Painted Woods Lake Mitigation Study
McLean County, North Dakota

Prepared for McLean County Water Resource District
December 2015

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REPORT:

MCLEAN COUNTY, NORTH DAKOTA PAINTED WOODS LAKE MITIGATION STUDY

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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

The Painted Woods Lake Wildlife Management Area in McLean County, North Dakota has a history of frequent flooding. Water from the lake is being diverted, forming new channels over private land and increasing erosion problems which affect Sovereign Land. The Painted Woods Lake Flood Mitigation Study (the “Study”) presented in this report investigated the issues and considered alternatives for the Painted Woods Wildlife Management Area [1]. The Study also included the acquisition of topographic surveys, a hydrologic analysis of the entire basin, the development of an unsteady flow HEC-RAS model, an alternative analysis, and an evaluation of permits needed and development of a potential project schedule.

A control structure was placed at the outlet of the Lake in the early 1980’s to help control flows and manage fish and wildlife resources in the Management Area. The North Dakota State Water Commission (the “SWC”) studied alternatives in 1983 and 1984 to mitigate the flooding issues that were occurring. More recently, there has been some erosion problems along the banks of the Missouri River, causing damage to land near the Painted Woods Lake and, in time, that will jeopardize the integrity of the Sovereign Land (“Painted Woods Lake”).

The McLean County Water Resource District (the “District”) is evaluating alternatives of which one is based on the SWC study in 1983 and another on the south end of Painted Woods Lake to protect the Sovereign Land, alleviate the existing flooding issues, and alleviate damages to adjacent property. Preliminary work has already been completed at the expense of McLean County, which includes vital meetings with stakeholders including the SWC, ND Game and Fish, US Fish and Wildlife, Bureau of Reclamation and local landowners.

1.2 Location

Painted Woods Creek begins in Burleigh County in South-Central North Dakota and flows in a westerly direction. Painted Woods Creek flows into Painted Woods Lake, located about six miles southeast of Washburn in McLean County, North Dakota. Painted Woods Lake fills and begins discharging into Merry’s Creek, which then flows into the Missouri River about two miles downstream. The Painted Woods Creek watershed consists of 305 square miles which extends from McLean County into Burleigh County in South-Central North Dakota. Figure 1 shows the study area.

1.3 Previous Studies

This Study follows previous work accomplished by the SWC as presented in two reports:

a. Preliminary Engineering Report on Painted Woods Lake published by the SWC in March 1983[1]
b. Supplementary Engineering Report on Painted Woods Lake published by the SWC in May 1984[2]

The preliminary report evaluated existing conditions and developed preliminary cost estimates for proposals to alleviate flooding in the Painted Woods Lake area.

The supplementary report summarizes how the situation surrounding the Painted Woods Lake area has been reviewed and discussed for a number of years. The need in 1984 for a project in this area is based on three factors. The first is the continuing deterioration of Merry's Creek outlet. The erosion in this area was becoming increasingly severe with recent flooding and was beginning to threaten the integrity of the lake. The second factor was the almost annual flooding of agricultural lands in the areas surrounding the lake. The third factor was the Bureau of Reclamation's releases from the Garrison Diversion System into the Painted Woods System and their request for a permanent permit to discharge project waters into the

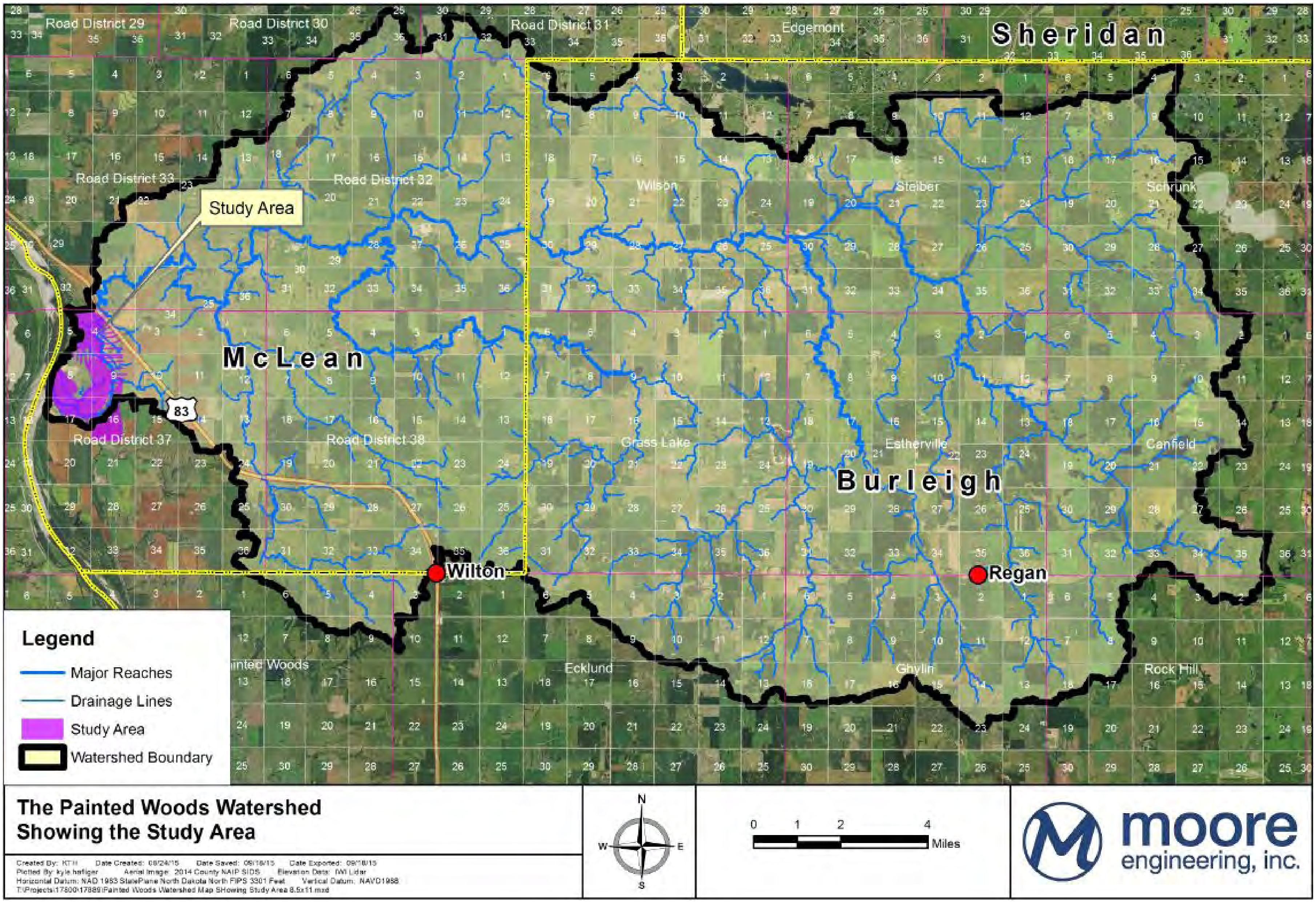


Figure 1 - Painted Woods Watershed Showing the Study Area

Painted Woods System. The result of these factors has been the creation of the Painted Woods Lake water management project by the McLean County Water Resource District. The purpose of which is for the preservation of the lake itself and to provide for a reasonable amount of flood control. Table 1 below is a tabulated list of the alternatives outlined in the supplementary report. The 1984 report states that "Because the lake-bed of Painted Woods Lake is owned by the State of North Dakota, and managed by the Garrison Conservancy District, Alternative I, as outlined in this (the 1984) report is not considered as a viable alternative." That report also presents detailed information on all alternatives including costs for the alternatives considered.

Table 1 - Summary of Alternatives Evaluated

Alternative	Proposal	Design Frequency	Comment
I	No Action	N/A	Not Viable Alternative
IIA-IID	Merry's Creek Improvements	< 10-Year	Bureau of Reclamation funding for Alternative IIA
III	Lake Restoration(Complete Purchase)	>10-Year	Eliminates issue of stability of the agricultural dikes.
IVA	Fahlgren Overflow	10-Year	Secondary Outlet from Painted Woods Lake
IVB	Fahlgren Overflow	>10-Year	Secondary Outlet from Painted Woods Lake
V	Diversion +Lake Protection	25-Year	Completely funded by local assessments.

1.4 Background

Previously the studies accomplished in 1983 and 1984 provide an extensive discussion on the background of Painted Woods Lake. Those studies also identified issues during that time period. Since that time, the current issues identified and shown on Figure 2 are:

1. Issue 1 - Inadequate capacity and ice jams which occur in Merry's Creek. Merry's creek outlet experienced erosion from the Missouri River in 2011.
2. Issue 2 - The condition of the control structure and crest elevation of the weir for the structure.
3. Issue 3 - Cattails and ice jams which occur in Painted Woods Lake. Cattails generally grow well when the water depth in a lake is less than approximately four feet.
4. Issue 4 - Erosion of dikes along the downstream end of Painted Woods Lake.
5. Issue 5 - Erosion of the outlet for the Fahlgren overflow area.
6. Issue 6 - Ice jams that occur at the U.S. Highway 83 bridge.

Alternatives identified for consideration since the 1984 studies are:

1. Alternative 1 - Construct a 350 foot wide channel with a 25 foot bottom. This alternative was removed from further consideration based on landowner concerns.
2. Alternatives 2A and 2B - Construct diversion channels to divert water for the entire reach from U.S. Highway 83 all the way to the outlet of the Fahlgren's overflow area. This alternative was not analyzed in this study.
3. Alternative 3A - Construct a diversion along the east side of the project area as close to the bluff as possible. This diversion has a 65 foot bottom width with 4H:1V side slopes. This diversion is sized to convey the 25-year 24-hour scenario with at least three feet of freeboard. There is a

control structure to allow the 2-year 24-hour discharge into Painted Woods Creek during the 25-year 24-hour scenario. The remainder of the discharge enters into the diversion.

4. Alternative 3B North Outlet - Construct a diversion along the Fahlgren overflow to the Missouri River. The diversion has a 100 foot bottom with 4H:1V side slopes, and is designed to convey the 25-year 24-hour scenario without overtopping. This alternative will require drop structures at the inlet and outlet of the considered diversion to prevent erosion. The upstream drop structure has a crest length of 300 feet and a height of slightly over seven feet. The downstream drop structure has a crest length of 100 feet and a height of 5.5 feet. Alternative 3B is not a viable option due to landowner and land acquisition issues. This alternative also affects landowner access, which requires additional bridge costs and maintenance. Lastly, this alternative could lead to potential permanent diversion of flows in new channel with very little flow into Painted Woods Lake.
5. Alternative 3C Control Structure - Modification of the existing control structure at the outlet of Painted Woods Lake for the purpose of reducing maintenance and raising the weir two feet, which would likely create larger water depths to reduce the prevalence of cattails.
6. Alternative 4 - Diversion of water through the area west of Painted Woods Lake.
7. Alternative 5 - Channel improvement on Merry's Creek from immediately downstream of the control structure to the outlet into the Missouri River. The modified channel will consist of 4H:1V side slopes with a typical bottom width of 20 feet. Due to the wide channel near the control structure, there will be a 50 foot bottom width immediately downstream of the control structure transitioning into an 80 foot bottom about 70 feet downstream. The channel then transitions to a 20 foot bottom width about 200 feet farther downstream. Erosion protection will consist of 18 inch rip-rap for the channel toe protection and the sides up to the low water level (determined from survey in October 2015). There will be 12 inch rip-rap on the side slopes from the low water level up to the 2-year 24-hour water level.

   Alternative 3C is the only alternative in which the control structure on Merry's Creek is modified.

The alternatives 3A, 3B, 3C, 4, and 5 are evaluated in this report, shown in Figure 3, along with the locations of the typical diversion channel cross sections for Alternatives 3A and 3B. The typical diversion cross sections are shown in Figure 4.

Fish passage is desired for the alternatives in this study. However, the evaluation of fish passage is not addressed in this report. If any of the alternatives are carried forward, fish passage will be considered at that time. Also, geotechnical issues on the proposed diversion slopes will be investigated for any alternative carried into the future.

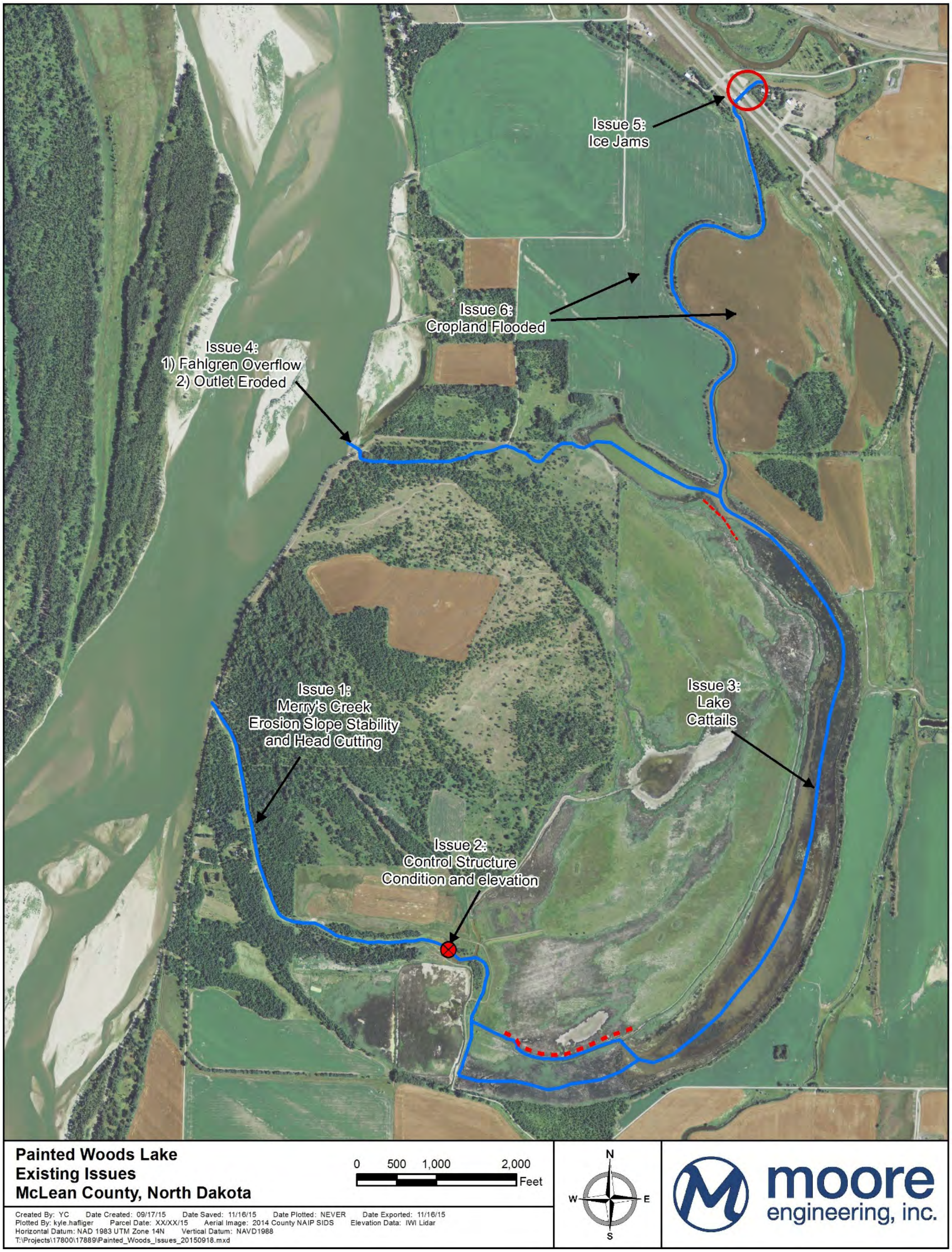


Figure 2 - Painted Woods Lake Existing Issues

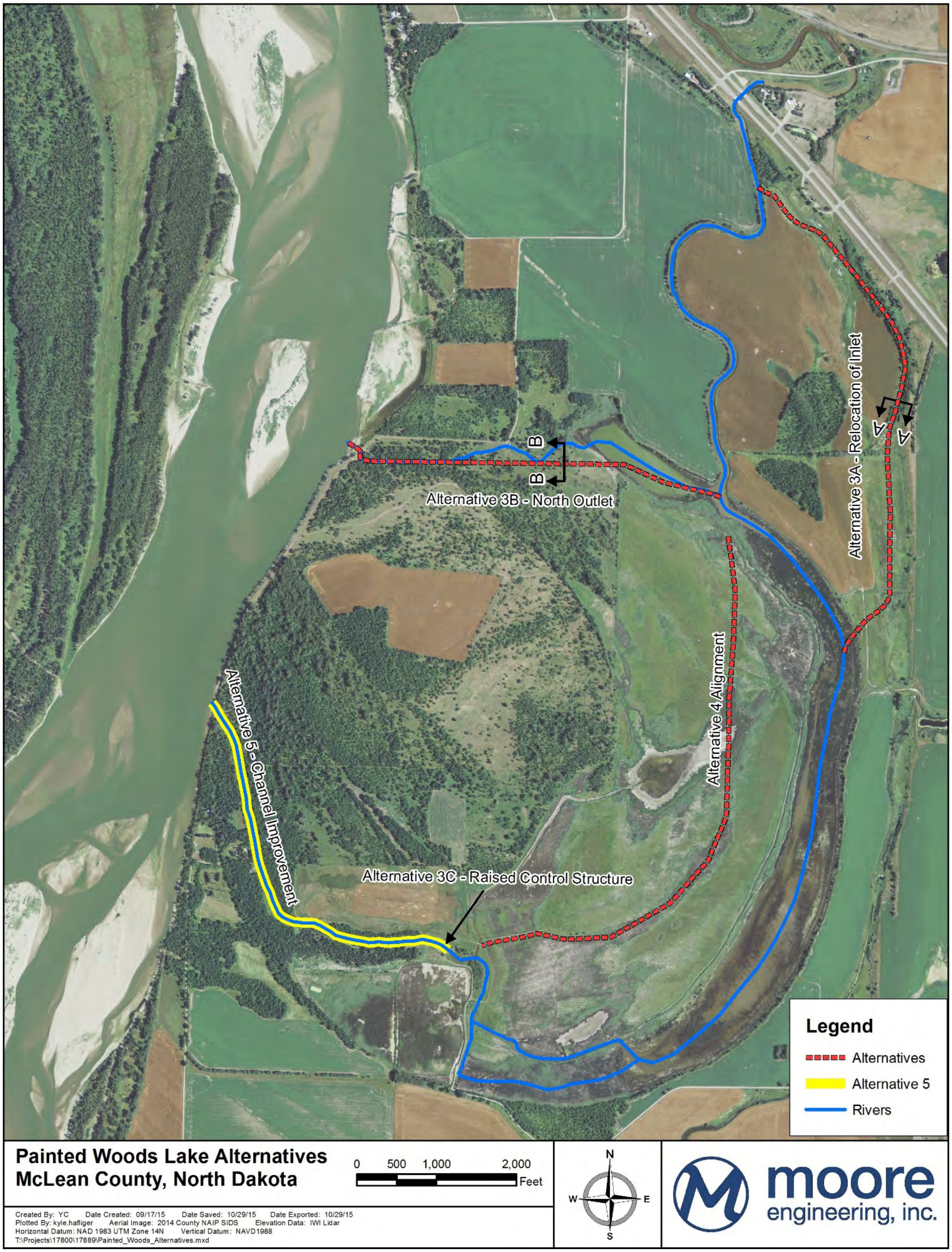
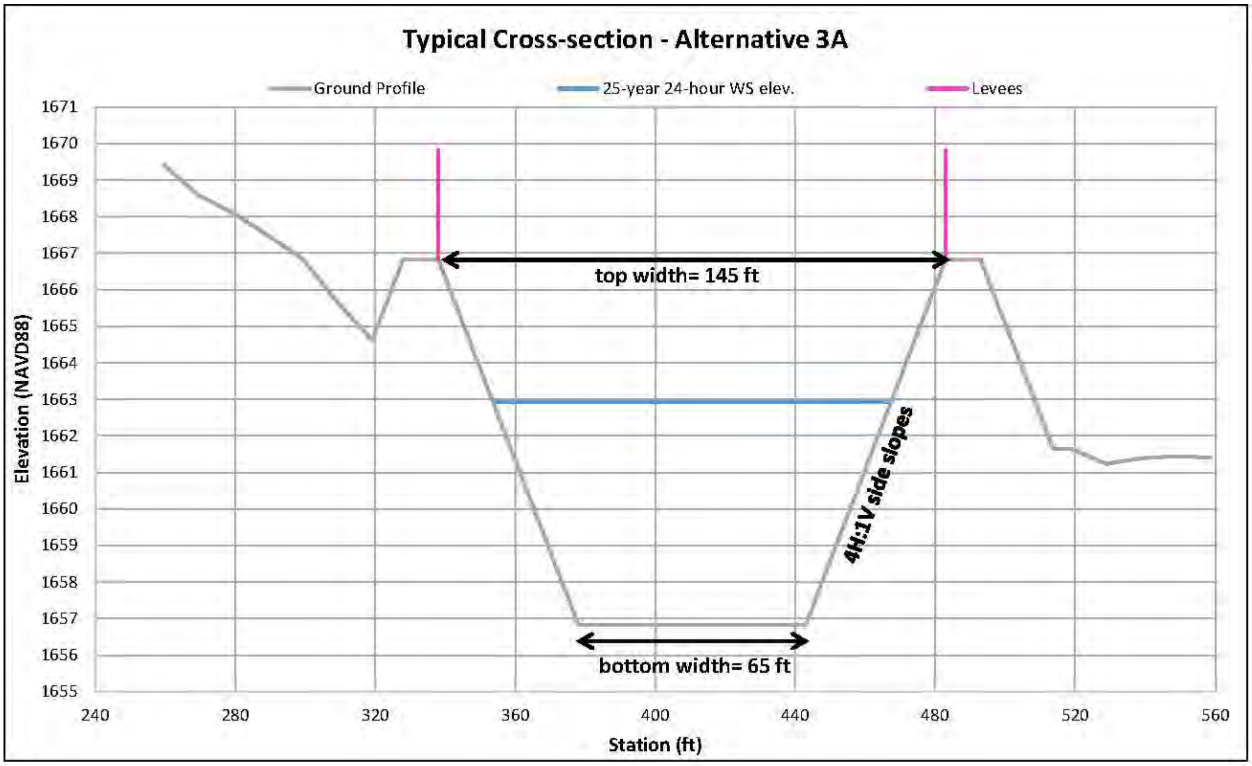


Figure 3 - Painted Woods Lake Alternatives



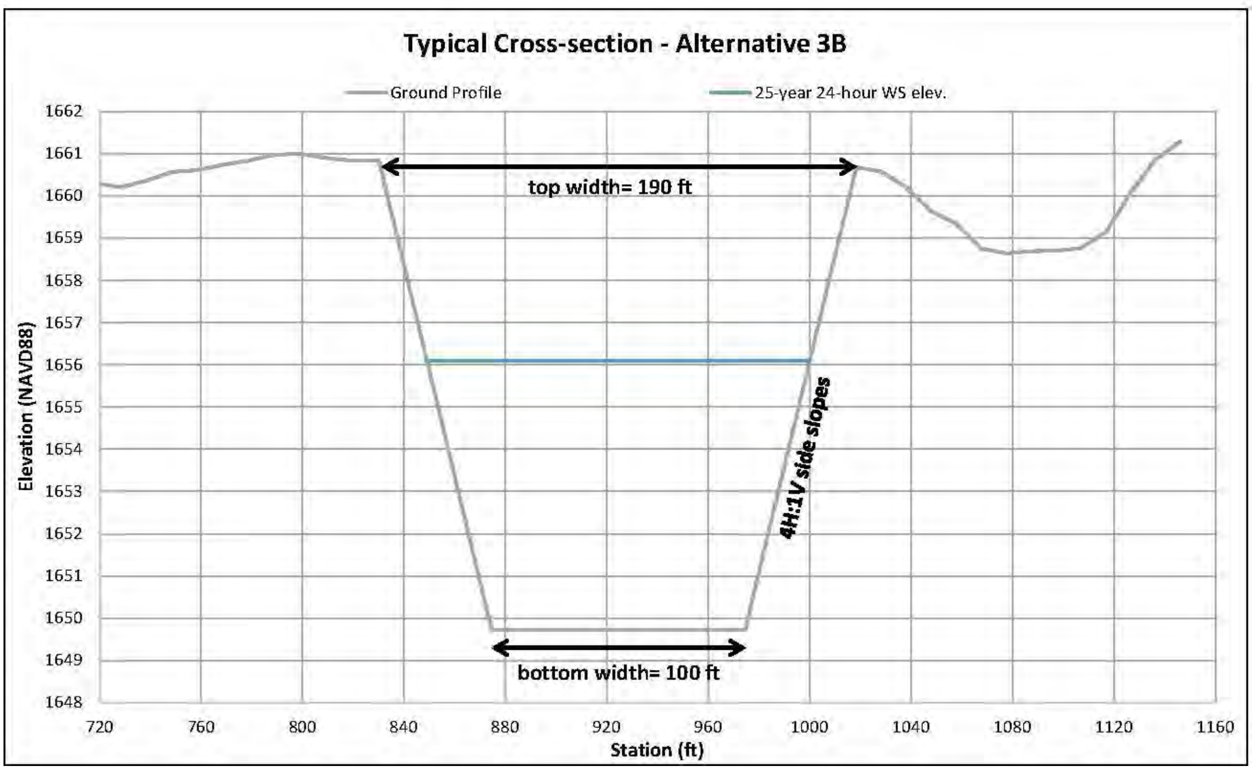


Figure 4 - Typical Cross-sections Used for Alternatives 3A and 3B

2 HYDROLOGY

2.1 General

A HEC-HMS model was created for the entire Painted Woods Creek watershed. This model will utilize the 2-year, 10-year, 25-year, and 100-year 24-hour synthetic scenarios. The resulting flows from the HEC-HMS model will be used for creating the unsteady HEC-RAS model in the project area located near the outlet of the Painted Woods Creek watershed. The HEC-RAS model, however, is limited to the area downstream of U.S. Highway 83 near Painted Woods Lake. Figure 5 shows a map of the Painted Woods Creek watershed showing the sub-basins.

2.2 Previous Hydrologic Studies

In 1983, the North Dakota State Water Commission (NDSWC) completed a study on the Panted Woods Creek watershed. The details of the study are outlined in the *Painted Woods Lake Flood Control - SWC Project #160* [1] report. In this study, they developed hydrology for the Painted Woods Creek watershed at four different locations: the USGS gage (two miles west of State Highway 41), the Lost Lake area (three miles east of Highway 83), at Highway 83, and at Painted Woods Lake. Table 2 shows the 10-year, 25-year, 50-year, and 100-year discharges at those four locations, stated in the NDSWC report [1] [2]. A supplement to NDSWC's 1983 report was completed by NDSWC in 1984 [2]. In this supplement study, an elevation-discharge relationship was developed for the Painted Woods Lake outlet resulting in a range of discharges from the lake into Merry's Creek for the range of discharges from the 2-year to the 10-year discharge. The resulting discharges entering Merry's Creek from the Painted Woods Lake outlet are shown in Table 2. The discharges stated in NDSWC's report and supplementary report were developed from a TR-20 hydrologic model completed by NDSWC in 1979.

Table 2 - Discharges in the Painted Woods Creek Watershed from the NDSWC Report

Painted Woods Creek Discharges from the NDSWC Report					
Scenario	Peak Discharge (cfs)				
	USGS Gage	Lost Lake	U.S. Hwy 83	Painted Woods Lake	Merry's Creek
2-year	–	–	–	–	300
10-year	1,400	1,550	1,770	1,800	1,800
25-year	2,870	3,200	3,550	3,600	–
50-year	3,970	4,450	5,000	5,080	–
100-year	4,900	5,580	6,300	6,360	–

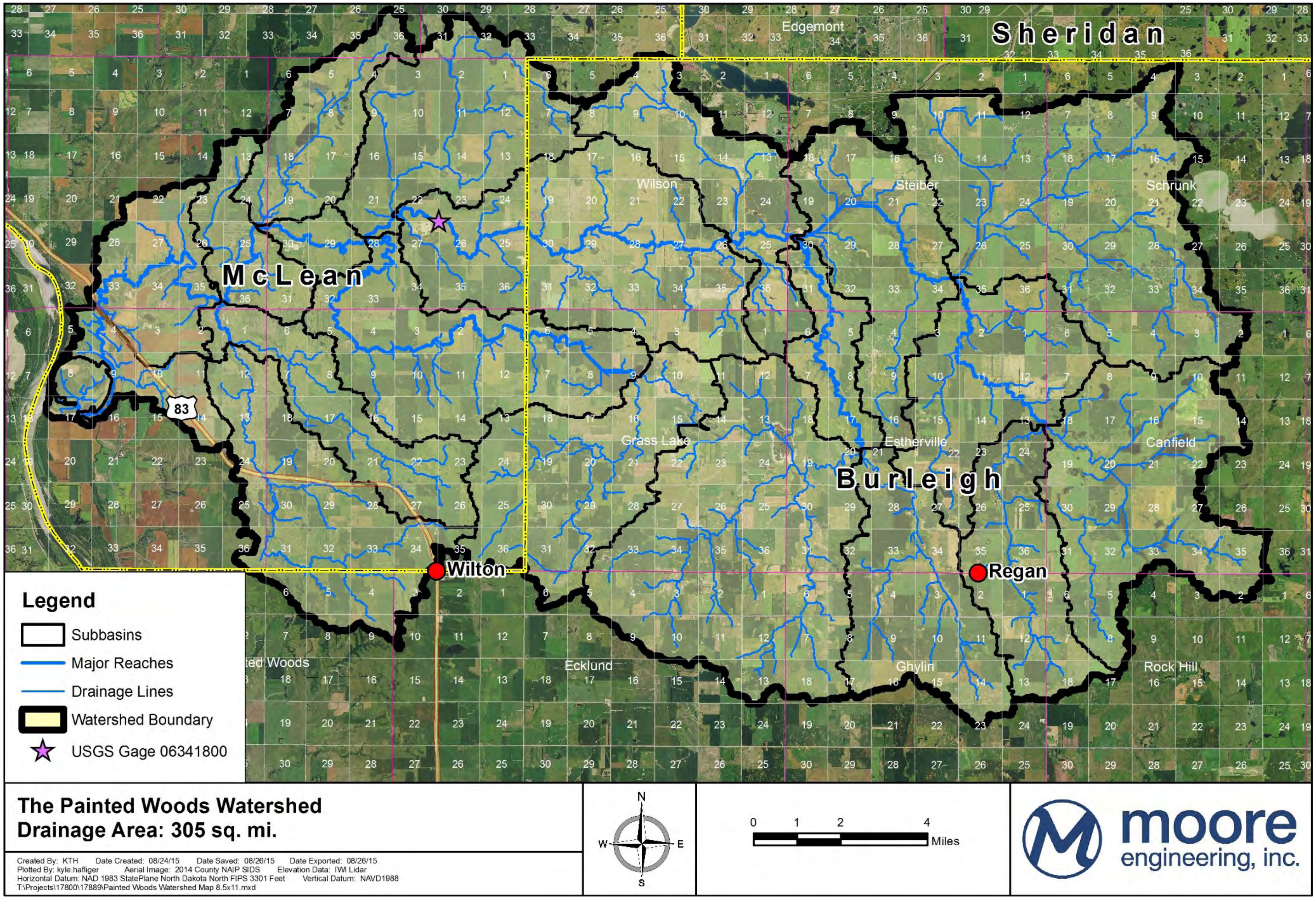


Figure 5 - The Painted Woods Creek Watershed

2.3 HEC-HMS Model Development

2.3.1 Watershed Boundary Delineation

Arc Hydro and HEC-GeoHMS tool sets in ArcGIS were used to delineate the Painted Woods Creek watershed. The watershed delineation was completed using a combination of a 10-meter by 10-meter digital elevation model (DEM) and LiDAR. The 10-meter DEM did not represent the ground elevations accurately in great detail, noticed especially in very small drainage ditches or tributaries. However, this was the best available topographic data for a majority of the watershed. The DEM was utilized for the area east of Highway 83 (over 95-percent of the watershed). For the area west of Highway 83 in the Painted Woods Lake area, the topography is much flatter, and the DEM was not considered to be detailed enough to produce accurate modeling. Fortunately, LiDAR data was flown along the Missouri River. This LiDAR dataset covers the remaining Painted Woods Creek watershed west of Highway 83, and provides a greater amount of detail which is beneficial for (fill in this area). Due to the better accuracy in the 10-foot LiDAR compared to the 10-meter DEM, the watershed boundary west of Highway 83 was delineated using the 10-foot LiDAR. The entire watershed boundary delineated from the USGS data was modified in the area west of Highway 83 to match the boundary developed from the 10-foot LiDAR data. Based on the delineation, the Pained Woods watershed has a total area of 305 square miles.

2.3.2 Sub-basin Delineations

Sub-basins in the Painted Woods Creek watershed were broken upstream of the confluence of each major tributary and at the outlet of each tributary. Breaks were created for large sub-basins and for sub-basins that have a very long drainage path. Lastly, breaks were created at reporting points, such as Highway 83 and at Painted Woods Lake, and all the necessary locations in the project area to develop local hydrographs for the unsteady HEC-RAS model.

2.3.3 Loss Method

The SCS curve number method was used to model the infiltration loss in HEC-HMS. Curve numbers were developed using GIS to assign to 2014 land use data collected from the cropland data layer from Crop Scape [3]. The curve number tables from HydroViz (a web-based program with various hydrologic data) were used to assign curve numbers, depending on cover type, hydrologic condition, and soil classification [4]. Assumptions were made for the cover type and hydrologic condition (assumed good for all land uses) for each land use. The soils in the Painted Woods Creek watershed were classified as type B, from the soil map in Chapter 2 of the ND Hydrology Manual [5]. After curve numbers were assigned to each land use, a weighted 24-hour curve number was assigned for each sub-basin.

2.3.4 Transform Method

There were various transform methods used in HEC-HMS to compare results to determine which method is best to use for this study, described in the sections below.

2.3.4.1 Time of Concentration Grid Development

The time of concentration (Tc) value for each sub-basin was estimated by utilizing a travel time routine within the GIS software. The travel time routine, developed by the Minnesota Department of Natural Resources, used the NCLD land use, slope, the NWI wetland information, and stream network to calculate the travel time for water to move from each grid cell to the outlet of the watershed. This routine was intended for use in the Red River Basin, but was considered acceptable in this watershed since there was no severely steep terrain and like land use. The time of concentration for each sub-basin was determined by subtracting the minimum travel time from the corresponding sub-basin to the watershed outlet from the maximum travel time from the corresponding sub-basin to the watershed outlet. The resulting Tc grid is shown on Figure 6. To test the accuracy of the Tc values from the grid, the Tc value of three of the sub-basins were determined using chapter 4 of the North Dakota Hydrology Manual [5].

The Tc value using the hydrology manual depends on the slope, the size of the channel, and the land use in the channel or the waterway. Each reach section is classified as overland flow, or channel flow with high, medium, or low retardance. Based on the results of those three sub-basins using the North Dakota Hydrology Manual, the results differed by less than 20-percent of the value determined from the Tc grid. Therefore, the Tc grid was acceptable to use.

2.3.4.2 Clark Unit Hydrograph Method

This transform method used the time of concentration (Tc) value determined from the grid and used a storage coefficient (R) value for each sub-basin. In HEC-HMS, these values are stated in hours. The value of R/Tc was determined for each sub-basin in GIS, depending on the percent of lakes and wetlands within each sub-basin. The formula used, from Houston Engineering's *Fargo-Moorhead Metro Basin-Wide Modeling Approach HEC-HMS Model Development* report, developed by USACE is: $R/Tc = 0.1875 + 0.0721(X_1) + 0.1801(X_2)$ [6]. X_1 represents the percentage of wetlands in each sub-basin and X_2 represents the percentage of lakes in each sub-basin. Once R/Tc was determined for each sub-basin, the R vale was determined using the sub-basin Tc value from the developed grid.

The Clark unit hydrograph method was also analyzed using an equation for Tc, developed from the *State of Colorado Office of the State Engineer Dam Safety Breach* [7]. The equation for Tc for each sub-basin is: $Tc = 2.4*A^{0.1}*L^{0.25}*L_{ca}^{0.25}*S^{-2}$, where A is the contributing area of the sub-basin, L is the sub-basin longest flow path, L_{ca} is the centroidal flowpath of the sub-basin (measures from the centroid to the outlet), and S is the slope of the sub-basin (using the 10-85 method). The time of concentration values are best suited for the Rocky Mountains, Great Plains, and the Colorado Plateau. The storage coefficient R was determined by, $R = 0.37*T_c^{1.11}*L^{0.8}*A^{-0.57}$.

2.3.4.3 SCS Unit Hydrograph Method

The SCS unit hydrograph transform method uses the lag value (minutes) for each sub-basin in HEC-HMS. This value represents time of concentration (Tc) value determined from the grid multiplied by a factor of 0.6. Two sensitivity analysis runs were performed in HEC-HMS, using the Tc value and 0.6*Tc.

2.3.5 Routing Method

The Muskingum-Cunge method was used in HEC-HMS to route the flow through the reaches. The Muskingum-Cunge method uses the slope of the reach, a typical cross section of the reach and manning's n values of the channel and overbanks for each reach. Reaches in the HMS model were broken up if there was a significant change in the cross section of the river, for example, the transition from Painted Woods Creek to Painted Woods Lake. Cross sections for each reach were cut using 3D Analyst in ArcGIS utilizing the 10-meter by 10-meter DEM in most of the watershed, except for east of Highway 83, where the LiDAR was utilized.

2.3.6 Synthetic Scenarios

Stated earlier, the 2, 10, 25, and 100-year 24-hour synthetic scenarios were modeled in this study. The 24-hour duration point rainfall totals (inches) came from NOAA's National Weather Service using Atlas 14. Point rainfall totals from all stations surrounding the Painted Woods Creek watershed were used to develop the synthetic scenarios. The rainfall distribution over the entire watershed was developed by creating a grid using ArcGIS. Zonal statistics were analyzed for each sub-basin to determine the average rainfall for each sub-basin based on the developed grid. The resultant rainfall for each sub-basin was multiplied by an area reduction factor based on contributing area A runoff distribution was developed that had a 24-hour duration using the standard SCS Type II distribution. This distribution produces an intense amount of rainfall at the middle of the 24-hour period (almost 50-percent of the rainfall occurring during the middle one-hour period).

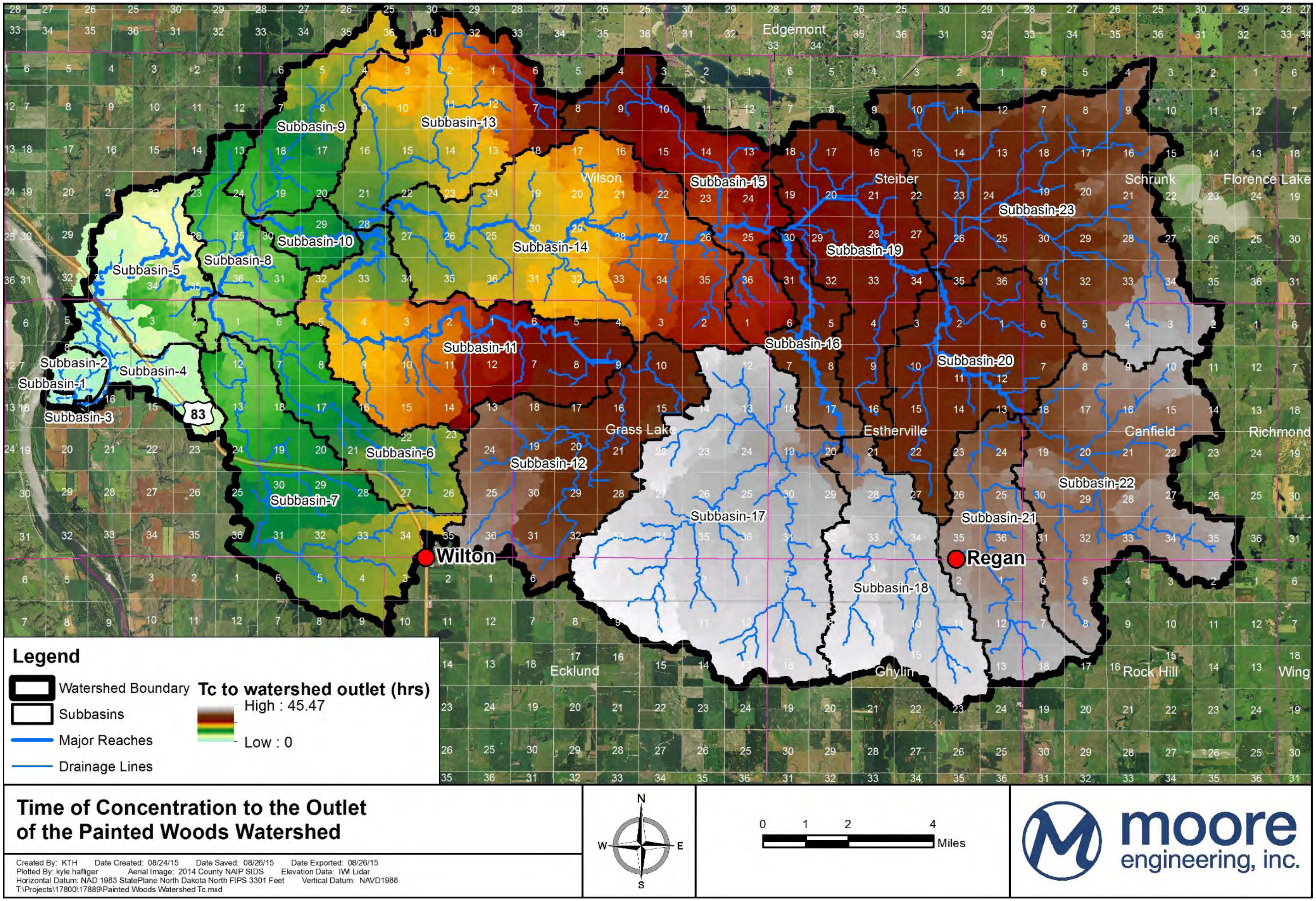


Figure 6 - Time of Concentration to the Outlet of the Painted Woods Creek Watershed

2.4 Results Using Various Hydrologic Methods

Table 3 shows the A compilation of the peak discharge results for the 2, 10, 25, and 100-year 24-hour scenarios using various hydrologic methods are summarized in Table 2 for the following locations: Painted Woods Creek at U.S. Highway 83, at Painted Woods Lake, and on Merry's Creek immediately downstream of the Painted Woods Lake outlet, These discharge results use the calculated parameters without any calibration to determine what method is best for this study in comparison to the discharges from the NDSWC study in the reporting points stated above [1] [2].

Table 3 - Peak Discharge for Different Hydrologic Analyses in the Painted Woods Creek watershed

2-year 24-hour Scenario					
Hydrologic Method	Transform Method	Sub-basins Used	Peak Discharge (cfs)		
			U.S. Hwy 83	Painted Woods Lake	Merry's Creek
HMS	Clark's Unit Hydrograph (using Tc Grid)	All Sub-basins Used	1,780	1,620	1,410
		One Basin Ups. Hwy. 83	690	680	560
	Clark's Unit Hydrograph*	All Sub-basins Used	2,170	1,890	1,670
		One Basin Ups. Hwy. 83	2,250	2,100	1,810
	SCS Unit Hydrograph (using Tc value for Lag)	All Sub-basins Used	1,760	1,630	1,430
		One Basin Ups. Hwy. 83	680	670	580
	SCS Unit Hydrograph (using 0.6*Tc value for Lag)	All Sub-basins Used	2,000	1,800	1,580
		One Basin Ups. Hwy. 83	1,100	1,080	930
USGS Regression Eq. (Reg. B)	N/A	N/A	740	740	750
USGS Regression Eq. (Reg. C)	N/A	N/A	310	310	310
Drainage Area Transfer	N/A	N/A	460	460	460

***Using the Colorado Office of the State Engineer Dam Safety Breach equations for Tc and R values**

10-year 24-hour Scenario					
Hydrologic Method	Transform Method	Sub-basins Used	Peak Discharge (cfs)		
			U.S. Hwy 83	Painted Woods Lake	Merry's Creek
HMS	Clark's Unit Hydrograph (using Tc Grid)	All Sub-basins Used	5,980	5,540	5,230
		One Basin Ups. Hwy. 83	2,140	2,120	1,980
	Clark's Unit Hydrograph*	All Sub-basins Used	7,920	7,060	6,690
		One Basin Ups. Hwy. 83	7,180	6,860	6,460
	SCS Unit Hydrograph (using Tc value for Lag)	All Sub-basins Used	5,930	5,590	5,280
		One Basin Ups. Hwy. 83	2,110	2,100	1,960
	SCS Unit Hydrograph (using 0.6*Tc value for Lag)	All Sub-basins Used	7,030	6,470	6,130
		One Basin Ups. Hwy. 83	3,430	3,340	3,120
USGS Regression Eq. (Reg. B)	N/A	N/A	3,460	3,500	3,510
USGS Regression Eq. (Reg. C)	N/A	N/A	1,700	1,720	1,720
Drainage Area Transfer	N/A	N/A	1,990	2,010	2,010

***Using the Colorado Office of the State Engineer Dam Safety Breach equations for Tc and R values**

25-year 24-hour Scenario					
Hydrologic Method	Transform Method	Sub-basins Used	Peak Discharge (cfs)		
			U.S. Hwy 83	Painted Woods Lake	Merry's Creek
HMS	Clark's Unit Hydrograph (using Tc Grid)	All Sub-basins Used	9,990	9,360	8,940
		One Basin Ups. Hwy. 83	3,480	3,430	3,240
	Clark's Unit Hydrograph*	All Sub-basins Used	13,770	12,260	11,760
		One Basin Ups. Hwy. 83	11,780	11,350	10,840
	SCS Unit Hydrograph (using Tc value for Lag)	All Sub-basins Used	9,890	9,400	8,980
		One Basin Ups. Hwy. 83	3,420	3,390	3,210
	SCS Unit Hydrograph (using 0.6*Tc value for Lag)	All Sub-basins Used	12,010	11,010	10,640
		One Basin Ups. Hwy. 83	5,590	5,520	5,220
USGS Regression Eq. (Reg. B)	N/A	N/A	5,630	5,690	5,710
USGS Regression Eq. (Reg. C)	N/A	N/A	2,960	2,990	3,000
Drainage Area Transfer	N/A	N/A	3,140	3,170	3,180

***Using the Colorado Office of the State Engineer Dam Safety Breach equations for Tc and R values**

100-year 24-hour Scenario					
Hydrologic Method	Transform Method	Sub-basins Used	Peak Discharge (cfs)		
			U.S. Hwy 83	Painted Woods Lake	Merry's Creek
HMS	Clark's Unit Hydrograph (using Tc Grid)	All Sub-basins Used	18,640	17,430	16,840
		One Basin Ups. Hwy. 83	6,180	6,150	5,890
	Clark's Unit Hydrograph*	All Sub-basins Used	27,200	24,400	23,660
		One Basin Ups. Hwy. 83	21,150	20,510	19,810
	SCS Unit Hydrograph (using Tc value for Lag)	All Sub-basins Used	18,320	17,360	16,780
		One Basin Ups. Hwy. 83	6,080	6,060	5,820
	SCS Unit Hydrograph (using 0.6*Tc value for Lag)	All Sub-basins Used	23,090	21,320	20,660
		One Basin Ups. Hwy. 83	9,940	9,820	9,430
USGS Regression Eq. (Reg. B)	N/A	N/A	9,610	9,720	9,750
USGS Regression Eq. (Reg. C)	N/A	N/A	5,370	5,420	5,440
Drainage Area Transfer	N/A	N/A	5,190	5,230	5,250

***Using the Colorado Office of the State Engineer Dam Safety Breach equations for Tc and R values**

2.4.1 Clark Unit Hydrograph Transform Method

2.4.1.1 Time of Concentration Using Developed Grid

Based on the results using the Clarks unit hydrograph method, the flows were very reasonable in comparison to the flows from the NDSWC report using the Tc grid and the R value based on wetland and lakes, assuming one large sub-basin upstream of U.S. Highway 83. The 25-year and 100-year 24-hour flows were within 5-percent of the flows from the NDSWC report.

2.4.1.2 Time of Concentration Using Dam Safety Breach Equations

Using all 23 sub-basins, the flows were much higher that the report, caused by the reach routing throughout the watershed. The Tc and R values based on the Colorado Office of the State Engineer Dam Safety Breach equations produces discharges that were much higher in comparison to using the Tc grid for using both one composite sub-basin and all 23 sub-basins (significantly higher than the discharges from the NDSWC report) [7]. Therefore, using the Tc grid and the R value based on wetland and lakes gives more accurate discharge results in comparison to the Colorado Office of the State Engineer Dam Safety Breach equations, so the dam safety breach equations will not be considered.

2.4.2 SCS Unit Hydrograph Transform Method

The SCS unit hydrograph method produced very similar peak discharge results in comparison to the Clark's Unit Hydrograph method using Tc (from the grid) as the lag value. When using th**e** true lag value (0.6*Tc), the discharges were roughly 50-percent higher than using Tc. The Tc grid was only used since the Tc values from the Colorado Office of the State Engineer Dam Safety Breach equations provided inaccurate results [7].

2.4.3 USGS Regression Equations

Results were analyzed at the three reporting points using the USGS regression equations from the report *Techniques for Estimating Peak-Flow Frequency Relations for North Dakota Streams – U.S. Geological Survey Water-Resources Investigations Report 92-4020* [8]. There are different equations used depending on the region in North Dakota. About half of the Painted Woods Creek watershed is in region B (western North Dakota) and the other half is in region C (southeastern North Dakota). Since the Painted Woods Creek watershed is in two different regions, flows were analyzed using the equations for both region B and region C. Based on the results, the region B discharges were 1.5 to 2 times higher than the discharges from the NDSWC report at all locations. The region C discharges were significantly lower than the region B discharges, and were slightly lower than the discharges from the NDSWC report. The disadvantage of the USGS regression equations is that it can only be analyzed for the peak discharges. Flows for an entire drainage network, timing of the peak flows, and hydrograph volume cannot be determined using the USGS method, like HEC-HMS.

2.4.4 Drainage Area Transfer Method

A Bulletin 17B flood frequency analysis was done at the Painted Woods USGS gage, located about 8 miles east of U.S. Highway 83. The discharges were similar to the NDSWC report for the smaller synthetic scenarios but significantly lower for the 25-year and 100-year scenarios [1]. The drainage transfer analysis was used to estimate the flows at the three reporting points, dependent on contributing area using the methodology in the USGS Water-Resources Investigations Report 92-4020, *Techniques for Estimating Peak-flow Frequency Relations for North Dakota Streams* [8]. The formula used is: $Q_{T(u)} = Q_{TW(g)}*(CA_u/CA_g)^X$. $Q_{T(u)}$ represents the peak flow for the ungaged site for a return period of T-years, $Q_{TW(g)}$ represents the peak flow of the gaged station for a return period of T-years, CA_u represents the contributing area (sq. mi.) of the ungaged site, CA_g represents the contributing area (sq. mi.) of the gaged station, and X represents the mean exponent for the appropriate hydrologic region (region B for this analysis) taken to be 0.58. The USGS gage, and points downstream of the gage are located in region B. This drainage area transfer method can only be used when the contributing drainage area of the ungaged site is from 75 to 150-percent of the contributing drainage area for the gaged site. The contributing area of Painted Woods Creek near the Painted Woods Lake outlet at Merry's Creek is about 160-percent of the contributing area at the USGS gage, which was still accepted since it is barely outside of the allowable extents. The final calculated discharges using the drainage transfer of the Bulletin 17B flows were slightly higher for the 2 and 10-year scenario, but smaller for the 25 and 100-year scenarios. Error can occur with this method since there are only 45 years of historical data from 1958 to 2003. Also, there is peak attenuation from Painted Woods Creek at Highway 83 to Merry's Creek, based on the HMS model, which cannot be accounted for when using the drainage area transfer method.

2.5 Calibration

The HEC-HMS discharge results from the Tc grid and the R value based on wetland and lakes for the Clark's unit hydrograph method was used for the final results for the unsteady HEC-RAS model. The results using one sub-basin provides the best results in comparison to the flows from the NDSWC report. However, the 2-year 24-hour discharge using one sub-basin upstream of Highway 83 was twice the discharge from the report, and all the other hydrologic methods used had higher discharges for the 2-year 24-hour scenario as well. Therefore, the 2-year 24-hour discharge results were still acceptable, considering the Clark's unit hydrograph method using the Tc grid and the R value based on wetland and lakes. In the case of a hydrologic model to be developed for points upstream of U.S. Highway 83, the model with all of the 23 sub-basins was used for the final results rather than the model with one sub-basin upstream of Highway 83. The model with all 23 sub-basins was calibrated to match the discharge results of using one sub-basin upstream of U.S. Highway 83.

The discharge using all 23 sub-basins was much higher than the flows from the model using one sub-basin upstream of U.S. Highway 83. The Tc values from the grid and R values based on percentage lakes and wetlands were calibrated to match the discharge. The final values, based on calibration, was a Tc value of 2*Tc and an R value of 6.35*R for all 23 sub-basins, which is similar to multipliers used for Tc and R in other hydrologic studies done on various watersheds the Red River Basin.

2.6 Hydrology Used for Study

The upstream boundary condition on Painted Woods Creek for the unsteady HEC-RAS model is immediately upstream of Highway 83. The calibrated flows from the HEC-HMS results were used for the unsteady HEC-RAS model. Downstream of U.S Highway 83, the HEC-HMS sub-basin inflows were used as the local inflows for the HEC-RAS model. For tributaries that join Painted Woods Creek, Painted

Woods Lake, or Merry's Creek, point inflows were used in the HEC-RAS model. For small sub-basins that drain into the river over a long distance, uniform lateral inflows were used. Table 4 shows the calibrated HEC-HMS results at U.S. Highway 83, Painted Woods Lake, and on Merry's Creek. Figure 7 shows hydrographs for all of the modeled synthetic scenarios for the upstream boundary condition of the HEC-RAS model at U.S Highway 83.

Table 4 - Calibrated HEC-HMS results in the Painted Woods Creek Watershed

Peak Discharge (cfs)			
Scenario	**U.S. Hwy 83**	**Painted Woods Lake**	**Merry's Creek**
2-year 24-hour	710	690	530
10-year 24-hour	2,140	2,130	1,950
25-year 24-hour	3,480	3,420	3,200
100-year 24-hour	6,180	6,180	5,870

***Using Calibrated Tc and R parameters (2*Tc, 6.35*R)**

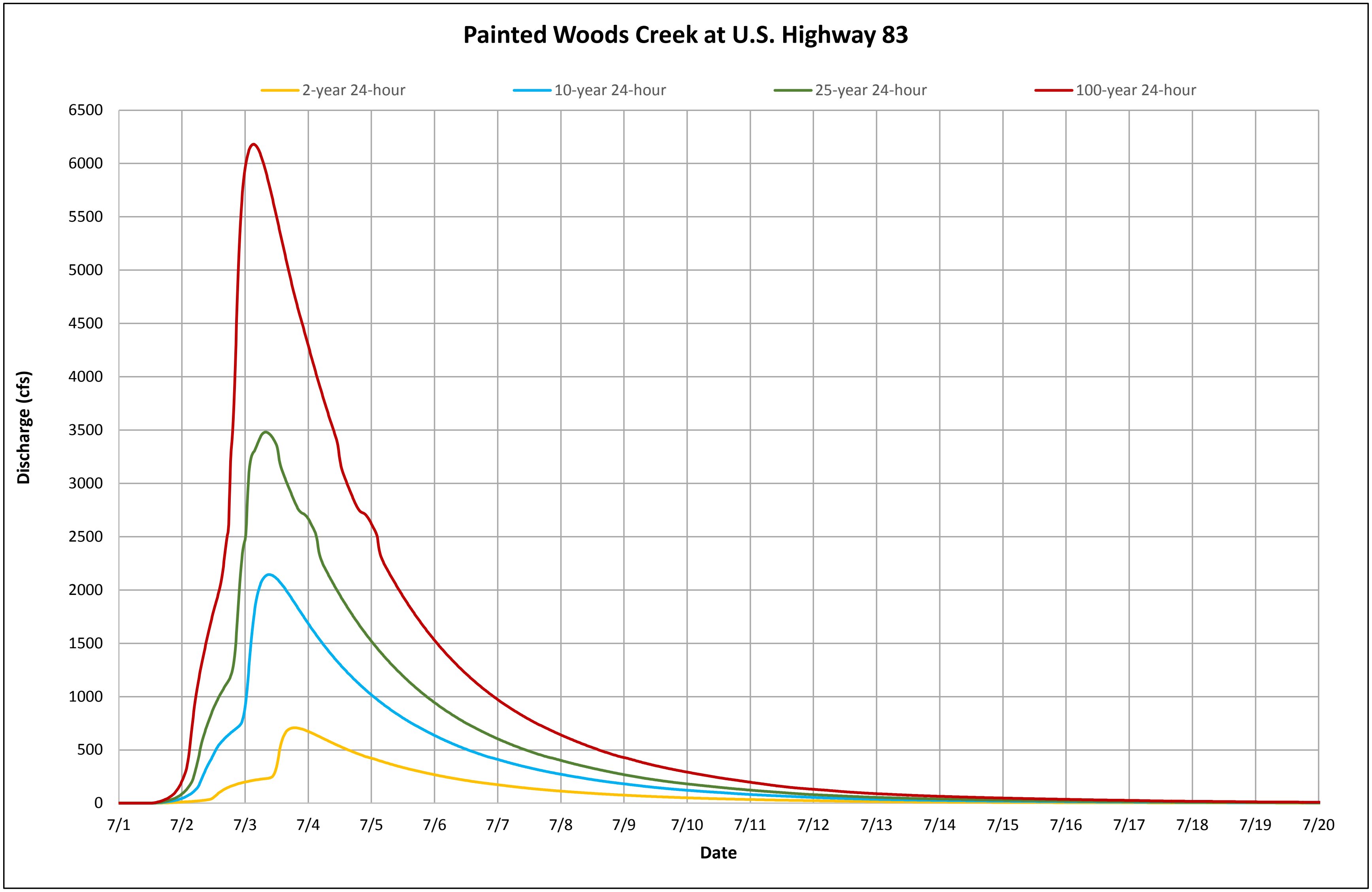


Figure 7 - Painted Woods Creek at U.S. Highway 83

3 HYDRAULICS

3.1 General

As stated earlier, an unsteady flow HEC-RAS model was developed for the portion of the Painted Woods watershed from immediately upstream of U.S. Highway 83 to the outlet of Merry's Creek. The upstream extent of the HEC-RAS model on Painted Woods Creek is 300 feet upstream of U.S Highway 83. The model includes Painted Woods Creek, Painted Woods Lake, and Merry's Creek. Two other reaches in the model is breakout to the west in to the Missouri River just north of Painted Woods Lake, and breakout into the source of Merry's Creek at the southwest corner of Painted Woods Lake. Storage areas were used to model the entire watershed of Painted Woods Creek, representing the overland flooding. Another storage area was added on the south side of Painted Woods Lake, capturing breakout flow that flows south, exiting the Painted Woods Creek watershed. Breakout in this area only occurs during large scenarios of 25-years and greater. Figure 8 shows the unsteady HEC-RAS model for the Painted Woods Lake project, showing the river reaches, cross sections, lateral structures, storage areas, and storage area connections.

3.2 HEC-RAS Model Development

3.2.1 Coordinate System

The vertical datum used for the Painted Woods Creek unsteady HEC-RAS model is the North Dakota Vertical Datum of 1988 (NAVD1988). The horizontal datum used is NAD 1983, State Plate North Dakota, North, with linear units of feet.

3.2.2 Cross Sections

Cross sections were cut from 3-meter resolution LiDAR, covering the entire model extent using the program HEC GeoRAS. GeoRAS is a HEC (Hydrologic Engineering Center) program, but is run using Arc-GIS. Since the LIDAR grid was converted to linear units of feet, each LiDAR pixel was 10-foot resolution. The station number for a river section represents the number of feet to the outlet of that corresponding river. Painted Woods Creek, Painted Woods Lake, and Merry's Creek uses continuous stationing representing the distance to the outlet at Merry's Creek. Cross sections are generally spaced 25 to 50 feet apart near inline structures and 50 to 100 feet apart near bridges. Elsewhere, the cross sections are spaced much farther apart ranging from 500 feet to 1,000 feet, except near river junctions, where the spacing is much less.

3.2.3 Bank Stations

Bank stations were estimated to be at the elevation of the 2-year water surface on both sides of the river. In most cases, the bank station was at or slightly below the top of the levee where the channel dramatically spreads out in the overbank. In Merry's Creek downstream of the control structure, the bank stations are over five feet below top of the levee elevation in most areas.

3.2.4 Lateral Structures

Lateral structures were used to connect the edge of the cross sections with the adjacent storage areas on the left and right sides of the cross sections. The lateral structures are placed on the highest possible ground representing levees, roads, or the highest natural ground. Weir coefficient values were chosen based on the recommended values from the report, *Combined 1D and 2D Modeling with HEC-RAS* [9]. Weir coefficient values of 0.2 were used for the lateral structures over non elevated natural ground, 0.5 for natural ground barriers elevated one to three feet, 1.0 for levees or roadways elevated less than three feet above the ground, and 2.0 for levees or roadways elevated three feet or more above the ground.

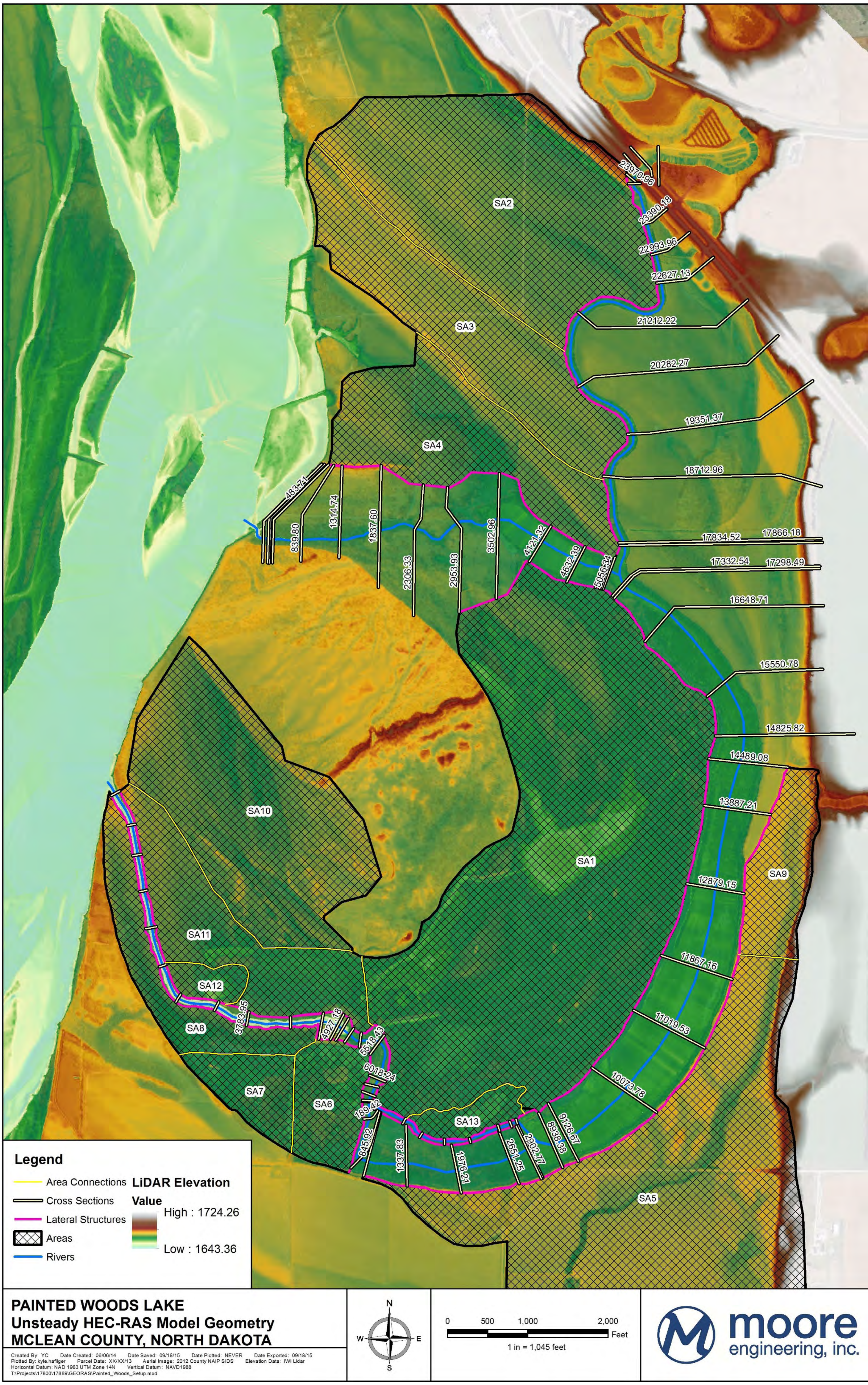


Figure 8 - Painted Woods Lake Unsteady HEC-RAS Model Geometry

3.2.5 Storage Areas

Storage areas represent the model area outside of the cross sections. This represents overbank flow leaving the cross sections and overtopping the lateral structure, thus flowing into the storage area. Storage areas are modeled using a water surface elevation (feet) vs. volume of water (acre-feet) relationship. The LiDAR surface is used to develop the elevation vs. volume relationship using HEC-GeoRAS. Storage areas were developed for almost the entire watershed due to the flat terrain except for high areas well out of the 100-year floodplain.

3.2.6 Storage Area Connections

Storage area connections represent the weirs and culverts between two storage areas. Storage area connections are across either natural high ground, roads, driveways, or levees. Weir coefficients for all storage connections were set using the same methodology as for the lateral structures.

3.2.7 Culverts

To prevent major attenuation and loss of flow across the storage areas, culverts were added into the storage area connections and lateral structures throughout the HEC-RAS model. Every culvert across section line roads, driveways, or levees that crossed a storage area connection or lateral structure was incorporated into the HEC-RAS model. Since all the lateral structures and storage area connections were across levees or high natural ground, there was only one culvert that was incorporated into the model. The culvert drains breakout from the north side of Painted Woods Lake entering back into Merry's Creek immediately upstream of the control structure.

3.2.8 Inline Structures

There is one inline structure used for the Painted Woods model for existing conditions and three for project conditions. One is the control structure on Merry's Creek about one half mile downstream of Painted Woods Lake for existing and project conditions. Inline structures are used at the upstream and downstream end of the diversion for Alternative 3B, the north outlet alternative. Those two inline structures act as drop structures to avoid using a steep slope for the diversion channel and prevent head cutting from occurring. The inline structure on Merry's Creek is based on available survey data including weir elevations and the two gates, which ware each four feet wide and six feet high. It was assumed that the gates provided a one foot opening for modeling purpose. The two drop structures assume the ground is the same as the upstream cross section, but the weir is raised one to one and a half feet.

3.2.9 Survey Data

Soundings (obtained by survey shots of the channel) were merged with the cross sections cut from LiDAR at the upstream portion of the model near U.S. Highway 83, and on Merry's Creek from immediately downstream of Painted Woods Lake to the outlet into the Missouri River. The LiDAR data does not represent the bottom of the river channel due to water in the channel. When the LiDAR was acquired, the bottom of the channel from the LiDAR data represents the water surface and can be several feet above the actual channel bottom based on the soundings data. In many cases, the surveyed channel bottom was over five feet lower than the LiDAR elevation. Since the survey data did not perfectly line up with the cross sections, only the channel portion of the cross section was used for merging the survey data to avoid error. The LiDAR elevations were generally within 0.5 feet of the survey elevations in the portion of the cross sections above the water surface, which is considered acceptable.

Survey data was also used for the lateral structures on the west side of Painted Woods Creek immediately downstream of the breakout area to the north of Painted Woods Lake. There is a breach in the levee in this area so survey data was used to more accurately represent the weir elevation. Survey data was also used near the source of Merry's Creek on the west levee.

3.2.10 Levee Systems

Levees were used for the diversion channel of Alternative 3A to obtain three feet of freeboard. The design scenario for the levees is the additional flow left over from the 25-year 24-hour scenario that does not enter into the culvert on Painted Woods Creek and flows into the diversion.

3.2.11 Bridge Parameters

All bridge crossings in each reach of the HEC-RAS model extent were incorporated into the HEC-RAS model. There were three bridge crossings, two bridges for the northbound and southbound U.S. Highway 83, and one bridge on Merry's Creek upstream of the control structure. Detailed bridge survey data was available for all bridge crossings. The bridge data included bridge widths, high and low chord elevations, bridge thickness, and culverts through the bridge (for the bridge on Merry's Creek).

3.2.12 Model Calibration

In the Painted Woods HEC-RAS model extent, there was no available high water marks on Painted Woods Creek, Painted Woods Lake, or Merry's Creek. Therefore, the model could not be calibrated for stage. Manning's n values of 0.045 were used for most channels and 0.035 to 0.04 for Painted Woods Lake. For the overbank areas, a value of 0.07 was used for most areas with values up to 0.1 for heavily wooded areas, for example, the downstream end of Merry's Creek. The stage and discharge results were dependent mainly on the manning's n values, the weir coefficients, and the weir elevation of the control structure on Merry's Creek. Due to the flat terrain in the Painted Woods Lake area, there are significant breakouts and flow attenuation. Therefore, the discharges on Painted Woods Lake and Merry's Creek are far lower than the discharges obtained from the HEC-HMS model. The HEC-HMS model assumed no breakout, explaining the higher discharges. Breakout flow can only be estimated using an unsteady HEC-RAS model, so the flow was not calibrated to the HEC-HMS flows on Painted Woods Lake and Merry's Creek by adjusting the local inflows. The original local inflows from the HEC-HMS results were used without any adjustment to the multipliers.

3.2.13 Known HEC-RAS Modeling Issues

As stated earlier, it is difficult to calibrate the Painted Woods HEC-RAS model accurately, without historical high water mark data. The manning's n values were estimated based on aerial photography. This can cause errors in the water surface elevations since the water surface elevations are highly dependent on manning's n values. Weir coefficients for the lateral structures were estimated based on recommended values from the report, *Combined 1D and 2D Modeling with HEC-RAS* [9]. There was a range of typical values of coefficients for different conditions, which is dependent on if the lateral structure is on natural ground, a levee, or a roadway. To be conservative for modeling stage, the lower value of the range was used. There can be significant error in the breakout discharges across the lateral structures when the coefficients need to be estimated. Also, survey data for the channel bottom was only available near U.S. Highway 83 and on Merry's Creek near the control structure. There can be differences in the modeled water surface when using the actual surveyed channel bottom versus the channel bottom from LiDAR.

3.3 Existing Conditions

Figures 9 through 12 show inundation maps for the 2, 10, 25, and 100-year 24-hour scenarios during existing conditions. Figure 18 shows discharges at selected points in the Painted Woods Creek HEC-RAS model study area for the 2, 10, 25, and 100-year 24-hour scenarios during existing conditions. According to the results, there is significant breakout to the west of Painted Woods Creek from U.S. Highway 83 to the upstream end of Painted Woods Lake, mainly for scenarios of 10-years and larger. There is breakout to the north of Painted Woods Lake for all scenarios of 2-years and larger. This breakout occurs to the west on the north end of Painted Woods Lake due to erosion of the levee. This flow enters back into Merry's Creek immediately upstream of the control structure. Minor breakout occurs on the south end of Painted Woods Lake for scenarios greater than 25-years, leaving the Painted

Woods watershed. The breakout for the 100-year scenario on the south side of Painted Woods Lake is about 200 cfs.

3.4 Alternative Results

Figures 13 through 17 show inundation maps for the 25-year 24-hour scenarios for all of the alternatives. Figures 19 through 23 show discharges at selected points in the Painted Woods Creek HEC-RAS model study area for the 2, 10, 25, and 100-year 24-hour scenarios for each of the different alternatives analyzed. Figures 24 through 27 show water surface profile plots on Painted Woods Creek, Painted Woods Lake, and Merry's Creek comparing existing conditions with the different alternatives analyzed for each modeled synthetic scenario.

3.4.1 Alternative 3A

This alternative shows water surface elevation stage reductions mainly on Painted Woods Creek parallel to the north portion of the diversion with stage reductions ranging from one half foot to one foot. There are no stage reductions on Painted Woods Lake parallel to the south portion of the diversion. The benefits diminish for the larger flood scenarios with almost no stage reduction for the 100-year scenario. There are impacts with this alternative upstream of the diversion for scenarios of 10-years and larger, especially for the larger scenarios. The impacts are due to flow constriction from raising the levees on the west side Painted Woods Creek to prevent flooding of the land to the west, and also from only allowing the 2-year flow through the control structure on Painted Woods Creek. The 2-year scenario still shows a stage reduction upstream of the diversion due to channel widening on Painted Woods Creek to provide room for the control structure, consisting of three 10 foot by 6 foot box culverts. All locations downstream of the diversion to the outlet of Merry's Creek into the Missouri River, there are no stage reductions with this alternative for all modeled synthetic scenarios.

3.4.2 Alternative 3B

This alternative shows significant stage reductions throughout from immediately downstream of the north outlet channel (for this alternative) to the outlet of Merry's Creek at the Missouri River. The stage reductions are the greatest on Merry's Creek downstream of the control structure with stage reductions ranging from two feet for the 2-year 24-hour scenario to seven feet for the 100-year 24-hour scenario. The large scenarios provide significantly higher stage reducitons in comparison to the smaller scenarios. There is a slight impact on Painted Woods Creek upstream of the outlet channel for the smaller scenarios.

3.4.3 Alternative 3C

This alternative shows almost no stage reductions and by far the most impacts compared to the other alternatives. Raising the control structure by two feet causes the lake level to rise to a higher elevation, explaining the impacts on Painted Woods Lake. There are also impacts downstream of the control structure. This is caused by water breaking out of Painted Woods Lake to the north, which then breaking out to the west (to the north of the control structure). This breakout enters back into Merry's Creek downstream of the control structure. Raising the control structure significantly increases the breakout flows in those areas, explaining the impacts downstream of the control structure.

3.4.4 Alternative 4

This alternative shows slight stage reductions on Painted Woods Lake parallel to the diversion to the north of Painted Woods Lake. The stage reductions range from about 0.4 feet for the 2-year 24-hour scenario to just a few hundredths of a foot for the 100-year 24-hour scenario. The larger scenarios provide smaller stage reductions. For the smaller scenarios, there is a slight impact in the area of Merry's Creek from the downstream end of the diversion to the control structure.

3.4.5 Alternative 5

Alternative 5 shows significant stage reductions on Merry's Creek downstream of the control structure with the 10-year 24-hour scenario showing the most stage reduction and the 100-year 24-hour scenario showing the least stage reduction. This alternative also shows significant stage reductions on Painted Woods Lake for the 10, 25, and 100-year 24-hour scenarios. The 2-year 24-hour scenario provides no stage reduction upstream of the control structure. The 100-year 24-hour scenario shows the most stage reductions upstream of the control structure, with stage reductions seen on Painted Woods Creek as far upstream as just downstream of U.S. Highway 83. Table 5 shows the velocities on Merry's Creek for Alternative 5 and existing conditions 60 feet downstream of the control structure and less than 200 feet upstream of the outlet of Merry's Creek.

Table 5 - Velocities on Merry's Creek

Velocities on Merry 's Creek (ft/s)		
Condition	Location	
	Control Structure	Outlet
Existing Conditions	0.3	3.8
Alternative 5	0.4	2.6

Note: These velocities are subject to change when more detail analysis is accomplished in the future

3.4.6 Breakout Flow to the North of the Control Structure on Merry's Creek

For all of the synthetic scenarios of 2-years and larger (especially for scenarios of 10-years and larger), there is a problem of breakout flow that flows around the north and south sides of the control structure on Merry's Creek. During existing conditions, the breakout flow to the north of the control structure is greater than the flow through the control structure on Merry's Creek for the 25-year and 100-year 24-hour scenarios. Most of the breakout flow on the north side of the control structure is flow that overtops the dike along Painted Woods Lake. That flow enters into a tributary that flows into Merry's Creek just upstream of the control structure. However, much of that flow in the tributary breaks out to the west just to the north of Merry's Creek and flows past the control structure on the north side, entering back into Merry's Creek downstream of the control structure. Breakout on the south side occurs for scenarios of 10-year 24-hours and larger and is less significant compared to on the north side. Table 6 shows the percentage of flow on Merry's Creek that flows around the control structure for existing conditions and the different alternatives during each synthetic scenario.

Table 6 - Percentage of Total Discharge Flowing Around the Control Structure on Merry's Creek

Percentage Breakout Flow				
Condition	Synthetic Scenario			
	2-yr 24-hr	10-yr 24-hr	25-yr 24-hr	100-yr 24-hr
Existing Conditions	21	51	69	76
Alternative 3A	20	51	69	76
Alternative 3B	0	17	27	40
Alternative 3C	80	79	82	84
Alternative 4	13	42	61	72
Alternative 5	18	60	69	78

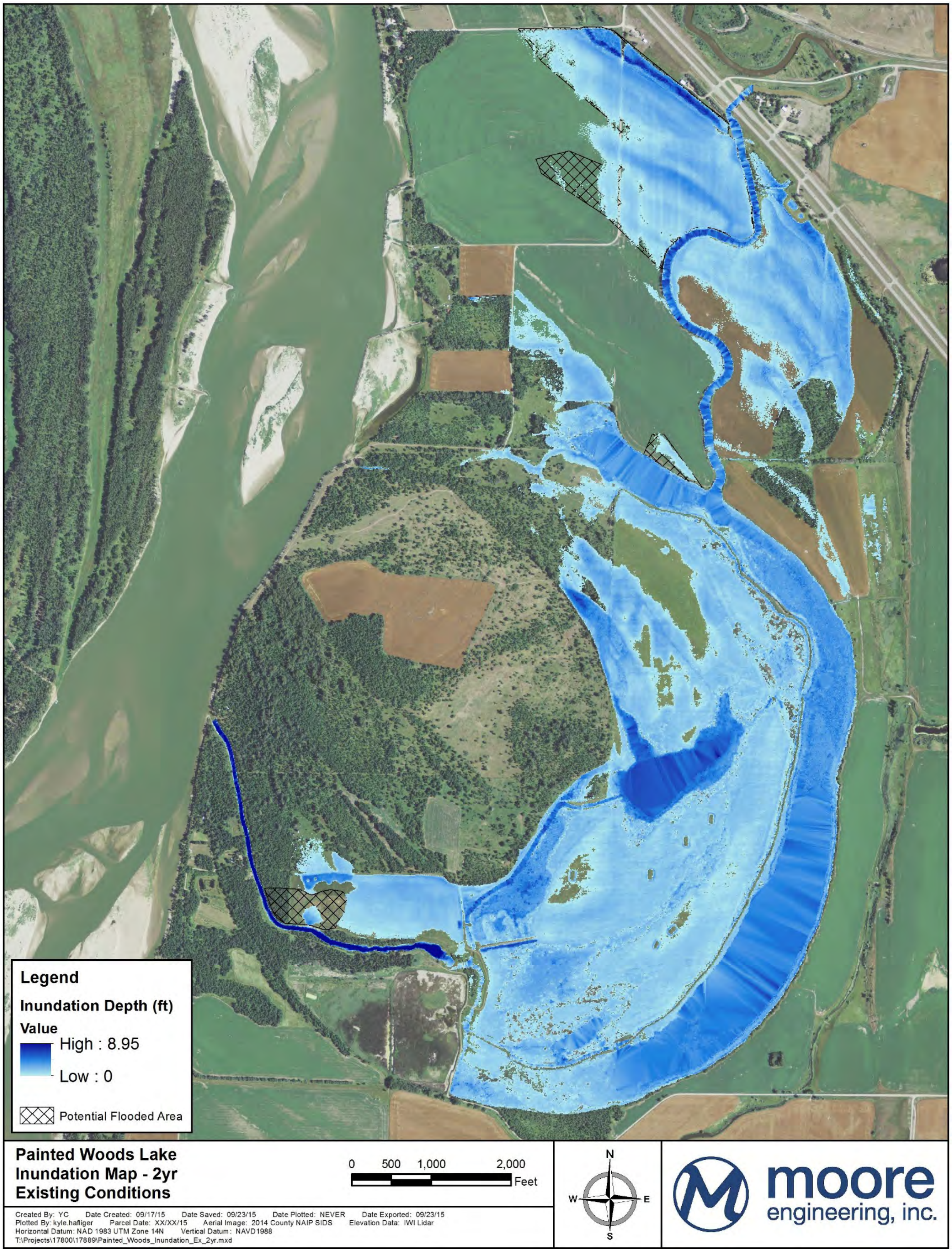


Figure 9 - Painted Woods Lake 2-year 24-hour Inundation Map - Existing Conditions

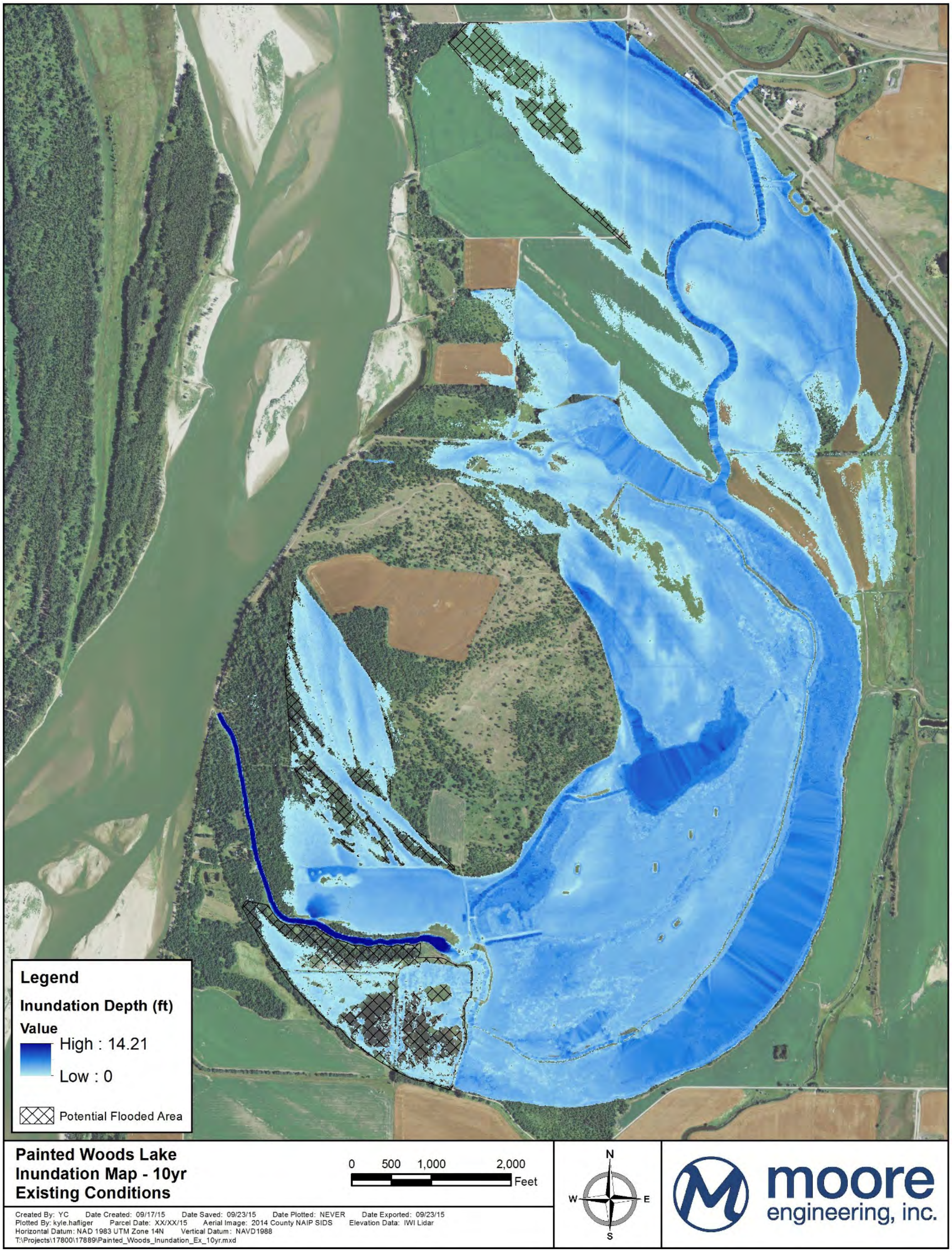


Figure 10 - Painted Woods Lake 10-year 24-hour Inundation Map - Existing Conditions

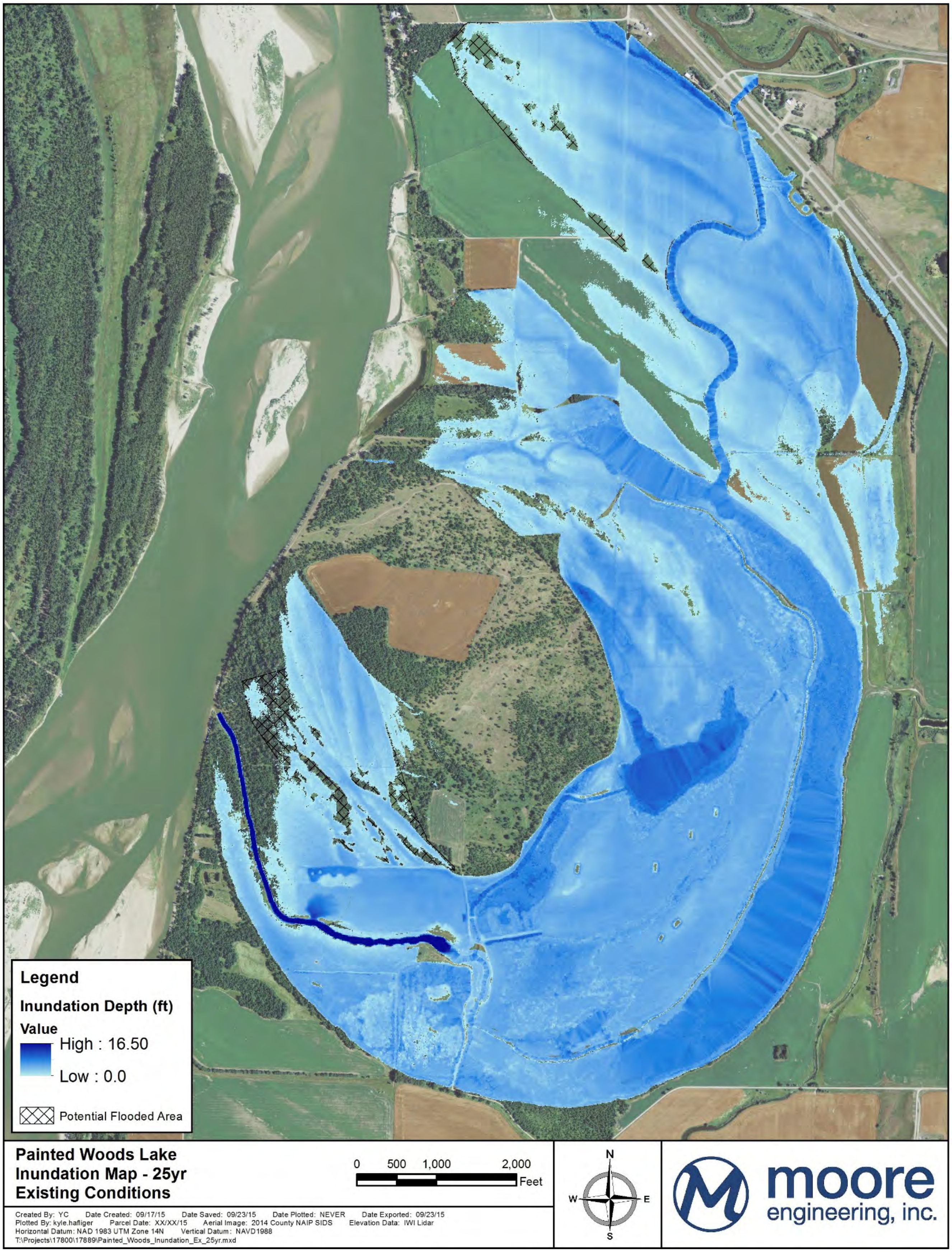


Figure 11 - Painted Woods Lake 25-year 24-hour Inundation Map - Existing Conditions

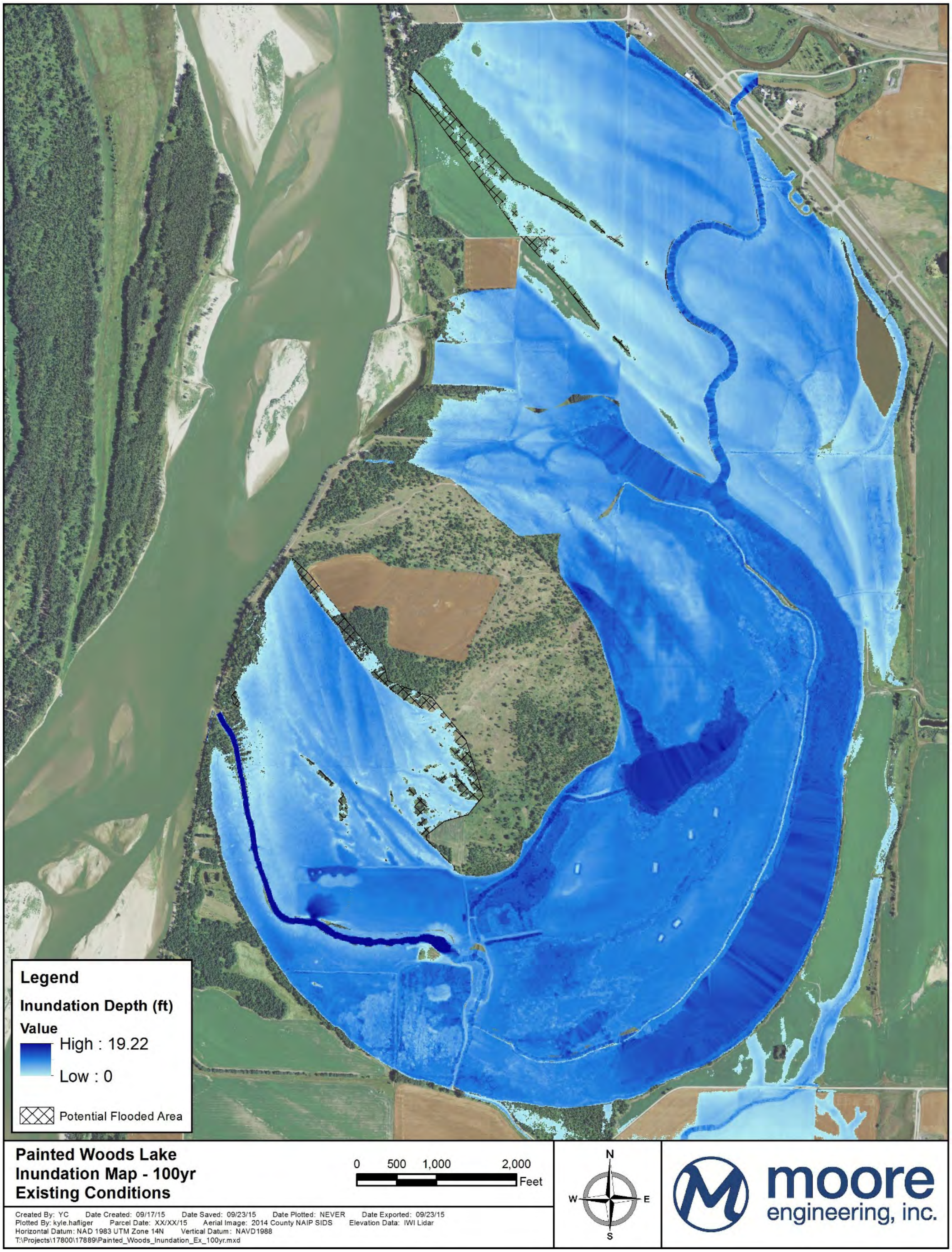


Figure 12 - Painted Woods Lake 100-year 24-hour Inundation Map - Existing Conditions

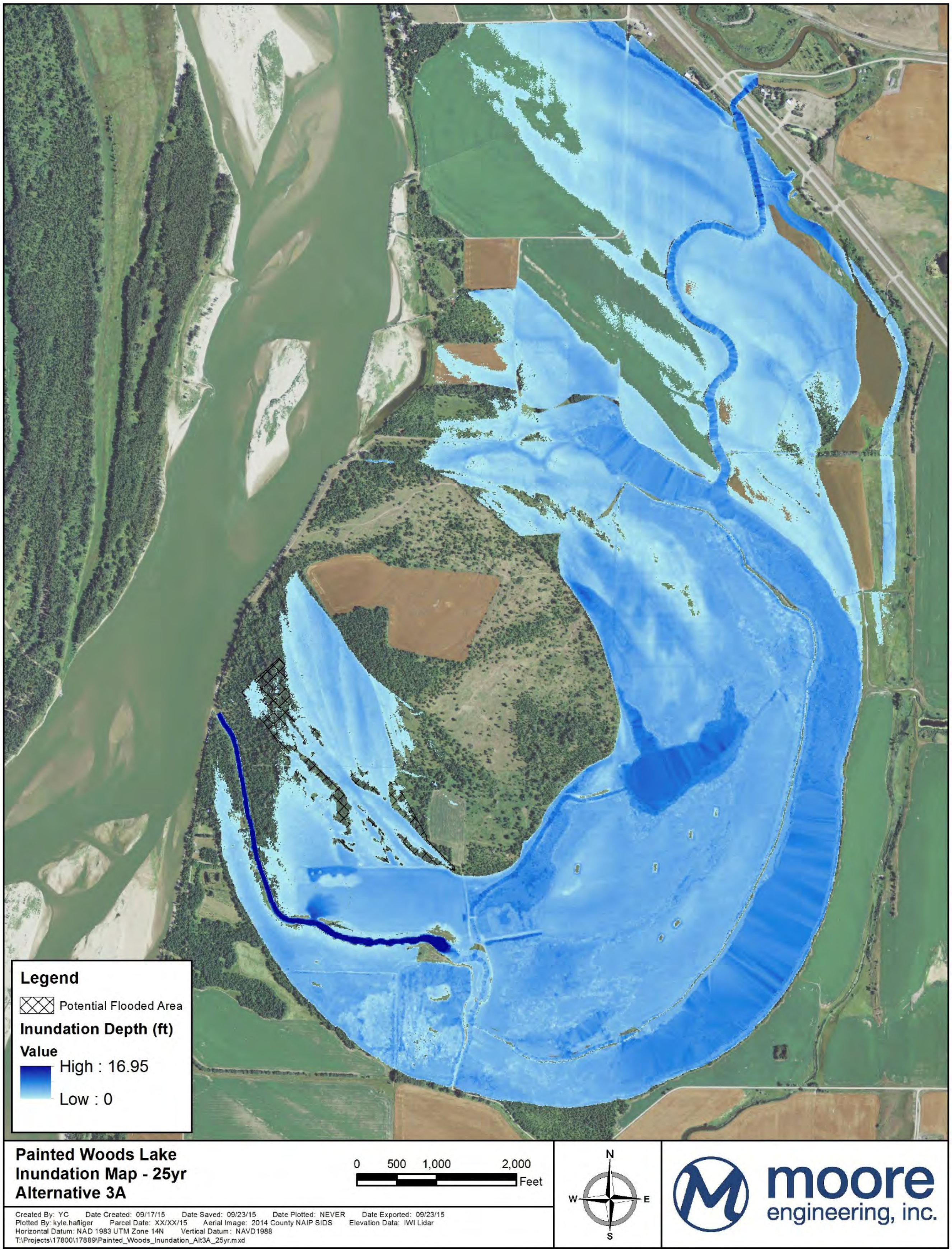


Figure 13 - Painted Woods Lake 25-year 24-hour Inundation Map - Alternative 3A

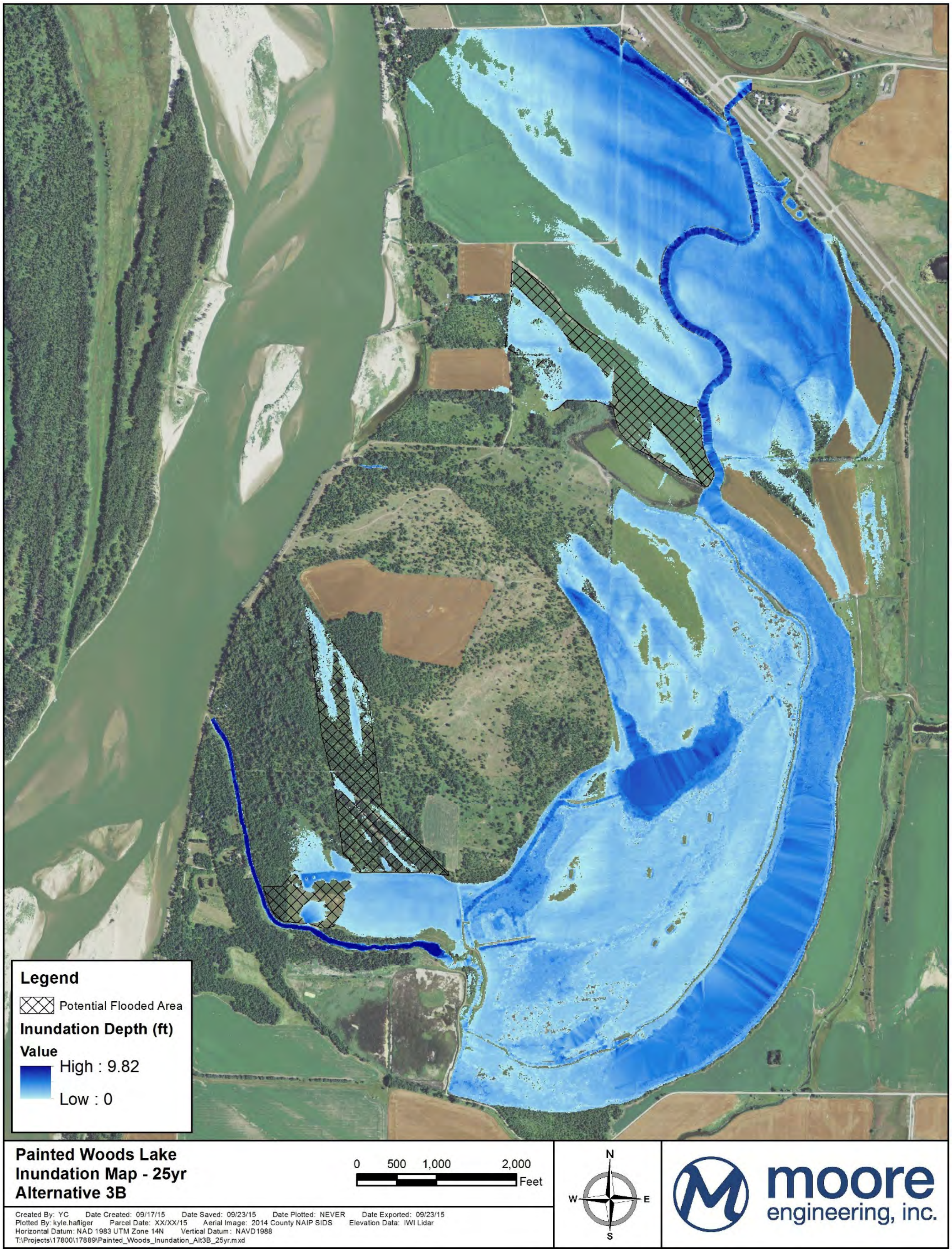


Figure 14 - Painted Woods Lake 25-year 24-hour Inundation Map - Alternative 3B

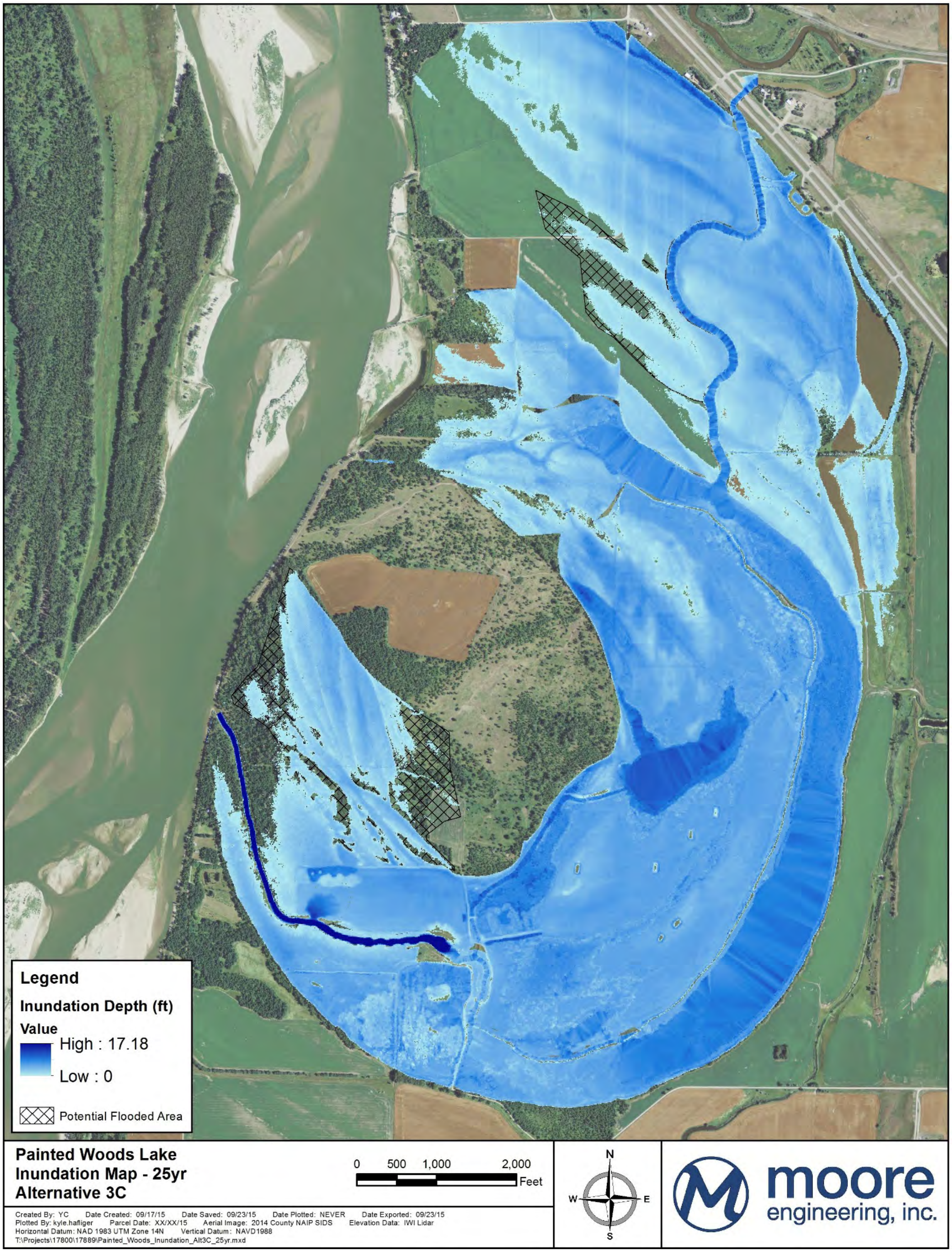


Figure 15 - Painted Woods Lake 25-year 24-hour Inundation Map - Alternative 3C

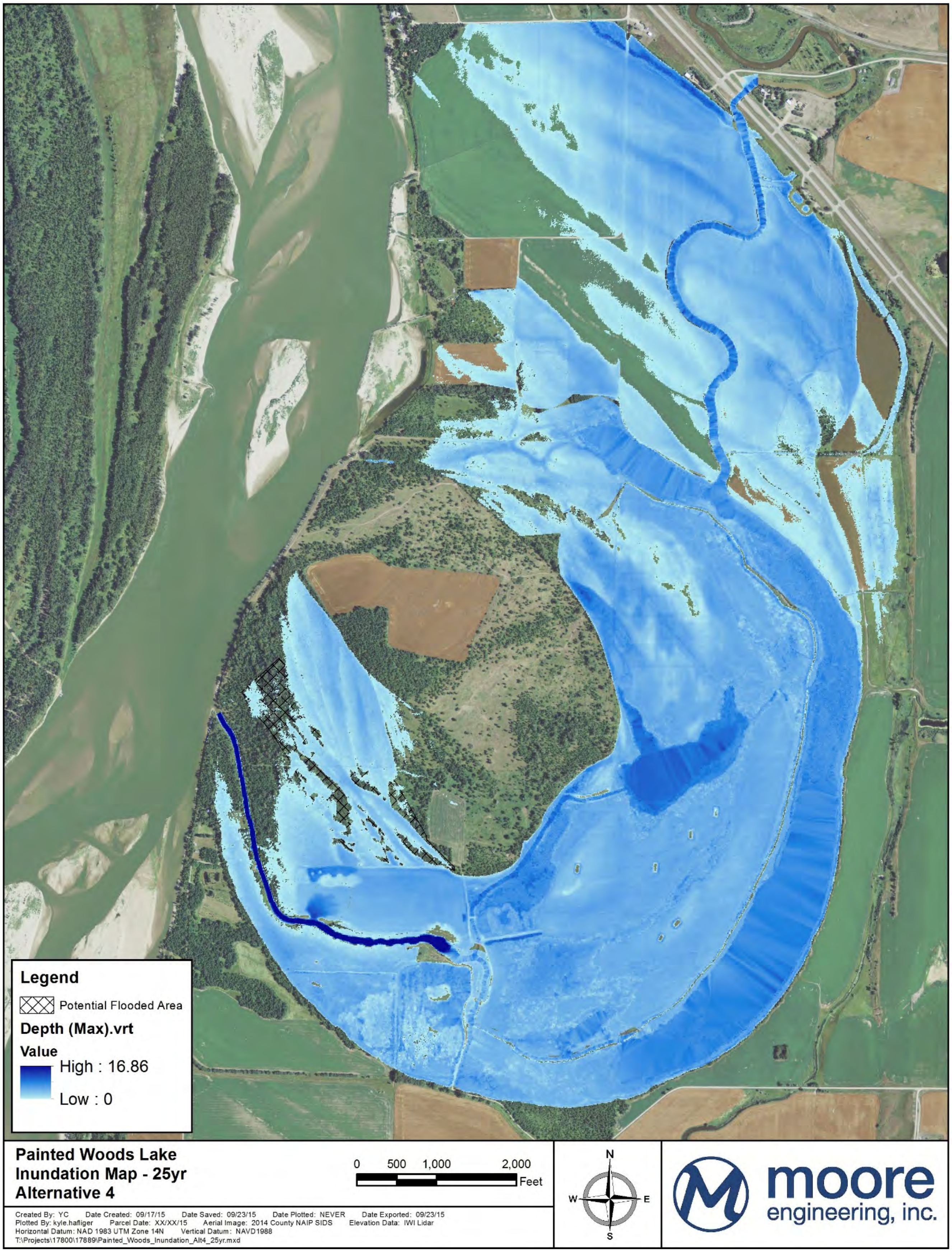


Figure 16 - Painted Woods Lake 25-year 24-hour Inundation Map - Alternative 4

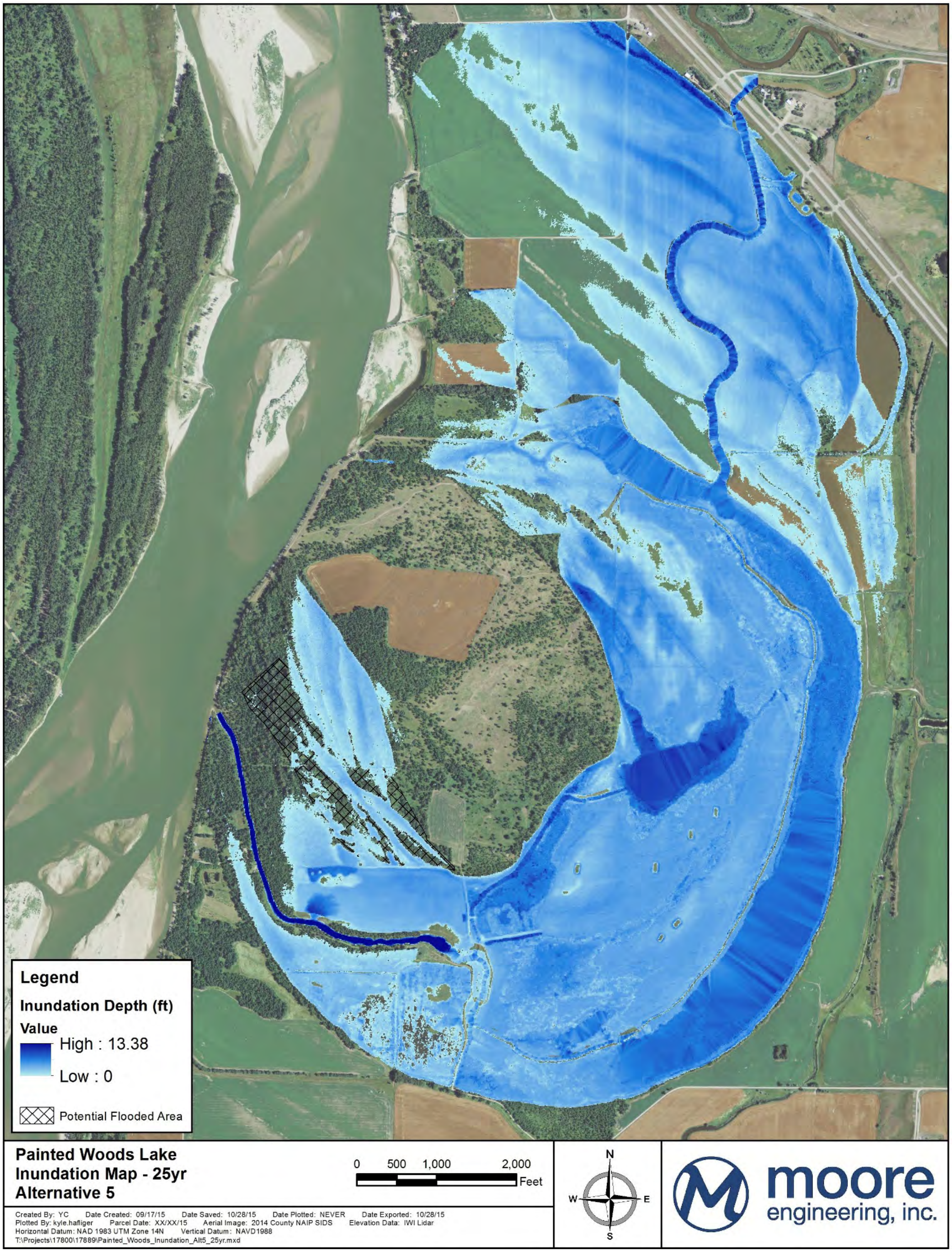


Figure 17 - Painted Woods Lake 25-year 24-hour Inundation Map - Alternative 5

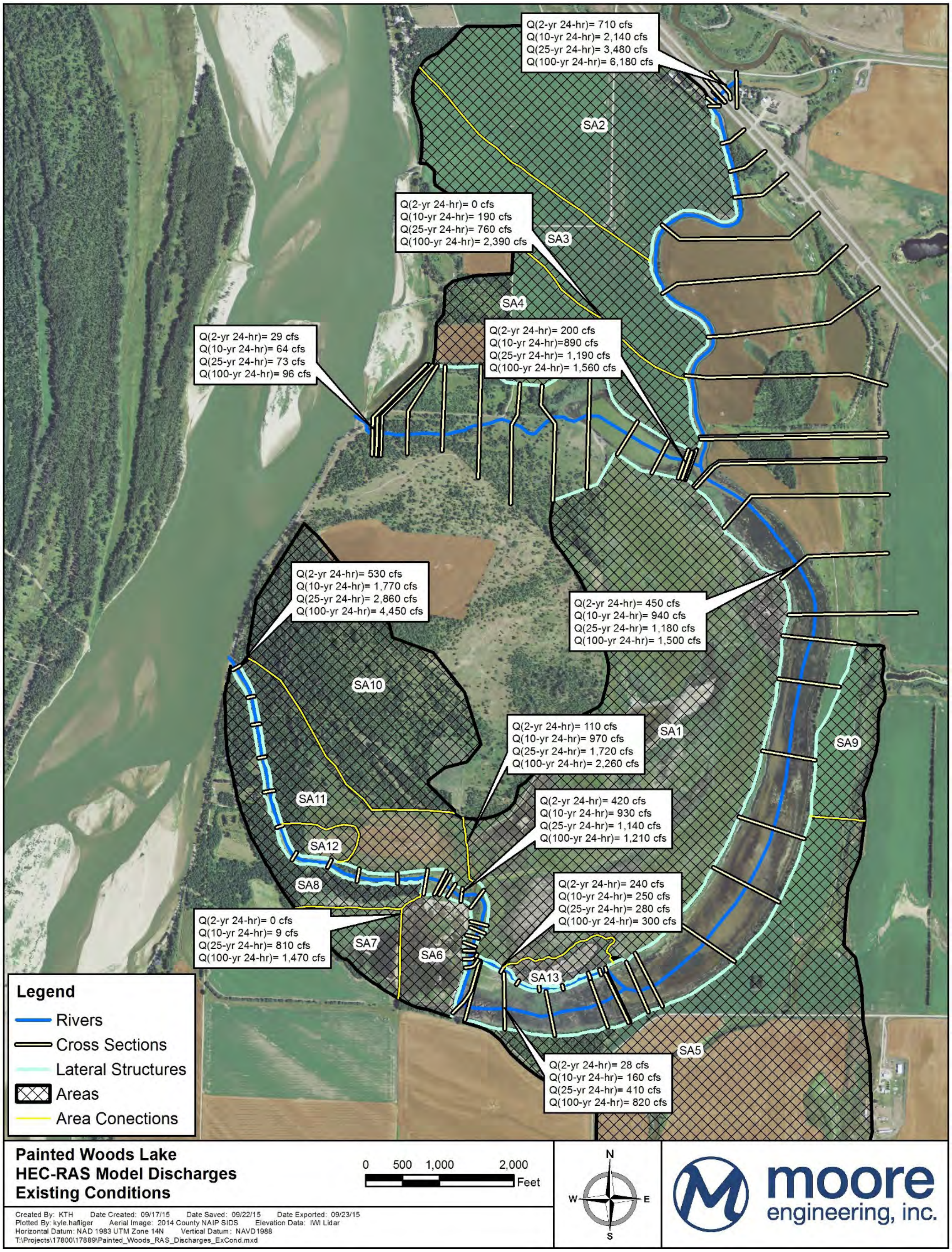


Figure 18 - Painted Woods Lake HEC-RAS Model Discharges - Existing Conditions

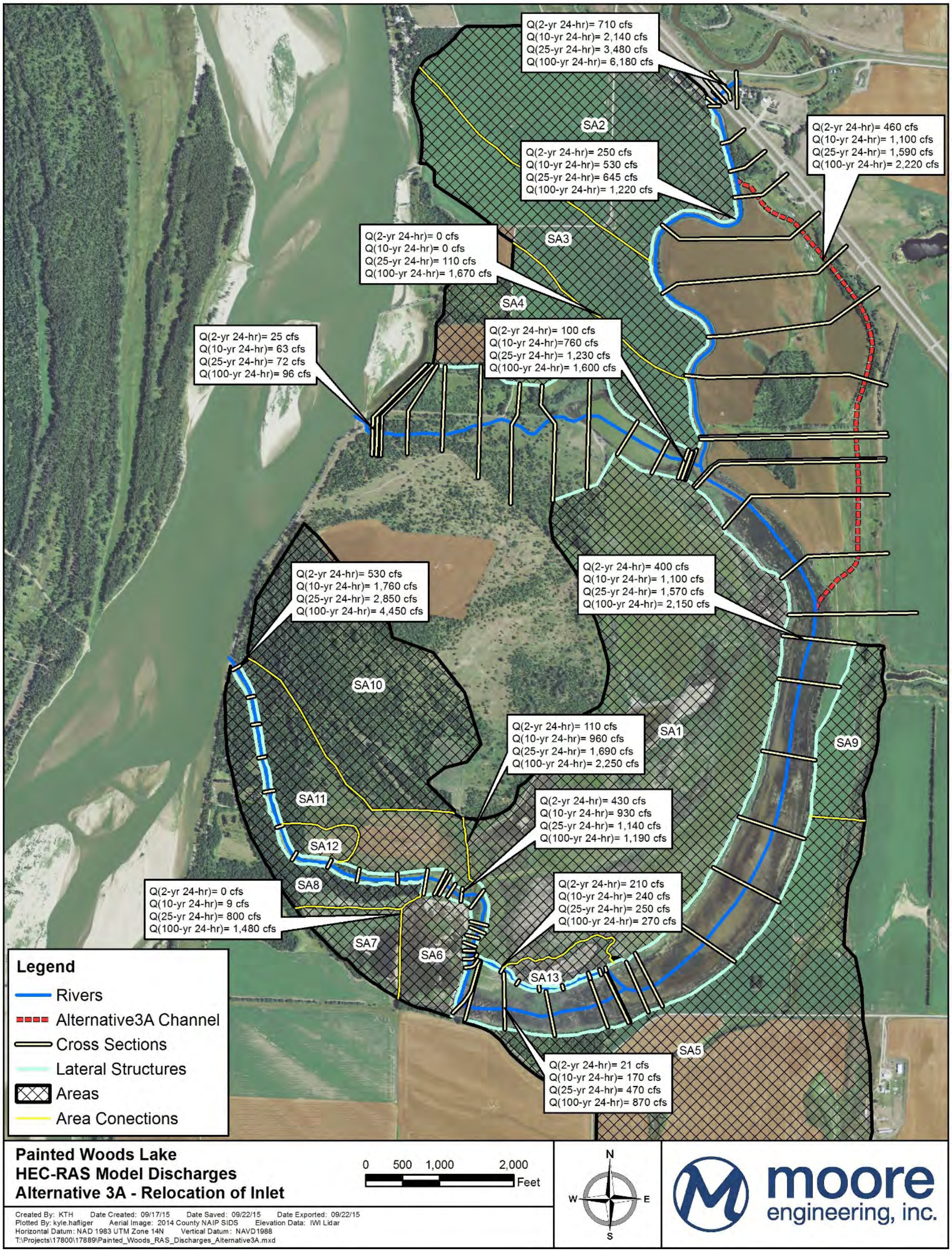


Figure 19 - Painted Woods Lake HEC-RAS Model Discharges - Alternative 3A

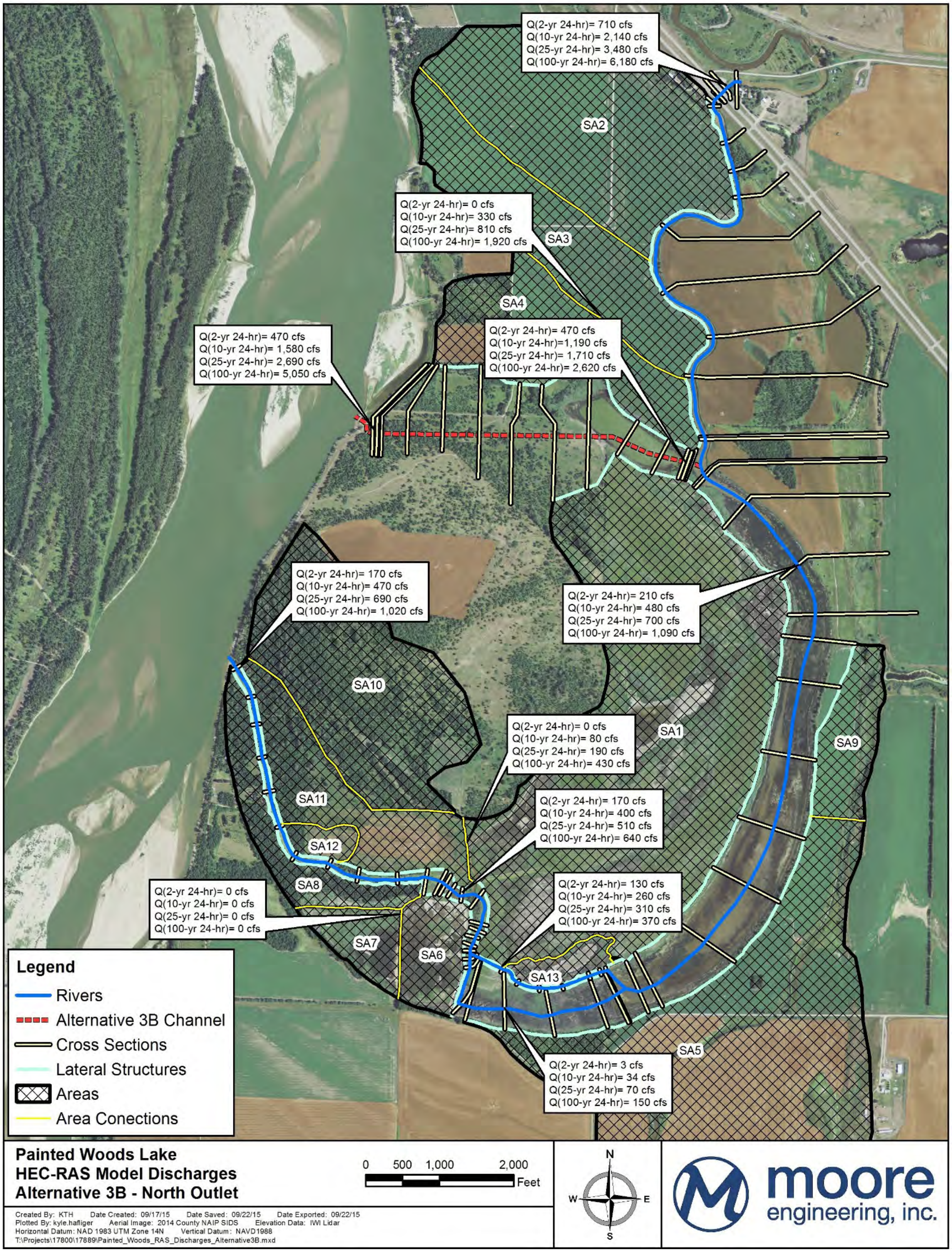


Figure 20 - Painted Woods Lake HEC-RAS Model Discharges - Alternative 3B

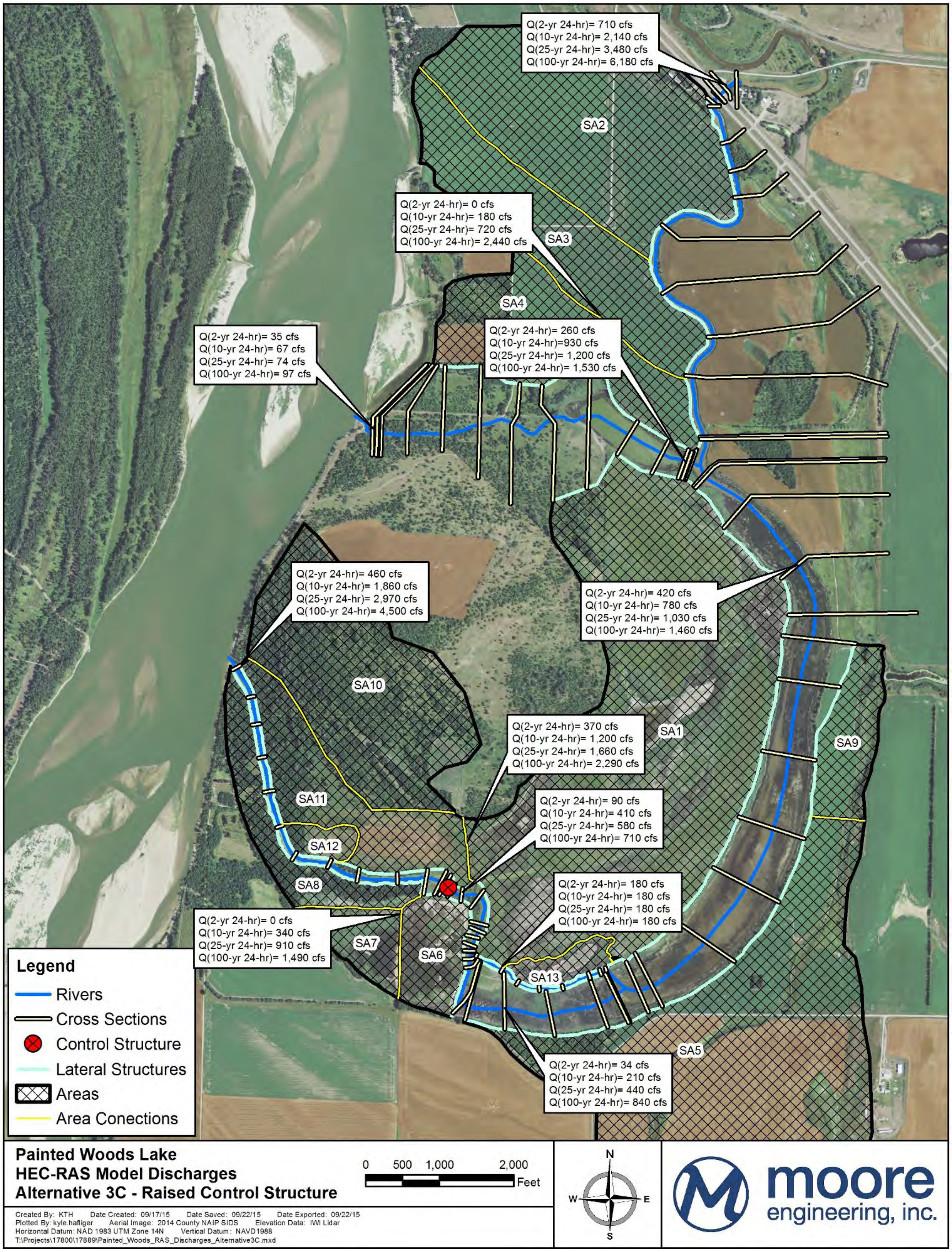


Figure 21 - Painted Woods Lake HEC-RAS Model Discharges - Alternative 3C

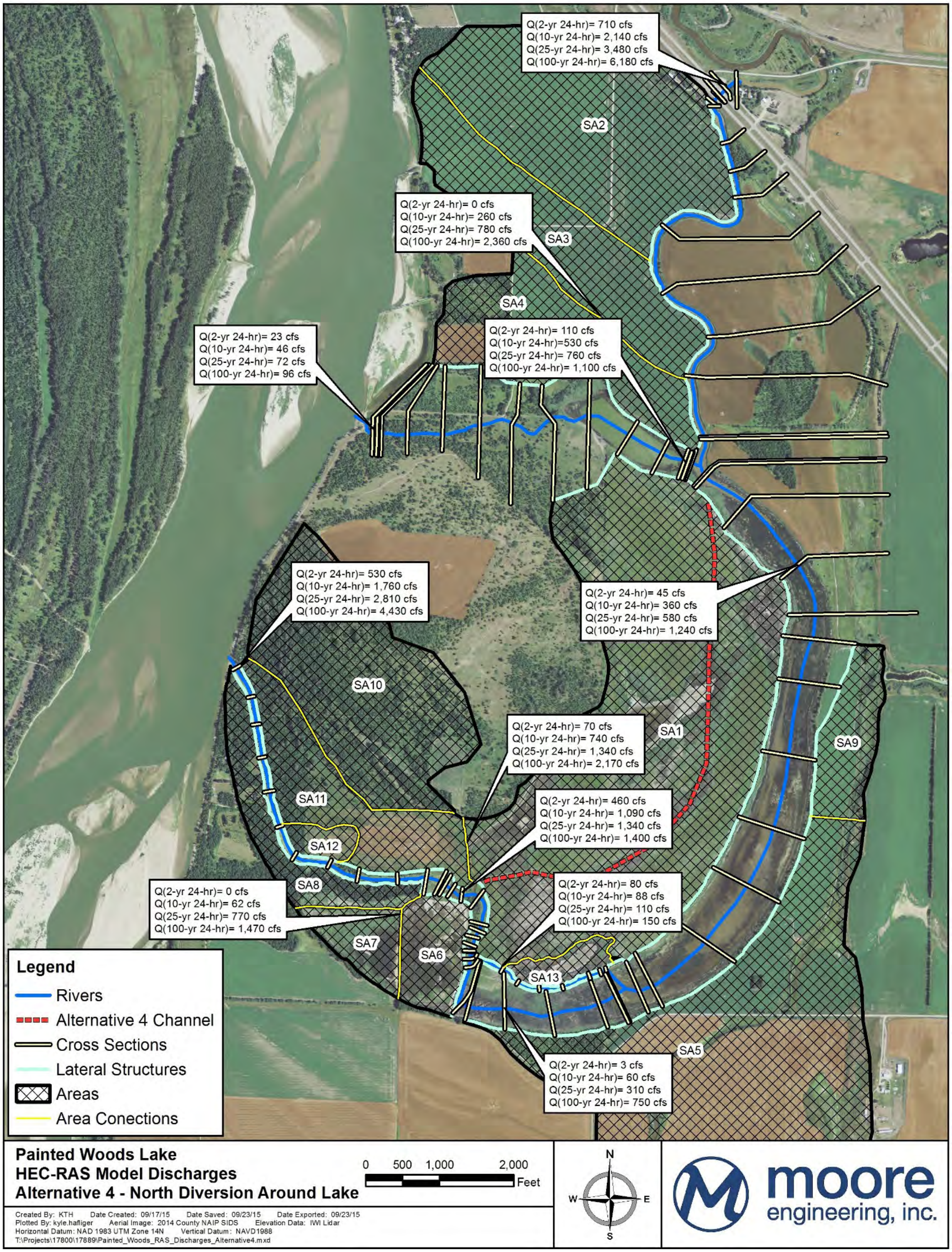


Figure 22 - Painted Woods Lake HEC-RAS Model Discharges - Alternative 4

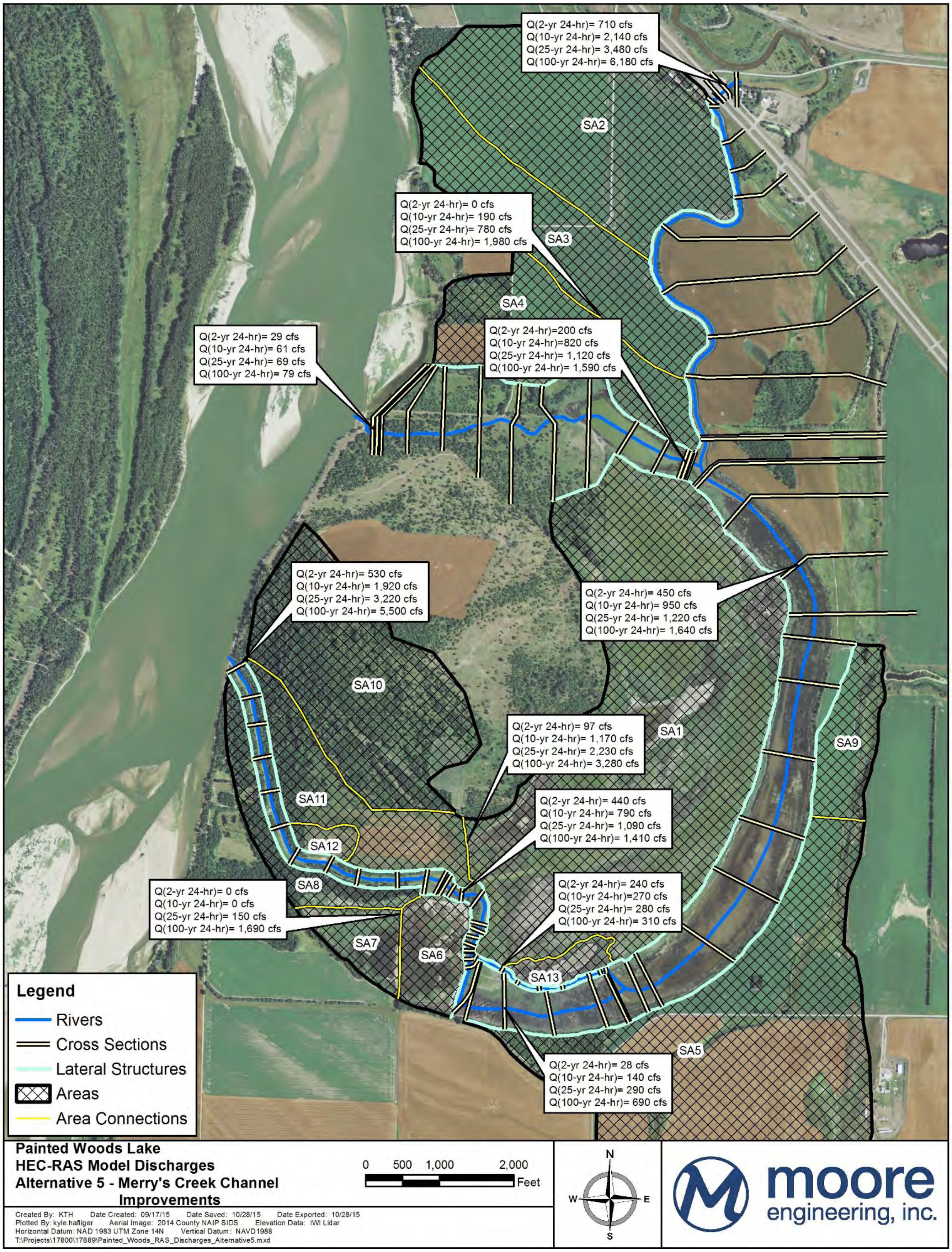


Figure 23 - Painted Woods Lake HEC-RAS Model Discharges - Alternative 5

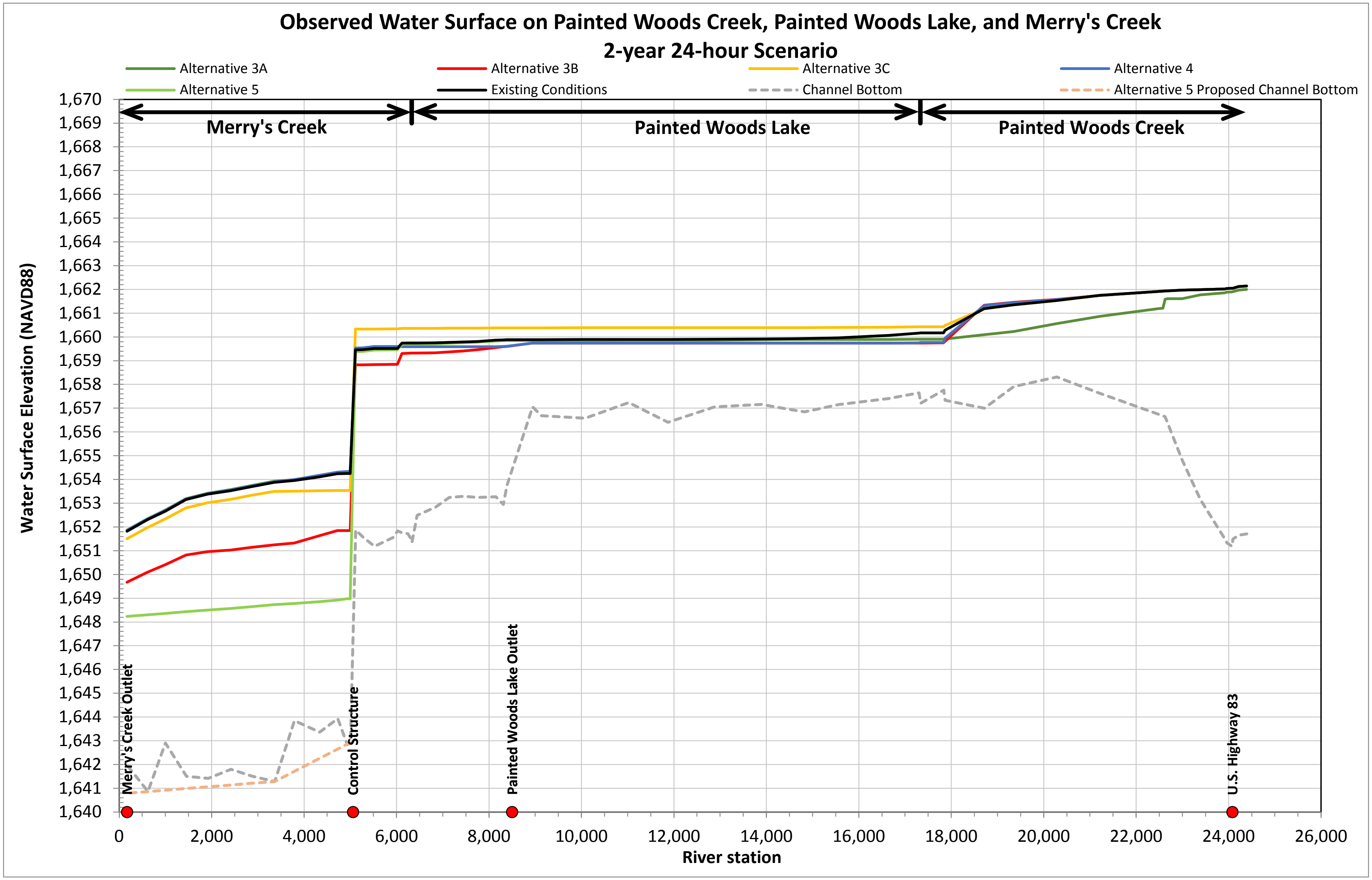


Figure 24 - 2-year 24-hour Scenario Water Surface Profile Plot

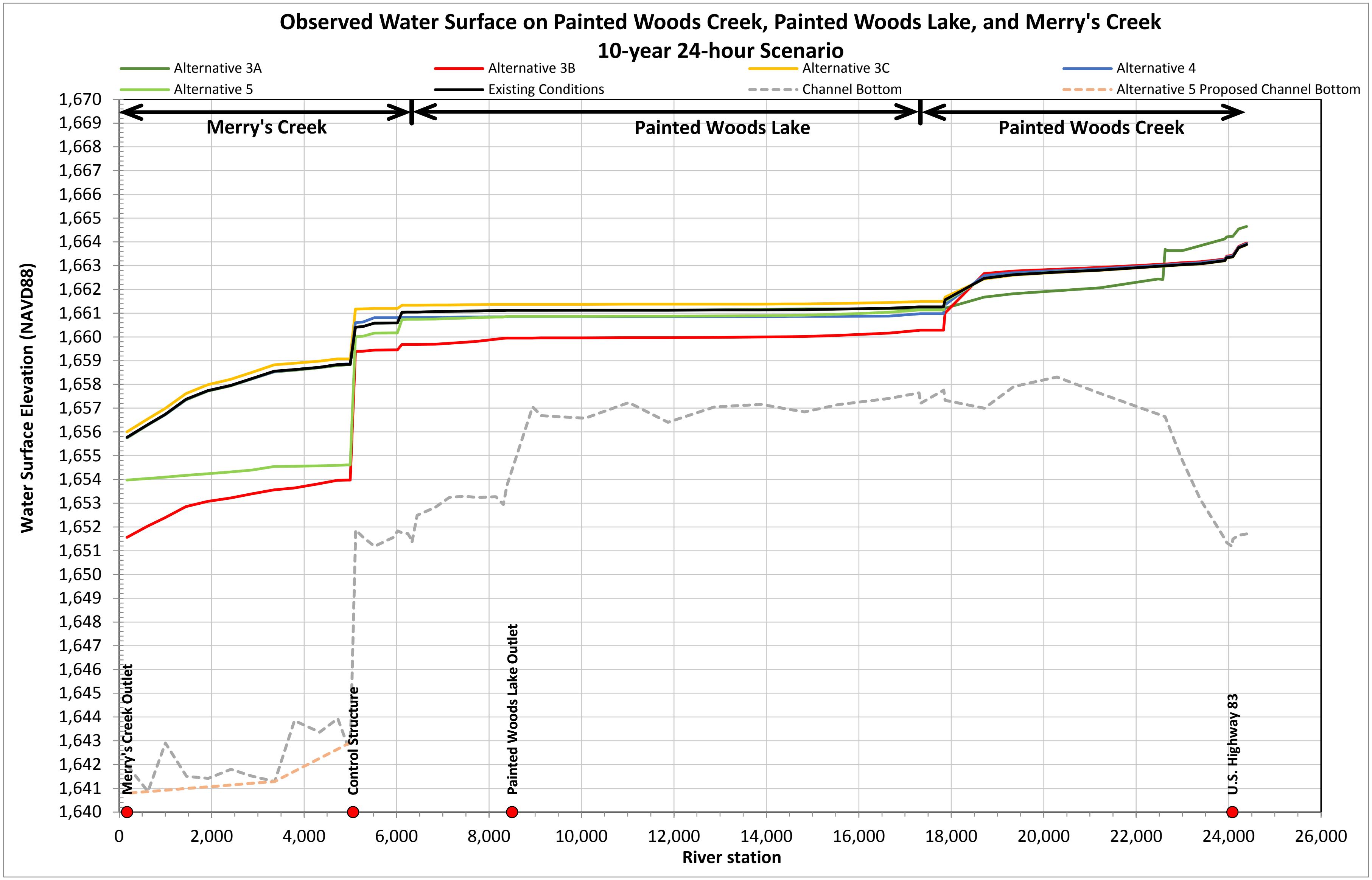


Figure 25 - 10-year 24-hour Scenario Water Surface Profile Plot

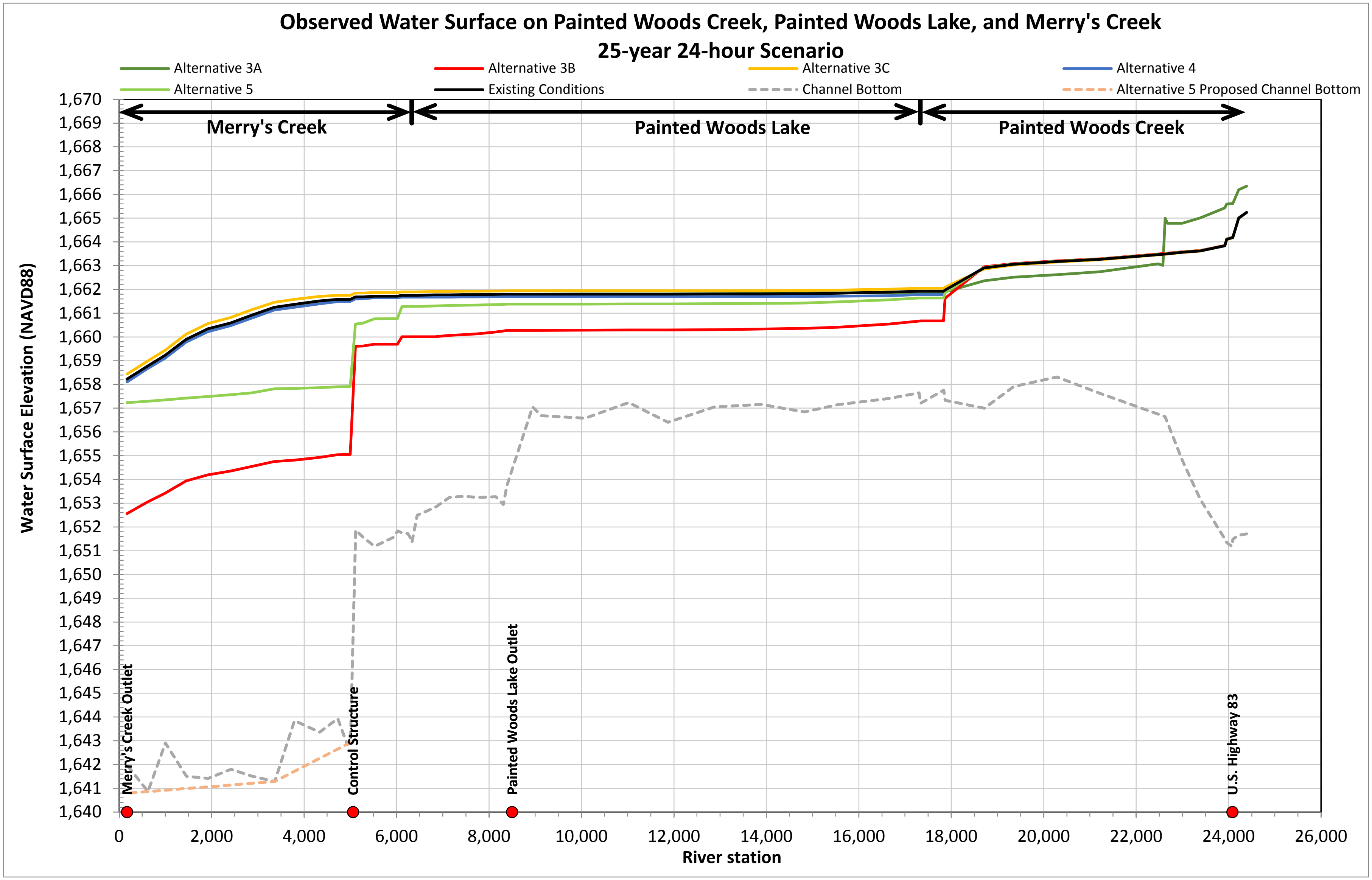


Figure 26 - 25-year 24-hour Scenario Water Surface Profile Plot

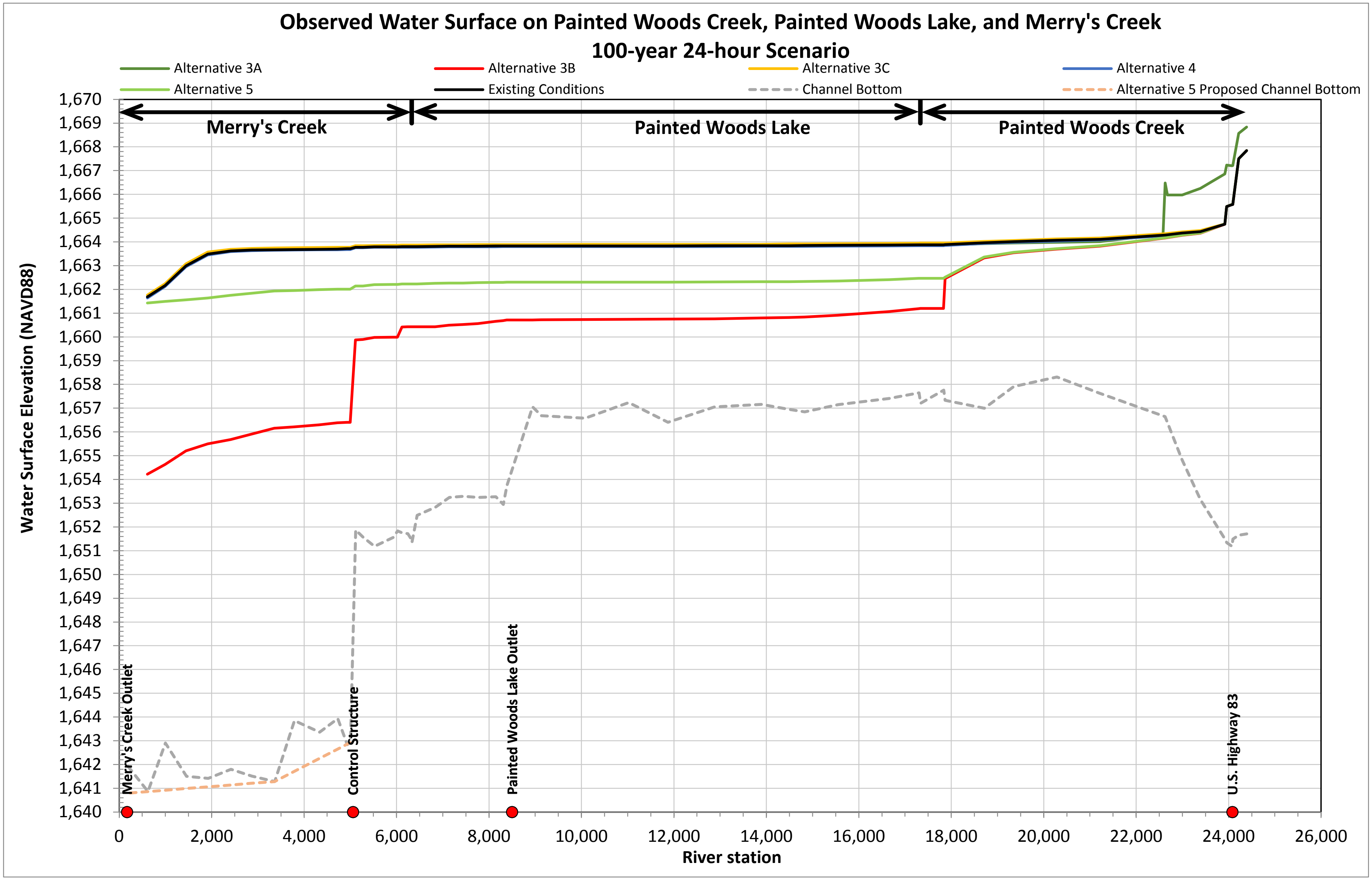


Figure 27 - 100-year 24-hour Scenario Water Surface Profile Plot

3.5 Conclusions

Based on the results, Alternative 3B (shown on Figures 3 and 4) and Alternative 5 provide significant benefits compared to the other alternatives. Alternative 3B provides as much as 2.6 feet stage reduction for the 2-year 24-hour scenario, 5 feet for the 10-year 24-hour scenario, 6.6 feet for the 25-year 24-hour scenario, and 8 feet for the 100-year 24-hour scenario, with the significant stage reductions located downstream of the control structure on Merry's Creek. In the Painted Woods Lake area, Alternative 3B provides stage reductions of about 0.4 feet for the 2-year 24-hour scenario, 1.2 feet for the 10-year 24-hour scenario, 1.5 feet for the 25-year 24-hour scenario, and 3.1 feet for the 100-year 24-hour scenario.

Alternative 5 provides significant stage reductions downstream of the control structure with 4 to 5 feet stage reduction for the 2-year 24-hour scenario, 2 to 4.5 feet for the 10-year 24-hour scenario, 1 to 3.5 feet for the 25-year 24-hour scenario, and just under 2 feet for the 100-year 24-hour scenario. There is minor stage reductions upstream of the control structure with a 0.3 foot stage reduction for the 10-year 24-hour scenario, 0.4 feet for the 25-year 24-hour scenario, and 1.5 feet for the 100-year 24-hour scenario. The 2-year 24-hour scenario provides no stage reductions upstream of the control structure. The stage reductions spread farther upstream the larger the scenario with the stage reductions spanning all the way to U.S. Highway 83 for the 100-year 24-hour scenario. On the Fahlgren Overflow area to the north of Painted Woods Lake, there are minimal stage reductions for the 2 and 10-year 24-hour scenario. The 25-year 24-hour scenario provides stage reductions of 0.9 feet and the 100-year 24-hour scenario provides 1.8 feet stage reduction. Figure 28 shows the location of Alternative 5.

Alternative 3B and Alternative 5 both provide more significant benefits on Merry's Creek compared to the other alternatives. For the 2-year 24-hour scenario, Alternative 5 provides more stage reduction than Alternative 3B. However, Alternative 3B provides more benefits on Painted Woods Lake and Painted Woods Creek compared to Alternative 5. Alternative 3B also provides far more benefits to the Fahlgrens Overflow area compared to Alternative 5 for all synthetic scenarios. Stage reductions on Fahlgrens Overflow are 5 to 7 feet lower for Alternative 3B compared to Alternative 5. Table 7 shows the range of stage reductions on Merry's Creek, Painted Woods Lake, and the Fahlgren Overflow area for Alternatives 3B and 5. See Figures 14 and 17 for the inundation maps for alternatives 3B and 5, respectively. Both Alternatives 3B and 5 show significant benefits to the area on the south side of Merry's Creek downstream of the control structure with Alternative 3B showing no flooding on the south side of Merry's Creek during the 25-year 24-hour scenario. However, there is significant inundation to the north of Merry's Creek downstream of the control structure for Alternatives 3B and 5 during the 25-year 24-hour scenario, but noticeably less compared to existing conditions, especially for Alternative 3B. Alternative 3B shows a significant benefit in the Fahlgran overflow area, but there is very little benefit from Alternative 5.

Alternative 3A, shown on Figures 3 and 4, only has a maximum stage reduction of slightly over one foot for the 2-year 24-hour scenario, 0.5 to one foot for the 10 and 25-year 24-hour scenarios, and almost no stage reduction for the 100-year 24-hour scenario. However, Alternative 3A also has stage impacts upstream just downstream of U.S. Highway 83 ranging from 1 foot for the 10-year 24-hour scenario to 2 feet for the 100-year 24-hour scenario. There are no impacts for the 2-year 24-hour event from Alternative 3A.

Alternative 4 provides a slight stage reduction that is only seen on Painted Woods Lake. Stage reduction is generally less than 0.5 foot for the smaller scenarios, approximately a 0.1 foot benefit for the 25-year 24-hour scenario, and almost no benefit for the 100-year 24-hour scenario.

Table 7 - Maximum Stage Reductions for Alternatives 3B and 5

Maximum Stage Reduction (ft)					
Alternative	Location	Synthetic Scenario			
		2-yr 24-hr	10-yr 24-hr	25-yr 24-hr	100-yr 24-hr
3B	Merry's Creek	2.6	5.0	6.6	8.0
	Painted Woods Lake	0.4	1.2	1.5	3.1
	Fahlgren Oveflow	7.3	7.0	7.1	6.8
5	Merry's Creek	5.3	4.2	3.7	1.9
	Painted Woods Lake	0.0	0.3	0.4	1.5
	Fahlgren Oveflow	0.0	0.2	0.9	1.8

There was no stage reductions on Painted Woods Creek, Painted Woods Lake, or Merry's Creek from Alternative 3C. Impacts are seen from Alternative 3C throughout Painted Woods Lake and Merry's Creek. Impacts are 1 foot for the 2-year 24-hour scenario, 0.5 feet for the 10-year 24-hour scenario, less than 0.2 feet for the 25-year 24-hour scenario, and minimal impact for the 100-year 24-hour scenario. One benefit from Alternative 3C is that it would provide greater depth of water for normal conditions, which would likely help to reduce the cattail growth.

Stated earlier in section 3.4.6, there is an issue with breakout flow to the north and south of the control structure, especially for 24-hour scenarios of 10 years and larger. Alternative 3B reduces the breakout to the north of the control structure and eliminates breakout to the south side of the control structure. Alternative 5 is not as effective in reducing the breakout flow around the control structure. Additional measures are needed to prevent flow from bypassing the structure. With the amount of flow bypassing the structure, there is a potential for erosion and head cutting around the control structure.

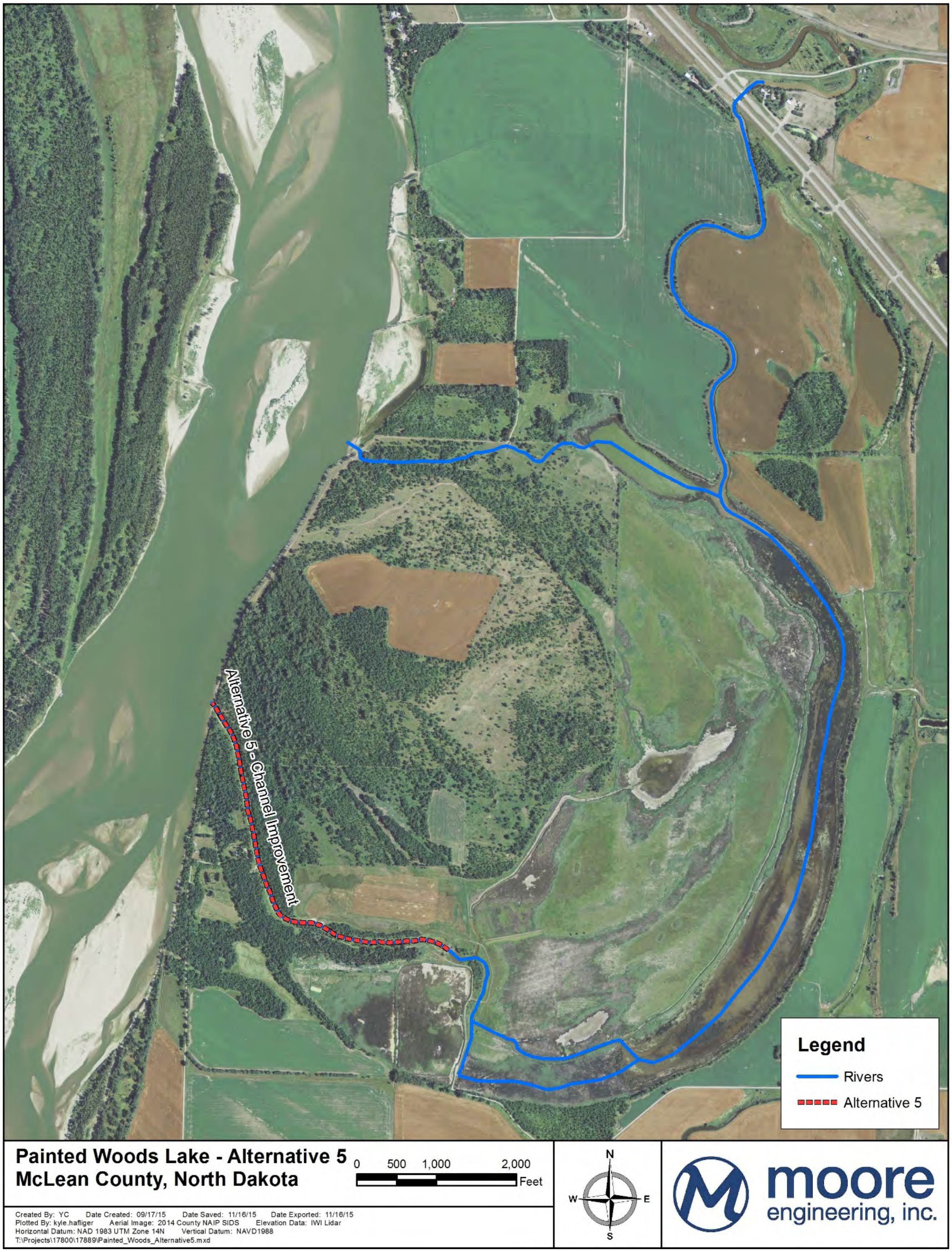


Figure 28 - Painted Woods Lake Alternative 5

References

[1] North Dakota State Water Commission, "Painted Woods Lake Flood Control Project, McLean County, North Dakota - SWC Project No. 160," Bismarck, ND, 1983.

[2] North Dakota State Water Commission, "Supplement Preliminary Engineering Report - Painted Woods Lake Flood Control Project, McLean County, North Dakota - SWC Project No. 160," Bismarck, ND, 1984.

[3] National Arricultural Statistics Service, "CropScape - Cropland Data Layer," United States Depertment of Agriculture, 2014. [Online]. Available: http://nassgeodata.gmu.edu/CropScape/.

[4] University of Louisiana at Lafayette, "Hydroviz," 2010. [Online]. Available: http://www.hydroviz.org/HYDRO/11_curve_nymber.html.

[5] A. Fisk and R. A. Moum, Hyrdology manual for North Dakota, Bismarck, North Dakota: U.S. Department of Agriculture Soil Conservation Service.

[6] Houston Engineering Inc. et. al., "Fargo-Moorhead Metro Basin-Wide Modeling Approach Hydrologic Modeling, HEC-HMS Model Development Various Tributaries above the Red River of the North at Halstad, MN," Fargo, ND, 2011.

[7] State of Colorado Office of the State Engineer Dam Safety Branch, "Hydrologic Basin Response - Parameter Estimation Guidelines," Tierra Grande International, Inc., Scottsdale, AZ, 2008.

[8] T. Williams-Sether, "Report 92-4020 - Techniques for Estimating Peak-Flow Frequency Relations for North Dakota Streams," North Dakota Department of Transportation; North Dakota Department of Transportation, Bismarck, ND, 1992.

[9] G. W. Brunner, "Combined 1D and 2D Modeling with HEC-RAS," Hydrologic Engineering Center, 2014.