CROOKED CREEK WATERSHED PROTECTION PLAN

Prepared for the

SARGENT COUNTY WATER RESOURCE DISTRICT

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

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1. INTRODUCTION

1.1. Purpose

This study developed the hydrologic and hydraulic modeling for the Crooked Creek Watershed Protection Plan. A combined unsteady 1-D/2-D HEC-RAS model was created for the entire Crooked Creek watershed. The purpose of this model is to provide existing conditions data to assist the watershed team in identifying problems within the watershed.

1.2. Location

Crooked Creek is a tributary of the Wild Rice River and its watershed is located in Sargent County, North Dakota. Crooked Creek starts near Forman, North Dakota near State Highway 32 and continues in an easterly direction before flowing northeast through Buffalo Lake and a couple other small lakes, and then flowing in an east and then southeasterly direction until the outlet at the confluence with the Wild Rice River about three miles north of Cayuga, North Dakota.

Crooked Creek has a total watershed area of 147 square miles, shown in Figure 1. A large portion of the Crooked Creek watershed consists of lakes and potholes, which is non-contributing area to Crooked Creek, with almost the entire west and southwest portion of the watershed consisting of non-contributing area.

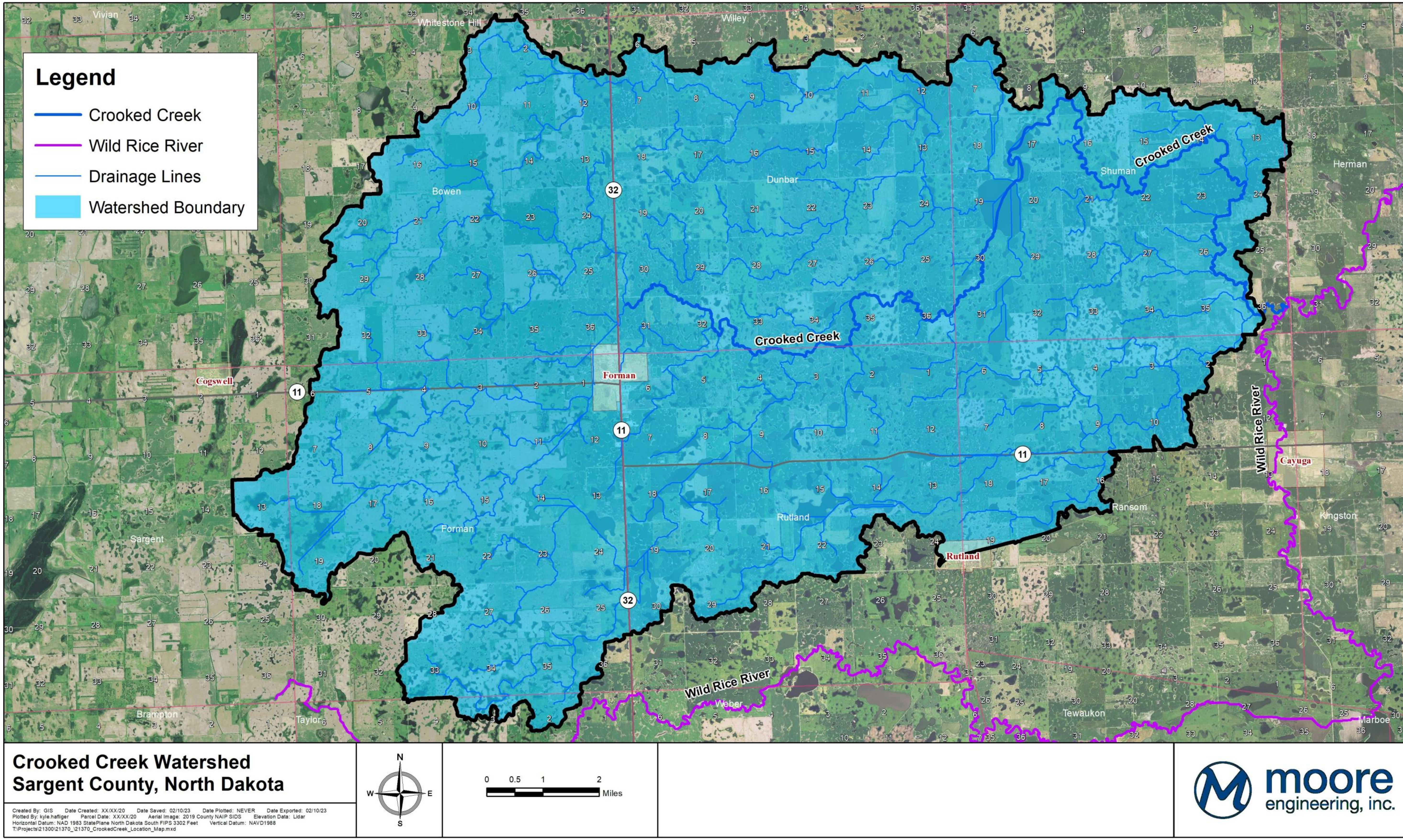

Figure 1 - Crooked Creek Watershed

2. HYDROLOGY AND HYDRAULICS

2.1. Hydrology

2.1.1. Existing Hydrologic Models

A study was completed in 2011, known as the "Basin Wide Modeling Approach", in which HEC-HMS models were created for all major tributary watersheds that drain into the Red River of the North upstream of Halstad, Minnesota [1]. The Wild Rice River watershed was one of the HEC-HMS models created in the 2011 study, which includes the Crooked Creek watershed.

The Wild Rice River HEC-HMS model created from the 2011 "Basin Wide Modeling Approach" study was updated for the "Wild Rice River Comprehensive Detention Plan" study completed in 2013 [2].

2.1.2. Watershed Delineation

The Crooked Creek watershed boundary was slightly modified from the watershed boundary from the 2013 model by identifying extra culverts along the watershed boundary or removing unnecessary culverts. The updated boundary was used to create the hydrology to be used for the 2-D portion of the HEC-RAS model.

2.1.3. Rainfall

The hydrology for the HEC-RAS model was updated from the 2011 Basin Wide Modeling Approach study, which focuses on tributaries of the Red River of the North upstream of Halstad, Minnesota. Hydrology was created on Crooked Creek for the 2-, 5-, 10-, 25-, 50-, and 100-year events with return periods of 24 hours. Instead of using the total precipitation that is used from the Basin Wide modeling approach for each synthetic scenario, the total precipitation uses the Atlas-14 values, which are slightly higher [3]. Table 1 shows the average Atlas-14 rainfall for the Crooked Creek watershed for each 24-hour synthetic event.

Table 1 - Atlas-14 Rainfall (Average Over Entire Watershed)

Event	Rainfall (in.)
2-year 24-hour	2.38
5-year 24-hour	3.00
10-year 24-hour	3.56
25-year 24-hour	4.39
50-year 24-hour	5.08
100-year 24-hour	5.82

***Note: Average rainfall for each 2-D area is either slightly higher or lower than the values in the table.**

2.1.4. Updated HEC-HMS Model

The 2013 HEC-HMS model was updated to further define the downstream boundary condition for the combined 1-D/2-D HEC-RAS model on the Wild Rice River, and to compare peak discharges and total volume on Crooked Creek with the 1-D/2-D HEC-RAS model, modeled using HEC-HMS version 4.2.1 [4]. The model was truncated to only include the portion of the Wild Rice Watershed upstream of the Shortfoot Creek outlet, which is about one mile downstream of where Crooked Creek flows into the Wild Rice River. The rainfall in the model was updated to use the Atlas-14 rainfall instead of the TP-40 rainfall for the 24-hour events. The updated HEC-HMS model includes all six of the 24-hour synthetic events with return periods of 2 through 100 years.

2.2. Hydraulic Modeling

2.2.1. Hydraulic Model Overview

Hydraulic modeling was performed using the Hydrologic Engineering Center River Analysis System (HEC-RAS) version 6.1 [5]. An unsteady combined 1-D/2-D HEC-RAS model was created for the entire Crooked Creek watershed and small portion of the Wild Rice River. The Crooked Creek watershed is modeled using 2-D areas while the Wild Rice River portion is 1-D from about 1.5 miles upstream of the confluence with Crooked Creek to about one-half mile downstream of the confluence with Crooked Creek (from 100 feet upstream of the crossing upstream of Crooked Creek to 100 feet downstream of the crossing downstream of Crooked Creek). A map of the Crooked Creek HEC-RAS geometry is shown in Figure 2.

2.2.2. Coordinate System

The vertical datum used for the unsteady combined 1-D/2-D HEC-RAS model is the North American Vertical Datum of 1988 (NAVD88). The horizontal datum used is North Dakota State Plane South (NDSPS).

2.2.3. Boundary Conditions

There are no inflow hydrographs applied in the 2-D portion of the HEC-RAS model in the Crooked Creek watershed. Instead, precipitation runoff volume is applied over the entire extent area of the 2-D portion of the HEC-RAS model, described in further detail in Section 2.2.13. The 2-D areas cover the entire Crooked Creek watershed area. There are sinks around the entire watershed that captures any flow that leaves the watershed. There are a few minor small areas at the edge of the 2-D portion of the model outside of the watershed boundary that will just flow out of the model into the sink when precipitation is applied in that area. The outlet of Crooked Creek flows into the 1-D portion of the model on the Wild Rice River through a lateral structure. An inflow hydrograph is applied at the upstream end of the 1-D portion of the HEC-RAS model on the Wild Rice River, which comes from the updated HEC-HMS model. The downstream boundary condition on the Wild Rice River assumes normal depth, with an assigned river slope.

2.2.4. 2-D Areas

There are six 2-D areas that represent the entire Crooked Creek watershed. The 2-D area boundaries are mainly on major roads with high elevations that have minimal weir flow over the road. The 2-D area is modeled using a mesh grid with 250-feet by 250-feet cell resolution. The edge of each cell acts as a weir in the model, calculating flow over the weir. The weir is defined by the LiDAR surface, set up in RAS mapper in the model. The smaller the resolution of the mesh grid cells, the more accurate the flow is over the 2-D areas. The cell sizes are small enough where most of the high points in the LiDAR are captured, which can greatly influence the calculated discharge. Due to the large size of the watershed, a 250-foot cell size was adequate for the model. At 2-D connections and breaklines, the cell size is smaller, usually with a resolution of 50 to 100 feet.

2.2.5. Breaklines

Breaklines represent high ground that splits the mesh cells to better define the mesh terrain for accuracy. Breaklines are necessary to ensure the 250-foot mesh cell covers the high ground and abrupt grade changes accurately. The breaklines are mainly located along each section line across the roadways or high ground. Some other embankments and high ground barriers also have breaklines as well, for example, around the lakes on Crooked Creek in the northeast portion of the watershed. Without the breaklines, the cell faces will not always line up across the highest ground and water would flow across the roadway or high ground barriers at a lower elevation than actual elevation, greatly influencing the discharge or water surface in that location. The edge of each cell acts as a weir in the model, calculating flow over the weir. The weir is defined by the LiDAR surface used in the model. Along the breaklines, the mesh cell resolution in the model is much finer, ranging from 50 feet to 100 feet, which captures the highest ground.

2.2.6. 2-D Connections

In the HEC-RAS model, 2-D connections are used wherever there is a culvert crossing or weir structure, or at the boundary between two 2-D areas. The breaklines already define the weir elevations across the roadways, so the 2-D connections only span on the roadway near the culvert crossing (about 50 feet on each side of the culvert). The 2-D connections that border between two 2-D areas span across the entire area rather than only at the culvert crossing since that is the only option for flow to transfer from 2-D area to 2-D area.

Connections within the same 2-D area use the 2-D equation method for overtopping rather than the weir equation, which calculates the flow the same way as crossing over the breaklines away from the culvert crossings. The 2-D connections that border two 2-D areas can only use the weir equation for overtopping. Weir coefficient values were chosen based on the recommended values from the report, *Combined 1D and 2D Modeling with HEC-RAS* [6].

2.2.7. LiDAR Modifications

Due to the LiDAR surface being several feet above the culvert elevations with survey data available along the larger culverts on Crooked Creek, the LiDAR surface was modified along Crooked Creek. A channel was burned into the LiDAR surface, lowering the LiDAR along Crooked Creek about two feet, bringing the LiDAR elevation much closer to the surveyed culvert elevations, mostly within one foot. The high LiDAR elevations are caused by lots of water or vegetation in the channel when the LiDAR was flown. This is not as much of a problem at smaller crossings, which do not have as much water or vegetation in the channel. The LiDAR used was collected in 2008.

2.2.8. Culverts

All larger culverts in the watershed and culverts across section line roadways where there is a breakline were added into the HEC-RAS model to prevent major attenuation and loss of flow across the 2-D areas to accurately model the flow. Survey data was available for many culverts in the watershed, collected by Moore Engineering in December 2021. The survey included culvert size, type, and invert elevations. For areas where culverts were not surveyed, culverts were identified using Google Earth, and the length, size, and type were estimated by the imagery. Any culvert that looked small in the imagery and was hard to identify the size and type was assumed to be a 24-inch CSP culvert. The culvert inverts were estimated by the LiDAR elevations.

In the HEC-RAS model, the elevation of each mesh cell was derived from the LiDAR surface (DEM) directly, which cannot be changed in HEC-RAS. The model requires that the culvert invert should not be lower than the elevation of the mesh cell. Due to this, the LiDAR elevation was used instead of the surveyed elevation when the LiDAR elevation was higher than the surveyed elevation. The elevation from the LiDAR surface is usually higher than the surveyed culvert invert due to surface resolution. Using the LiDAR elevation for the smaller culverts usually does not have an impact on the modeling results in the watershed. Most of the time, the smaller culverts do not have enough capacity to convey the water without pooling upstream. The upstream area uses the LiDAR elevation, which makes the result difference insignificant when the elevation of the culvert is lowered, which will provide almost no extra storage upstream of the culvert.

2.2.9. Cross Sections

Cross sections were cut from 1-meter resolution LiDAR, which is along the Wild Rice River in the 1-D portion of the HEC-RAS model upstream and downstream of the confluence of Crooked Creek. The station number for the river section represents the number of feet to the downstream end of that corresponding river. The cross sections are spaced 50 to 100 feet apart near the bridges and spaced much farther apart elsewhere, usually spaced less than 1,000 feet apart.

2.2.10. Bridges

There is one bridge crossing in the 2-D portion of the model along Crooked Creek immediately upstream of where it flows through Buffalo Lake, which was modeled in the 2-D area. For both the 1-D and 2-D portions of the model, the bridge width, low chord, and high chord had to be estimated based on LiDAR and aerial imagery.

2.2.11. Lateral Structures

Lateral structures were used to connect the downstream end of the 2-D portion of the model at the outlet of Crooked Creek with the 1-D cross sections along the Wild Rice River. The lateral structures are placed on the highest possible ground representing levees (embankments), section line roads, or the highest ground, except for the Crooked Creek channel. Weir coefficient values were chosen based on the recommended values from the report, *Combined 1D and 2D Modeling with HEC-RAS*, similar to the 2-D connections [6].

2.2.12. Manning's n Values

Manning's n values were assigned to the 2-D area in the HEC-RAS model. Either a single n value can be assigned to a 2-D area or a land cover raster grid can be used assigning different n values for each land use category. Since the 2-D area falls in several different land use categories such as open water, wetlands, pasture, etc. a land cover raster grid was used instead of a single value. The land cover data is from the National Land Cover Database (NCLD) and the raster dataset is in 30-meter by 30-meter resolution. The land cover raster was clipped within the 2-D model area. The developed raster grid has an assigned n value for each land use and is used within RAS mapper to link the HEC-RAS 2-D area with the land use grid. The Manning's n values in the model are mostly within the range of recommended values from the HEC-RAS 2-D User's Manual [7]. A high percentage of the watershed consists of cultivated crops, which are assumed to have a Manning's n value of 0.05. The section line roads are mainly in the developed, open space category, with an assumed Manning's n value of 0.035. The Manning's n values in the Wild Rice River cross sections in the 1-D portion of the model assumed values of 0.04 in the channel and 0.05 in the overbanks.

2.2.13. Model Hydrology

The Atlas 14 precipitation hyetographs (only including the runoff excluding the infiltration) are uniformly applied to each 2-D area in the watershed rather than inflow hydrographs applied on the main river. The total runoff hyetograph rather than the total rainfall hyetograph is applied in the HEC-RAS model, since there is no infiltration in the HEC-RAS model. To determine the total runoff, the total drainage area and average curve number of each 2-D area is calculated. The average curve number for each 2-D area is calculated based on the raster grid of the curve numbers used for the Basin Wide Approach study. Taking the adjusted total rainfall, curve number, and basin area into account for each 2-D area, the total runoff for each synthetic scenario can be determined for each 2-D area. The SCS Type-II rainfall distribution is assumed, the same as in the Basin Wide Modeling Approach.

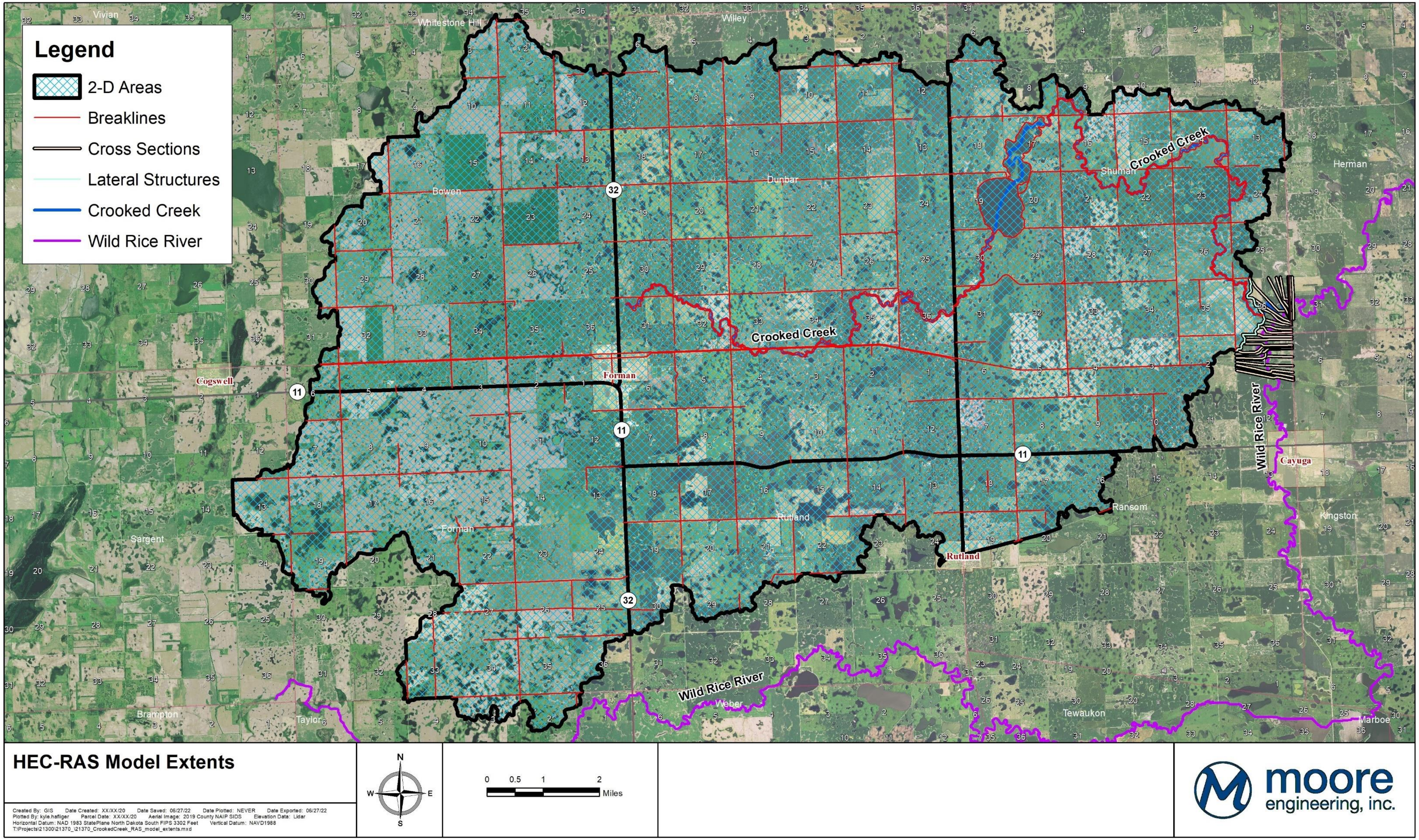

Figure 2 - HEC-RAS Model Extents

3. RESULTS

3.1. Model Validation

There are no available USGS gages or aerial photos showing inundation on Crooked Creek available to compare with the results of the HEC-RAS model for validation of the results. However, the model results were presented to the project team which consisted of numerous landowners distributed through the watershed. The project team compared the modeled results to local knowledge of the area during times of flooding and provided positive feedback that the models were producing results comparable to what they have experienced throughout the watershed. In addition to the project team review, the results of the updated HEC-HMS model created for the Crooked Creek watershed (uses the updated Atlas 14 rainfall) was compared with the HEC-RAS model results. Table 2 shows the peak discharge and total volume comparisons on Crooked Creek comparing the HEC-RAS model with the updated HEC-HMS model. The reporting locations in the table are downstream of 138th Ave. SE and at the outlet at the confluence with the Wild Rice River, shown for all the modeled synthetic 24-hour events.

Table 2 - Peak Discharge and Total Volume Comparisons on Crooked Creek

Event	Peak Discharge (cfs)				Total Volume (ac-ft)			
	HEC-HMS Model		HEC-RAS Model		HEC-HMS Model		HEC-RAS Model	
	Dws. 138th Ave. SE	Outlet	Dws. 138th Ave. SE	Outlet	Dws. 138th Ave. SE	Outlet	Dws. 138th Ave. SE	Outlet
2-yr 24-hr	49	110	15	118	772	2,396	148	464
5-yr 24-hr	82	184	38	201	1,266	3,957	432	1,130
10-yr 24-hr	116	261	67	291	1,767	5,551	789	2,047
25-yr 24-hr	171	387	120	497	2,593	8,175	1,578	4,107
50-yr 24-hr	221	500	178	752	3,326	10,524	2,484	6,351
100-yr 24-hr	276	624	256	1,056	4,143	13,132	3,507	8,942

3.2. Results Comparisons

Based on the results in the table, there is less total volume on Crooked Creek in the HEC-RAS model compared to the HEC-HMS model, especially for the smaller 24-hour events. The reason for this is that the non-contributing areas in the HEC-HMS model only include the area contained by TR60 (100-year runoff event), which has more total volume compared to the largest modeled 24-hour event [8]. There are more non-contributing areas during smaller events due to the significant amount of ponding areas throughout the watershed. The larger the event, the greater likelihood that the lake or pothole fills and runs off downstream. Another reason for the lower total volume in the HEC-RAS model is the total run simulation time. Some of the lakes and potholes in the HEC-RAS model take a significant amount of time to drain, which has an effect on the total volume reported.. Most of the Crooked Creek watershed consists of potholes in which many do not have an outlet and flow gets contained in the pothole and does not continue flowing downstream. For the larger 24-hour events, there is enough flow that some of the potholes overtop and flow can continue downstream, but there is less of that for the smaller events.

In the upstream portion of Crooked Creek, the peak discharge in the HEC-RAS model is less than the HEC-HMS model, especially for the smaller events. At the outlet, the HEC-RAS model has larger discharges compared to the HEC-HMS model, even though there is less total volume in the HEC-RAS model. There are no USGS gages on Crooked Creek and the 2013 HEC-HMS model was calibrated to the USGS gages on the Wild Rice River by adjusting the time of concentration (Tc) and storage coefficient (R) values. Due to no USGS gages on Crooked Creek or several tributaries draining into the Wild Rice River, many of the discharges in the tributaries could either be underestimated or overestimated. However, based on to the discussion from the landowners, who compared the HEC-RAS model inundation results with the local knowledge of the flooding on Crooked Creek, the HEC-RAS models are producing similar results to that is actually occurring in the watershed.

The HEC-RAS model discharges at the outlet of Crooked Creek were higher than the HMS model even with less volume, meaning the HEC-HMS model might have underestimated the peak discharge. The time of concentration is much longer in the HEC-HMS model with a much later peak compared to the HEC-RAS model, which has a smaller peak than hydrographs with a shorter time of concentration. The peak from Crooked Creek comes in earlier with the discharge from the lakes and potholes moving through much later. One other factor is that the peak on Crooked Creek in the HEC-RAS model is much earlier than the peak on the Wild Rice River, so the water surface on the Wild Rice River has only a minor effect on the peak discharge on Crooked Creek at the outlet. The backwater effect on Crooked Creek caused by the peak flows on the Wild Rice River occurs well after the peak discharge on Crooked Creek. The HEC-RAS model was also run with the peak of Crooked Creek at the outlet stacked with the peak of the Wild Rice River at Crooked Creek. This only slightly increased the water surface elevation of Crooked Creek at the outlet (about 0.1 to 0.2 feet higher compared to the earlier peak of Crooked Creek). This concludes that the Wild Rice does not have a significant impact on the flooding of Crooked Creek at the outlet.

4. REFERENCES

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