

# North Dakota Statewide Irrigation Feasibility Study

## Final Report

Submitted to

North Dakota Irrigation Association  
North Dakota Department of Water Resources  
Garrison Diversion Conservancy District  
NDSU Office of Research and Creative Activity

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## Table of Contents

Executive Summary .....	3
1 Introduction.....	7
2 Phase I – Updating Soil Irrigability Maps .....	8
2.1 Classification methods .....	8
2.2 Soil irrigability maps.....	11
3 Phase II – Land Availability and Suitability for Irrigation .....	15
3.1 Removing unavailable land.....	15
3.2 Removing unsuitable land.....	18
3.3 Summary .....	26
4 Phase III – Water and Power Availability .....	31
4.1 Estimating existing irrigated cropland .....	31
4.2 Feasible parcels for irrigation development.....	33
4.3 Irrigation development potential from surface water sources.....	35
4.4 Irrigation development potential from groundwater sources .....	38
4.5 Irrigation development potential from power availability .....	45
5 Acknowledgement .....	48
6 References.....	48
A. Appendices.....	50
A.1. Soil Relative Irrigability.....	50
A.2. Identifying the existing center-pivot sprinkler systems .....	55
A.3. Relative Elevation Model (REM) .....	58

## Executive Summary

According to the USDA National Agricultural Statistics Service’s Census of Agriculture, less than one percent of cropland in North Dakota was irrigated in 2022. It was the least among the ten states that are entirely or partially covered by the Missouri River Basin and below the US average irrigated cropland, 14.4% (Table ES.1). To identify the locations and areas of the North Dakota croplands that have potential for future irrigation development, we conducted a statewide irrigation feasibility study.

**Table ES.1.** Irrigated cropland in the ten Missouri River Basin states.

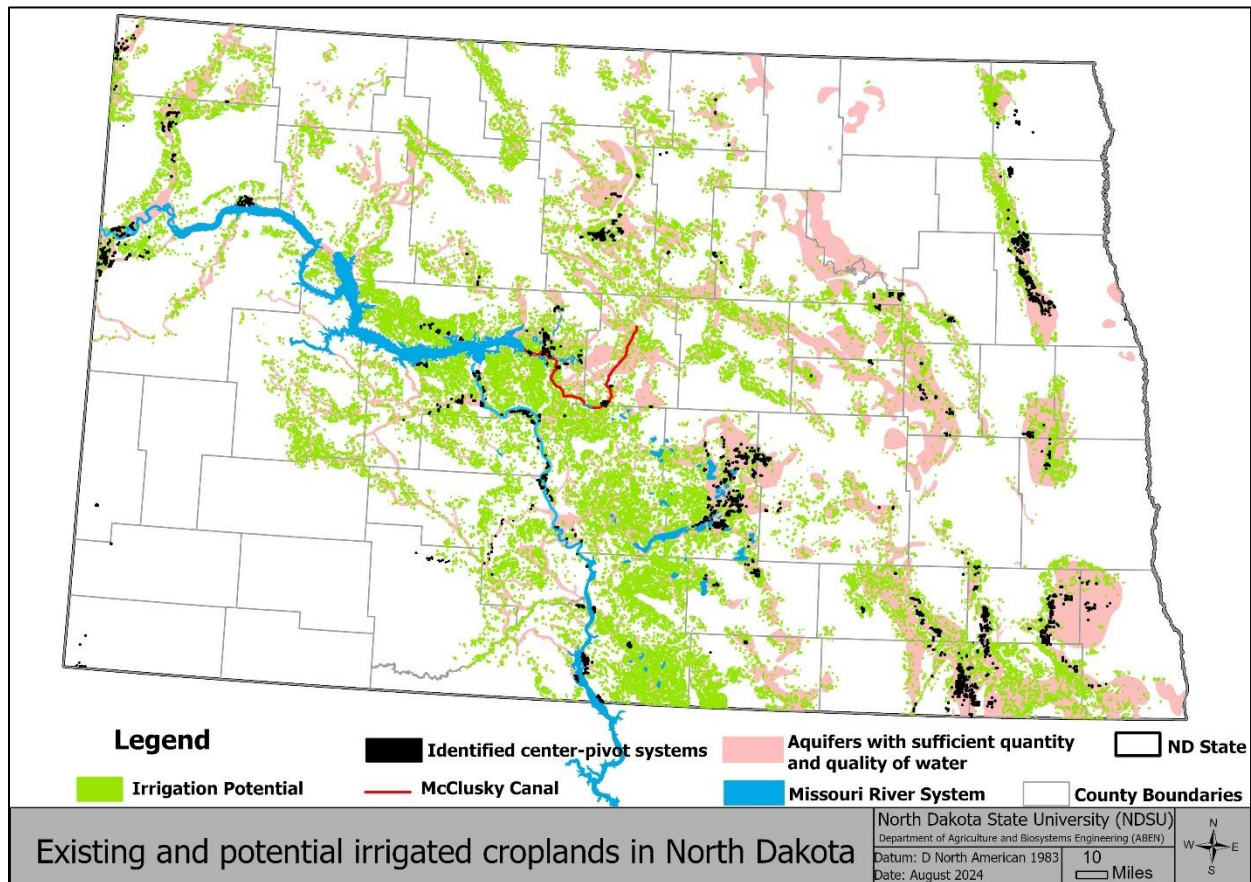
States	Cropland (Thousand acres)	Irrigated Cropland (Thousand acres)	Irrigated Cropland (%)
<b>Colorado</b>	10,479	2,288	21.8
<b>Iowa</b>	25,882	260	1.0
<b>Kansas</b>	28,341	2,245	8.3
<b>Minnesota</b>	21,544	648	3.0
<b>Missouri</b>	14,765	1,335	9.0
<b>Montana</b>	16,070	1,725	10.7
<b>Nebraska</b>	21,218	7,966	37.5
<b>North Dakota</b>	26,260	248	0.94
<b>South Dakota</b>	18,489	411	2.2
<b>Wyoming</b>	2,326	1,273	54.7
<b>Total</b>	<b>185,374</b>	<b>18,499</b>	<b>10.0</b>
<b>The U.S.</b>	<b>382,356</b>	<b>54,930</b>	<b>14.4</b>

This statewide irrigation feasibility study was carried out in three phases. In Phase I, we updated the North Dakota Department of Water Resources (DWR) soil irrigability map using the most recent Soil Survey Geographic Database (SSURGO) data. In Phase II, we removed the lands that were unavailable or unsuitable for developing irrigation projects from the updated soil suitability map. In Phase III, we identified and estimated the locations and areas of cropland with irrigation potential by examining the nearby water and three-phase power availabilities. This report summarizes the methods employed and the results obtained in this study.

It is important to note the limitation of our study which was intended to provide a statewide assessment of land in North Dakota for potential irrigation development. When assessing the potential of developing irrigation projects for specific areas, in-depth feasibility studies should be conducted to consider additional factors, including but not limited to design, cost, landowner preferences, environmental concerns, water permit applications, etc.

In summary, about 2.2 million acres of cropland in North Dakota have suitable soils and available water for irrigation. Among these croplands, approximately one-quarter (0.25) of a million acres have already been developed for irrigation, leaving approximately two million acres of cropland

statewide for future irrigation development. About one million acres of such cropland are located around the Missouri River corridor and the other one million acres are spread across the state where good-quality groundwater is available (Figure ES.1).

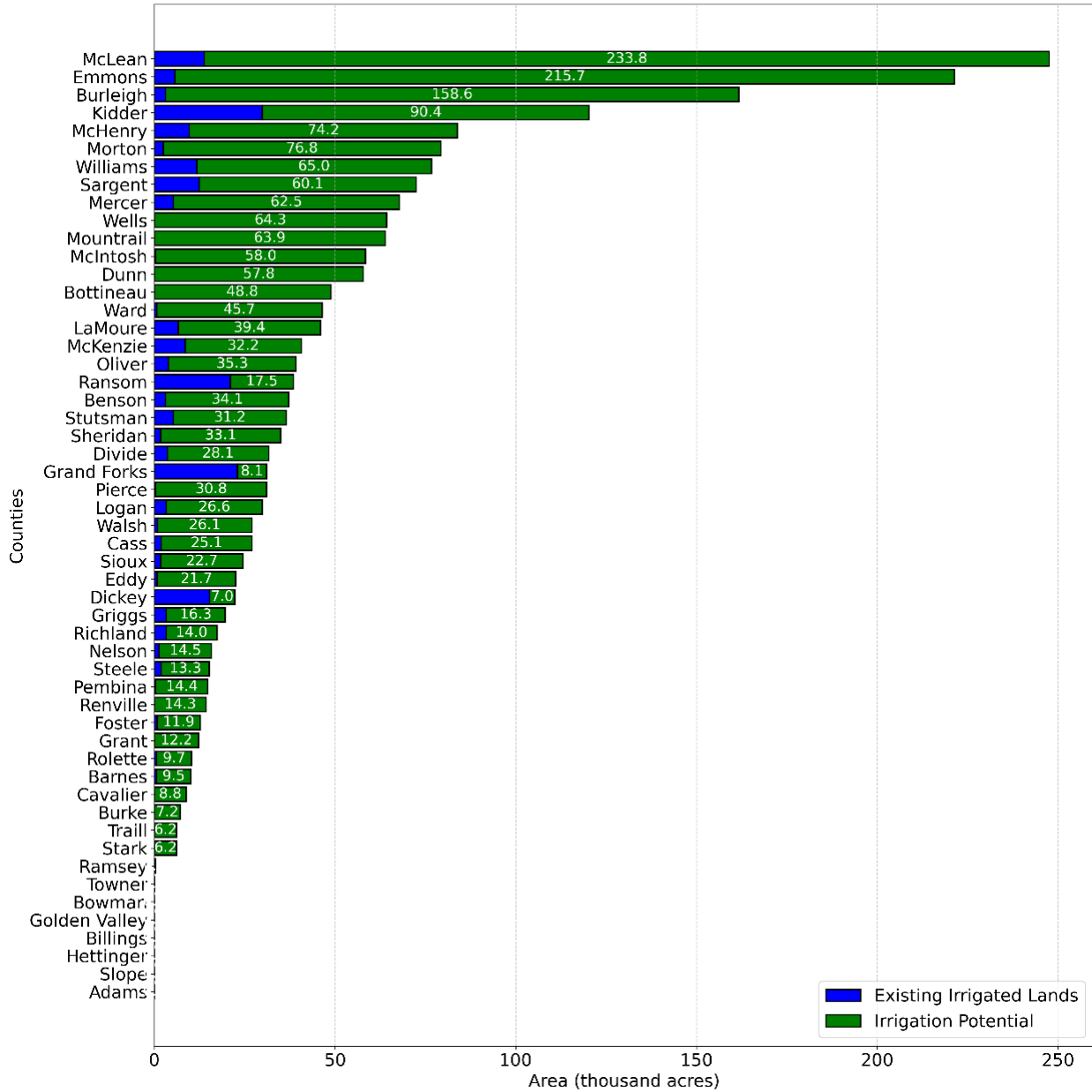


**Figure ES.1.** Existing irrigated and potentially irrigable croplands in North Dakota.

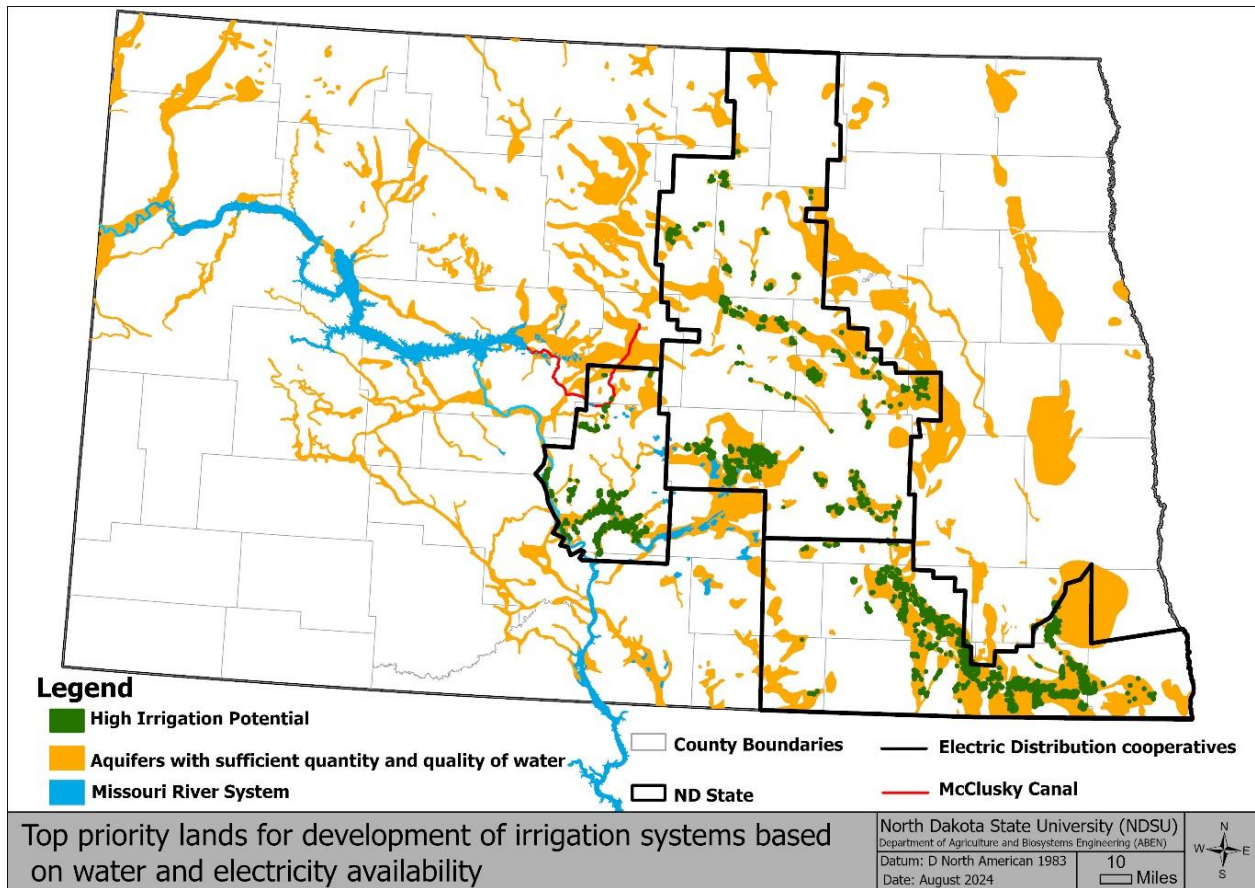
The areas of county-level existing and potentially irrigable croplands are ranked in Figure ES.2, which shows that central North Dakota counties (e.g., McLean, Emmons, Burleigh, Kidder, McHenry, Morton) have the most areas of cropland for potential irrigation development. Not surprisingly, the counties in southwestern North Dakota (e.g., Adams, Bowman, Billings, Golden Valley, Hettinger, Slope) do not have much land for irrigation development, nor do Ramsey and Towner counties in northeastern North Dakota. Statewide, 37 counties have more than ten thousand acres of cropland potential for future irrigation development.

Due to data privacy concerns, we can only access three-phase power distribution lines from three North Dakota electric distribution cooperatives (i.e., Capital Electric, Dakota Valley, Northern Plains) out of the 17 North Dakota electric distribution cooperatives. In the three above-mentioned electric cooperatives’ service areas, approximately three-quarters (0.75) of a million acres of cropland are within a one-mile distance of the existing three-phase power lines, which are about 7.8% of the croplands with irrigation potential based on soil suitability and water availability analysis (Figure ES.3). Thirteen (13) out of the 18 counties served by these three

electric cooperatives have more than 1,000 acres of croplands that are readily available for future irrigation development.



**Figure ES.2.** Areas of the existing irrigated and potentially irrigable croplands in North Dakota counties (The numbers over the green bars are thousands of acres of croplands with irrigation potential in each county).



**Figure ES.3.** Croplands with irrigation potential within one mile distance of three-phase power lines of Capital Electric, Dakota Valley, and Northern Plains Cooperatives.

## 1 Introduction

According to the USDA National Agricultural Statistics Service’s Census of Agriculture (NASS, 2022a), approximately 14.4% of the US cropland was irrigated in 2022. In the ten states that are entirely or partially covered by the Missouri River basin, the percentages of irrigated cropland ranged from 0.94% (North Dakota) to 54.7% (Wyoming). As shown in Table 1.1, less than one-quarter of a million acres out of 26+ million acres of cropland in North Dakota were irrigated in 2022.

**Table 1.1** Irrigated cropland in the ten Missouri River Basin states (NASS, 2022a).

States	Cropland (Thousand acres)	Irrigated Cropland (Thousand acres)	Irrigated Cropland (%)
<b>Colorado</b>	10,479	2,288	21.8
<b>Iowa</b>	25,882	260	1.0
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<b>Total</b>	<b>185,374</b>	<b>18,499</b>	<b>10.0</b>
<b>The U.S.</b>	<b>382,356</b>	<b>54,930</b>	<b>14.4</b>

The goal of this technical feasibility study is to identify and estimate the locations and areas of the land in North Dakota that have high potential for developing irrigation projects in the future. The study is carried out in three phases. In Phase I, we updated the North Dakota Department of Water Resources (DWR) soil irrigability map using the most recent Soil Survey Geographic Database (SSURGO) data. In Phase II, we removed the lands that were unavailable or unsuitable for developing irrigation projects from the updated soil suitability map. In Phase III, we identified and estimated the locations and areas of cropland with irrigation potential by examining the nearby water and three-phase power availabilities. This report summarizes the methods employed and the results obtained in the three phases.

It is important to note the limitation of our study which was intended to provide a statewide assessment of land in North Dakota for potential irrigation development. However, in evaluating irrigation development for specific areas, more in-depth feasibility studies should be conducted to consider additional factors, including but not limited to design, cost, landowner preferences, environmental concerns, water permit applications, etc.

## 2 Phase I – Updating Soil Irrigability Maps

### 2.1 Classification methods

The updated soil irrigability map was developed based on the SSURGO data updated by the United States Department of Agriculture (USDA) Natural Resources Conservation Service in October 2023 (USDA-NRCS, 2024). The SSURGO datasets consist of soil map units and tabular data of soil components and their properties. The map units are linked to tabular data in the database. As outlined in the SSURGO Table Diagram (Figure 2.1), each soil map unit consists of multiple soil components. There are several options for aggregating component properties to the map unit level (USDA-NRCS, 2023). The existing North Dakota DWR soil irrigability map used a “Dominant Component” approach. However, we decided to use the “Dominant Condition” approach in this study. For a given soil property, referred to here as a “condition”, the “Dominant Component” approach assigns the condition associated with the largest component within the map unit. In contrast, the “Dominant Condition” approach assigns the most frequent condition found within the map unit.

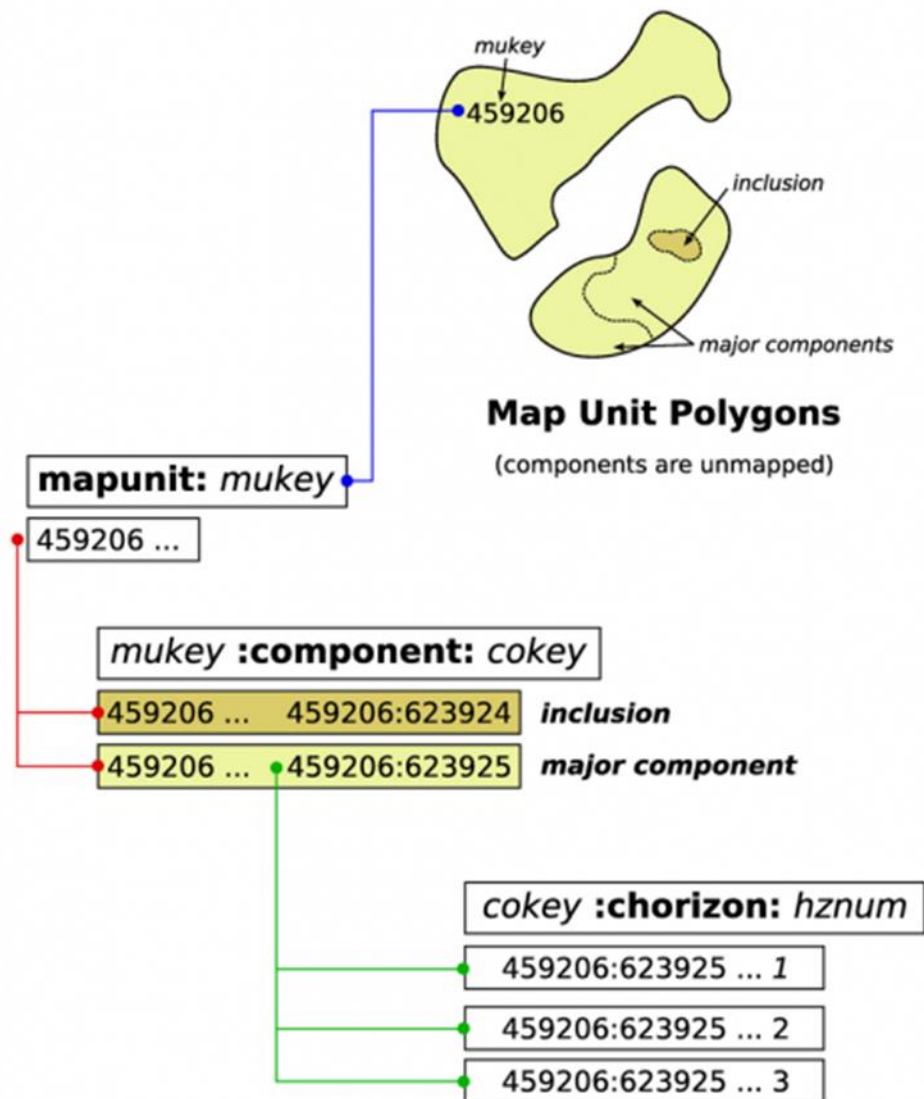
To illustrate the difference between these two methods, let’s use an example of a map unit with three components (USDA-NRCS, 2023). Soil A has a “severe” rating and is 45% of the map unit. Soil B has a “moderate” rating and is 30% of the map unit. Soil C has a “moderate” rating and is 25% of the map unit. Using the “Dominant Component” method, the rating value for Soil A (i.e., “severe”) is used because Soil A makes up most of the map unit (45%). Using the “Dominant Condition” method, the rating value of “moderate” is used because Soil B and C both have a “moderate” rating and together they make up most of the map unit (55%).

In the NDSU Extension Bulletin AE1637 - *Compatibility of North Dakota Soils for Irrigation* (Revised March 2023), Scherer et al. (2023) categorized North Dakota soil series into 29 irrigability groups, with each irrigability group belonging to one of three Irrigation Types: irrigable (1i-7i), conditional (8c-22c), and non-irrigable (23n-29n). Therefore, there are four different *Irrigation Types*:

- 1) Water,
- 2) Irrigable,
- 3) Conditional, and
- 4) Non-irrigable.



# SSURGO Table Diagram



**Figure 2.1.** SSURGO Table Diagram.

Since there are several reasons why a soil may be classified as conditional, Scherer (undated) developed three sub-categories for conditionally irrigable soils:

- i. Poor internal drainage, moderately slow and slow permeability (8c – 11c, 21c),
- ii. Restricted drainage, high permeability layer with restricted layer below (12c – 14c), and
- iii. Supplemental drainage required, poorly drained, high water table and salinity concerns (15c – 20c, 22c).

We have also implemented this level of specificity into this study and termed them as *Irrigation Functional Groups*: conditional – permeability, conditional – restricted, and conditional – drainage, water table, salinity. In addition, we further classified certain non-irrigable soils into a “non-irrigable due to slope” irrigation functional group, using the following criteria concerning representative slope and texture of the top soil layer (Scherer et al., 2023):

- a) Soil components with slopes  $> 6\%$ , for soil textures that are more susceptible to erosion, including coarse sand, coarse sandy loam, fine sand, fine sandy loam, loamy coarse sand, loamy fine sand, loamy sand, loamy very fine sand, sand, sandy loam, very fine sandy loam;
- b) Soil components with slopes  $\geq 9\%$ , for soil textures that are less susceptible to erosion, including those not listed above.

Therefore, there are seven different *Irrigation Functional Groups*:

- 1) Water,
- 2) Irrigable,
- 3) Conditional – restricted layer,
- 4) Conditional – permeability,
- 5) Conditional – drainage, water table, salinity,
- 6) Non-irrigable due to slope, and
- 7) Non-irrigable.

We included *all* soil components within a map unit to aggregate soil component irrigability ratings to the map unit level. For each map unit, we employed a two-step process with tiebreakers specified in Table 2.1 for the permissive and restrictive scenarios, respectively. In the two-step process, we first classified the soils in terms of the four irrigation types, and then in terms of the seven irrigation functional groups. During the classification process, we also needed to make assumptions about tiebreaking scenarios when determining the dominant conditions as we aggregated the soil component properties to the soil irrigability ratings at the map unit level. We made different assumptions under two different scenarios: permissive and restrictive. Under the permissive scenario, we prioritized the conditions *most* suitable for irrigation (given water is not a dominant condition), while under the restrictive scenario, we prioritized the conditions *least* suitable for irrigation (given water is not a dominant condition).

In addition, each soil description may have different local phases of slope and other properties, such as saline, wet, drained, frequently flooded, etc., that may affect the soil’s suitability for irrigation. These local phase properties were not considered in the NDSU Extension Bulletin AE1637 (Scherer et al., 2023) as these local phase properties are ephemeral and may be responsive to management. In this study, we did not consider the local phase soil properties under the permissive scenario but considered them under the restrictive scenario. Given these assumptions, we expect more soils will be categorized as irrigable or conditionally irrigable under the permissive scenario than under the restrictive scenario.

**Table 2.1.** Assumptions underlying the permissive and restrictive scenarios.

Item	Permissive scenario	Restrictive scenario
Local phase <sup>a</sup>	Not considered	Considered
Dominant condition tiebreak order <sup>b</sup>	<p>Prioritize the condition most suitable for irrigation, unless water is the dominant condition.</p> <p><b>Irrigation Types:</b></p> <ol style="list-style-type: none"> <li>1. Water</li> <li>2. Irrigable</li> <li>3. Conditional</li> <li>4. Non-irrigable</li> </ol> <p><b>Irrigation Functional Groups:</b></p> <ol style="list-style-type: none"> <li>1. Water</li> <li>2. Irrigable</li> <li>3. Conditional – restricted layer</li> <li>4. Conditional – permeability</li> <li>5. Conditional – drainage, water table, salinity</li> <li>6. Non-irrigable due to slope</li> <li>7. Non-irrigable</li> </ol>	<p>Prioritize the conditions least suitable for irrigation, unless water is the dominant condition.</p> <p><b>Irrigation Types:</b></p> <ol style="list-style-type: none"> <li>1. Water</li> <li>2. Non-irrigable</li> <li>3. Conditional</li> <li>4. Irrigable</li> </ol> <p><b>Irrigation Functional Groups:</b></p> <ol style="list-style-type: none"> <li>1. Water</li> <li>2. Non-irrigable due to slope</li> <li>3. Non-irrigable</li> <li>4. Conditional – drainage, water table, salinity</li> <li>5. Conditional – permeability</li> <li>6. Conditional – restricted layer</li> <li>7. Irrigable</li> </ol>

<sup>a</sup>Phase criterion to be used at a local level, in conjunction with “component name” to help identify a soil component.

<sup>b</sup>When determining the dominant condition within a map unit, how are any ties handled? Which condition is displayed on the map?

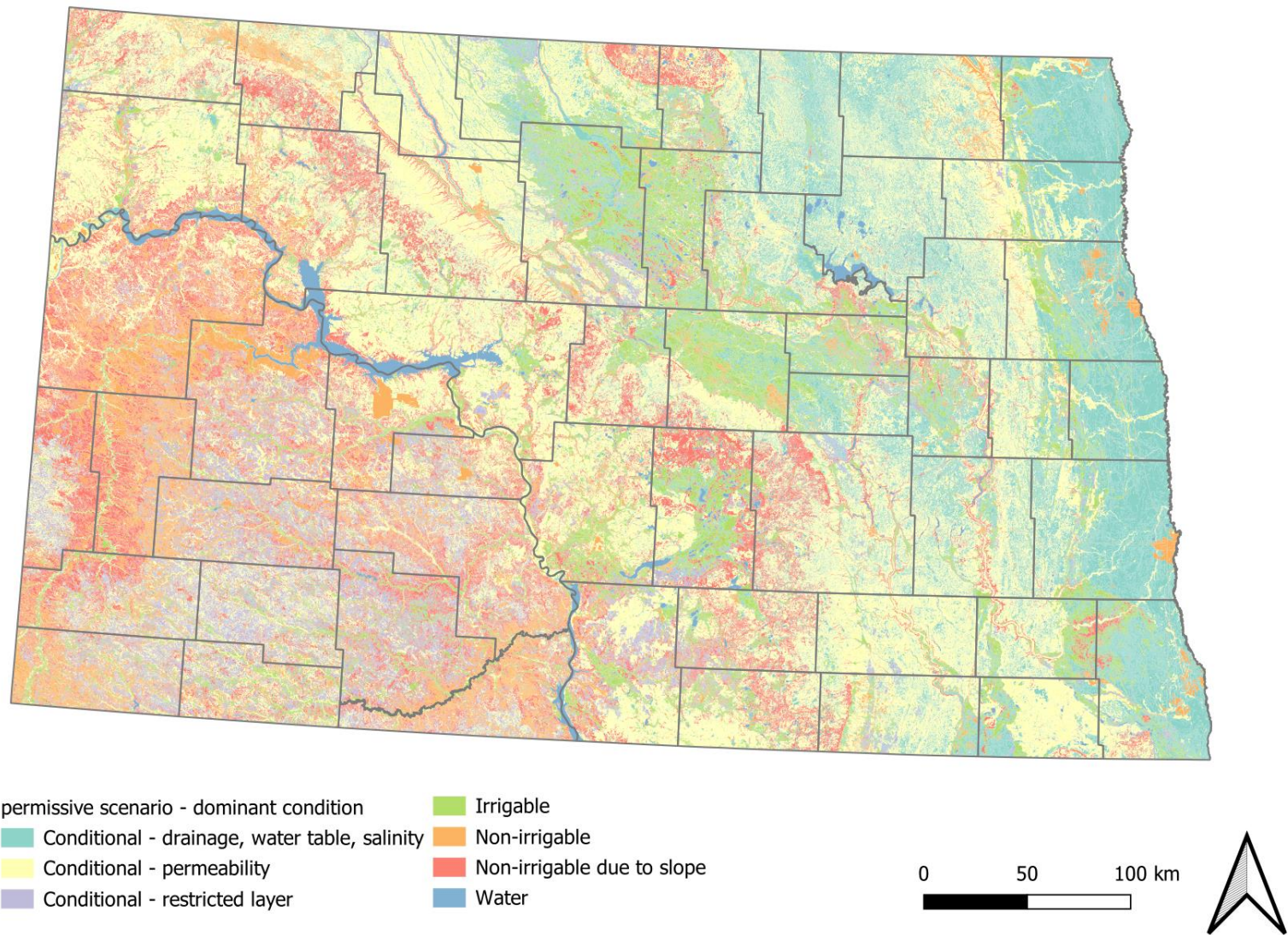
The above classification process will produce a soil irrigability map that is based on dominant conditions within map units. In other words, only the dominant irrigation functional group (one out of the seven) within each map unit will be selected and displayed on the map, given the tiebreaker assumptions defined in Table 2.1 for each scenario. An alternative classification method is described in Appendix A.1, which will produce the relative irrigability maps under both scenarios.

## 2.2 Soil irrigability maps

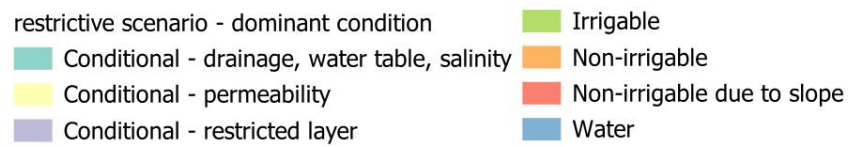
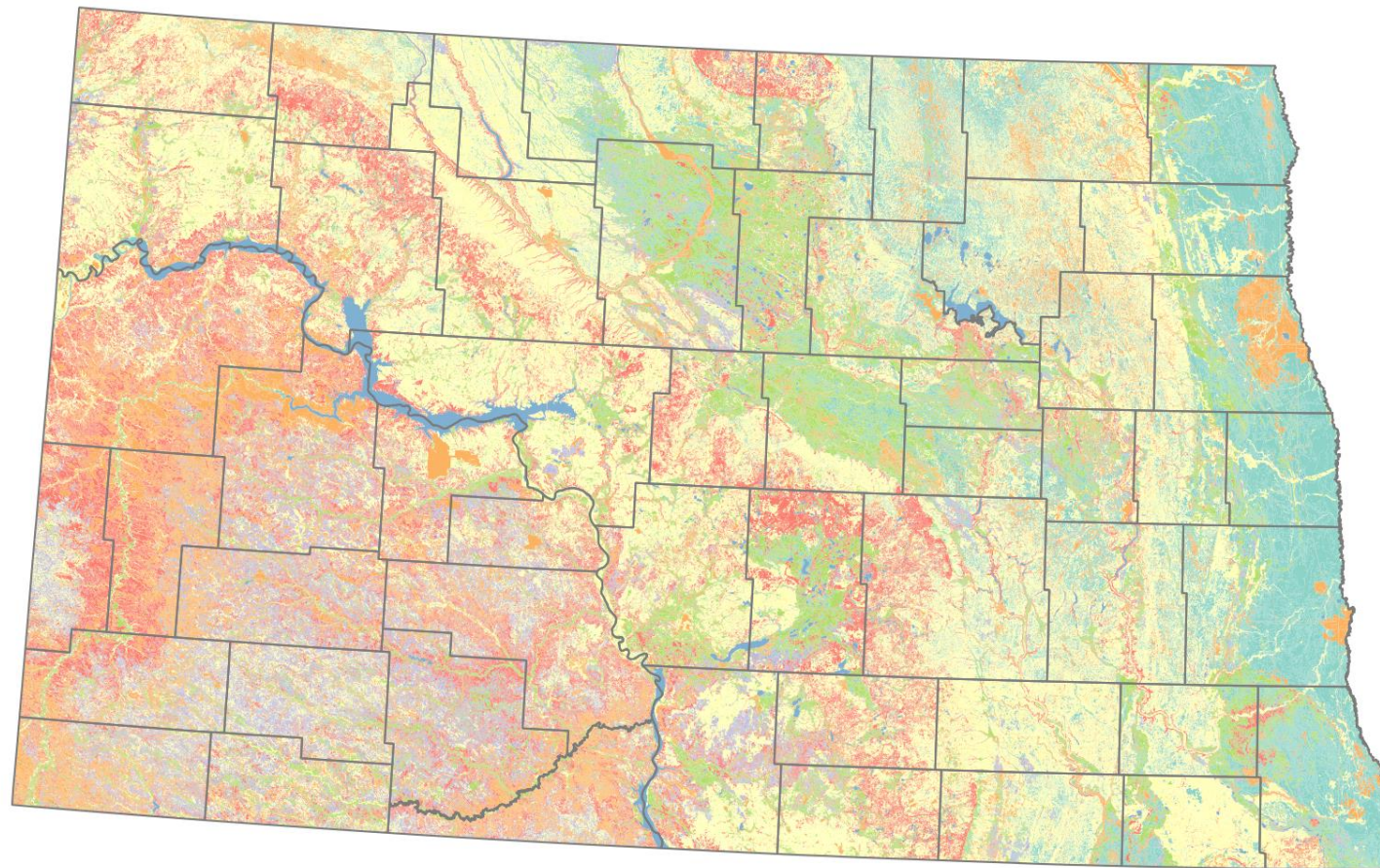
Table 2.2 summarizes the soil irrigability classification for all soil series in North Dakota (45.3 million acres) under the permissive and restrictive scenarios. It shows that around 5.4 million acres (11.9%) are irrigable soils, about 25.1 to 27.6 million acres (55.2% to 60.9%) are conditionally irrigable soils, and about 11.2 to 13.8 million acres (24.7% to 30.5%) are non-irrigable soils. Table 2.2 also shows that the assumptions made about tiebreaking and local phase consideration under the two different scenarios did not make a big difference for almost all irrigation functional groups except for “conditional – drainage, water table, salinity”. About 2.25 million acres of soils (~25%) in the “conditional – drainage, water table, salinity” group under the permissive scenario were classified as “non-irrigable” soils under the restrictive scenario. Figures 2.2 & 2.3 display the soil irrigability maps of dominant conditions under the permissive and restrictive scenarios, respectively. A close inspection of these two figures shows that this change in classification mostly occurred in Grand Forks County in northeast North Dakota.

**Table 2.2.** Summary of soil irrigability classification of dominant conditions.

<b>Dominant condition</b>	<b>Permissive scenario</b>		<b>Restrictive scenario</b>	
	<b>map unit count</b>	<b>million acres</b>	<b>map unit count</b>	<b>million acres</b>
<i>Irrigation Type</i>				
Water	187	0.96	187	0.96
Irrigable	1666	5.41	1648	5.38
Conditional	5116	27.65	4369	25.13
Non-irrigable	2451	11.23	3216	13.78
<i>Irrigation Functional Group</i>				
Water	187	0.96	187	0.96
Irrigable	1666	5.41	1648	5.38
Conditional – restricted layer	810	3.36	809	3.36
Conditional – permeability	2109	15.15	2014	14.89
Conditional – drainage, water table, salinity	2197	9.14	1546	6.89
Non-irrigable	1118	4.09	1990	6.82
Non-irrigable due to slope	1333	7.14	1226	6.97



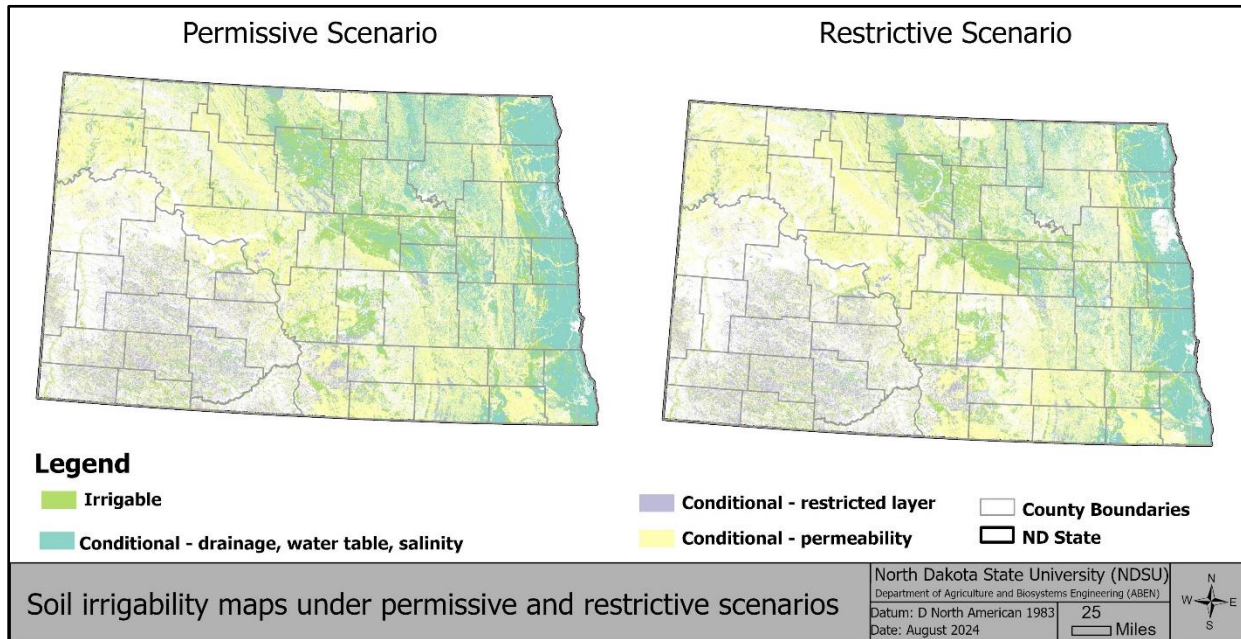
**Figure 2.2.** Soil irrigability map of dominant condition for the permissive scenario.



**Figure 2.3.** Soil irrigability map of dominant condition for the restrictive scenario.

### 3 Phase II – Land Availability and Suitability for Irrigation

The soil irrigability maps under the permissive and restrictive scenarios (Figures 2.2 & 2.3) are re-displayed in Figure 3.1 with the non-irrigable soils and water omitted for simplicity.



**Figure 3.1.** Soil irrigability maps under permissive and restrictive scenarios.

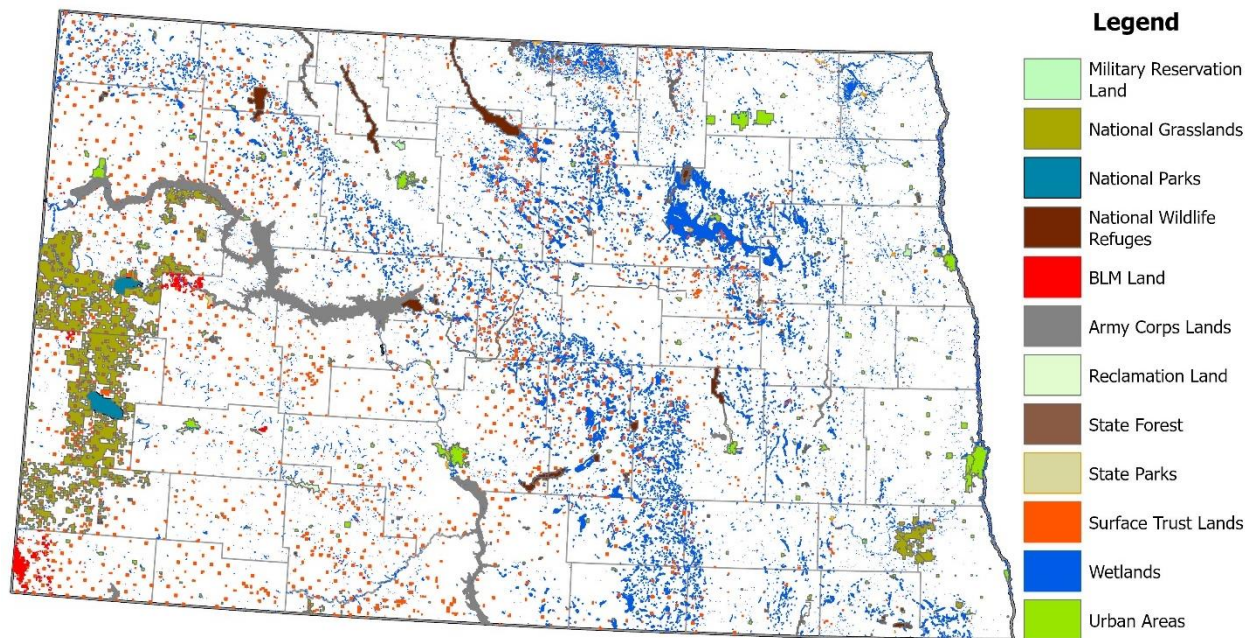
#### 3.1 Removing unavailable land

Our goal in this phase is to remove from the irrigable and conditionally irrigable soil layers those lands that are unavailable or unsuitable for developing irrigation projects. First, we removed unavailable lands: federal and state public lands and urban areas that are prohibited from developing any irrigation projects. These lands are listed in Table 3.1 and the GIS layers of these lands were downloaded from the ND GIS Hub. Figure 3.2 shows a schematic view of these layers.

**Table 3.1.** Lands unavailable for developing irrigation projects.

No.	Layer Name	Description
1	City Boundaries	Geographic boundaries defining the limits of municipalities or cities, used for administrative and governance purposes.
2	National Grasslands	Federally managed lands primarily designated for the conservation and management of native grassland ecosystems.
3	National Parks	Protected areas established and maintained by federal governments to conserve the natural environment, provide recreation opportunities, and preserve cultural and historical resources.
4	National Wildlife Refuge	Protected areas designated to conserve wildlife and their habitats, managed by the U.S. Fish and Wildlife Service.
5	State Forests	Publicly owned forests managed at the state level for conservation, recreation, and sustainable timber production.
6	State Parks	Parks established and maintained by state or federal governments for recreation, conservation, and the protection of natural and cultural resources.
7	Wetlands	Areas where water covers the soil or is present near the surface for part of the year, providing crucial habitat for wildlife and contributing to flood control and water purification.
8	Surface Trust Lands	Lands held in trust by the state or federal government for specific purposes, such as supporting public schools or managing natural resources.
9	Army Corps Lands	Lands managed by the U.S. Army Corps of Engineers, primarily used for flood control, infrastructure projects, and recreation
10	BLM Land	Lands managed by the Bureau of Land Management (BLM), used for a variety of purposes including grazing, recreation, and resource extraction
11	Military Reservation Land	Land designated for military use, including training, defense infrastructure, and operations
12	Reclamation Land	Land managed by the Bureau of Reclamation primarily focused on water resource management, irrigation, and reclamation of previously irrigated or developed lands

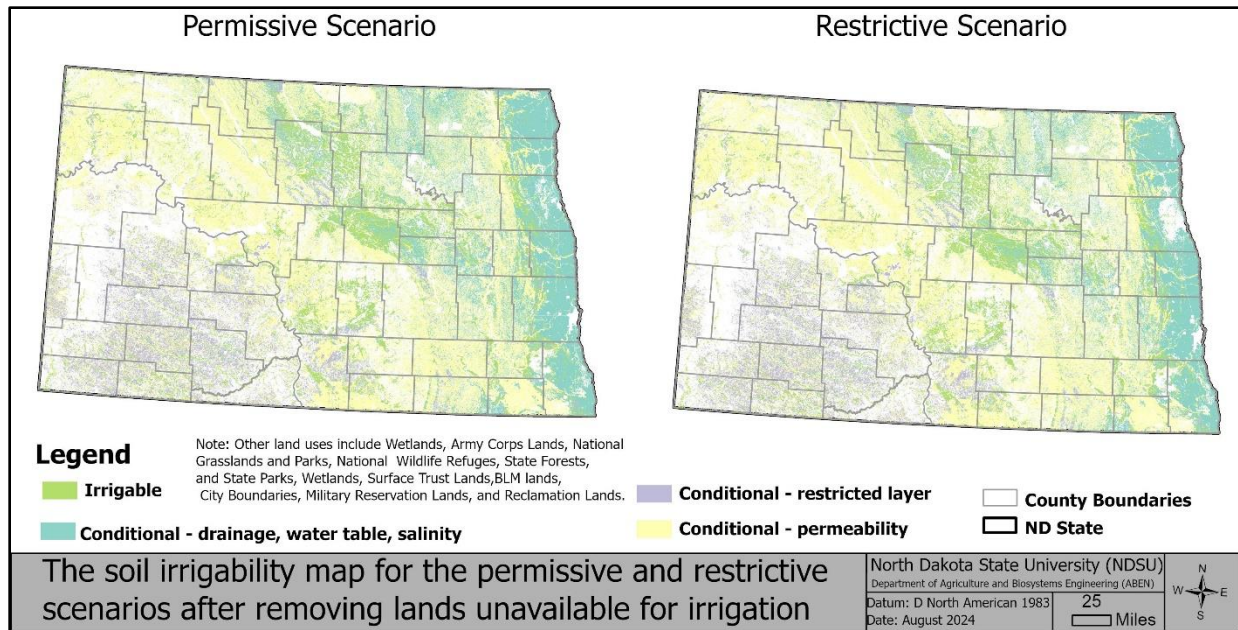




Schematic view of lands removed from the irrigable and conditionally irrigable soils	North Dakota State University (NDSU)		
	Department of Agriculture and Biosystems Engineering (ABEN)		
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Date: August 2024	Miles		

**Figure 3.2.** Schematic view of lands removed from the soil irrigability maps.

Figure 3.3 shows the map units of irrigable and conditionally irrigable soils, under the restrictive and permissive scenarios, after removing these land areas considered unavailable for irrigation. Table 3.2 provides a statewide summary of irrigable and conditionally irrigable acreage, which only saw a slight reduction under either scenario.



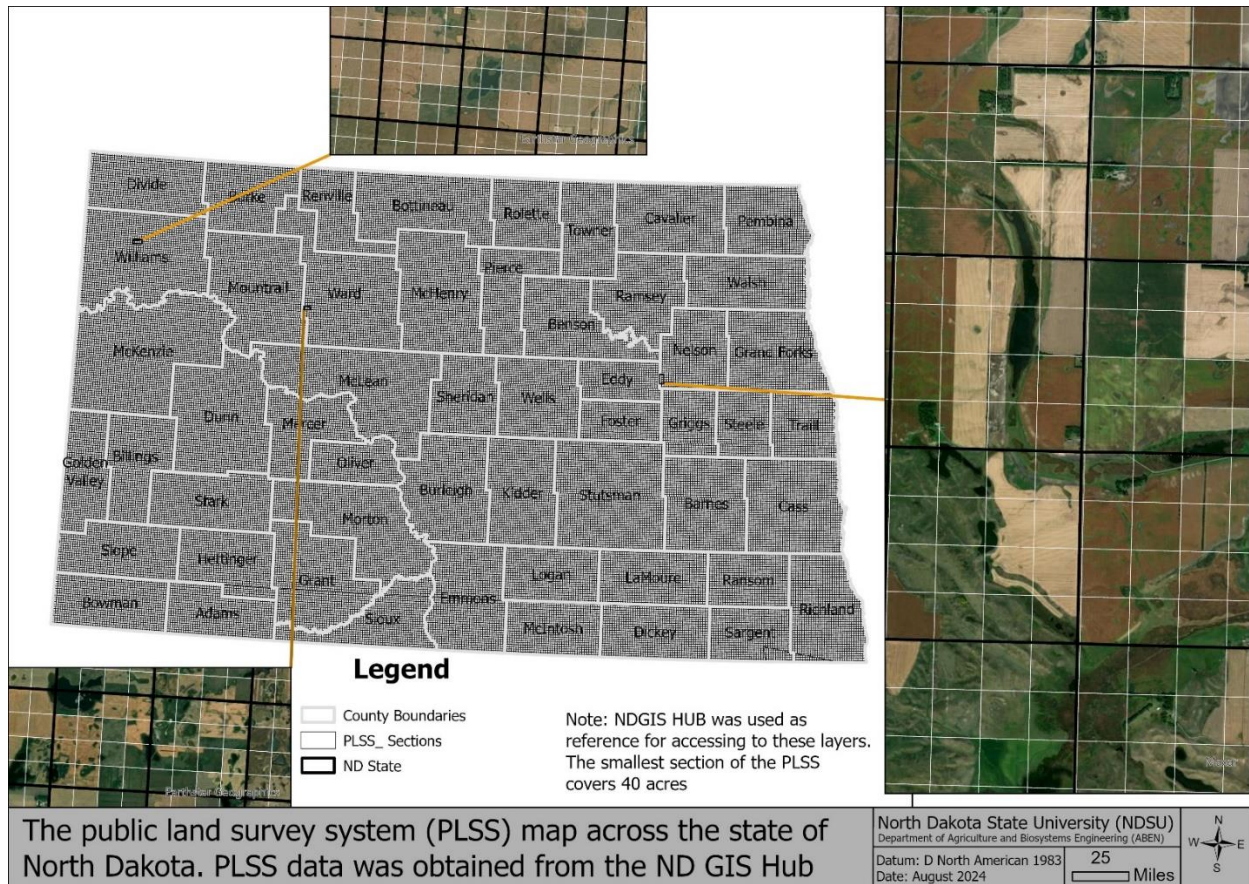
**Figure 3.3.** The soil irrigability map for the permissive and restrictive scenarios after removing lands unavailable for irrigation.

**Table 3.2.** Summary of soils after removing lands unavailable for irrigation.

Dominant condition	Permissive scenario (Million acres)		Restrictive scenario (Million acres)	
	Before	After	Before	After
<i>Irrigation Type</i>				
Irrigable	5.40	4.96	5.37	4.95
Conditional	27.64	24.38	25.11	23.12
<i>Irrigation Functional Group</i>				
Irrigable	5.40	4.96	5.37	4.95
Conditional – restricted layer	3.35	3.21	3.35	3.21
Conditional – permeability	15.15	14.15	14.88	13.93
Conditional – drainage, water table, salinity	9.14	7.02	6.88	5.98

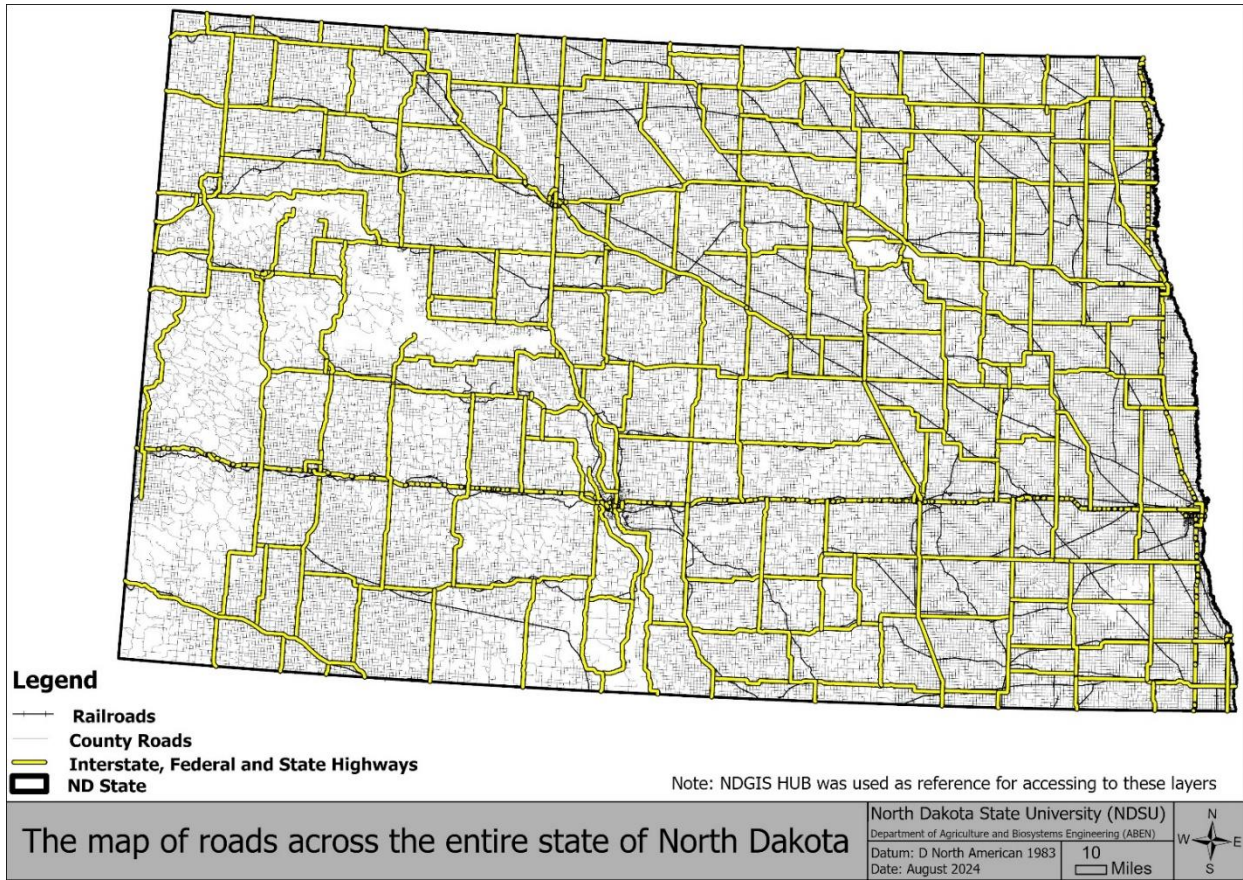
### 3.2 Removing unsuitable land

Next, we removed the lands that were unsuitable for developing irrigation projects. We defined unsuitable lands as Public Land Survey System (PLSS) quarter-quarter (Q-Q) sections (Figure 3.4) featuring substantial intersections with railroads, roads, streams, rivers, overhead power transmission lines, buildings, or other structures. This is based on our assumption that a piece of land (in this case, a quarter-quarter section or 40 acres) featuring a large structure (such as a building or a wind turbine) or substantially bisected by railroads, roads, streams, rivers, or overhead transmission lines is unsuited for the installation of a center-pivot irrigation system.

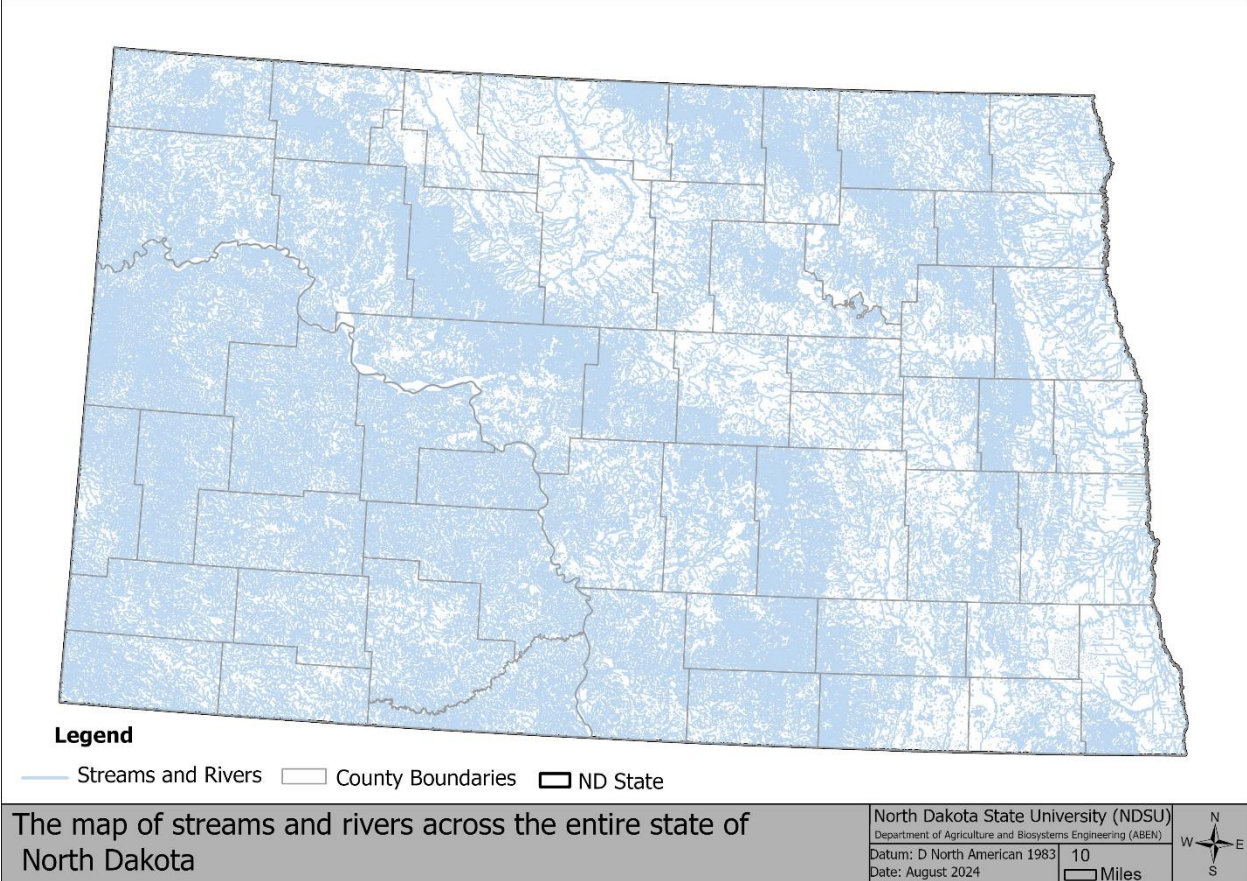


**Figure 3.4.** The public land survey system (PLSS) maps across the state of North Dakota. Note: The PLSS data was obtained from the North Dakota GIS Hub.

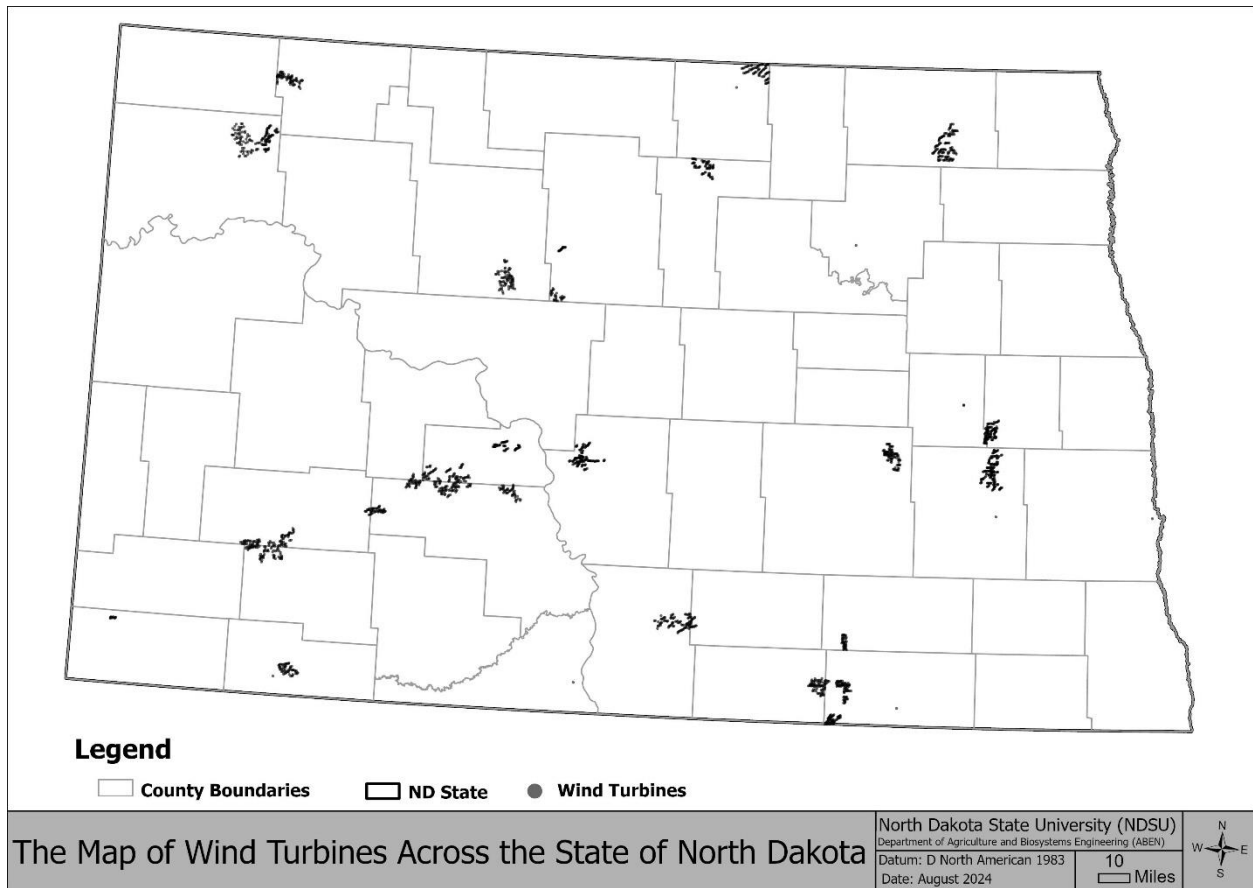
Road features, including (i) railroads, (ii) interstate, federal and state highways, and (iii) county roads, were downloaded from the ND GIS Hub and merged into a single layer (Figure 3.5). The 1:24K scale streams and rivers hydrography data (Figure 3.6) and locations of wind turbines (Figure 3.7) were also downloaded from the ND GIS Hub.



**Figure 3.5.** The road features across the state of North Dakota.

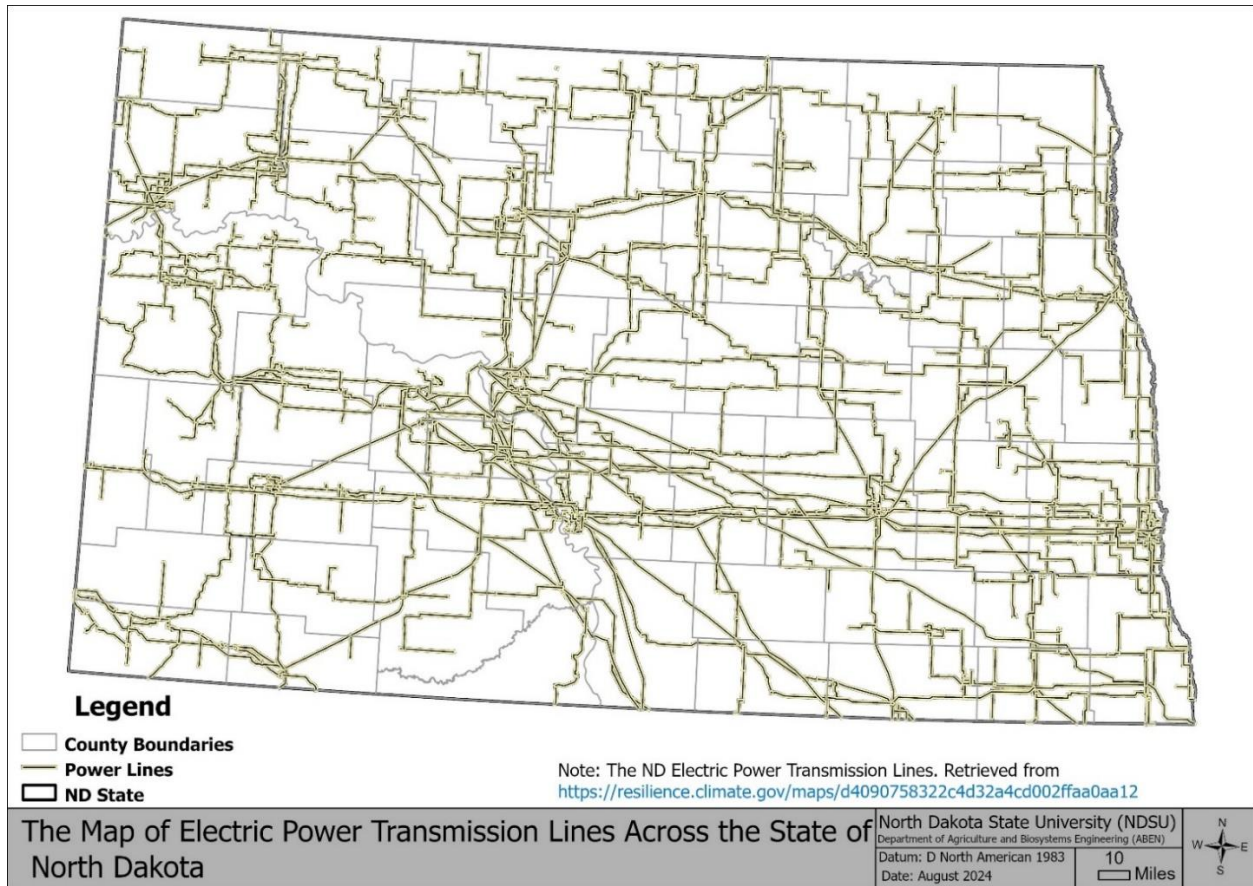


**Figure 3.6.** The streams and rivers across the state of North Dakota.

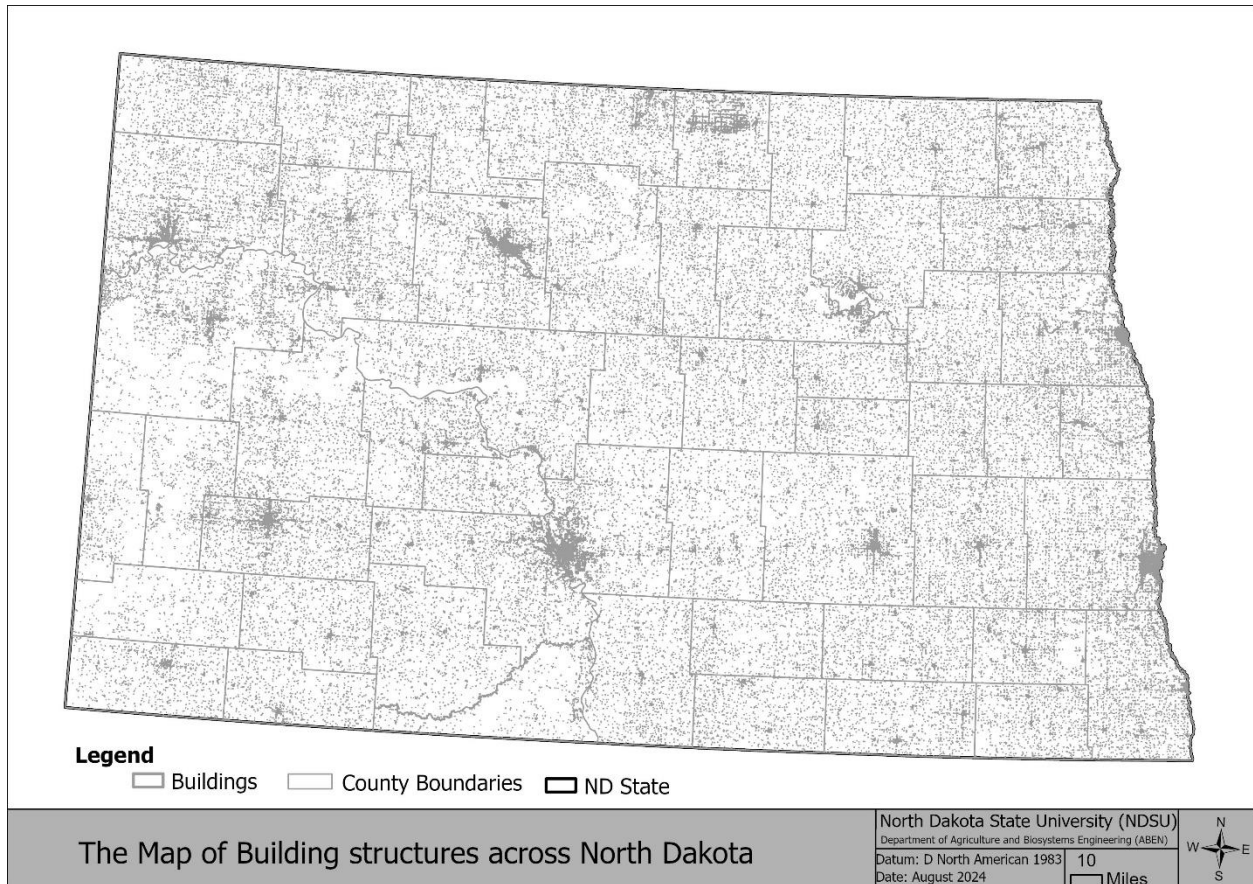


**Figure 3.7.** The locations of wind turbines across the state of North Dakota.

Additionally, North Dakota electric power transmission lines (Figure 3.8) were retrieved from the [Climate Mapping for Resilience and Adaptation](#). Building structures were obtained from the FEMA's USA Structures State GDB Download Site (Figure 3.9). This dataset uses FEMA's data and displays, for the United States and its territories, all structural footprints larger than 450 square feet.



**Figure 3.8.** Electric power transmission lines across the state of North Dakota.



**Figure 3.9.** Building structures across the state of North Dakota.

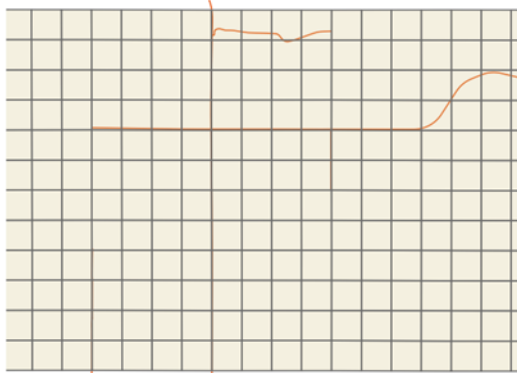
Using the Select By Location tool in ArcGIS Pro, we modified the PLSS Q-Q section layer by detecting and removing any parcel that contained one or more large structures such as buildings or wind turbines. Therefore, we assumed that the existence of a wind turbine or any building larger than 450 square feet on a PLSS Q-Q section would obstruct the implementation of an irrigation system. This is a conservative criterion, but we feel it is justified because many building structures are accompanied by additional infrastructure — such as driveways, windbreaks, or landscaping— that is unaccounted for in the building structures dataset. Furthermore, testing of a less conservative criterion had minimal impact on the number of PLSS parcels removed by this screening process.

Figure 3.10 illustrates the steps taken to further modify the PLSS Q-Q section layer by removing any parcel featuring substantial intersections with any of the other obstacle layers (railroads, roads, streams, rivers, or overhead transmission lines). The PLSS layer (Figure 3.10a) was converted into a polyline layer and a 70-meter buffer was created around the polylines (Figure 3.10b). All polylines of the obstacle layers outside the 70-meter buffer were selected (Figure 3.10c) and used to remove the corresponding polygons of the Q-Q sections from the original PLSS layer (Figure 3.10d). This cleared the PLSS layer of all Q-Q sections where roads, power lines, streams, and rivers transected the parcel rather than running along a parcel boundary. The 70-meter buffer distance was chosen after comparisons against two additional buffer distances: 30 meters and 50

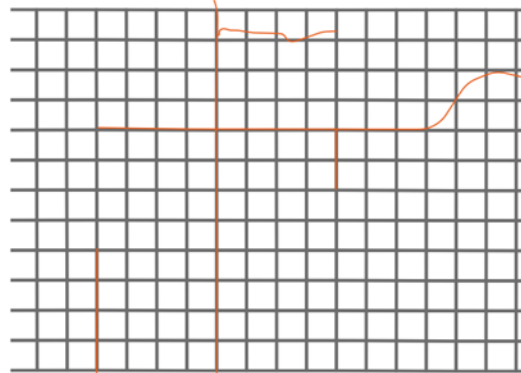


meters. The 70-meter buffer distance demonstrated better performance in excluding the PLSS Q-Q sections that intersected substantially with roads, power lines, streams, and rivers.

**a) Roads and PLSS**



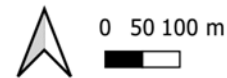
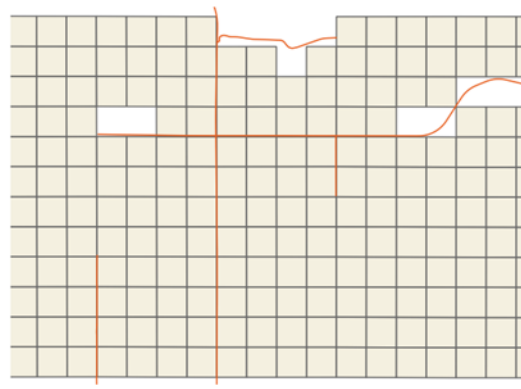
**b) Roads and PLSS Lines  
70m Buffer**



**c) Difference - Roads  
(input) and PLSS Lines  
70m Buffer (overlay)**

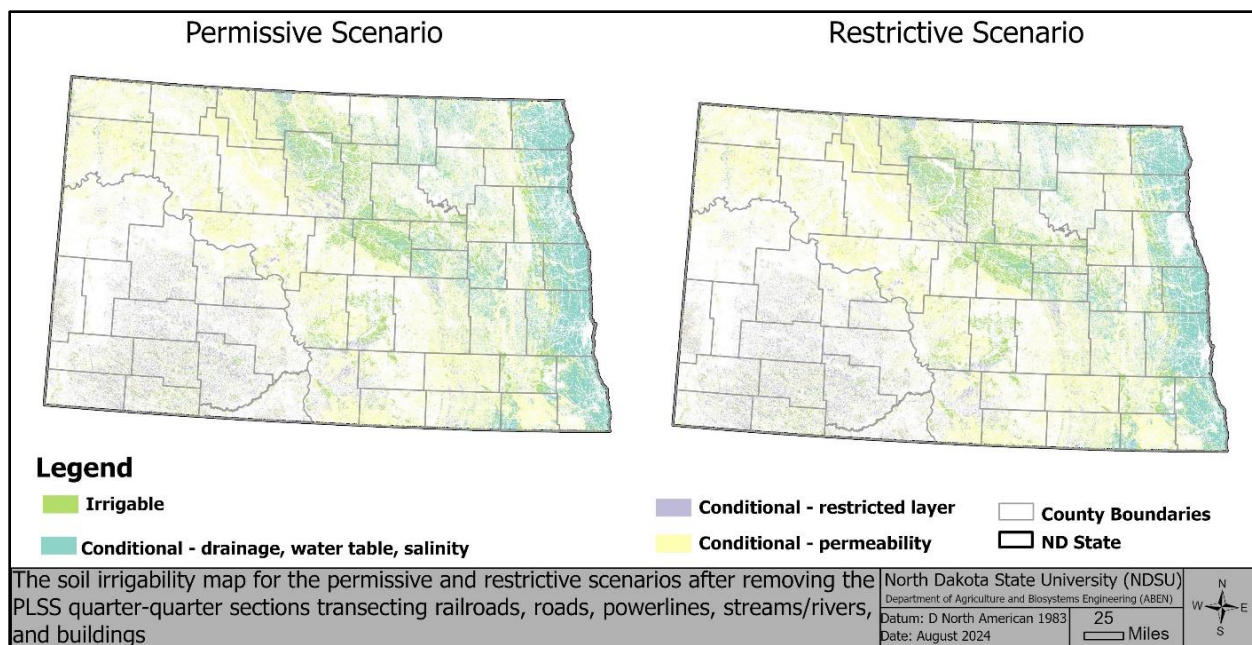


**d) Select by Location - Features  
from PLSS that intersect Step 3  
output, then DELETE**



**Figure 3.10.** Cleaning the PLSS layer from roads, power lines, streams, and rivers.

The soil irrigability maps, minus lands unavailable for irrigation (Figure 3.3), were then clipped based on the modified PLSS Q-Q section layer. This workflow removed from the soil irrigability maps all soils within the PLSS parcels considered unsuitable for irrigation: where roads, power lines, streams, rivers, or large structures are obstacles to installing center-pivot sprinkler systems. Figure 3.11 displays the updated soil irrigability maps and Table 3.3 shows the updated statewide summary of irrigable and conditionally irrigable acreages, which were substantially reduced under both scenarios in this step.



**Figure 3.11.** The soil irrigability map for the permissive and restrictive scenarios after removing lands unsuitable for irrigation by clearing the PLSS quarter-quarter sections transecting railroads, roads, powerlines, streams/ivers, and buildings.

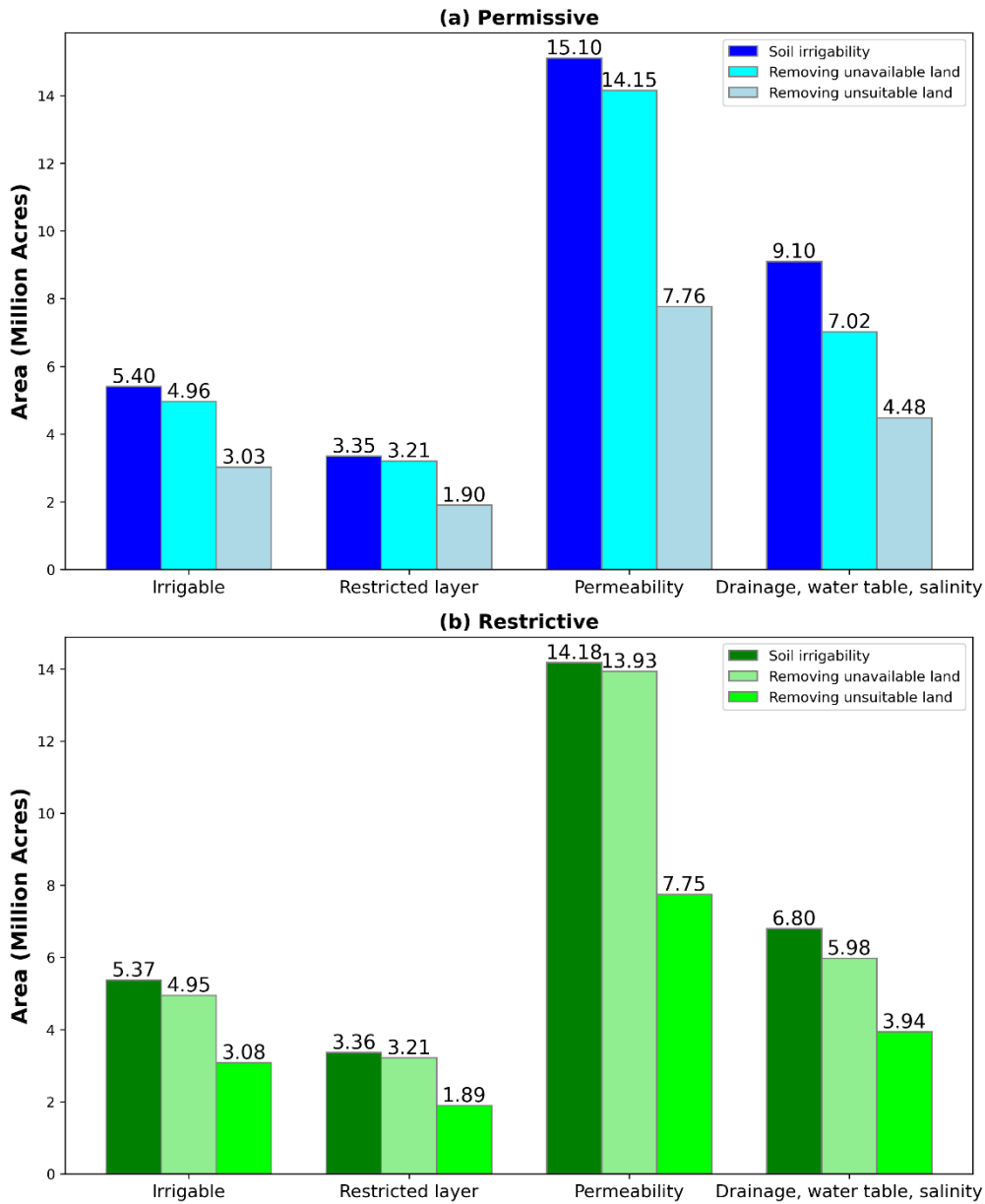
**Table 3.3.** Soil parcels in each dominant condition after removing the PLSS quarter-quarter sections transecting railroads, roads, powerlines, streams, rivers, and large structures.

Dominant condition	Permissive scenario (Million acres)		Restrictive scenario (Million acres)	
	Before	After	Before	After
<i>Irrigation Type</i>				
Irrigable	4.96	3.03	4.95	3.05
Conditional	24.38	14.13	23.12	13.58
<i>Irrigation Functional Group</i>				
Irrigable	4.96	3.03	4.95	3.08
Conditional – restricted layer	3.21	1.89	3.21	1.89
Conditional – permeability	14.15	7.76	13.93	7.75
Conditional – drainage, water table, salinity	7.02	4.48	5.98	3.94

### 3.3 Summary

Figure 3.12 summarizes the statewide area reductions in irrigable and conditionally irrigable soils after removing the lands considered unavailable or unsuitable for irrigation. Table 3.4 summarizes, on a countywide and statewide basis, the areas of irrigable and conditionally irrigable soils

considered available and suitable for developing irrigation projects. Statewide, there are about 17.0 million acres (~37.5%) of land available and suitable for irrigation.



**Figure 3.12.** Land area reductions after removing unavailable and unsuitable lands under (a) permissive scenario and (b) restrictive scenario.

**Table 3.4.** Summary of irrigable and conditionally irrigable land available and suitable for developing irrigation projects.

County name	County area	Irrigable		Conditional – restricted layer		Conditional – permeability		Conditional – drainage, water table, salinity		Total Irrigable & Conditional	
		P <sup>a</sup>	R <sup>b</sup>	P	R	P	R	P	R	P	R
----- thousand acres-----											
<b>Adams</b>	630	64.6	64.6	103.0	103.0	68.8	68.2	1.5	1.5	<b>238.0</b>	<b>237.4</b>
<b>Barnes</b>	970	33.5	33.5	4.1	4.1	259.7	262.9	173.9	143.2	<b>471.1</b>	<b>443.6</b>
<b>Benson</b>	910	115.0	121.4	1.4	1.4	153.2	155.3	107.5	84.2	<b>377.1</b>	<b>362.3</b>
<b>Billings</b>	740	9.7	9.5	28.6	28.6	6.2	6.0	0.2	0.2	<b>44.6</b>	<b>44.3</b>
<b>Bottineau</b>	1080	123.8	123.8	28.6	28.6	336.2	330.5	151.0	141.1	<b>639.7</b>	<b>624.1</b>
<b>Bowman</b>	750	41.8	41.8	113.8	113.7	38.0	37.6	0.4	0.4	<b>194.0</b>	<b>193.4</b>
<b>Burke</b>	720	10.8	10.8	2.6	2.6	165.0	165.0	34.0	31.0	<b>212.4</b>	<b>209.3</b>
<b>Burleigh</b>	1060	117.1	117.0	22.4	22.4	252.3	250.2	5.9	2.9	<b>397.8</b>	<b>392.5</b>
<b>Cass</b>	1130	60.2	60.2	11.6	11.6	106.7	106.7	509.7	485.0	<b>688.2</b>	<b>663.5</b>
<b>Cavalier</b>	960	11.2	11.2	0.0	0.0	206.1	206.0	199.6	155.8	<b>417.0</b>	<b>373.1</b>
<b>Dickey</b>	730	33.8	33.8	14.1	14.1	201.3	200.4	71.8	63.5	<b>321.0</b>	<b>311.8</b>
<b>Divide</b>	830	30.5	30.5	9.7	9.7	225.7	225.7	14.4	8.8	<b>280.3</b>	<b>274.7</b>
<b>Dunn</b>	1330	27.1	26.9	151.1	151.1	81.6	78.6	0.3	0.3	<b>260.0</b>	<b>256.8</b>
<b>Eddy</b>	410	101.7	103.7	4.9	4.9	35.7	34.8	51.6	47.5	<b>193.9</b>	<b>190.9</b>
<b>Emmons</b>	990	66.4	66.3	94.2	94.2	208.7	208.6	2.5	1.9	<b>371.9</b>	<b>371.0</b>
<b>Foster</b>	410	56.8	63.2	5.1	5.1	65.3	65.2	114.4	84.6	<b>241.7</b>	<b>218.1</b>
<b>Golden Valley</b>	640	6.9	6.6	72.0	72.0	49.3	48.9	0.1	0.1	<b>128.3</b>	<b>127.5</b>
<b>Grand Forks</b>	920	73.7	73.7	0.9	0.9	71.9	71.9	334.4	245.8	<b>481.0</b>	<b>392.3</b>
<b>Grant</b>	1060	84.9	84.2	198.3	198.3	42.1	41.4	2.2	2.1	<b>327.4</b>	<b>326.1</b>
<b>Griggs</b>	460	69.5	72.3	13.9	13.9	49.3	49.3	104.5	82.3	<b>237.3</b>	<b>217.9</b>
<b>Hettinger</b>	730	45.8	45.8	171.7	171.7	91.3	90.5	2.4	2.4	<b>311.3</b>	<b>310.4</b>
<b>Kidder</b>	910	137.9	137.9	28.1	28.1	95.1	95.1	12.9	11.2	<b>274.0</b>	<b>272.3</b>
<b>LaMoure</b>	740	18.8	18.8	7.6	7.6	300.2	299.9	37.0	27.5	<b>363.6</b>	<b>353.7</b>
<b>Logan</b>	650	44.6	44.6	19.3	19.3	91.2	91.2	4.1	3.2	<b>159.2</b>	<b>158.3</b>
<b>McHenry</b>	1220	271.1	270.9	70.5	70.5	155.1	155.1	128.3	112.2	<b>625.0</b>	<b>608.7</b>
<b>McIntosh</b>	640	49.7	49.7	13.6	13.6	155.2	155.2	4.2	2.8	<b>222.7</b>	<b>221.3</b>
<b>McKenzie</b>	1830	12.6	12.6	34.1	34.1	138.9	138.3	0.6	0.6	<b>186.2</b>	<b>185.6</b>
<b>McLean</b>	1490	80.1	80.1	14.2	14.2	406.7	406.5	6.5	4.8	<b>507.5</b>	<b>505.6</b>

County name	County area	Irrigable		Conditional – restricted layer		Conditional – permeability		Conditional – drainage, water table, salinity		Total Irrigable & Conditional	
		P	R	P	R	P	R	P	R	P	R
----- thousand acres -----											
<b>Mercer</b>	710	23.2	23.2	34.3	34.3	89.0	88.7	0.7	0.4	<b>147.2</b>	<b>146.5</b>
<b>Morton</b>	1240	35.5	35.5	144.3	144.3	104.9	104.1	0.1	0.0	<b>284.8</b>	<b>283.9</b>
<b>Mountrail</b>	1240	35.0	34.9	3.4	3.4	309.4	309.2	15.4	12.9	<b>363.1</b>	<b>360.3</b>
<b>Nelson</b>	640	23.4	23.4	2.2	2.2	165.2	165.1	89.5	67.1	<b>280.4</b>	<b>257.9</b>
<b>Oliver</b>	470	15.7	15.7	46.4	46.4	58.6	58.4	0.7	0.5	<b>121.4</b>	<b>120.9</b>
<b>Pembina</b>	720	30.2	30.2	0.6	0.6	36.9	36.9	388.2	374.5	<b>456.0</b>	<b>442.3</b>
<b>Pierce</b>	690	203.2	210.6	8.2	8.2	58.9	59.3	68.5	51.3	<b>338.8</b>	<b>329.4</b>
<b>Ramsey</b>	840	3.0	3.0	0.3	0.3	161.1	161.1	131.1	101.8	<b>295.5</b>	<b>266.2</b>
<b>Ransom</b>	550	76.7	76.7	3.5	3.5	129.8	129.5	74.1	69.3	<b>284.1</b>	<b>279.0</b>
<b>Renville</b>	570	8.1	8.1	8.8	8.8	316.1	315.9	39.6	38.4	<b>372.7</b>	<b>371.2</b>
<b>Richland</b>	920	68.0	68.0	9.1	9.1	61.7	66.1	393.2	379.5	<b>532.1</b>	<b>522.8</b>
<b>Rolette</b>	600	39.3	39.4	6.7	6.7	83.2	83.3	54.8	47.4	<b>184.0</b>	<b>176.8</b>
<b>Sargent</b>	550	41.7	41.7	5.0	5.0	182.5	186.0	75.4	63.7	<b>304.6</b>	<b>296.4</b>
<b>Sheridan</b>	640	65.0	69.1	3.9	3.9	106.7	107.0	24.0	12.9	<b>199.6</b>	<b>192.8</b>
<b>Sioux</b>	720	33.4	32.7	64.7	64.7	47.7	47.2	0.1	0.0	<b>145.8</b>	<b>144.6</b>
<b>Slope</b>	780	36.2	35.9	99.8	99.8	50.7	50.3	0.2	0.2	<b>187.0</b>	<b>186.2</b>
<b>Stark</b>	860	25.0	24.9	158.1	158.1	40.4	39.9	0.5	0.5	<b>224.0</b>	<b>223.4</b>
<b>Steele</b>	460	32.0	32.0	4.1	4.1	84.0	84.0	71.5	65.3	<b>191.5</b>	<b>185.4</b>
<b>Stutsman</b>	1470	38.3	38.3	23.8	23.8	371.2	371.3	108.4	88.6	<b>541.6</b>	<b>522.0</b>
<b>Towner</b>	660	8.8	8.8	4.0	4.0	106.9	106.9	156.6	134.3	<b>276.4</b>	<b>254.0</b>
<b>Traill</b>	550	35.5	35.5	2.5	2.5	18.4	18.4	338.1	333.0	<b>394.5</b>	<b>389.4</b>
<b>Walsh</b>	830	30.7	30.7	5.1	5.1	151.1	150.3	253.2	237.3	<b>440.2</b>	<b>423.5</b>
<b>Ward</b>	1310	22.4	22.3	2.3	2.3	422.4	419.7	25.4	21.7	<b>472.5</b>	<b>466.0</b>
<b>Wells</b>	820	246.6	246.9	0.2	0.2	118.2	117.6	93.0	89.0	<b>458.0</b>	<b>453.7</b>
<b>Williams</b>	1370	55.3	55.0	18.5	18.5	432.8	432.7	7.6	5.1	<b>514.2</b>	<b>511.4</b>
----- million acres -----											
<b>ND State</b>	<b>45.3</b>	<b>3.03</b>	<b>3.05</b>	<b>1.89</b>	<b>1.89</b>	<b>7.76</b>	<b>7.75</b>	<b>4.48</b>	<b>3.94</b>	<b>17.18</b>	<b>16.65</b>

<sup>a</sup> Permissive  
<sup>b</sup> Restrictive

Figure 3.13 shows the areas of irrigable and conditionally irrigable soils in each county under the permissive and restrictive scenarios. The asterisk (\*) on the figure indicates those counties where the acreage totals between the two scenarios differ by more than 5%.

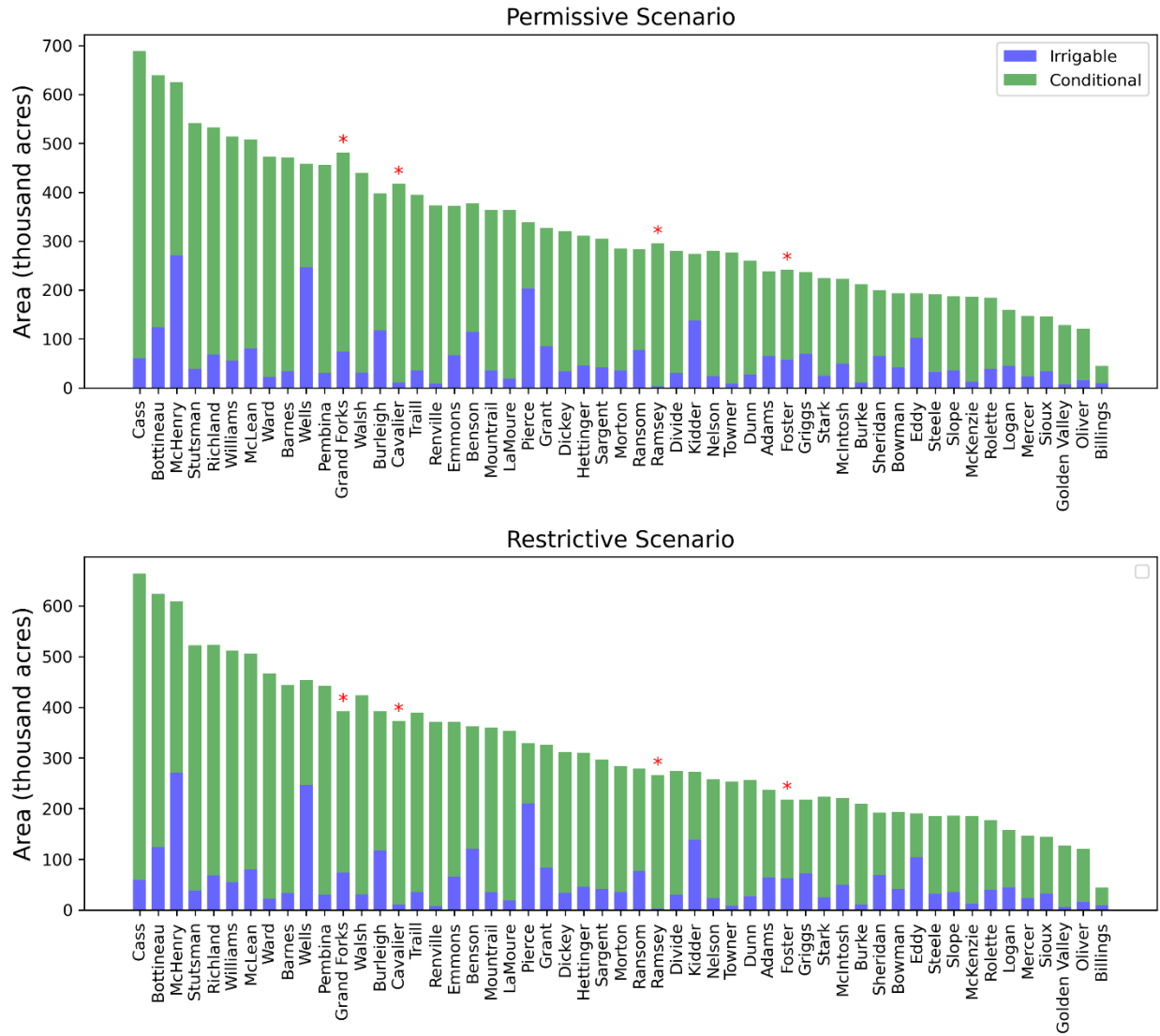


Figure 3.13. Irrigable and conditionally irrigable acreages in North Dakota counties.

## 4 Phase III – Water and Power Availability

### 4.1 Estimating existing irrigated cropland

We employed two methods to identify the existing irrigated lands in North Dakota. The first method was to apply the object detection deep learning model, Mask R CNN (convolution neural network), to process the Landsat 8 satellite images to identify and estimate the locations and irrigated areas of the existing center-pivot irrigation systems. The method is described in detail in Appendix A.2. The second method was to compile the 2017 and 2022 Census of Agriculture data (NASS, 2022b) and the active perfected irrigation permits issued by the North Dakota Office of State Engineer. It should be noted that the first method only identified the areas irrigated by center-pivot sprinkler systems. In contrast, the second method included all irrigated lands including flooding and water-spreading surface irrigation methods. The county-level results from the two methods are compared in Table 4.1. The locations of the identified center-pivot systems are shown in Figure 4.1.

**Table 4.1.** Estimation of existing irrigated lands in North Dakota.

County	Area	Identified center-pivot systems		NASS (2017)	NASS (2022)	Active irrigation permits
	thousand acres	count	area (acres)	area (acres)	area (acres)	area (acres)
<b>Adams</b>	633	0	0	0	0	179
<b>Barnes</b>	969	5	633	2,481	2,343	2,210
<b>Benson</b>	912	27	3,311	2,028	1,158	3,843
<b>Billings</b>	738	0	0	0	0	1,330
<b>Bottineau</b>	1,087	0	0	29	4	1,113
<b>Bowman</b>	747	8	862	878	373	2,899
<b>Burke</b>	722	0	0	0	0	77
<b>Burleigh</b>	1,068	29	3,097	4,001	5,740	9,383
<b>Cass</b>	1,131	16	1,953	13,871	11,724	14,081
<b>Cavalier</b>	966	0	0	318	2,592	33
<b>Dickey</b>	731	129	15,570	14,813	15,650	19,737
<b>Divide</b>	829	28	3,661	2,265	2,348	3,644
<b>Dunn</b>	1,332	0	0	788	117	3,986
<b>Eddy</b>	412	8	864	0	0	1,419
<b>Emmons</b>	996	59	6,803	10,090	8,404	15,246
<b>Foster</b>	414	6	801	2,788	1,681	6,500
<b>Golden Valley</b>	641	3	363	1,106	19	2,036
<b>Grand Forks</b>	921	194	23,280	27,498	25,594	30,843
<b>Grant</b>	1,066	14	1,028	2,146	2,793	16,751
<b>Griggs</b>	459	26	3,313	1,504	2,408	6,308

<b>Hettinger</b>	726	0	0	0	0	585
<b>Kidder</b>	917	240	30,126	23,722	23,888	36,338
<b>LaMoure</b>	737	64	6,800	5,528	5,795	8,170
<b>Logan</b>	647	26	3,346	2,372	718	4,112
<b>McHenry</b>	1,223	78	9,738	6,226	5,965	12,085
<b>McIntosh</b>	637	5	558	694	0	413
<b>McKenzie</b>	1,830	90	8,795	26,683	36,902	20,749
<b>McLean</b>	1,490	123	14,159	8,098	6,679	11,299
<b>Mercer</b>	712	43	5,504	2,431	2,326	9,738
<b>Morton</b>	1,245	33	2,814	4,684	5,529	4,829
<b>Mountrail</b>	1,242	0	0	9	450	1,584
<b>Nelson</b>	646	13	1,324	2,884	2,084	3,167
<b>Oliver</b>	468	34	3,976	2,734	4,793	7,968
<b>Pembina</b>	718	17	1,880	1,449	3,539	3,533
<b>Pierce</b>	693	4	636	782	470	628
<b>Ramsey</b>	842	0	0	0	0	506
<b>Ransom</b>	553	180	21,269	28,943	16,817	28,498
<b>Renville</b>	571	0	0	6	0	175
<b>Richland</b>	925	27	3,337	6,093	6,118	5,170
<b>Rolette</b>	601	4	596	967	820	793
<b>Sargent</b>	555	97	12,512	16,773	8,702	18,432
<b>Sheridan</b>	644	17	1,850	0	0	380
<b>Sioux</b>	722	17	1,836	0	0	361
<b>Slope</b>	780	1	198	0	0	1,594
<b>Stark</b>	858	0	0	476	35	904
<b>Steele</b>	458	15	1,923	6,621	5,828	9,371
<b>Stutsman</b>	1,471	43	5,363	4,209	4,357	7,843
<b>Towner</b>	667	0	0	0	0	236
<b>Trail</b>	552	0	0	0	0	777
<b>Walsh</b>	828	21	2,879	1,741	1,632	3,529
<b>Ward</b>	1,316	5	759	523	598	2,637
<b>Wells</b>	826	0	0	1,010	840	952
<b>Williams</b>	1,375	104	11,927	21,065	16,337	41,468
<b>North Dakota</b>	<b>45,248</b>	<b>1,853</b>	<b>219,658</b>	<b>263,327</b>	<b>244,170</b>	<b>390,439</b>

Table 4.1 shows that 18 North Dakota counties (Adams, Billings, Bottineau, Burke, Eddy, Golden Valley, Hettinger, McIntosh, Mountrail, Pierce, Ramsey, Renville, Rolette, Slope, Stark, Towner, Traill, and Wells) have less than 1,000 acres of irrigated land. In contrast, eight counties (Dickey, Grand Forks, Kidder, McKenzie, McLean, Ransom, Sargent, and Williams) have more than 10,000 acres of irrigated land. The remaining 27 counties have about a few thousand acres of irrigated

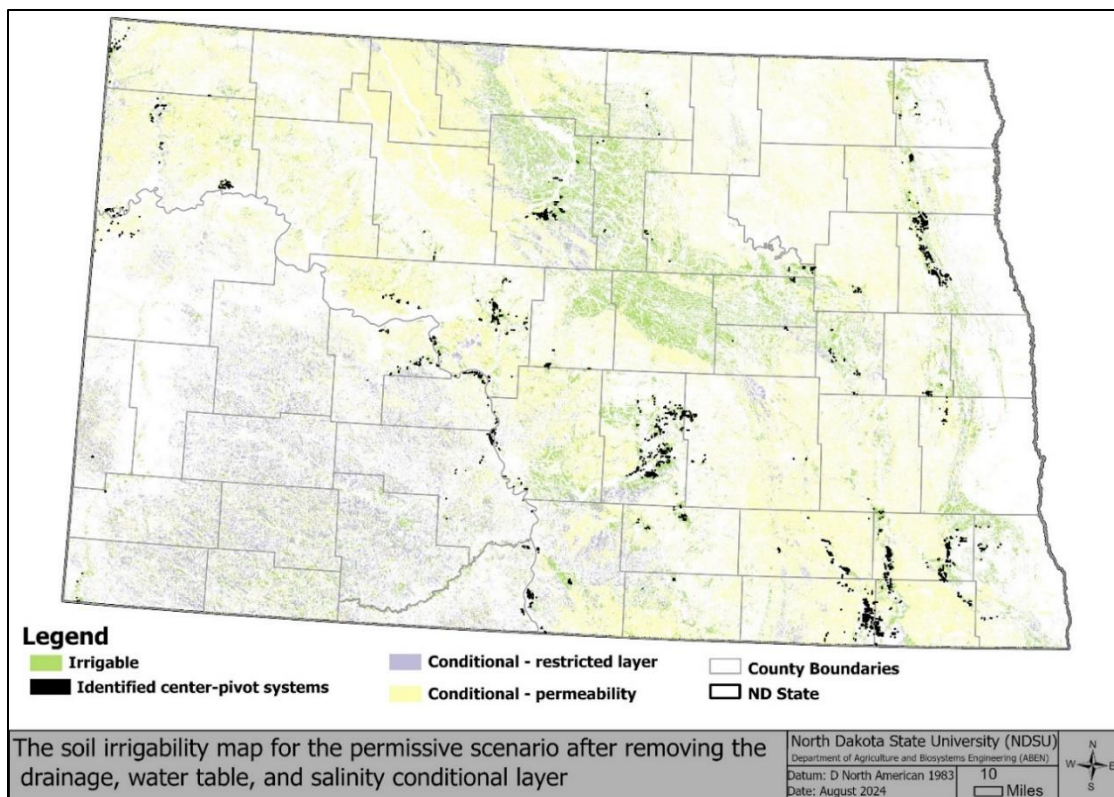


land. It is interesting to note that Sheridan and Sioux counties each have about 2,000 acres of identified irrigated lands but less than 400 acres of active permits and no reported irrigated acres in the NASS' Census of Agriculture. In contrast, Barnes, Cass, Foster, McKenzie, Steele, and Williams counties have considerably fewer identified irrigation acres than the reported ones. Cavalier and McKenzie counties have considerably fewer acreages of active irrigation permits than the reported acreages of irrigated land.

According to the compiled active irrigation permits, about 85% of the approved acreages are irrigated using center-pivot sprinkler systems statewide, and the remaining are using flooding and water-spreading surface irrigation methods. Approximately one-third of the approved acreages use surface water while two-thirds use groundwater as an irrigation water source (not shown in the table).

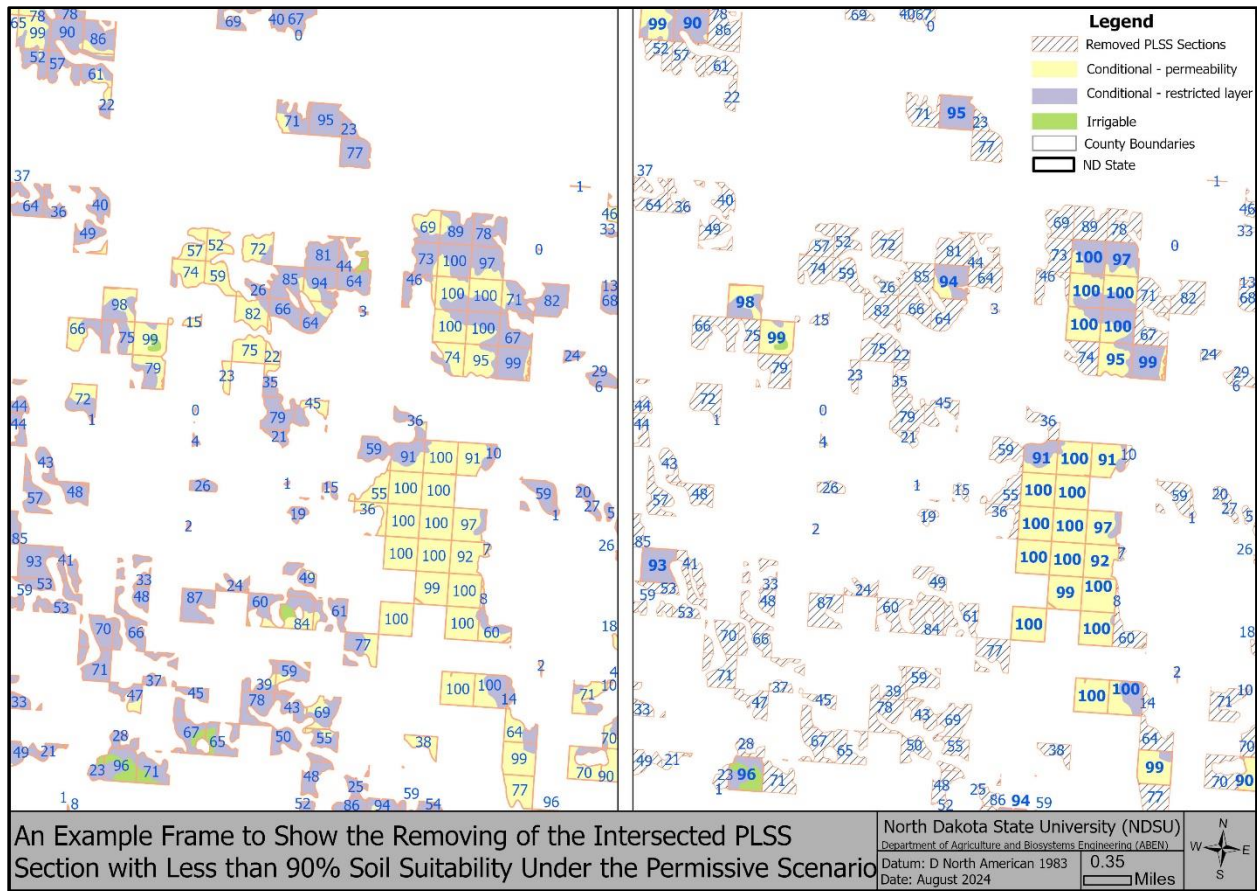
#### 4.2 Feasible parcels for irrigation development

Since irrigation development for conditionally irrigable soils *due to poor drainage, high water table, and salinity* requires large-scale drainage for management, which would require additional infrastructure and greater long-term planning and be subject to intense regulatory scrutiny (Olson and Schuh, 1995), we excluded this type of conditional soils from further analysis. Figure 4.1 presents the soil irrigability maps under the permissive scenario after removing conditional soils due to drainage, water table, and salinity, which are mostly found in the Red River Valley counties such as Cass, Grand Forks, Pembina, Richland, Traill, and Walsh. It should be noted that after excluding this category of conditional soils, the coverages of soil irrigability maps under the permissive and restrictive scenarios are very similar. Therefore, only the results under the permissive scenario will be shown from here forward.



**Figure 4.1.** Soil irrigability maps under permissive scenarios after excluding the conditional soils – drainage, water table, and salinity.

The modified PLSS layer served as the base for creating a feasibility map for deploying irrigation systems across North Dakota. This layer was merged into the soil irrigability map and the total areas of the irrigable and conditional soils were calculated for each PLSS unit. By dividing these areas by the total area of each PLSS unit, we obtained the percentage of land that is irrigable or conditionally irrigable for each PLSS Q-Q section (left panel of Figure 4.2). For further analysis we only accept the PLSS Q-Q sections that contain 90% or more irrigable or conditionally irrigable soils (right panel of Figure 4.2) (Scherer et al., 2023).



**Figure 4.2.** Land parcels with less than 90% of irrigable and conditional soils deemed not feasible for irrigation development

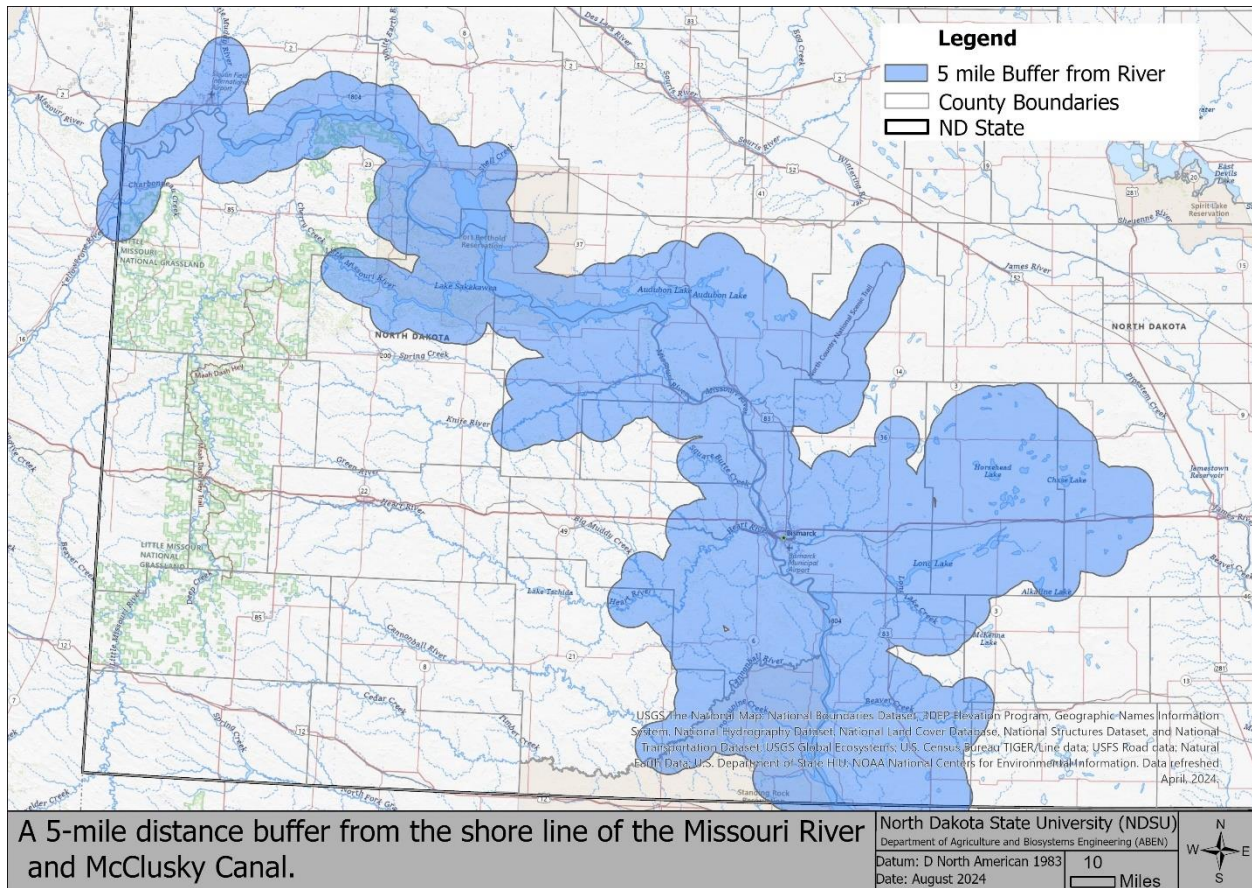
#### 4.3 Irrigation development potential from surface water sources

Irrigation development has two main limiting factors: suitable soil and suitable water. There are two types of water sources for irrigation development in North Dakota – surface water and groundwater. Although other lakes and streams have been permitted for irrigation water use in the past, the most reliable surface water resource for irrigation in North Dakota is the Missouri River systems within the state, which include the Missouri River and its major tributaries, three lakes on the Missouri River—Lake Sakakawea, Lake Oahe, and Lake Audubon—and the McClusky canal which diverts water from the Missouri River (Olson and Schuh, 1995).

Therefore, in terms of surface water availability, we only consider lands near the Missouri River systems for irrigation development in this study. The proximity requirements for surface water include (1) static lift for water transport cannot exceed 260 feet, and (2) irrigation must be within five miles of the water source (Olson and Schuh, 1995).

The static lift limit refers to the elevation difference between the water surface and the highest point along the water delivery path to the land. We adopted the Relative Elevation Model (REM) method to calculate the static lift for the lands in the Missouri River corridor. The details of the

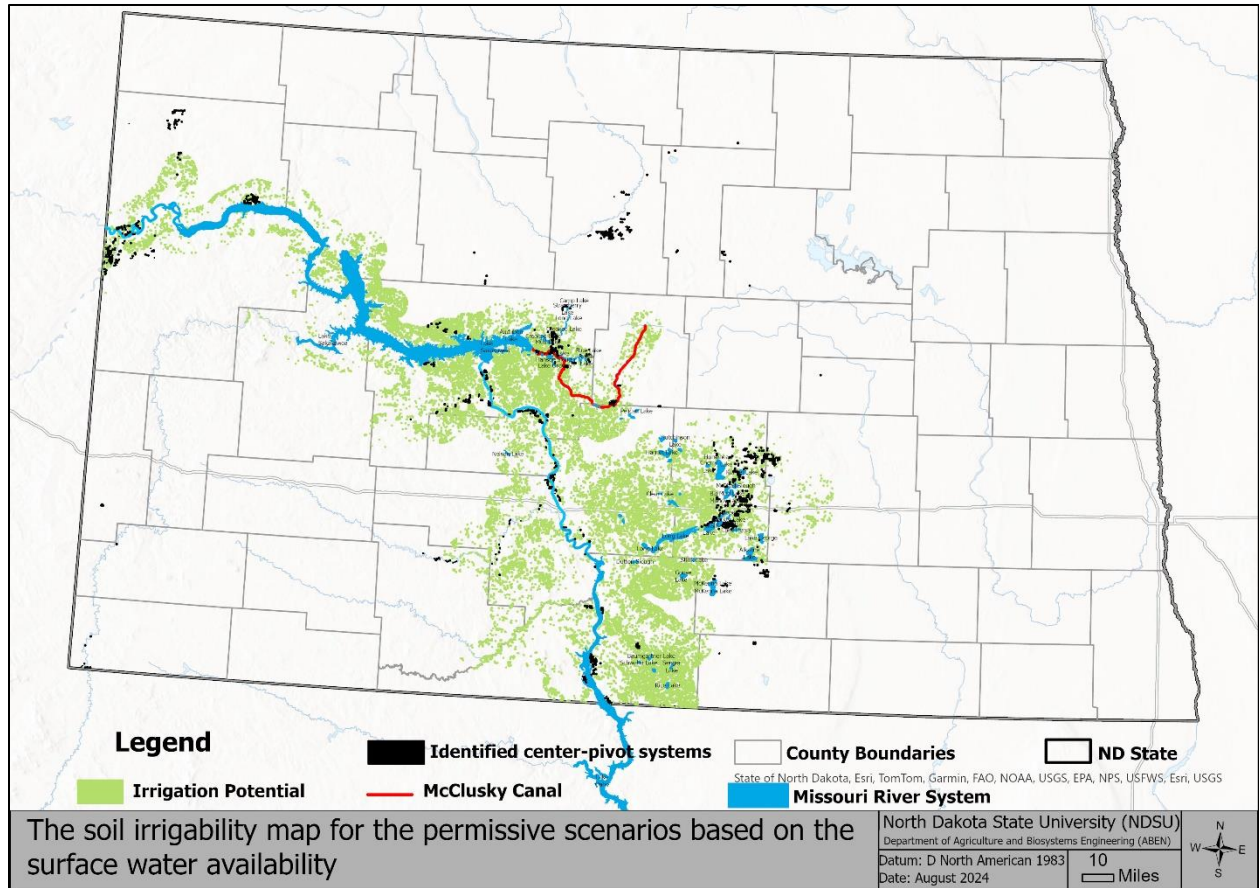
REM method are further explained in Appendix A.3. The PLSS Q-Q sections within 5 miles of the Missouri River system and McClusky Canal were selected as shown in Figure 4.3.



**Figure 4.3.** A 5-mile distance buffer from the shoreline of the Missouri River system and McClusky Canal.

Figure 4.4 shows the PLSS Q-Q parcels that meet the following conditions: (1) within 5 miles of the Missouri River system or McClusky Canal, (2) having no more than 260 ft static lift along their straight-line path to the river system or canal, and (3) having 90% or more of their areal extent<sup>1</sup> consisting of irrigable or conditional soils under permissive scenarios. These land parcels have the potential to develop irrigation projects.

<sup>1</sup> We adopted the dominant condition, rather than the dominant component, method in the SSURGO database to create the soil irrigability maps. This approach may not represent the exact spatial coverage under some peculiar situations.



**Figure 4.4.** The potential lands for irrigation development along the Missouri River corridor.

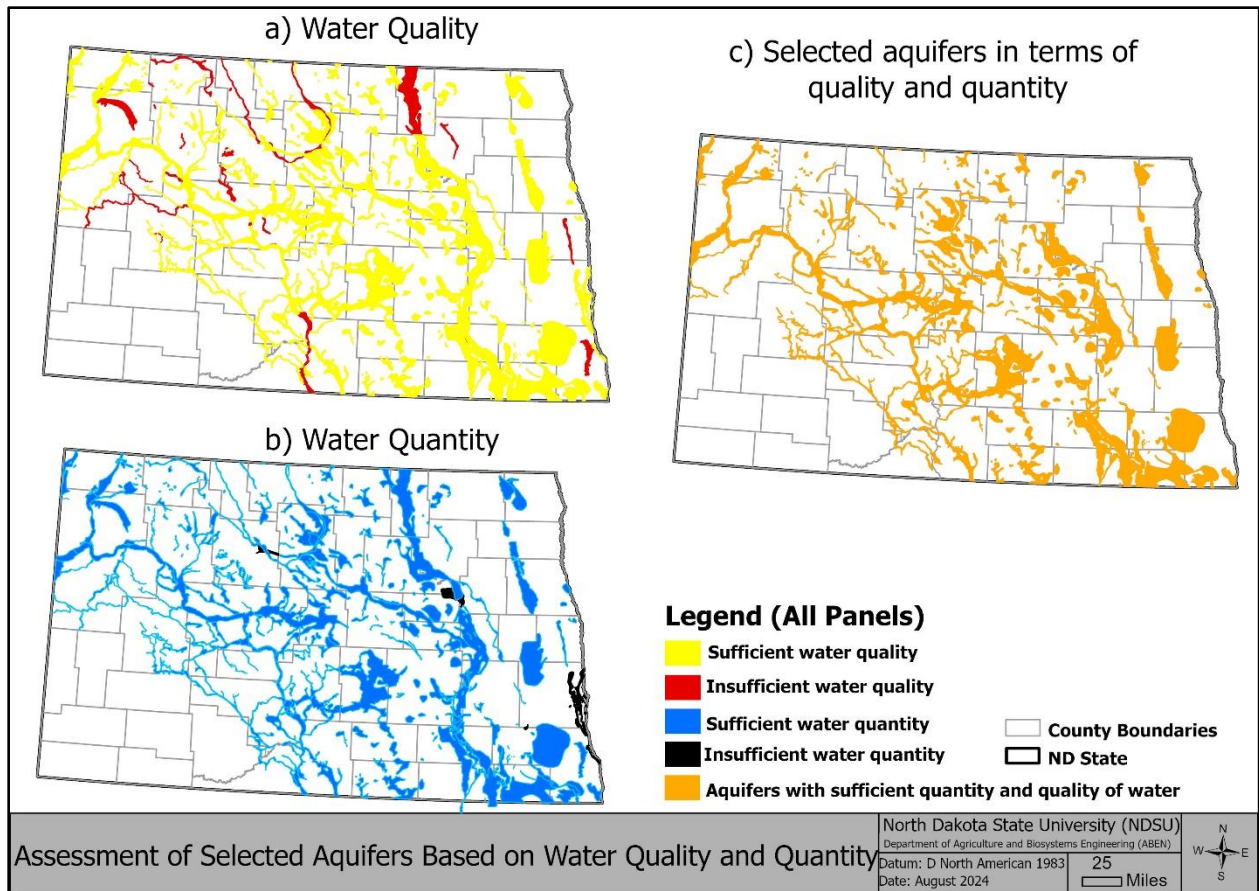
Table 4.2 summarizes the areas for each class of soil irrigability across these parcels in the 17 counties along the Missouri River system and McClusky Canal. Results for the restrictive scenario are similar and not shown here. In this region, there are about 1.05 million acres of land that may be irrigated using the water from the Missouri River. Burleigh, Emmons, Kidder, and Mclean counties have the most land areas, whereas Dunn, Grant, Logan, and McIntosh have the least areas.

**Table 4.2.** Areas of land parcels for potential irrigation development along the Missouri River corridor under the permissive scenario.

County	Conditionally Irrigable Soils		Irrigable Soils	Total
	Permeability	Restricted Layer		
-----thousand acres -----				
<b>Burleigh</b>	91.9	7.6	49.5	149.0
<b>Dunn</b>	3.1	2.3	1.1	6.5
<b>Emmons</b>	137.5	44.1	38.3	219.9
<b>Grant</b>	1.3	5.3	5.6	12.2
<b>Kidder</b>	45.2	10.1	64.7	120.0
<b>Logan</b>	4.2	1.5	1.9	7.6
<b>McIntosh</b>	0.6	0.6	0.6	1.9
<b>McKenzie</b>	26.3	0.3	1.4	28.0
<b>McLean</b>	175.3	8.4	34.0	217.7
<b>Mercer</b>	43.1	10.3	11.1	64.5
<b>Morton</b>	31.5	26.6	11.5	69.6
<b>Mountrail</b>	26.2	0.7	2.3	29.2
<b>Oliver</b>	17.2	9.1	4.8	31.1
<b>Sheridan</b>	8.2	0.1	9.8	18.2
<b>Sioux</b>	8.2	8.0	8.4	24.6
<b>Stutsman</b>	8.0	0.1	5.1	13.2
<b>Williams</b>	29.4	0.9	7.3	37.6
-----million acres -----				
<b>Total</b>	<b>0.66</b>	<b>0.14</b>	<b>0.26</b>	<b>1.05</b>

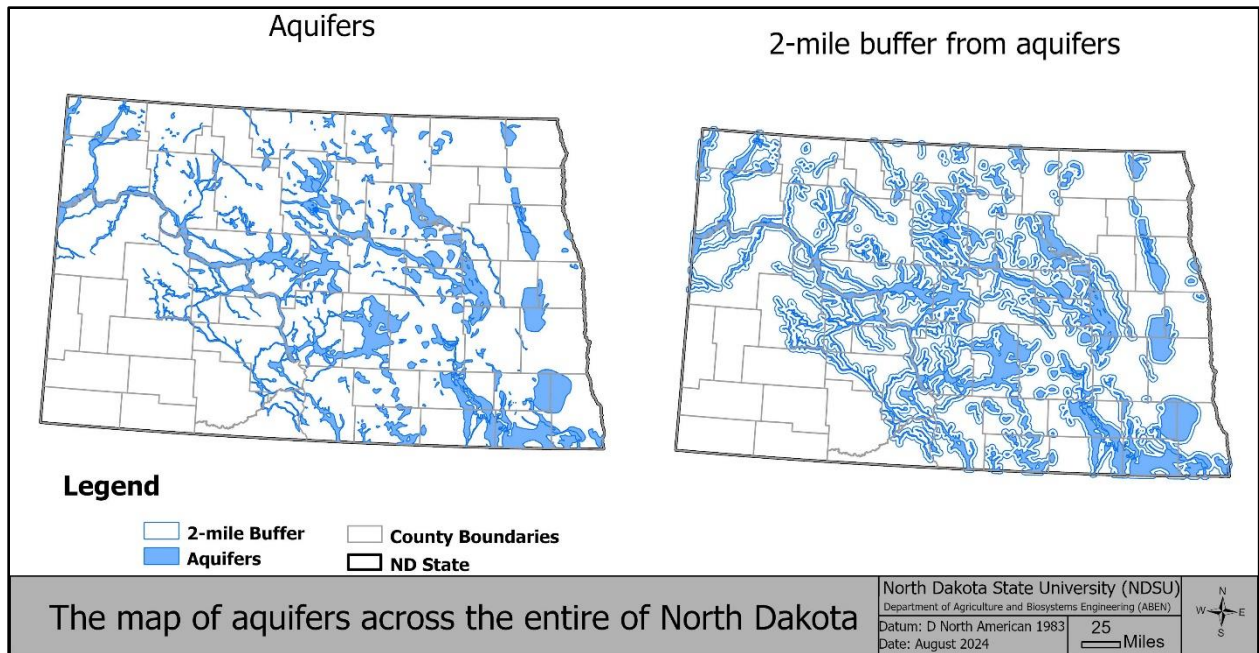
#### 4.4 Irrigation development potential from groundwater sources

The unconsolidated glaciofluvial aquifers across North Dakota generally have good water quality, and most of them can be and have been developed for irrigation water use. The shapefile of these aquifers resulting from the Department of Water Resources’ managed aquifer recharge (MAR) project (Patch, 2024) was used to evaluate groundwater suitability for irrigation by considering both quality (Figure 4.5.a) and quantity (Figure 4.5.b). For groundwater quality, aquifers with a median TDS (Total Dissolved Solids) value greater than 1,500 mg/L were considered unsuitable for irrigation. For groundwater quantity, aquifers ranked as “Excellent” and “Very Good” for recharge potential were deemed insufficient for irrigation, as these rankings reflect less water availability. Finally, the intersection of polygons indicating good groundwater quantity and quality was used for further analysis (Figure 4.5.c).



**Figure 4.5.** Selection of aquifers with good water quality and quantity.

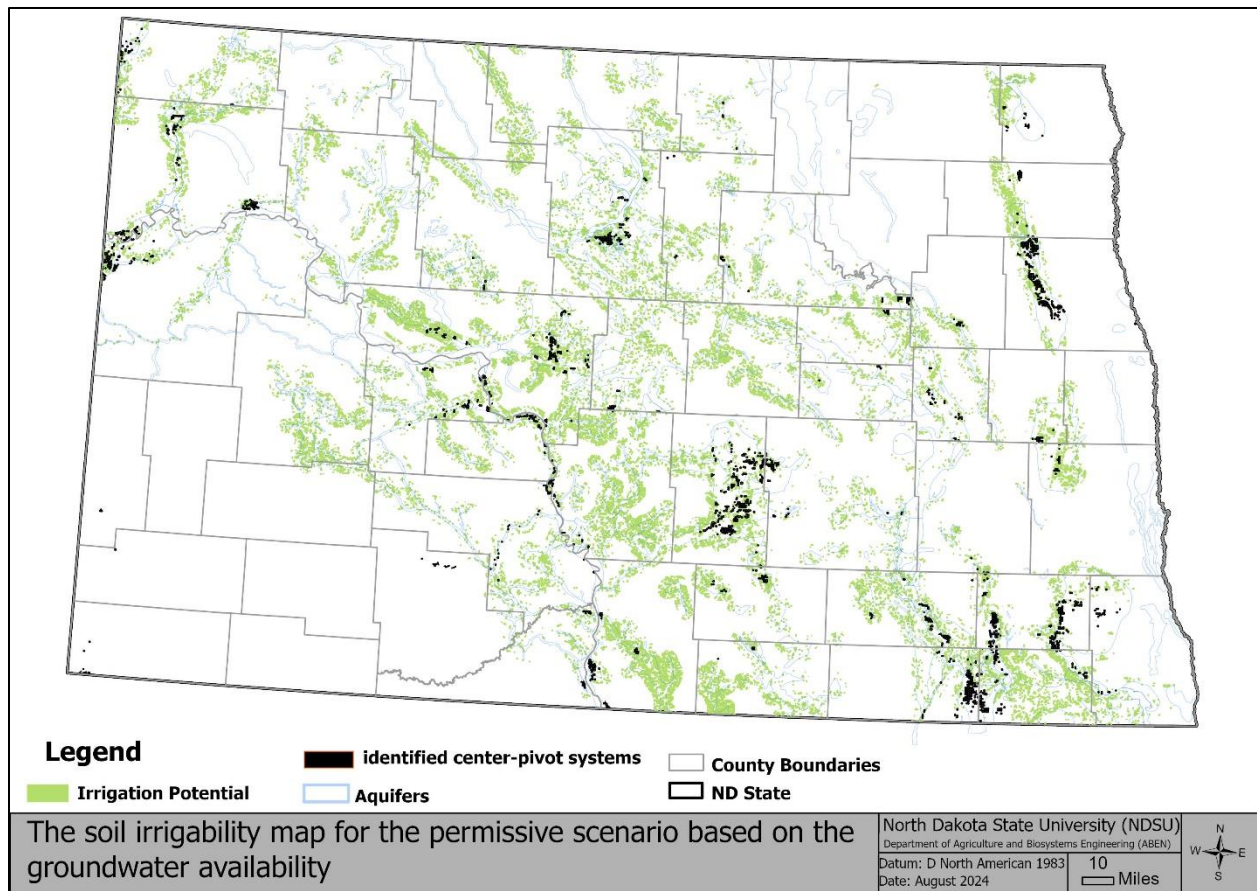
Since the water from the production wells in an aquifer may be transported to irrigate lands outside the aquifer’s coverage to a certain distance (Tom Scherer, personal communication, October 2024), we first created a 2-mile buffer around the aquifers with sufficient and good groundwater (Figure 4.6).



**Figure 4.6.** The map of aquifers (left panel) and the 2-mile buffer around aquifers (right panel).

In the next step, the soil suitability layer (excluding conditional soils – drainage, water table, and salinity) was clipped using the boundary of the 2-mile buffer around these aquifers. The resulting layer identifies the lands suitable for irrigation using groundwater (Figure 4.7).





**Figure 4.7.** Lands with irrigation potential based on groundwater availability.

Finally, the overlapping areas between the land irrigated using water from the Missouri River and the land irrigated using groundwater were removed for the 17 counties along the Missouri River corridor. The total areas of land that may be irrigated using groundwater and water from the Missouri River for each county are summarized in Table 4.3 and redisplayed in Figure 4.8. When overlaying these land parcels with the 2023 USDA Cropland Data Layer (<https://nassgeodata.gmu.edu/CropScape/>), all of these lands are related to agriculture land uses including cropland and pastures.

In summary, approximately 2.2 million acres of cropland in North Dakota have suitable soils and available water for irrigation. Among these croplands, approximately 0.25 million acres have already been developed for irrigation, leaving about two million acres of cropland statewide for future irrigation development. About one million acres of cropland are located around the Missouri River corridor while the other one million acres are spread across the state where good-quality groundwater is available.

**Table 4.3.** Areas of land parcels for potential irrigation development using groundwater and water from the Missouri River under the permissive scenario.

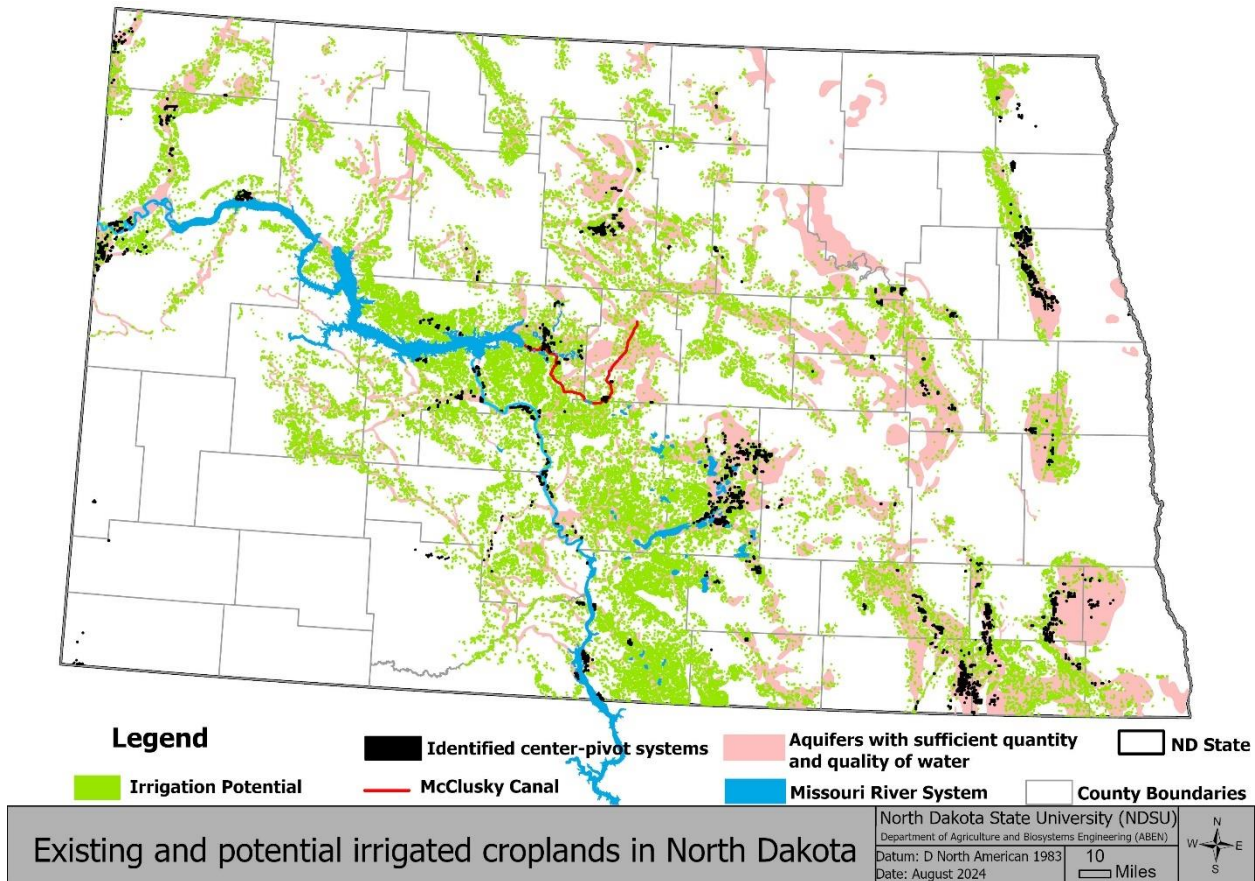
<b>County</b>	<b>Ground-water</b>	<b>Missouri River</b>	<b>Overlap</b>	<b>Combined<sup>a</sup></b>	<b>Existing Irrigated Lands<sup>b</sup></b>	<b>Irrigation Potential<sup>c</sup></b>
----- thousand acres -----						
<b>Adams</b>	0.0			0.0	0.0	0.0
<b>Barnes</b>	10.1			10.1	0.63	9.5
<b>Benson</b>	37.2			37.2	3.1	34.1
<b>Billings</b>	0.0			0.0	0.0	0.0
<b>Bottineau</b>	48.8			48.8	0.0	48.8
<b>Bowman</b>	0.0			0.0	0.0	0.0
<b>Burke</b>	7.2			7.2	0.0	7.2
<b>Burleigh</b>	122.8	149.0	110.1	161.7	3.1	158.6
<b>Cass</b>	27.0			27.0	1.9	25.1
<b>Cavalier</b>	8.8			8.8	0.0	8.8
<b>Dickey</b>	22.3			22.3	15.3	7.0
<b>Divide</b>	31.7			31.7	3.6	28.1
<b>Dunn</b>	52.2	6.5	0.9	57.8	0.0	57.8
<b>Eddy</b>	22.5			22.5	0.86	21.7
<b>Emmons</b>	96.4	219.9	94.9	221.4	5.7	215.7
<b>Foster</b>	12.7			12.7	0.80	11.9
<b>Golden Valley</b>	0.0			0	0.0	0.0
<b>Grand Forks</b>	31.1			31.1	23.0	8.1
<b>Grant</b>	3.5	12.2	3.5	12.2	0.0	12.2
<b>Griggs</b>	19.6			19.6	3.3	16.3
<b>Hettinger</b>	0.0			0	0.0	0.0
<b>Kidder</b>	89.1	119.9	88.7	120.3	29.9	90.4
<b>LaMoure</b>	46.0			46.0	6.6	39.4
<b>Logan</b>	27.7	7.6	5.4	29.9	3.3	26.6
<b>McHenry</b>	83.9			83.9	9.7	74.2
<b>McIntosh</b>	56.5	2.0	0.08	58.4	0.46	58.0
<b>McKenzie</b>	25.7	28.0	13.0	40.7	8.5	32.2
<b>McLean</b>	159.1	217.8	129.3	247.6	13.8	233.8
<b>Mercer</b>	37.5	64.5	34.3	67.8	5.3	62.5
<b>Morton</b>	40.7	69.8	31.2	79.3	2.5	76.8
<b>Mountrail</b>	48.3	29.2	13.6	63.9	0.0	63.9
<b>Nelson</b>	15.8			15.8	1.3	14.5
<b>Oliver</b>	22.6	31.1	14.5	39.2	3.9	35.3
<b>Pembina</b>	14.8			14.8	0.38	14.4
<b>Pierce</b>	31.1			31.1	0.32	30.8

<b>Ramsey</b>	0.34			0.34	0.0	0.34
<b>Ransom</b>	38.5			38.5	21.0	17.5
<b>Renville</b>	14.3			14.3	0.0	14.3
<b>Richland</b>	17.3			17.3	3.3	14.0
<b>Rolette</b>	10.3			10.3	0.60	9.7
<b>Sargent</b>	72.5			72.5	12.4	60.1
<b>Sheridan</b>	33.5	18.2	16.8	34.9	1.8	33.1
<b>Sioux</b>	12.4	24.5	12.4	24.5	1.8	22.7
<b>Slope</b>	0.0			0	0.0	0.0
<b>Stark</b>	6.2			6.2	0.0	6.2
<b>Steele</b>	15.2			15.2	1.9	13.3
<b>Stutsman</b>	30.1	13.2	6.8	36.5	5.3	31.2
<b>Towner</b>	0.15			0.15	0.0	0.15
<b>Traill</b>	6.2			6.2	0.0	6.2
<b>Walsh</b>	27.0			27.0	0.89	26.1
<b>Ward</b>	46.4			46.4	0.76	45.7
<b>Wells</b>	64.3			64.3	0.0	64.3
<b>Williams</b>	60.8	37.6	21.8	76.7	11.7	65.0
-----million acres-----						
<b>North Dakota</b>	<b>1.71</b>	<b>1.05</b>	<b>0.60</b>	<b>2.16</b>	<b>0.21</b>	<b>1.95</b>

<sup>a</sup> Calculated by adding the areas in the “Groundwater” and “Missouri River” columns and subtracting the areas in the “Overlap” column.

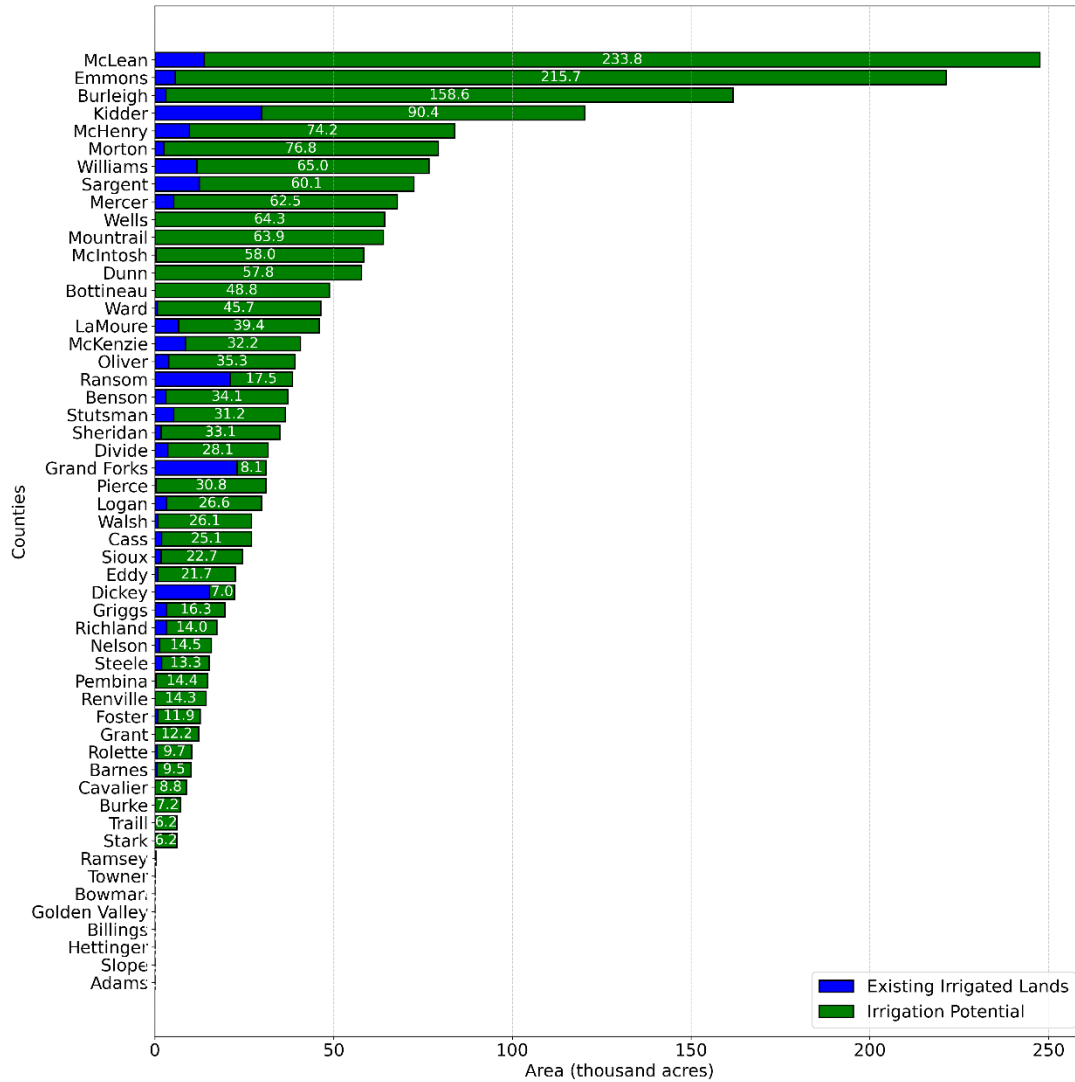
<sup>b</sup> Identified land areas irrigated using center-pivot sprinkler systems, which is smaller than the actual area of irrigated croplands estimated at ~250 thousand acres.

<sup>c</sup> Calculated by subtracting the “Existing Irrigated Land” column from the “Combined” column.



**Figure 4.8.** The map of croplands with irrigation potential after removing the overlapping areas based on surface water and groundwater availability.

The areas of county-level existing and potentially irrigable croplands are ranked in Figure 4.9, which shows that central North Dakota counties (e.g., McLean, Emmons, Burleigh, Kidder, McHenry, Morton) have the most areas of cropland for potential irrigation development. Not surprisingly, the counties in southwestern North Dakota (e.g., Adams, Bowman, Billings, Golden Valley, Hettinger, Slope) do not have much land for irrigation development, nor do Ramsey and Towner counties in northeastern North Dakota. Statewide, 37 counties have more than ten thousand acres of cropland potential for future irrigation development.



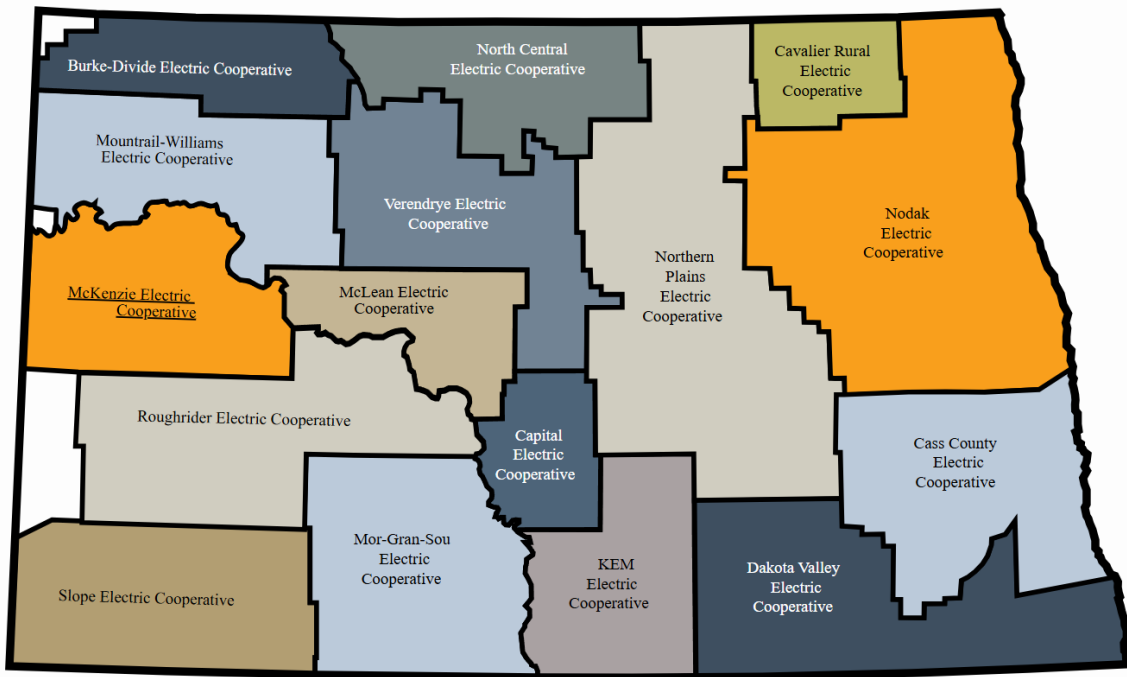
**Figure 4.9.** Areas of the existing irrigated and potentially irrigable lands in North Dakota counties.

#### 4.5 Irrigation development potential from power availability

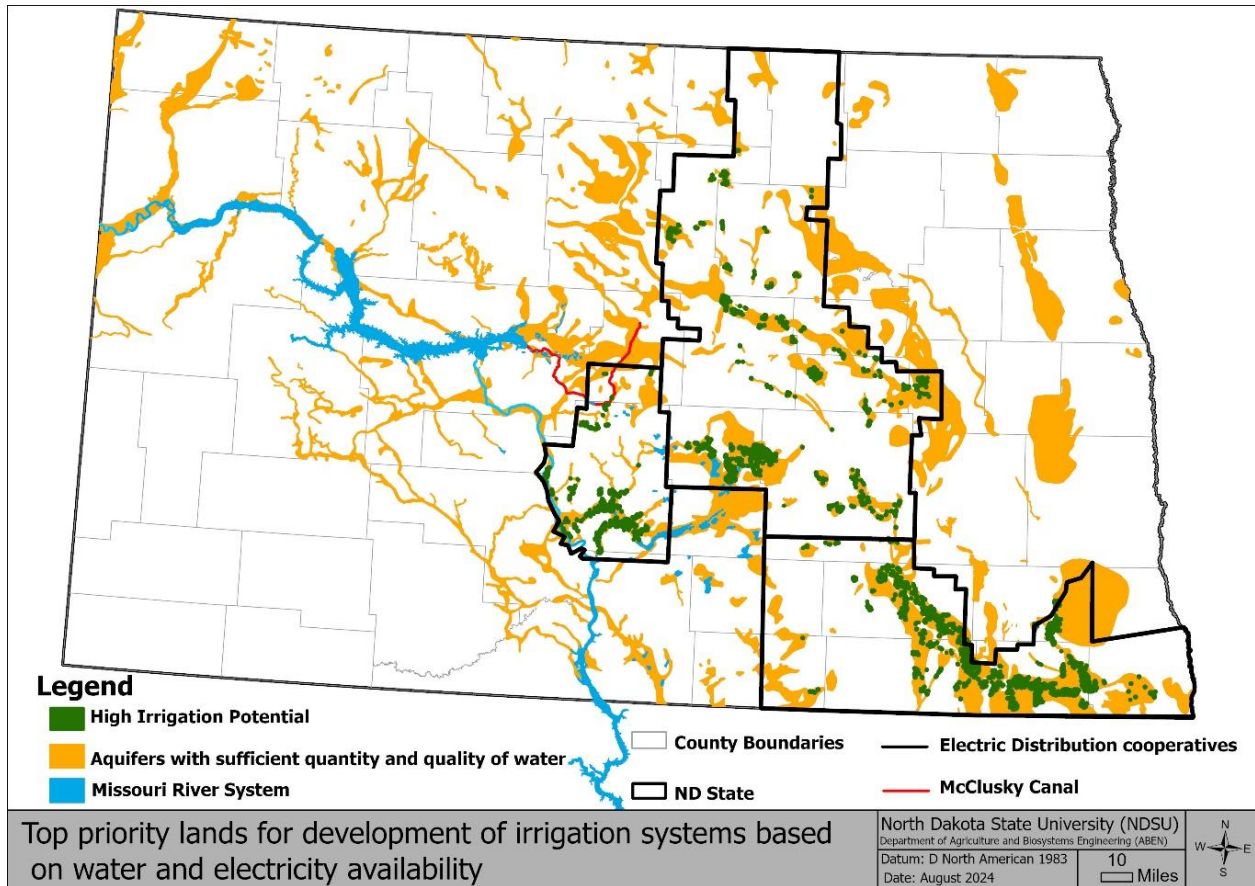
Three-phase power electricity is generally the preferred source of power for irrigation pumps, over internal combustion engines, due to advantages such as lower pumping costs, less maintenance, greater reliability, and ease of operation. However, if the existing power lines are more than one mile from the pump site, it may not be economical due to high construction costs and repayment for the extension of power lines (Scherer, 2022).

Due to data privacy concerns, we can only access three-phase power distribution lines from three North Dakota electric distribution cooperatives (i.e., Capital Electric, Dakota Valley, Northern Plains) out of the 17 North Dakota electric distribution cooperatives (Figure 4.10). After creating a 1-mile buffer around the three-phase power lines provided by these three electric cooperatives, we clipped the layer of irrigation potential land against the electric availability layer to obtain the locations and areas of cropland with irrigation potential based on soil suitability and water and

power availabilities. Figure 4.11 shows the locations of these lands and Table 4.4 summarizes the areas of these land parcels with the highest potential for future irrigation development.



**Figure 4.10.** North Dakota’s electric distribution cooperatives (Source: North Dakota Association of Rural Electric Cooperatives).



**Figure 4.11.** Croplands with irrigation potential within one mile from three-phase power lines of Capital Electric, Dakota Valley, and Northern Plains Cooperatives.

Table 4.4 shows that in the three above-mentioned electric cooperatives' service areas, approximately 0.75 million acres of cropland are within a one-mile distance of the existing three-phase power lines of these cooperatives, which are about 7.8% of the croplands with irrigation potential based on soil suitability and water availability analysis. Thirteen (13) of these 18 counties have more than 1,000 acres of croplands that are readily available for irrigation development.

**Table 4.4.** Areas of land parcels with irrigation potential within one mile distance of three-phase power lines of Capital Electric, Dakota Valley, and Northern Plains Cooperatives.

County	Irrigation Potential	Irrigation Potential Considering 3-Phase Power Availability	
	(acre) <sup>a</sup>	(acre) <sup>b</sup>	(%)
<b>Benson</b>	34,100	1,610	4.7
<b>Burleigh</b>	158,600	13,930	8.8
<b>Dickey</b>	7,000	5,910	84.4
<b>Eddy</b>	21,700	410	1.9
<b>Emmons</b>	215,700	200	0.1
<b>Foster</b>	11,900	3,170	26.6
<b>Griggs</b>	16,300	1,340	8.2
<b>Kidder</b>	90,400	7,430	8.2
<b>LaMoure</b>	39,400	10,230	26.0
<b>McIntosh</b>	58,000	200	0.3
<b>Morton</b>	76,800	280	0.4
<b>Pierce</b>	30,800	2,400	7.8
<b>Ransom</b>	17,500	2,240	12.8
<b>Richland</b>	14,000	1,570	11.2
<b>Sargent</b>	60,100	15,640	26.0
<b>Sheridan</b>	33,100	140	0.4
<b>Stutsman</b>	31,200	5,710	18.3
<b>Wells</b>	64,300	4,330	6.7
<b>Total</b>	<b>980,900</b>	<b>76,740</b>	<b>7.8</b>

<sup>a</sup> These numbers are taken from the last column of Table 4.3.

<sup>b</sup> Areas are rounded to tens, and counties with areas less than 100 acres are not listed.

## 5 Acknowledgement

This study is supported by the North Dakota Irrigation Association, North Dakota Department of Water Resources, Garrison Diversion Conservancy District, and NDSU Office of Research and Creative Activity (ND Economic Diversification Research Fund). We want to express our gratitude to Dr. Tom Scherer and Dr. David Franzen for their expertise and assistance in updating the soil irrigability maps. We also would like to thank Andrew Nygren, Rod Bassler, Paul Moen, and Patrick Fridgen for their help with water resources data in North Dakota. Dr. James Kim is affiliated with the United States Department of Agriculture’s Agricultural Research Service.

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## A. Appendices

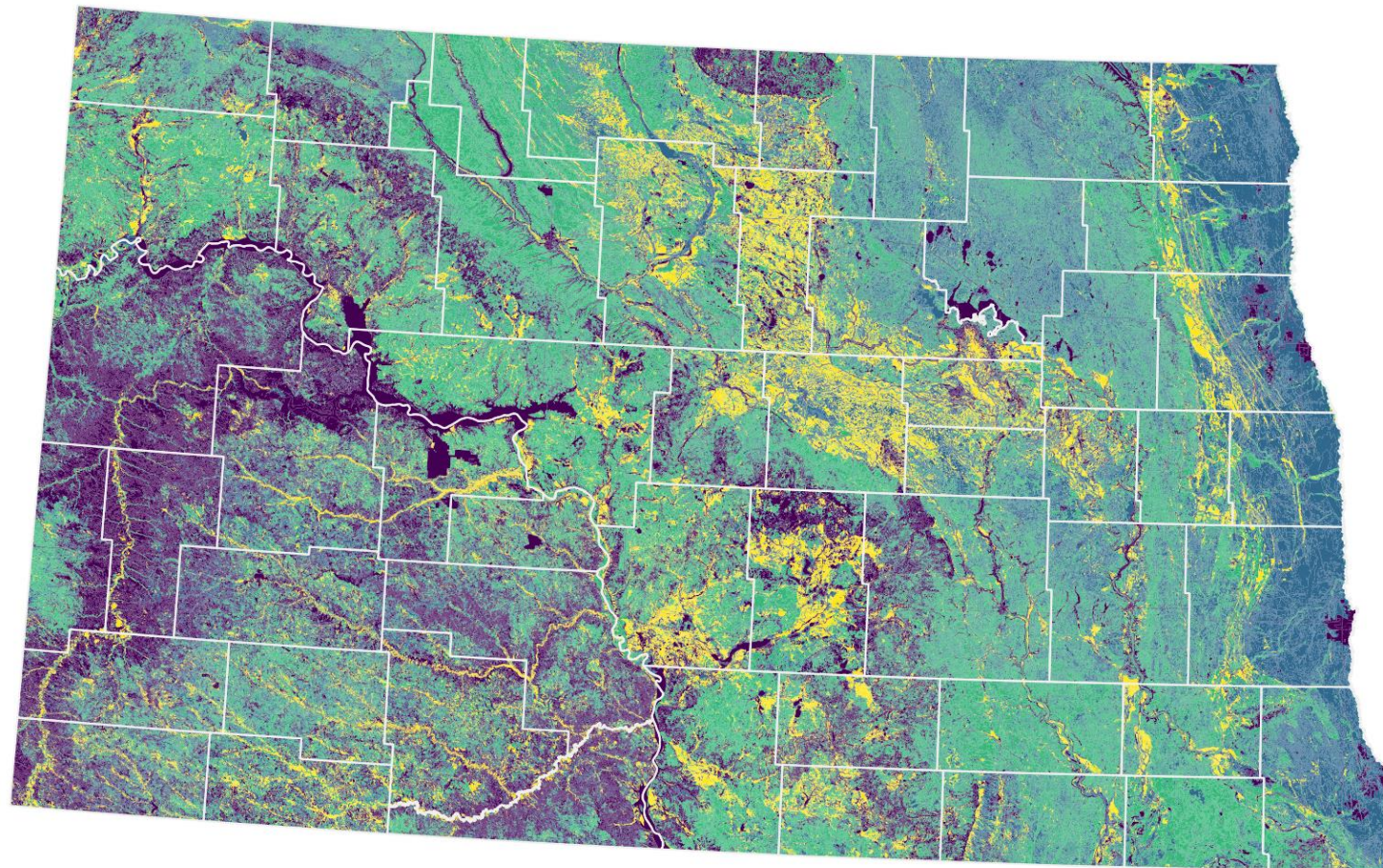
### A.1. Soil Relative Irrigability

An alternative approach to classifying soil irrigability according to dominant conditions is to assign a numerical value for each soil component based on its Irrigation Functional Group (see Table A.1) and calculate the weighted average across all soil components within each map unit. The relative irrigability analysis assumes that soils within the *Conditional – drainage, water table, and salinity* functional group are more difficult to manage than any other conditionally irrigable soils. The numerical values for all functional groups are listed in Table A.1, which were chosen to mimic the McClusky Canal irrigation feasibility study report (Garrison Diversion Conservancy District, 2016).

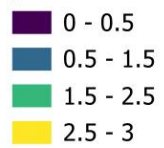
**Table A.1.** Numerical values assigned to soil irrigation functional groups for relative irrigability analysis.

<b>Irrigation Functional Group</b>	<b>Numerical value</b>
Irrigable	3
Conditional – permeability	2
Conditional – restricted layer	2
Conditional – drainage, water table, salinity	1
Non-irrigable	0
Non-irrigable due to slope	0
Water	0

Figures A.1 and A.2 display the statewide soil relative irrigability maps under the permissive and restrictive scenarios, respectively. Figures A.3 and A.4 show the relative irrigability rating by dominant conditions under the permissive and restrictive scenarios, respectively.



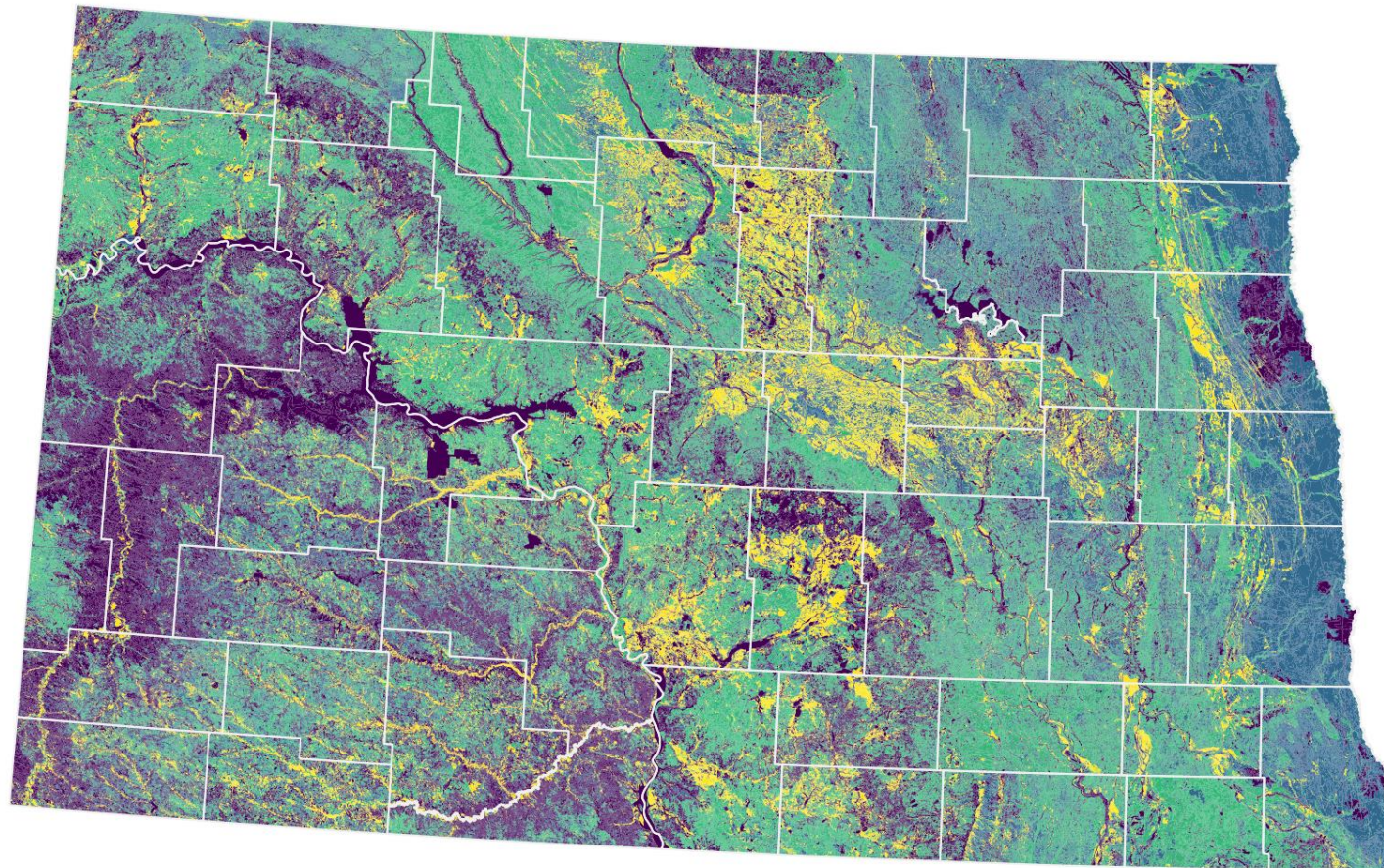
permissive scenario - relative irrigability



0 50 100 km



**Figure A.1.** Soil relative irrigability map under the permissive scenario.



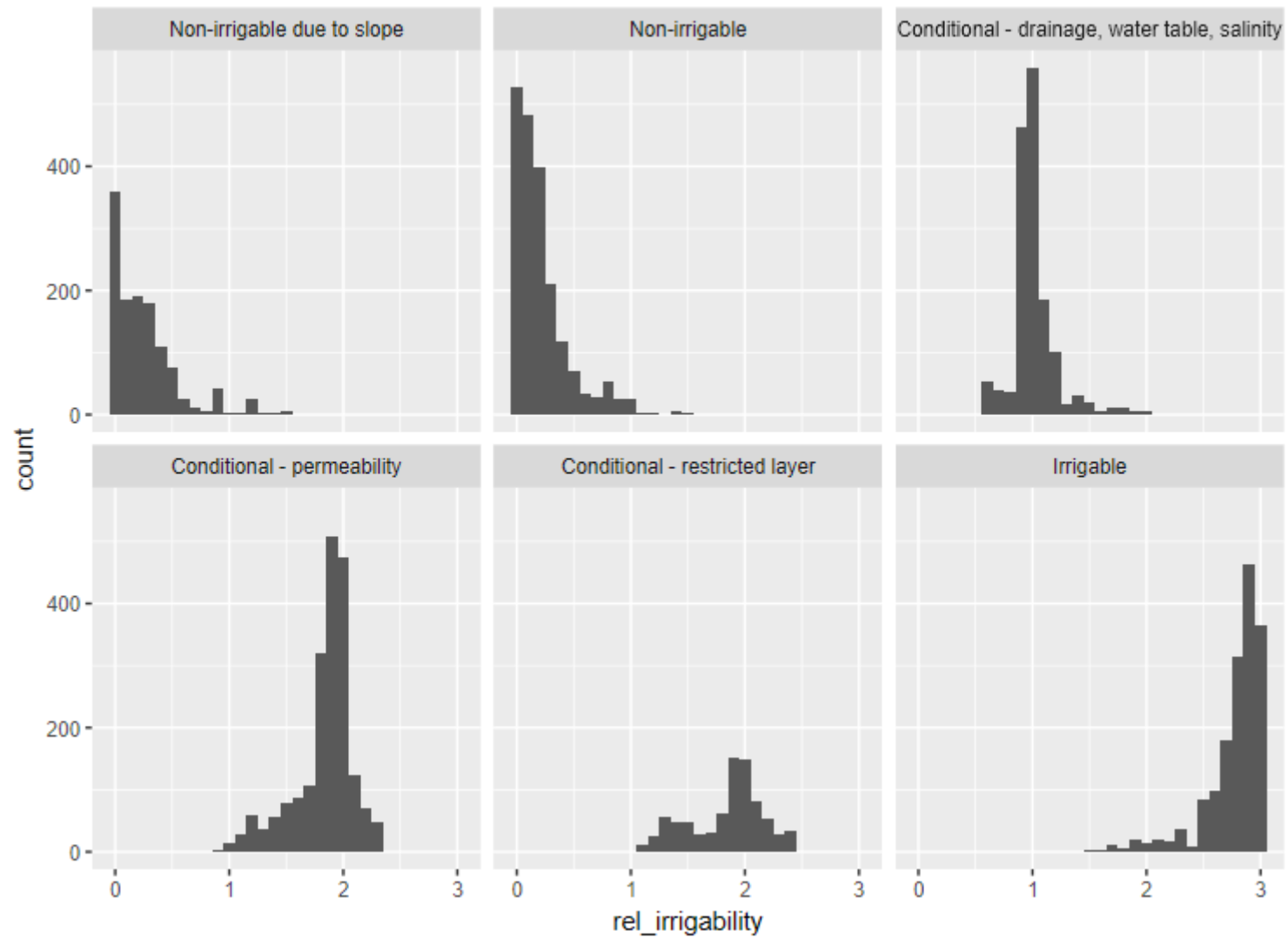
restrictive scenario - relative irrigability

- 0 - 0.5
- 0.5 - 1.5
- 1.5 - 2.5
- 2.5 - 3

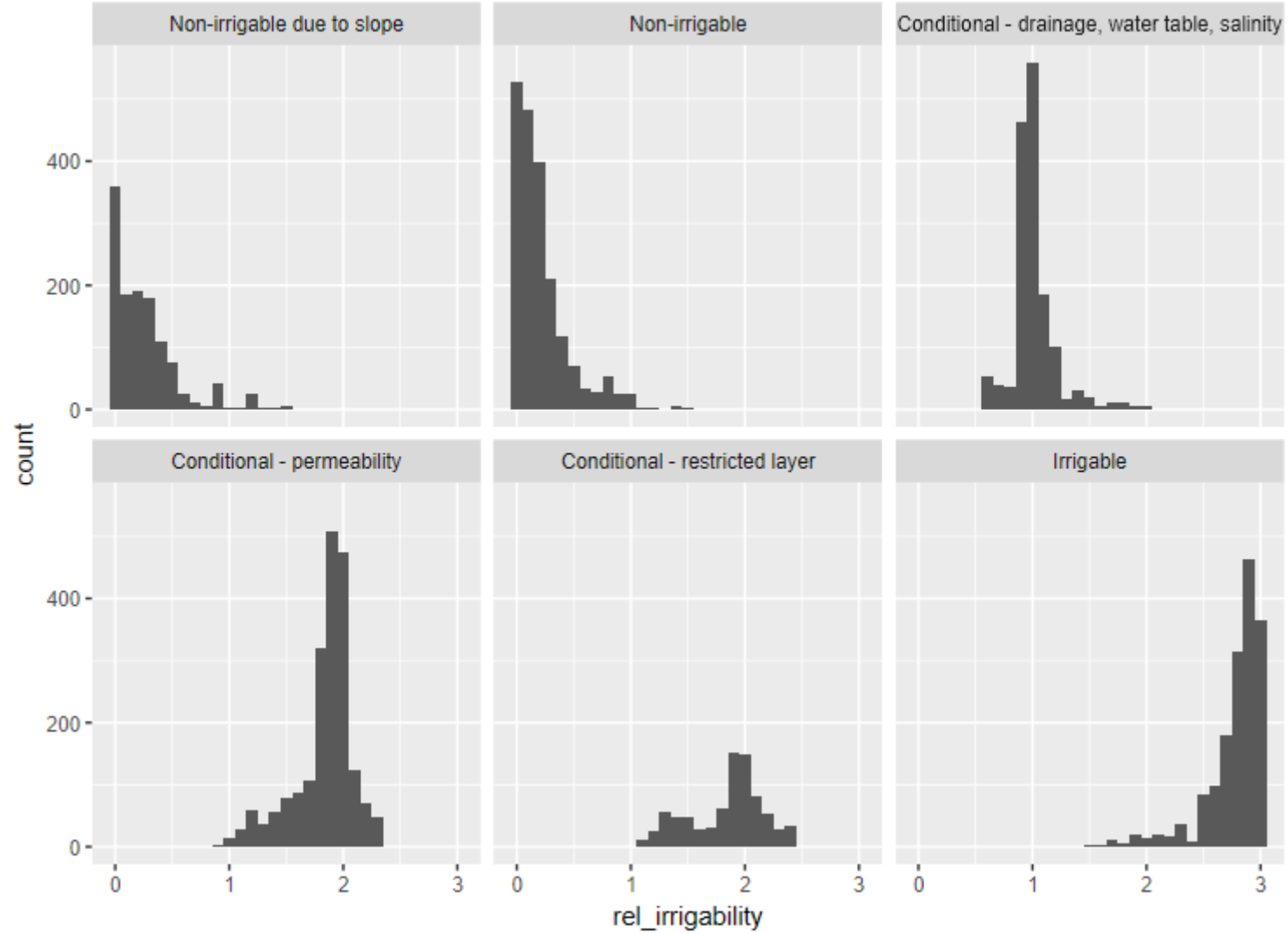
0 50 100 km



**Figure A.2.** Soil relative irrigability map under the restrictive scenario.



**Figure A.3.** Relative irrigability rating by the dominant condition under the permissive scenario.



**Figure A.3.** Relative irrigability rating by the dominant condition under the restrictive scenario.

## A.2. Identifying the existing center-pivot sprinkler systems

To identify the existing center-pivot sprinkler systems we employed the object detection deep learning model to process the Landsat 8 satellite images covering North Dakota. We downloaded 14 frames of the panchromatic band of Landsat 8 images captured in summer 2024, with a spatial resolution of 15 meters, from the [GloVis](#) website (Figure A.5 & Figure A.6).



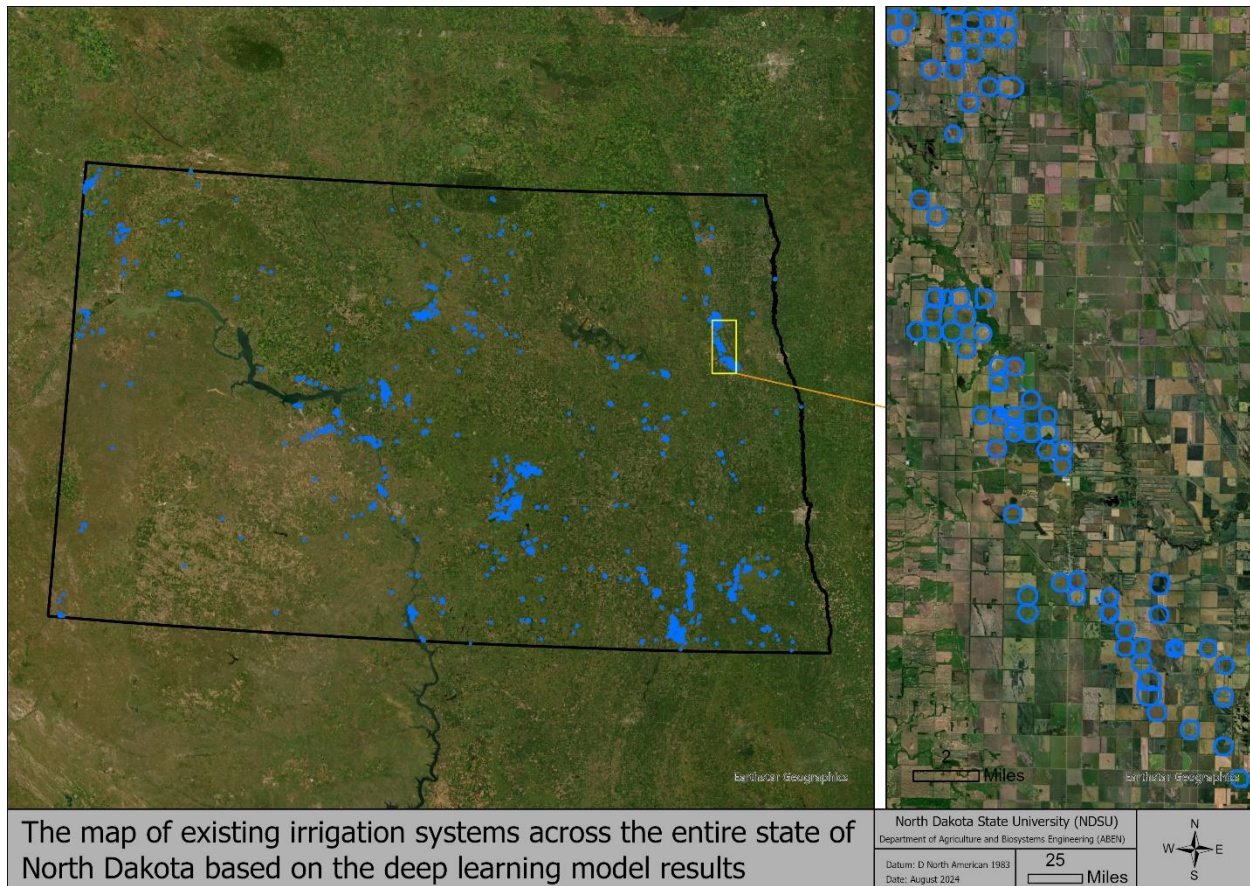
**Figure A.5.** The coverage of the state of North Dakota by 14 frames of Landsat 8 images.



**Figure A.6.** Signatures of center-pivot, sprinkler irrigation systems on the panchromatic band of Landsat 8 images.

After downloading the 14 frames of Landsat 8, we created an orthomosaic image in ArcGIS Pro (version 3.3.0) and used the Image Analysis package to export a training dataset (85% of the data) and a testing dataset (15% of the data) to train and test the Mask R-CNN object detection model for identifying the center-pivot, sprinkler irrigation systems. The ResNet-152 was used as the backbone model, with a batch size of 4 and 300 epochs. Overall, the trained deep learning model was able to locate the existing center-pivot systems with 75% accuracy from the Landsat 8 imagery (Figure A.7).



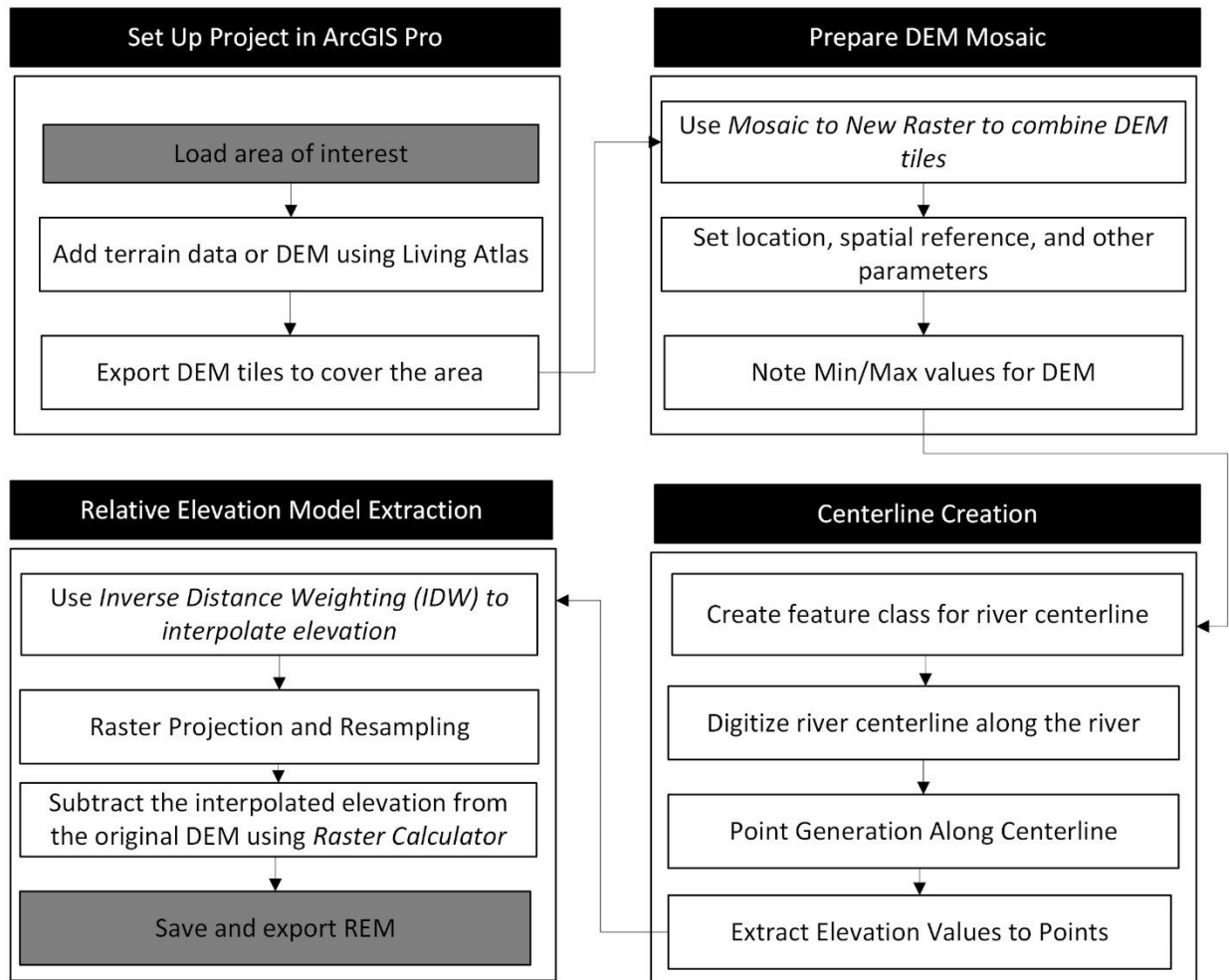


**Figure A.7.** The map of existing irrigation systems across North Dakota based on the deep learning model results.

To improve the accuracy of the existing layer of irrigation systems identification, we manually inspected the presence of the center-pivot systems based on the Landsat images and Google Images by dividing the state of North Dakota into 499 grids of equal size of 99,841 acres. The inspection was conducted at a zoom level of 1:12,000. By the systematic manual inspection, we corrected the shapes of irrigation systems detected by the deep learning model, identified irrigation systems that the model failed to detect, and removed polygons that were mistakenly identified as irrigation systems by the model. It should be noted that this method can only identify the circular pattern of a parcel of land actively irrigated by a center-pivot sprinkler system. It cannot identify an idle center-pivot sprinkler system or linear sprinkler system or any other type of irrigation system such as flooding and water-spreading surface irrigation systems.

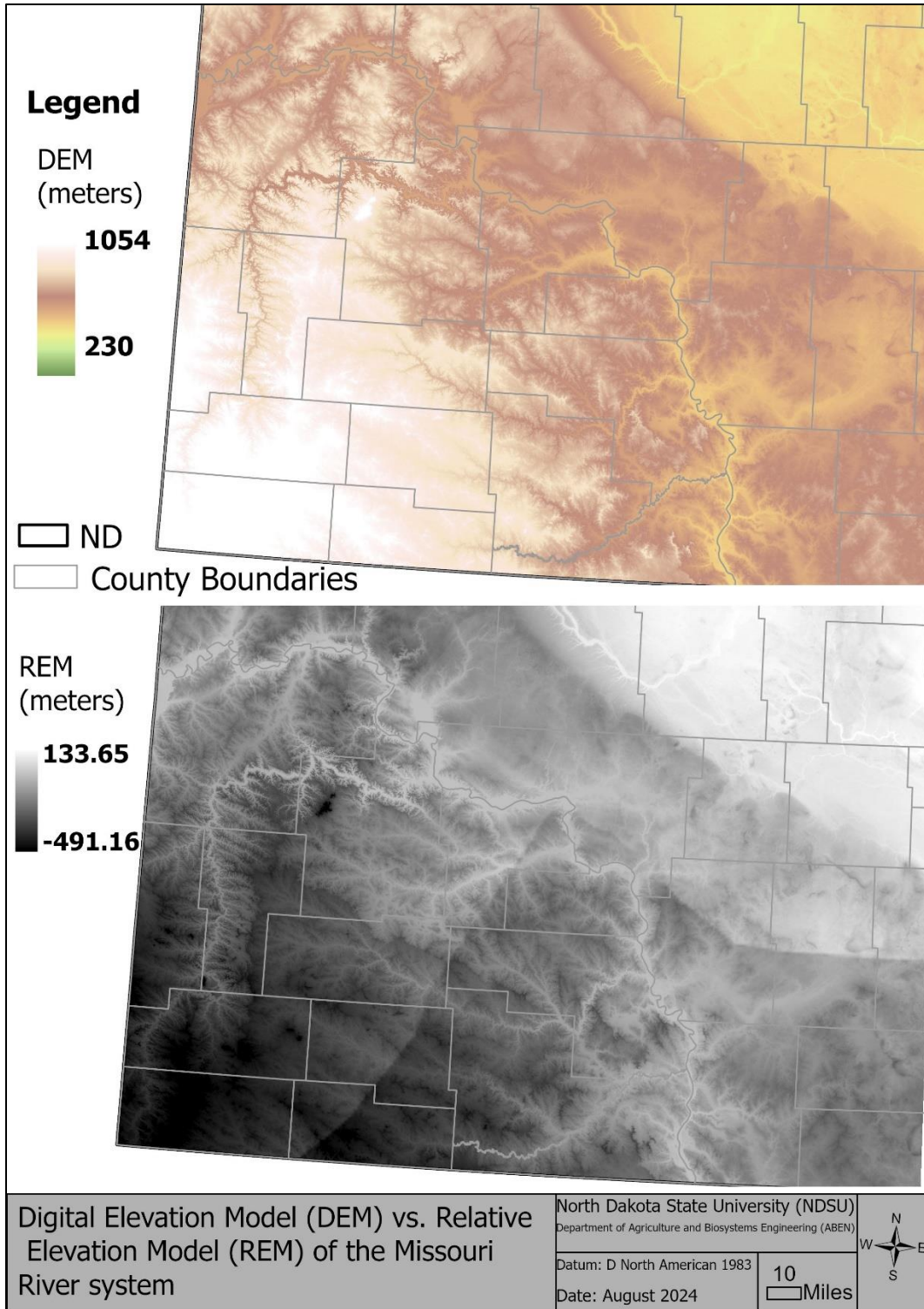
### A.3. Relative Elevation Model (REM)

A REM is a digital elevation model adjusted to show the elevation of land relative to a specific feature, such as a river or water body, rather than sea level. This approach highlights subtle topographic changes, making it especially useful for visualizing landforms, floodplains, and geomorphological features that may otherwise blend into the surrounding terrain. By calculating the elevation difference between each point in the terrain and a nearby baseline (e.g., water surface), REMs reveal detailed structural patterns that are valuable in environmental analysis, hazard assessment, and ecosystem monitoring. Figure A.8 shows the steps taken to calculate the REM in ArcGIS Pro.



**Figure A.8.** Flowchart of calculating Relative Elevation Model (REM) in ArcGIS Pro.

To conduct this analysis, a digital elevation model (DEM) with a spatial resolution of 0.24 meters was downloaded from the ND GIS Hub website and used as the base dataset. Figure A.9 shows a graphical overview of the DEM of the Missouri River system vs. a REM.



**Figure A.9.** Digital Elevation Model (DEM) vs. the Relative Elevation Model (REM) of the Missouri River system