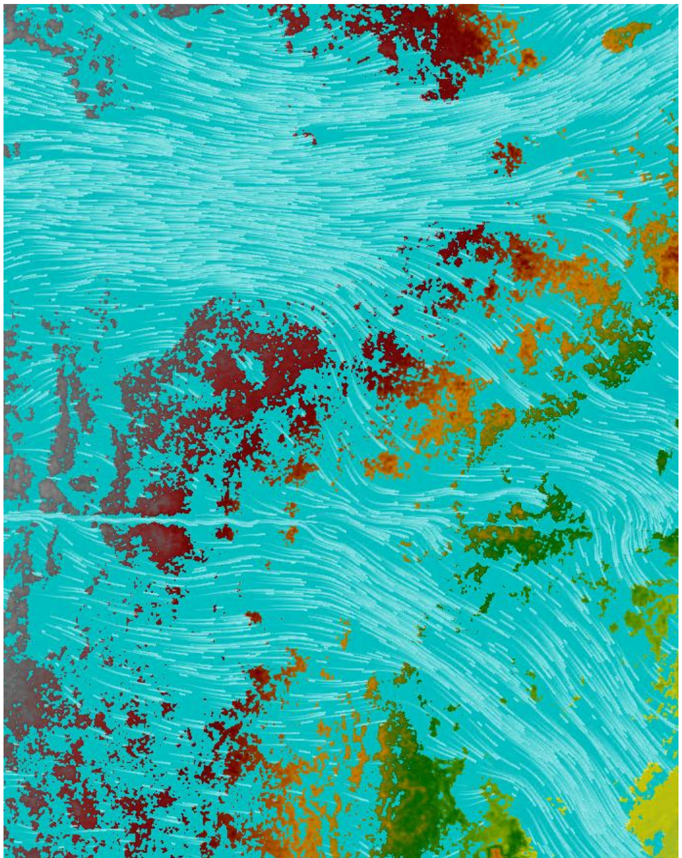

Winter Road Peatland Area

Restoration Modeling Report

Lake of the Woods County and Roseau County, MN

August 29, 2025

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1 Introduction

The Winter Road Lake Peatlands Scientific and Natural Area (SNA) is located about 7 miles south of Roosevelt, MN, and span both Roseau and Lake of the Woods Counties. This land is divided into parcels managed by federal, state, and tribal entities for habitat conservation and forestry. Three distinct ditch systems (Judicial Ditch 23, Judicial Ditch 62, County Ditch 10) were designed and constructed in the early 1900s as part of a larger statewide effort to drain forests and wetlands to promote agricultural production and settlement. These ditch systems were generally unsuccessful at converting wetlands into fertile agricultural land. Today, much of the region is owned/administered by public agencies and the Red Lake Nation. The ditch systems are administered by 2 drainage authorities (Roseau County, Lake of the Woods County).

The purpose of this analysis is to assess the feasibility of restoring pre-development hydrology at the 6 targeted reaches identified by the Lake of the Woods Soil and Water Conservation District (SWCD) and the Minnesota Department of Natural Resources (DNR). Six ditch reaches within the mentioned ditch systems were selected due to their lack of adjoining private parcels, existing data collection, and location within the headwaters or two major watersheds. Drainage design records for the 6 existing ditches were provided by the ditch authorities and utilized to model existing conditions. These six ditches, shown in Figure 1, are evaluated hydraulically in this report. The assessment includes modeling of current and future event scenarios within the target reaches, where the existing conditions are compared to a proposed condition where the ditches are filled in. The hydraulic analysis was completed using U.S. Army Corps of Engineer’s Hydrologic Engineering Center River Analysis System (HEC-RAS) Version 6.6.

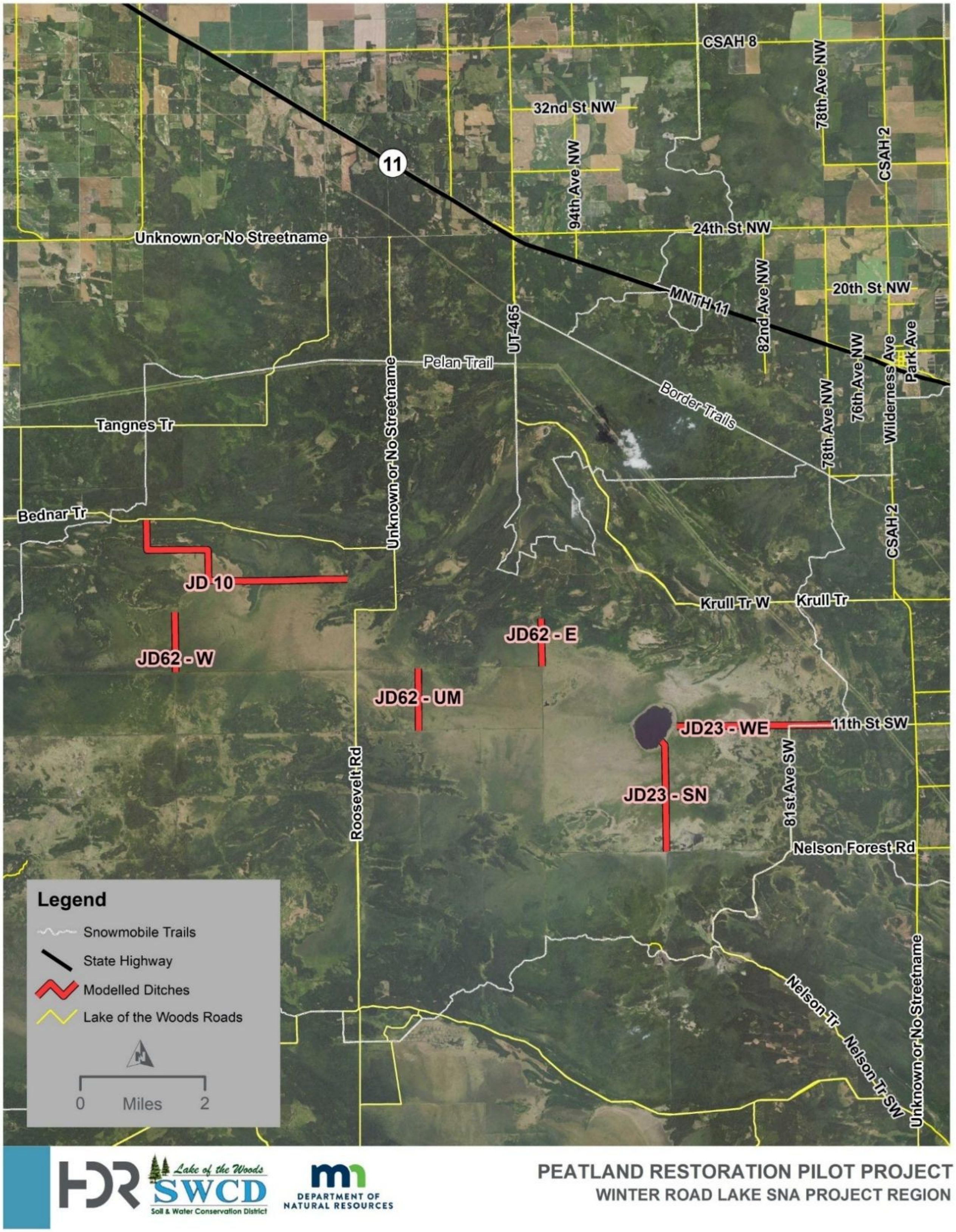


Figure 1. Winter Road Lake Peatland SNA – Site Map

2 Background

The following subsections provide an overview of historical conditions, drainage patterns, and hydrology to contextualize the site. This background information informed modeling decisions described in Section 3 of this report.

2.1 Site Drainage

In the early 1900's the project area was drained as part of a statewide initiative to improve agricultural production and promote settlement. Legal drains within the project area were initiated by court order (Judicial Ditches) or petitioned to or by the county (County Ditch). Ditch alignments were focused along section boundaries and typically terminate at existing waterbodies, streams or lakes.

Within the project area the subject ditches were dredged to a standard dimension determined by an engineer, ditches were excavated by a floating or walking dredge, and the spoil was cast to one side of the ditch. These spoil piles were sometimes leveled and graded to provide access to lands that were drained. The combination of the excavated channel and the adjacent spoil disrupted surface water and shallow groundwater connections which resulted in alterations to vegetative communities along the ditch corridors and resulted in increased downstream discharges. The alteration to hydrology was intentional for the benefit of promoting agricultural production, while evident that hydrology had been altered it was not sufficient to sustain agriculture within the project area, and as a result the lands were either retained or forfeited to the current entities which manage the landscape.

The following images in Figure 2- Figure 9 are publicly available at the MNDNR Landview websites. These images illustrate the effects of drainage post-construction, human alterations to the landscape, and vegetative patterns which illustrate natural flow directions.

Figure 2. Site 1 (JD 10) Aerial Photograph from 1940

Site #1 (JD 10) 1940 aerial photograph courtesy of MNDNR Landview website. Note the string and flark pattern around the sand ridge and evidence of recent timber harvest adjacent the ditch corridor.

Figure 3. Site 1 (JD 10) Aerial Photograph from 1966

Site #1 (JD 10) 1966 aerial photograph courtesy of MNDNR Landview website. Note the string and flark pattern around the sand ridge is more pronounced compared to 1940 imagery and lack of evidence of recent timber harvest adjacent the ditch corridor.

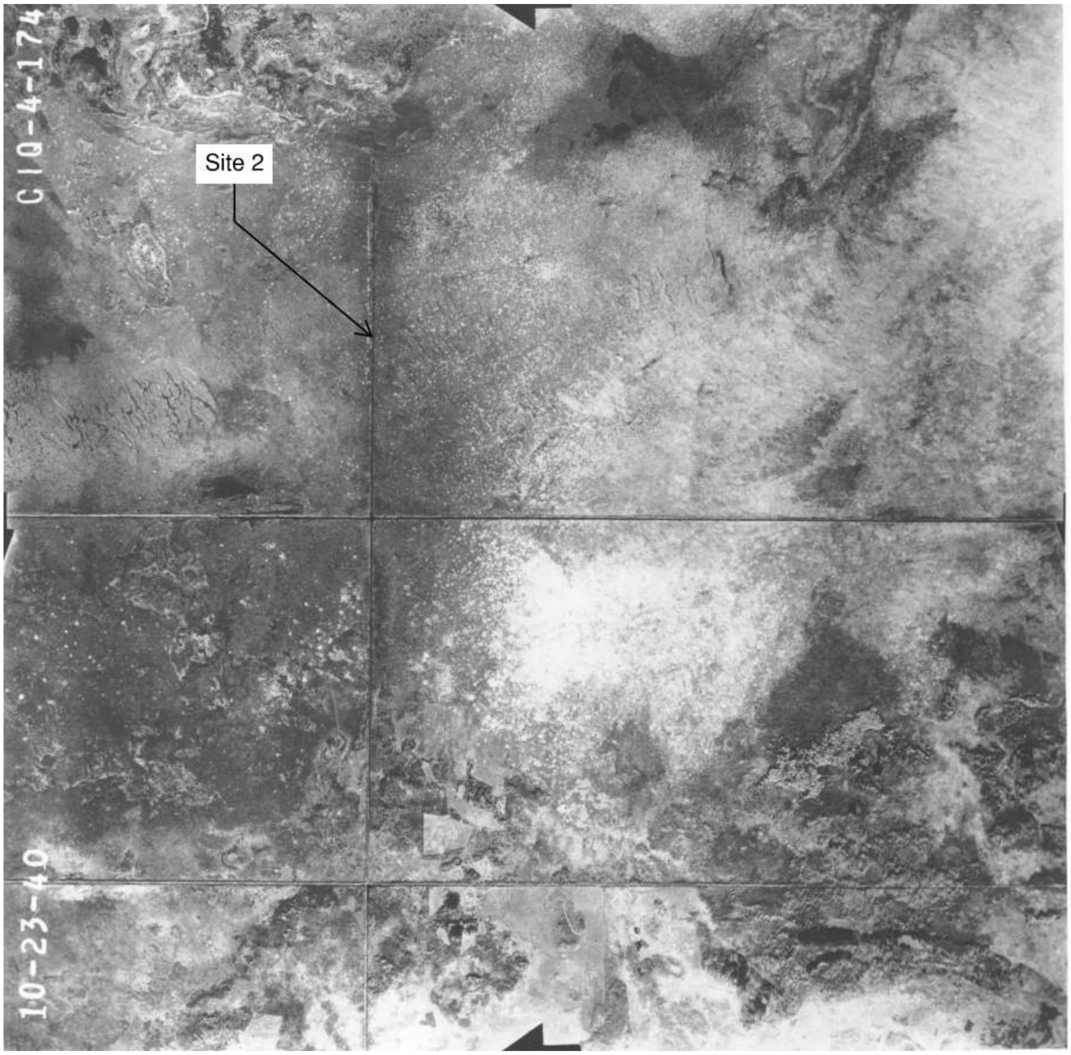


Figure 4. Site 2 (JD62 - W) Aerial Photograph from 1940

Site #2 (JD62 - W) 1940 aerial photograph courtesy of MNDNR Landview website. Note the string and flark pattern extending west to east across the ditch corridor. Vegetation appears to be modified in proximity to the ditch, this is likely due to altered hydrology.

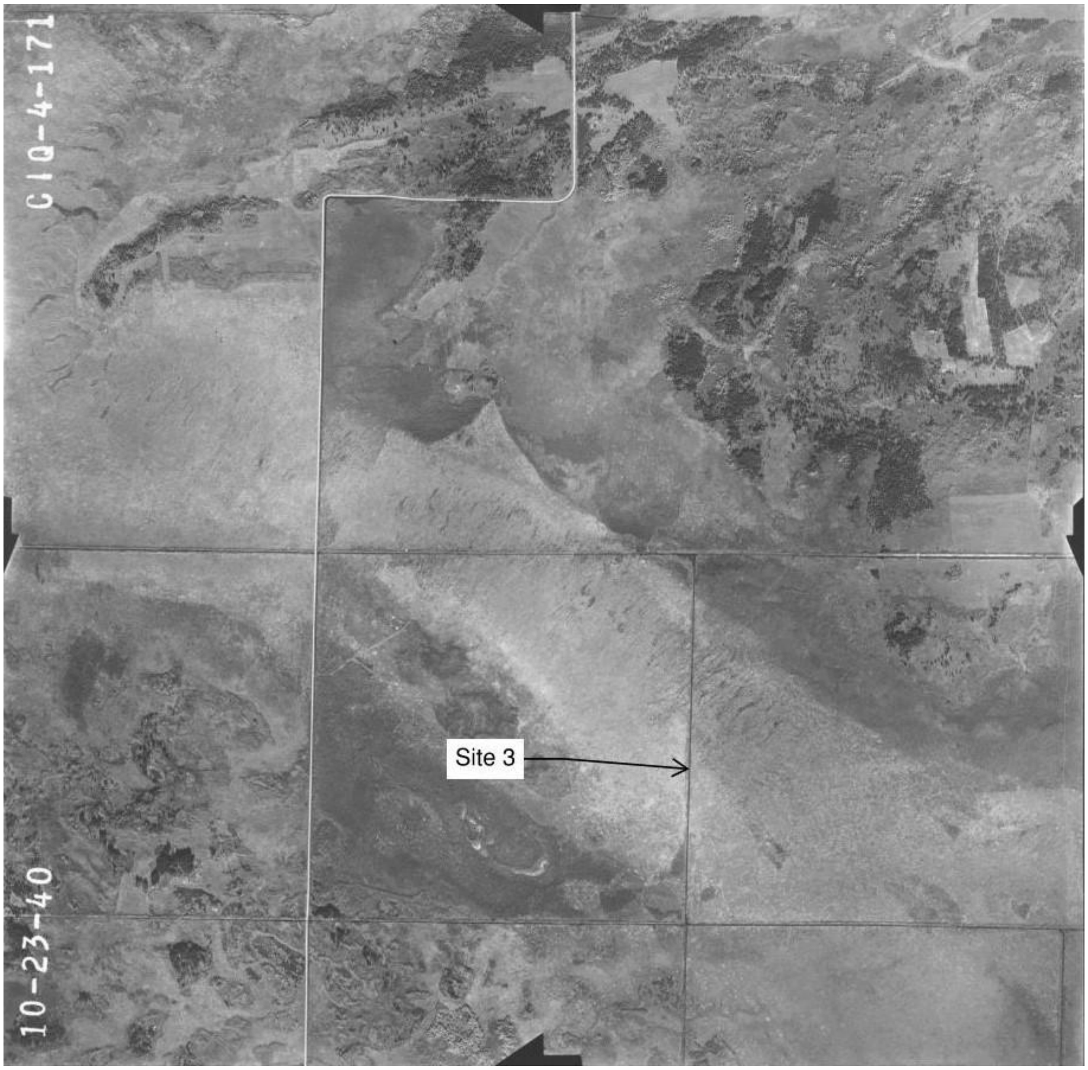


Figure 5. Site 3 (JD62 - UM) Aerial Photograph from 1940

Site #3 (JD62 - UM) 1940 aerial photograph courtesy of MNDNR Landview website. Note the string and flark pattern extending southeast to northwest across the ditch corridor.

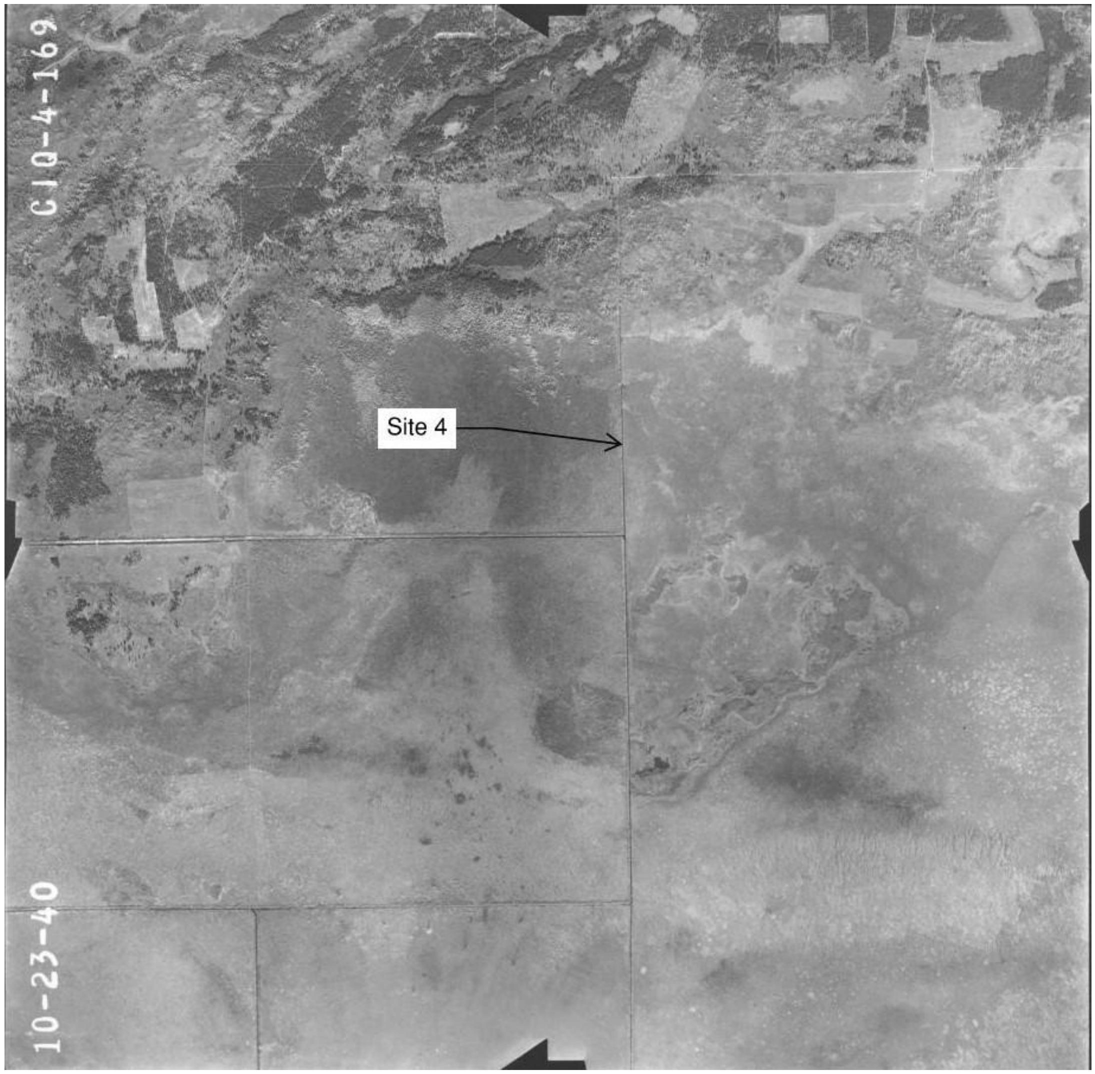


Figure 6. Site 4 (JD62 - E) Aerial Photograph from 1940

Site #4 (JD62 - E) 1940 aerial photograph courtesy of MNDNR Landview website. Vegetation appears to be modified in proximity to the ditch primarily in the southern limits near the confluence with JD 61 Lateral 1.

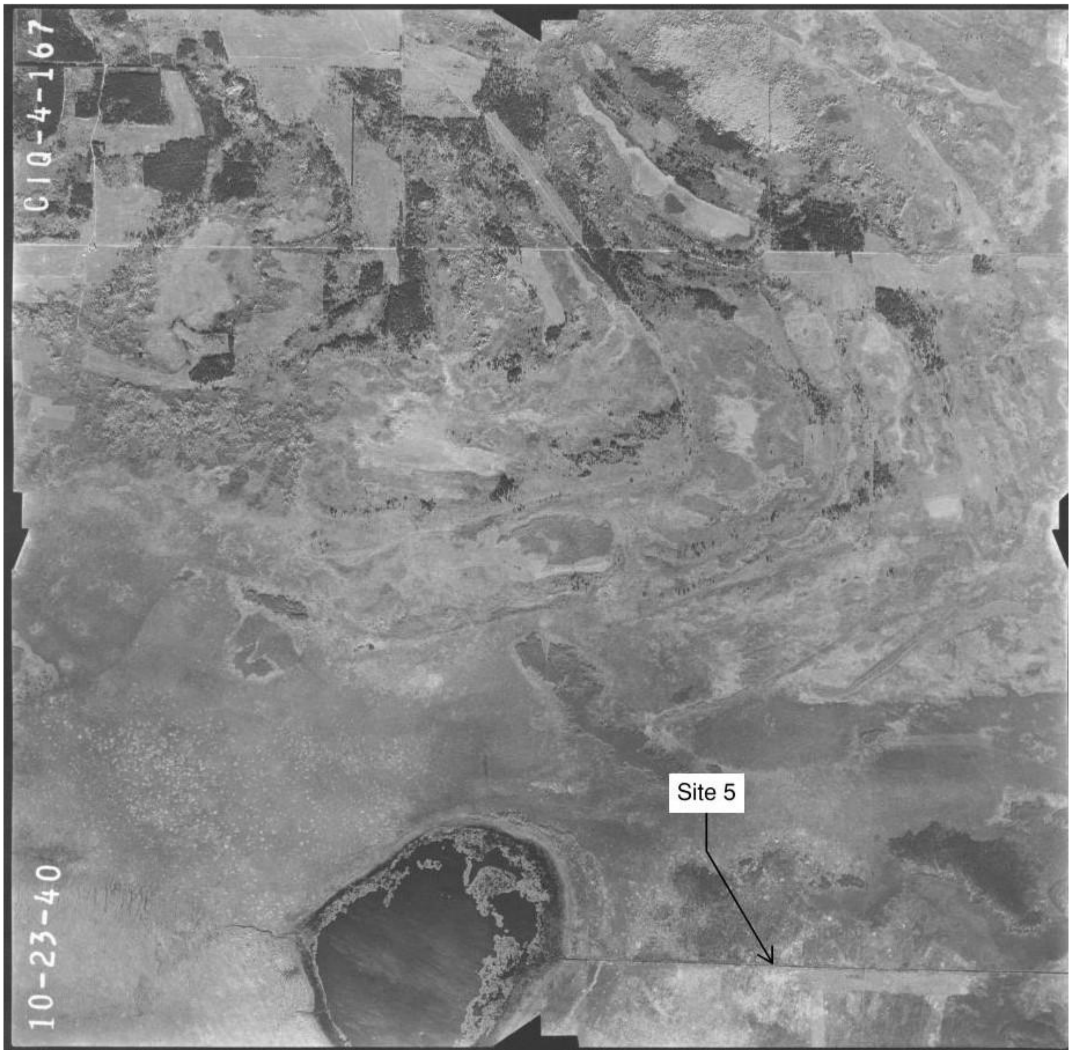


Figure 7. Site 5 (JD23 - WE) Aerial Photograph from 1940

Site #5 (JD23 - WE) 1940 aerial photograph courtesy of MNDNR Landview website, image captures the west half of the site. Evidence of recent timber harvest south of the ditch corridor.

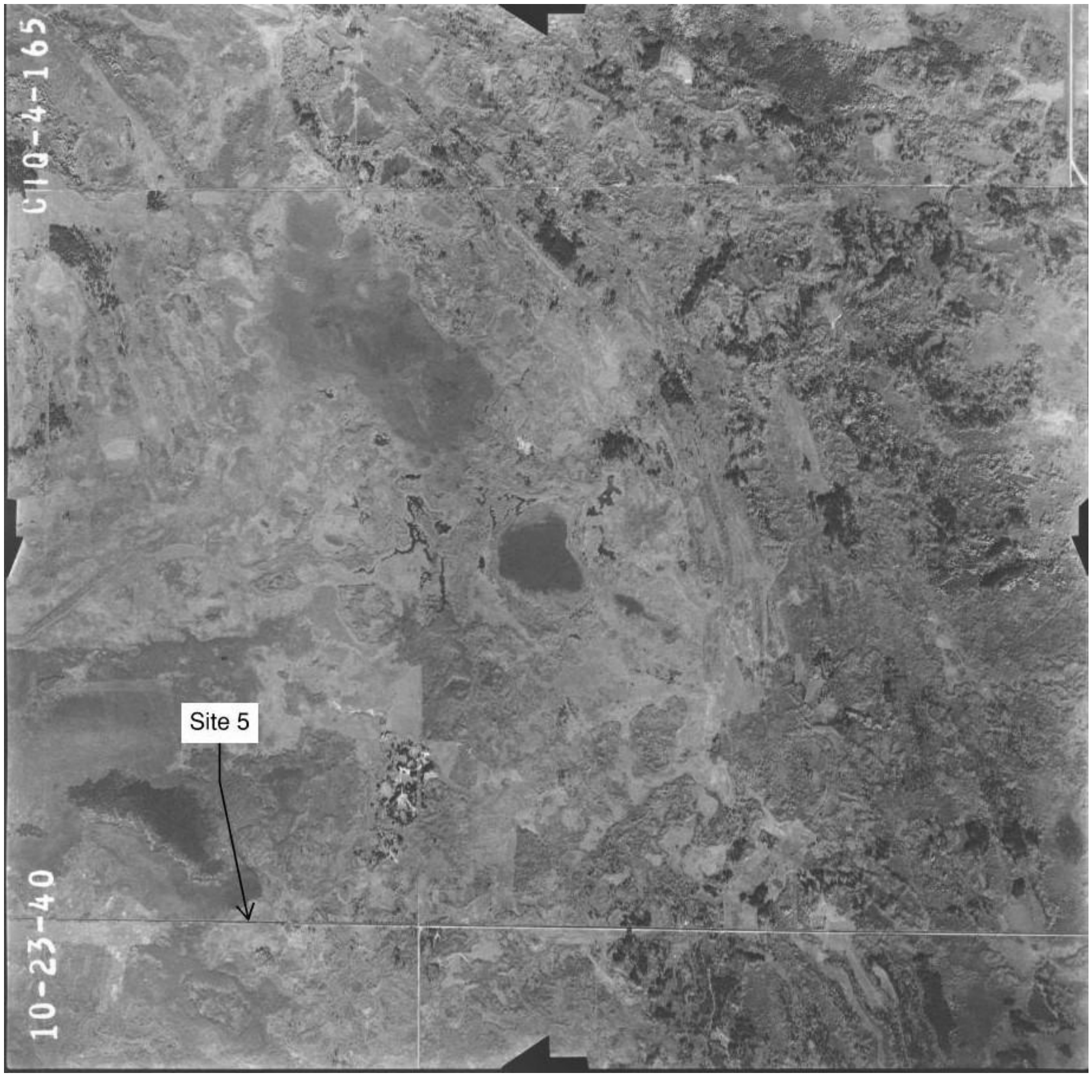


Figure 8. Site 5 (JD23 - SN) Aerial Photograph from 1940

Site #5 (JD23 - SN) 1940 aerial photograph courtesy of MNDNR Landview website, image captures the east half of the site. No noticeable vegetation impact on this plate, spoil berm appears more intact that recent imagery and was likely more accessible for human access.

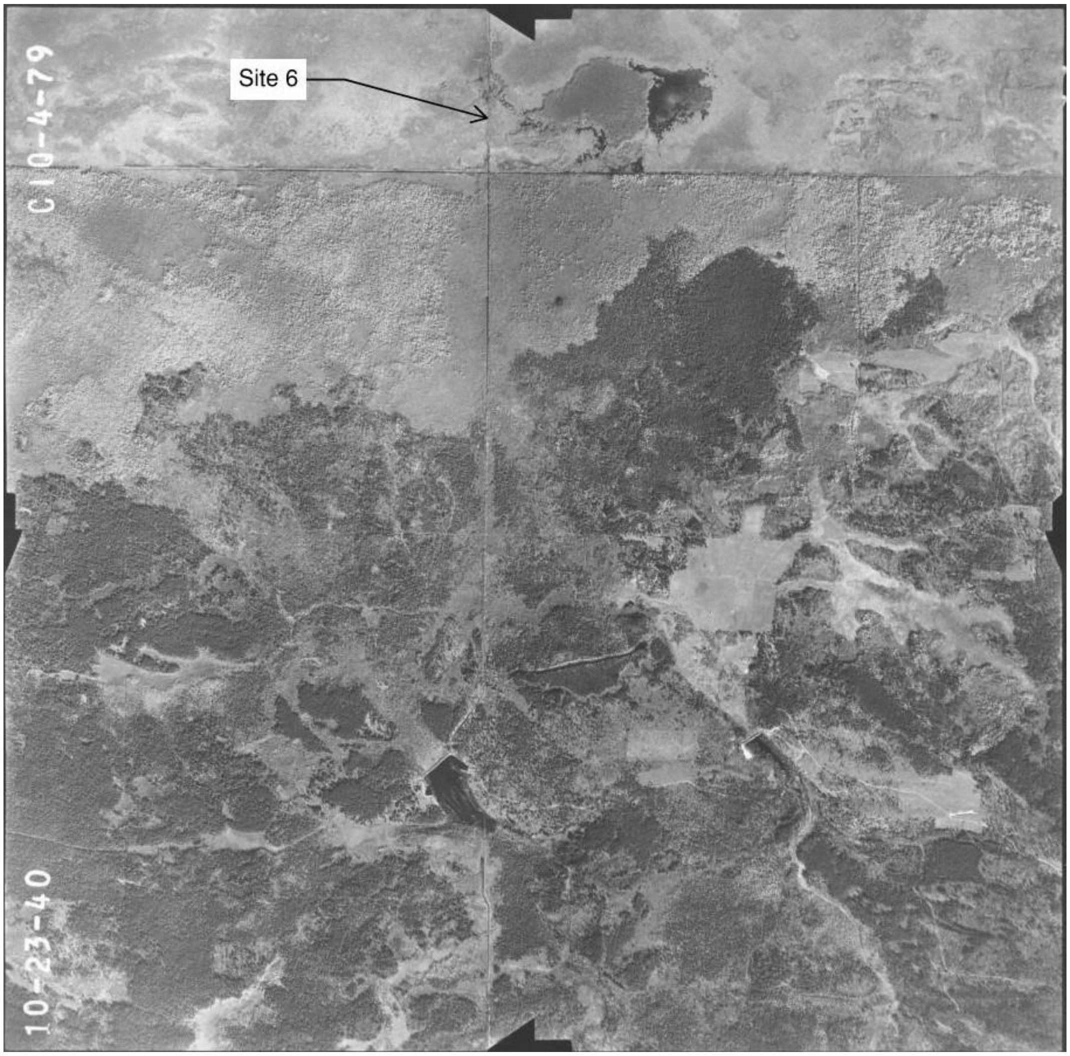


Figure 9. Site 6 (JD23 – SN) Aerial Photograph from 1940

Site #6 (JD23 - SN) 1940 aerial photograph courtesy of MNDNR Landview website. 1940 imagery only captured the southern limits of this site. The ditch appears to be partially filled in prior to the 1940 photo collection.

2.2 Site Hydrology

Hydrology at the sites is characterized by surface water inputs from precipitation and contributions from shallow groundwater. Groundwater contributions are evident within the site due to the vegetative communities and their patterns, prior site monitoring conducted by MNDNR, and the geologic and landform position of the site. The overall contribution of groundwater to the total water budget of the region is difficult to quantify and outside the scope of the modeling performed for this assessment.

Review of historical precipitation data illustrates that average annual rainfall is 23.34" during the period of record which has increased to 26.40" in the last 30-year period average. Average precipitation during the growing season has been documented as 17.89" in the last 30-year period, an increase from 15.87" average warm season rainfall throughout the period of record. Climatological trends from the latest 30 year rolling average indicate that "normal conditions" would consist of 2.05" or 13% increase in annual rainfall and 2.02” or 12.7% increase in growing season rainfall when compared to the period of record.

3 Modeling Approach

HDR Engineering, Inc. (HDR) used HEC-RAS version 6.6 to develop and apply a two-dimensional (2D) rain-on-grid model representing the rainfall-runoff response and maximum inundation extents for 2-, 5-, and 10-year return period precipitation events in the project area.

3.1 Precipitation

The 2-, 5-, and 10-year, 24-hour precipitation events were developed using NOAA Atlas-14 data for the project area.

Table 1 lists the precipitation-duration-frequency data extracted from NOAA Atlas-14 using the coordinates at the centroid of the model domain. A balanced (nested) temporal distribution was used to apply the precipitation-duration-frequency data to hyetographs for each event. The nested storm pattern is intended to capture the critical durations at all increments less than the full 24-hour event, by replicating the NOAA Atlas 14 precipitation depths at each shorter-duration interval. The resulting precipitation hyetographs for each event, shown in Figure 10-12, were applied uniformly across the model domain in their respective simulations.

Atlas 14 Point Precipitation Frequency Estimates (Inches)			
Duration	Average Recurrence Interval (year)		
	2	5	10
5-min	0.377	0.478	0.565
10-min	0.552	0.699	0.828
15-min	0.673	0.853	1.01
30-min	0.899	1.14	1.35
60-min	1.15	1.45	1.7
2-hr	1.39	1.75	2.06
3-hr	1.55	1.95	2.28
6-hr	1.82	2.26	2.64
12-hr	2.07	2.57	3.02
24-hr	2.34	2.91	3.46

Table 1. Precipitation-Duration-Frequency Data from NOAA Atlas-14

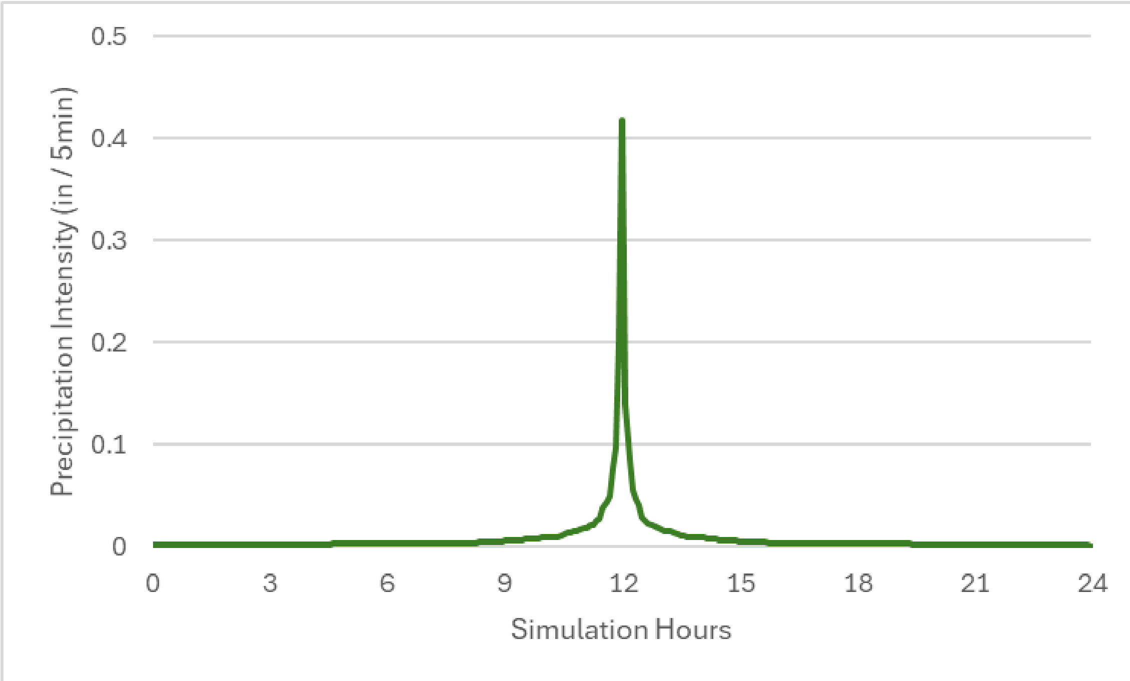


Figure 10. 2-Year Nested Precipitation Hyetograph developed from NOAA Atlas-14 Data

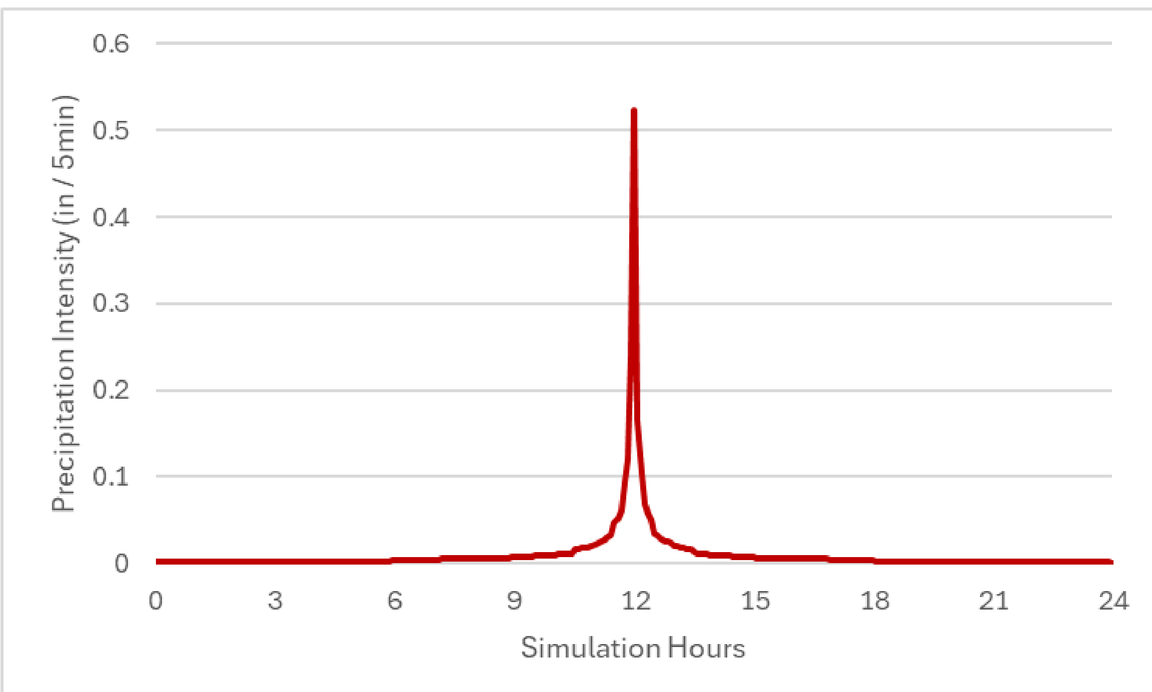


Figure 11. 5-Year Nested Precipitation Hyetograph developed from NOAA Atlas-14 Data

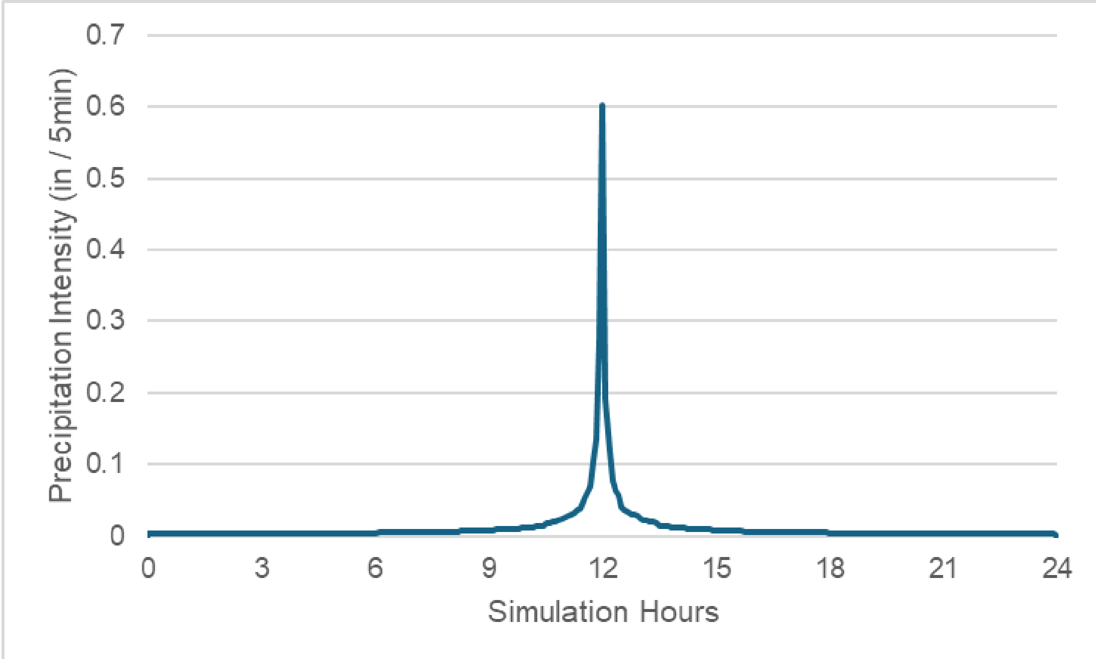


Figure 12. 10-Year Nested Precipitation Hyetograph developed from NOAA Atlas-14 Data

3.2 Modeling Approach

This section outlines the overall modeling framework, key assumptions, and data sources used to represent drainage conditions within the study area. The approach described below was selected to best capture the physical characteristics of the site and surface flow dynamics movement across the watershed.

Hydrology

Each ditch being analyzed has a contributing watershed, but under certain hydraulic conditions, water can flow overland between adjacent watersheds. Due to the interconnected nature of the ditches and contributing watersheds, a 2D surface water model was determined to be the most appropriate tool for simulating drainage patterns across the area. HDR used HEC-RAS version 6.6 for the 2D modeling. HEC-RAS version 6.6 includes industry leading 2D surface water modeling capabilities that are well suited for simulating complex unconfined floodplains. These capabilities are increasingly adopted across the national hydrologic and hydraulic modeling community.

While HEC-RAS offers robust 2D surface water modeling, its ability to simulate flow interactions between the subsurface and surface remains limited. Although subsurface flow does exchange with surface water, incorporating this interaction into an HEC-RAS model is difficult without extensive, spatially specific, data. Groundwater discharge and sinks can be represented through internal boundary conditions; but without reliable location-specific data, doing so introduces uncertainty. Given these limitations, the modeling approach selected was to use a 2D rain-on-grid method that allows HEC-RAS to perform hydrologic calculations. Subsurface flows contributing to surface water were not included in the model. Soils data were incorporated to apply potential percolation rates based on soil type. All simulated flows in the model will be a result of the initialization condition, precipitation over the model domain, and surface water losses from infiltration.

Model Extents

The model extents were determined by combining the contributing watersheds for each of the ditches being modeled. The model domain must match or exceed the contributing area in size for the rain-on-grid hydrology to capture rainfall across the entire contributing watershed and represent the timing and magnitude rainfall runoff response throughout the ditch system. The combined watershed was expanded slightly greater than the delineated watersheds to round out some hard corners in the delineation which can make for some error inducing cell shapes in the 2D mesh. Runoff in areas outside of the drainage area to the ditches but inside of the model domain is allowed to leave the model via external boundary conditions. Figure 13 shows the model domain extents.

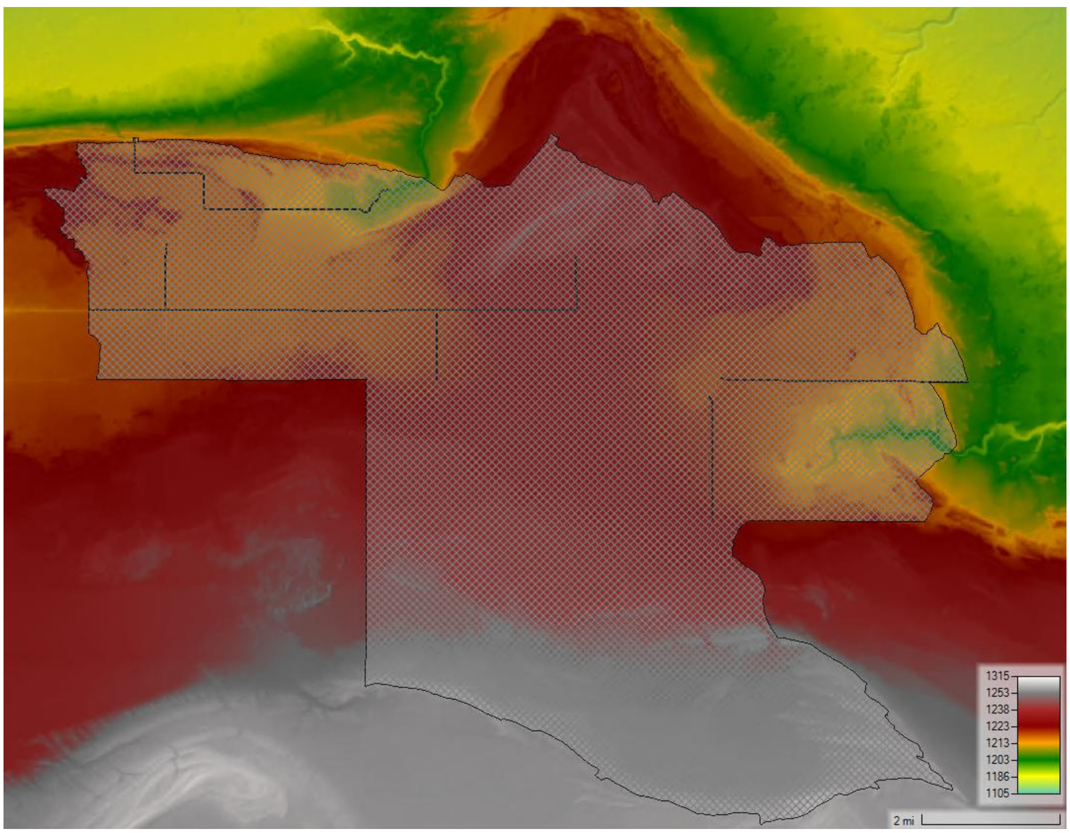


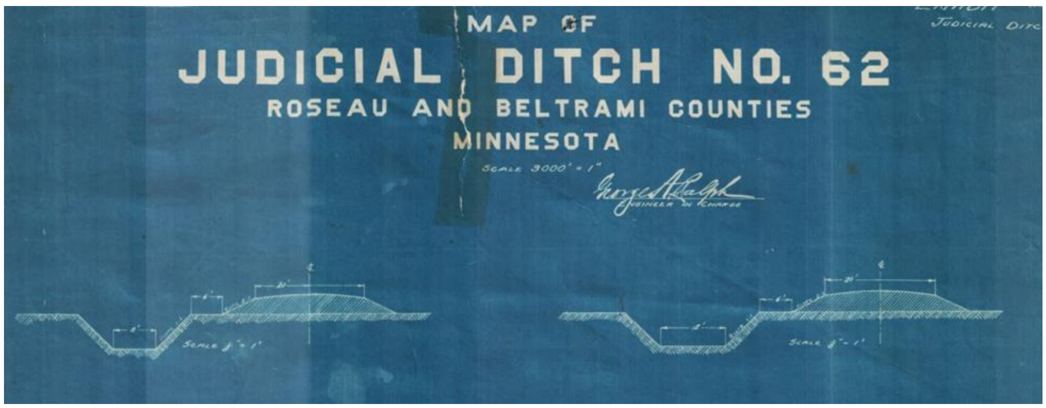
Figure 13. HEC-RAS Model Domain Extents

Terrain

A 2D rain-on-grid HEC-RAS model requires a terrain surface covering the full model extents. A Laser Airborne Survey (LAS) dataset provided by the Minnesota Department of Natural Resources (DNR) was processed and converted to a raster with one foot resolution by HDR. The LAS dataset covered most of, but not the entire, model domain. Additional LiDAR terrain data covering the missing area at the south end of the model domain, sourced from the United States Geological Survey (USGS) at 1-meter resolution, was mosaicked with the surface developed from the LAS dataset to create the base terrain.

LAS and LiDAR data typically do not represent the bathymetry of water bodies and channels well because the laser pulses used to collect data often fail to penetrate water surfaces and heavy vegetation. This can result in data gaps or ground surface elevation errors in those areas. To incorporate channel bathymetry, terrain modifications were made to the base surface along each modeled ditch in RAS Mapper. As-Builts from the original construction of the ditches, shown in Figure 14, were referenced to define the existing conditions cross-sectional geometry for each ditch. Table 2 lists the relevant geometry data for each ditch incorporated into the initial condition terrain.

JD62 Original Plan – Typical Section



CD10 Bednar Original Plan – Typical Section

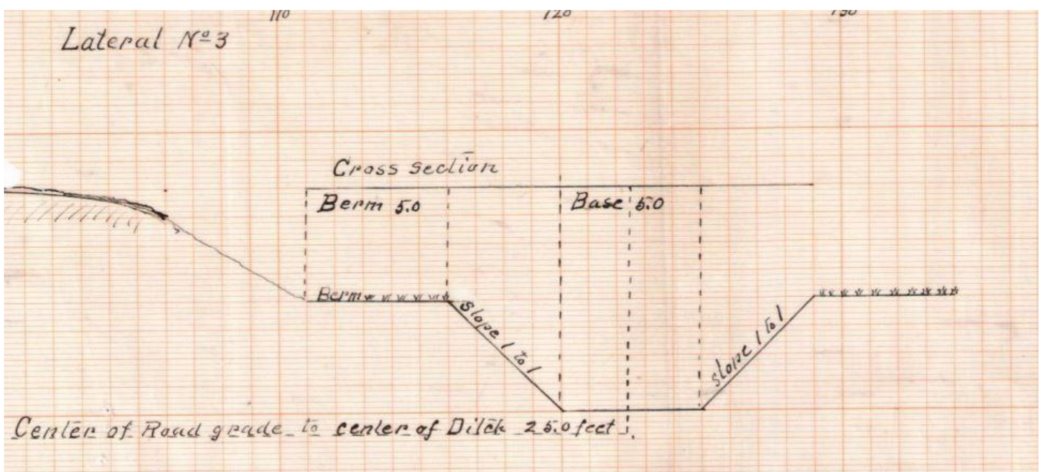


Figure 14. As-Built Typical Cross-Sections Applied in Terrain Modifications

Table 2. Summary of Cross-Sectional Geometry Data from As-Builts for Terrain Modifications

Ditch Site	Notes from As-Built Analysis	Applied Geometry
Site 1 – Ditch 10 Bednar (JD 10)	No depth recorded; 6 ft depth estimated based on nearby legal drains and reference reaches	5 ft bottom width 6 ft depth 1:1 side slopes
Site 2 – JD 62 West (JD62 - W)	Dimensions sourced directly from ditch records	6 ft bottom width 5 ft depth 1:1 side slopes
Site 3 – JD 62 Middle Reach (JD62 - UM)	Channel appears to be an undocumented extension of JD 62 Lateral 1; dimensions inferred from nearby records	6 ft bottom width 5 ft depth 1:1 side slopes
Site 4 – JD 62 East (JD62 - E)	Dimensions sourced directly from ditch records	6 ft bottom width 5 ft depth 1:1 side slopes
Site 5 – JD 23 East (JD23 - WE)	No cross section available; JD 62 geometry used as reference due to similar construction era and setting	6 ft bottom width 5 ft depth 1:1 side slopes
Site 6 – JD 23 South (JD23 - SN)	No cross section available; JD 62 geometry used as reference due to similar landscape and purpose	6 ft bottom width 5 ft depth 1:1 side slopes

The existing conditions of the ditches and surrounding land cover are highly variable, influenced by beaver activity, bank sloughing, vegetative debris, and storm-related damage. Given the irregular and dynamic nature of the flow regime across the systems, the ditches were modeled either as maintained to their original design or as absent from the landscape.

Modeling scenarios evaluated multiple runoff conditions, comparing discharge rates and peak flow timing between a maintained (as-designed) condition and a proposed condition in which the ditches are filled. In the proposed condition, the terrain reflects the existing topography, with terrain modifications to fill the ditch alignments.

Land Cover

The model includes a land cover layer that extends across the entire model domain. This layer is based on the 2021 National Land Cover Database (NLCD), with corresponding Manning's roughness coefficients shown in Table 3. NLCD-based roughness values along the six ditches were overridden with calibration regions to better represent surface roughness along the ditches, which influence water surface elevations and conveyance throughout the model domain. Calibration regions were added to each ditch and given a Mannings of 0.05, which is a representative roughness value for unmaintained excavated channels, lined with uncut weeds and brush, and a bank-full flow stage (Chow, 1959).

Table 3. Land Cover Manning's N Input Values

Classification Area	Manning's N
Woody Wetlands	0.02
Emergent Herbaceous Wetlands	0.1
Evergreen Forest	0.06
Developed, Open Space	0.05
Mixed Forest	0.1
Developed, Medium Intensity	0.03
Developed, Low Intensity	0.05
Shrub-Scrub	0.2
Deciduous Forest	0.1
Grassland-Herbaceous	0.2
Open Water	0.002
Pasture-Hay	0.07
Cultivated Crops	0.06
Developed, High Intensity	0.025

2D Mesh

The 2D Flow Area in the hydraulic model consists of 47,020 computational cells. The base cell size in the computational mesh is 250 feet. Breaklines were drawn along all analyzed ditches and other areas where flow is concentrated to align the mesh with flow paths. Along each ditch, the mesh was also refined to a 25-foot cell size to allow for more detailed hydraulic calculations and output. Breaklines were also used along major topographic ridges to align a cell face with the ridge, preventing artificial flow "leaking" across these elevated features. An example section of the 2D mesh is shown in Figure 15.

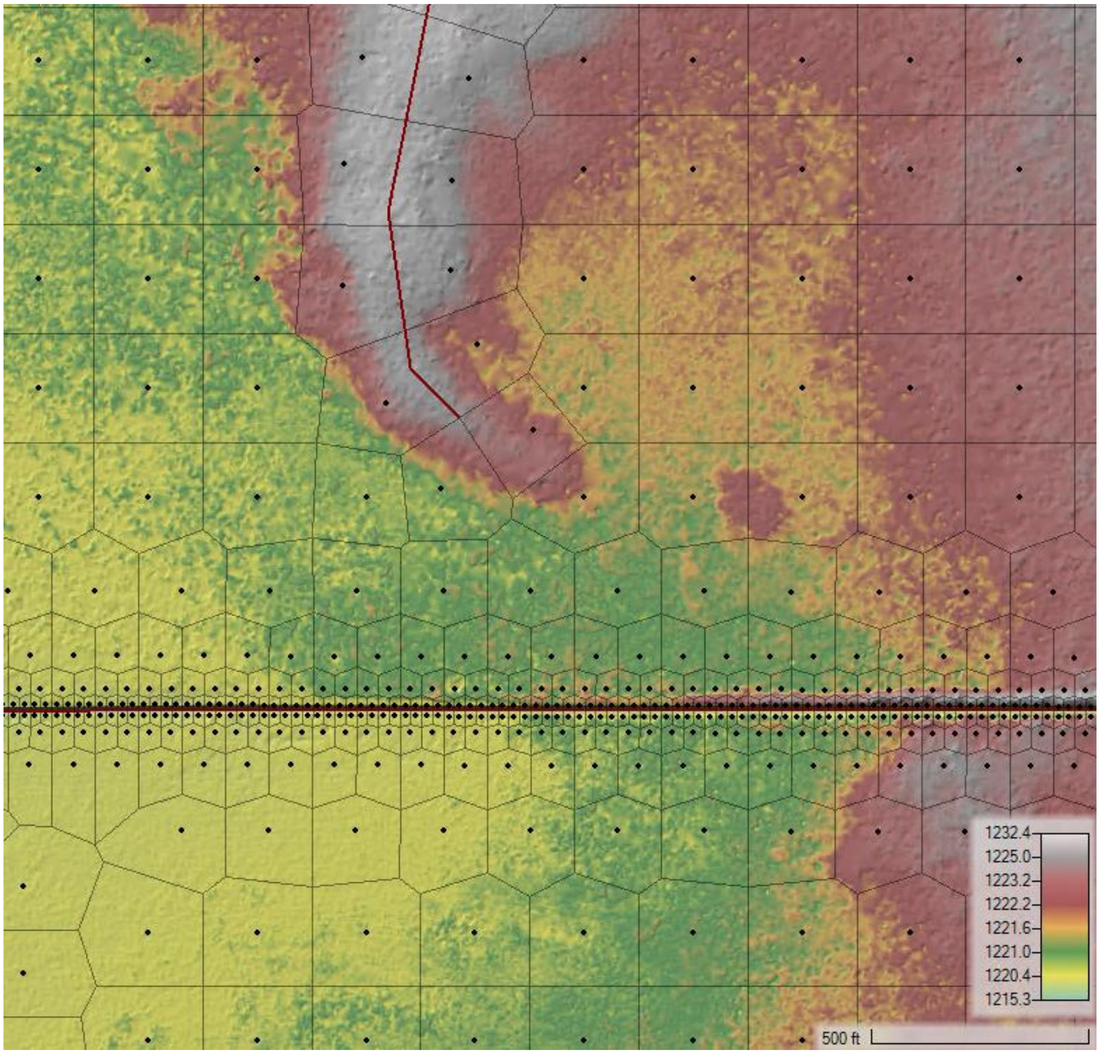


Figure 15. Example 2D Mesh Section

Boundary Conditions

Boundary conditions were created along the edge of the model domain at locations where flow was expected to leave the system. These outlets, shown as blue lines in Figure 16, include the Winter Road River, Warroad River West Branch, Warroad River East Branch, and at the east end of the domain near 11th Street. All boundary conditions are normal depth based and allow flow to exit the model freely. The energy grade line slope, which was assumed to match the ground surface slope, was measured and input to the model. At each boundary, the model used the local depth, roughness, velocity, and flow area to apply Manning's equation and compute the resulting outflow rate.

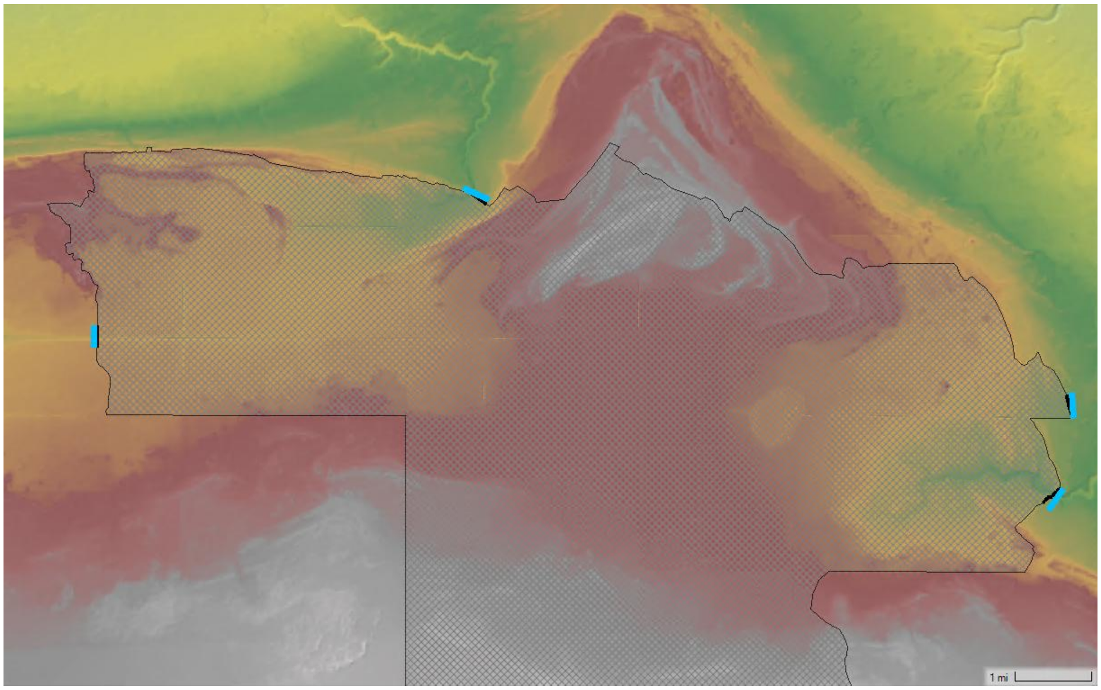


Figure 16. Boundary Condition Line Locations

Soils

A review of soils within the model domain was conducted using historic aerial imagery, soil borings from reference peatlands, and data from the USDA Web Soil Survey for Roseau and Lake of the Woods County. Soils across the site are predominantly organic, consisting of 0–40 inches of peat or mucky peat overlying poorly drained glaciolacustrine silty clays and clay loams. These soils are primarily classified as hydric, having formed under prolonged saturation that promotes anaerobic conditions. Field observations and the United States Department of Agriculture (USDA) Web Soil Survey data indicate widespread oxidation and decomposition of peat layers, with sparse pockets of less-decomposed relict plant material, likely preserved due to limited disturbance from tillage or fire.

A soils layer covering the entire model domain is required for a 2D rain-on-grid model. A spatially varied grid of soil physical properties was downloaded from the USDA Web Soil Survey for model application. Saturated hydraulic conductivity (Ksat) values were used to determine the percolation rates for soils throughout the model domain. Potential percolation rates by soil type in the model are listed in Table 4.

Table 4. Potential Percolation Rates

Soil Type	Potential Percolation Rate (in/hr)
Rifle-Rifle, ponded, complex, 0 to 1 percent slopes	13.04
Cormant loamy fine sand, 0 to 2 percent slopes	13.04
Hiwood loamy fine sand, 0 to 6 percent slopes	13.04
Leafriver muck	8.13
Markey muck, occasionally ponded, 0 to 1 percent slopes	3.97
Redby loamy fine sand, 0 to 3 percent slopes	13.04
Grygla loamy fine sand	11.48
Bullwinkle muck, 0 to 1 percent slopes	3.40
Clearriver loamy fine sand, 0 to 3 percent slopes	13.00
Northwood muck, wooded, 0 to 1 percent slopes	6.90
Meehan loamy sand, 0 to 3 percent slopes	13.04
Tawas muck	3.12
Leafriver muck, wooded, 0 to 1 percent slopes	8.76
Cormant-Redby complex, 0 to 2 percent slopes	13.04
Faunce loamy fine sand, 0 to 3 percent slopes	13.00
Grygla mucky loamy fine sand, depressional, 0 to 1 percent slopes	13.00
Lupton-Lupton, ponded, complex, 0 to 1 percent slopes	3.97
Wurtsmith loamy sand, map 22-30, 0 to 3 percent slopes	13.00
Berner muck, wooded, 0 to 1 percent slopes	4.72
Fluvaquents, frequently flooded-Hapludalfs complex, 0 to 60 percent slopes	10.62
Pits, gravel-Udipsamments complex, 1 to 50 percent slopes	0.00
Karlstad loamy sand, 0 to 3 percent slopes	8.88
Marquette loamy sand, 6 to 12 percent slopes	16.55
Cathro muck, occasionally ponded, 0 to 1 percent slopes	3.97
Seelyeville-Seelyeville, ponded, complex, 0 to 1 percent slopes	3.97
Markey muck, ponded	3.12
Epoufette sandy loam, 0 to 2 percent slopes	16.24
Eckvoll loamy fine sand	13.04
Sax, frequently ponded-Spooner complex, 0 to 1 percent slopes	2.73

Soil Type	Potential Percolation Rate (in/hr)
Littleswan silt loam, 0 to 3 percent slopes	0.72
Northwood muck	9.39
Spooner-Littleswan complex, 0 to 2 percent slopes	1.02
Water	0.00
Strandquist sandy loam	10.07
Menahga loamy sand, 1 to 8 percent slopes	13.04
Pelan sandy loam	11.55
Cathro muck, ponded	2.86
Bullwinkle-Cathro mucks	3.12
Enstrom loamy sand	13.04
Tacoosh muck	3.22
Chilgren fine sandy loam	1.63
Fordum fine sandy loam	1.93

Variable Peatland Saturation Conditions

The values in Table 4 (above) are only relevant for a “dry” condition scenario, as opposed to a saturated condition. To review, two wetness conditions were evaluated in this analysis: a “dry” condition where the channels are assumed to have little to no standing water and good soil infiltration potential, and a “saturated” condition where the channels are assumed to be close to bank full, with small ponding present in locally low areas of the surface, with no infiltration. When fully saturated, peatlands lack voids in the soil through which water can pass through (infiltrate).

These two wetness conditions were assigned to evaluate potential benefits or impacts during climate extremes, prolonged wet and prolonged dry cycles. These conditions were applied under existing and proposed ditch conditions for each AEP (2-, 5-, and 10-year events). All modeled combinations of ditch conditions, wetness conditions, and event return periods are summarized in Table 5.

Table 5. Summary of Existing and Proposed Conditions Simulations

Ditch Condition	Wetness Condition	Return Period
Existing	Dry	2-Year
Existing	Dry	5-Year
Existing	Dry	10-Year
Existing	Saturated	2-Year
Existing	Saturated	5-Year

Ditch Condition	Wetness Condition	Return Period
Existing	Saturated	10-Year
Proposed (filled)	Dry	2-Year
Proposed (filled)	Dry	5-Year
Proposed (filled)	Dry	10-Year
Proposed (filled)	Saturated	2-Year
Proposed (filled)	Saturated	5-Year
Proposed (filled)	Saturated	10-Year

4 Model Results

The four conditions described within Section 3 were modeled for the 6 selected ditches. Model results were evaluated by analyzing boundary condition lines and ditch locations. Boundary condition lines indicate the total conveyance out of the model and help to analyze how impactful the existing ditch system is during flooding response to 2-, 5- and 10-year precipitation events. Spatial results show how proposed changes impact flooding inundation for the same precipitation events in the ditches being analyzed.

4.1 Boundary Conditions

Table 6 relates which ditches convey flow to each boundary condition location.

Table 6. Contributing Ditches to Each Boundary Condition Location

Boundary Condition	Contributing Ditches
Winter Road River	County Ditch 23
Warroad River (West Branch)	Judicial Ditch 62
Warroad River (East Branch)	County Ditch 10
CSAH 2 Outlet	County Ditch 23

Tables 7-10 present the peak flow and peak stage results for existing and proposed conditions under both saturated and dry scenarios at each boundary condition line. Relative differences between peak flow and stage results indicate how conveyance is impacted between existing and proposed conditions for the contributing area to that boundary condition.

Table 7. Hydraulic Model Results at Winter Road River Boundary Condition

Simulation Conditions		Peak Stage (ft)	Peak Flow (cfs)
Dry, 2-Year	Existing	1198.61	0.57
	Proposed	1198.68	0.92
	Difference	**0.07**	**0.35**
Dry, 5-Year	Existing	1198.68	0.92
	Proposed	1198.77	1.59
	Difference	**0.09**	**0.67**
Dry, 10-Year	Existing	1198.75	1.43
	Proposed	1198.86	2.34
	Difference	**0.11**	**0.91**
Saturated, 2-Year	Existing	1204.51	634.51
	Proposed	1204.91	729.33
	Difference	**0.40**	**94.82**
Saturated, 5-Year	Existing	1205.75	960.55
	Proposed	1206.08	1062.34
	Difference	**0.33**	**101.79**
Saturated, 10-Year	Existing	1206.74	1278.66
	Proposed	1207.04	1378.27
	Difference	**0.30**	**99.61**

Flows increase under proposed conditions for all modeled combinations. Under dry conditions, increases are small but consistent, with flow differences ranging from 0.35 cfs (2-year) to 0.91 cfs (10-year). Stage increases are limited to less than 0.11 ft. Under saturated conditions, the proposed scenario results in more substantial flow increases, ranging from 94.82 cfs to 101.79 cfs, with corresponding stage increases up to 0.4 ft. The largest change in flow occurs in the 5-year saturated scenario, highlighting increased conveyance or runoff contribution under wetter and higher-flow conditions.

Table 8. Hydraulic Model Results at Warroad River (West Branch) Boundary Condition

Simulation Conditions		Peak Stage (ft)	Peak Flow (cfs)
Dry, 2-Year	Existing	1210.25	0.95
	Proposed	1210.22	0.85
	Difference	**-0.03**	**-0.10**

Simulation Conditions		Peak Stage (ft)	Peak Flow (cfs)
Dry, 5-Year	Existing	1210.48	1.36
	Proposed	1210.41	1.20
	Difference	**-0.07**	**-0.16**
Dry, 10-Year	Existing	1210.64	1.77
	Proposed	1210.55	1.52
	Difference	**-0.09**	**-0.25**
Saturated, 2-Year	Existing	1217.3	83.48
	Proposed	1217.28	83.19
	Difference	**-0.02**	**-0.29**
Saturated, 5-Year	Existing	1217.56	99.17
	Proposed	1217.55	98.91
	Difference	**-0.01**	**-0.26**
Saturated, 10-Year	Existing	1217.73	111.03
	Proposed	1217.73	110.80
	Difference	**0.00**	**-0.23**

Differences between existing and proposed conditions are minimal across all dry and saturated scenarios. Under dry conditions, flows decrease slightly under the proposed scenario, with the maximum change being -0.25 cfs for the 10-year event, and stage differences no greater than -0.09 ft. In saturated scenarios, flow differences remain below 0.3 cfs, and stage differences are negligible (≤ 0.02 ft). These results suggest that proposed changes have little to no measurable impact on flows or water surface elevations at this outlet.

Table 9. Hydraulic Model Results at Warroad River (East Branch) Boundary Condition

Simulation Conditions		Peak Stage (ft)	Peak Flow (cfs)
Dry, 2-Year	Existing	N/A	0.00
	Proposed	N/A	0.00
	Difference	**N/A**	**0.00**
Dry, 5-Year	Existing	N/A	0.00
	Proposed	N/A	0.00
	Difference	**N/A**	**0.00**
Dry, 10-Year	Existing	N/A	0.00

Simulation Conditions		Peak Stage (ft)	Peak Flow (cfs)
	Proposed	N/A	0.00
	Difference	**N/A**	**0.00**
Saturated, 2-Year	Existing	1207.12	540.83
	Proposed	1207.01	511.53
	Difference	**-0.11**	**-29.30**
Saturated, 5-Year	Existing	1207.92	758.09
	Proposed	1207.82	729.72
	Difference	**-0.10**	**-28.37**
Saturated, 10-Year	Existing	1208.41	957.14
	Proposed	1208.47	984.50
	Difference	**0.06**	**27.36**

No flow occurs under any dry condition, and no stage changes are observed, indicating that the dry events are not sufficient to activate this boundary. Under saturated conditions, small reductions in flow occur in the 2- and 5-year events (up to -29.3 cfs), while the 10-year event shows a moderate increase of 27.36 cfs. Stage changes remain minor (within ±0.11 ft), indicating only limited sensitivity of this boundary to proposed conditions, except under the highest flow scenario.

Table 10. Hydraulic Model Results at CSAH 2 Outlet Boundary Condition

Simulation Conditions		Peak Stage (ft)	Peak Flow (cfs)
Dry, 2-Year	Existing	1202.07	31.10
	Proposed	1205.3	0.12
	Difference	**3.23**	**-30.98**
Dry, 5-Year	Existing	1202.11	32.16
	Proposed	1205.37	0.26
	Difference	**3.26**	**-31.9**
Dry, 10-Year	Existing	1202.14	33.04
	Proposed	1205.41	0.38
	Difference	**3.27**	**-32.66**
Saturated, 2-Year	Existing	1205.88	211.38
	Proposed	1207.52	84.96
	Difference	**1.64**	**-126.42**

Simulation Conditions		Peak Stage (ft)	Peak Flow (cfs)
Saturated, 5-Year	Existing	1206.20	233.89
	Proposed	1207.70	112.88
	Difference	**1.50**	**-121.01**
Saturated, 10-Year	Existing	1206.67	266.52
	Proposed	1207.82	138.89
	Difference	**1.15**	**-127.63**

The CSAH 2 Outlet boundary condition shows larger differences from existing to proposed conditions than other boundary conditions in the model. In dry scenarios, flows are nearly eliminated (reductions of ~31–33 cfs) despite a stage increase of over 3.2 ft, suggesting that the proposed changes may restrict outflow or reroute it away from this outlet. Under saturated conditions, flow is reduced by over 120 cfs across all events, with the largest change being -127.63 cfs in the 10-year event. Despite these reductions, stage increases remain relatively moderate (1.15–1.64 ft), indicating increased storage or reduced outlet capacity in the proposed condition.

4.2 Ditches

Hydraulic model results were also evaluated along the ditches using flow and water surface elevation time-series plots, as well as spatial inundation plots. Figures 17 and 18 contextualize the ditch cross section of the four modeled scenarios (dry condition/open ditch, saturated condition/open ditch, dry condition/filled ditch, saturated condition/filled ditch). Figure 17 illustrates a pre-restoration ditch cross section under dry vs. saturated conditions. Figure 18 illustrates a post-restoration ditch cross section (i.e., where spoil or organic material has been placed within the ditch)under dry vs. saturated conditions.

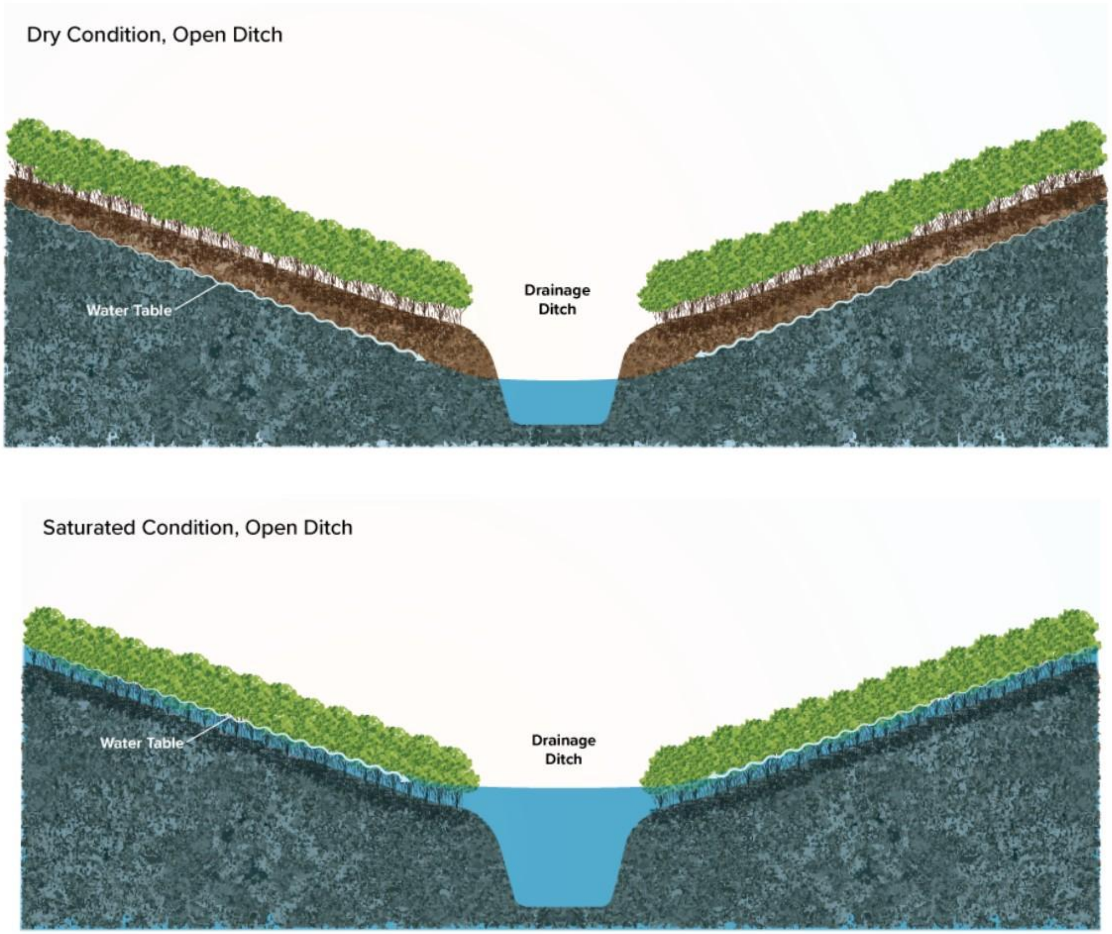


Figure 17. Dry and Saturated Condition, Typical Open Ditch

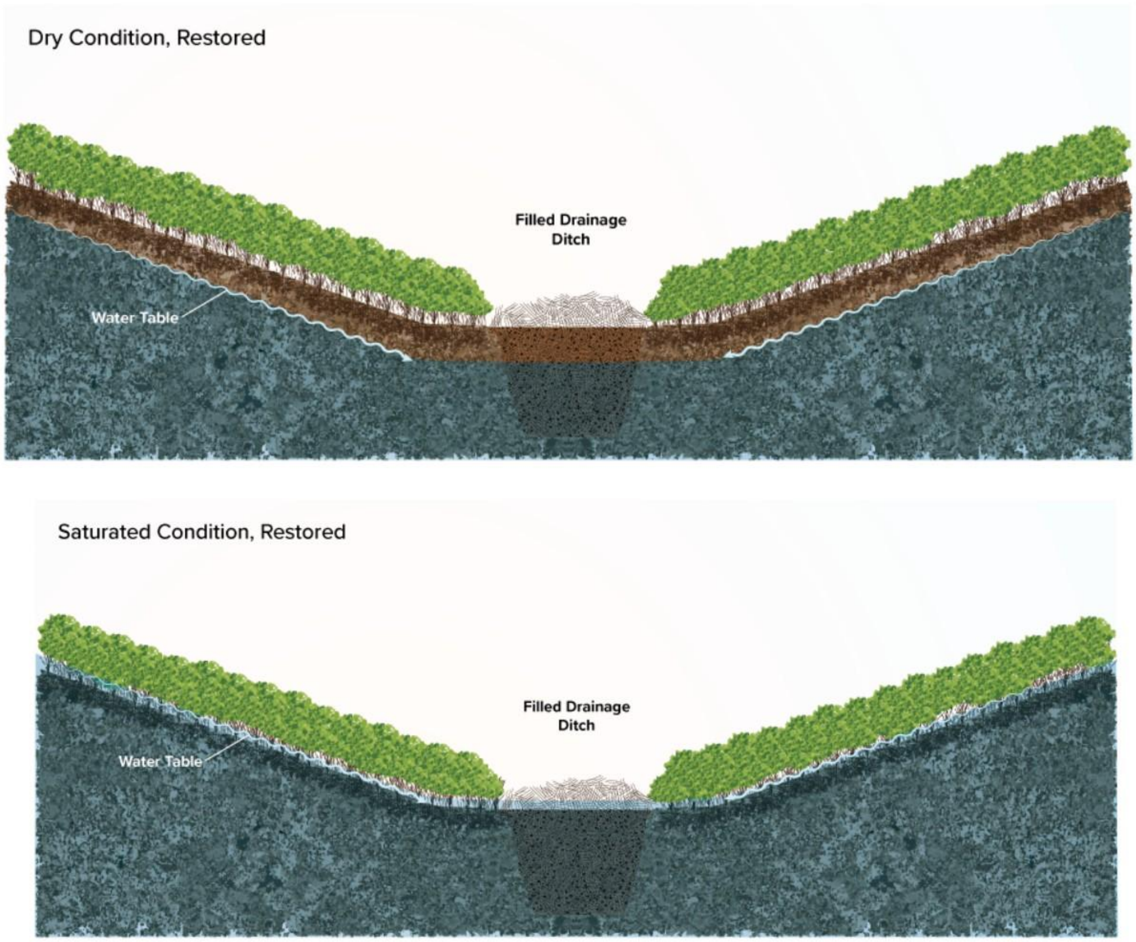


Figure 18. Dry and Saturated Condition, Filled/Restored Ditch

Figure 17 depicts a typical cross section of a maintained trapezoid where the surrounding landscape tapers towards the channel due to oxidation and subsidence of the peat profile. Figure 18 depicts a cross section in which the former ditch trapezoid is filled with adjacent spoil or other organic material, limiting conveyance to the former ditch outlet. The elevation of the fill material does not exceed the former top of bank elevation of the prior ditch.

Hydraulic model results were evaluated at various site locations throughout the model domain. Time series results for flow and water surface elevation, as well as spatial inundation maps, for existing and proposed conditions are shown in Figure 19 through Figure 30.

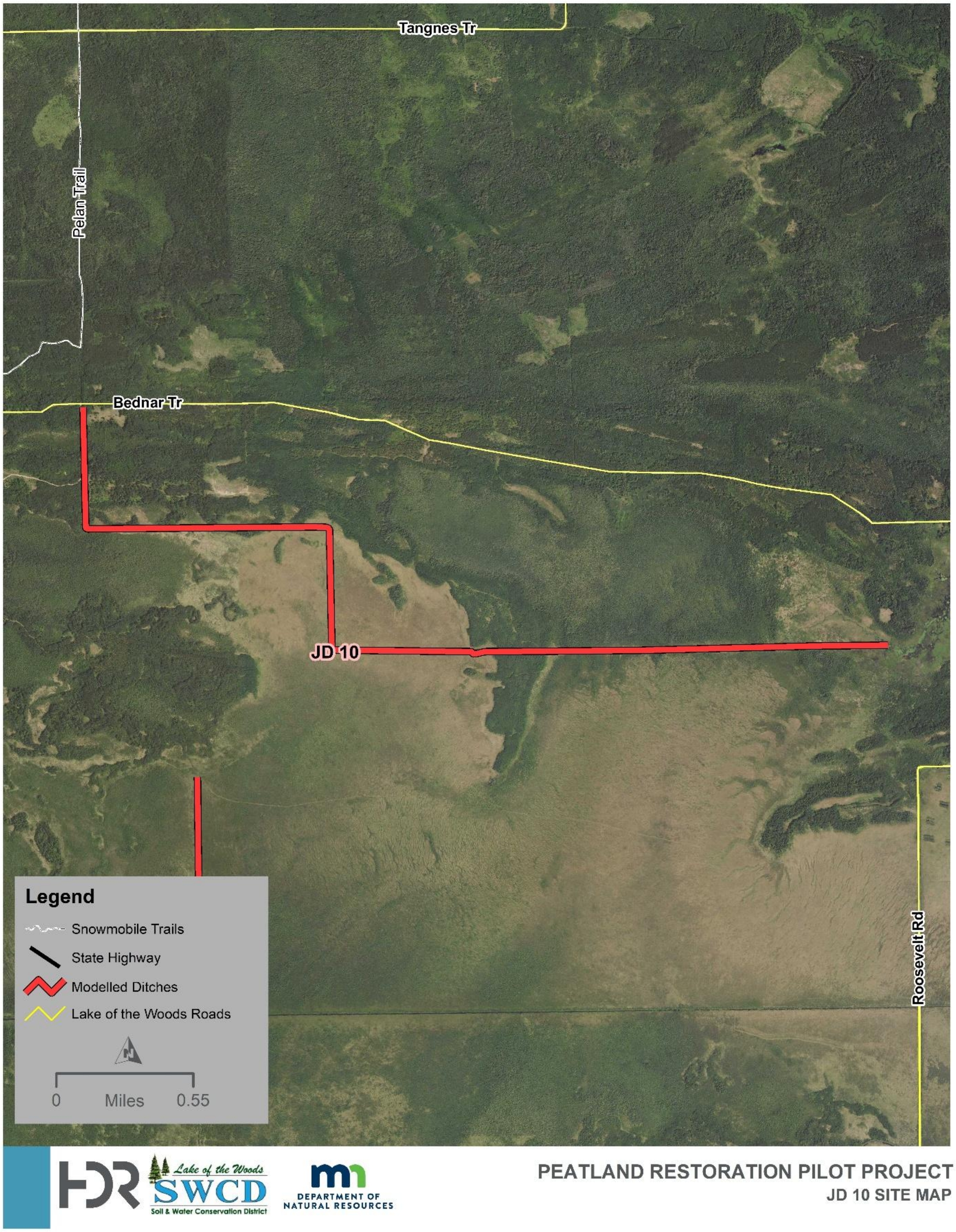


Figure 19. JD 10 Site Map

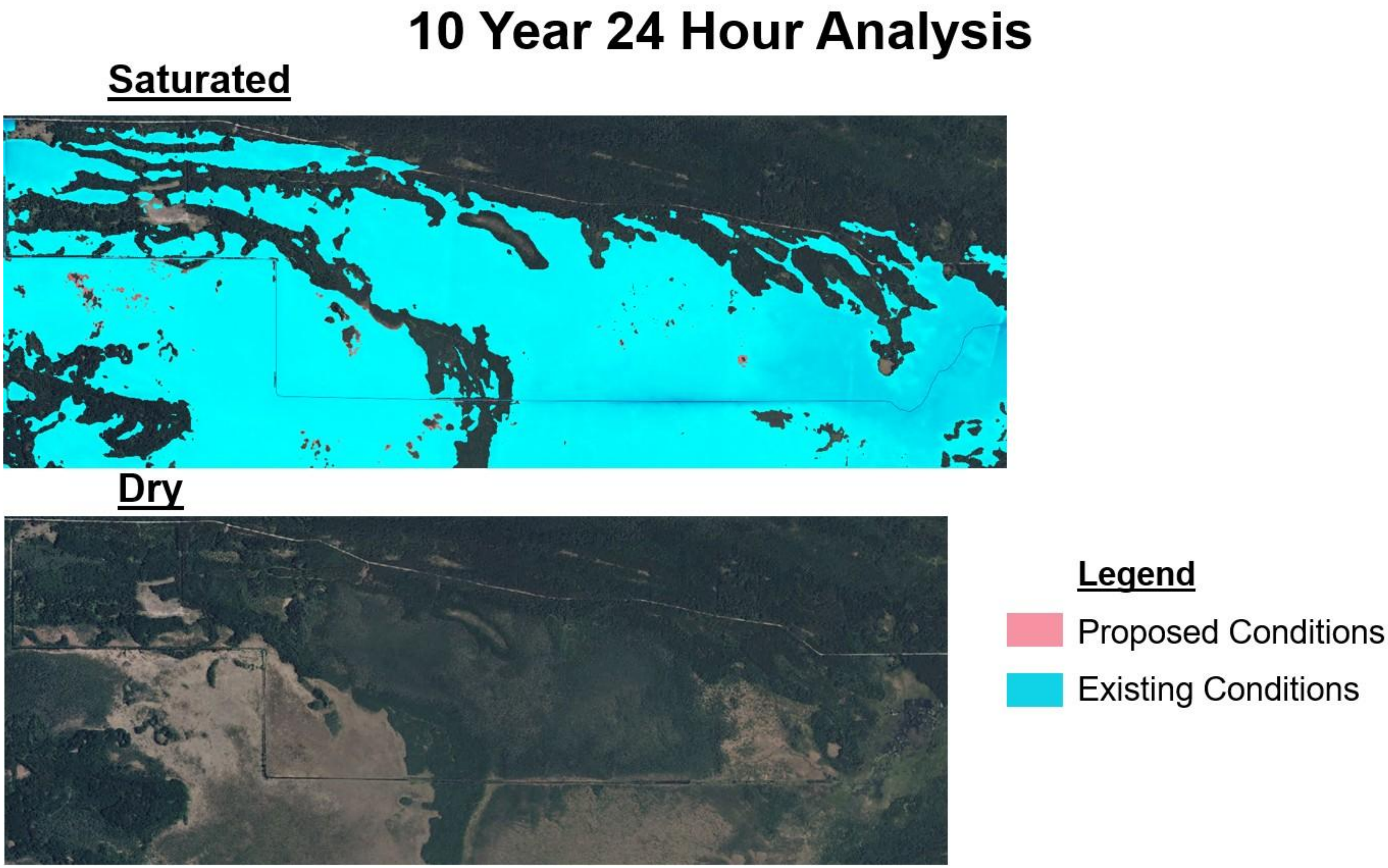


Figure 20. JD 10 Inundation Graphic

Inundation under proposed and existing conditions was generally unchanged, with fringe locations in the emergent peatland having slight increase in inundation.

10 Year 24 Hour Analysis

Saturated

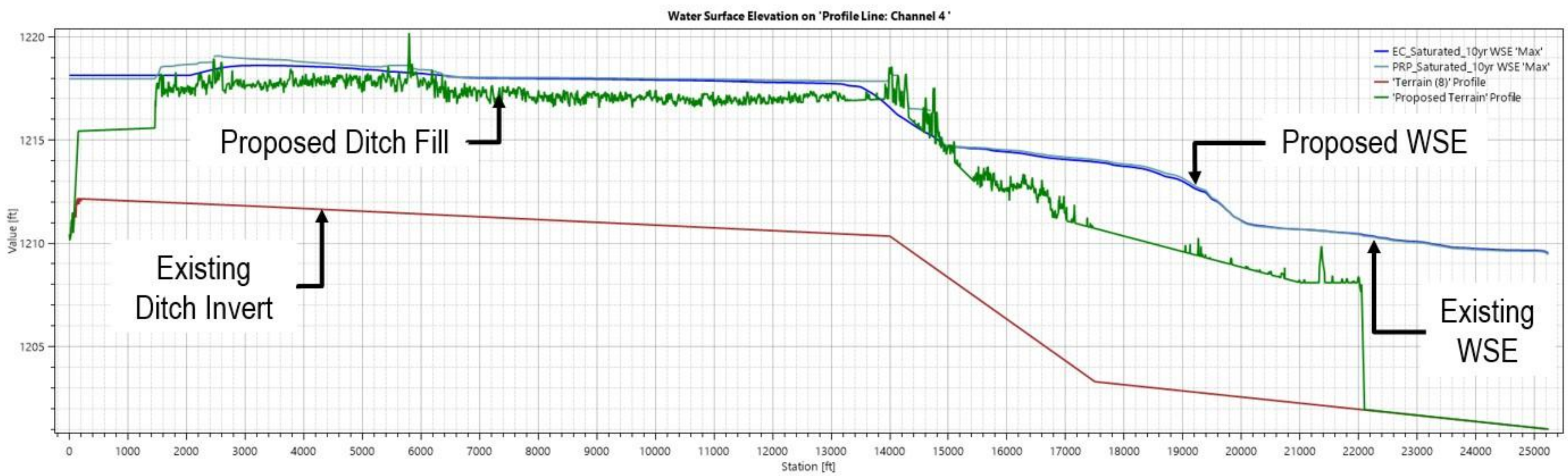


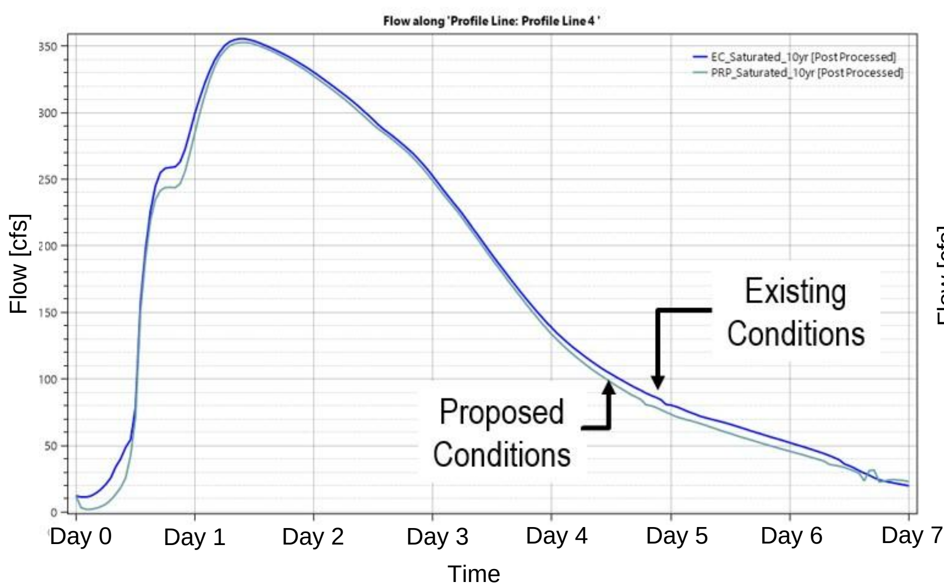
Figure 21. JD 10 Profile

JD 10 profile depicts a slight rise in water surface elevation in upper limits under the proposed condition.

10 Year 24 Hour Analysis

Saturated

Dry



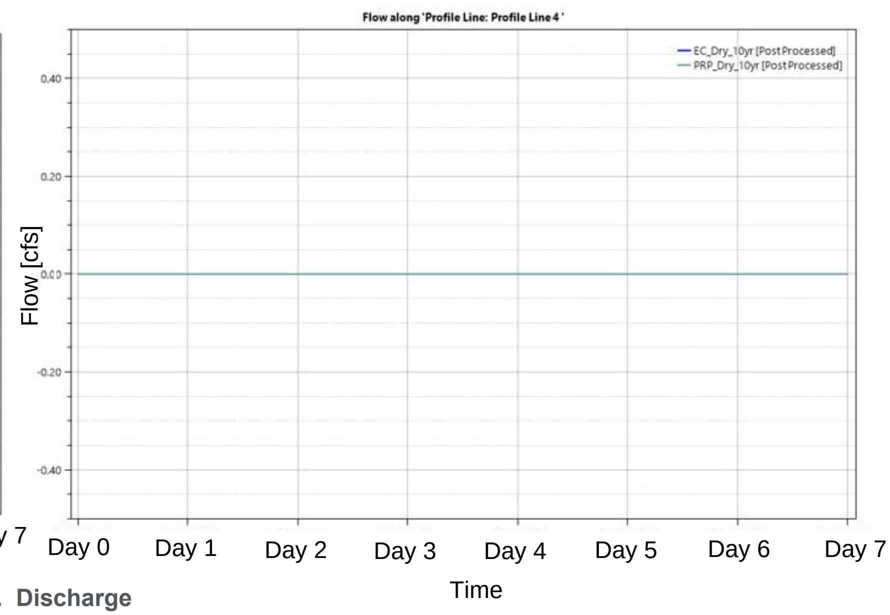


Figure 22. Discharge

Discharge tables found no measured discharge under dry conditions and a slight reduction from the proposed saturated condition.

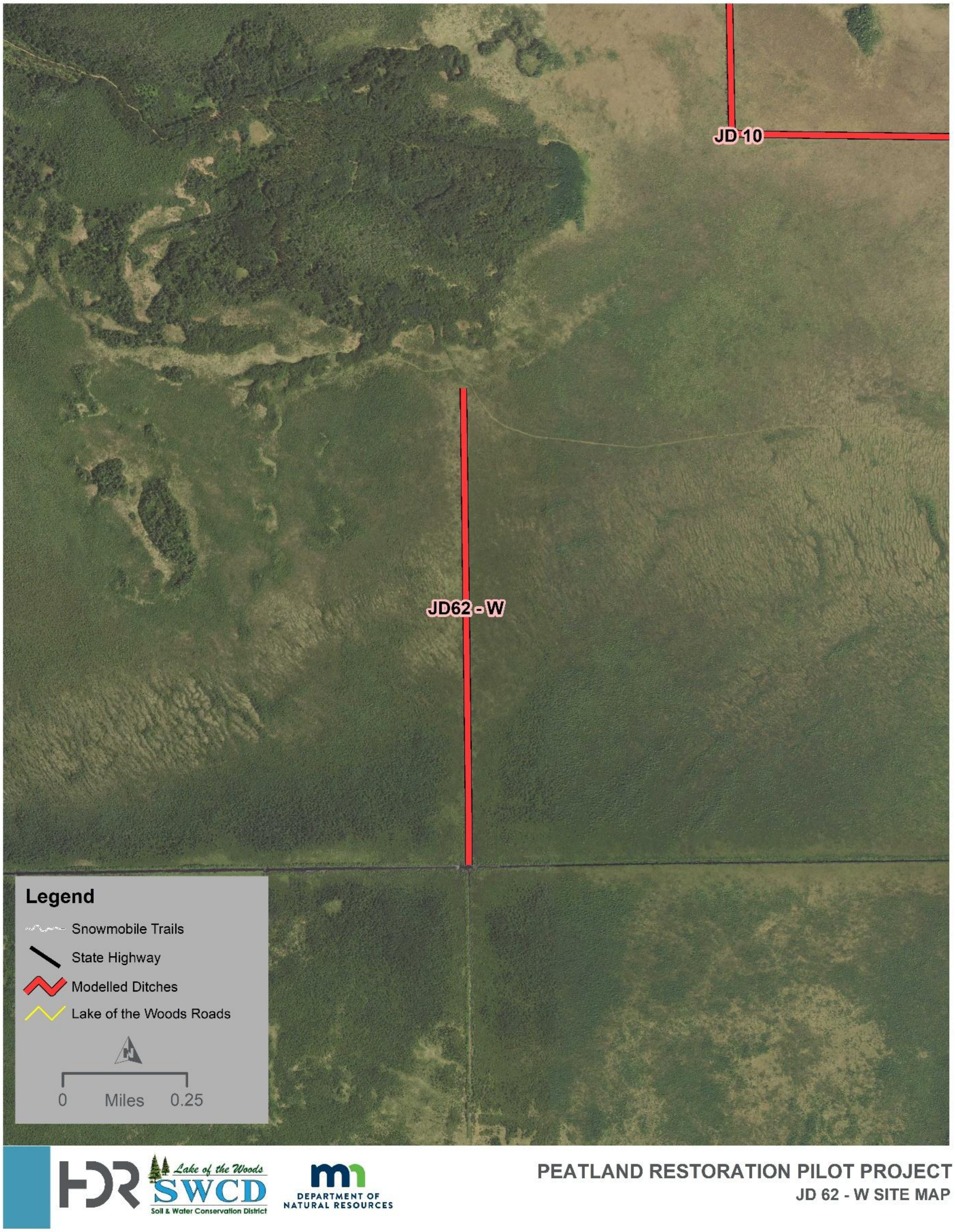


Figure 23. JD62 - W Site Map

10 Year 24 Hour Analysis

Saturated | **Dry**

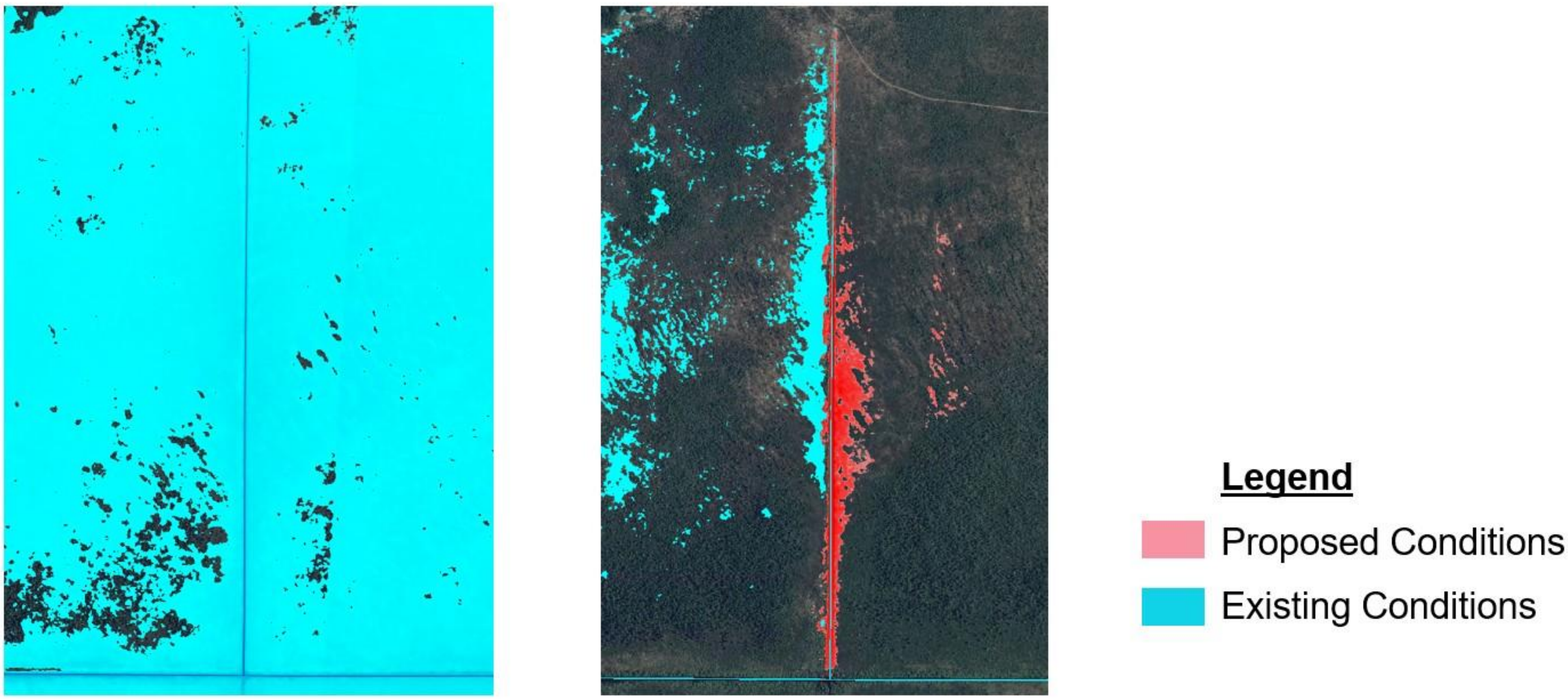
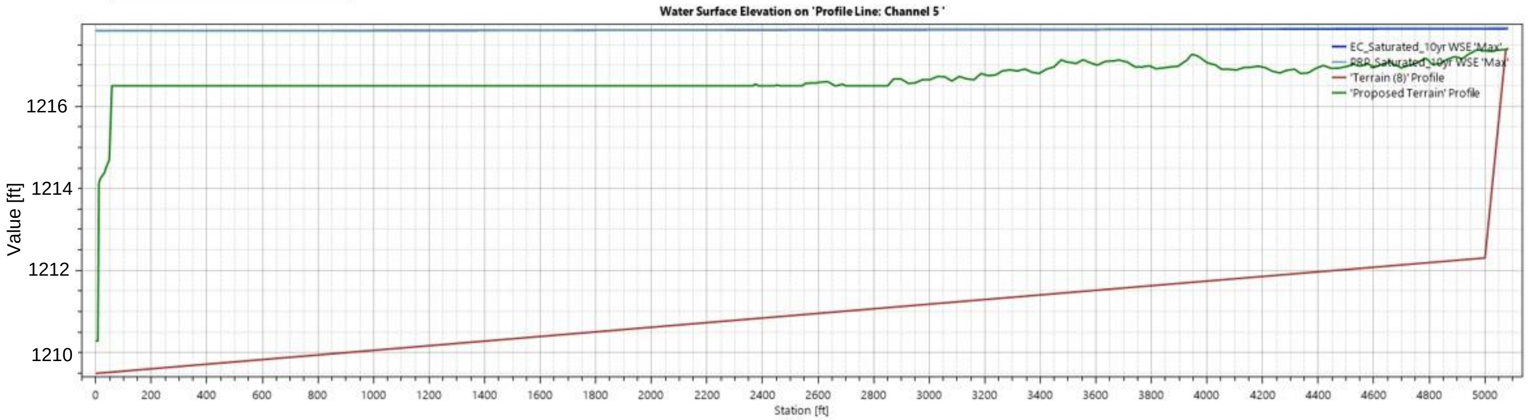


Figure 24. JD62 - W Inundation Graphic

Inundation under proposed and existing conditions were unchanged in a saturated scenario, increased inundation was found east of the ditch corridor within the modelled dry scenario.

10 Year 24 Hour Analysis

Saturated



Dry

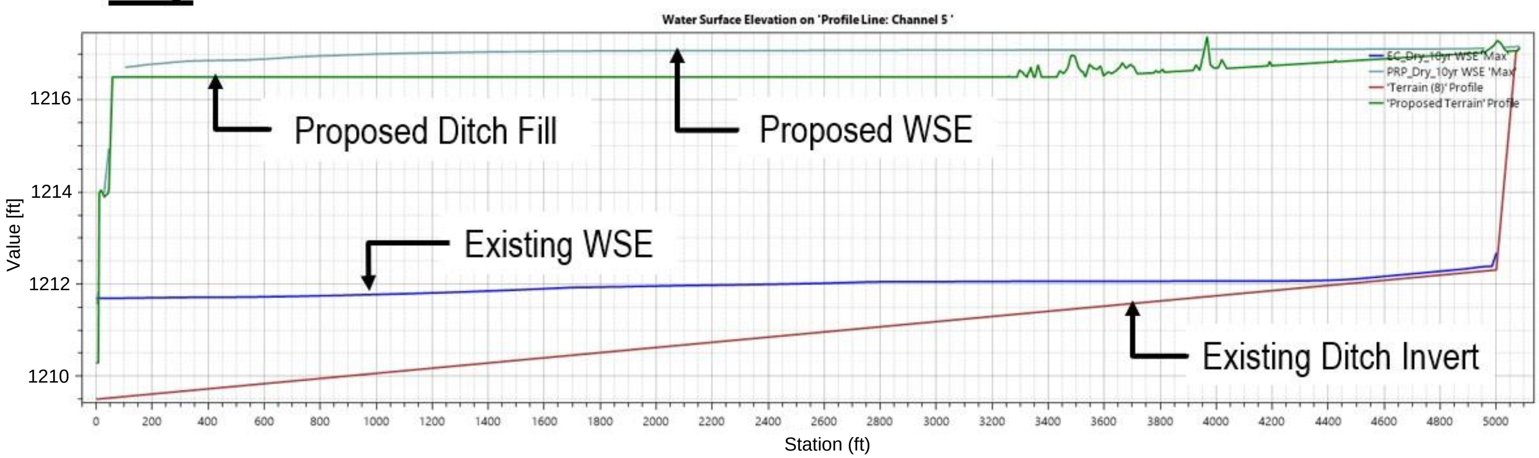


Figure 25. JD62 - W Profile and Discharge

JD62 - W profile depicts no change under a saturated condition, a significant rise in water surface elevation was found within the dry condition.

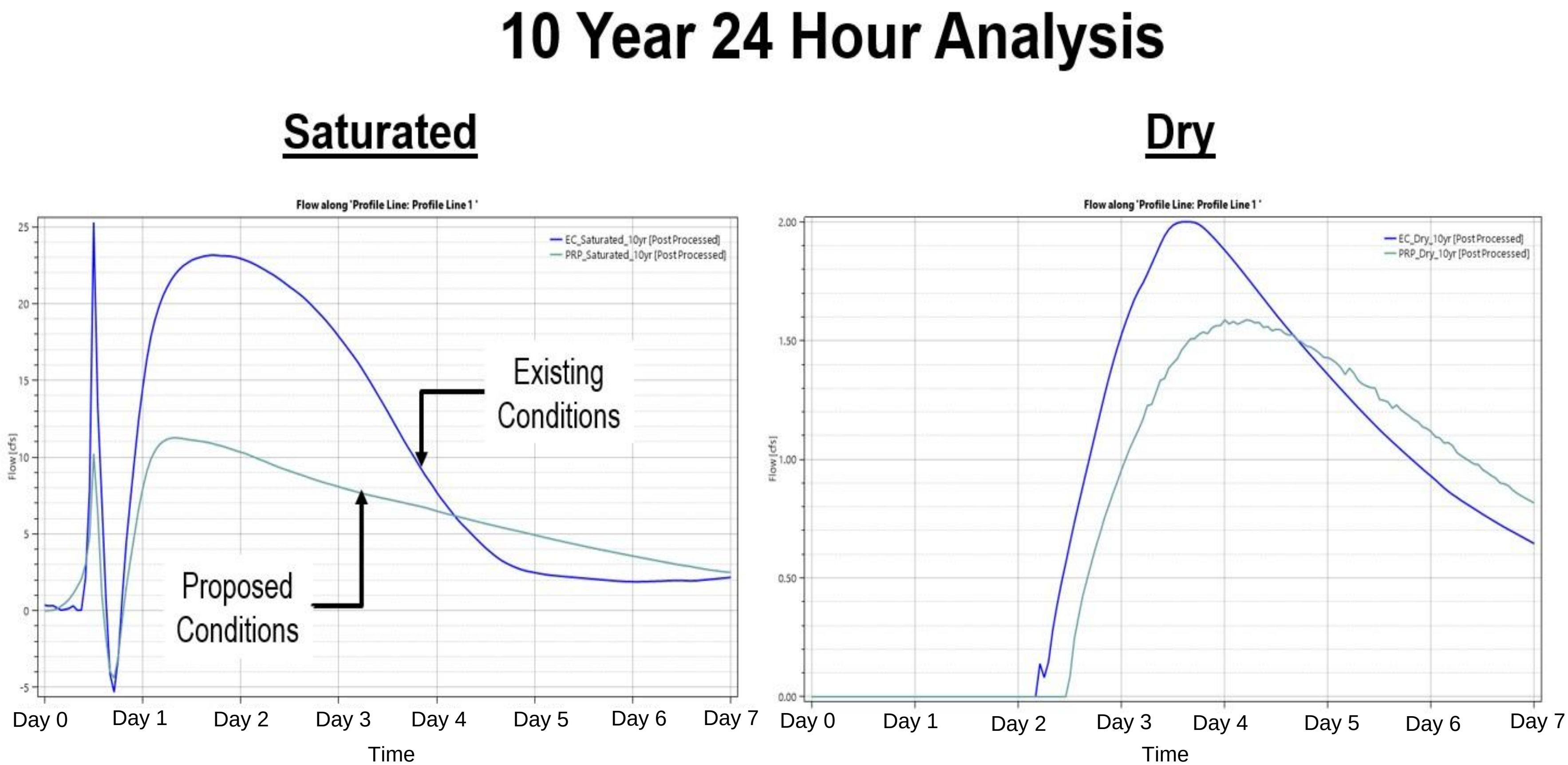


Figure 26. JD62 - W Discharge

JD62 - W Discharge tables show a reduction under both saturated and dry conditions. Dry conditions had a smaller reduction relative to the proposed saturated conditions

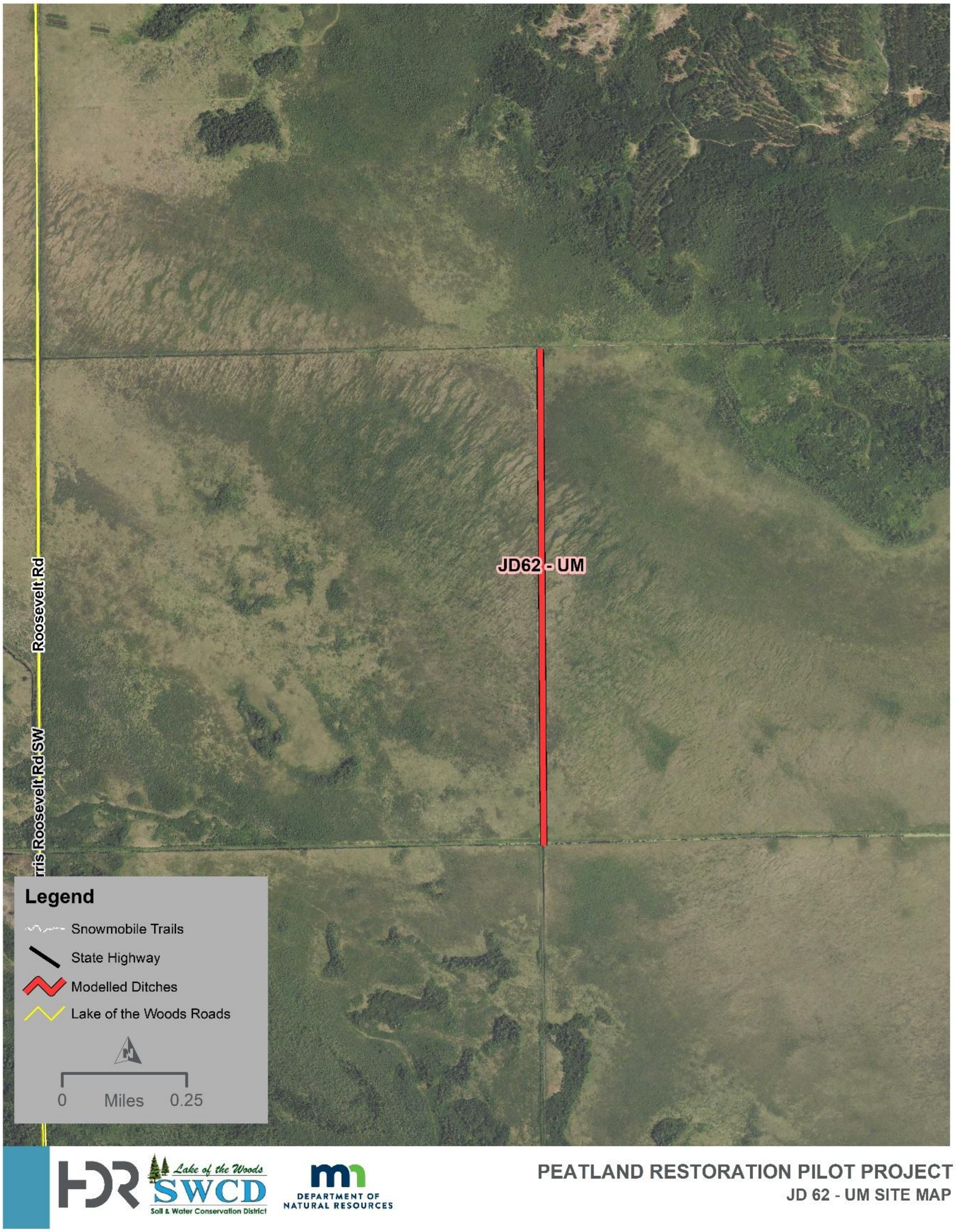


Figure 27. JD62 - UM Site Map

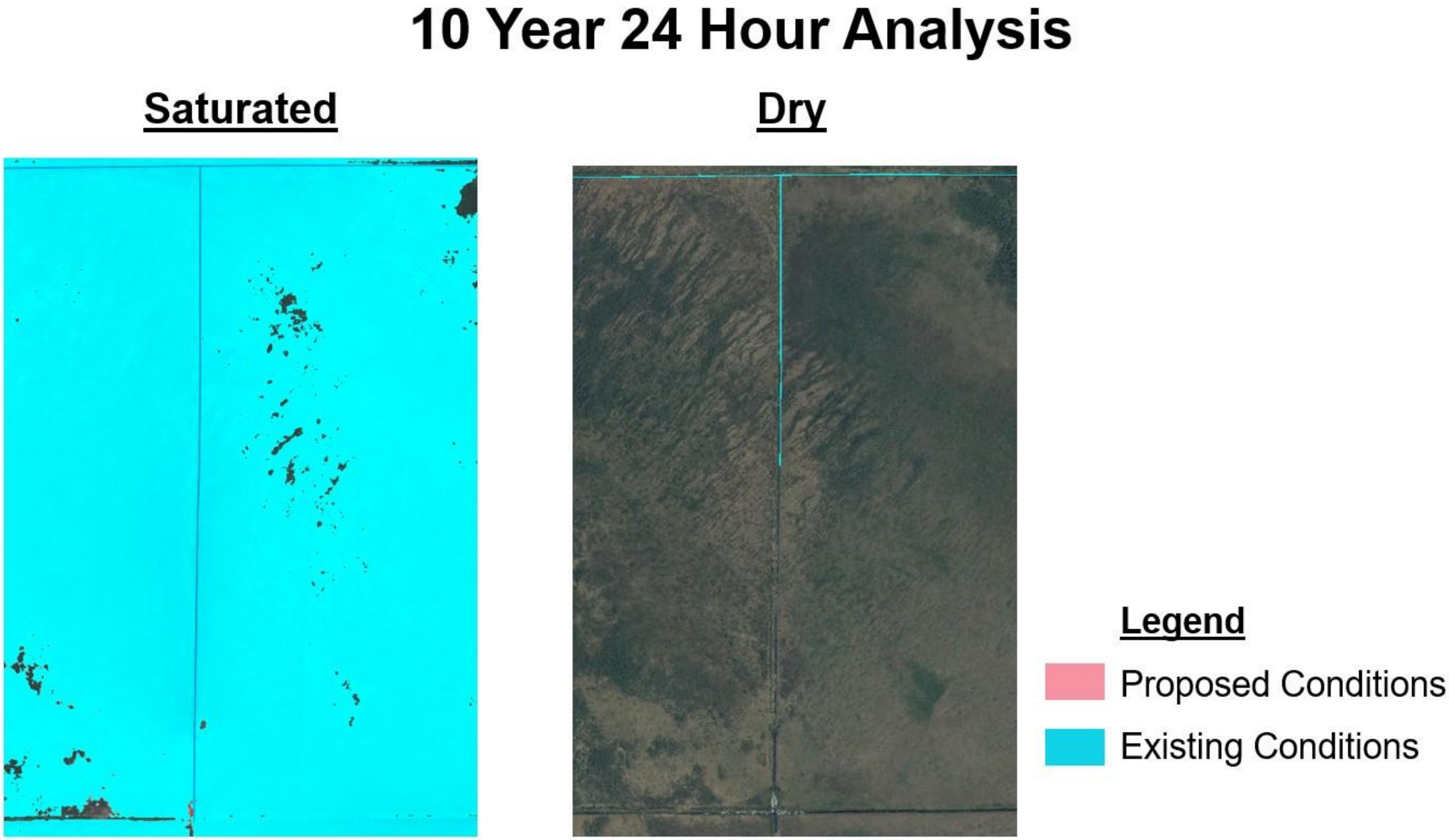


Figure 28. JD62 - UM Inundation Graphic

Inundation under proposed and existing conditions were unchanged in both dry and saturated scenario.

10 Year 24 Hour Analysis

Saturated

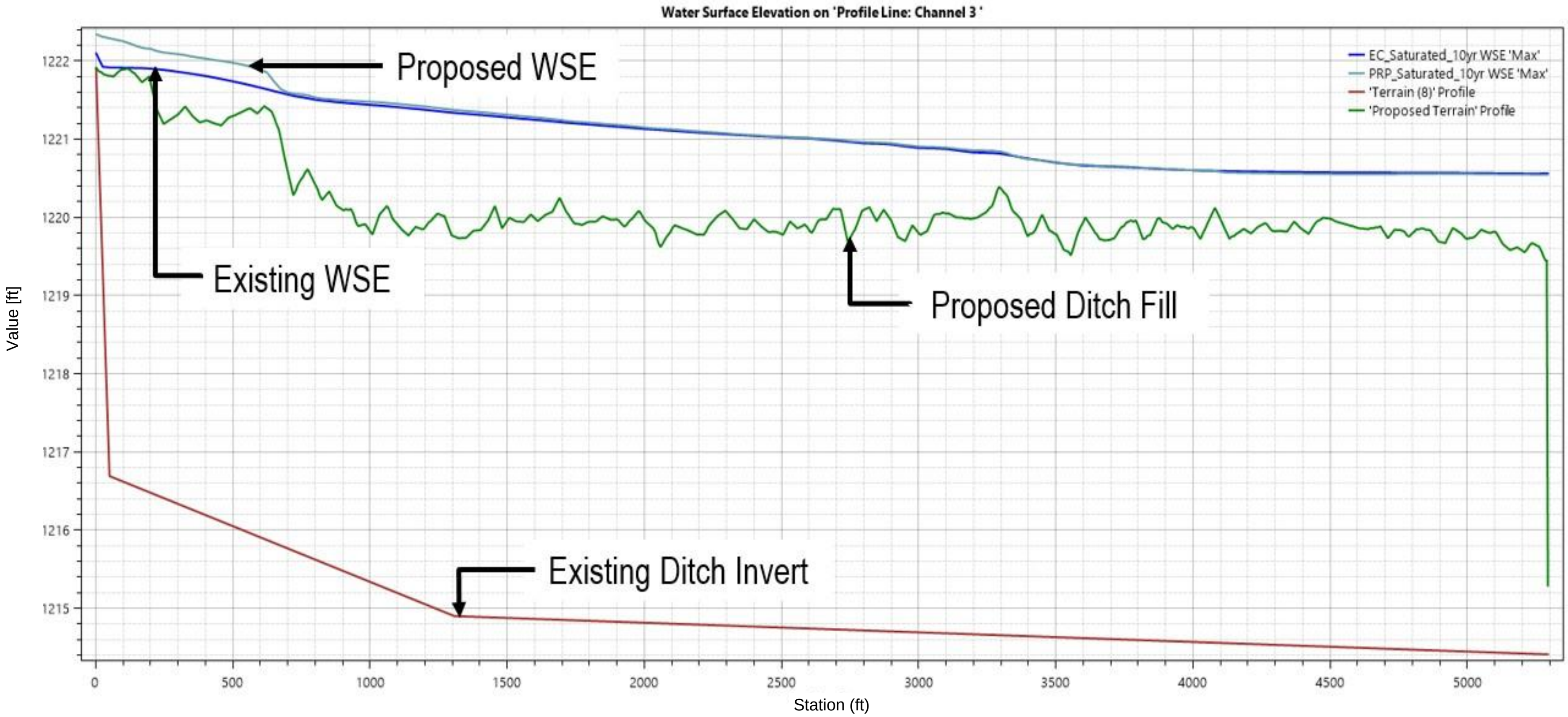


Figure 29. JD62 - UM Profile

JD62 - UM profile depicts a slight rise in water surface in the upper limits of the ditch reach.

10 Year 24 Hour Analysis

Saturated **Dry**

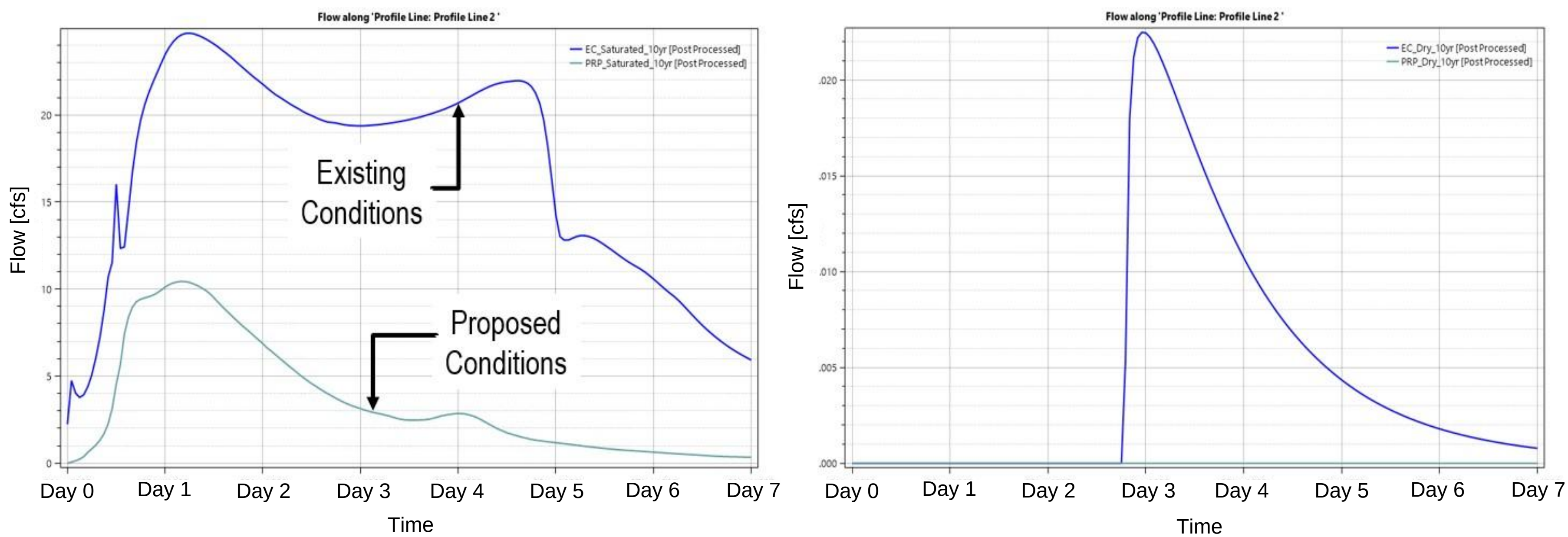


Figure 30. JD62 - UM Discharge

JD62 - UM Discharge tables reduction under both conditions, dry conditions had a slight reduction with the proposed saturated condition being significant.

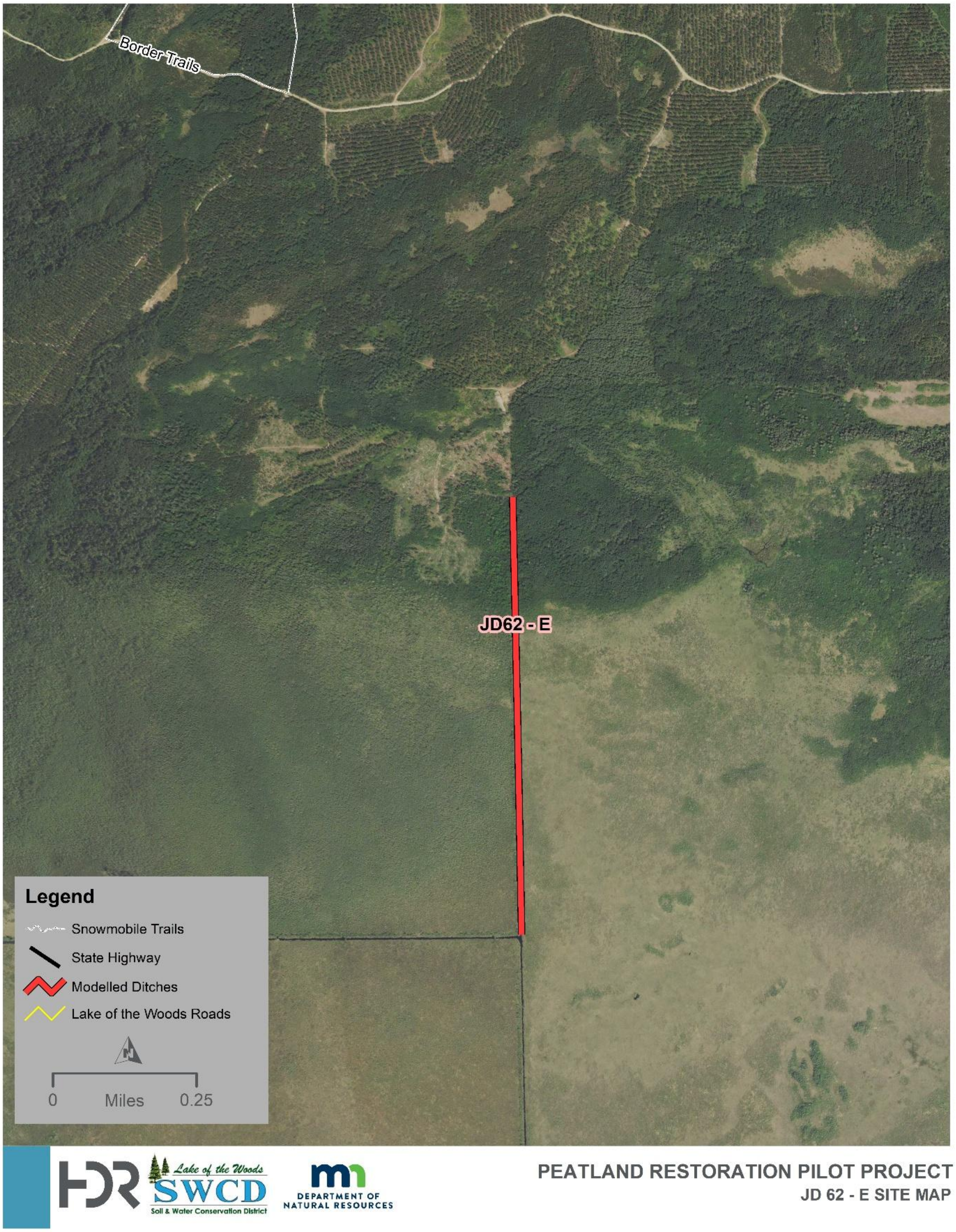


Figure 31. JD62 - E Site Map

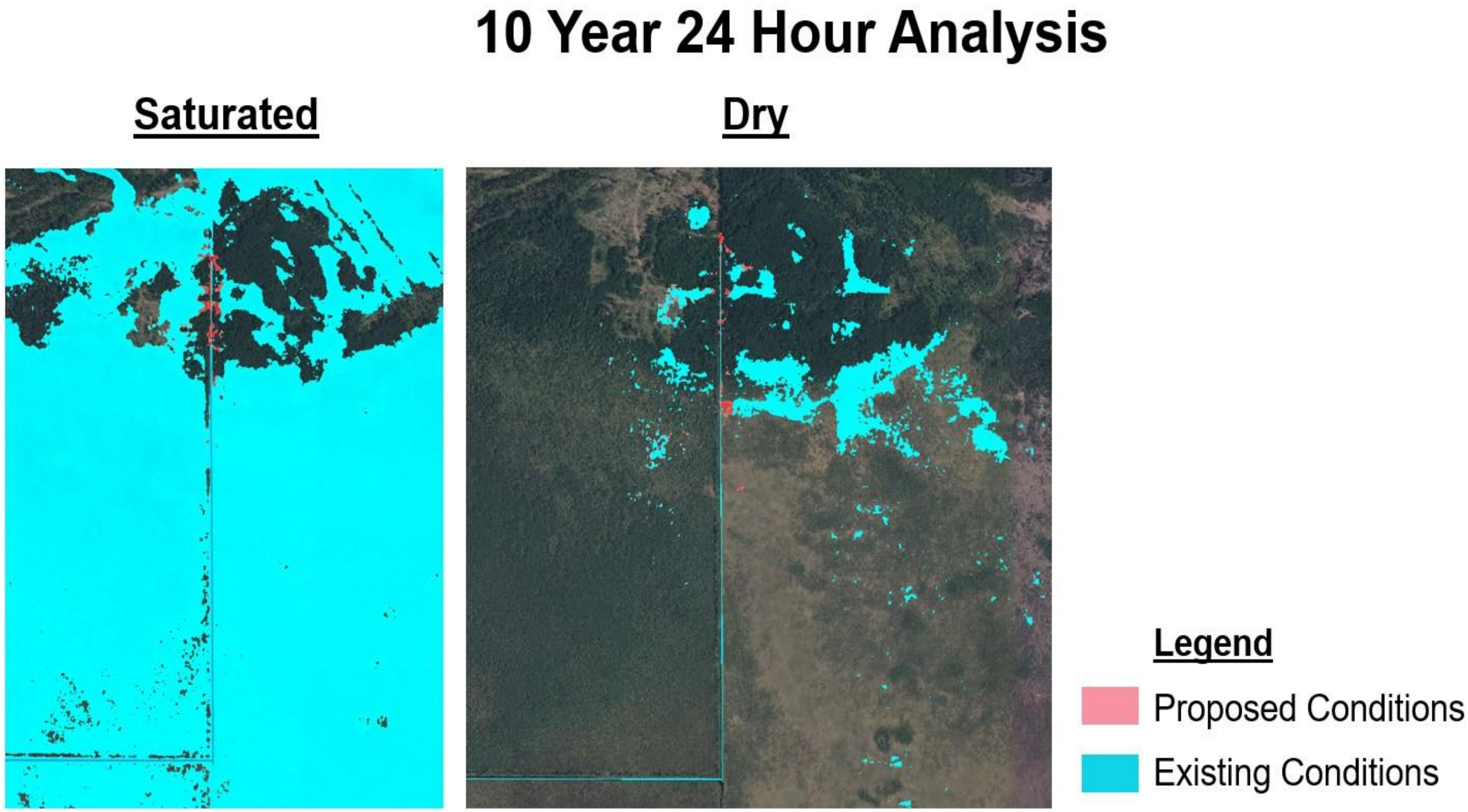


Figure 32. JD62 - E Inundation Graphic

JD62 – E Inundation was found to have a slight increase in depressed areas along the ditch in both dry and saturated scenarios.

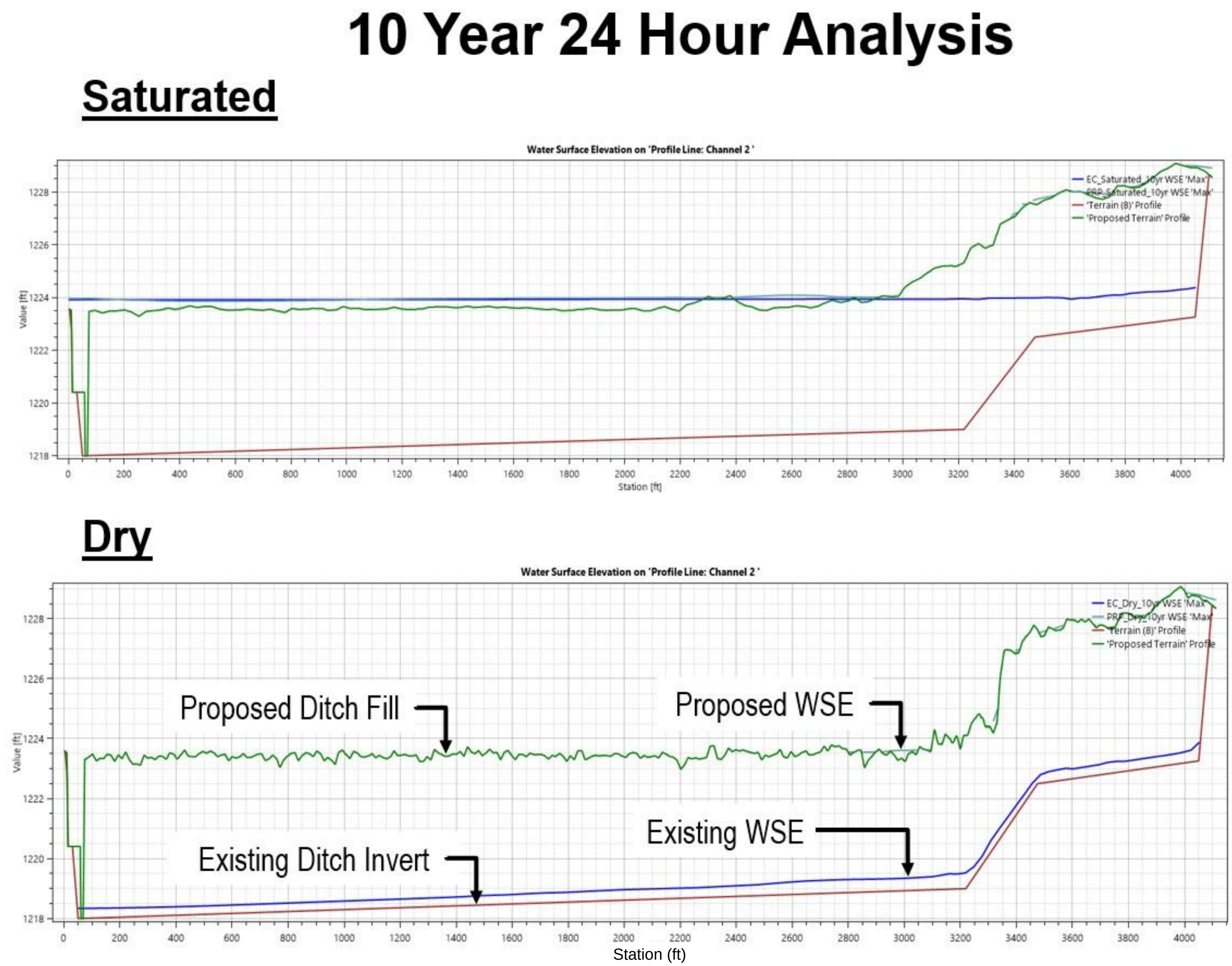
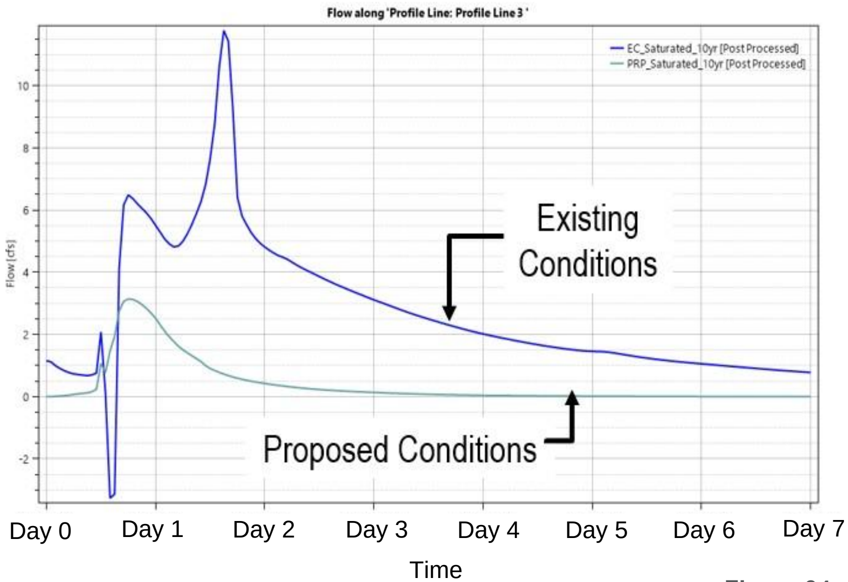


Figure 33. JD62 - E Profile

JD62 - E profile depicts a slight rise in water surface in the upper limits of the ditch reach.

10 Year 24 Hour Analysis

Saturated



Dry

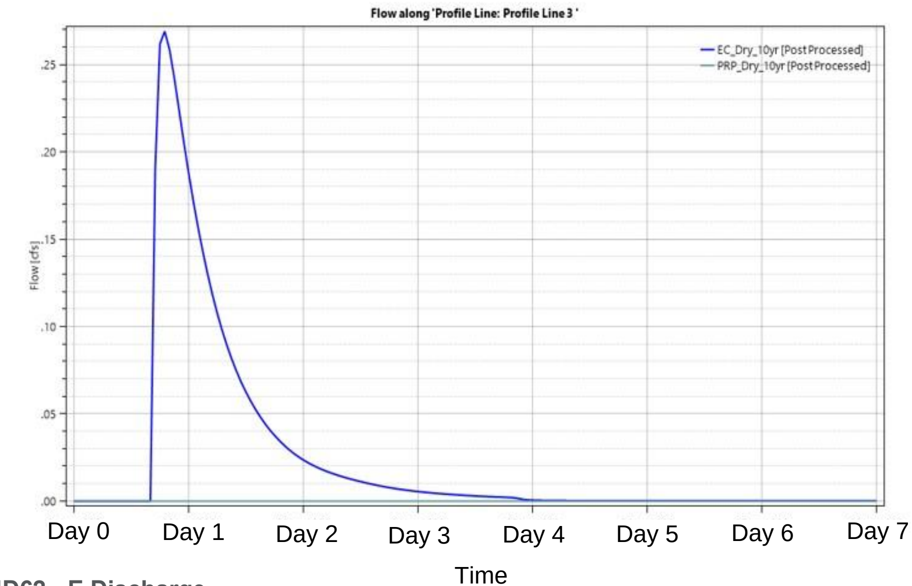


Figure 34. JD62 - E Discharge

JD62 - E Discharge tables show reduction under both conditions; dry conditions had a slight reduction with the proposed saturated condition being significant.

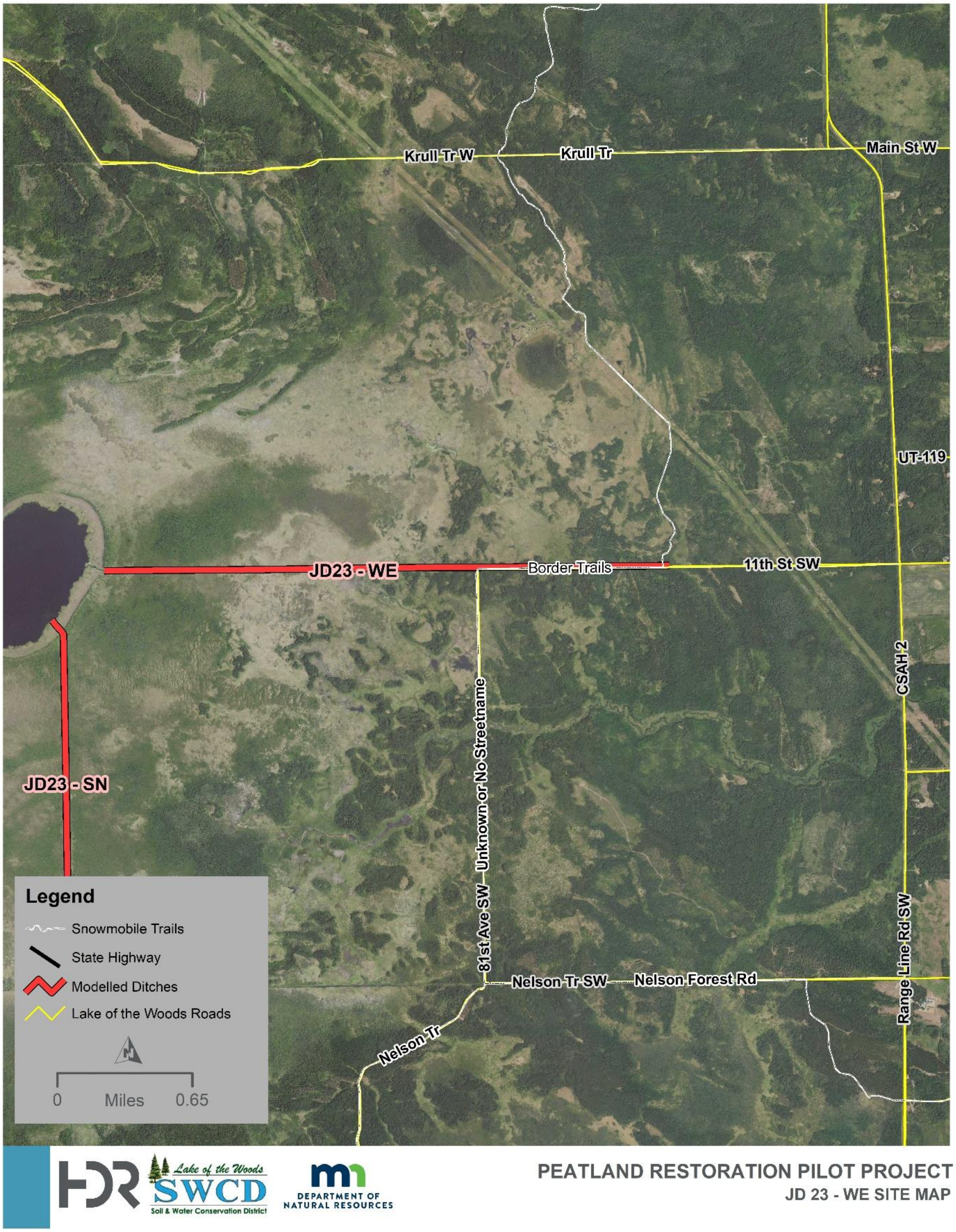


Figure 35. JD23 - WE Site Map

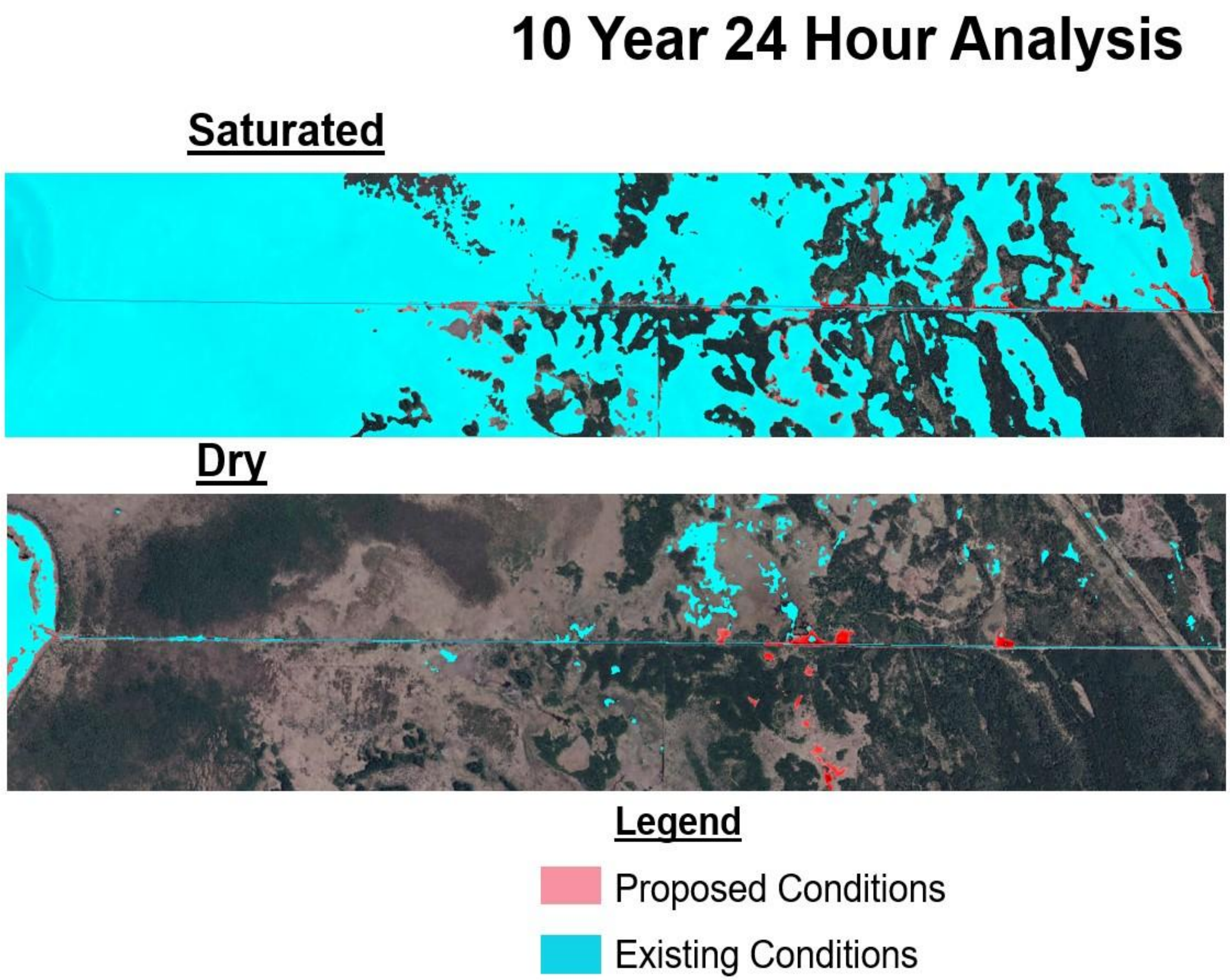


Figure 36. JD23 - WE Inundation Graphic

JD23 – WE Inundation was found to have a slight increase in depressed areas along the ditch and south of the ditch corridor in both dry and saturated scenarios.

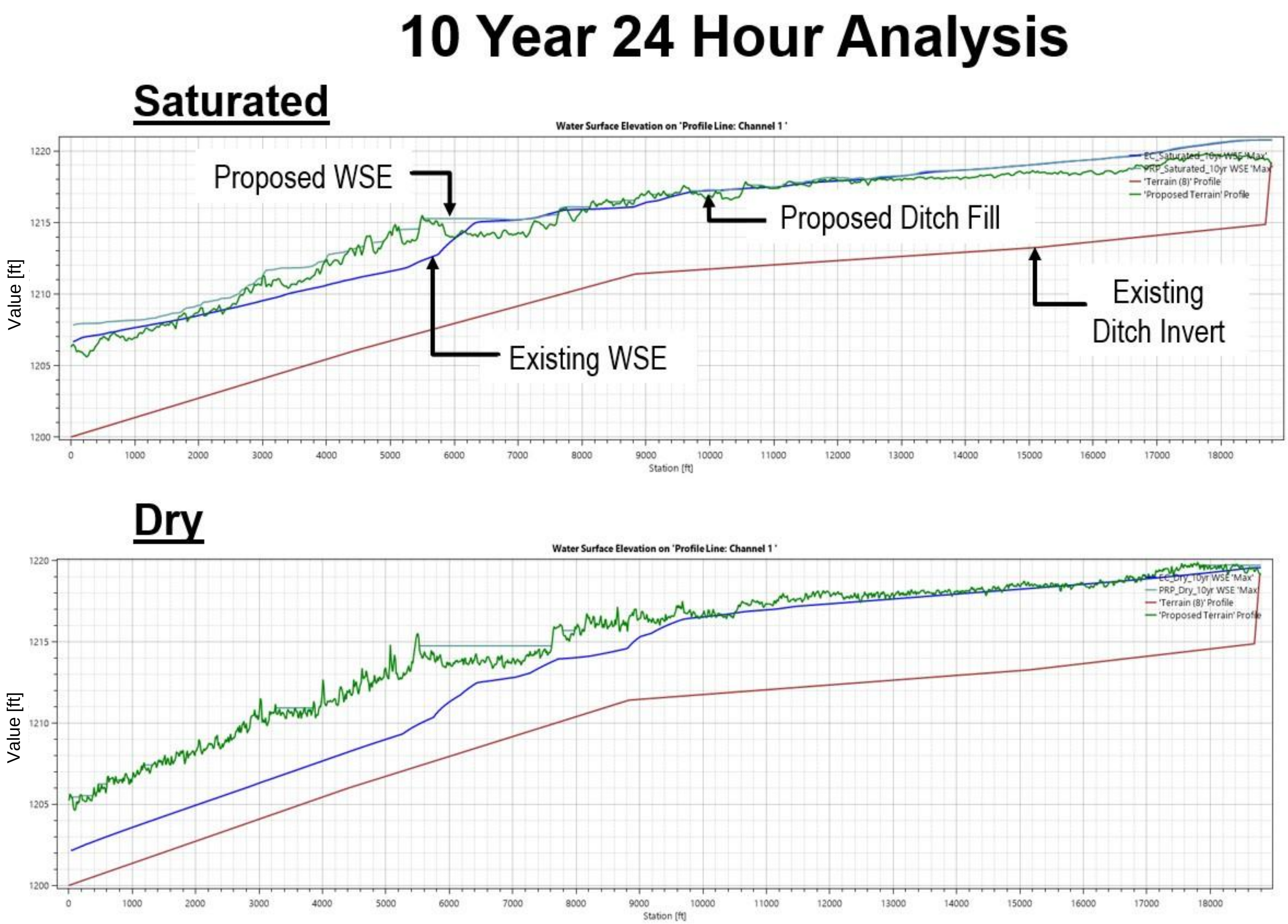


Figure 37. JD23 - WE Profile

JD23 - WE profile depicts a slight rise in water surface throughout the ditch reach under both conditions.

10 Year 24 Hour Analysis

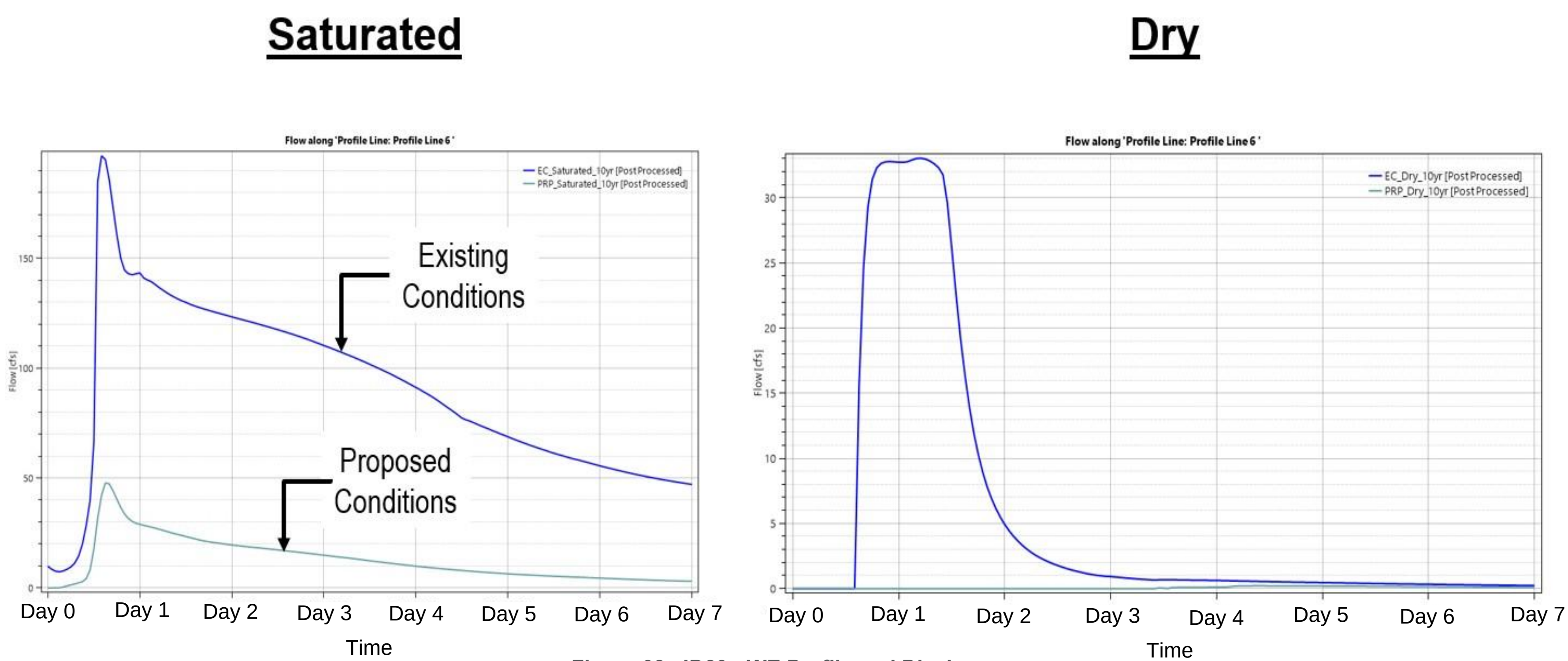


Figure 38. JD23 - WE Profile and Discharge

JD23 - WE Discharge tables found significant reduction under both conditions.

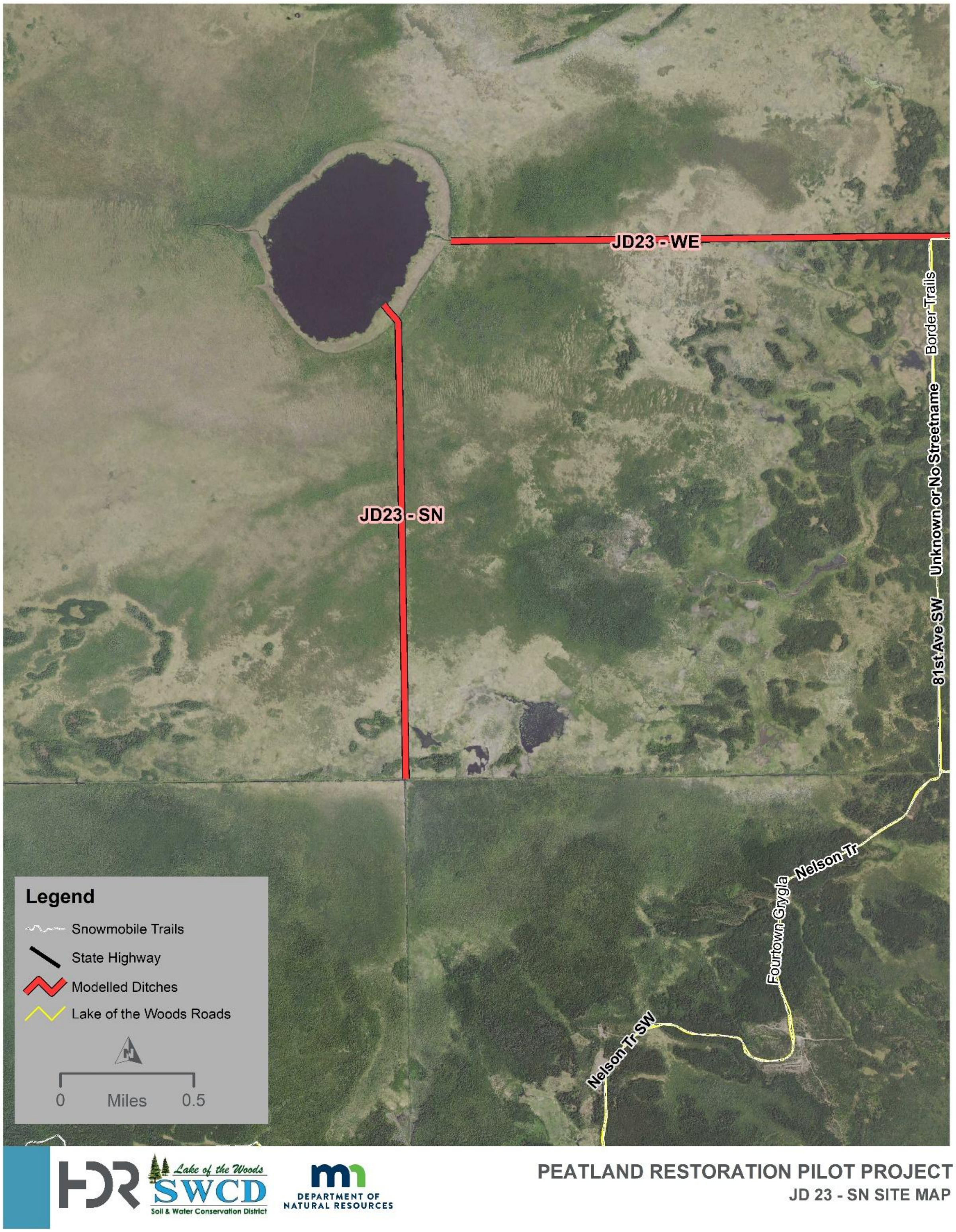


Figure 39. JD23 - SN Site Map

10 Year 24 Hour Analysis

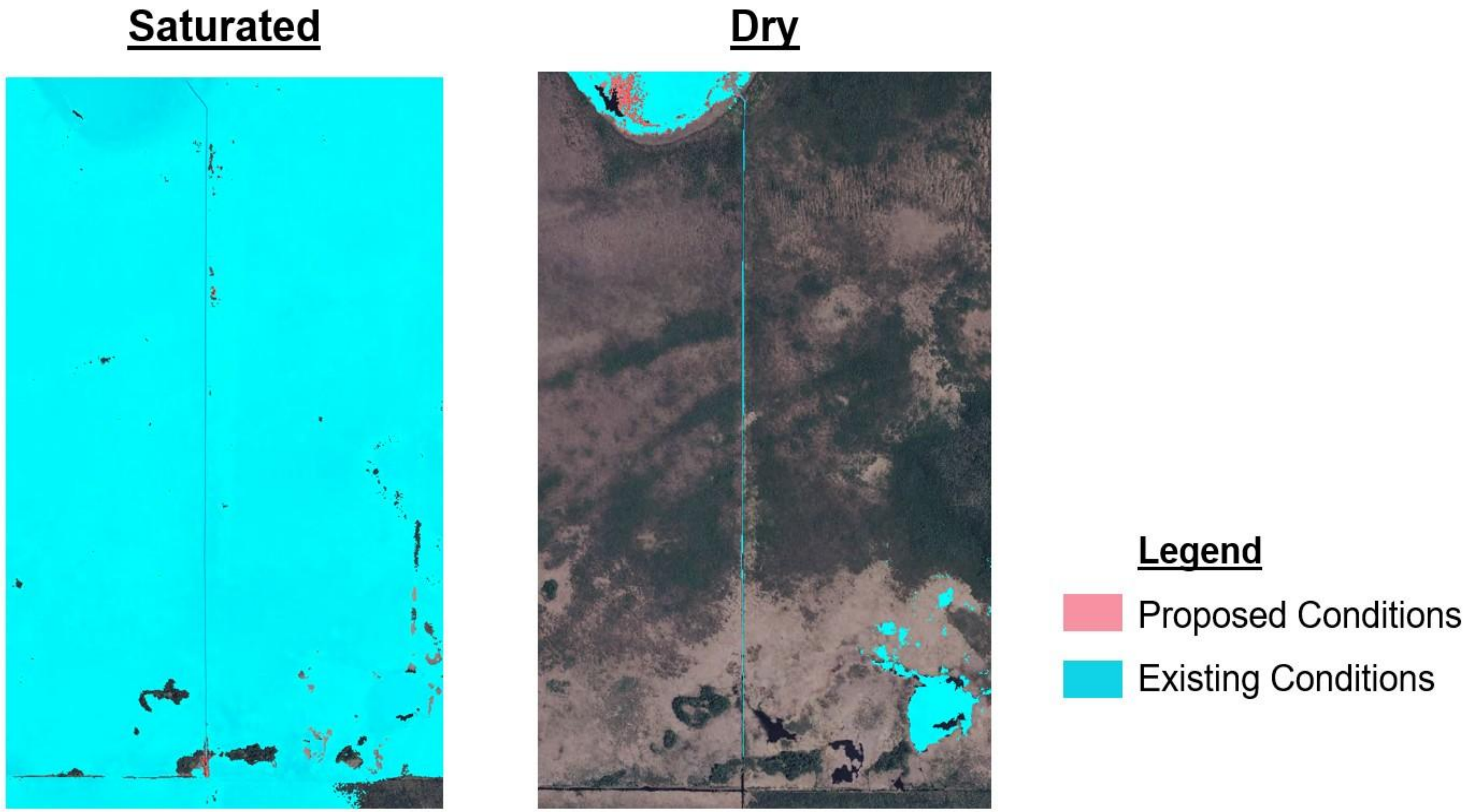


Figure 40. JD23 - SN Inundation Graphic

JD23 – SN Inundation was found to have a slight increase in upper limits of the ditch under saturated conditions, and a slight rise in the south shoreland area of the lake under dry conditions.

10 Year 24 Hour Analysis

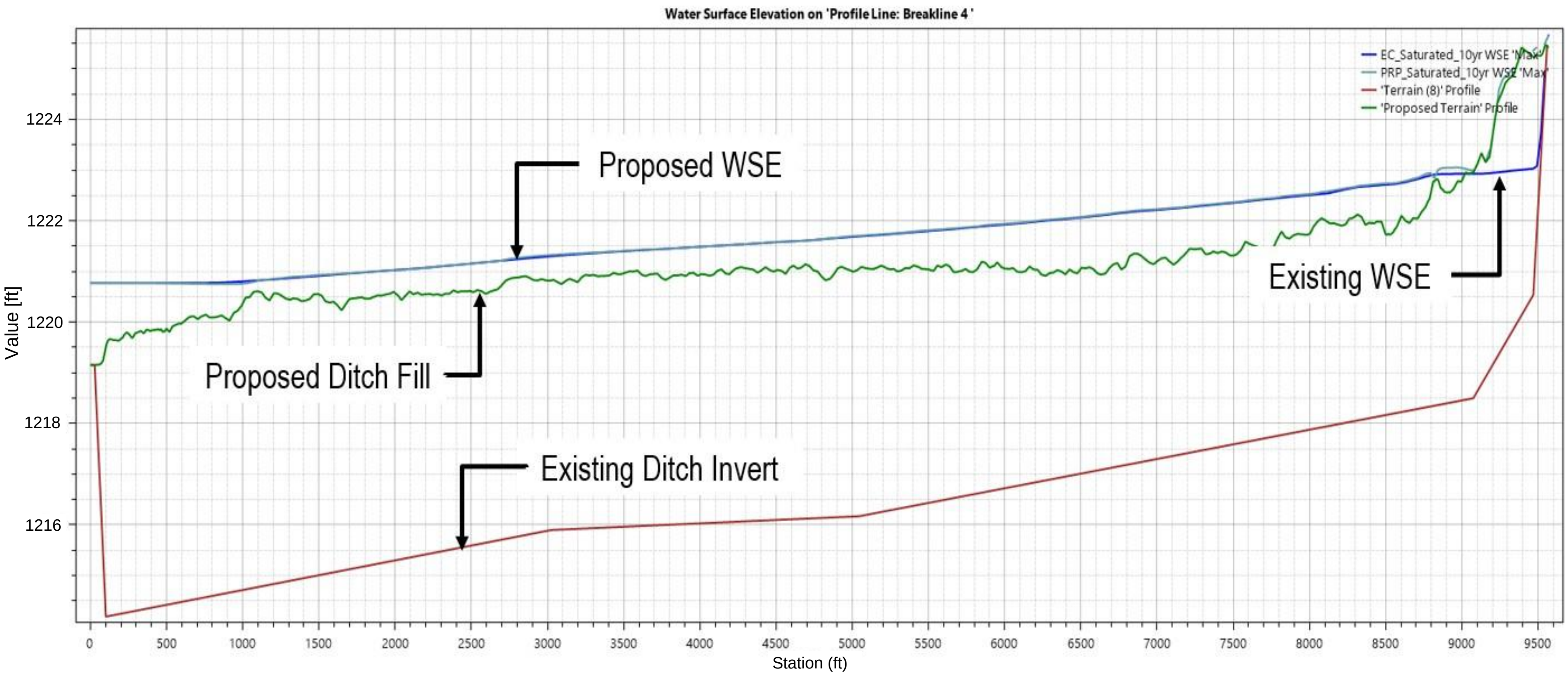
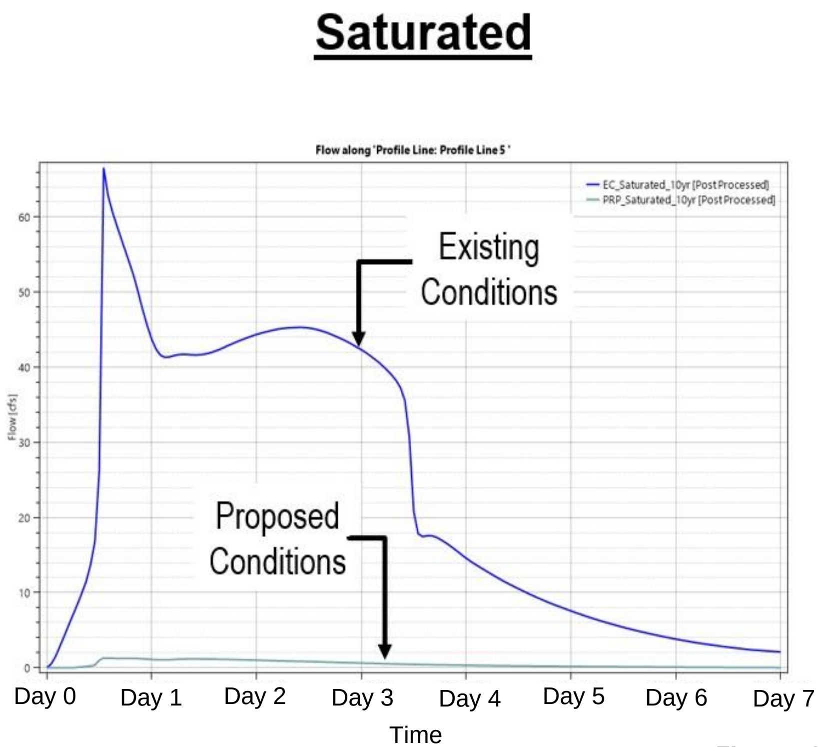


Figure 41. JD23 - SN Profile

JD23 - SN Profile depicts a slight rise in water surface upper limits of the ditch under dry conditions.

10 Year 24 Hour Analysis



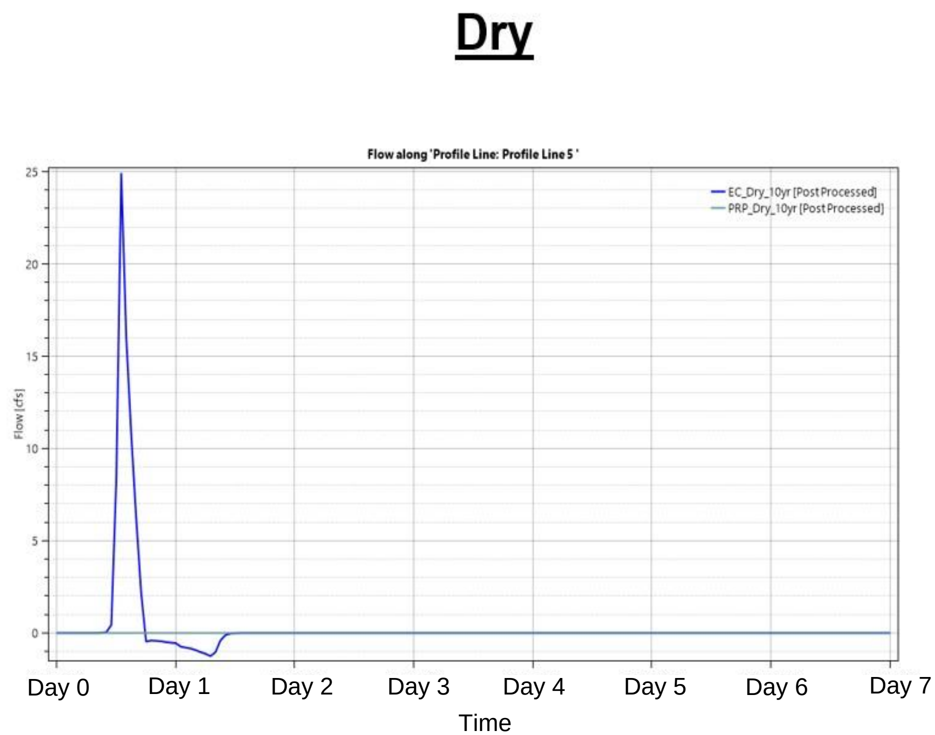


Figure 42. JD23 - SN Discharge

JD23 - SN Discharge tables found significant reduction in both saturated and dry conditions.

5 Future Conditions

The primary goal of modeling the 6 selected sites was to determine hydrologic response to restoring ditched peat based on existing spatial data. Based on the modeled existing 24-hour rainfall events, restoration of drained peat could increase climate resilience through peak flow reduction, increased saturation, and the accumulation of peat and its constituent nutrients.

An additional evaluation of future conditions was completed to assess how climate change–driven changes in precipitation frequency could affect the results. The analysis simulates precipitation-runoff flood risk projected 30 years into the future. Precipitation trends for 2055 were forecasted using the L-Moment Regional Analysis Program (L-RAP). These forecasted values were then analyzed in HEC-RAS and compared with the existing conditions results.

5.1 Changes from Existing/Proposed to Future Conditions

The only changes made to model parameters for the future conditions modeling was to the precipitation hyetographs input to the model. Precipitation hyetographs were updated based on the forecasted point precipitation results developed in L-RAP.

Atlas 14’s point precipitation estimates were developed using rainfall data through 2010. HDR conducted a precipitation analysis using past precipitation trends to forecast the precipitation estimates for a 24-hour 2-, 5-, and 10-year events for 2055 (30-year trajectory). L-RAP version 1.5.6.0 was used to complete this task.

Due to the site’s remote area, site-specific precipitation records were unavailable. A nearby station was selected for the analysis to represent the modeled domain. The Warroad, Minnesota station (ID 21-8679) located approximately 16 miles northwest of the modeled domain, provided an extensive record of precipitation (1910 – 2010).

Tabular point precipitation frequency estimates for each timeframe were developed using the annual maximum precipitation values provided by Atlas 14. Annual maximum datasets (through 2010) were analyzed using the L-RAP software for a 24-hour duration. L-RAP can be used for identifying the best fitting probability distribution of the annual precipitation maximums based on the weighted average of the station’s regional L-Skewness and L-Kurtosis. The test can also be done visually using the L-Moment ratio diagram (MGS L-Moment Regional Analysis Program User’s Manual, 2019).

The regional L-Skewness and L-Kurtosis values obtained from the Warroad station are plotted on the ratio diagram as shown in Figure 43.

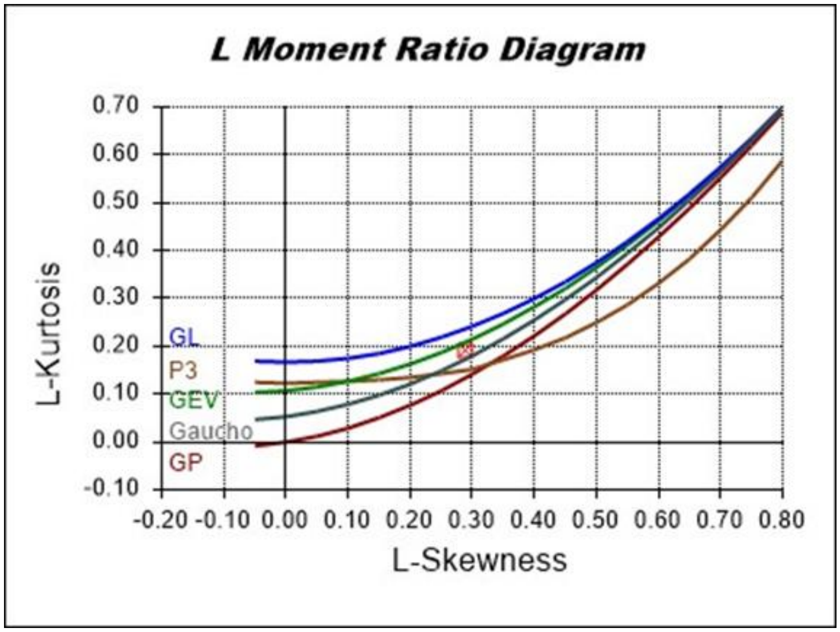


Figure 43. Warroad, Minnesota Station ID 21-8679 L-Kurtosis vs L-Skewness

L-RAP contains seven probability distributions for regional analysis, which encompass a wide range of L-Moment statistics and are useful in analyzing meteorological data. These distributions include:

- Generalized Logistic (GLO)
- Generalized Extreme Value (GEV)
- Generalized Normal (GNO)
- Gaucho
- Generalized Pareto (GPA)
- Pearson 3 (P3)
- Kappa distribution (KAP)

The distribution that best matched the region's L-Kurtosis and L-Skewness values was selected for the region's duration. The generalized extreme value (GEV) was the best-fitting probability distribution for the Warroad station as noted by the red “x” in Figure 43.

In accordance with the L-Moment Regional Analysis Program User’s Manual (2019), point precipitation frequency estimates were then determined by multiplying the GEV quantile values (best fitting distribution for all events) by the mean precipitation depth for the station. The mean is defined as the sample average annual maximum precipitation for the station’s specified duration (MGS L-Moment Regional Analysis Program User’s Manual, 2019).

To project the 2055 2, 5, and 10 year, 24-hour runoff events, the annual maximum precipitation values were separated into three timeframes.

- Timeframe 1: 1910 – 1943
- Timeframe 2: 1944 – 1977

- Timeframe 3: 1978 – 2010

These three separate timeframes were selected based on the World Meteorological Organization (WMO) 30-year standard for measuring climate patterns. This 30-year standard was developed to smooth short-term variabilities and capture long term trends with multiple weather cycles. To fit the 100 years of data provided by Atlas 14, timeframes were adjusted to capture all the precipitation data available (33–34-year intervals) (WMO, 2020).

Precipitation trends were identified using the 3 timeframes described above. LRAP computed the change in the estimated 2, 5, and 10-year 24-hour precipitation values for each of the time frames. A linear trend was then fit to the data to forecast the 2055 estimated point precipitation frequencies, yielding the following results in Table 11.

Table 11. 2055 Point Precipitation Frequency Analysis Depth Results

Event	Existing Atlas-14 Depth (in)	Proposed 2055 Depth (in)	Change (%)
2-Year	2.34	2.63	+12.2
5-Year	2.92	3.21	+10.4
10-Year	3.47	3.71	+7.3

Point precipitation estimates for each duration saw an increase. The greatest increase occurred for the smaller event (2-year) which saw an increase of 12.2%. The overall increase for each event was compared with the differences recorded between Atlas 14 Volume 8 and its predecessor, Atlas 2 Volume 3 (developed in 1973). For the 100-year 24-hour event point precipitation estimates, the Peatland restoration site saw an 11-20% increase as shown in Figure 44. The values developed by HDR align with the low side of this increase observed between 1973 and 2010 (NOAA, 2013).

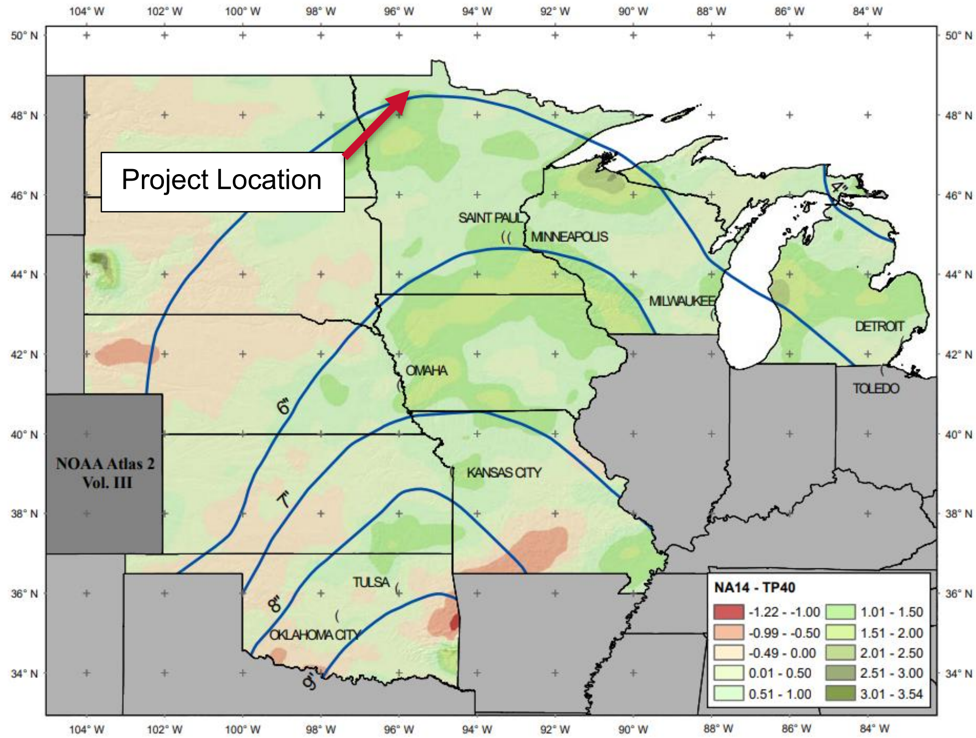


Figure 44. Percent Change Between Atlas 2 and Atlas 14

The same approach from section 3.1 was used to develop the projected hyetographs for each event. The nested temporal distribution hyetographs for the 2, 5, and 10 – year 24-hour precipitation events are shown in Figure 45-47.

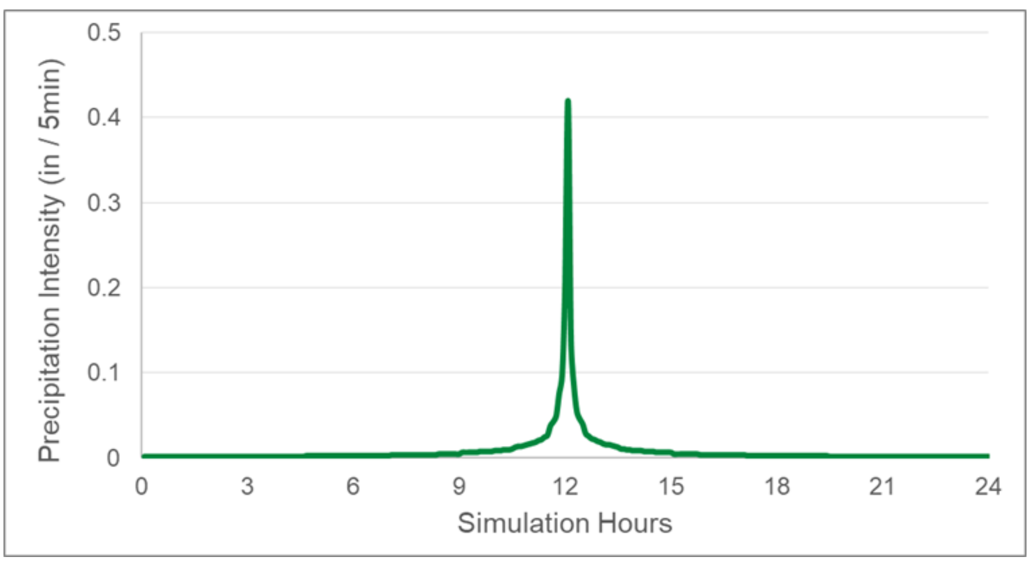


Figure 45. 2055 2-Year Nested Precipitation Hyetograph

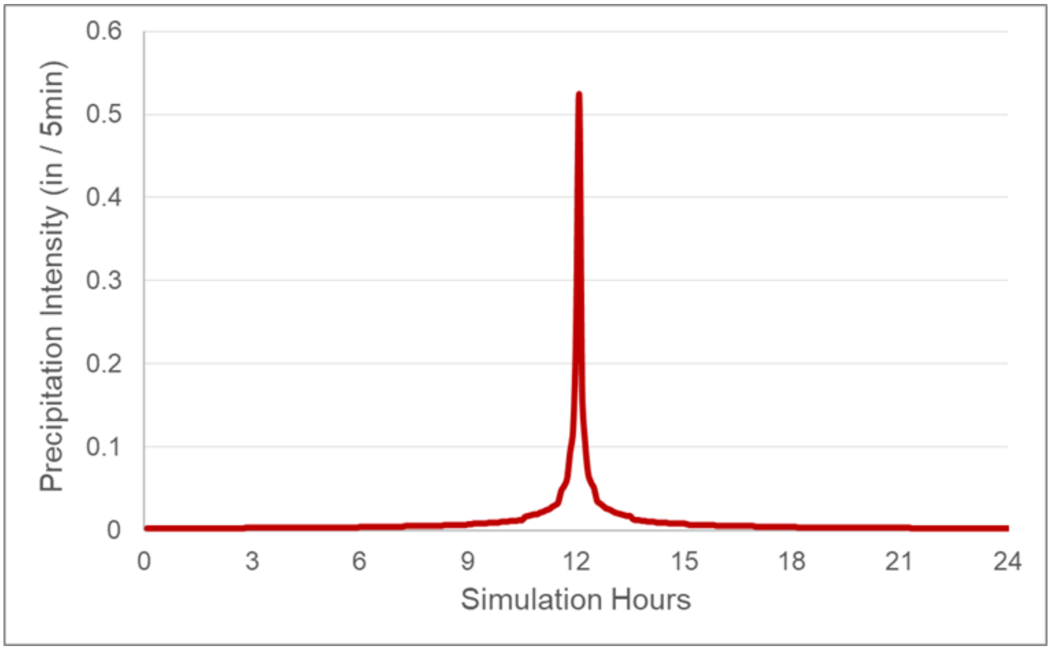


Figure 46. 2055 5-Year Nested Precipitation Hyetograph

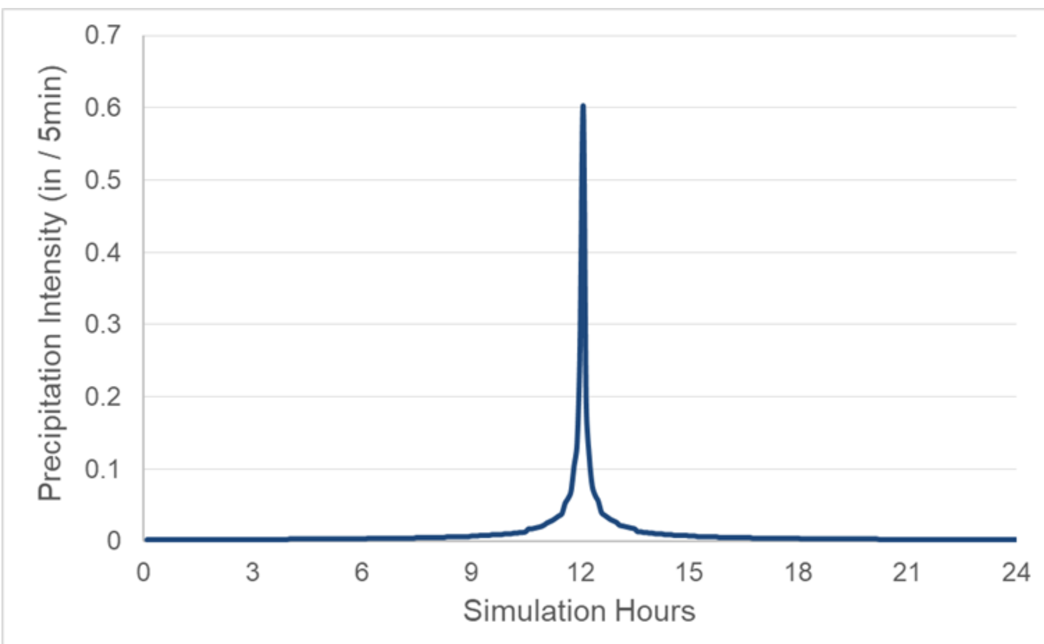


Figure 47. 2055 10-Year Nested Precipitation Hyetograph

5.2 Future Conditions Analysis Results

Results from simulations using the 2055 hyetographs indicated a consistent increase in discharge for each ditch relative to existing conditions. Figure 48 shows the change in discharge at ditch 10-C for the saturated 10-year 24-hour runoff event.

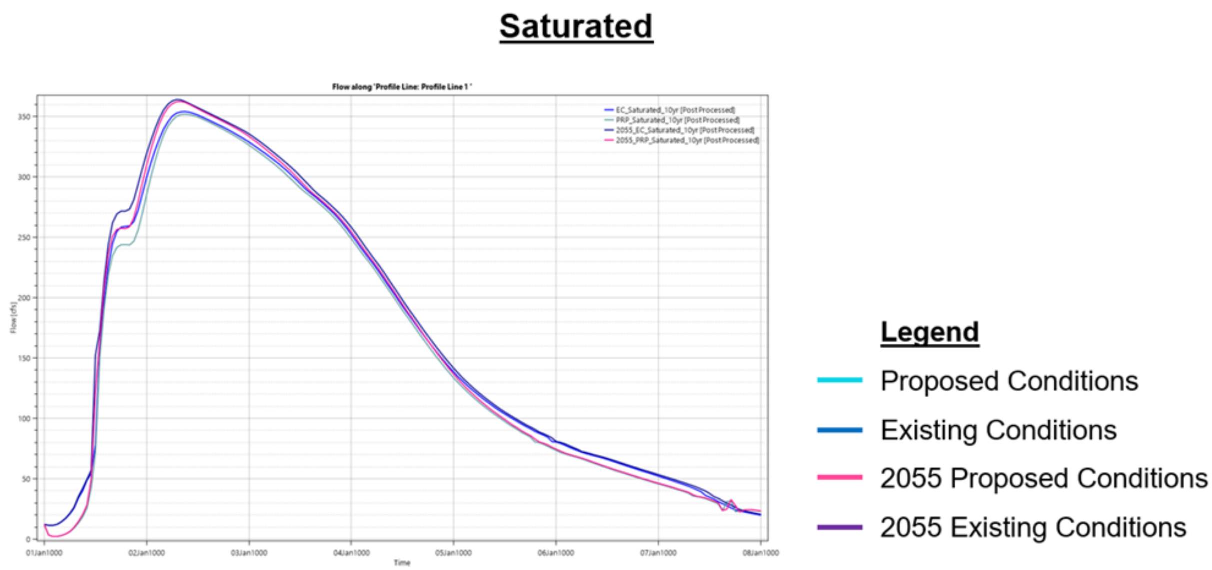


Figure 48. Ditch 10-C 10-year 24-hour Existing vs 2055 Discharge

While the 2055 trends suggest a 7.3% increase in the 10-year 24-hour precipitation event, The hydrograph in Figure 48 shows only a 2.7% increase. In addition, the peak under proposed conditions is slightly lower than the existing conditions. Cumulative volume results for ditch 10-C are shown in Figure 49.

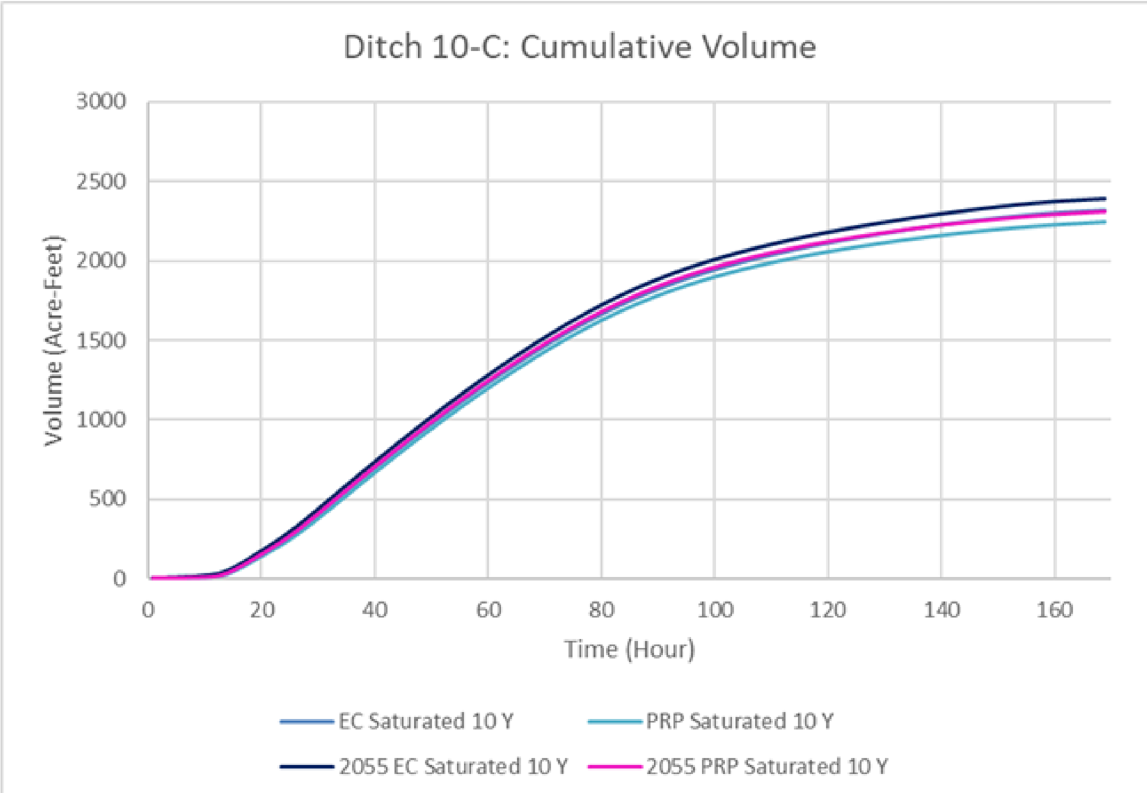


Figure 49. Ditch 10-C 10-Year 24-Hour Existing vs 2055 Cumulative Volume

Ditch 10-C cumulative volume Figure 49 shows an increase in total discharged from the site if left in its current state. If the ditches are plugged, the 2055 volume discharge will closely represent the current conditions of the site.

6 Discussion and Recommendations

Lake of the Woods SWCD and MNDNR have targeted the Winter Road Peatlands as a suitable region to conduct a pilot peatland restoration project. Modelling saturated and unsaturated conditions, ditch open and ditch restored conditions will aid in selecting suitable sites to initiate restoration activities. It is understood that restoring hydrology to peatlands improves/enhances/preserves sensitive habitat and increases climate resiliency. A primary concern of peatland restoration is evaluating if changes in hydrology have adverse impacts within the localized site or within the connected drainage network.

HDR Engineering, Inc. (HDR) used HEC-RAS version 6.6 to develop and apply a two-dimensional (2D) rain-on-grid model representing the rainfall-runoff response and maximum inundation extents for 2-, 5-, and 10-year return period precipitation events in the project area.

Discharge at the model outlets illustrates varied changes under proposed saturated conditions. Winter Road River exhibited increased discharges, while CSAH 2 found significant reduction in discharge. These results are likely due to the hydrologic connection to the Winter Road River headwaters being restored, increasing flows to the stream and therefore reducing flows to the ditch outlet at CSAH 2. The East Branch Warroad River encountered a reduction in flows during the 2-year and 5-year events, with increased peak discharge during the 10-year event. It is unknown if the pool at the Bednar Dam or other terrain features influence this dynamic between the rainfall events. West Branch Warroad River illustrated a fractional reduction in peak discharge across all three rainfall events. The limited reduction in peak discharge is likely due to the size of the catchments of proposed restoration sites in relation to the overall size of the drainage system's catchment.

Localized benefits of individual sites when saturated under restored conditions were varied, with all sites exhibiting reductions in peak discharge at their respective outlets. Increased inundation footprint was either a slight rise within the peatlands or no rise, indicating low potential impact on adjacent land use, low potential inundation impacts to peatland habitat through increased depth or duration, and no measured impact to private lands.

Results of the modelling were presented and distributed to the steering committee, review of the data and discussion regarding potential constraints were evaluated to determine which site(s) would be suitable to carry forward to construction. Based on the localized benefits, low potential impact, and support of the steering committee, JD62 – E, JD62 – UM, and JD62 – W are the ditch reaches most suitable for restoration.

7 References

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