# TONGUE RIVER WATERSHED PLAN

## Appendix D-1: Existing Conditions Hydrology and Hydraulics Report

*Spring 2019 Image of Turtle River between Manvel and I-29 (Bottom portion) and I-29 to Red River of the North (Top portion)*

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# 1 Introduction

The Grand Forks County Water Resource District (GFCWRD) entered into a Cooperative Agreement with the Natural Resource Conservation Service (NRCS) in 2019 to complete a Watershed Plan/Environmental Assessment (EA) for the Upper Turtle River Dam #10 under the Watershed Flood Prevention Operations (WFPO) Program.

Upper Turtle River Dam #10 (UTR 10) Watershed is a subwatershed of the Turtle River Watershed and is shown in **Figure D-1-1**. As part of the watershed planning effort, the existing conditions hydrology and hydraulics as it relates to flooding are evaluated. This report summarizes the development of the hydrologic and hydraulic models used to evaluate Upper Turtle River Dam #10.

# 2 Previously Developed Models

Prior to 2011 several hydrology models existed for the tributary rivers of the Red River of the North (RRN), 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 HMS Model

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 Upper Turtle 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).

## 2.2 RAS Model

Development of the HEC-RAS model for the Turtle 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-RAS model that was initially used and subsequently modified as part of the this 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).

### 2.2.1 Extent and Layout

The Turtle River section extended 68.8 River Miles (RM) from downstream face of Hwy 2, just downstream of USGS (5082625, at Turtle R State Park Nr Arvilla, ND) to confluence with Red River of the North. 1-D cross sections were used to model the Turtle River main channel, which typical range was 200 to 500 feet long. The floodplain was modeled with 2-D areas connected with lateral structures to river reach. The base elevation data was LiDAR published in 2010 (IWI, 2008-2009), which was quality level QL3.

### 2.2.2 One-Dimensional (1-D) Parameters

The Turtle River cross sections typical spacing was ~0.3 miles. Bathymetry (elevations below water surface) was only cut for lower ~6 miles based on surveys. Channel roughness (Manning's N) varied from 0.035 to 0.045. Overbank roughness were all 0.065. Lateral structure weir coefficients were set to 0.2. Bridges were included in the model as well.

### 2.2.3 Two-Dimensional (2-D) Parameters

There were two 2-D areas, one on left and one for right overbank area. The average grid cell size is 900,000 $ft^2$, which typical polygon was ~950 foot x 950 foot square, plus some smaller cells at confluence with river or roads. The roughness was set at 0.06.

# 3 Turtle River Watershed Existing Conditions

The Upper Turtle River Watershed (above USGS Streamgauge 05082625) is an approximate 311 square mile subwatershed of the 683 square mile Turtle River Watershed. The Turtle 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 Upper Turtle 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 model, and development of synthetic rainfall event simulations.

## 3.1 HMS MODEL PARAMETERS

There are two HEC-HMS (v.4.9) models developed to generate flows from subbasins and along the Turtle River based on rainfall and snowmelt. The HMS results are input to the HEC-RAS model described in next section. The reason for two models is that summer conditions are needed for benefit analysis, including frequency-based precipitation events; this model is calibrated using the 2000 June precipitation event. However, the 2000 event has no observations to use for calibration of the RAS model. Therefore, the April 2022 rain on snow event was modeled in HMS to obtain subbasin flows to use in the RAS model calibration.

### 3.1.1 Subbasin Boundaries

Subbasins were delineated to match RAS model geometry, such as hydraulic routing storage locations, road crossings, and size limitations for design guidance. The entire Turtle River basin, upper basin (above USGS gauge), subbasin boundaries, existing watershed dams (UTR 1 – 9), and proposed dam #10 is shown in **Figure D-1-2**. County Ditch (CD) #12 flows to Lake Ardoch and Forest River, however subbasins are included because Turtle River overbank flows breakout and flow into CD #12; therefore these flows are appropriate to add for economic analyses.

### 3.1.2 Initial Runoff Curve Number

The spring 2022 rain on snow event was preceded by below freezing temperatures and frozen ground conditions. The Runoff Curve Number (RCN) for all subbasins is determined from calibration to USGS 5082625 (Turtle River at Turtle R State Park Nr Arvilla, ND) and found to be 97, which is appropriate considering frozen ground conditions. The initial abstraction for all basins is found to be 1.0. The basin is predominately rural, and therefore no impervious areas are included. The subbasins below USGS gauge RCN was therefore assigned a value of 97, initial abstraction 1.0, with no impervious areas.

Initial summer 2000 calibration RCN's were calculated based on methods described in Part 650 NEH Chapter 2: Estimating Runoff Volume and Peak Discharge (NRCS, 2021), which are considered Antecedent Runoff Condition (ARC) II. The summer 2000 precipitation event RCN are considered a 24-hour value as majority of the precipitation occurred within 9 hours, and ARC II because of normal climatic condition prior to rainfall event. There is no RCN correlation less than 24-hours. Hydrologic Soil Groups (HSG) were adopted from Soil Survey Geographic Database (SSURGO) (Soil Survey Staff, 2022). Hydrologic soil groups include A, B, C, and D; for those with multiples in raw data (C/D), drainage was evaluated, with lower letter assigned if drainage was apparent, and higher letter if no drainage was apparent. National Land Cover Database (NLCD) (Homer, et al., 2015) was used to assign cover treatment. Initially calculated RCN are identified in **Figure D-1-2**. Watershed soils and land uses are shown in figures **Figure D-1-3** and **Figure D-1-4**.

### 3.1.3 Initial Unit Hydrograph Parameters

The spring 2022 rain on snow event time of concentration (Tc) was calculated with watershed lag method (NRCS, 2010). Equation 15-4b was used for six subbasins in the upper Turtle River watershed, considering flow length, watershed land slope, and runoff curve number (97). These calculated Tc were plotted against drainage area (DA) size, resulting in equation Tc = 0.11DA + 3.4. The remaining 97 subbasins were applied time of concentrations based on equation and drainage basin size. The Clark's Storage Coefficient (R) represents subbasin flood storage (for example, lakes and wetlands) and is important factor for basin hydrologic response to rainfall and snowmelt. The ratio of R/Tc is typically consistent in a region; other modeling efforts found the range in Eastern North Dakota is generally from 0.5 to 2.0. Therefore, the R is set equal to Tc.

The summer 2000 precipitation event Tc was calculated with watershed lag method (NRCS, 2010). Equation 15-4b was used for seven subbasins in the upper Turtle River watershed, considering flow length, watershed land slope, and runoff curve number (variable). These calculated Tc were plotted against drainage area (DA) size, resulting in equation $Tc = -0.0149DA^2 + 0.9581DA + 3.1173$. Furthermore, five other subwatersheds were used for validation, which one fit on the line, two above and two below. The remaining 97 subbasins were applied time of concentrations based on equation and drainage basin size. R was determined from Tc and R/Tc ratio; R/Tc is based on amount of non-contributing area, landscape slopes and drainage. Non-contributing area shapefile was provided by IWI (IWI, 2022), which is shown in **Figure D-1-5**. The majority of non-contributing areas are along the fringes of the watershed boundary and along beach ridge, which are due to glacial ground moraines. Landscape drainage is most prevalent in the lowest portion of the watershed, including large ditch networks mostly following the regular one square mile road network. R is a primary calibration input parameter, see calibration section for calibrated R/Tc values.

### 3.1.4 Reservoir and Reach Routing Parameters

The spring 2022 rain on snow event adopted Phase 2 parameters for eight watershed dams and routing parameters. The dam/reservoir inputs include Elevation-Area and Elevation-Discharge functions, with primary as Elevation-Area function. Initial elevations were set to crest of first stage of principle spillway. Reach routing method is primarily Muskingum-Cunge, which relies on length, slope, roughness, cross section, and celerity. Length, slope, and cross sections were adopted from Phase 2 model, and validated with spatial measurements. Channel roughness are set to 0.04 and overbanks to 0.065, see section 3.2.2 for rationale. The Turtle River reaches below USGS gauge 5082625 used Modified Pulse storage routing method using previous RAS models to define the storage-outflow relationship. Index celerity for most applications 5 ft/s is adequate (USACE, 2022 November), however based on physical properties of the channel and flood wave dynamics. Calibration found a value of index celerity of 6 ft/s was more applicable for this flood event in the Turtle River basin.

The summer 2000 precipitation event started with same reservoir and reach routing parameters as described above. The eight watershed dam parameters were re-calculated based on as-builts or recent assessments completed; Elevation-Area and Elevation-Discharge functions are slightly different and input in the reservoir elements, and primary method was changed to Elevation-Discharge. The gaps in these curves were filled in for higher precision at critical reservoir levels, i.e. shallow depths over auxiliary spillway, based on weir calculations and calculated weir coefficients at documented levels.

## 3.2 RAS MODEL PARAMETERS

An unsteady HEC-RAS (v.6.2) model was developed and used to generate water surface profiles by hydraulically routing runoff hydrographs generated by the HEC-HMS model. The HEC-RAS model consists of channel cross sections to route the channel flows, lateral structures to transfer overbank flows from 1-D cross sections to 2-D areas, and 2-D area elements to route the overland or breakout flows. Details of channel cross sections, lateral structures, and 2-D areas are described below. LiDAR (NDSWC, 2019-2021) published in 2022 by North Dakota State Water Commission (NDSWC), attained between 2019 and 2021, was used as the elevation terrain for the entire model.

### 3.2.1 Extent and Layout

The Turtle River Phase 2 cross sections (RM 0.05 to 68.8), hereafter "lower reach", were adopted and new cross sections were included up to the proposed Dam 10 site (RM 69.065 to 91.863). The new cross sections, hereafter "upper reach" have similar ~0.3 mile reach lengths. Since the upper reach landscape is incised with high terraces only 1-D cross sections were used, no 2-D areas. The floodplain in this upper reach varies between 700 and 1,500 feet wide; therefore cross section lengths are ~3,000 feet to span from left to right terraces. The RAS model features are identified in **Figure D-1-6**.

Since the Turtle River gets a close as 50 feet from watershed boundary with Forest River numerous times between RM 44 and 50, high flows can easily pass over the low divide and transfer river basins. Flow from the Turtle River that crosses this boundary enters into County Ditch 20 and eventually Lake Ardoch and Forest River. Therefore, County Ditch 20 is included in the 2-D area on the north side of the Turtle River, and Lake Ardoch and outlet are included in 1-D features.

### 3.2.2 One-Dimensional (1-D) Parameters

Bathymetry is included within the entire modeled reach (RM 0.05 to 69.065). Bathymetry for the lower reach was included based on average max depth of 1.8 feet from recent surveys with a parabolic shape. Two analyses were completed to determine the average maximum bathymetry depth. The first evaluated surveyed cross sections between RM 0.05 to 6.0 from Phase II study. RM 0.05 to 3.0 were backwater affected by the RRN, which had significantly higher depths from 2010 LiDAR than cross sections above that (RM 3.2 to 5.9). Therefore, the average maximum depth of the ten cross sections between RM 3.2 to 5.9 was 1.8 feet. In 2020 HDR surveyed 23 cross sections between Hwy 2 and Grand Forks Air Fork Base (GFAFB). Cross sections at bridges showed significantly higher depth than those not at bridges due to contraction of flow. Therefore, the average maximum depth of the twelve cross sections between RM 68.8 to 54.75 was 1.8 feet. Since the majority of cross sections applying bathymetry were not at bridges, and that these two separate analyses agreed on maximum average depth from 2010 LiDAR (1.8 feet), this value was applied to all lower reach cross sections besides.

The upper reach main channel bathymetry was derived from GPS field survey by HDR in 2020. Cross sections were surveyed throughout the model reach at approximately 2,000-foot intervals. Additional cross-sectional data was collected upstream and downstream of hydraulic structures. The data was processed in AutoCAD Civil3D 2018 into an interpolated surface that represented the river channel. This channel surface was merged with 2010 LiDAR data to create a seamless terrain within the HEC-RAS model. The terrain was processed in GIS to eliminate false high points in the combined terrain. The upper reach also included survey data by HDR in 2020 for applicable bridges, including high and low chord, abutments, and roadway elevations. Each bridge was modelled with a cross-section immediately upstream and downstream of the structure. Ineffective flow areas were added to the adjacent cross-sections. Expansion coefficients were set to 0.5 and contraction coefficients were set to 0.3 for the cross-section next to the bridges.

Field survey and site visits indicated noticeable facets including riffle, run, pool, and glides; while aerial photos indicate strong meanders patterns. Channel material was variable based on geologic landscape, including fines in the lowest lacustrine reach, sand in geologic deltas, and gravel/cobbles in moraines and other high energy reaches. Wood debris also varied based on buffer management. The channel roughness value was set to 0.04 as the description best fits "Clean, winding, some pools and shoals" (USACE, September 2022). This description was generally true throughout, which was maintained for consistency even though this is an extensive reach with landscape variability. Overbank roughness was set to 0.065 as these floodplain areas are a mix of pasture, brush, and trees. **Table 1** below identifies condensed standard modeling roughness values appropriate for the Turtle River channel and floodplains. A sensitivity analysis is included in Section 4.

Table 1: Critical Manning's N-Values by land use (USACE, September 2022)

| Type | Description | Minimum | Normal | Maximum |
|---|---|---|---|---|
| Main Channel | Clean, straight, full, no rifts or deep pools | 0.025 | 0.03 | 0.033 |
| Main Channel | Clean, winding, some pools and shoals | 0.033 | 0.04 | 0.045 |
| Main Channel | Sluggish reaches, weedy, deep pools | 0.05 | 0.07 | 0.08 |
| Floodplain | Pasture - High Grass | 0.03 | 0.035 | 0.05 |
| Floodplain | Cultivated - Mature field crops | 0.03 | 0.04 | 0.05 |
| Floodplain | Brush - Medium to dense brush, in winter | 0.045 | 0.07 | 0.11 |
| Floodplain | Trees - Heavy stand of timber, few down trees, little undergrowth, flow below branches | 0.08 | 0.1 | 0.12 |

Lateral Structure (LS) layouts were adopted from the Phase II RAS model, which typically span 1-2 river miles. Elevations were recomputed with 2022 LiDAR as they are important feature in the model. Some LS had very low or no flow in 2022 calibration run; these sections the weir coefficient was not changed and remained 0.2. The critical section of LS is from RM 64 to 40, the calibrated weir coefficient resulted in 0.05, which is due to extensive length, flat topography, little to no head, and influence on flows returning to the channel.

Lake Ardoch Storage-Elevation and outlet Flow-Elevation rating curves were adopted from Forest River Planning hydraulic model.

### 3.2.3 Two-Dimensional (2-D) Parameters

There were two 2-D areas, one on left and one for right overbank area. The average grid cell size is 700,000 $ft^2$, which typical polygon was ~900 foot x 900 foot square. Considerable refinement is used to create smaller cells at critical portions of the model, including confluence with river, roads, and overbank areas with considerable flow. Also, thirty 2-D connections were added at critical locations where roads back up water and culvert exists to relieve pressure on the roads. 2-D overbank roughness was set to 0.045 as these floodplain areas are predominately crop fields, with small areas of pasture, brush, and trees.

### 3.2.4 Boundary Conditions

Hydrographs generated from the 2022 calibrated HEC-HMS model were applied to the HEC-RAS model to simulate that flood event. Hydrographs from subwatersheds or junctions within the HEC-HMS model were applied at the appropriate cross sections within the HEC-RAS model as lateral inflows or uniform lateral inflows as appropriate. Further downstream, HEC-HMS subbasin hydrographs were applied to the cross sections and 2-D areas within the HEC-RAS model as appropriate. The downstream boundary condition is stage of RRN, which was assumed to be elevation 811 during the Turtle River peak runoff from April 2022 event. Elevation 811 at confluence of Turtle and RRN is observed from satellite imagery on 27April2022 (EOS, 2022).

## 3.3 HMS & RAS Calibration

The hydrologic model (HEC-HMS) is calibrated based on a spring rain on snow event that occurred in April 2022, and rainfall event that occurred in mid-June of 2000. The middle growing season time frame is critical event for agricultural damages in the basin, as growing crops will experience more damages than would be expected from spring event, when crops haven't been planted yet. The hydraulic model (HEC-RAS) is calibrated based on a rain on snow event that occurred in mid-April of 2022. The 2022 event was used because it was severe flood event with considerable overland flooding and breakout flows that water levels were documented in several places. No water levels, besides USGS gauge (5082625), were documented from 2000 flood.

### 3.3.1 HMS Calibration (Spring 2022 Rain on Snow)

The spring 2022 rain on snow event calibration of model parameters were adjusted to optimal correlation to the USGS gauge (5082625). Initial basin parameters are described in section 3.1. Some adjustments were completed to account for unique physical features and calibration precision. The meteorological model included precipitation and snowmelt parameters. Precipitation and temperature for each subbasin is assigned from closest NDAWN weather gauge using Thiessen Polygon method; **Figure D-1-7** shows weather station assignments to subbasins. Weather stations include hourly data at Alvarado 4N, Emerado 2E, Grand Forks 3S, Grafton10E , Inkster 3W, Logan Center 2E, Kempton 6SE, and Michigan 2W. Initial Snow Water Equivalent (SWE) is set to value at each weather station on the end of 19APR2022 from North Dakota Department of Water resources (NDDWR, 2022) Mapservice SWE map from that day. The upper basin (above USGS gauge) HEC-HMS basin layout and snowmelt meteorological parameters are shown in **Figure D-1-8**. These meteorological parameters are identical for all subbasins, match freezing point of water values, and are within the typical ranges described in HEC-HMS User's Manual.

There are two places where basin parameters were adjusted based on calibration. The first are transform parameters in two subbasins just upstream of USGS Gauge (W9570 and W7840). The Tc and R are adjusted to 14 hours, which is due to alignment along the Turtle River, which enter in many small catchments that follow along river, instead of whole catchment consolidating to confluence with Turtle River. These small catchments then follow along river at 0.1% slope, instead of land slope of 2%. The other adjustment are routings of Salt Water Coulee and Fresh Water Coulee upstream of the confluence with Turtle River. These routing values are adjusted to channel roughness of 0.07, overbanks 0.12, and celerity of 3 ft/s; these adjustments are due to large upstream drainage area upstream, extensive floodplain storage, and increased roughness in flat lacustrine lake plain below beach ridge.

Daily SWE calibration results are strong comparing HMS to Mapservice values; the average difference is within 1% between all the weather stations for the time period April 19 – April 24, 2022. **Table 2** shows end of day error between modeled to measured SWE. **Figure D-1-9** shows SWE plot comparisons for Inkster and Logan Center. **Figure D-1-9** also shows flow hydrograph from HMS comparing modeled and observed. The peak and timing correlate very well; there is some error between plots before rising limb and along receding limb of hydrograph. The errors were not able to be reduced any further without affecting the strong correlation of peak and timing, which are more critical for use in providing subbasin flows to RAS calibration run. Further details about calibration correlation are documented in next section 3.3.2 RAS Details, as the HMS results are used for RAS boundary condition inputs.

Table 2: April 2022 Runoff event SWE error between HMS (modeled) and Mapservice (Measured)

| Location | Avg Error between HMS & Mapservice SWE (End of Day) | | | | |
|---|---|---|---|---|---|
| | Apr. 20 | Apr. 22 | Apr. 23 | Apr. 24 | Average |
| Michgan | 0% | 12% | -3% | -3% | 1% |
| Inkster | 0% | 3% | -18% | -19% | -8% |
| Kempton | 6% | 7% | -19% | 31% | 6% |
| Logan Center | 2% | 12% | -17% | -6% | -2% |
| Average | 2% | 8% | -14% | 1% | -1% |

### 3.3.2 HMS Calibration (Summer 2000)

The summer 2000 rainstorm event calibration of model parameters were adjusted to optimal correlation to testimonials of Upper Turtle River dam auxiliary spillway max depth and the USGS gauge (5082625). Initial basin parameters are described in section 3.1. The primary adjustment parameter was Clark's Storage Coefficient (R) due to variability in storage throughout the basin and NEH guidance for calculation of RCN and Tc. Therefore, initial calculations of RCN and Tc were adopted as final. The final R/Tc values are summarized in **Figure D-1-10**.

The meteorological model includes precipitation from local gauges and Storm Precipitation Analysis System (SPAS). SPAS for the event was completed for the ND PMP Study (Applied Weather Associates, 2021); the storm code is 1726 with maximum precipitation of 20 inches within 24 hours and was a critical storm for Probable Maximum Precipitation (PMP) values in North Dakota. The storm was very localized, the total precipitation raster is plotted in **Figure D-1-11**. Subwatershed precipitation values were assigned based on centroids, which are plotted in **Figure D-1-12**. Beyond the timeframe and extents of SPAS data the Forest River and Grand Fork hourly precipitation gauges were used, that area is below gauge and included minimal precipitation well after peak of hydrograph based on 20-inch storm; these values are not sensitive to calibration of model.

The primary parameter used for calibration was R/Tc. R is based on landscape storage, which is affected by non-contributing areas, drainage, and slopes. Final R/Tc values are summarized in **Figure D-1-10**. The range is 0.7 in east to 5 in west. This range and trend follow other planning efforts in the region, i.e. Tongue River, and Forest River).

Initial reach routing parameters described in Section 3.1.4 were adopted, i.e. Muskingum-Cunge method based on eight-point cross sections, measured slope, channel roughness 0.04, overbank roughness 0.065, and index celerity of 6 ft/s. Length from Phase 2 modeling were re-analyzed as values represented channel centerlines lengths. Since majority of flow, on such large floods are in overbanks the valley length was adopted instead; this made improvements in calibration optimization.

Within South Branch Turtle River watershed, subbasin 9C-2 has two reaches flowing through, one from subbasin 9C-1 and the other from Dam 6. These reaches combine to one in the middle of 9C-2, and directly adjacent to the boundary between North Branch and South Branch Turtle River. Overbank flows spread to the north and cross the boundary to North Branch Turtle River. A 2D HEC-RAS model was completed to discern the flow that transfers from the South Branch to North Branch Turtle River. Approximately 30% of flow above bankfull (50 cfs) stays in the South Branch and 70% diverts to the North Branch at this split. A rating curve was developed to mimic the split and input in HEC-HMS model.

Calibration of the HMS model considered local testimonials of Upper Turtle River Dam reservoir levels and USGS gauge (5082625) observed flows.

**Table 3** shows dam critical elevations, modeled reservoir levels, and testimonials from Rich Axvig and John Sucor (Axvig and Sucor, 2022). The USGS gauge pressure transducer for automated sampling did not work during most of the flood due to such large event and heavy debris. There were five manually measured samples between June 13-15; the highest value was 12,200 cfs at 15:30 on June 13, which was considered poor accuracy due to debris. The 12,200 cfs is assumed close to the peak, however the peak flow is uncertain. No volume calculations are relevant due to non-continuous data. The modeled vs. measured hydrograph points are documented in **Figure D-1-13**, along with picture of USGS taking manual measurements on 6-13-2000. The HMS model results matched well to testimonials at watershed dams. Dam 7 was observed to have overtopped during the flood, however due to upstream roads and railroads overtopping causing a flood wave breach that is not able to be modeled in HMS; therefore, results considered adequate. Dam 9 (Larimore Dam) is the most critical to flows at USGS gauge, which peak at ~6,000 cfs and ~18 hours delayed from peak on North Branch, see **Figure D-1-14** for hydrographs.

The HMS modeled peak flow at gauge is 12,417 cfs, which aligns well with highest measurement. The timing of modeled flows match well to three measurements on 6-13-2000, however are higher on second two on 6-14-2000 and 6-15-2000. This discrepancy in calibration at gauge in days following peak cannot be improved while maintaining water levels at dams, notably Dam 9 (Larimore Dam). The two testimonials of reservoir level and outflow from Dam 9 contrast with flows measured at the gauge on 6-14-2000 and 6-15-2000. Therefore, these results are considered optimized as they hit approximate peak flow and rising limb at gauge, and testimonials for reservoir levels. A final note that this rainfall event was a PMP level at local level (~4 square miles), and 1,000-year at gauge, testimonials also noted flow was rumored to have crossed boundaries such as in the upper South Branch basin to Goose River, and lower North Branch basin to Forest River. There are no measurements for these cross boundary flows, plus with poor rating and scatter of USGS gauge measurements; the inputs calculations are based on sound references and match other nearby basin studies, the input parameters are considered sound for frequency based analyses.

*Table 3: June 2000 Upper Turtle River Dam testimonials and modeled water levels*

| Turtle River Dam Critical Elevations & 2000 HMS model Results (NAVD88, ft) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Dam # | 1 | 2 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1st Stage/Orifice | 1190.7 | 1307.7 | 1241.2 | 1248.2 | 1251.2 | 1213.2 | 1221.2 | 1068.9 |
| 2nd stage | 1201.95 | 1327.7 | 1260.7 | 1272.2 | 1280.7 | 1222.2 | 1234.95 | 1083.2 |
| Auxiliary Spillway (AS) | 1210.9 | 1338.2 | 1272.5 | 1290.2 | 1292.7 | 1225.8 | 1240 | 1090.5 |
| Top of Dam (TOD) | 1216.6 | 1343.2 | 1277.2 | 1295 | 1297.7 | 1230.8 | 1245 | 1100.8 |
| | | | | | | | | |
| HMS Peak WSEL | 1201.5 | 1328.4 | 1272.8 | 1283.7 | 1293.4 | 1226.6 | 1241.3 | 1094.5 |
| Head on AS | -9.4 | -9.8 | 0.3 | -6.5 | 0.7 | 0.8 | 1.3 | 4 |
| Below TOD | 15.1 | 14.8 | 4.4 | 11.3 | 4.3 | 4.2 | 3.7 | 6.3 |
| | | | | | | | | |
| Jon Sucor testimonial: | Not AS flow | Not AS flow | barely (~0.5') | Not AS flow | barely (~0.5-1') | Overtop dam, due to CR & RR Tressel breach | barely (~1') | ~4-5' |
| Rich testimonial | | | | | barely (~0.8') | May not have breached until after 6-14-00 | | ~4' peak, Ran for 3-4 days |

### 3.3.3 RAS Calibration (Spring 2022)

Calibration of model parameters were adjusted to optimal correlation to the USGS gauge (5082625), as well as six other flood inundation or stage testimonials by landowners or individuals that work in Grand Forks County. Initial values were set based on HEC-RAS Hydraulic Reference Manual (USACE, 2022). Initial roughness values were maintained; refinement to mesh and lateral structure weir coefficients were primary adjustments used in calibration effort. Roughness and weir coefficients both had effects on breakout flow inundation extents, roughness tables are more standard than weir coefficients without head and extending many miles, therefore weir coefficients used for primary calibration parameter. The hydrograph in the model was compared to recorded discharge, stage, and timing at the Turtle River USGS Streamgauge 05082625 Near Arvilla, ND. The simulated HEC-RAS peak flow rate, volume, and timing are consistent with observed flow rates and similar on volumes at the gage during the event. The 8-day duration wasn't run in HEC-RAS, therefore results are from HEC-HMS model. **Table 4** summarizes the peak flow rates, water levels, and timing, as well as the 4-day and 8-day volumes centered on the peak flow rate (i.e. the 4-day and 8-day volumes were computed by finding the area under the hydrograph centered on the peak ±2 days and ±4 days respectively).

Table 4: Peak Flow and Volume Comparison at USGS Gage 05082625 Turtle River near Arvilla, ND

| Location | Peak Flow (cfs) | Peak WSEL (feet) | Peak Flow Time | Volume (Ac-ft) 4-Day | 8-Day (HMS) |
|---|---|---|---|---|---|
| USGS 5082625 Turtle Riv Nr Arvilla | 3,679 | 971.2 | 24Apr2022, 21:45 | 10,611 | 14,409 |
| HEC-RAS Model | 3,668 | 970.0 | 24Apr2022, 21:00 | 12,399 | 14,032 |
| % Diffrence | -0.3% | -0.1% | - | 16.9% | -2.6% |

Inundation mapping was used to compare the HEC-RAS model floodplain against testimonials from landowners, people working in the area, and satellite imagery. Detailed testimonials included approximate maximum water levels (i.e. 6 inches over road) compared to top of roadways, and adjacent to buildings from late April 2022 timeframe; further lines include roads overtopped or not overtopped with approximate length, but not depths. **Figure D-1-15** is a summary of these sites. **Figure D-1-16** shows flood inundations near Manvel taken from satellite imagery on 27April 2022 (EOS, 2022). These inundations matched the testimonials around Manvel. Satellite images from EOS were taken each odd day in April 2022, however days prior to 27 April 2022 were cloudy and inundation was not discernable.

The hydraulic model results matched road overtopping lines, satellite images, and detailed testimonials. Satellite image inundation extent was compared to LiDAR, which matched very well to detailed testimonial in and around Manvel. A water level comparison summary is included **Table 5** These three sites provided critical information for calibration of the hydraulic model, notably determining lateral structure weir coefficients, as breakout flows start just upstream of Mekinock, around RM 58 and remain critical to RM 39. The testimonials around Mekinock discerned how much flow broke out between RM 58 and 48 by the water level at Mekinock, and corresponding flow required for that stage. The Manvel testimonial discerned how much flow from upstream breakouts re-entered the river or crossed the boundary to Forest River watershed, plus further broke out between RM 48 and 39. Finally, the USGS gauge (Turtle River at Manvel, ND; 5083000) rating curve from annual peak flows match RAS model results, which correlates to RM 20.1.

Table 5: Hydraulic model calibration - Water level comparison at detailed testimonial sites

| Location | Description | Observed WSEL | Modeled WSEL | Difference (ft) |
|---|---|---|---|---|
| Mekinock | Landowner stated Rice Street overtopped by ~8" | 862.3 | 862 | -0.3 |
| One mile south of Mekinock | Landowner stated inundation next to NE corner of building | 859.4 | 859.4 | 0.0 |
| Manvel | Park District stated max WSEL 6" below Western Drive crown | 819.5 | 819.9 | 0.4 |

# 4 Modeling Results

## 4.1 HMS Results

The final calibrated HMS model was adopted for synthetic rainfall analyses; RCN values are considered 24-hour values. Three synthetic event durations were simulated; 24-hour, 4-day, and 10-day, to determine which duration storm event produces the highest peak flow and greatest impacts. The 10-day RCN followed the lookup correlation from 24-hour RCN in Table 21-2 Part 630 NEH Ch. 2 (USDA, 2019). The 4-day RCN was calculated following linear relationship between 24-hour and 10-day. NOAA Atlas 14 (NOAA, 2022) rainfall depths were adopted from the point at Mekinock, ND, due to its central location in the Turtle River watershed (see

***Table*** 6). The HMS Frequency Storm meteorological model was used to distribute rainfall in nested format.

Table 6: Turtle River watershed frequency based precipitation

| PRECIPITATION FREQUENCY ESTIMATES | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Duration | 1 | 2 | 5 | 10 | 25 | 50 | 100 | 200 | 500 | 1000 |
| 5-min: | 0.333 | 0.395 | 0.501 | 0.593 | 0.725 | 0.832 | 0.943 | 1.06 | 1.22 | 1.35 |
| 10-min: | 0.487 | 0.578 | 0.733 | 0.868 | 1.06 | 1.22 | 1.38 | 1.55 | 1.79 | 1.97 |
| 15-min: | 0.594 | 0.705 | 0.894 | 1.06 | 1.3 | 1.49 | 1.68 | 1.89 | 2.18 | 2.41 |
| 30-min: | 0.778 | 0.923 | 1.17 | 1.39 | 1.7 | 1.96 | 2.23 | 2.51 | 2.91 | 3.22 |
| 60-min: | 0.963 | 1.14 | 1.45 | 1.73 | 2.13 | 2.45 | 2.79 | 3.16 | 3.66 | 4.06 |
| 2-hr: | 1.15 | 1.36 | 1.74 | 2.07 | 2.55 | 2.94 | 3.36 | 3.8 | 4.41 | 4.9 |
| 3-hr: | 1.26 | 1.5 | 1.91 | 2.28 | 2.81 | 3.26 | 3.72 | 4.22 | 4.91 | 5.47 |
| 6-hr: | 1.47 | 1.74 | 2.22 | 2.65 | 3.29 | 3.83 | 4.39 | 5 | 5.87 | 6.56 |
| 12-hr: | 1.71 | 2 | 2.54 | 3.04 | 3.8 | 4.44 | 5.13 | 5.89 | 6.96 | 7.84 |
| 24-hr: | 1.94 | 2.27 | 2.88 | 3.45 | 4.32 | 5.08 | 5.9 | 6.79 | 8.09 | 9.14 |
| 2-day: | 2.18 | 2.55 | 3.23 | 3.87 | 4.85 | 5.69 | 6.61 | 7.62 | 9.06 | 10.2 |
| 3-day: | 2.37 | 2.75 | 3.46 | 4.12 | 5.14 | 6 | 6.95 | 7.98 | 9.46 | 10.7 |
| 4-day: | 2.54 | 2.93 | 3.65 | 4.31 | 5.34 | 6.21 | 7.15 | 8.18 | 9.66 | 10.9 |
| 7-day: | 2.99 | 3.4 | 4.13 | 4.8 | 5.82 | 6.68 | 7.61 | 8.62 | 10.1 | 11.2 |
| 10-day: | 3.4 | 3.83 | 4.6 | 5.3 | 6.34 | 7.22 | 8.15 | 9.15 | 10.6 | 11.7 |

Peak discharges were calculated at the USGS Streamgauge 05082625 Near Arvilla, ND and Manvel, ND for the three storm durations shown in **Table 7**. Discharge hydrographs are plotted in **Figure D-1-17** and **Figure D-1-18**, at USGS gauge 5082625 (Turtle River Nr Arvilla) and at USGS gauge 5083000 (Turtle River at Manvel), respectively.

Table 7: Modeled HMS Peak Flow Rates

| HMS Flow | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | USGS Gauge (Hwy 2/State Park) | | | Manvel | | |
| AEP | Flood | 24Hr | 4Day | 10Day | 24Hr | 4Day | 10Day |
| 0.5 | 2yr | 672 | 963 | 1,094 | 1,213 | 1,886 | 2,211 |
| 0.2 | 5yr | 1,343 | 1,674 | 1,707 | 2,186 | 3,050 | 3,353 |
| 0.1 | 10yr | 2,051 | 2,447 | 2,373 | 3,281 | 4,292 | 4,489 |
| 0.04 | 25yr | 3,382 | 3,839 | 3,503 | 5,038 | 6,306 | 6,163 |
| 0.02 | 50yr | 4,665 | 5,129 | 4,561 | 6,774 | 8,605 | 8,170 |
| 0.01 | 100yr | 6,170 | 6,606 | 5,779 | 9,101 | 11,408 | 10,500 |
| 0.002 | 500yr | 10,599 | 11,026 | 9,330 | 16,516 | 20,161 | 17,836 |

## 4.2 Flow Recurrence vs Rainfall Recurrence

All-seasons 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. The all-seasons peak flow statistical analysis was completed using HEC-SSP (Reference), 17C EMA methods at Turtle River USGS Streamgauge 05082625 Near Arvilla, ND. The gauge has 30 years of peak streamflow data, from 1993 to 2022. The calculated station skew is 0.3; which is very high for North Dakota, but due to a 1000-year event within 30 years of data. From the USGS SIR 2015-5096, the regional general skew is -0.509 (Williams-Sether, 2015). Therefore, the weighted skew result is 0.02. The result of the statistical analysis with varying skews (-0.509, 0.02, and 0.3), even with same 30 years of data, give drastically varying results. For example, the 100-year flow for skews (-0.509, 0.02, and 0.3) are 5,385, 7,895, and 9,587 cfs, respectively.

To have better confidence on adopting a skew, the June 2000 rainfall event frequency was determined to be ~1,000 year event. The average watershed precipitation amount was determined to be 7.6 inches, while amount at centroid of upstream watershed is 7.4 inches; therefore the June 2000 rainfall above gauge is considered 7.5 inches. The SPAS 1726 storm information indicate that 99% of the maximum 20 inches of rain fell within 10-hour time period (**Figure D-1-11**). The frequency-based correlation (NOAA, 2022) for this location with 7.5 inches in 10 hours is ~1,000-year event. Therefore, anchoring the 1,000-year frequency to 12,440 the adopted skew should be -0.2. This value is well within the range of possible skews (-0.509 to 0.3), and chosen to be the adopted skew for determining frequency based flows at the USGS gauge. The frequency-based HMS results from previous section compare favorably to gauge statistical analysis, see **Figure D-1-19** for comparison. Therefore, the HMS results in previous section (representing summertime rainfall) also represent the all-seasons condition for structural economic impacts.

## 4.3 RAS Results

The upper/western portion of the Turtle River watershed is located above the Lake Agassiz floodplain and beach ridge, in the Drift Plains eco region. This portion of the watershed was only modeled in HEC-HMS, therefore there are no HEC-RAS results. The next lower/eastern eco region is the Beach Ridge, which is where Dam #10 is proposed. The Turtle River through the beach ridge is an entrenched valley, which is approximately 1,000 feet wide; high flows, including the 500-year inundation, remains confined to this valley through the beach ridge. The transition from beach ridge to Glacial Lake Agassiz eco region occurs around Hwy 2, Turtle River State Park, and USGS Streamgauge 05082625 Near Arvilla, ND. Below the state park the floodplain is no longer entrenched and flood flows spread out widely on both sides of the river centerline. The flows that spread on the south side re-enter the Turtle River downstream, which occurs prior to the confluence with Kelly Slough. Some of the flows on the north side enter back into the Turtle River near Manvel, some downstream of that, and others cross the divide into the Forest River watershed, and flow to Lake Ardoch. The 4-Day 10-year and 100-year inundation depths are documented in **Figure D-1-20, Figure D-1-21,** and **Figure D-1-22.**

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*Modeling.*

## FIGURES

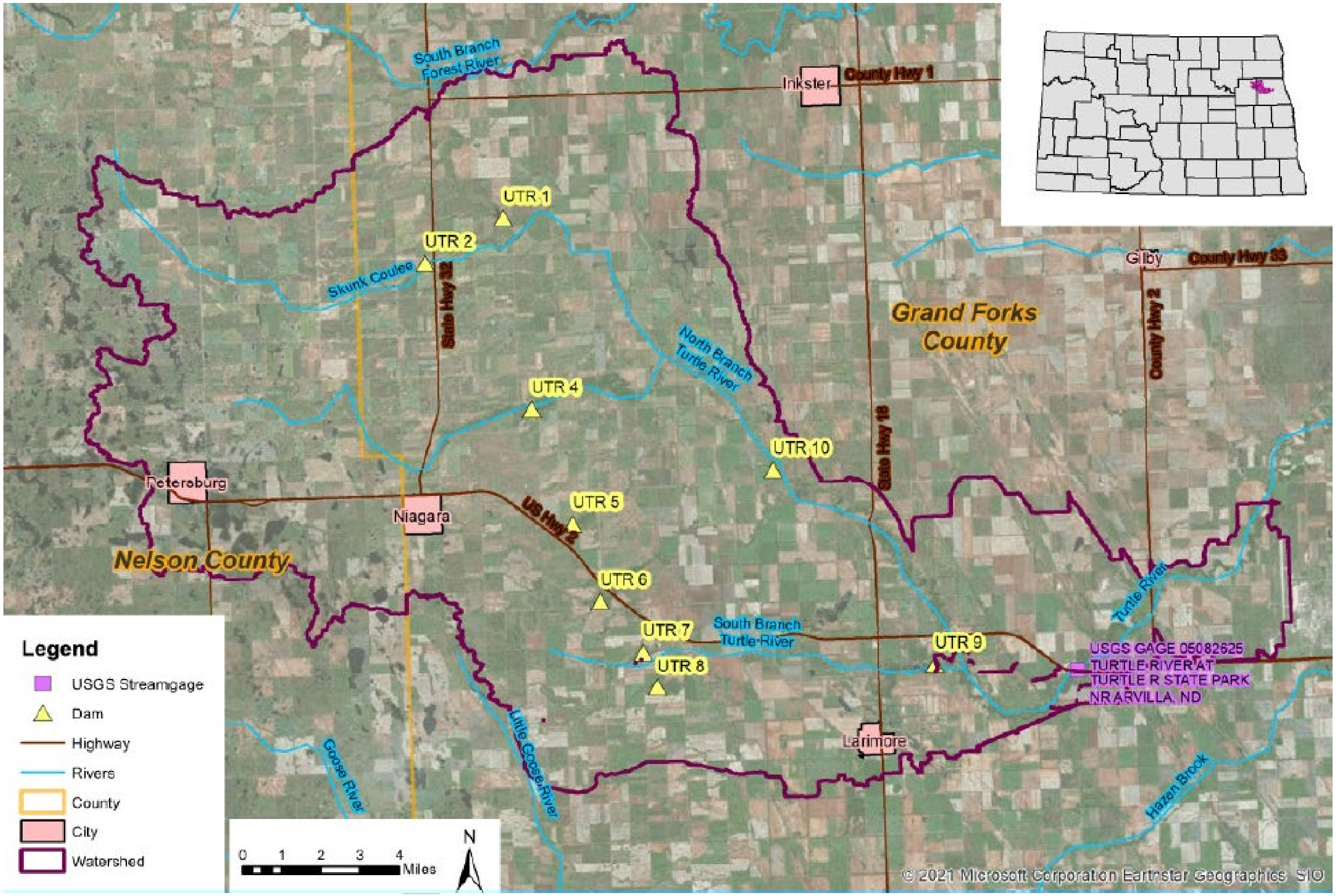



Figure D-1-1: Upper Turtle River Watershed

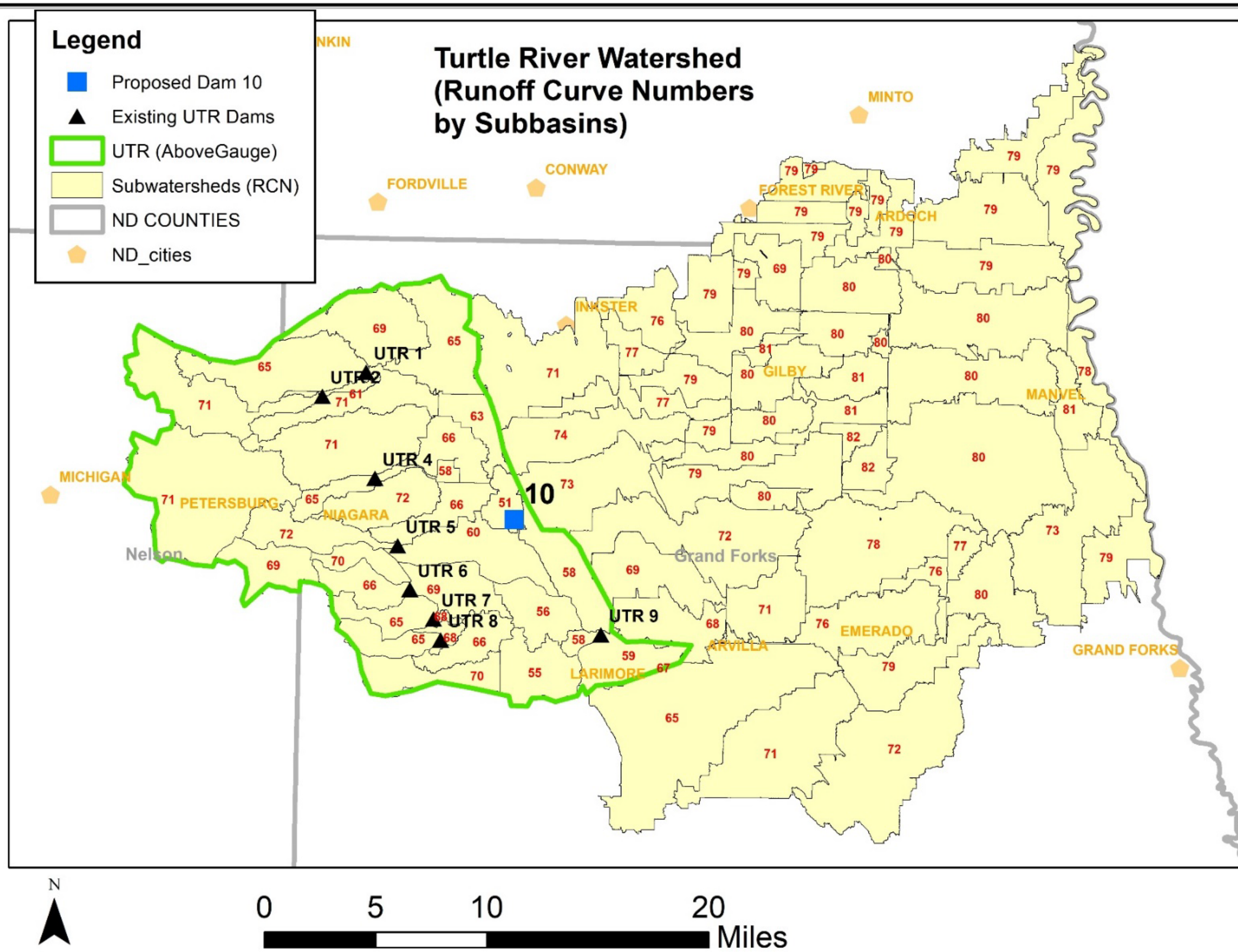



Figure D-1-2: Turtle River Subbasin Boundaries with Runoff Curve Numbers

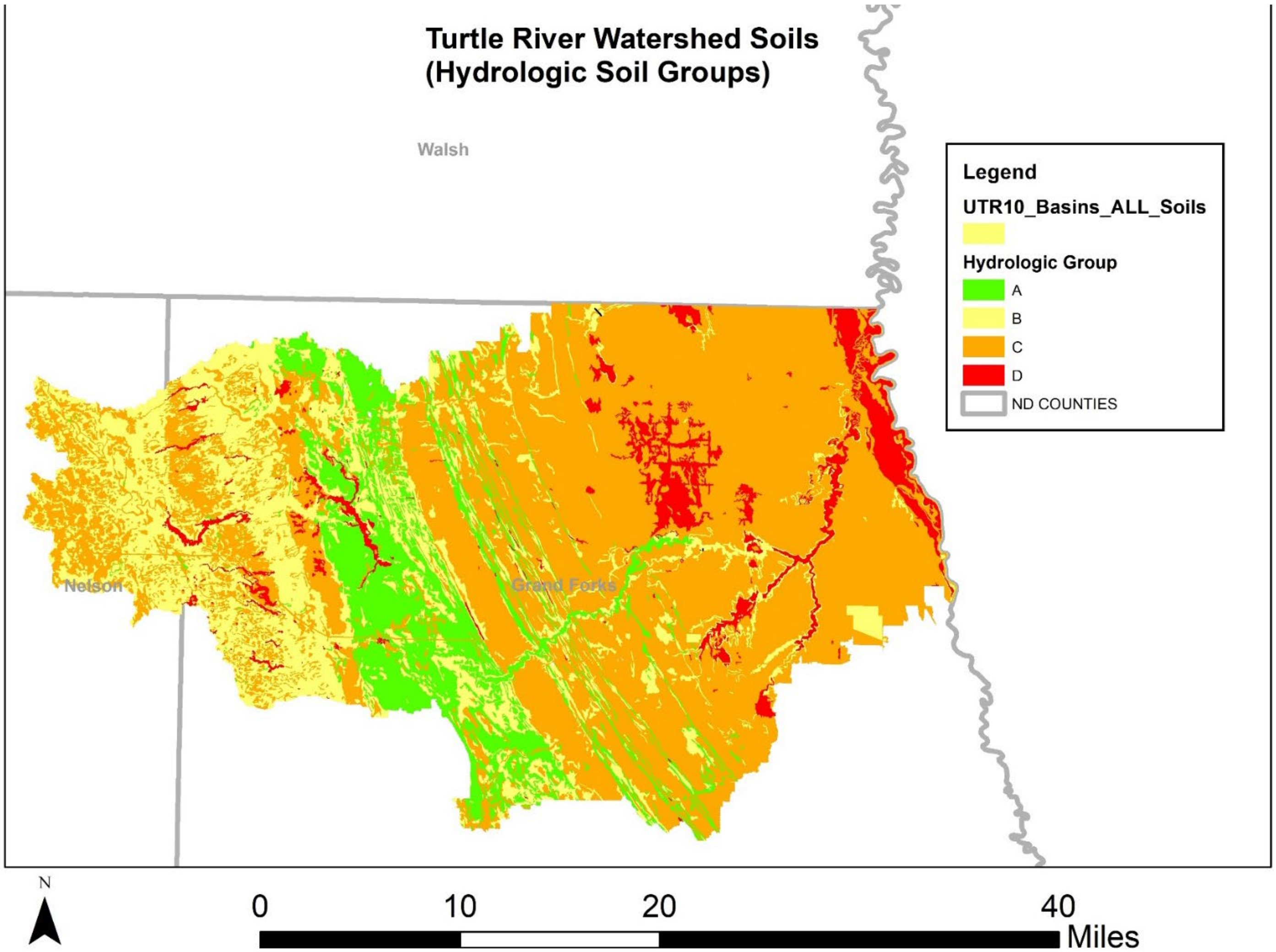



Figure D-1-3: Turtle River Hydrologic Soil Group Map

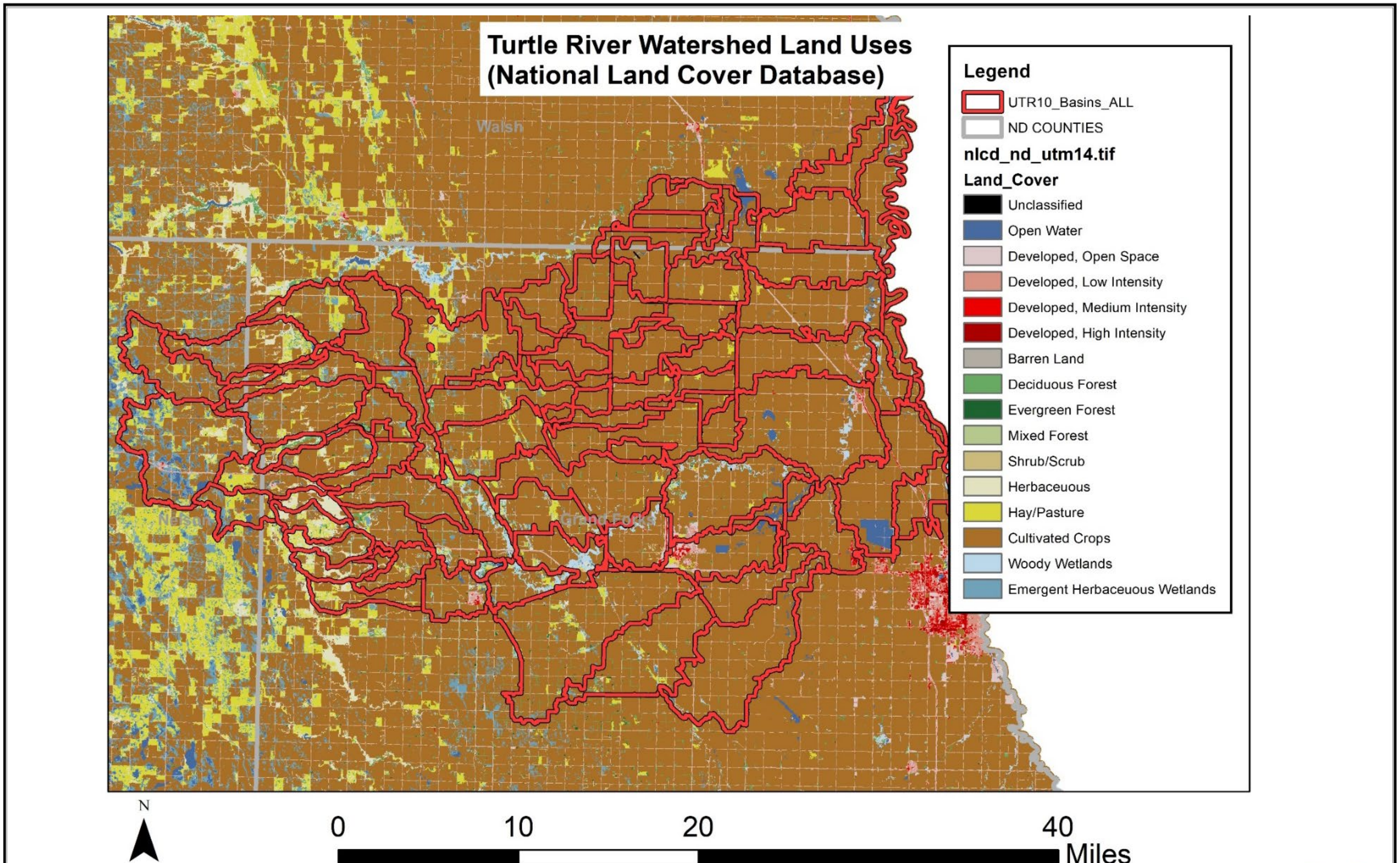



Figure D-1-4: Turtle River Land Cover Map

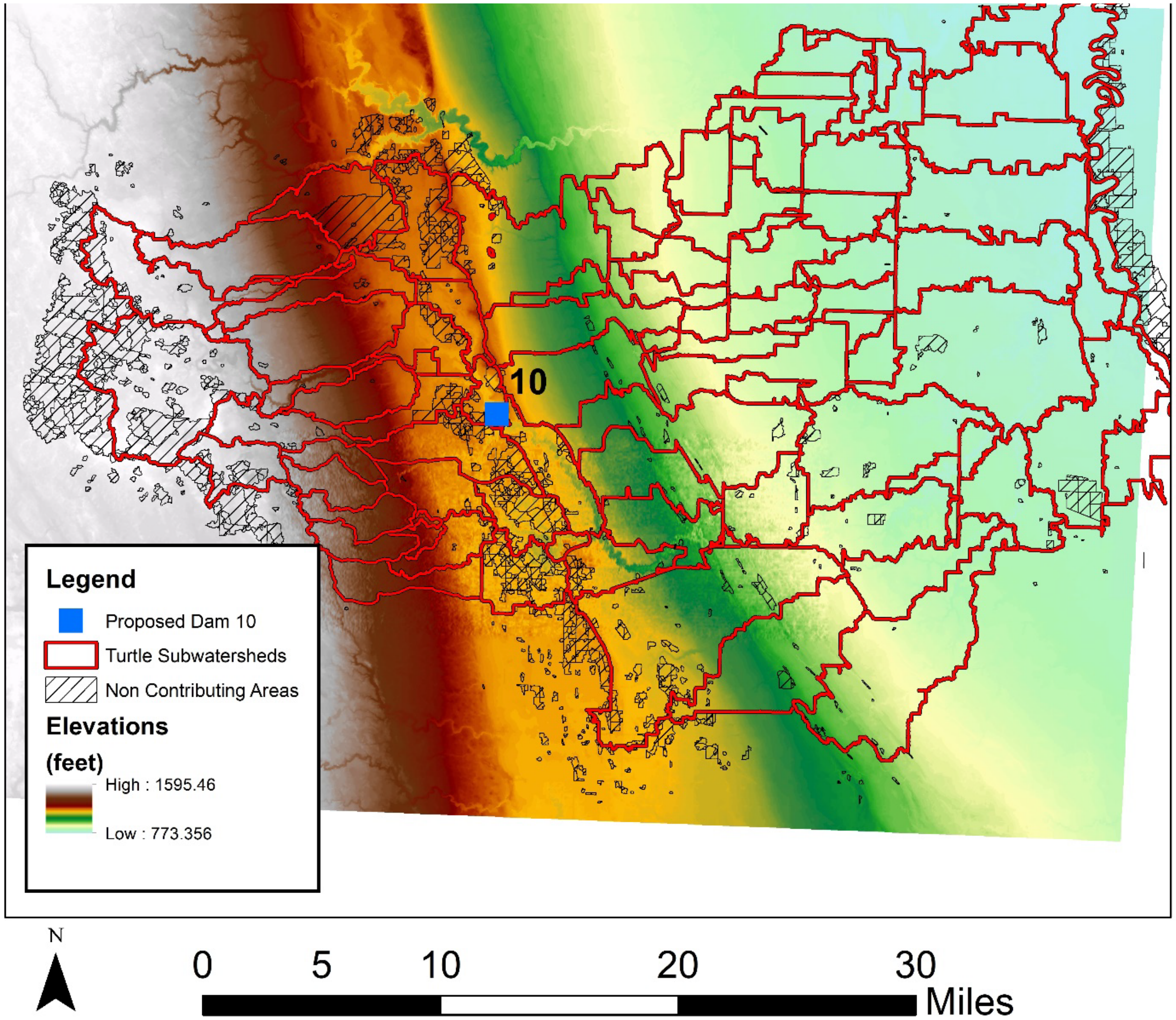



Figure D-1-5: Turtle River Elevation and Non-Contributing Areas Map

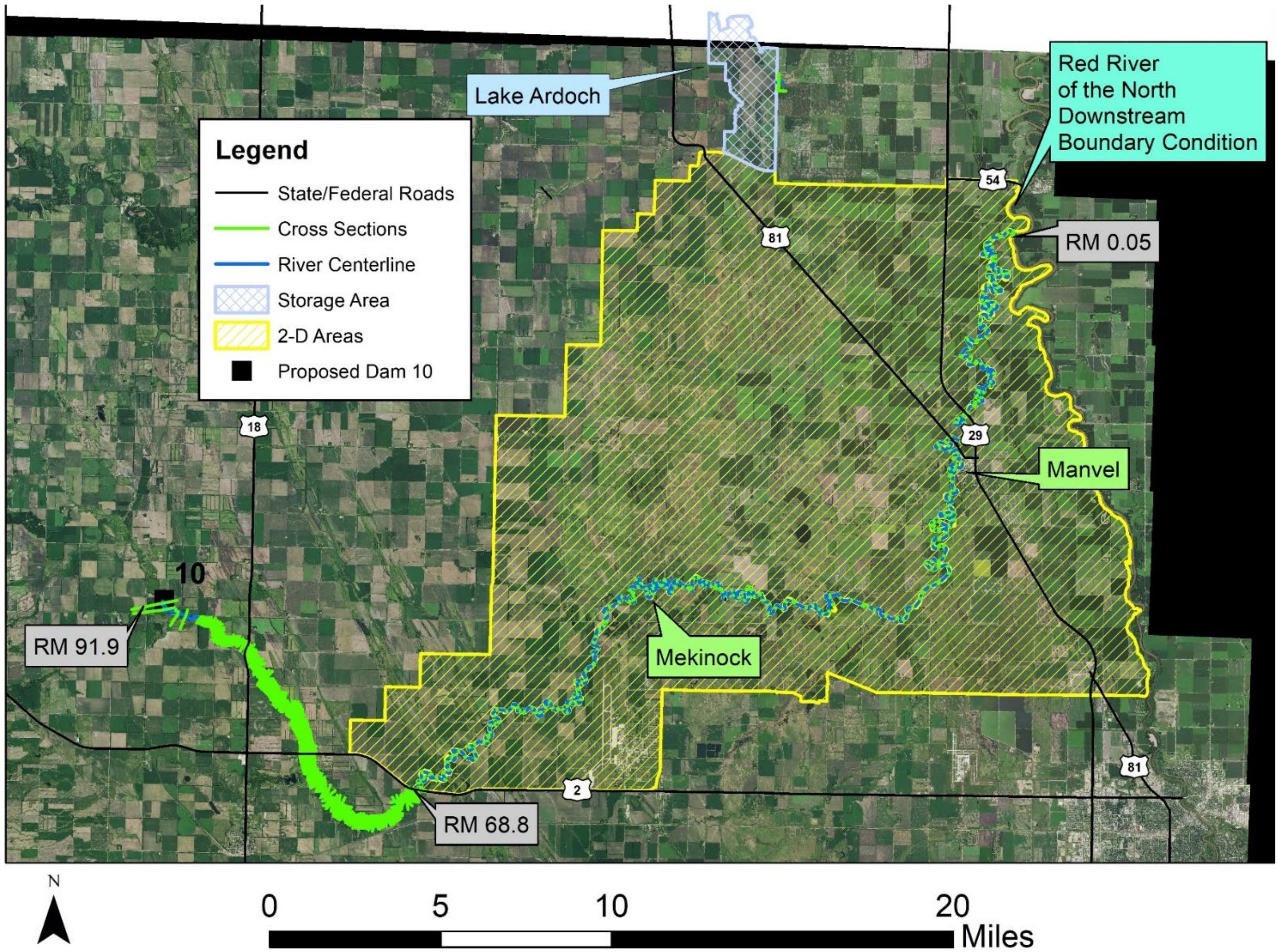



Figure D-1-6: Turtle River Hydraulic Model (HEC-RAS) Features

USDA

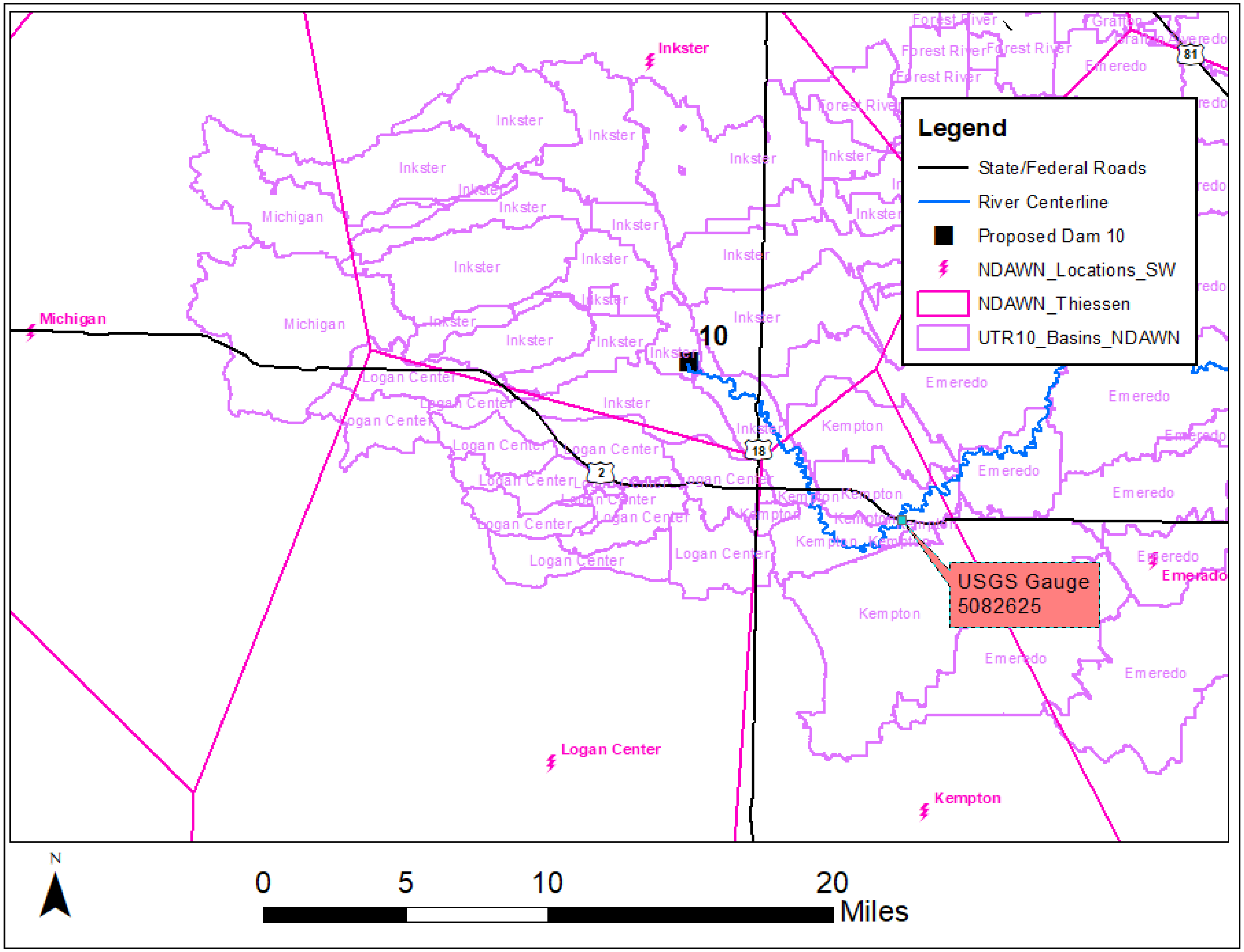



Figure D-1-7: Turtle River NDAWN Weather Gauge Assignments for 2022 Calibration Event

NRCS

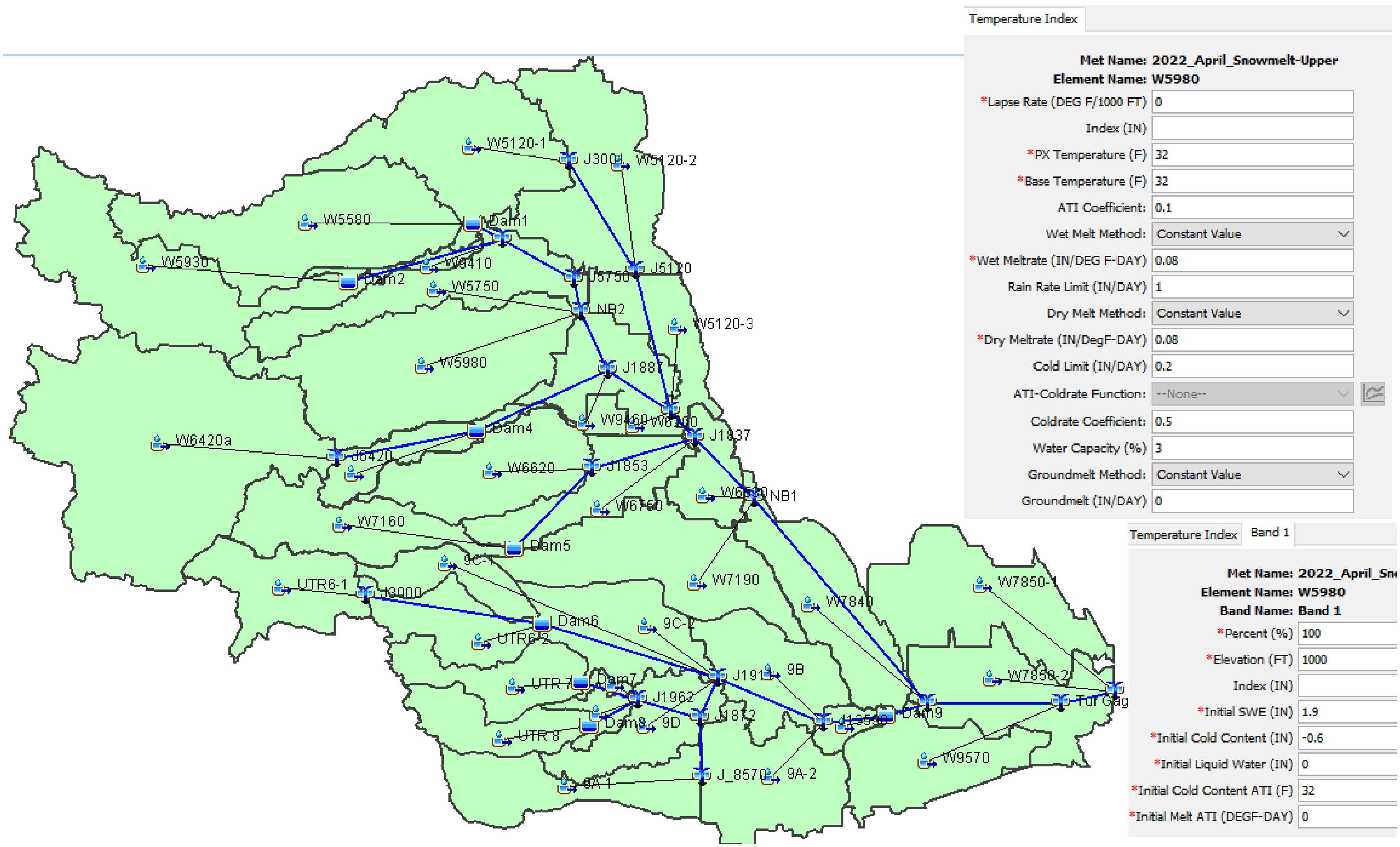



Figure D-1-8: Turtle River HEC-HMS Basin Layout and Meteorological Values for April 2022 Calibration Event

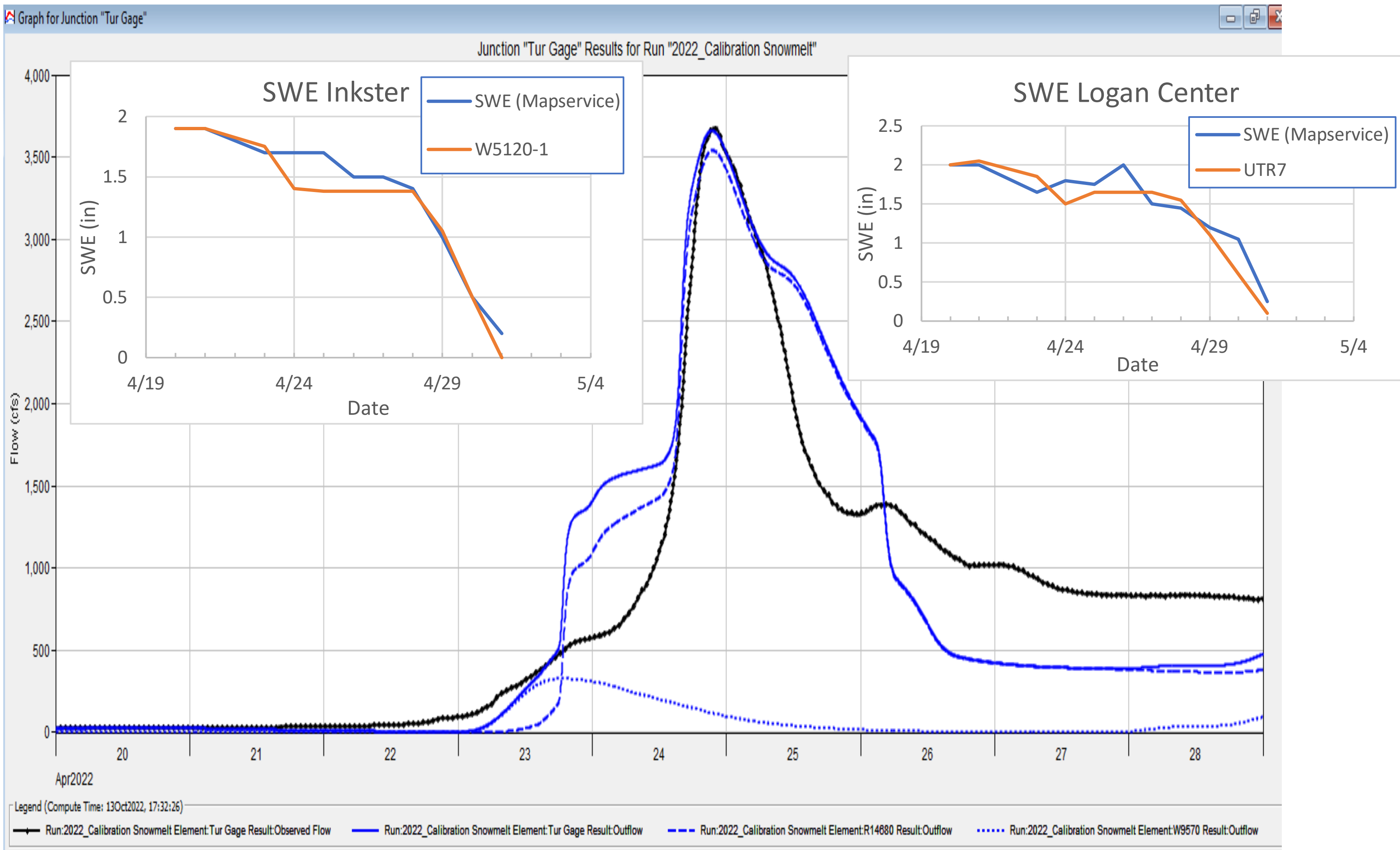



Figure D-1-9: HEC-HMS April 2022 Calibration results, SWE at Inkster and Logan Center, and flow at USGS 05082625

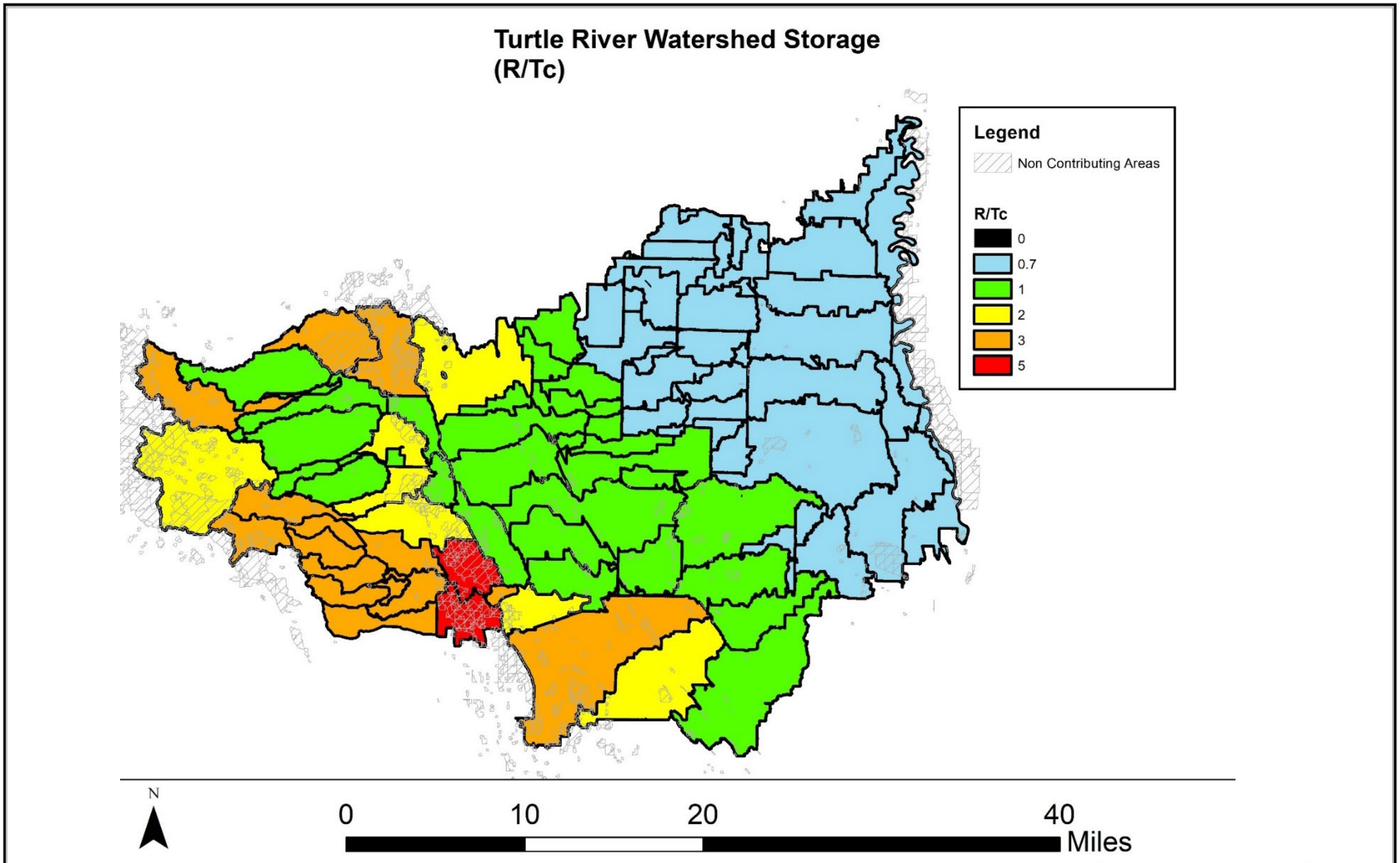



Figure D-1-10: Turtle River Watershed Storage R/Tc Map

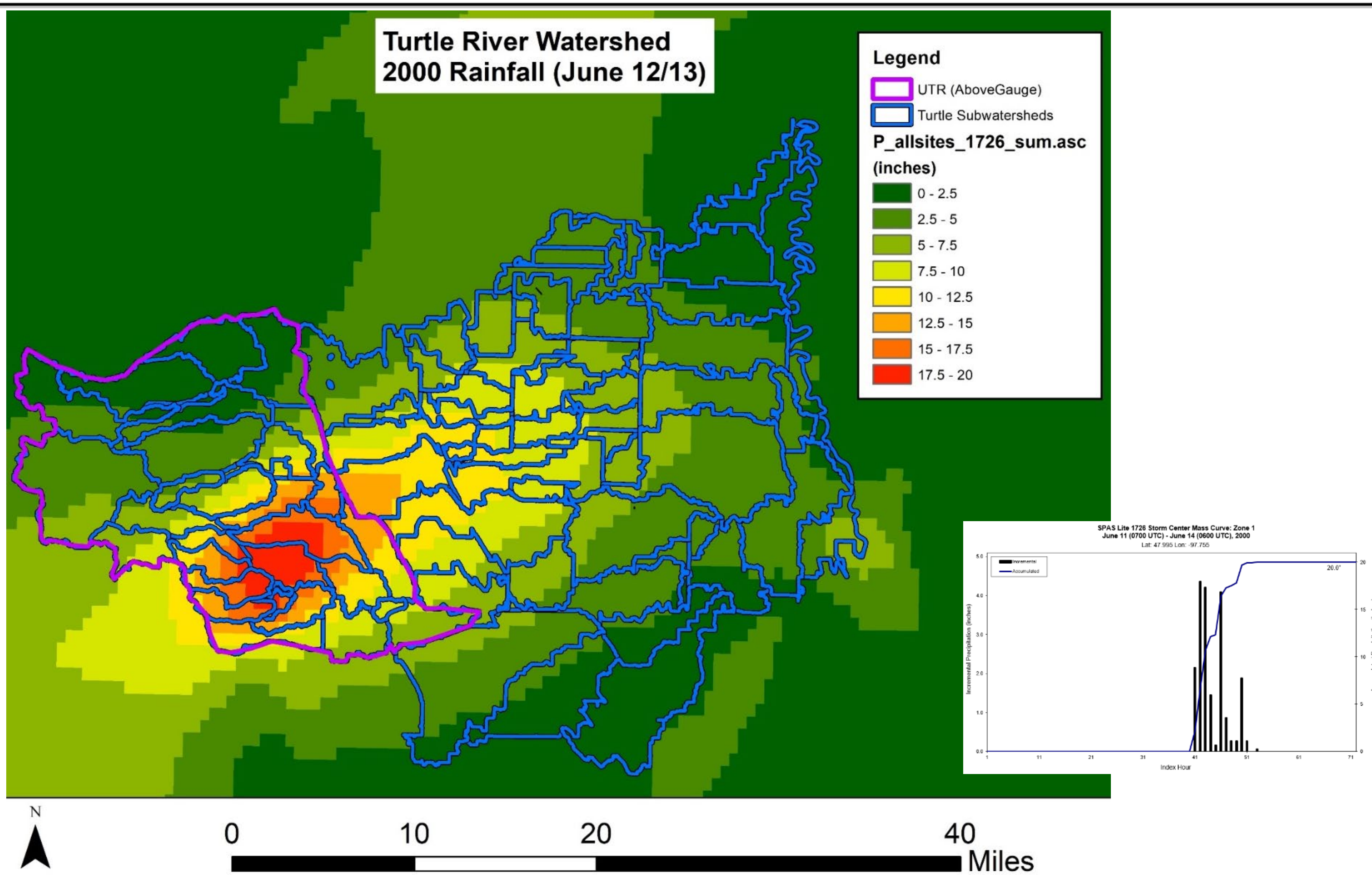



Figure D-1-11: April 2022 Rainfall Grid

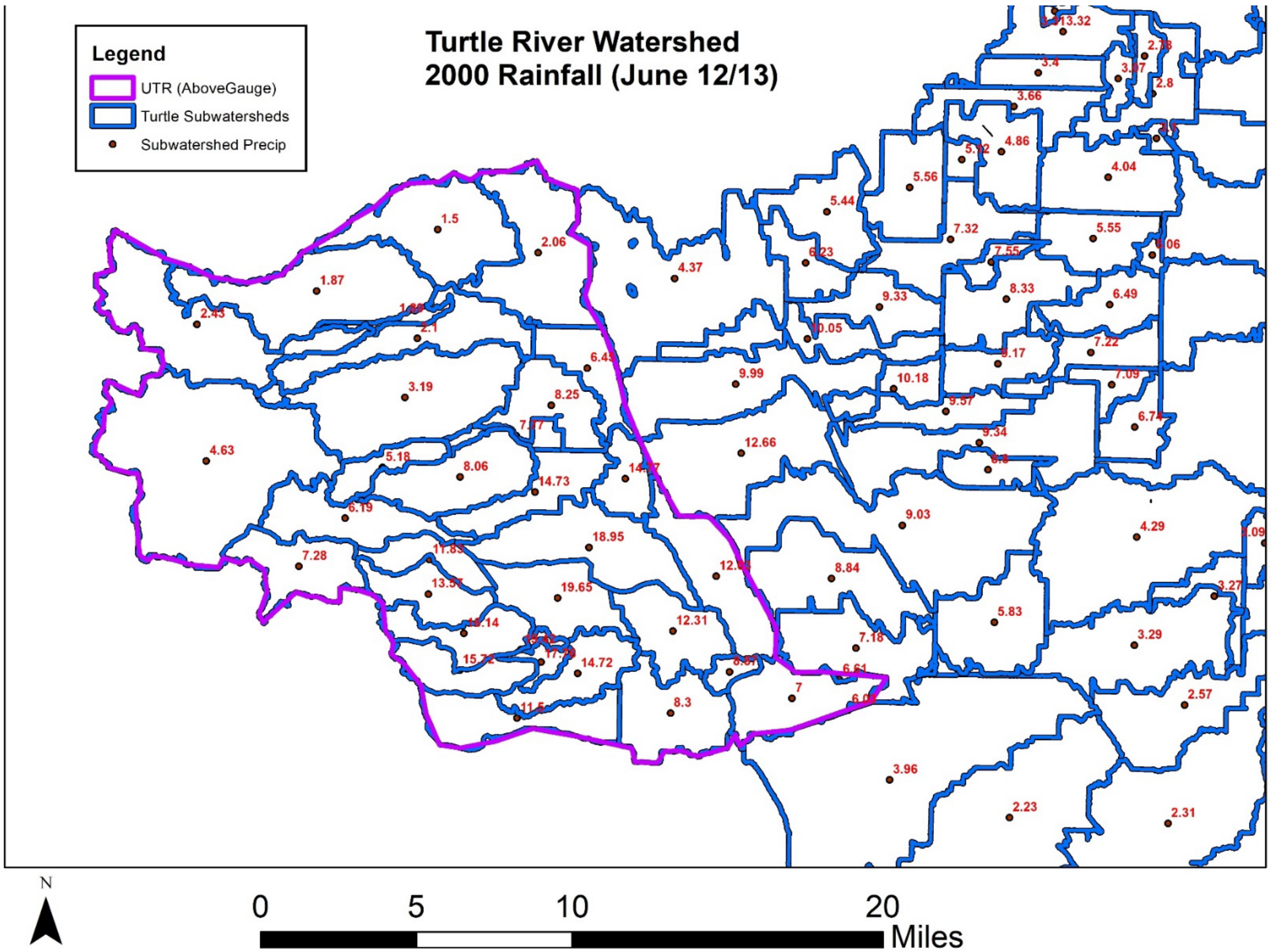



Figure D-1-12: April 2022 Rainfall at Subwatershed Centroids

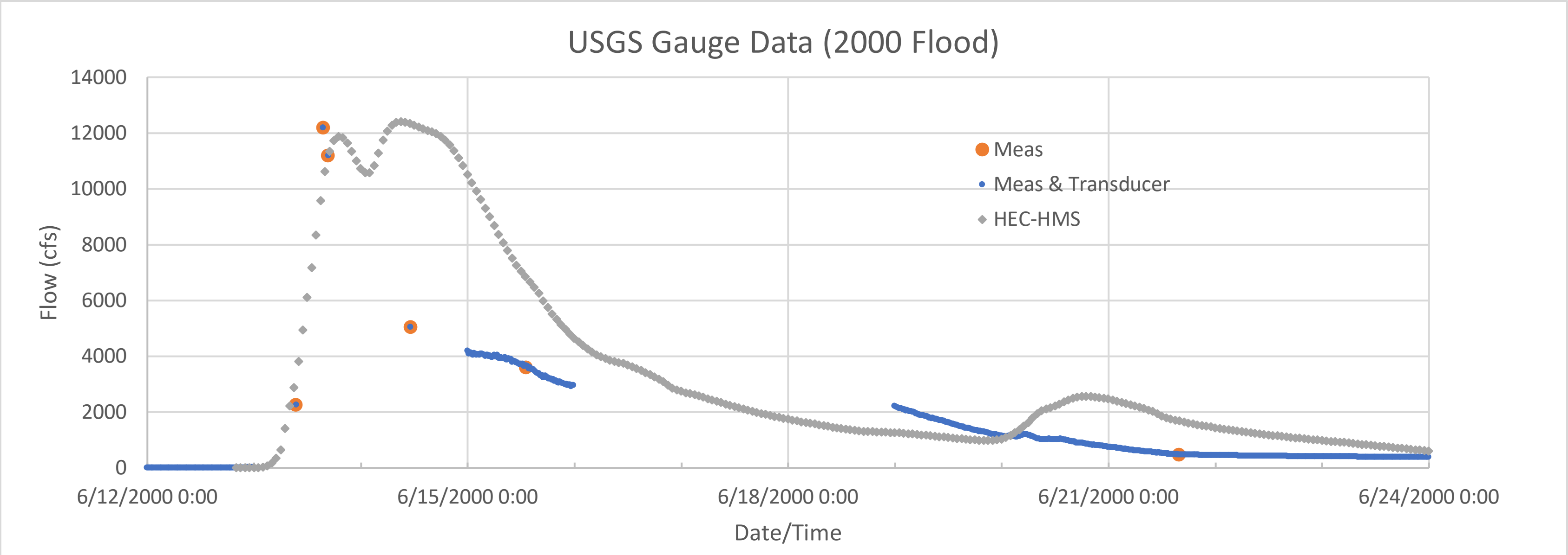
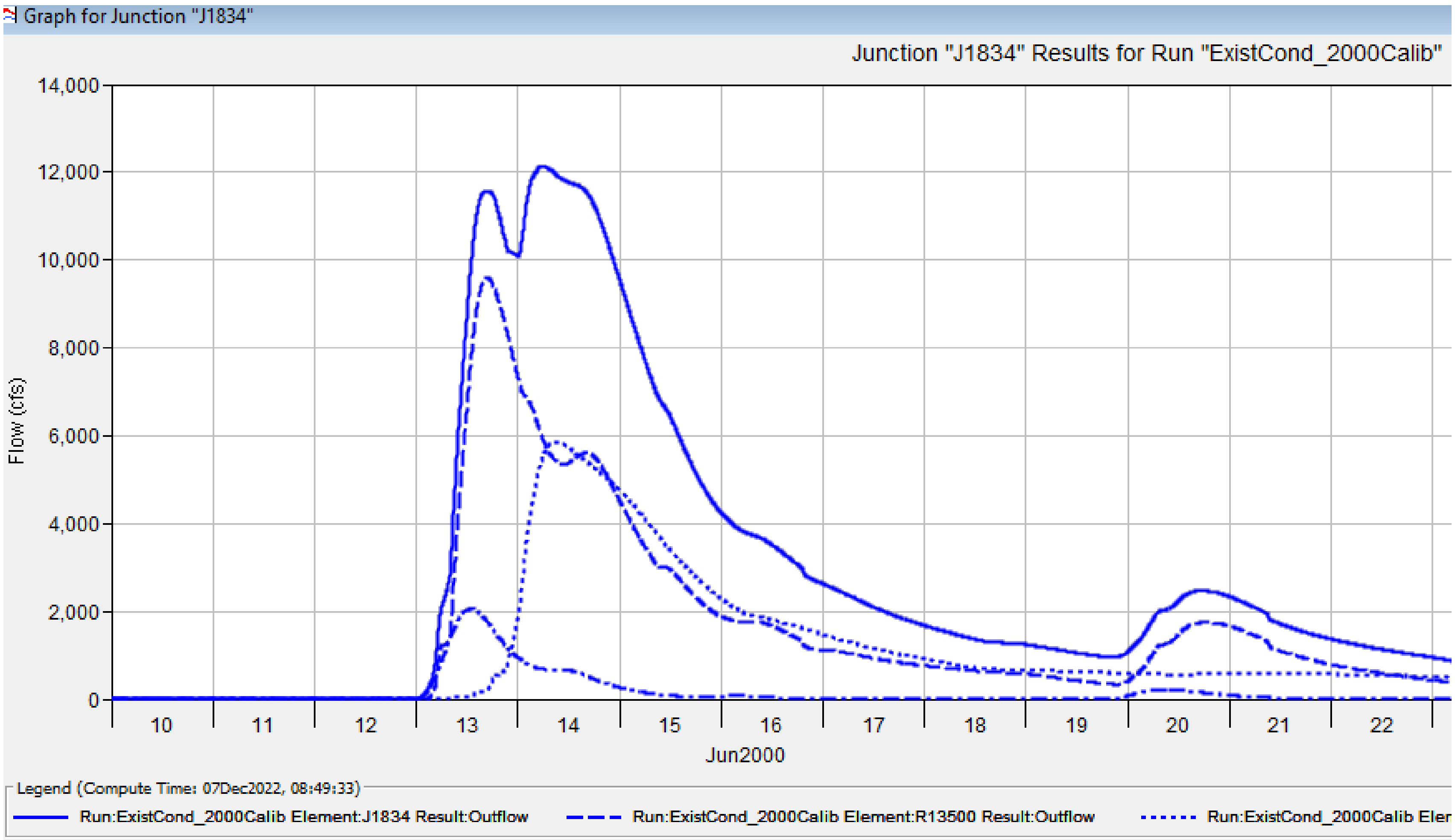



Figure D-1-13: USGS gauge (5082625) Calibration results and manual measurement taken 6/13/2000




Legend: North Branch (R13500), South Branch (R13550) and local (W7840), total is J1834

**Figure D-1-14:** HMS Modeled Flow at Turtle River North – South Branch Junction

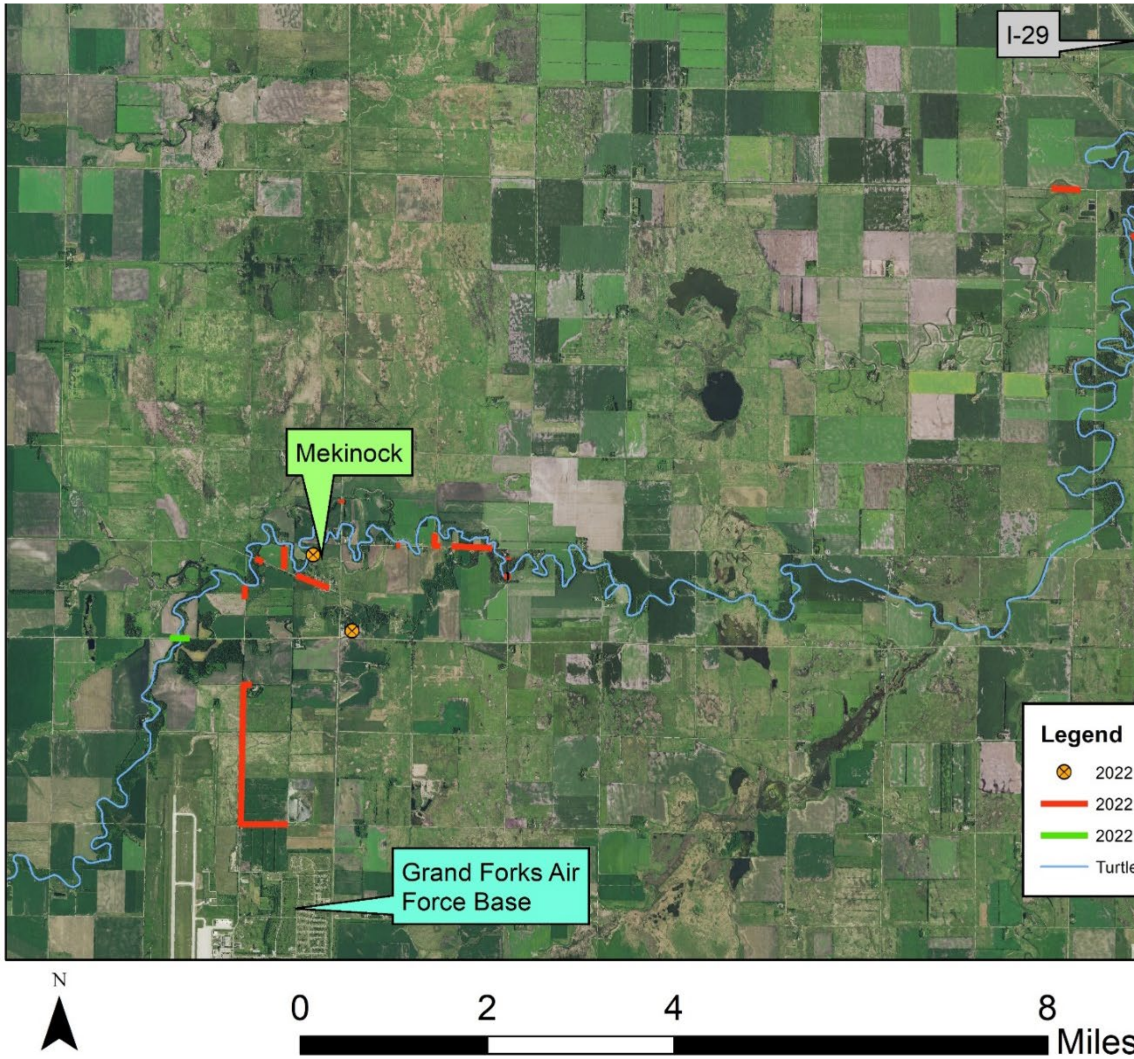



Figure D-1-15: Hydraulic model calibration summary of locations from testimonials

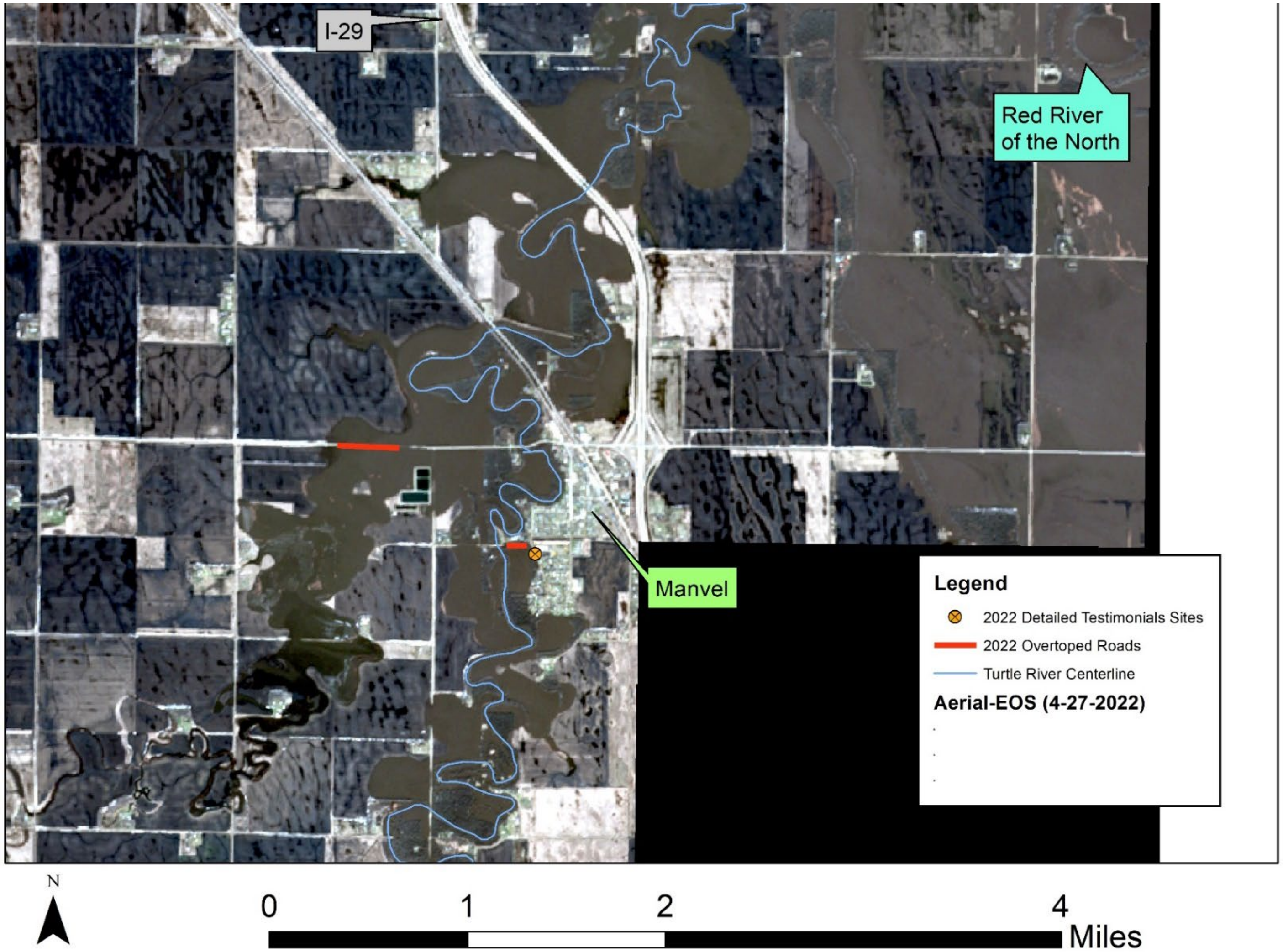



Figure D-1-16: Aerial Satellite image from EOS taken 4-27-2022

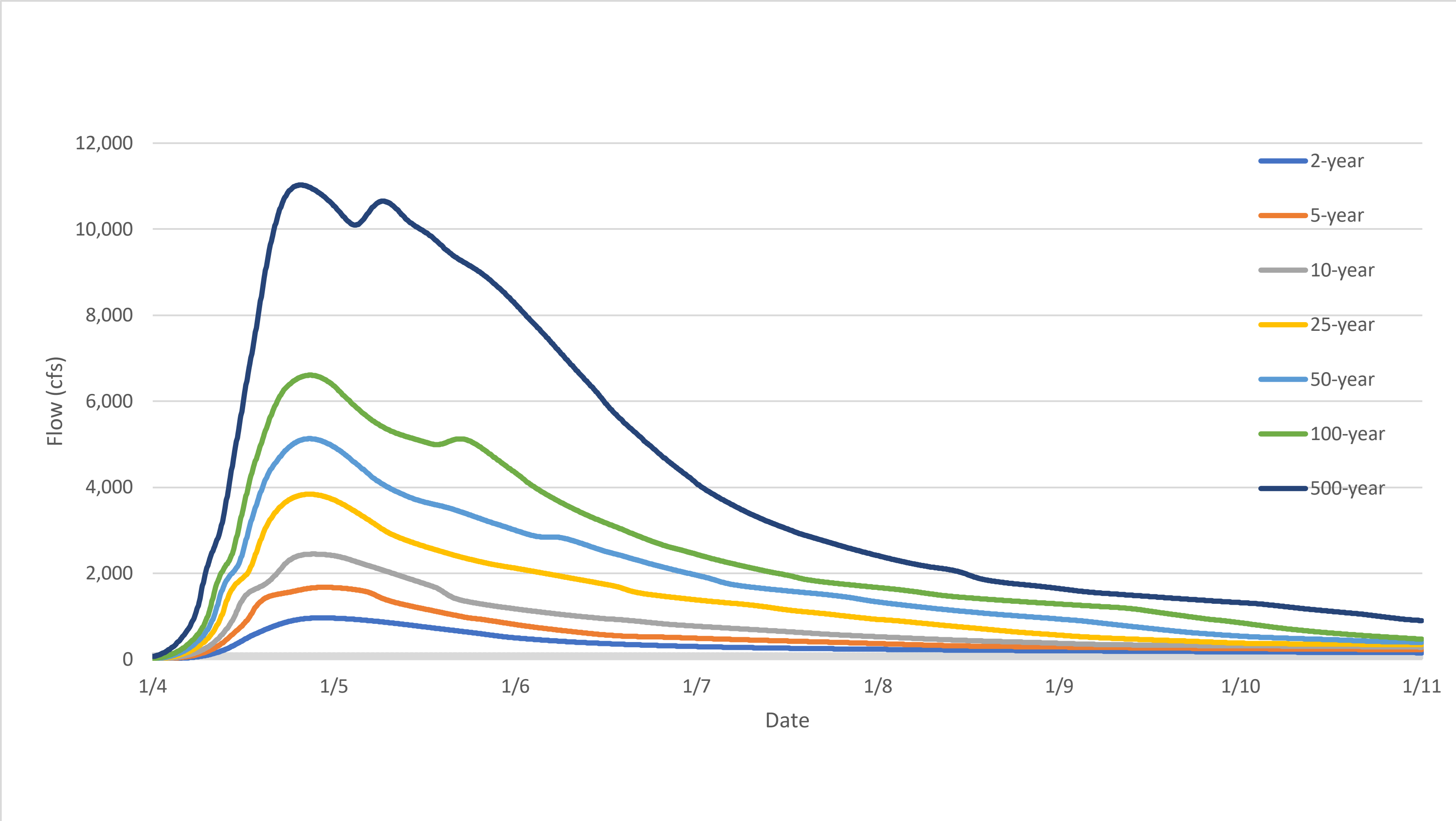



Figure D-1-17: Turtle River Synthetic Hydrographs at USGS (Nr Arvilla), 4-Day from HMS

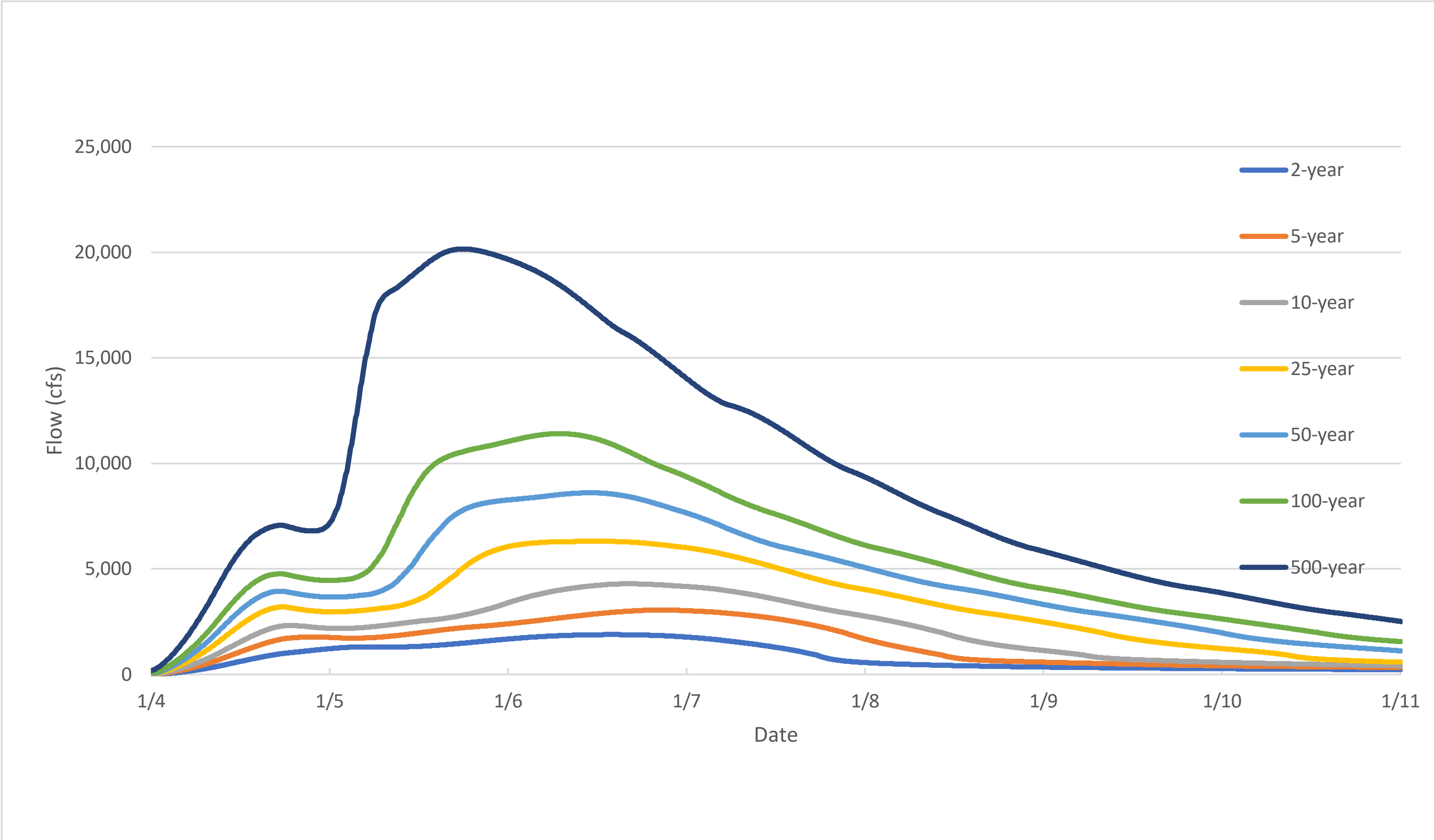



Figure D-1-18: Turtle River Synthetic Hydrographs at USGS (At Manvel), 4-Day from HMS

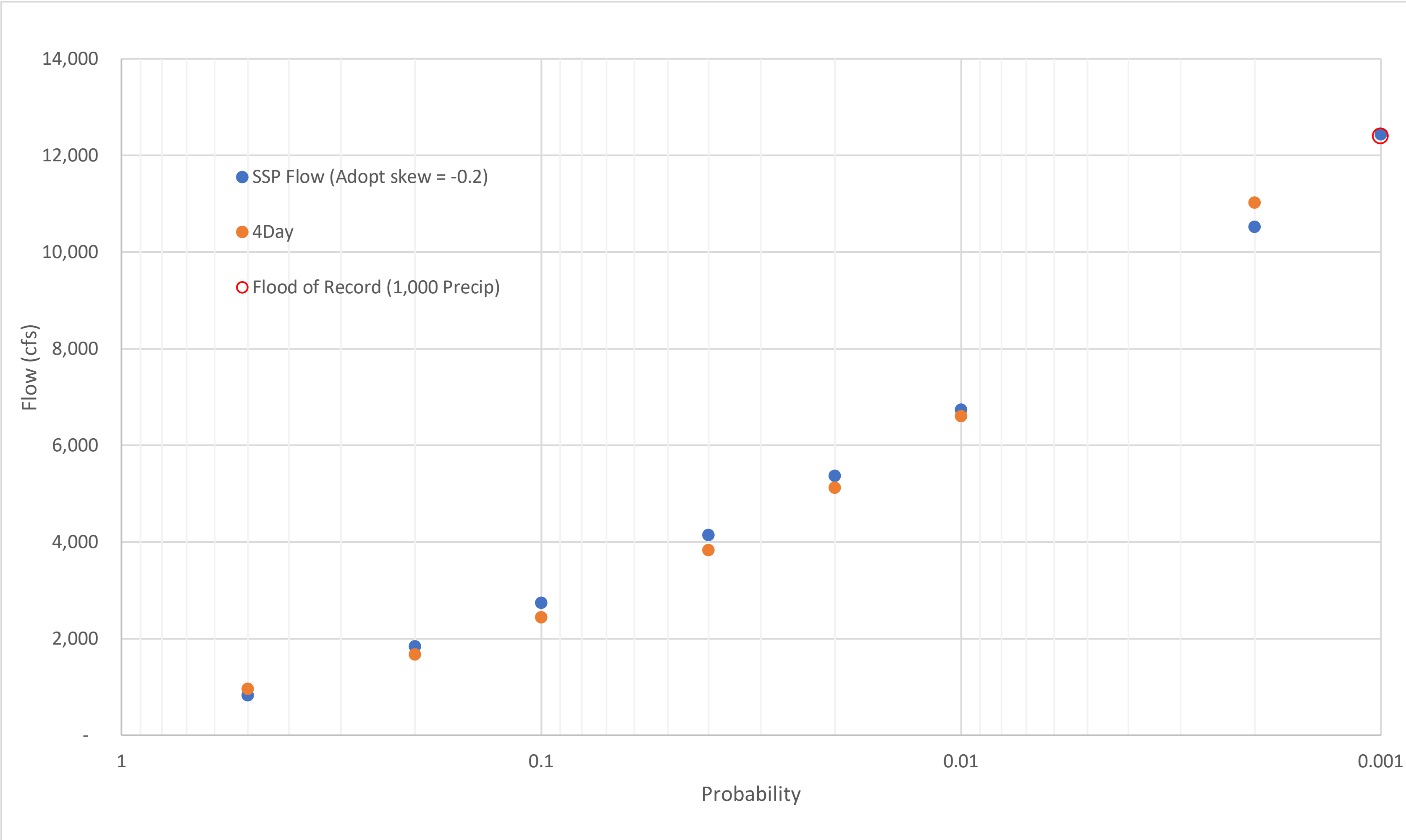



Figure D-1-19: Statistical Analysis vs. HMS Model of Turtle River at USGS 5082625 (nr Arvilla)

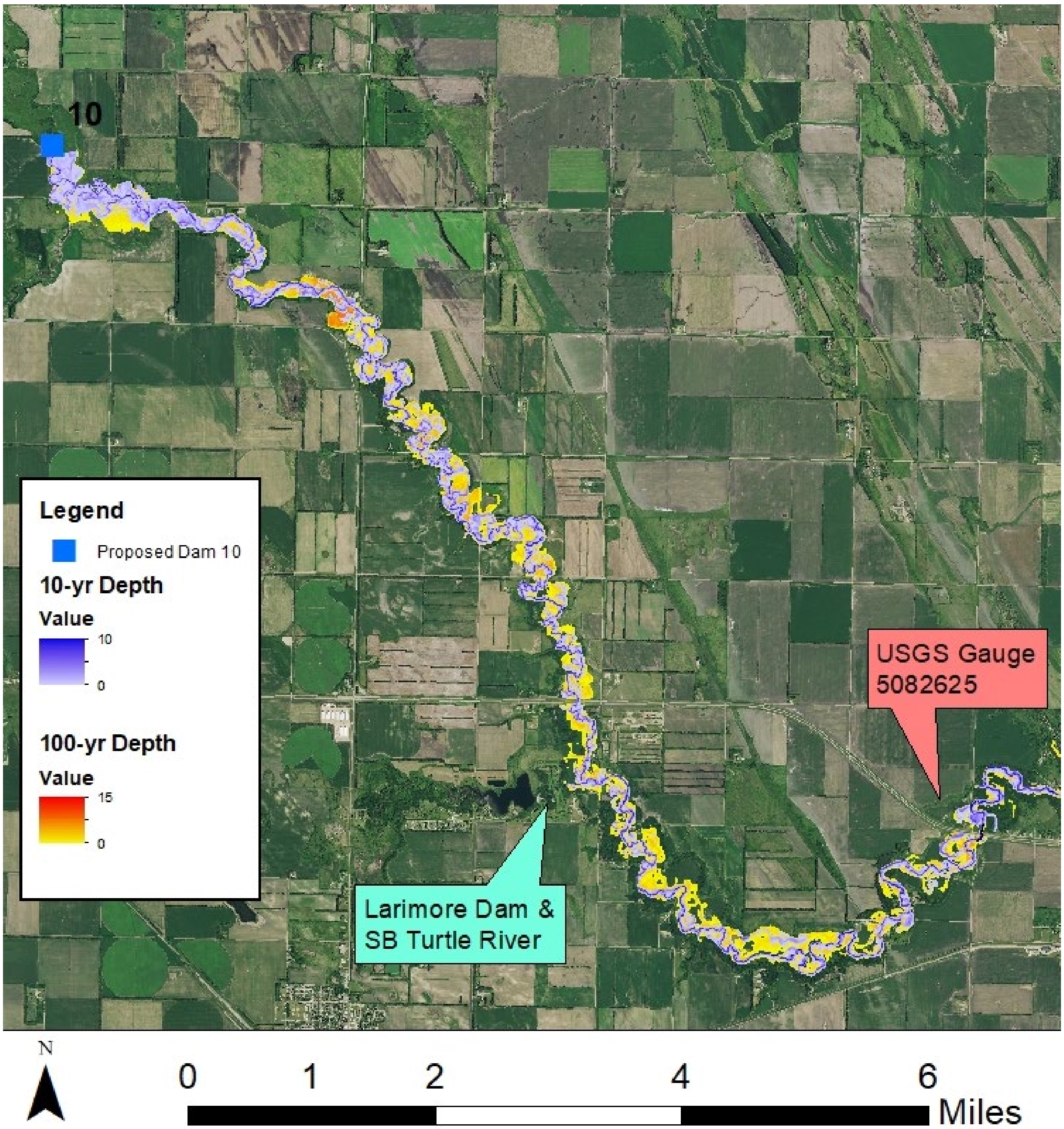



Figure D-1-20: Existing Conditions RAS Inundation Extents (Upper)

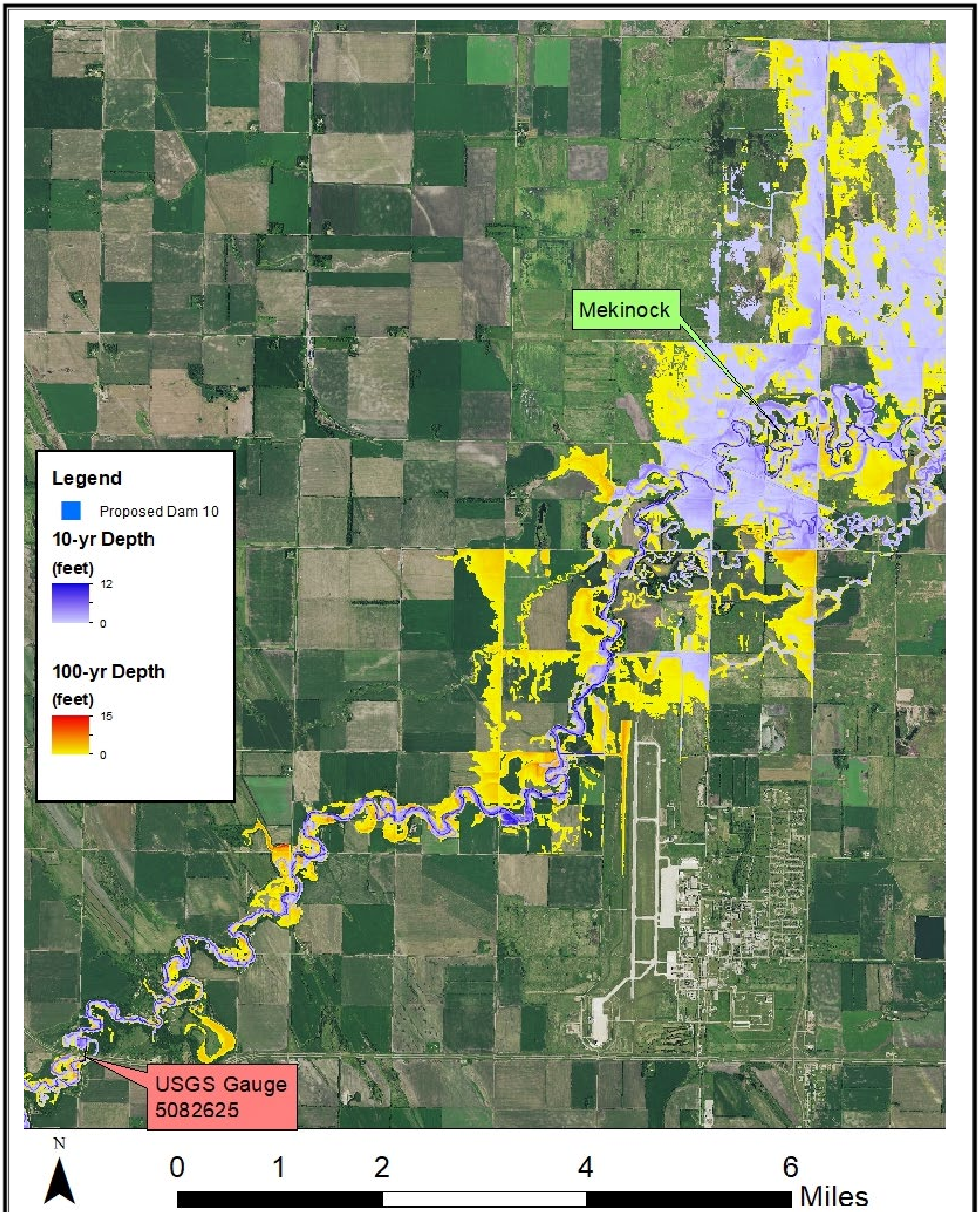



Figure D-1-21: Existing Conditions RAS Inundation Extents (Middle)

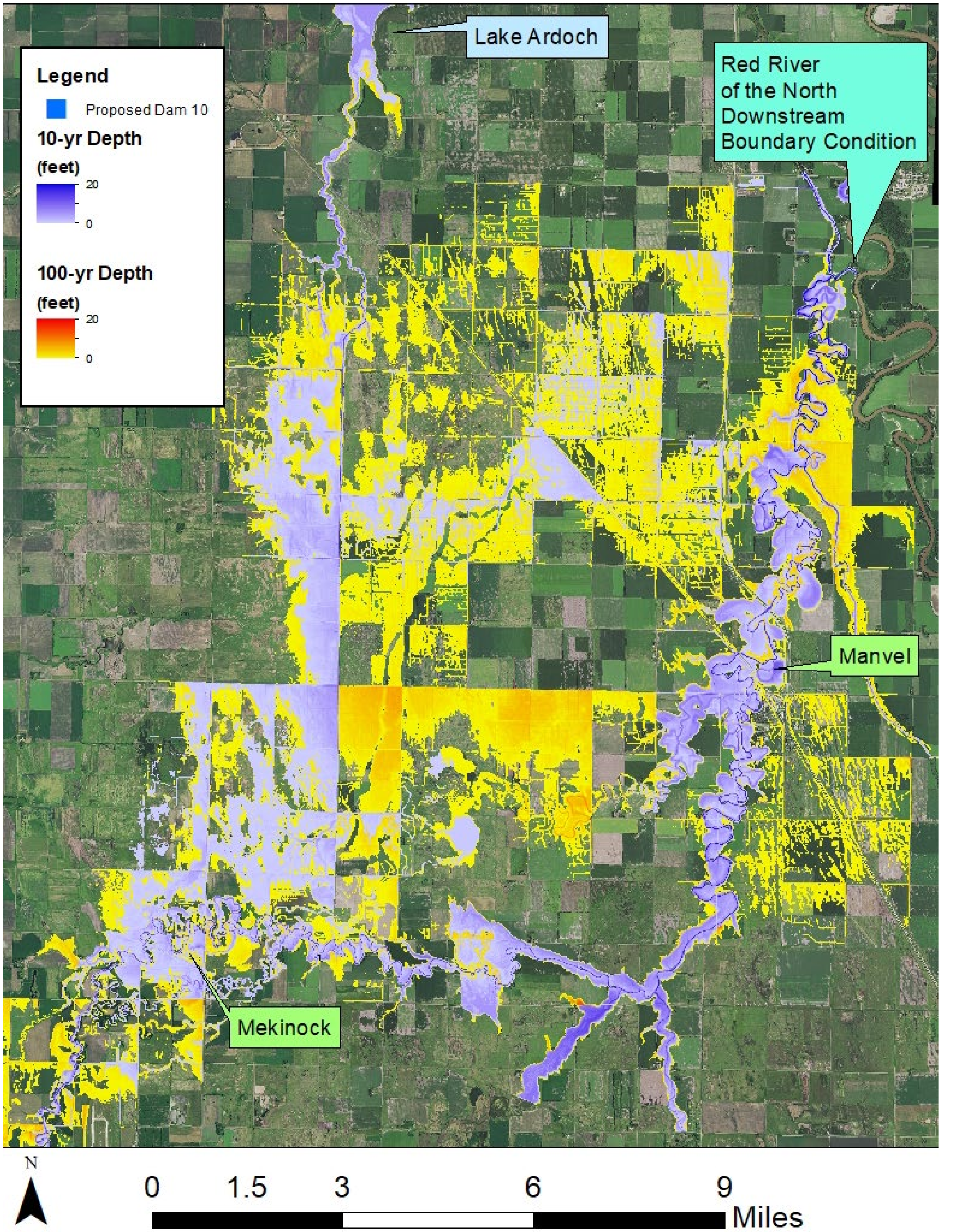



Figure D-1-22: Existing Conditions RAS Inundation Extents (Lower)

NRCS