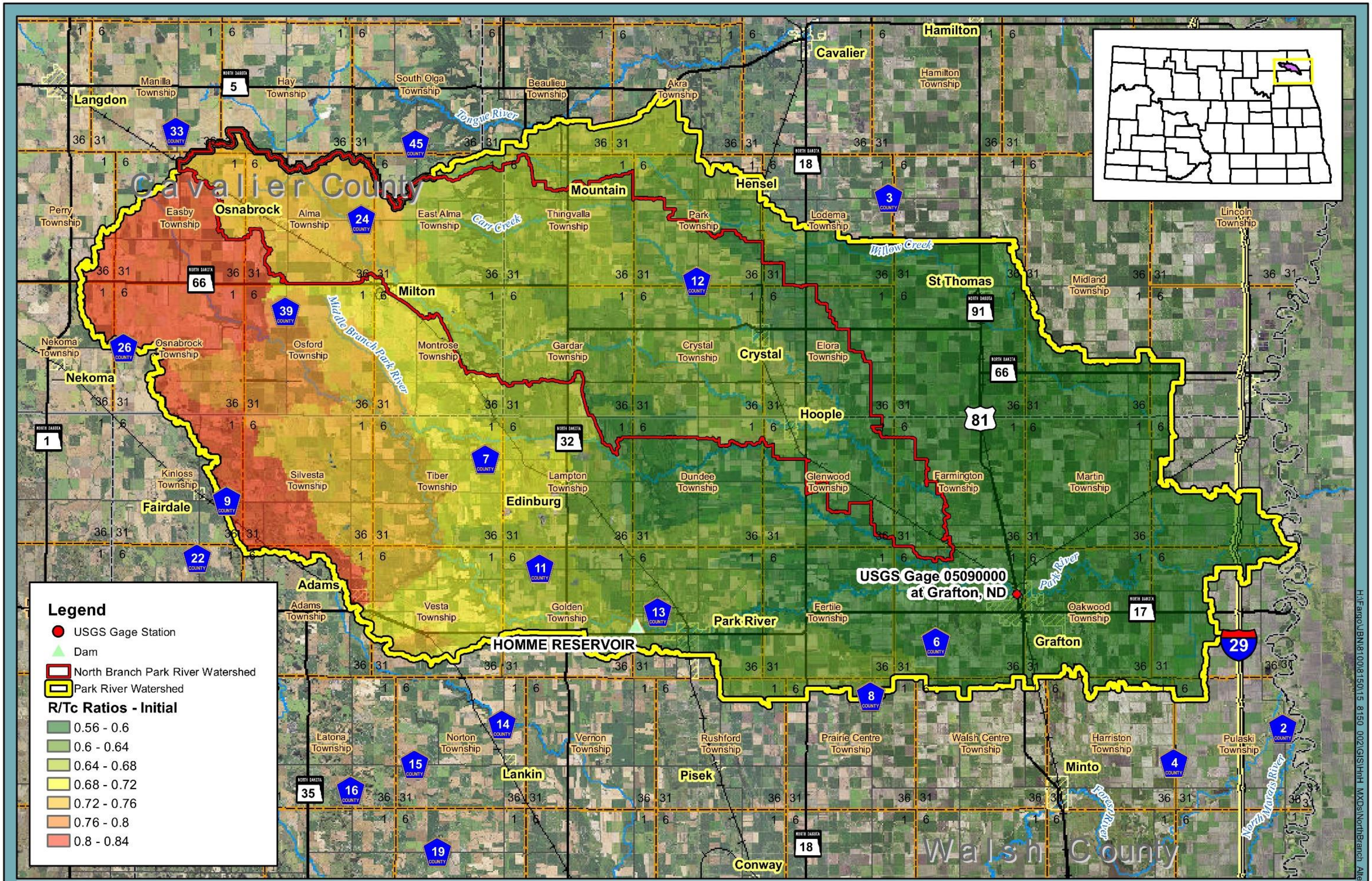

Figure 3.1.3: R/Tc Ratios - Initial

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F-3.1.3

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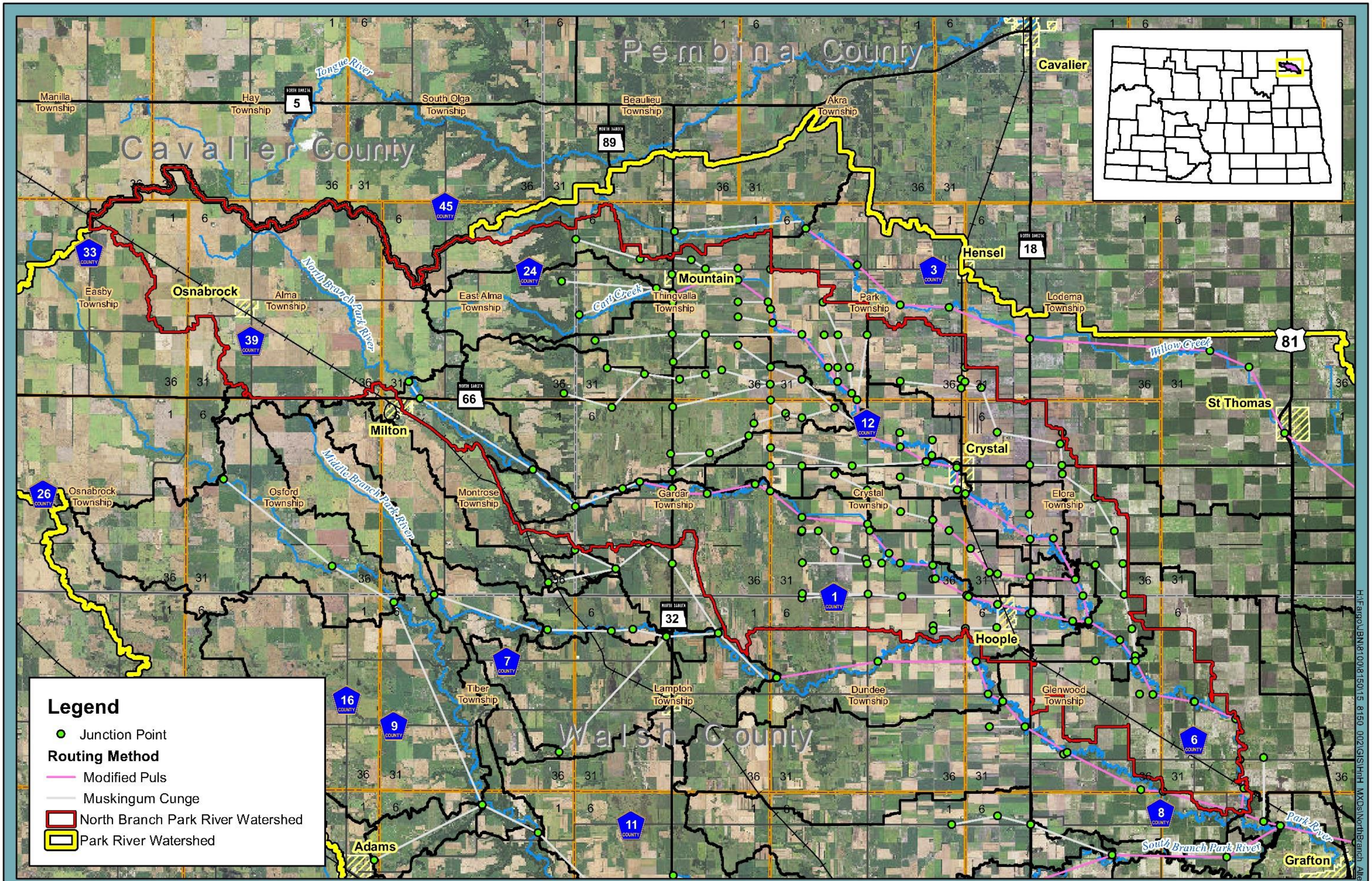

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F-3.1.4

Figure 3.1.4: HEC-HMS Routing

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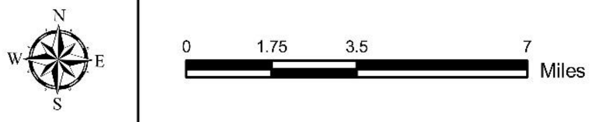

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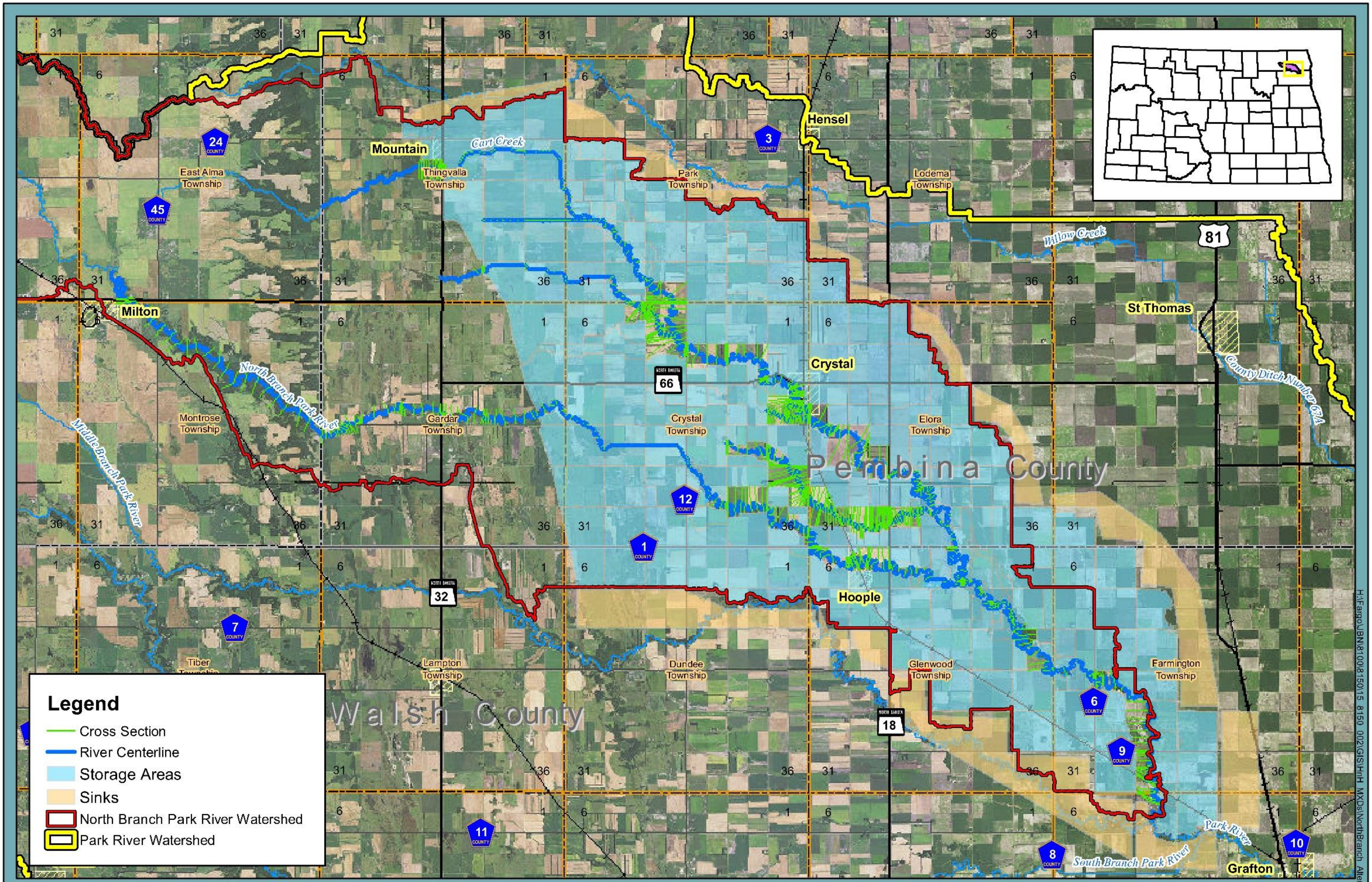

F-3.2

Figure 3.2: HEC-RAS Model Schematic

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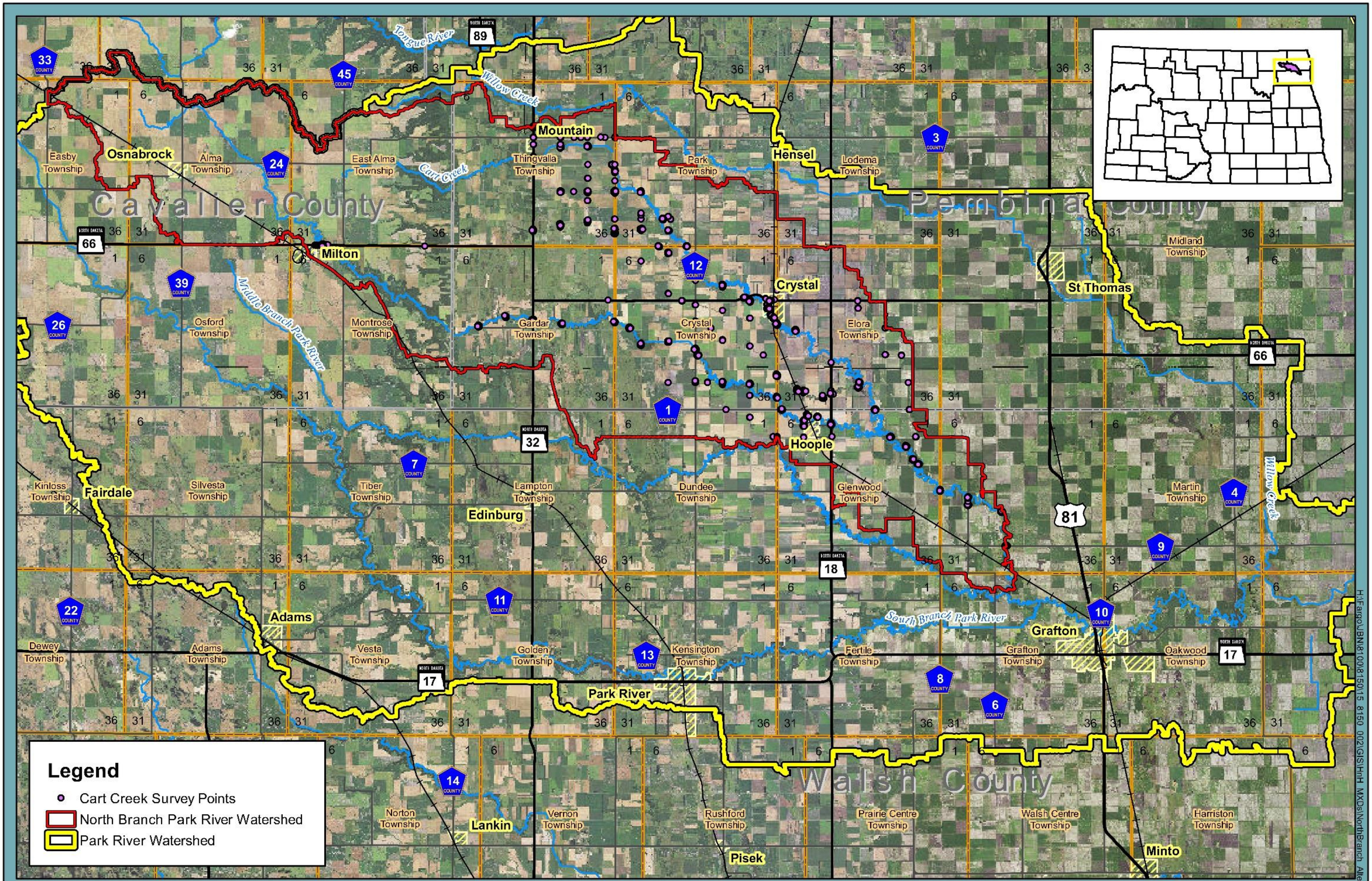

F-3.2.2

Figure 3.2.2: Field Survey Data

North Branch Park River Watershed
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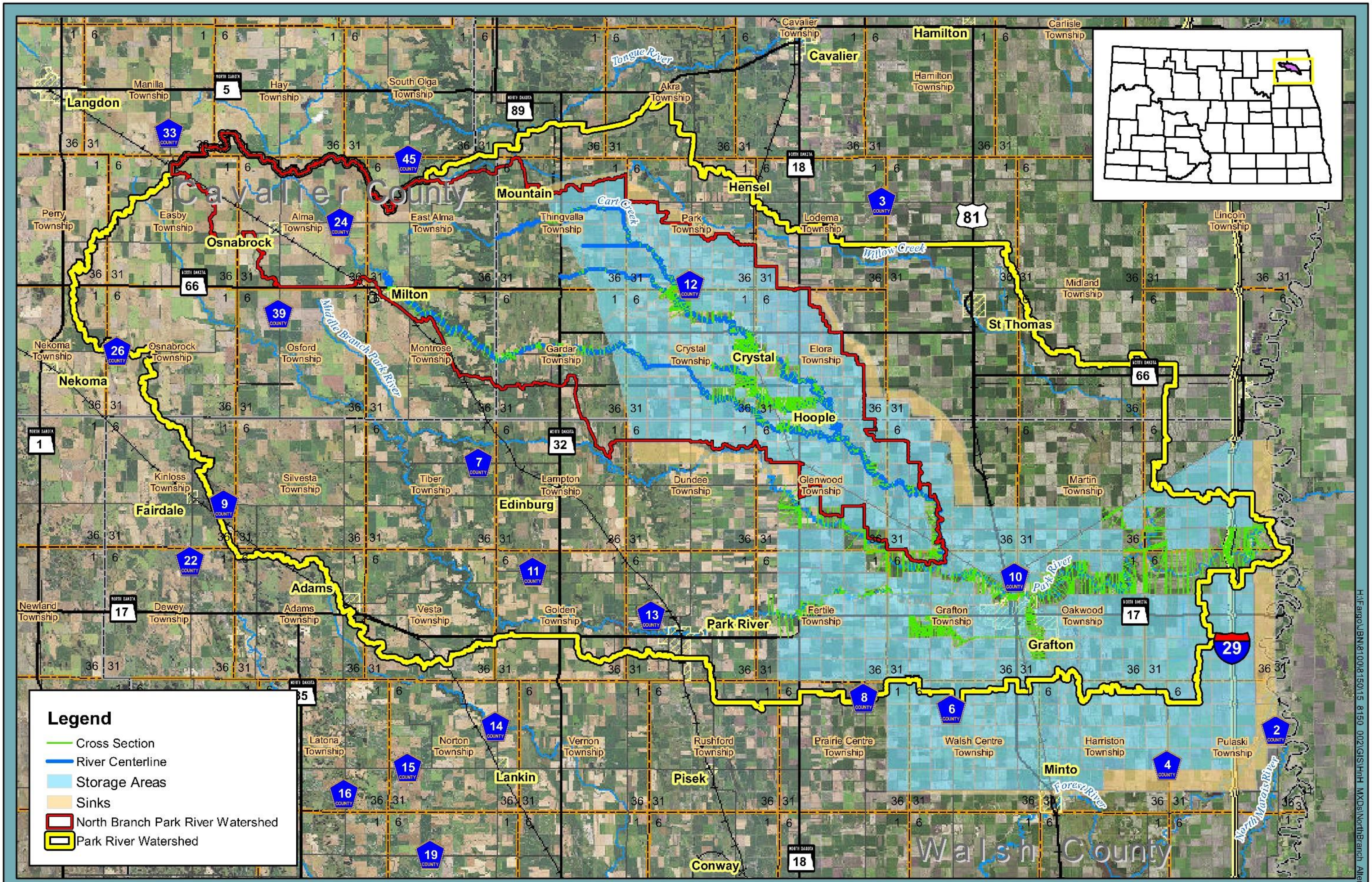

F-3.2.5a

Figure 3.2.5a: HEC-RAS Expanded Model Schematic

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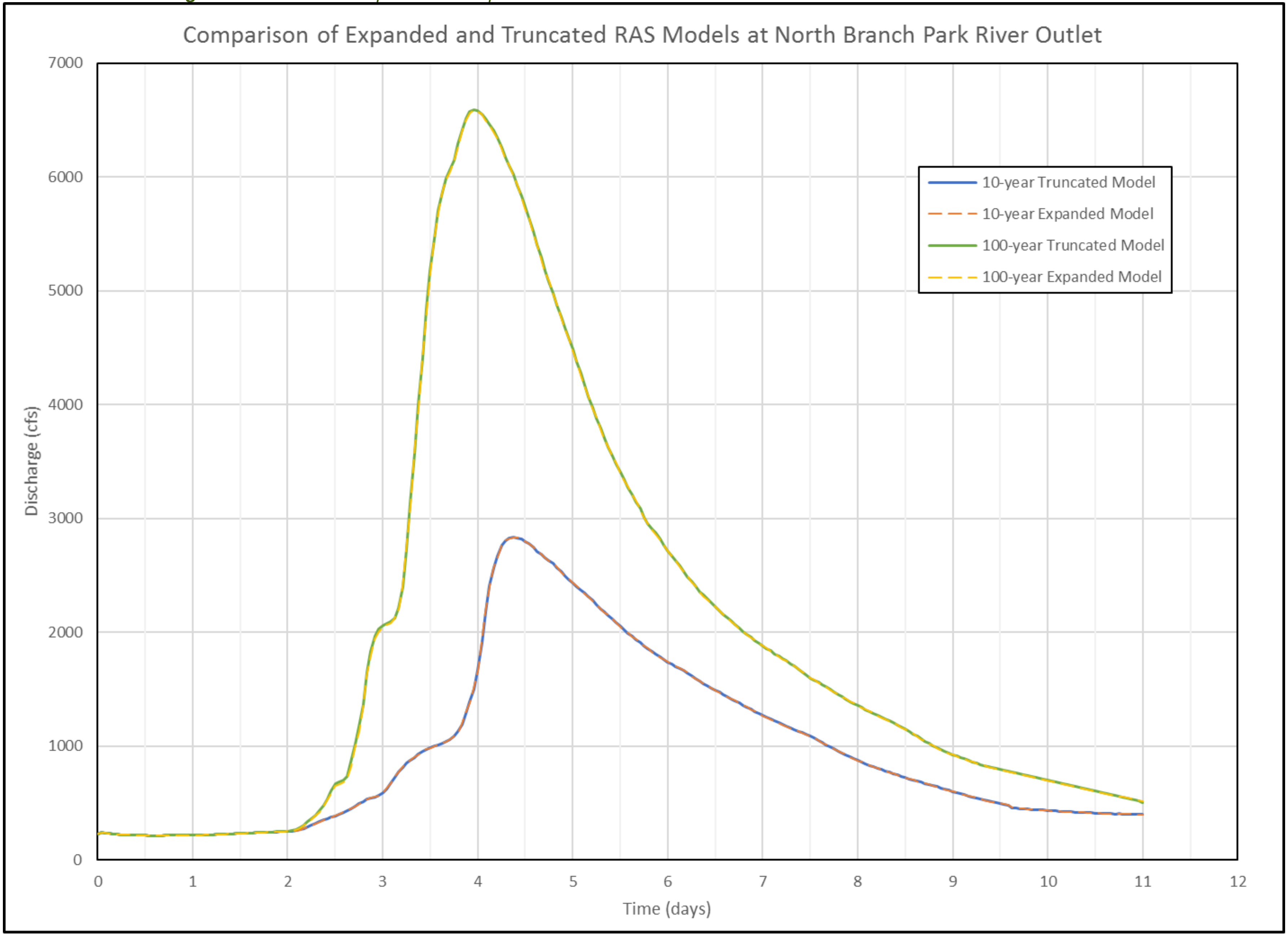
Figure D-1-3.2.5b: *Comparison of Expanded and Truncated RAS Models at the North Branch Park River Outlet*



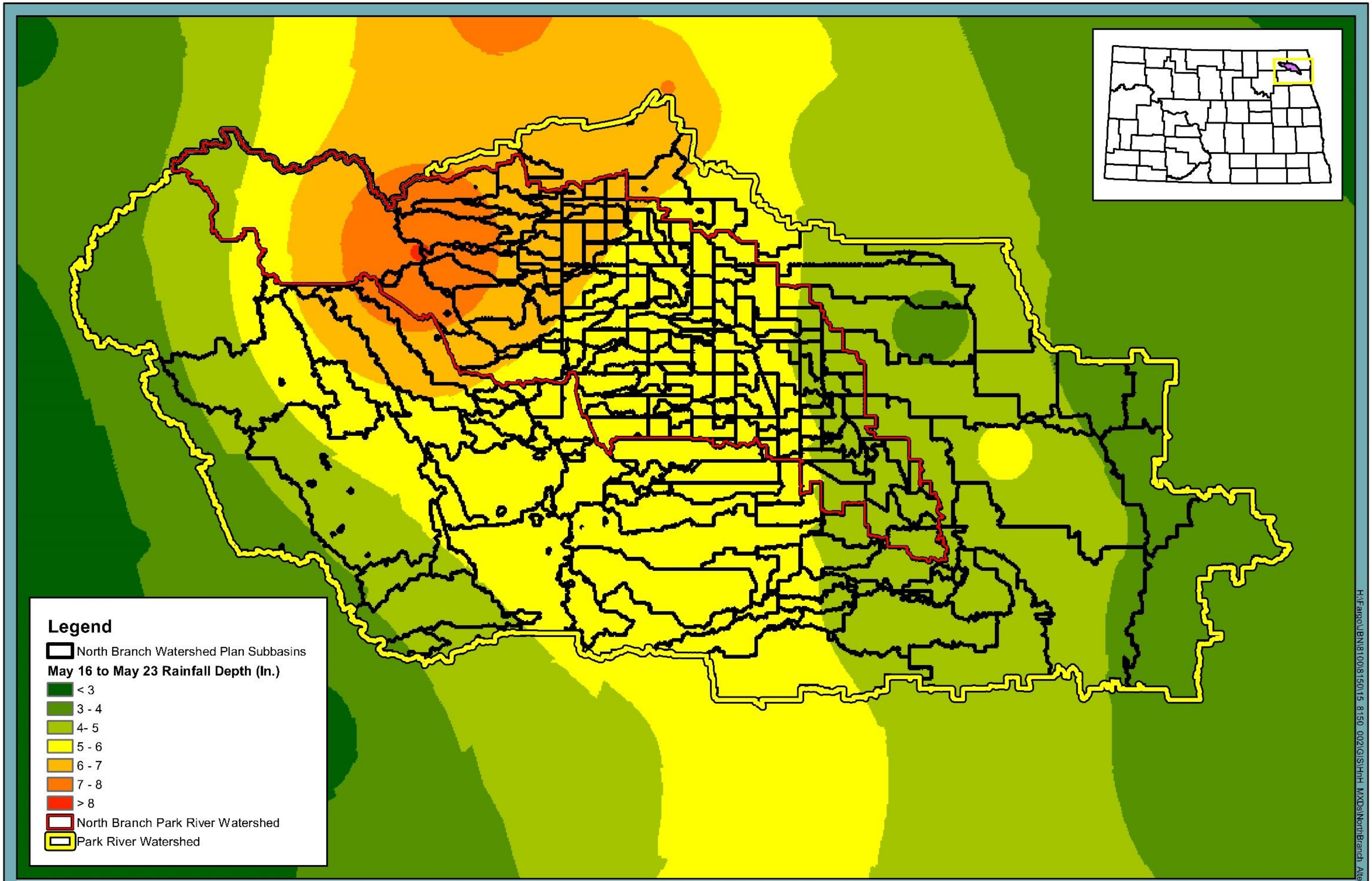


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Figure 3.3a: 2013 Historic Event Rainfall

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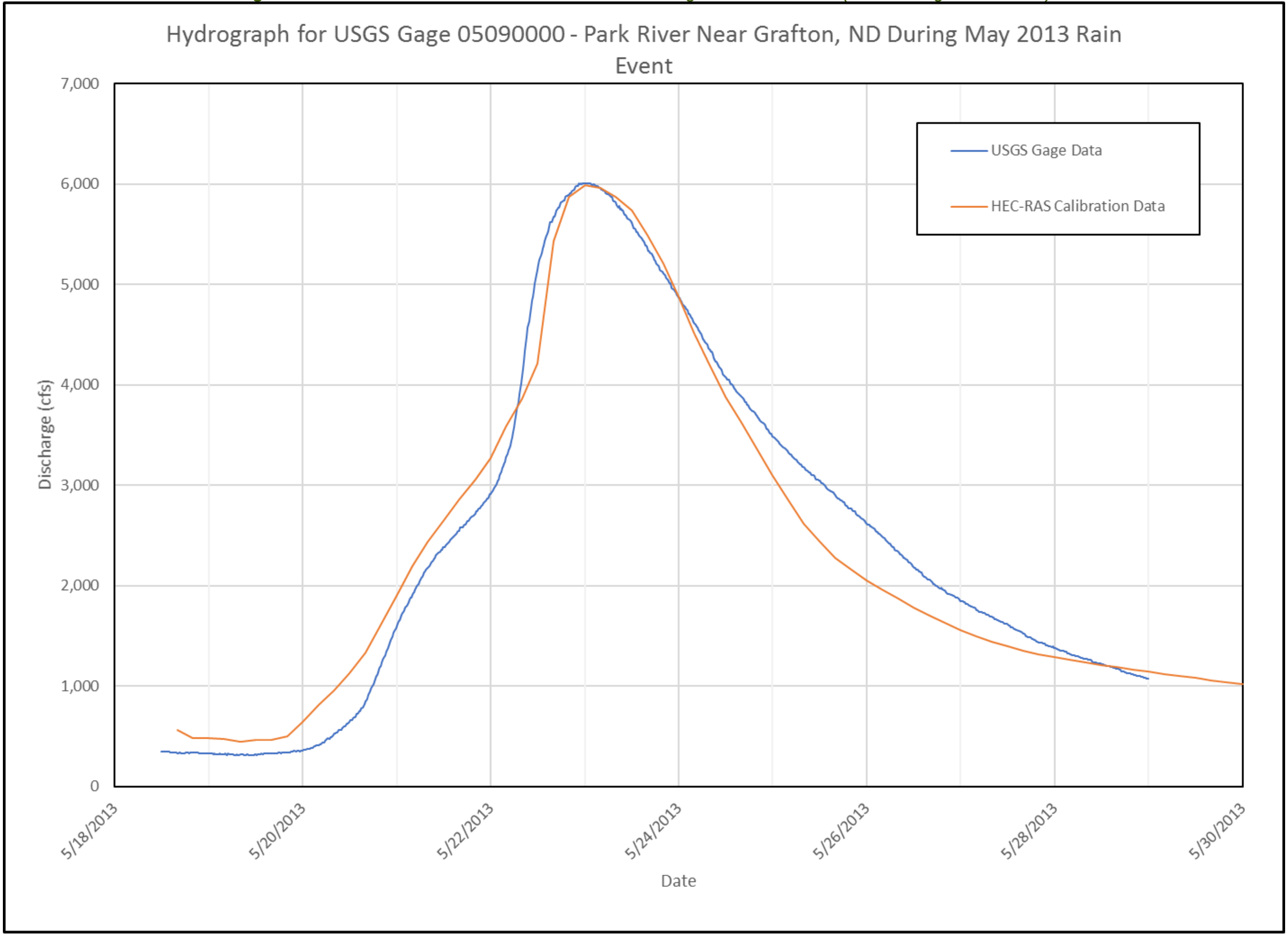
***Figure D-1-3.3b:** 2013 Historic Event - Peak Discharge at Grafton, ND (USGS Gage 05090000)*



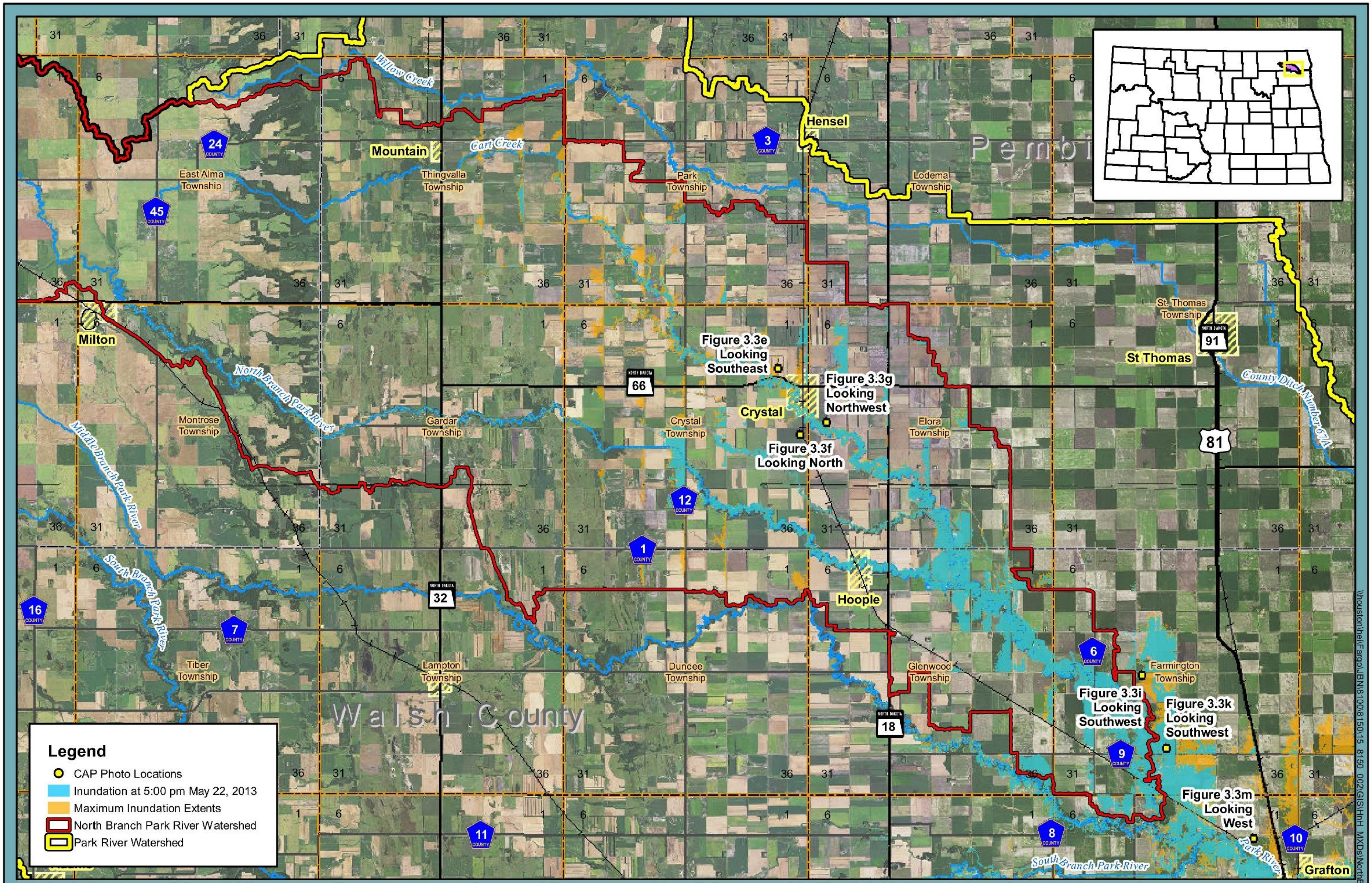


Figure 3.3c: 2013 Historic Event Inundation

North Branch Park River Watershed
Existing Conditions Hydrology and Hydraulics Report
Park River Joint Water Resource District

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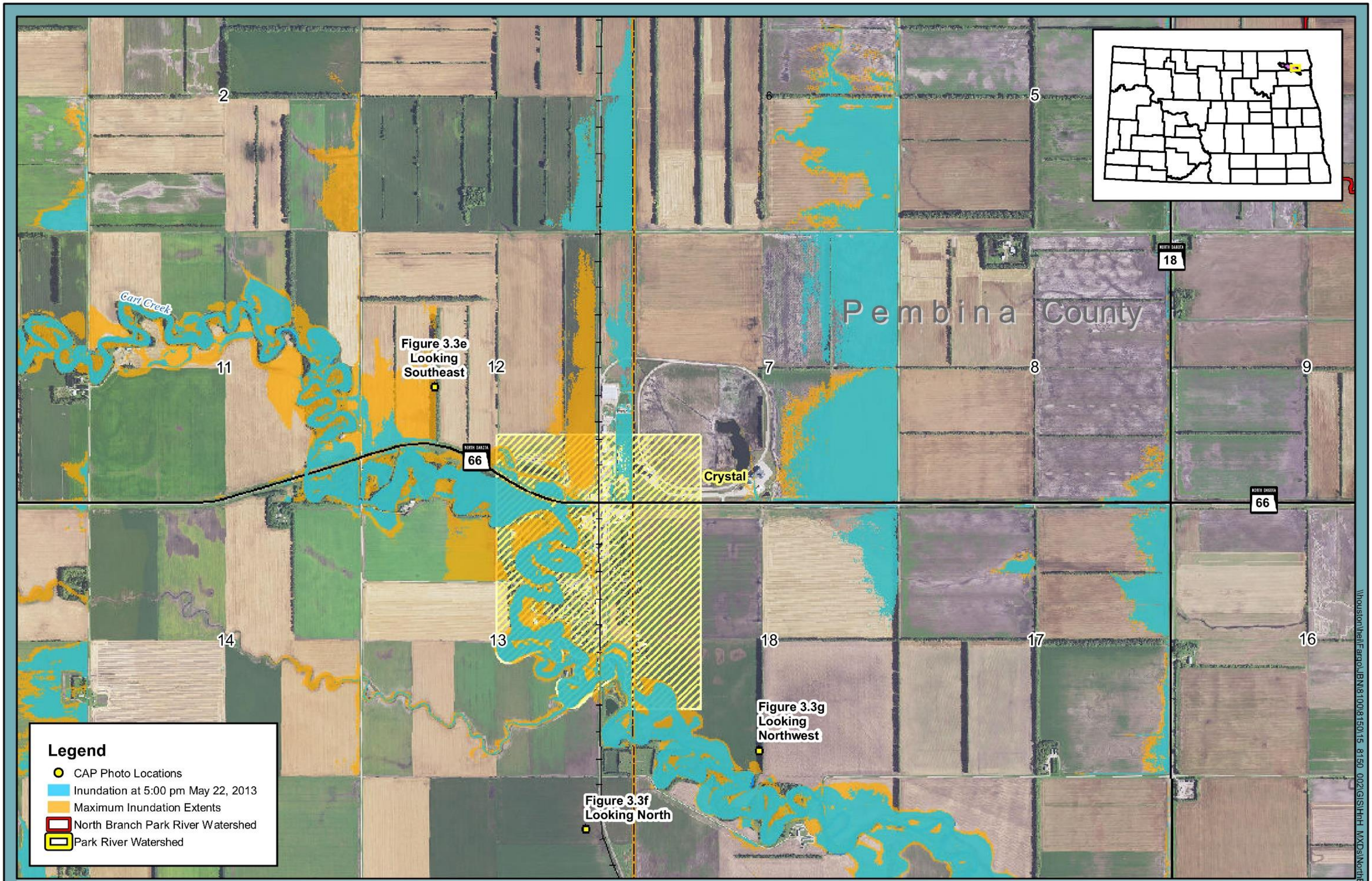

Figure 3.3d: 2013 Historic Event Inundation for Crystal, ND

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Park River Joint Water Resource District

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Figure D-1-3.3e: *2013 Historic Event Aerial Photo for Cart Creek near Crystal, ND Looking Southeast*

Figure D-1-3.3f: *2013 Historic Event Aerial Photo for Cart Creek near Crystal, ND Looking North*

Figure D-1-3.3g: *2013 Historic Event Aerial Photo for Cart Creek near Crystal, ND Looking Northwest*

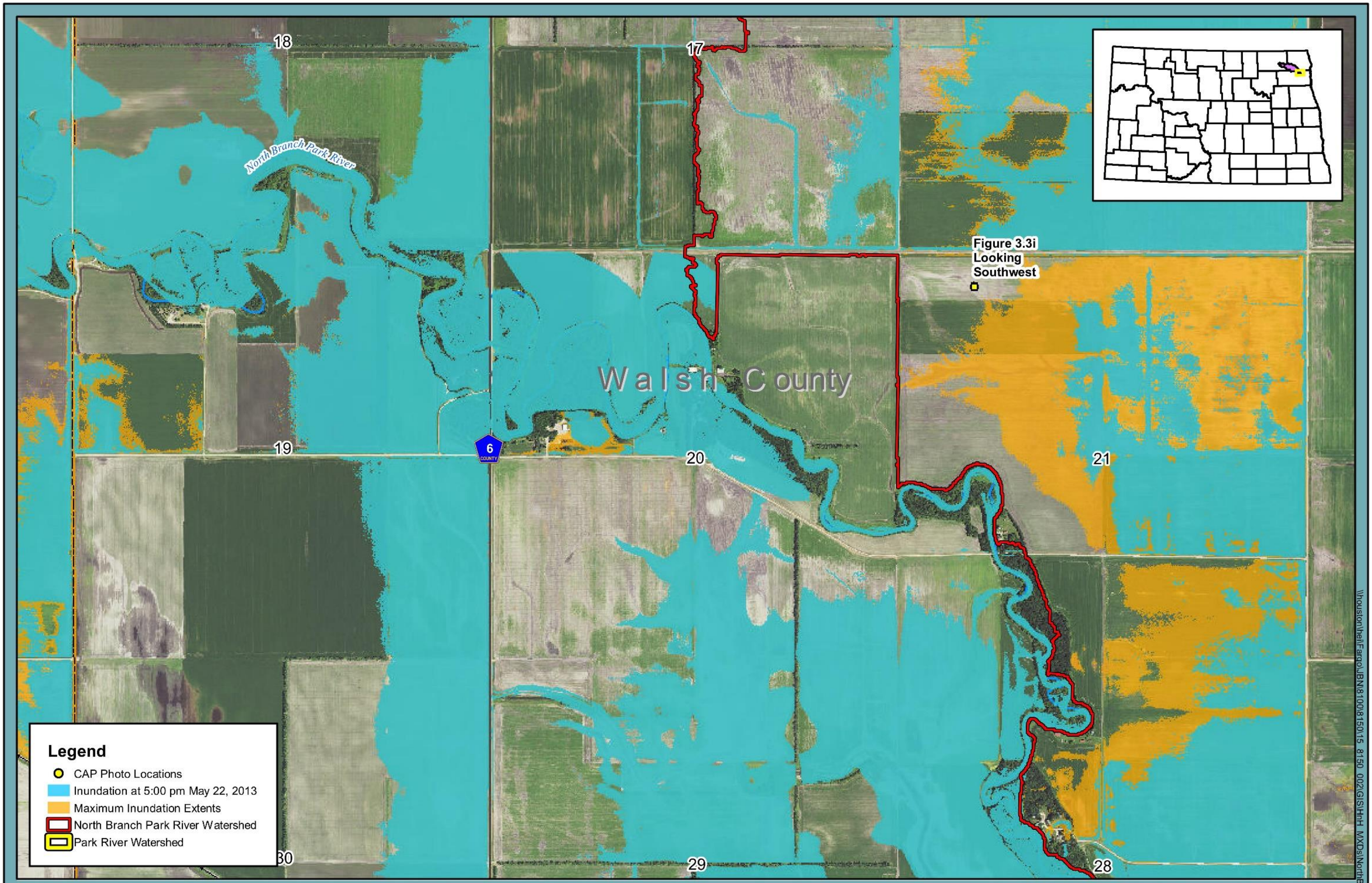

Figure 3.3h: 2013 Historic Event Inundation at 74th Street NE

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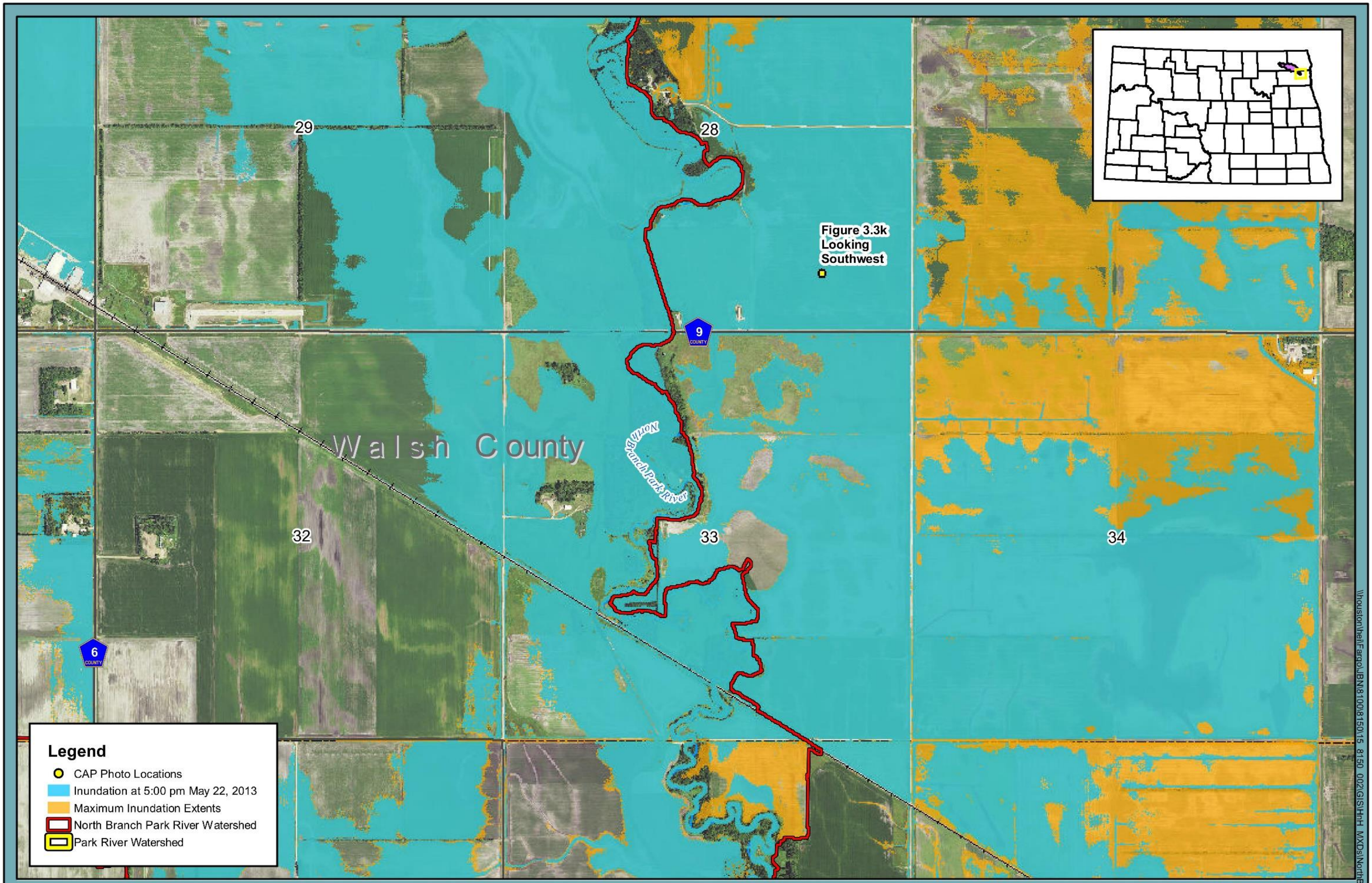
Figure D-1-3.3i: *2013 Historic Event Aerial Photo for Cart Creek at 74th Street NE Looking Southwest*



F-3.3j

Figure 3.3j: 2013 Historic Event Inundation at 73rd Street NE

North Branch Park River Watershed
Existing Conditions Hydrology and Hydraulics Report
Park River Joint Water Resource District

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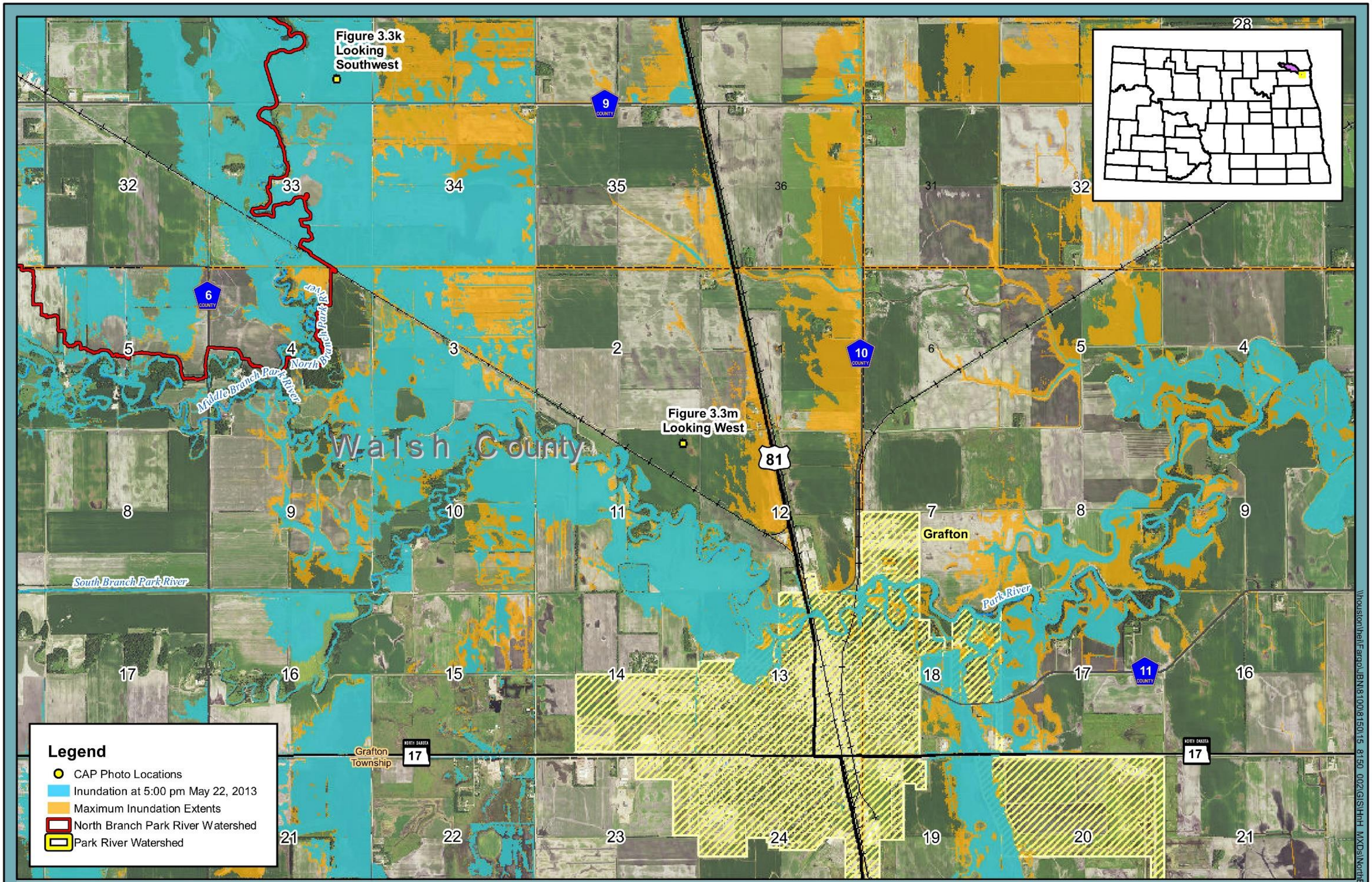
Figure D-1-3.3k: *2013 Historic Event Aerial Photo for Cart Creek at 73rd Street NE Looking Southwest*



F-3.3l

Figure 3.3l: 2013 Historic Inundation of NB & SB Park Rivers

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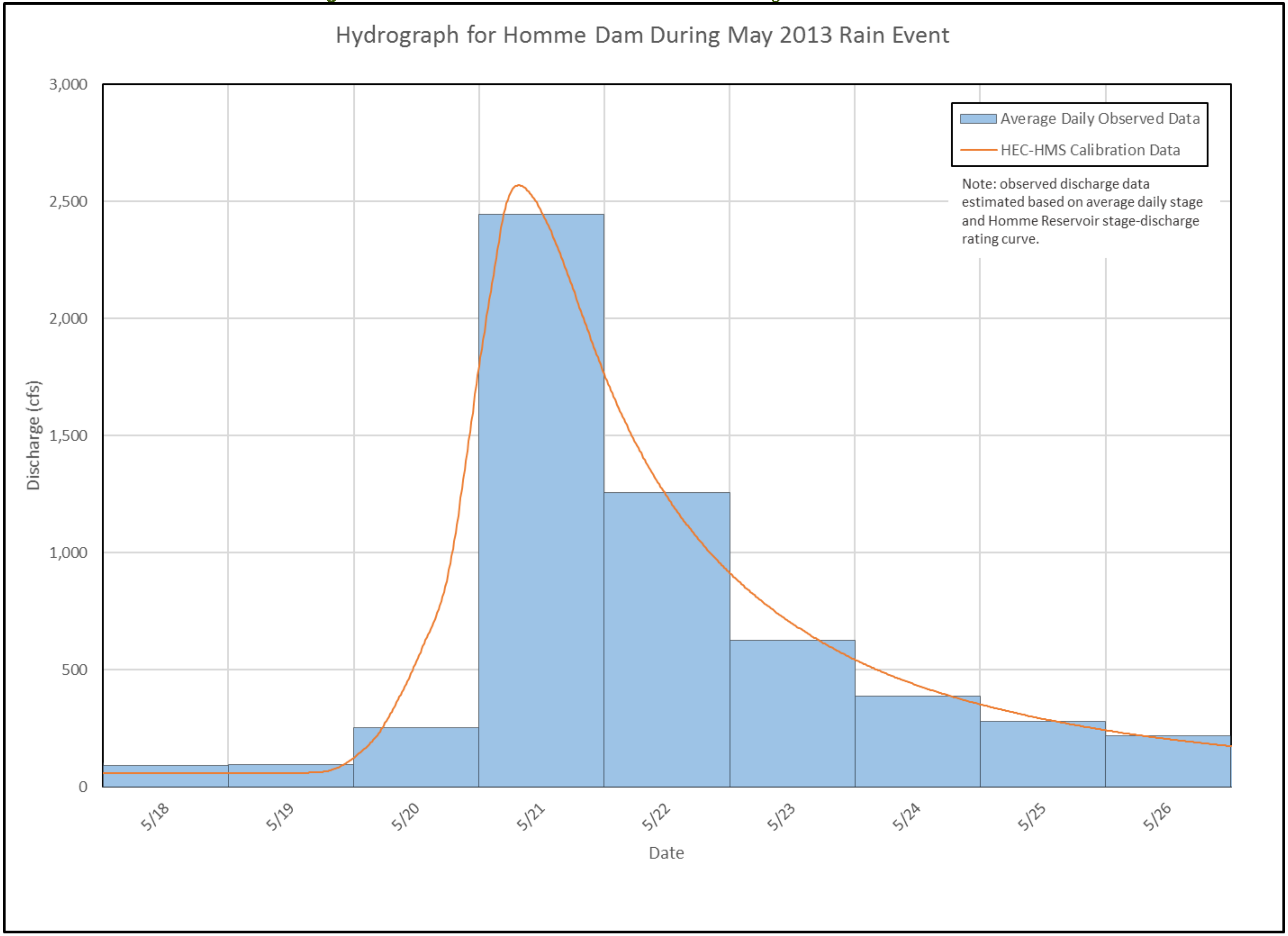
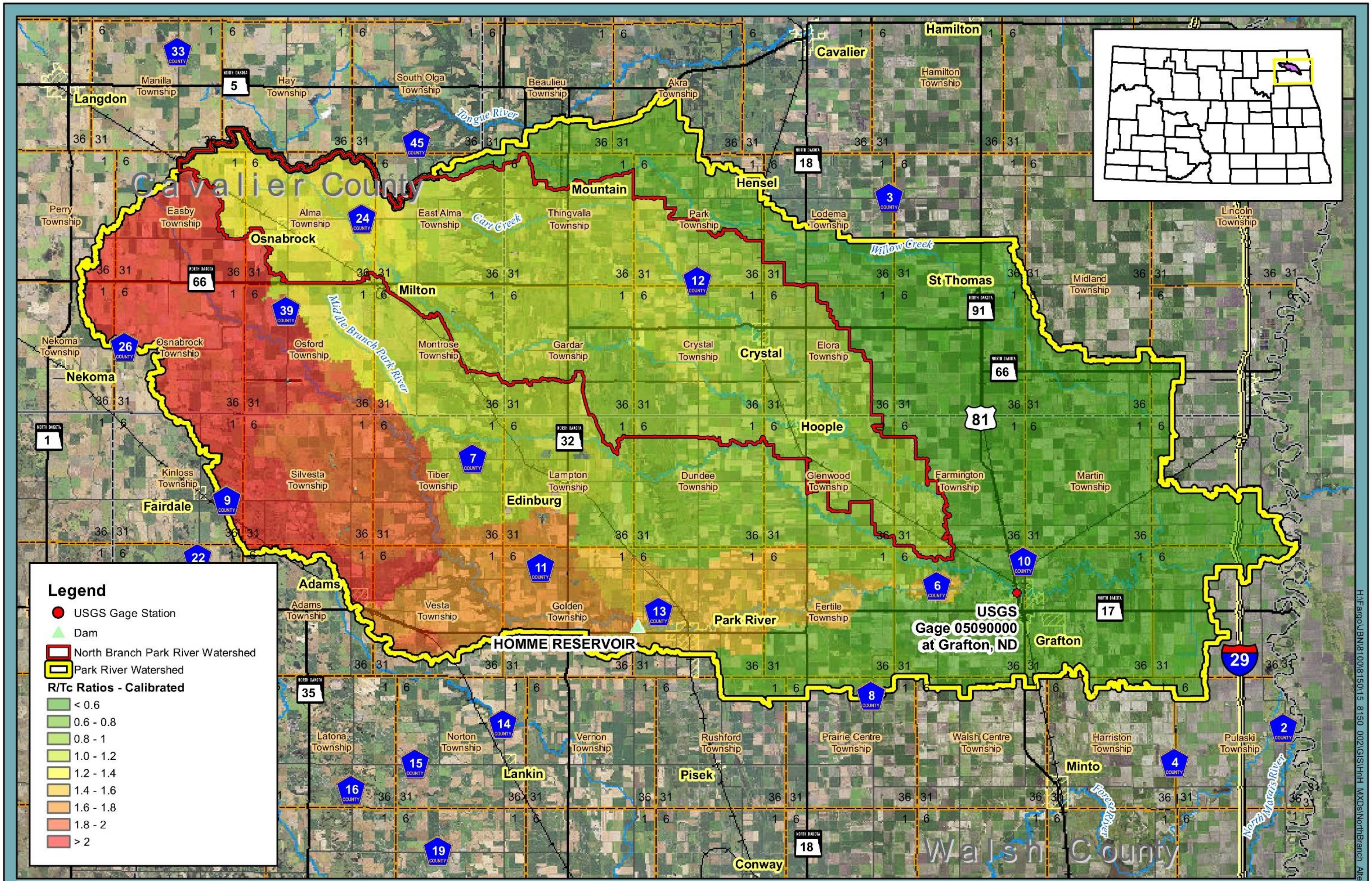
Figure D-1-3.3m: *2013 Historic Event Aerial Photo for the Confluence of North Branch and South Branch Park River Looking West*

Figure D-1-3.3n: *2013 Historic Event – Peak Discharge at Homme Reservoir*





F-3.3o

Figure 3.3o: R/Tc Ratios - Calibrated

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ATTACHMENT D-1-A

Red River Basin 24-Hour Runoff Curve Number Conversion Table

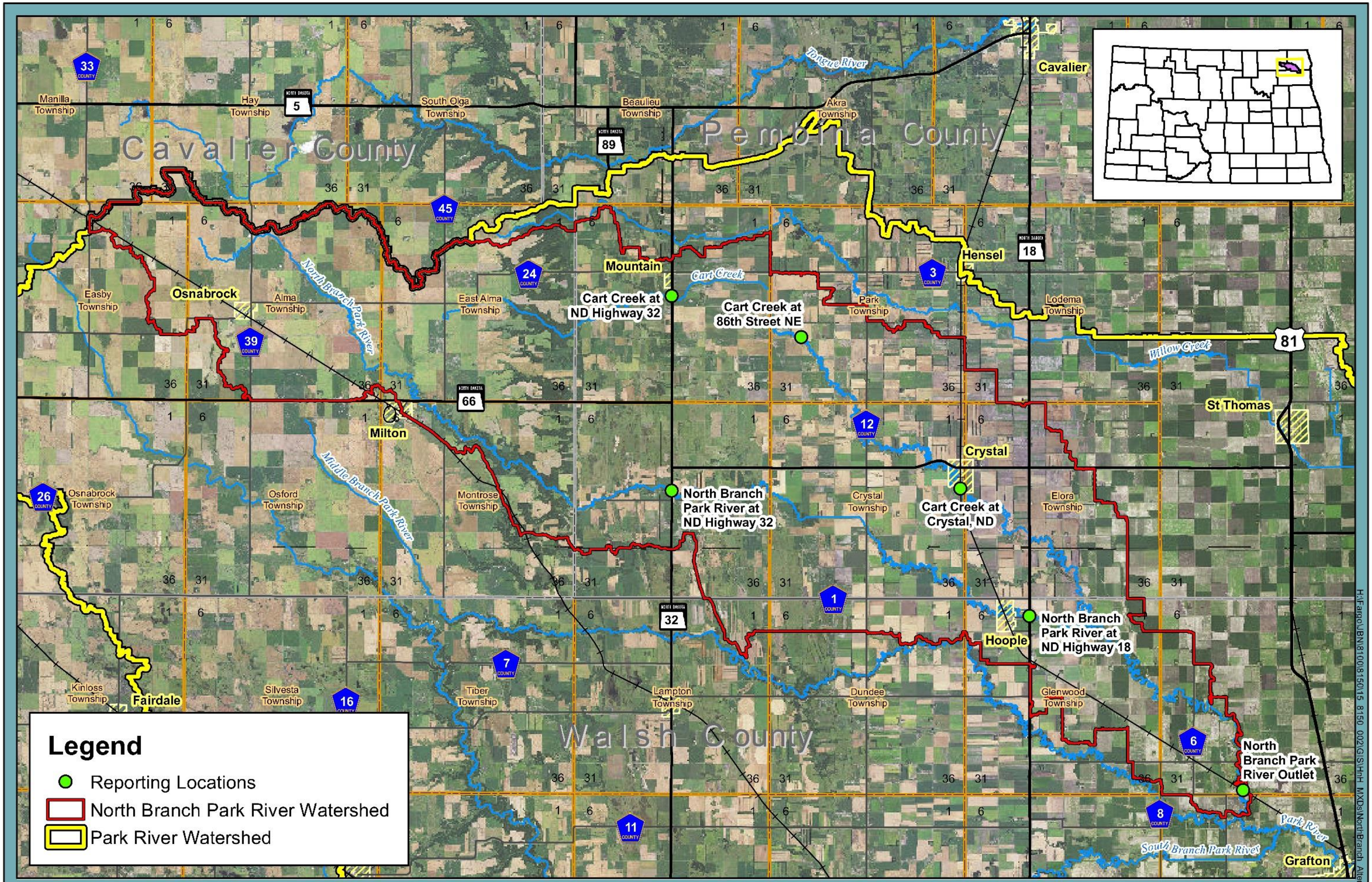
FM Metro Basin-Wide Modeling Approach
Runoff Curve Number (2001 NLCD/SSURGO)

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

ATTACHMENT D-1-B

Existing Conditions Hydrographs and Inundation



F-B.1

Figure B.1: Synthetic Model Results Reporting Locations

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Existing Conditions Hydrology and Hydraulics Report
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Figure D-1-B.2: *Cart Creek at ND Highway 32*

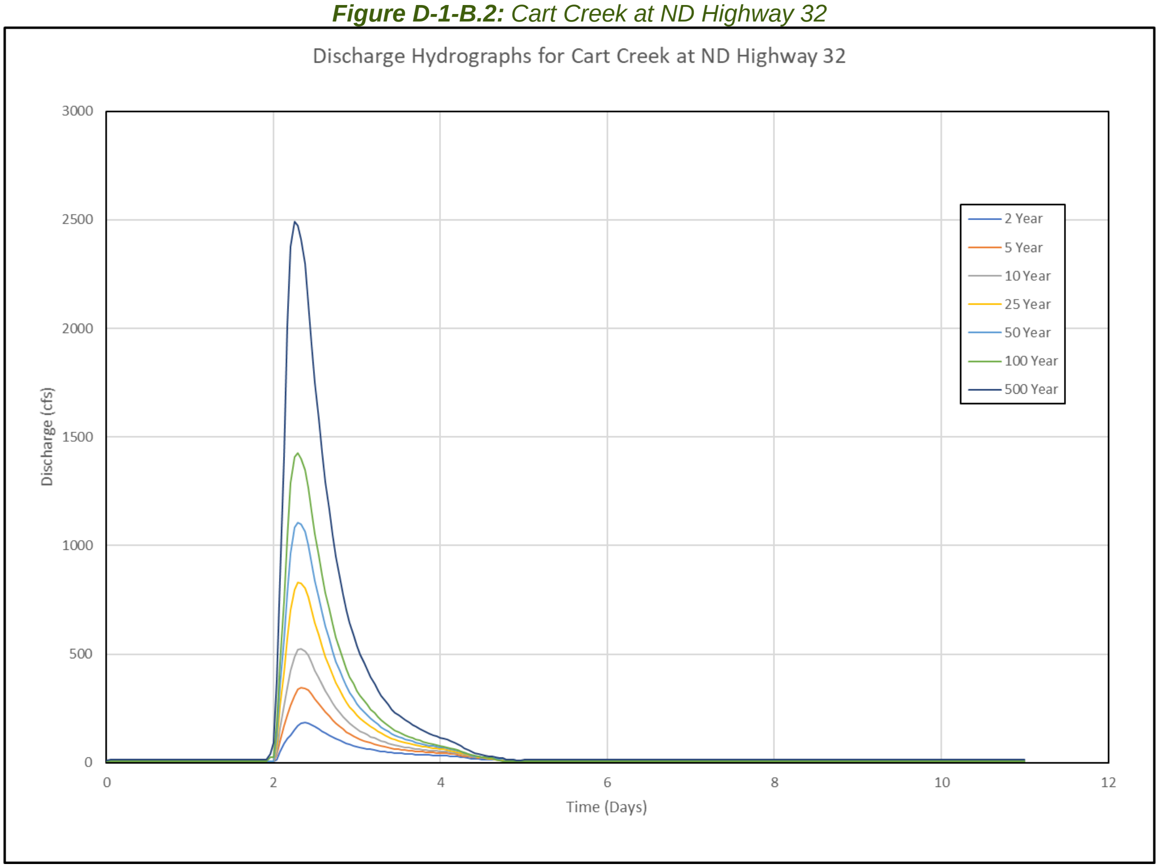


Figure D-1-B.3: *Cart Creek at 86th Street NE*

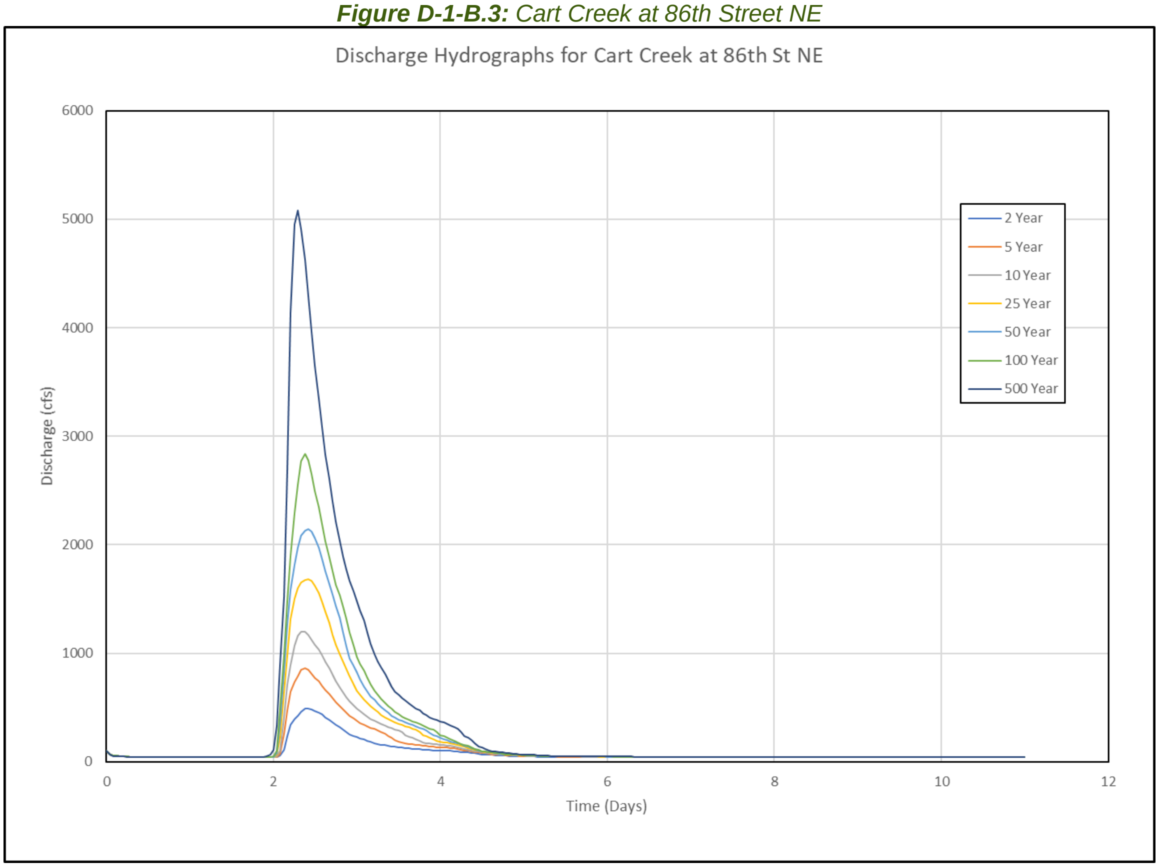


Figure D-1-B.4: *Cart Creek at Crystal, ND*

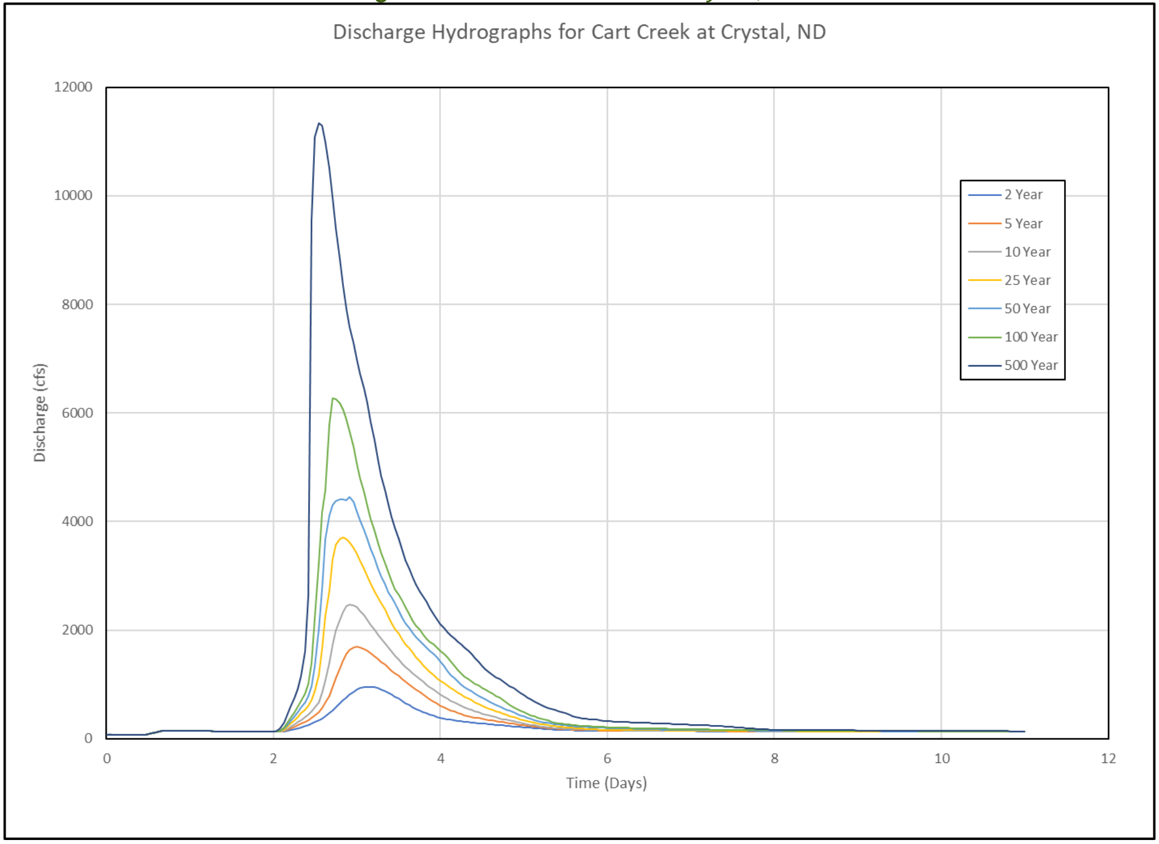


Figure D-1-B.5: *North Branch at ND Highway 32*

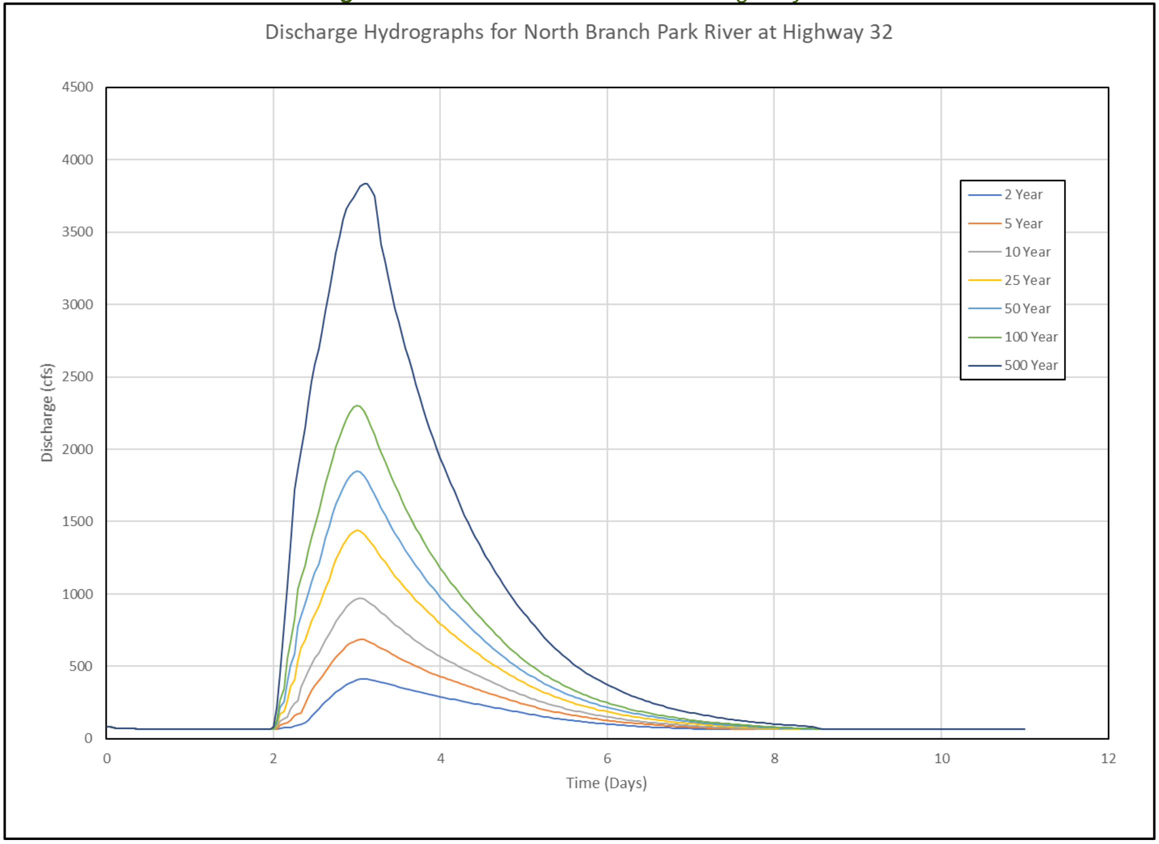


Figure D-1-B.6: *North Branch at ND Highway 18*

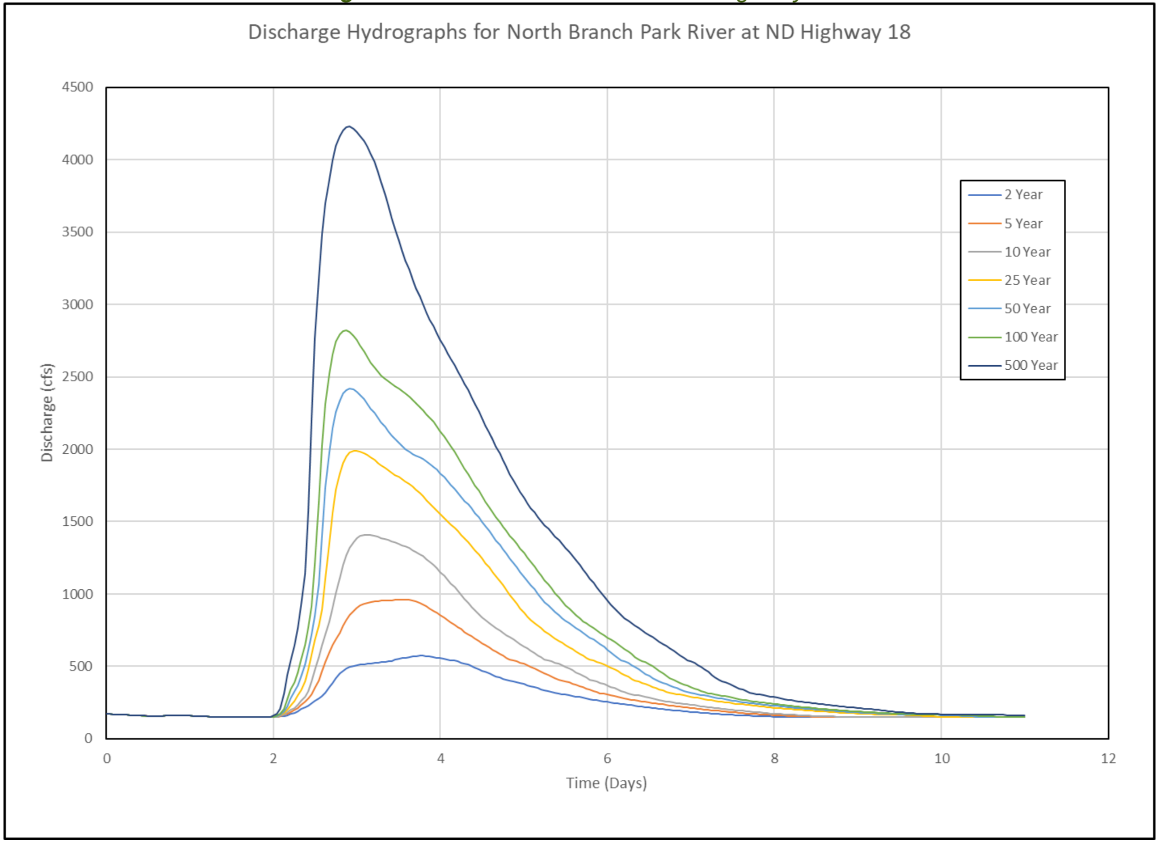


Figure D-1-B.7: *North Branch Outlet (Channel Only)*

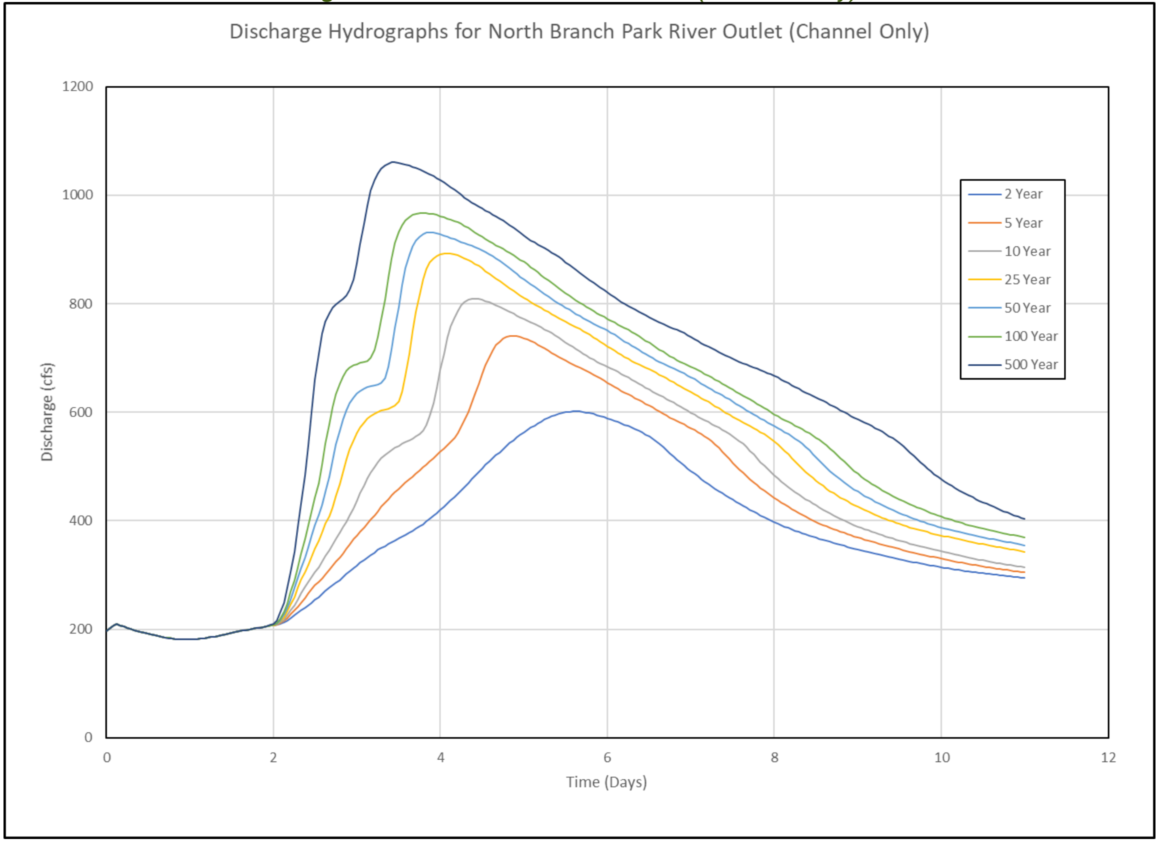
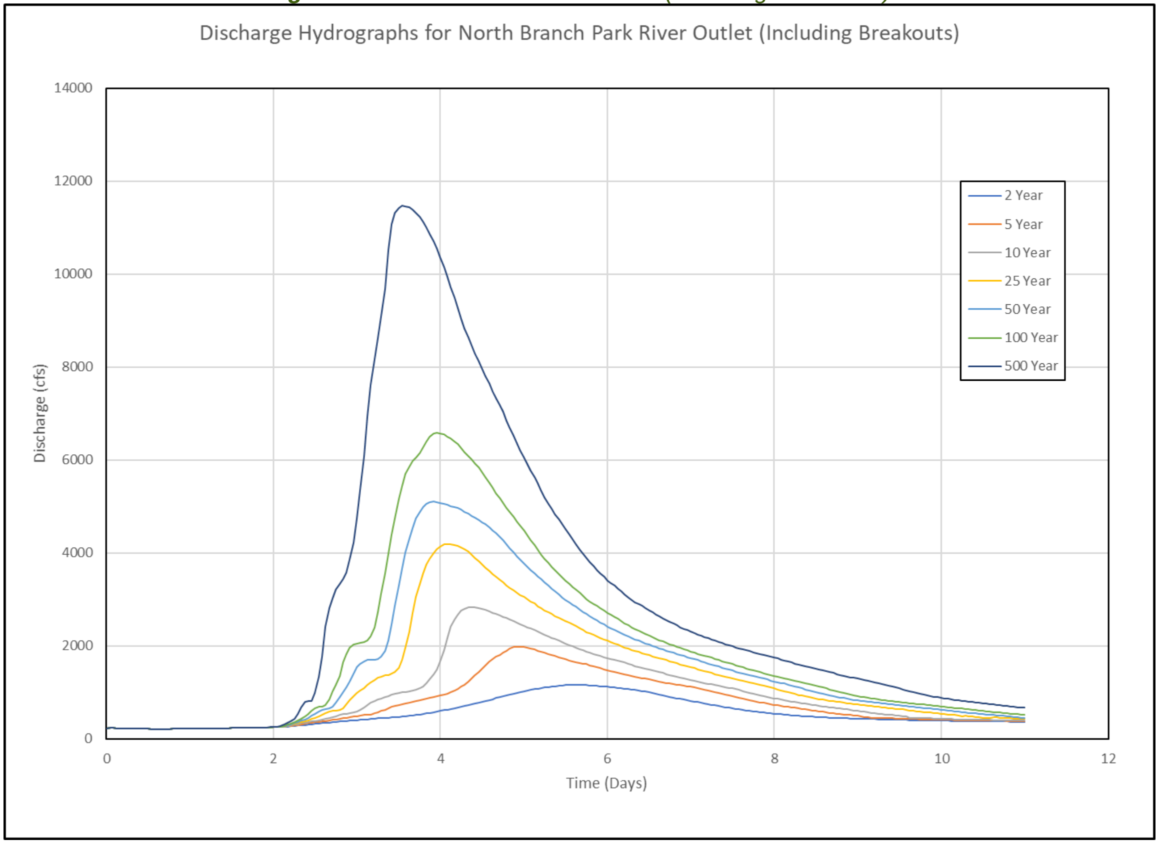
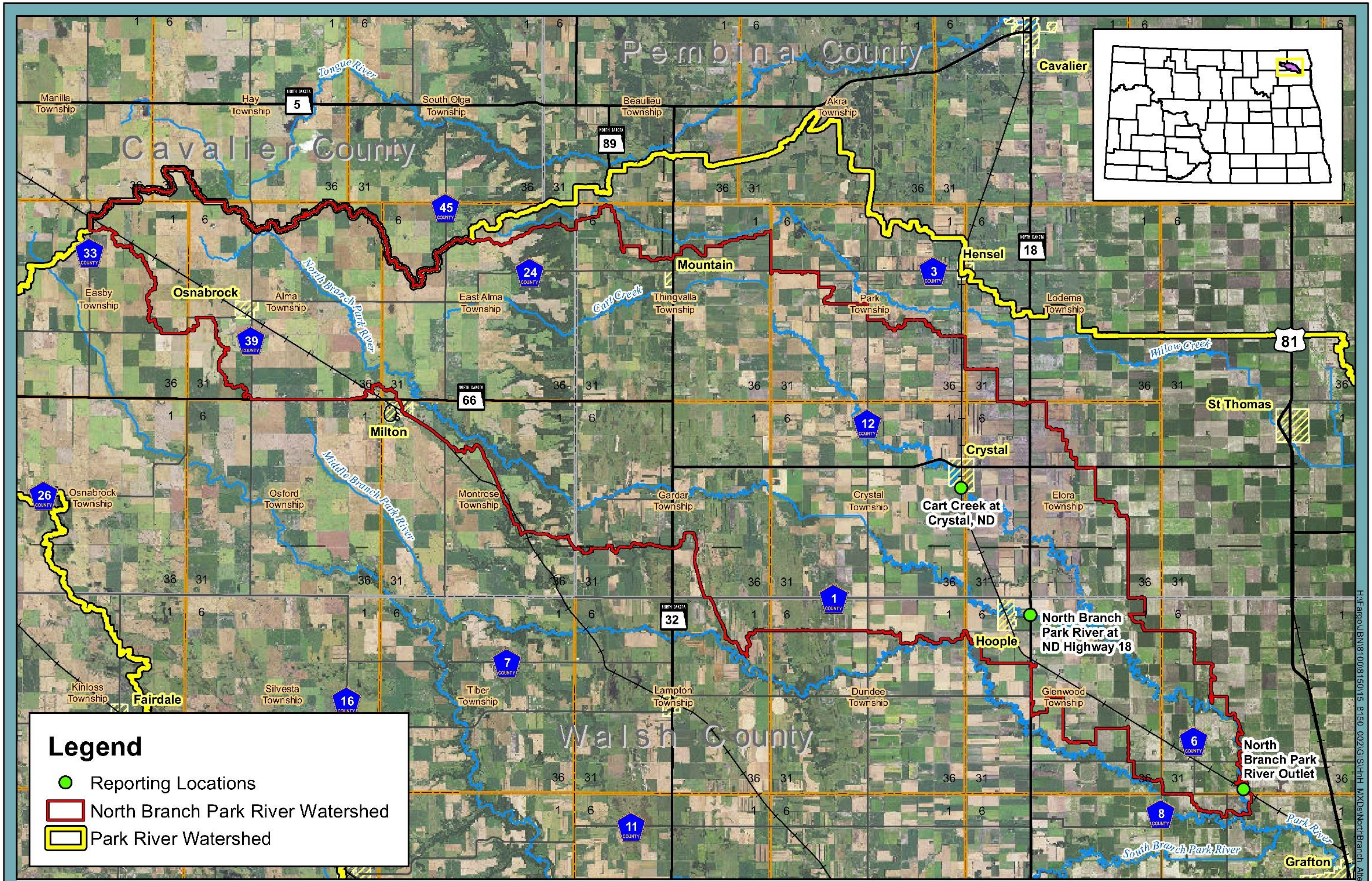


Figure D-1-B.8: *North Branch Outlet (Including Breakouts)*



ATTACHMENT D-1-C

Model Sensitivity Analysis



F-C.1

Figure C.1: Sensitivity Analysis Reporting Locatiomns

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Park River Joint Water Resource District

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Figure D-1-C.2: *Manning's N-Value Hydrographs – Cart Creek at Crystal, ND*

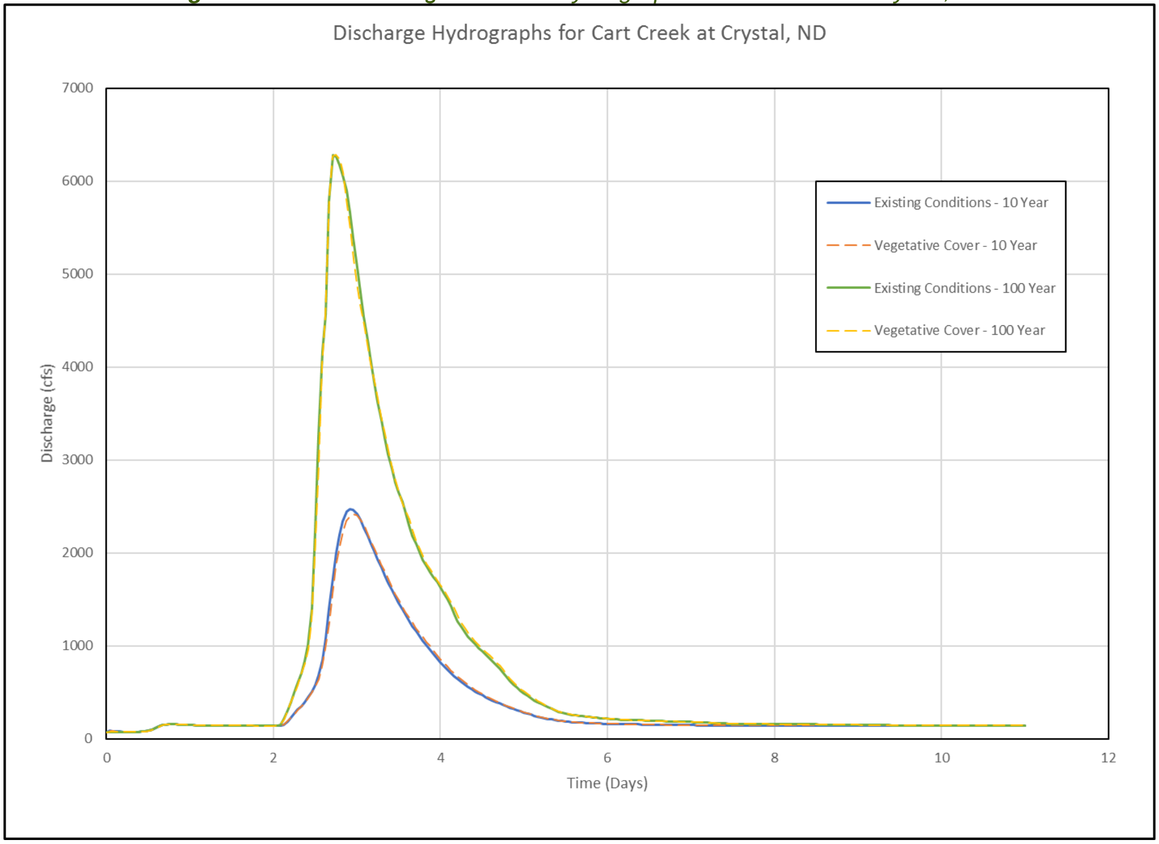

Figure D-1-C.3: *Manning's N-Value Hydrographs – North Branch at ND Highway 18*

Figure D-1-C.4: *Manning's N-Value Hydrographs – North Branch Outlet (Channel Only)*

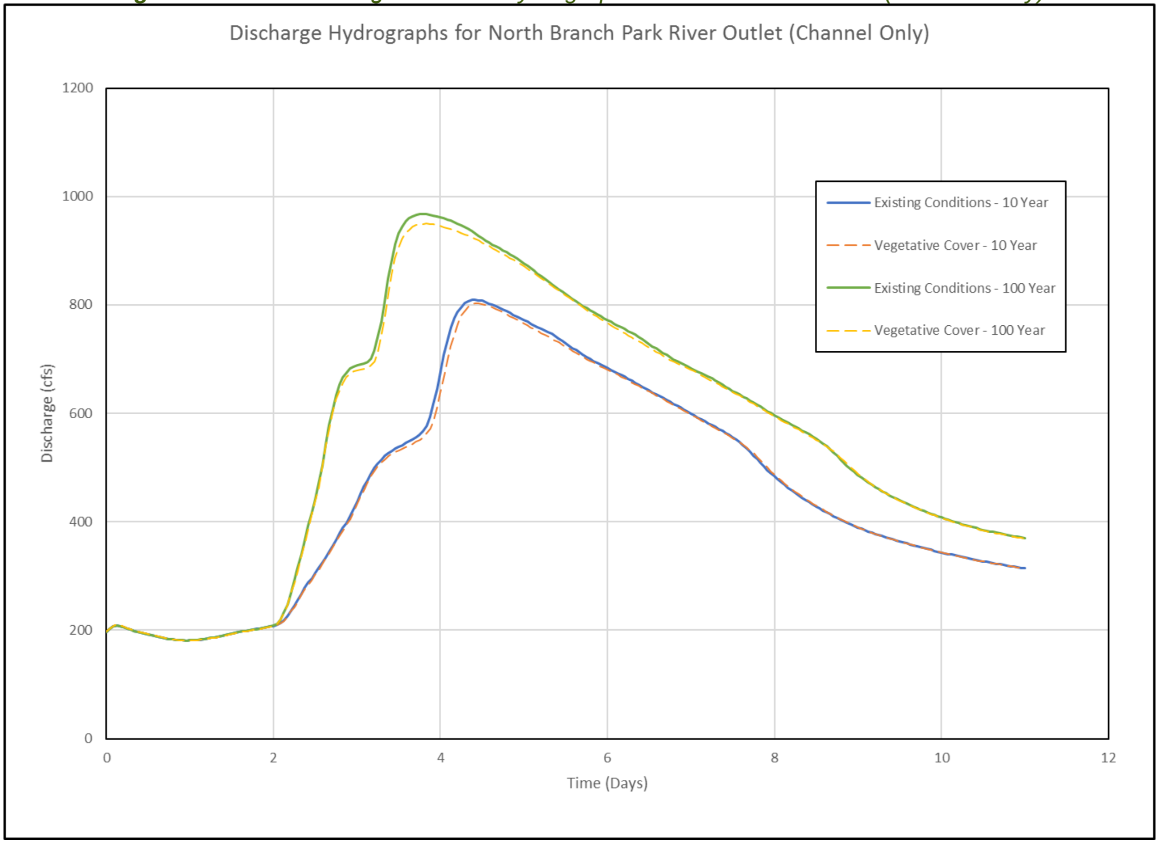

Figure D-1-C.5: *Manning's N-Value Hydrographs – North Branch Outlet (Including Breakouts)*

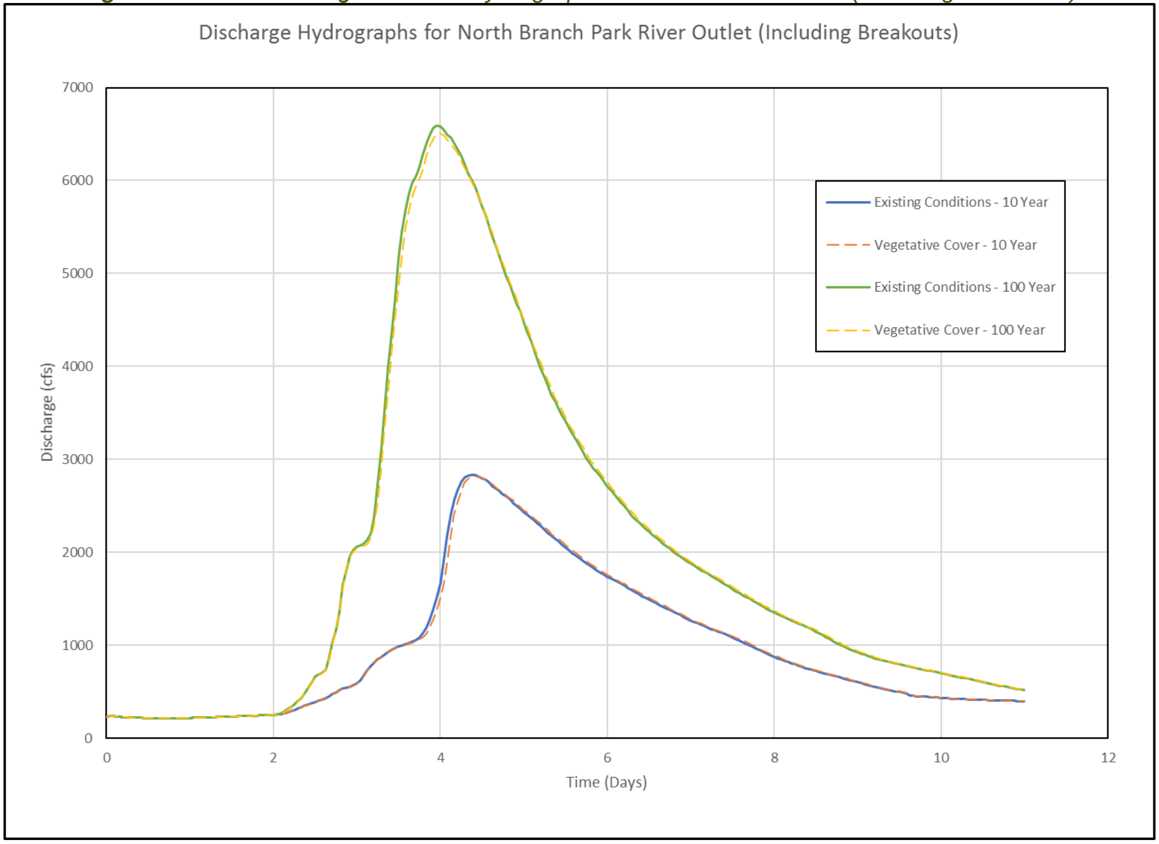

Figure D-1-C.6: *Duration Hydrographs – North Branch Outlet (Channel Only)*

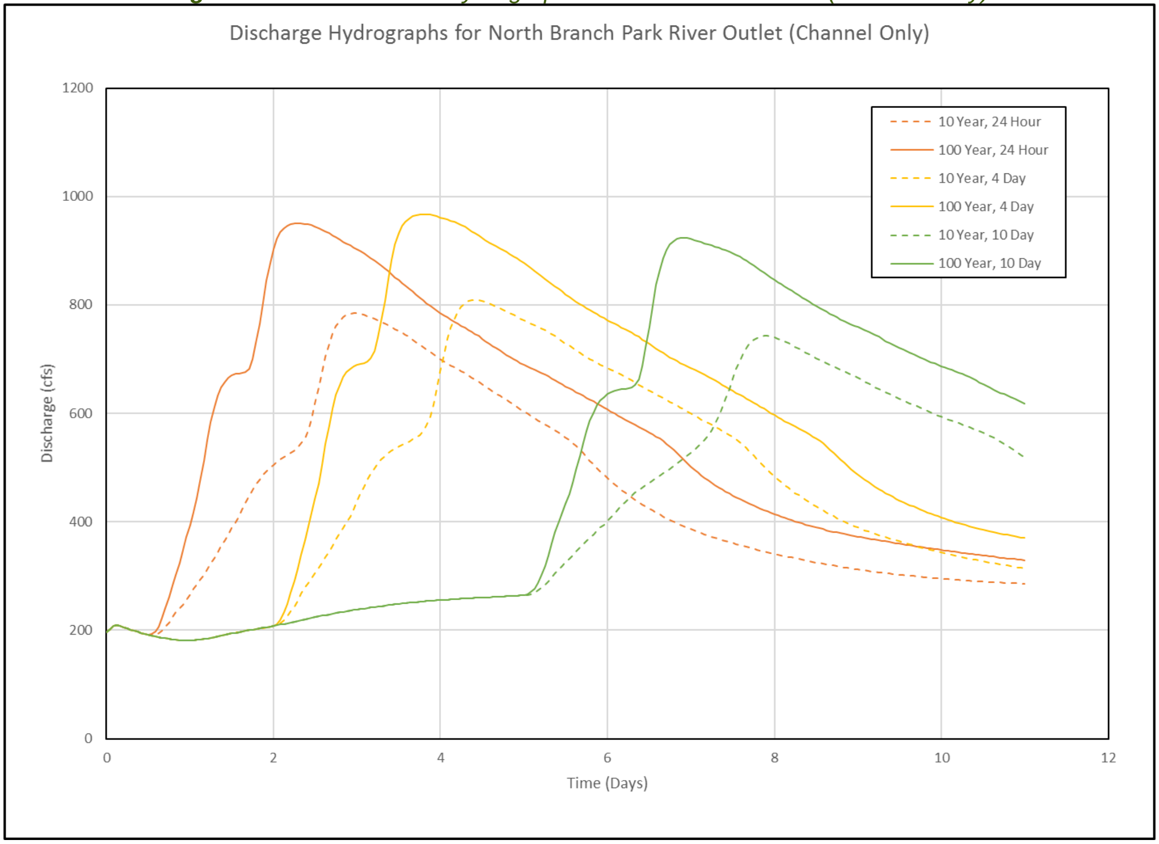

Figure D-1-C.7: *Duration Hydrographs – North Branch Outlet (Including Breakouts)*