Soil Salinization Hazards Associated with Devils Lake Flood Damage Reduction Alternatives

Upper Basin Storage Alternative

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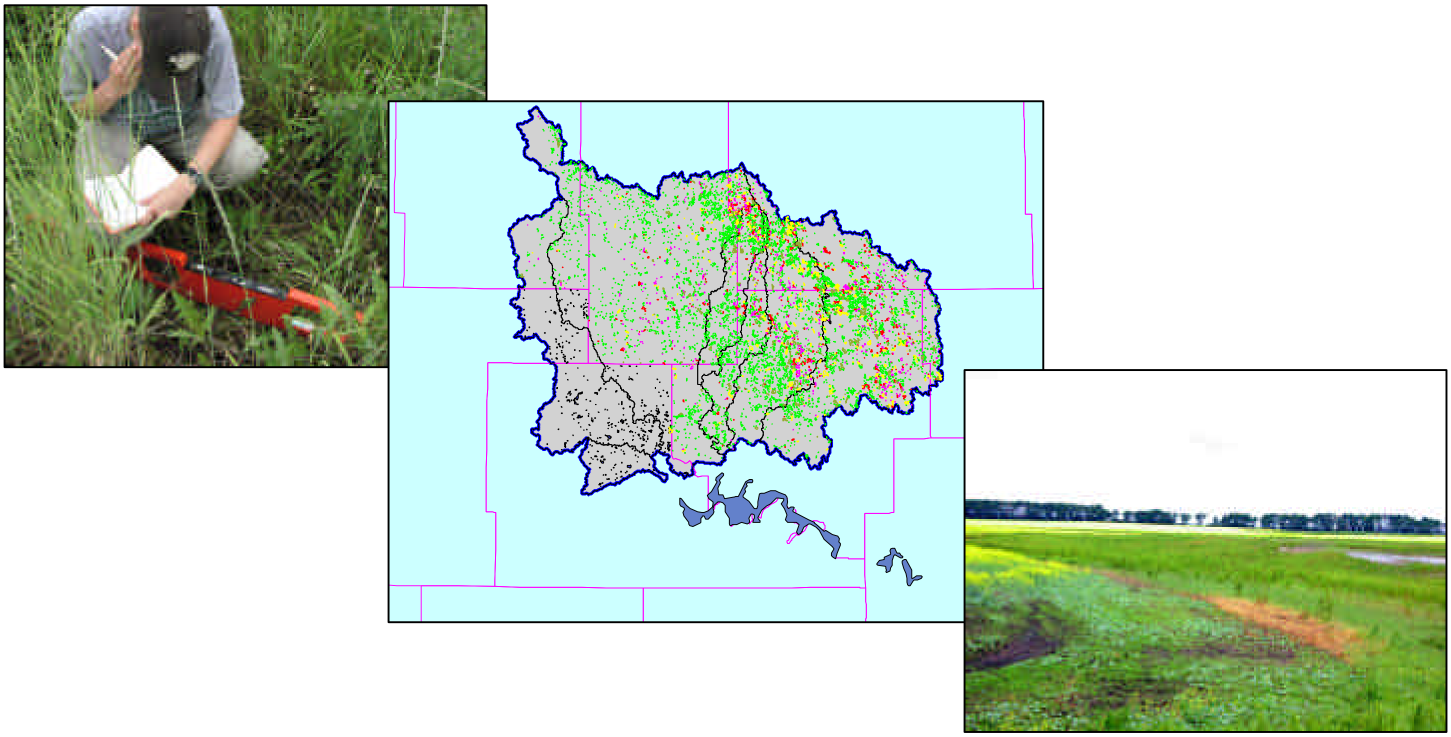

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Submitted By:

PETERSON ENVIRONMENTAL CONSULTING, INC.
1355 Mendota Heights Road, Suite 100
Mendota Heights, Minnesota 55120

Project Manager: Ronald P. Peterson, J. D.
Assistant Project Manager: James L. Arndt, Ph.D., LPSS

PETERSON
ENVIRONMENTAL

US Army Corps
of Engineers
St. Paul District

EXECUTIVE SUMMARY

BACKGROUND

This report addresses the potential soil salinization hazards associated with Upper Basin Storage (UBS), which is being considered as one alternative for reducing the impacts of Devils Lake flooding. The UBS alternative consists of increasing surface water storage volume in the watersheds of the Devils Lake Upper Basin through the restoration of wetlands historically drained for agriculture. Large numbers of Upper Basin wetlands have been drained and are potentially restorable. Agency estimates of drained wetland area range from 37,000 to 189,000 acres. Under contract to the St. Paul District, USACE, West Consultants, Inc. ("West") applied GIS digital terrain modeling and air photo interpretation techniques to identify 92,429 acres of drained wetlands in the Upper Basin, with a cumulative potential storage volume of approximately 133,000 acre-feet. Of these drained wetlands, West estimated 13,464 to be suitable restoration candidates, with a cumulative surface area of 79,762 acres and a total recoverable storage volume of 127,835 acre-feet.

The Upper Basin of Devils Lake consists of 2616 square miles in 7 North Dakota counties and encompassing 7 major watersheds. Upper Basin topography is dominated by low, undulating relief with poorly integrated drainage networks. The majority of the acreage in the Upper Basin is agricultural cropland. Saline soils in the Upper Basin are extensive, and are typically associated with wet areas where the groundwater is at or near the surface.

The Upper Basin Storage (UBS) alternative has a potential soil salinization hazard by raising the watertables in areas adjacent to the restored wetlands and mobilizing subsoil salts. Areas at particular risk are existing saline wetlands and areas that are adjacent to wetlands that characteristically have a periphery of saline or saline-sodic soils. Salt accumulation in North Dakota is associated with specific hydrogeologic settings generally associated with groundwater discharge, shallow groundwater depths, and intermittent ponding. Salts accumulate in the vadose (i.e. unsaturated) zone when unsaturated flow brings groundwater containing dissolved salts into the rooting zone. The attendant evapotranspirative withdrawal of pure water leaves the salts to accumulate. Although saline soils are the product of long term hydrogeologic conditions, salts are readily mobilized when recharge/discharge/ponding dynamics change.

In the Upper Basin, most wetlands can be classified as recharge, flowthrough, and discharge types based on hydrology, water chemistry, and soil physical and chemical characteristics. Recharge wetlands are; (1) typically located in higher positions in the landscape, (2) seasonally ponded with fresh water and (3) characterized by soils that have a morphology associated with frequent wetting and drying cycles and dominantly downward water movement Recharge wetlands are typically non-saline. Flowthrough wetlands; (1) are located in intermediate landscape positions, (2) are typically more permanently ponded and (3) receive more of their water from groundwater discharge and are thus generally brackish (i.e. moderately saline). Discharge wetlands are permanently saturated or semi-permanently-to-permanently ponded, reflecting the dominance of groundwater discharge. Soils are calcareous and are usually quite saline, especially around the wetland periphery.

Much of the research on salinity in the northern prairies has been performed in hummocky till topography with relief of 10 to 20 meters. Recharge-flowthrough-discharge relationships between wetlands and salinity are distinct and easily studied and recognized in such areas. However, much of the Upper Basin has low relief on the order of 1 to 5 meters. The relationships between groundwater flow and salinity still hold in low relief landscapes but the topography and the relationships between recharge and discharge are more subtle and are dominated by localized groundwater recharge and discharge. The flowthrough zone is essentially the wetland periphery and groundwater discharge occurs in the low relief areas adjacent to the wetland. In these areas, the presence of a groundwater mound associated with recharge maintains elevated watertables in soils that are transitional between wetland and upland conditions. These elevated watertables supply a source of dissolved solids that can be concentrated by evapotranspiration in the soil profile in the somewhat poorly drained soils that are adjacent to the wetlands.

Hydrologic alterations in and around wetlands can reorganize groundwater flow patterns developed over time, resulting in a significant mobilization of existing salts. Wetland drainage by surface ditching essentially moves the edge of the wetland to the pond interior adjacent to the ditch. Strongly saline soils can develop near such ditches over just a few decades. Drainage of flowthrough and discharge type wetlands typically results in; (1) the mobilization of salts to the pond interior, (2) the translocation of salts from the subsoil of the drained wetland to the soil surface, and (3) the desalinization of soils at the wetland edge. It is the remobilization of salts historically translocated by drainage that is primary soil salinization issue associated with wetland restoration in the Upper Basin.

METHODS

A quantitative, predictive assessment of salinization hazards associated with the UBS alternative is precluded by the; (1) magnitude of the area to be assessed (2616 square miles), (2) large number of potential restoration candidate wetlands identified (13,457), (3) complexity of the geomorphic, sedimentary, pedologic, and geochemical factors involved, and (4) non-specific nature of the soil map units in the county soil surveys. Accordingly, a qualitative/semi-quantitative assessment of salinization hazards was carried out. It was assumed that West's characterization of potential restoration candidates within the Upper Basin accurately reflects their sizes, numbers, distribution and storage volumes. Wetlands were classified as either drained or undrained; partial drainage of wetlands was not considered. It was assumed that drained wetlands would be restored to their original dimensions, that no additional acreage would be flooded and that salinization hazards would be limited to mobilization of existing soluble salts in the soils or subsoils in and within a 200-foot buffer around each drained wetland. For purposes of this assessment, saline soils have been limited to those mapped by the NRCS as consociations (a single dominant saline soil) and as major saline components of soil complexes. Salinization hazards have been semi-quantitatively estimated based on the percentage of mapped saline soils within each drained wetland and its surrounding 200-foot buffer.

Digital soil data (SSURGO, STATSGO) were obtained from the NRCS for Ramsey, Cavalier, Walsh, Towner, and Rolette counties. Data from these counties were extrapolated to Pierce and Benson counties for which digital data was unavailable. All potentially restorable wetlands identified by West were incorporated into an Arcview GIS and Access database. Polygons were created to represent each individual wetland and a 200-foot buffer around it. Each buffer was attributed with the unique polygon ID assigned to the potential restoration candidate wetland by West. GIS polygon clipping methods were employed to exclude all soils outside of the wetland and its associated 200-foot buffer. Existing and historic salinity conditions were assessed using digital and hardcopy soil survey data (SSURGO and county soil surveys, respectively), combined with MUIR attribute data. Some drained wetlands were examined in the field to provide representative examples in hydrogeologic settings with soil catenas that include saline or potentially saline soil components and to verify concepts regarding wetland drainage and salinity. In general, map units with major soil components that had listed salinities greater than 4 dS/m were considered saline soils.

For the purposes of evaluation, the soil polygons contained within the buffer and the drained wetland were reduced to two categories: saline soils and non-saline soils. Saline soils consisted of somewhat poorly drained or wetter soils that were listed in the soil survey as being saline soils or saline variants of non-saline soils or that had ECspe values in the MUIR database greater than 4 dS/m in the surface soil layers. Only major map unit components were considered and included soils of minor percentage were ignored. The acreage and percentage of saline soils within the wetland boundary, and within the surrounding 200-foot buffer were determined using GIS and database methods. Salinization hazard classes were developed for each wetland and wetland buffer based on the percentage of saline soils included within each polygon pair.

Five salinization classes were developed: 0-5%, >5-25%, >25-50%, >50-75%, and >75-100% represent None-to-Slight, Low, Moderate, High, and Severe classes respectively. Wetland and wetland buffers were analyzed separately. Restoration candidate wetlands lacking saline soils within the buffer or wetland polygons were placed in the None-to-Slight salinity category. The presence of inclusions, uncertainties regarding accurate mapping and the broad ranges in ECspe provided as representative of individual soil series precluded the development of a pure "None" category. Restoration candidate wetlands that contain >75-100% soil map units with major saline components have been placed into the severe category. Soils that have intermediate percentages of soil map units with major saline components have been placed in intermediate categories (>5-25%, >25-50%, and >50-75% represent low, moderate, and high salinity hazard categories, respectively). The intermediate categories are somewhat arbitrary and were developed to represent a representative, equally spaced gradation of salinization hazards from Low to Severe.

Database methods were used to associate the potential restoration volume (in acre-feet) and wetland area calculated by West with the salinity hazard class of individual wetlands. The results are provided in Arcview format permitting the identification of potentially restorable wetlands. Each potential restoration candidate wetland was color coded to its respective wetland and buffer hazard class.

RESULTS

SOIL ASSOCIATIONS

Surface geology and the STATSGO map unit data exhibit similar distribution patterns because of the close relationship between soil associations and geological parent material and topography. Seven soil associations comprise over 2330 square miles (89%) of the Upper Basin area. The three most extensive STATSGO soil map units include ND046 (Barnes-Svea-Hamerly, 896 square miles), ND043 (Svea-Buse-Hamerly; 765 square miles), and ND040 (Hamerly-Tonka-Svea, 223 square miles). These three soil associations comprise 1884 square miles, or just over 72% of the 2616 square mile total for the entire Upper Basin. All three associations are mapped on hummocky collapsed till and share many of the same soil components. They vary mainly as to relief. Two additional associations comprise slightly less than 10 percent (over 253 square miles) of the total area of the Upper Basin and are associated with water-worked glacial drift. ND005 (Bearden-Great Bend-Overly) accounts for over 127 square miles of the total basin area and is associated with relatively fine-textured lacustrine material derived from ice-walled, glacial lake sediments. ND041 (Hegne-Hamerly-Fargo) accounts for 126 square miles of the total Upper Basin area and is associated with wave-washed (eroded) glacial sediment. One additional STATSGO map unit accounts for a significant area within the Upper Basin. ND051 (Svea-Cresbard-Hamerly) comprises 198 square miles and is generally associated with hummocky collapsed till similar to ND043 (Svea-Buse-Hamerly); however, sodicity is more common in ND051, likely because of shallower depths to Pierre Shale and a more significant shale component to the local tills. NRCS data indicate sodic soils in somewhat poorly, poorly and very poorly drained landscape positions are of very limited extent in the Upper Basin. Accordingly, this analysis focuses on salinity alone.

Wetland soil series in the Upper Basin are dominated by non-saline Tonka (*fine, smectitic, frigid Argiaquic Argialbolls*), Parnell (*fine, smectitic, frigid Vertic Argiaquolls*) and Hegne soils (*fine, smectitic, frigid Typic Calciaquerts*). Saline and potentially salinizable soils on wetland peripheries consist predominantly of Hamerly (*fine-loamy, mixed, superactive, frigid Aeric Calciaquolls*), Vallers (*fine-loamy, mixed, superactive, frigid Typic Calciaquolls*) and Bearden soils (*Fine-silty, mixed, superactive, frigid Aeric Calciaquolls*).

DISTRIBUTION STATISTICS AND THE RELATIONSHIP BETWEEN SALINITY HAZARD CLASS AND POTENTIAL STORAGE VOLUME

The majority of the potentially restorable wetlands are extremely small with limited water storage potential. The majority of the storage associated with wetland restoration would come from the restoration of a few larger wetlands with higher storage volumes. For the None/Slight Buffer Salinization Hazard class, just under 50,000 acre feet of storage (75% of the total) is contained within only 10% (approximately 900) of the 9107 restoration candidates identified by West (exclusive of wetlands in Benson and Pierce counties). Similarly, for the None/Slight Wetland Salinization Hazard class, approximately 45,000 acre feet of storage (71% of the total) is contained within only 10% (approximately 960) of the 9625 wetlands in the None/Slight Wetland Hazard Class. These data demonstrate that efforts to acquire and restore wetlands under the UBS alternative should be focused on a subset of larger wetlands that represent the majority of the recoverable storage volume.

SALINIZATION HAZARDS ASSOCIATED WITH WETLAND RESTORATION

Table 4 presents a breakdown of wetland acreage and potential restoration volumes by Buffer Salinization Hazard Class and county. The salinity hazard classification category with the largest number, acreage, and storage volume is the None/Slight category, followed by the low, moderate, high, and severe categories. The lowest percentage of total storage volume in the None/Slight salinity hazard category was in Cavalier county (45.3%), followed by Ramsey (50.7%), Towner (76.4%), Rolette (87.2%), and Walsh (91%) counties. Benson and Pierce counties were not analyzed because spatial digital soils data on map unit distribution were lacking. However, based on the percentages in the five counties where salinity was assessed, a

50% value for total storage volume in the None/Slight category would be a conservative estimate for Benson and Pierce counties. Even though Ramsey and Towner Counties have the smallest percentage of wetlands in the None/Slight hazard class, they have the largest number of restorable wetlands and available storage, followed by, Cavalier, Rolette, and Walsh counties.

Exclusive of Benson and Pierce counties, 66,861 acre-feet of storage are in the None/Slight category, representing approximately half of the total available storage of 127,853 acre-feet. Since the UBS alternative assumes restoration of 50% of the available storage identified by West (63,926 acre-feet), the data suggest that this restoration percentage is attainable with limited salinization hazards. If a conservative estimate of 50% of the available storage were assumed to be in the None/Slight salinity hazard category for Benson and Pierce counties, the total recoverable storage volume would rise from 66,861 acre-feet to 71,570 acre-feet.

Table 5 presents a breakdown of wetland number, acreage and potential restoration volumes by Wetland Salinization Hazard Class and county. In general, the data are very similar to that discussed above for the 200-foot buffer around each wetland. Again, the salinity hazard classification category with the largest number, acreage, and storage volume is the None/Slight category. The distribution of wetlands by Wetland Salinity Hazard category is slightly different in that the None/Slight category is followed by the moderate, then low and severe categories. The lowest percentage of total storage volume in the None/Slight salinity hazard category was in Cavalier county (40.4%), followed by Ramsey (51.3%), Walsh (54.3%), Rolette (71.7%), and Towner (71.9%) counties. Benson and Pierce counties were not analyzed because spatial digital soils data on map unit distribution were lacking. However, based on the percentages in the five counties where salinity was assessed, a 50% value for total storage volume in the None/Slight category would be a conservative estimate for Benson and Pierce counties. Even though Ramsey and Towner Counties have the smaller percentage of wetlands in the None/Slight hazard class, they have the largest number of restorable wetlands and available storage, followed by, Cavalier, Rolette, and Walsh counties.

Exclusive of Benson and Pierce counties, 63,512 acre-feet of storage fall in the None/Slight category, again representing approximately half of the total available storage of 127,853 acre-feet. Again, as stated above, the UBS alternative assumes restoration of 50% of the available storage identified by West (63,926 acre-feet). Wetland Salinity Hazard data suggest that this restoration percentage is attainable with limited salinization hazards occurring within the restored wetlands. If a conservative estimate of 50% of the available storage were assumed to be in the None/Slight salinity hazard category for Benson and Pierce counties, the total restorable storage would rise from 63,512 acre-feet to 68,220 acre-feet. Based on a linear regression analysis, a strong statistical relationship was found between Buffer and Wetland Salinity Hazard classes for restoration candidate wetlands.

GIS MAPPING PRODUCTS

GIS layers for both wetland salinity hazard classes and soil maps are being provided to the St. Paul District, USACE. If the UBS alternative is pursued, these Arcview themes and associated attribute data can be used to identify potential wetland restoration candidates by location, size, geomorphic setting, and percentage of saline soils. Also included in the GIS products is a layer identifying saline soils that are adjacent to the 200-foot buffer polygons.

MANAGEMENT AND MITIGATION OF SOIL SALINITY

Salt and sodium in soils can limit their use and reduce crop yields. Depending on crop salt tolerance, significant yield reductions of intolerant crops occur beyond an EC of 4 dS/m. Crop tolerances to soil salinity/sodicity have been quantified and management techniques to reduce the negative impacts of soil salinity are known. Many of these techniques are already in general use on saline/sodic soils in the region. Secondary soil salinization associated with the UBS alternative may have a negative economic impact that can be quantified through an assessment of increased management costs, limits to use, and reduced crop yields. Soil water compatibility issues are well documented and salinity hazards can be readily identified and mitigated for. Common management techniques use adapted crops and manipulate watertables and groundwater flow to minimize soil salinization in sensitive areas. Land and water management practices that can help producers to reduce the risk of dryland salinization include but are not limited to:

- increasing minimum tillage or no-tillage
- increasing the area of forages, pastures, and tree crops
- reducing summer-fallow area
- including crops that are more salt-tolerant in rotations
- using inputs such as mineral fertilizers and animal manure more effectively
- using precision farming
- installing interceptor forage strips or strategic subsurface tile drainage.

CONCLUSIONS

Wetland restoration does not add salts to the landscape but rather remobilizes existing salts that have been translocated by drainage. With wetland restoration, salts are frequently translocated back to positions in the landscape that remain saline or that were saline prior to wetland drainage. When mobilized salts accumulate in locations where salinity was not common or was not a problem before, growers will perceive a salinization problem and possibly attribute it to wetland restoration. The data provided in this report suggest that the restoration of 50% of the potential storage volume contained in drained candidate wetlands identified by West Consultants, Inc. (2001) is attainable. The data suggest that well over 60,000 acre-feet of storage are available with a minimum of salinization hazards.

Restoration should be focused primarily on candidate wetlands in the None/Slight and Low salinization hazard classes. Few salinization problems are likely to be perceived in these wetlands and they represent the majority of the recoverable storage volume in the Upper Basin. Restoration of wetlands with intermediate salinization hazards (e.g. those wetlands in the Moderate Salinization hazard classes for both the wetland and the wetland buffer) should be avoided. Restoration of such wetlands would be likely to result in a perceived salinity problem associated with the existing saline land and potentially saline adjacent land. However, many candidate wetlands in the High and Severe hazard classes may be good candidates for restoration because they may no longer represent productive cropland. Many such wetlands are now unsuited or marginal for agriculture due to drainage-related salinity problems. Placing restored saline wetlands and their surrounding buffer zones into a conservation reserve program may be an attractive option to farmers whose land is not producing efficiently because of existing, drainage-related salinity problems. Existing programs such as the NRCS conservation set-aside program for saline lands and the Extended Storage Acreage Program (ESAP) could be combined to provide incentives for landowners to enroll in wetland restoration programs.

Restoration of candidate wetlands will likely have to take into consideration members of all salinization hazard groups due to uncertainties in land acquisition, the need to restore wetlands in certain locations, and the need to focus on larger wetlands with greater storage potential. GIS queries could be applied to the Arcview data layers generated by this study to rank wetlands by salinity hazard class, size, storage volume and location to develop the best possible mix of restoration alternatives that would maximize long term storage, grower, and wildlife concerns. For each wetland restoration project that is pursued, on-site investigations by qualified professional soil scientists should be performed beforehand. The extent of saline soils within and near the restoration candidate should be determined and the potential soil salinization response to restoration estimated. An on-site assessment is particularly important to identify saline soils that may be incorrectly mapped as non-saline and to identify the presence and extent of saline inclusions.

Table 4. Summary breakdown of wetland acreage and potential restoration volumes by Buffer Salinization Hazard Class and county. The last column provides a breakdown assuming that all wetlands in the None/Slight Buffer Salinity Hazard Class are restored.

COUNTY	Buffer Salinity Hazard Class	Number of Wetlands in Hazard Class	Wetland Acreage in Hazard Class (Acres)	Wetland Volume in Hazard Class (Acre Feet)	Total Volume by Hazard Class (Percent)	Restore Hazard Class None/Slight
All Counties exclusive of Benson and Pierce	None/Slight (0)	9107	44392	66861	56.5	
	Low (1)	1114	17735	32222	27.2	
	Moderate (2)	1004	9307	14546	12.3	
	High (3)	532	3060	4006	3.4	
	Severe(4)	250	785	801	0.7	
Grand Totals		***12007***	***75280***	***118436***	***100***	
County Breakdowns						
Cavalier	None/Slight (0)	1378	7935	13325	45.3	13325
	Low (1)	341	5912	12016	40.9	
	Moderate (2)	312	2523	3490	11.9	
	High (3)	135	497	490	1.7	
	Severe(4)	32	98	78	0.3	
Subtotal		2198	16966	29399	100	
Ramsey	None/Slight (0)	3587	19820	29711	50.7	29711
	Low (1)	533	9520	16694	28.5	
	Moderate (2)	488	5365	8699	14.8	
	High (3)	271	2157	3036	5.2	
	Severe(4)	116	454	449	0.8	
Subtotal		4995	37315	58589	100	
Rolette	None/Slight (0)	932	1974	2844	87.2	2844
	Low (1)	8	227	302	9.3	
	Moderate (2)	16	41	32	1.0	
	High (3)	10	21	34	1.0	
	Severe(4)	11	34	51	1.6	
Subtotal		977	2296	3263	100	
Towner	None/Slight (0)	3044	13636	19592	76.4	19592
	Low (1)	211	1974	3097	12.1	
	Moderate (2)	183	1356	2306	9.0	
	High (3)	115	382	444	1.7	
	Severe(4)	90	196	220	0.9	
Subtotal		3643	17544	25660	100	
Walsh	None/Slight (0)	166	1027	1388	91.0	1388
	Low (1)	21	102	113	7.4	
	Moderate (2)	5	23	19	1.3	
	High (3)	1	3	3	0.2	
	Severe(4)	1	3	2	0.2	
Subtotal		194	1159	1525	100	
Benson	Not Analyzed	1060	3595	8351		4175.5*
Pierce	Not Analyzed	390	891	1066		533*
Grand Total		**13457**	**79766**	**127853**		**66861**
						71570*

* - Assumes a conservative value of 50% restoration candidate wetlands in Benson and Pierce counties in the None/Slight Wetland Salinity Hazard Category.

Table 5. Summary breakdown of wetland acreage and potential restoration volumes by Wetland Salinization Hazard Class and county. The last column provides a breakdown assuming that all wetlands in the None/Slight Wetland Salinity Hazard Class are restored.

COUNTY	Wetland Salinity Hazard Class	Number of Wetlands in Hazard Class	Wetland Acreage in Hazard Class (Acres)	Wetland Volume in Hazard Class (Acre Feet)	Total Volume by Hazard Class (Percent)	Restore Hazard Class None/Slight
All Counties exclusive of Benson and Pierce	None/Slight (0)	9625	44156	63512	53.6	
	Low (1)	401	9188	16656	14.1	
	Moderate (2)	485	10583	20237	17.1	
	High (3)	500	5885	10730	9.1	
	Severe(4)	996	5467	7302	6.2	
Grand Totals		***12007***	***75280***	***118436***	*100*	
County Breakdowns						
Cavalier	None/Slight (0)	1485	7408	11877	40.4	11877
	Low (1)	92	1963	3820	13.0	
	Moderate (2)	160	3660	7376	25.1	
	High (3)	185	2182	3890	13.2	
	Severe(4)	276	1754	2436	8.3	
Subtotal		*2198*	*16966*	*29399*	*100*	
Ramsey	None/Slight (0)	3855	20705	30029	51.3	30029
	Low (1)	223	5348	9022	15.4	
	Moderate (2)	243	5813	11099	18.9	
	High (3)	224	2791	4875	8.3	
	Severe(4)	450	2657	3564	6.1	
Subtotal		*4995*	*37315*	*58589*	*100*	
Rolette	None/Slight (0)	937	1873	2339	71.7	2339
	Low (1)	4	289	684	21.0	
	Moderate (2)	7	51	112	3.4	
	High (3)	6	22	36	1.1	
	Severe(4)	23	61	92	2.8	
Subtotal		*977*	*2296*	*3263*	*100*	
Towner	None/Slight (0)	3182	13499	18438	71.9	18438
	Low (1)	76	1370	2757	10.7	
	Moderate (2)	72	889	1451	5.7	
	High (3)	76	855	1886	7.4	
	Severe(4)	237	930	1127	4.4	
Subtotal		*3643*	*17544*	*25660*	*100*	
Walsh	None/Slight (0)	166	671	828	54.3	828
	Low (1)	6	218	371	24.4	
	Moderate (2)	3	169	199	13.0	
	High (3)	9	35	44	2.9	
	Severe(4)	10	66	82	5.4	
Subtotal		*194*	*1159*	*1525*	*100*	
Benson	Not Analyzed	1060	3595	8351		4175.5*
Pierce	Not Analyzed	390	891	1066		533*
Grand Total		**13457**	**79766**	**127853**		**63512**
						68220*

* - Assumes a conservative value of 50% restoration candidate wetlands in Benson and Pierce counties in the None/Slight Wetland Salinity Hazard Category.

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1. INTRODUCTION

The US Army Corps of Engineers, St. Paul District (USACE) has contracted with Peterson Environmental Consulting, Inc. (PEC) to provide a Phase 2 assessment of soil salinization hazards associated with alternatives to reduce flood damage in the Devils Lake Basin.

Devils Lake is a large (greater than one hundred thousand acres) closed basin that has been filling since the early 1990s in response to pluvial conditions in the upper Midwest. The lake has risen approximately 24 feet between 1993 and 1999. Problems with infrastructure (e.g. roads) and the flooding of residences farm fields and pastures have become worse as the lake rises. The lake would discharge through a natural outlet from Stump Lake to the Sheyenne River if lake water reaches 1459 fASL. Salinity is variable depending upon lake stage and position within the lake chain. Salinity is highest in Stump Lake, which is the lowest in elevation of the Devils Lake chain of basins. Lake water and bottom sediment salinity is generally lowest in West Bay, and is intermediate in the intervening bays. Solution chemistry is dominated by sodium sulfate.

The geologic and hydrologic setting of Devils Lake, a summary of flooding issues, and prior reports are summarized along with selected hydrologic and chemical data in an in-house summary recently released by the USACE (St. Paul District USACE, Unpublished Memorandum).

Options to mitigate the ongoing Devils lake flooding have been legislatively mandated at the national level, with environmental impacts of proposed options to be assessed through the preparation of an Environmental Impact Statement (the Devils Lake Emergency Outlet Project; National Environmental Policy Act (NEPA) Process, USACE In-House Summary). Currently there are two broad alternatives being considered to reduce the impacts of Devils Lake flooding: (1) enhancing storage in the upper basin watershed (Upper Basin Storage Alternative), and (2) removing water from the lake through a created outlet (Outlet Alternative). Both alternatives have the potential to result in secondary soil salinization and possibly aggravated sodic conditions (defined as the anthropogenic creation of saline/sodic situations or the anthropogenic aggravation of existing saline/sodic conditions, respectively). Salinity, sodicity, and associated terms are defined in more detail in Section 1.1.3, below. Salinization hazards associated with the outlet alternatives were addressed in previous reports (Peterson Environmental Consulting, Inc., October 9, 2001; November 14, 2001). The present report addresses soil salinization hazards associated with restoration of drained wetlands in the Upper Basin of Devils Lake.

1.1. BACKGROUND

1.1.1. Upper Basin Storage (UBS) Alternative

It has been estimated that 60% of the original pre-settlement wetland area in North Dakota has been drained and converted to agriculture (Kantrud et al., 1989). Wetland drainage has been shown to aggravate flooding by reducing the amount of surface storage and increasing runoff to adjacent drainageways and surface water bodies (Hubbard et al., 1987; Mitch and Gosselink, 1993; Brinson; 1993; Kadlec and Knight, 1996; Brun et al., 1981; Lee et al., 1997). Wetland drainage in the Upper Basin of Devils Lake has been suggested as one factor aggravating flooding in Devils Lake during the past decade; however, there is some debate on the magnitude of the effect (NDSWC position paper, www.swc.state.nd.us/projects/devilslake/drainage.pdf; Schultz, 1999).

1.1.1.1. Wetland Drainage in the Upper Basin

The Upper Basin of Devils Lake is dominated by a gently rolling till topography. The landscape is a mosaic of closed depressions emplaced at varying elevations in the till. Wetlands that occupy the lowest portions of these depressions usually overflow only during periods of extremely heavy snowmelt in spring or during extremely heavy rainfall events and thus do not contribute surface drainage to Devils Lake. A poorly developed integrated drainage network exists that transports runoff accumulated during significant runoff events to the Chain of Lakes and subsequently to Devils Lake (**Figure 1**).

(Insert Figure 1 here)

Most wetland drainage in the upper basin is through surface ditches constructed to direct drainage water to wetlands, natural drainageways or other constructed ditches that are downstream of the drained wetland. The lack of well-integrated natural drainage networks complicates the efficient drainage of wetlands because there are limited downstream drainageways available to receive the water. Wetlands are drained by surface ditches connected to natural drainageways when natural drainageways are in close proximity to the wetlands. In situations where drainageways are unavailable, wetlands in elevated positions in the landscape are drained to wetlands lower in the landscape (wetland consolidation). Agricultural wetland drainage is frequently directed to road ditches that provide a conduit for the drainage water. Drained wetlands contribute runoff to Devils Lake when they are connected to the drainage network that eventually discharges to the lake. In recognition of the potential for the restoration of drained wetlands to reduce discharge from contributing areas to Devils Lake, the State of North Dakota initiated the Available Storage Acreage Program (ASAP) in 1996 to provide an economic incentive for landowners to restore wetlands in the Upper Basin. The program was recently renamed to the Extended Storage Acreage Program (ESAP), and provides payments of up to $40/acre-foot of storage per year for tracts of drained wetlands that meet the eligibility requirements. Information on this program is available from the North Dakota State Water Commission (NDSWC).

Several studies have attempted to quantify the acreage and distribution of drained wetlands in the Upper Basin (Ludden et al., 1983; Martinetti, 2000; Bell et al., 1999), and the effects of restoring these drained basins on reducing flooding in Devils Lake itself (West Consultants, Inc., 2001). While there is considerable variability in wetland drainage estimates, it is evident that large numbers of Upper Basin wetlands have been drained and are potentially restorable. West Consultants, Inc. (2001) compared their results to previous studies. They indicated that the surface area of drained wetlands ranged from a low of 37,000 acres estimated by the NDSWC to a high of 189,000 acres estimated by the United States Fish and Wildlife Service (USFWS). West Consultants, Inc. employed GIS techniques to identify 92,429 acres of drained wetlands in the Upper Basin, and determined their potential storage volume as approximately 133,000 acre-feet. West Consultants Inc. reduced this dataset to include only restorable drained wetlands. They concluded that there were 13,464 restoration candidates (26% of their total number of drained depressions) having a total surface area of 79,762 acres (86% of the total drained wetland acreage) and a total recoverable storage volume of 127,835 acre feet.

1.1.1.2. Salinity and Wetland Restoration in the Upper Basin

The Upper Basin Storage (UBS) alternative would enhance storage of water in the Upper Basin watershed of Devils Lake by restoring wetlands that have been partially or effectively drained for agriculture. This alternative has a potential soil salinization hazard by raising the watertables in areas adjacent to the restored wetlands and mobilizing subsoil salts. Areas at particular risk are existing saline wetlands or areas that are adjacent to wetlands that characteristically have a periphery of saline or saline-sodic soils. With restoration some lateral groundwater movement will result in the mobilization of salts from the drained interior of susceptible wetlands to their margins. However, it is believed that the majority of the secondary salinization produced by the UBS alternative will result from a mobilization of salts from deep in the profile to the soil surface in areas where the watertables rise above the "critical depth" (defined in section 1.1.3.1).

Not all wetlands will be similarly affected. A considerable number of seasonally ponded wetlands have a groundwater recharge function. These wetland typically have soil profiles that are leached and non-saline. Soils on the periphery of these wetlands are frequently non-saline but do accumulate calcium carbonate ($CaCO_3$), a sparingly soluble salt that is extremely common in many soils in North Dakota. A lack of stored salt in these soils combined with the freshness of the runon-water component would reduce the salinity risk associated with the restoration of these wetland types.

1.1.2. Setting

1.1.2.1. Hydrography

The Upper Basin of Devils Lake consists of 2616 square miles contained within 7 major watersheds: Calio, Comstock, Edmore, Hurricane Lake, Mauvais Coulee, St. Joseph, and Starkweather. The Upper Basin encompasses parts of 7 North Dakota Counties: Rolette, Towner, Cavalier, Walsh, Ramsey, Benson, and Pierce (see Figure 1). The Devils Lake Basin is a terminal, closed basin that has been shown to occasionally overflow out of the easternmost and lowest of its chain of lakes (Stump Lake). Overflow discharges through the Tolna Coulee to the Sheyenne River. The lake has not overflowed to the Sheyenne River within recorded history and appears to have overflowed within the last 1800 years (Bluemle, 1988).

The topography of the upper basin is dominated by low, undulating relief with poorly integrated drainage networks. The landscape is essentially a mosaic of closed drainage basins that occasionally overflow during very wet periods and intense storms. During such periods the basins overflow to a series of drainageways which coalesce into the major coulees that drain each watershed. Prior to 1979, streamflow from the major streams entered the interconnected chain of lakes to the north of Devils Lake proper. Water then flowed through Big Coulee to Devils Lake. In 1979, Channel A was constructed to divert a portion of this water from Dry Lake to Devils Lake via discharge to Six-Mile Bay (Wiche and Pusc, 1994).

1.1.2.2. Geology

The entire Upper Basin area was subject to the most recent Wisconsin glaciation (Clayton et al., 1980). The surface geology is dominated by glacial sediment of varying thickness and types (**Figure 2**). By far the most prevalent glacial material is collapsed glacial till (i.e., ground moraine) that varies from nearly level (map unit Qccg[1] in the western portion of the Upper Basin) to gently undulating (Qccu[2] in the eastern portion of the Upper Basin. Integrated drainage in this youthful landscape is poorly developed. The central portion of the upper basin is dominated by lacustrine sediments relict from a large, ice-walled glacial lake (Qcoh[3]) and an area of collapsed river sediment (Qcrh[4]) that is dominated by coarser textures than either the till or the lacustrine sediments. Wave-eroded glacial sediment with mixed till and lacustrine material is present to the south of the Qcoh unit. This sediment is relict from a period when the glacial precursor to Devils Lake was much larger. Till lithology is mixed and results from the incorporation of locally derived Pierre Shale with calcareous dolomite and limestone eroded by glaciation from exposures to the north in Canada and transported in glacial ice. Particle sizes of glacial sediments range from coarse-textured, water-worked sands and gravels to fine textured lacustrine clays.

(Insert Figure 2 here)

1.1.2.3. Soils

The majority of the acreage in the Upper Basin is agricultural cropland. Soil properties are integral to wise land-use management in agricultural areas, and essentially dictate the productivity of the land. Knowledge of soil properties is essential for any management program designed to maintain productivity in a sustainable manner without degrading the soil resource. Soils are also a geologic material that can provide much information regarding present and past environmental and hydrological conditions.

Saline soils in the Upper Basin are extensive, and are typically associated with wet areas where the groundwater is at or near the surface. For example, Ramsey and Cavalier counties comprise a significant portion of the Upper Basin and have over 17 and 19 percent, respectively, of their total area in saline soils. Most of these soils are somewhat poorly drained and poorly drained soils associated with high watertables adjacent to wetlands (NRCS Staff, 1987). Drainage of certain types of wetland soils has been shown to cause salinization of the wetland interior upon drainage (Seelig and Richardson, 1991).

1.1.2.3.1. Soil Resources

The Natural Resources Conservation Service (NRCS) has developed the State Soil Geographic (STATSGO) database for large-scale resource planning, management, and monitoring (USDA-NRCS, 1994). The STATSGO data essentially represent the soil associations maps presented in

[1] Hummocky collapsed till, 1-2 degrees slope.
[2] Hummocky collapsed till, 2-4 degrees slope.
[3] Ice-walled lake sediment.
[4] Collapsed glacial river sediment.

the County Soil Survey, and are appropriate to generally describe the soil characteristics over a broad area such as the Upper Basin. These data are presented for the Upper Basin in **Figure 3**.

(Insert Figure 3 here)

The NRCS has published county soil surveys at a scale of approximately 1:20000 for all of the counties in the upper basin. An NRCS program to digitize all of the county soil surveys is ongoing. Digital GIS-based soil surveys (Soils Survey Geographic Database, SSURGO, USDA-NRCS, 1995) are available for Ramsey, Walsh, Towner, Cavalier, and Rolette counties (http://www.ftw.nrcs.usda.gov/ssur_data.html). Hardcopy soil surveys are also available for Ramsey (Bigler and Liudahl, 1986), Walsh (Hetzler et al., 1972), Cavalier (Simmons and Moos, 1990), Rolette (DesLauriers and Lambert, 1997), Pierce (Thiele et al., 1978) and Benson (Strum et al., 1979) counties. County survey level physical, chemical, descriptive, and interpretative soil attribute data are available as the Map Unit Interpretations Record (MUIR; USDA-NRCS, 1984) via internet download (http://www.statlab.iastate.edu/soils/muir/)

Among other characteristics, soil texture, structure, permeability, salinity, sodicity, topography, and slope are associated with soil series designations. In North Dakota 264 soil series have been mapped and described in county soil surveys. The soil mapping units as provided in county soil surveys consist of varying aggregations of these soil series. Some map units (i.e. consociations) identified in the soil surveys consist of one dominant soil with included similar soils. Other map units (i.e. complexes) consist of two or more dissimilar soils occurring in a known and definable pattern. With complexes the pattern is so complex that individual components cannot be delineated at the scale of the mapping. Complexes are usually designated by the names of the dominant soil series.

A minor percentage of each map unit consists of soils that are not included in the name of the map unit. These minor soils are discussed in the map unit description in the hardcopy soil survey and are identified in the digital database products (SSURGO and MUIR) available from the NRCS. Percentages of included soils are provided in the database products; however, links to attribute data for the included soils are not provided.

Many map units in the Devils Lake Upper Basin consist of complexes of several soils with inclusions. In some cases inclusions can be accounted for if detailed attribute data is not required. However, in many cases, the properties of inclusions are not addressed in the digital database products available from the NRCS.

1.1.2.3.2. Soil Classification

Soil Scientists classify soils into orders, suborders, great groups, subgroups, families, and series based on soil morphology, mineralogy, hydrology, climate, and landscape position (USDA-NRCS staff, 1999). The soil taxonomic classification provides information on virtually all of the factors involved in the genesis of a specific soil by combining formative elements associated with the specific order, suborder, great group, and subgroup. For example, one of the most important saline soils associated with wetlands in the Upper Basin is the Vallers soil series (*fine-loamy, mixed, superactive, frigid Typic Calciaquolls)*. The taxonomic classification for Vallers soil indicates that it is in the M**oll**isol order, the **Aqu**oll suborder, the **Calci**aquoll great group, the **Typic** Calciaquoll subgroup, and the **fine-loamy, mixed superactive, frigid** family.

Virtually all of the soils in the Upper Basin are classified into the Mollisol soil order. Mollisols are zonal soils that develop primarily in subhumid areas under grassland plant communities. They are characterized by a thick, dark surface horizon that is high in organic matter. Mollisols characteristic of wetlands are placed into the Aquoll suborder to indicate the presence of an aquic moisture regime reflecting their characteristic wetness. Calciaquolls are Aquolls that are characterized by significant quantities of calcium carbonate precipitated in the soil by evapotranspirative concentration of calcareous groundwater. Typic Calciaquolls are those that are typical of the suborder. The fine-loamy, mixed, superactive, frigid family indicates the soil texture, the lithology, the activity of the clay component, and the climate of the soil, respectively. Typic Calciaquolls are characteristic of the periphery of semipermanent wetlands and in areas where the groundwater is close to the surface and is high in dissolved minerals.

Two other important wetland soils in the Upper Basin are the Tonka (*Fine, smectitic, frigid Argiaquic Argialbolls*) and Parnell (*fine, smectitic, frigid Vertic Argiaquolls*) soil series. Both of these wetland soils contain the formative element " Argi" at the great group level, which indicates the accumulation of clay translocated from higher in the soil profile. Clay translocation requires; (1) that calcium carbonate be leached from the soil, and (2) that periodic and frequent wetting and drying occur (Richardson, 1989). Thus Tonka and Parnell soils are characteristic of seasonally ponded, leached, recharge-type wetlands. In old soil surveys Parnell soils were mapped as poorly and very poorly drained phases. Parnell soils that are very poorly drained would not likely be considered Parnell soils today, and would probably be placed in the Southam soil series.

Combining soils information provided in the county soil surveys with a knowledge of salinization processes associated with wetlands permits a semi-quantitative assessment of salinization hazards associated with restoration of wetlands in the Upper Basin. Soils information for the Upper Basin will be presented in more detail in the Results section, below.

1.1.2.4. Climate

Precipitation, temperature, and evapotranspiration are the dominant climatic controls that distinguish wetlands in the subhumid prairie pothole region from wetlands in more humid climates. North Dakota is characterized by a continental climate characterized by cold winters, warm summers, and lower precipitation than more humid eastern regions with similar topography and geology. Average annual temperature in the Upper Basin varies from 38 to 39^{o}F (4^{o}C). Average length of frost-free periods is 115 to 120 days, and mean annual precipitation varies from 16 to 17 inches (40 to 43 cm). Winters are cold, resulting in frozen ground during most of the winter. Melted snow equivalents in the area of the Upper Basin average 3 to 4 inches (7 to 10 cm)(Jensen, No Date; Ramirez, No Date). Cold winters, frozen ground, and appreciable snowpack result in significant surface runoff to wetlands in Spring.

An important measure of climate that directly relates to wetlands is the difference between precipitation and pan evaporation. This measure integrates the effects of temperature and precipitation. The Upper Basin is characterized by an annual moisture deficit. This relationship has great bearing on groundwater recharge and discharge relationships as well as the development of integrated surface drainage. In the simplest sense, a precipitation surplus is the driving force that causes wetland to fill to the point where they spill over the lowest portions of their catchments to form integrated drainage networks. In eastern glaciated terrain where precipitation exceeds evaporation, drainage networks are present but poorly integrated due to the youthful, hummocky nature of the unconsolidated tills draped over the underlying bedrock. The Upper Basin landscape is similar; however, lower precipitation coupled with moisture deficits ensures that the wetlands will not generally fill to overflowing. The result is a hummocky landscape encompassing a mosaic of thousands of closed, undrained catchments emplaced at varying elevations in thick till. Wetlands, varying in ponding duration from ephemeral to permanent, occupy the lowest portions of these closed catchments. Only during very pluvial (wet) periods do many of these catchments overflow and contribute to the runoff that eventually reaches Devils Lake.

Artificial wetland drainage can "short circuit" this effect, releasing accumulated runoff to constructed drainageways and adding runoff water that would normally recharge groundwater or be stored on the landscape. With regard to downstream flooding, artificial drainage mimics extremely wet periods that would result in the filling and overflow of upgradient wetland catchments.

1.1.3. Applicable Soil Salinity and Sodicity Issues and Concepts

1.1.3.1. Soil Salinity

Soluble salts are defined as salts more soluble than gypsum, which has a solubility of approximately 2 grams per liter. There are eight ions commonly associated with soluble salts. Cations consist of calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), whereas anions consist of alkalinity (carbonate, CO_3; bicarbonate, HCO_3, and carbonic acid; H_2CO_3), sulfate (SO_4) and chloride (Cl). *Soil salinity* is essentially the sum total of soluble salts in the soil, generally limited to the root zone, and is operationally defined by the electrical conductivity of a soil saturation-paste extract (ECspe), expressed in deci-Siemens per meter (dS/m). Soils that have ECspe values greater than 4 dS/m within the rooting zone are considered by the NRCS to be saline variants of existing soils. For example, Vallers soils are listed as having soil salinity that varies from 2-4 dS/m. Vallers soils that have ECspe values higher than 4 dS/m are considered Vallers (Saline variant). Soils that typically have root zone salinity greater than 16 dS/m are considered to be saline soil series (e.g. Ryan soils). Elevated salt content in the rooting zone of a soil reduces crop yields by competing with plants for water (Bresler et al., 1982).

A *salinity hazard* is generally associated with landscape positions characterized by groundwater discharge and shallow water tables (Seelig and Richardson, 1991; Franzen et al., 1994). Soil salinity can be described by the interaction between soil-specific "critical depth" and "critical salinity" parameters. *Critical depth* is generally defined as the maximum amount that watertables with a given salinity can rise without resulting in salinization of the soil surface. *Critical salinity* is defined as the minimum amount of salt content that near-surface groundwater can have without resulting in salinization of the soil surface, regardless of the watertable depth (Maianu, 1981). Critical Depth and Critical Salinity are interrelated parameters that generally suggest the potential for soil salinization, and are to a large degree texture dependent. If the salinity of the near surface watertable is low, watertables can raise to near the soil surface without a significant salinization hazard. Similarly, if the salinity of the near surface watertable is high, the watertables must be deeper to ensure that capillary rise and plant evapotranspiration do not concentrate salts above a level that affects plant growth.

Specific critical depth and critical salinity values have not been developed for North Dakota soils; however, these concepts explain soil salinization in the presence of shallow watertables (Seelig et al., 1987). For example, the Hamerly soil (*fine-loamy, frigid Aeric Calciaquolls*) is a common soil adjacent to wetlands in the Upper Basin. Hamerly soils are somewhat poorly drained with a listed seasonal high watertable varying in depth from 1.5 to 3.5 feet from the surface. Both non-saline and saline phases are recognized; however, the non-saline phase is typically associated with strongly leached seasonally ponded wetlands, whereas the saline phase is associated with more permanently ponded wetlands. The presence of higher watertables elevated for a longer duration (groundwater above a critical salinity and watertables above a critical depth) results in the saline phase of the Hamerly soil being associated with more permanently ponded wetlands.

A *salinity risk* is the probability that a salinity hazard will become a problem (Bui et al., 1996). Areas at risk of salinization after alteration of watertable dynamics are those areas where stored salt is likely to be remobilized and redeposited by rising groundwater tables. Assessing the risk of salinization requires an estimate of pre-existing hydrology/salinity and the effects of the altered hydrology induced by elevated watertables.

1.1.3.2. Soil Sodicity

Soil sodicity is defined by the concentration of monovalent sodium relative to the concentrations of divalent calcium and magnesium on both the soil cation-exchange complex (yielding an exchangeable sodium percentage, or ESP) and in the soil solution (yielding an SAR). A soil with a sodium adsorbtion ratio greater than 13 is considered by the NRCS to be a sodic soil.

Elevated concentrations of sodium disrupt soil structure resulting in a "gumbo" type soil. Sodium-affected soils are hard and massive when dry. When wet, sodium-affected soils are structureless and dispersed, with dramatically reduced hydraulic conductivity and poor plant-available water characteristics (U.S. Salinity Laboratory Staff, 1954; Bresler et al., 1982).

Salinity and sodicity frequently coexist, resulting in sodic-saline soils; however, the deleterious effects of sodium are mitigated somewhat at high levels of salinity. Many areas of sodic and saline-sodic soils may be associated with groundwater discharge through underlying Pierre shale or through tills with high shale contents. The deleterious effects of both sodicity and salinity are also associated with texture, with fine textured soils being more severely affected than coarse textured soils (U.S. Salinity Laboratory Staff, 1954; Seelig and Richardson, 1991).

Salinity and sodicity are naturally occurring conditions in the Devils Lake watershed and are well-known, regional considerations for agriculture generally. Sodic soils are common in areas of the Upper Basin, but are usually associated with moderately well drained and well drained soils that would not be affected by wetland restoration. However, salinity is a common problem frequently associated with elevated watertables and wetlands. A considerable body of applicable research exists that assesses salinization/sodium hazards in area soils, techniques to mitigate the effects, and the tolerance of commonly grown crops (U.S. Salinity Laboratory Staff, 1954; Bresler et al., 1982; Franzen et al., 1996; Scherer et al., 1996).

1.1.4. Soil Salinization Processes and Wetlands

Salt accumulation in North Dakota is associated with specific hydrogeologic settings generally associated with groundwater discharge, shallow groundwater depths, and infrequent ponding (Seelig and Richardson, 1991); for example, areas adjacent to semipermanent wetlands and broad, low-relief flats (Arndt and Richardson, 1989; Holm and Henry, No date). Dissolved salts move with saturated and unsaturated groundwater flow. Areas of persistent groundwater recharge are leached, whereas areas of persistent groundwater discharge can have a range of salinity depending on the salinity and depth of the groundwater in question (Lissey, 1971; LaBaugh, 1988; Arndt and Richardson, 1989; Knuteson et al., 1989; Seelig and Richardson, 1994; van der Kamp and Hayashi, 1998). Salts accumulate in the vadose (i.e. unsaturated) zone when unsaturated flow brings groundwater containing dissolved salts into the rooting zone. The attendant evapotranspirative withdrawal of pure water leaves the salts to accumulate. A portion of the salt added to affected soils is converted into salts of limited solubility (e.g. Calcite and Gypsum) and is stored in the soil profile (Steinwand and Richardson, 1989; Arndt and Richardson, 1992). Although saline soils are the product of long term hydrogeologic conditions, salts are readily mobilized when recharge/discharge/ponding dynamics change (LaBaugh, 1988; Steinwand and Richardson, 1989; Arndt and Richardson, 1993b).

The assessment of soil salinization hazards associated with wetland restoration is based on several recent studies that indicate that salinity associated with wetlands in the Northern Plains is a predictable phenomenon associated with specific hydrogeologic settings. The relationship is explained in more detail by the following features characteristic of wetlands in specific hydrogeological settings.

1.1.4.1. Chemistry of Soil Salinity in the Upper Basin

Soluble salts in general are the products of rock and soil weathering processes (Bresler et al., 1982). However, concentration of soil solutions by evaporation and transpiration (evapotranspirative concentration) is the dominant process that results in soil salinity in the Northern Plains. Various researchers have found that the development of soil salinity in northern prairie wetlands generally follows the Hardie and Eugster (1970) model of closed basin brine development that considers the chemical composition of solutions undergoing evaporation to be the result of changes imposed by the successive precipitation of evaporite minerals. Under this model, the ultimate chemistry in saline evaporated water is dependent upon the initial ratios of dilute ions in solution. In tills of the Upper Basin, the initial composition of dilute solutions is the result of interactions between reduced sulfides present in the Pierre Shale component of the till interacting with the calcareous limestones and dolomites also present. Oxidation of the sulfides produces sulfuric acid, which then dissolves the carbonate minerals, releasing alkalinity as bicarbonate and Ca and Mg ions (Groenewald et al., 1983; Hendry et al., 1986; Mermut and Arshad, 1987). Evaporating the dilute solution results in the successive precipitation of calcite and gypsum. Calcite precipitation controls the concentration of alkalinity, and gypsum controls the concentration of calcium in solution. Highly saline solutions then become dominated by sulfates of magnesium and sodium. Thus, most saline soils in the Upper Basin are calcareous and many will have gypsum present in the profiles as well (Arndt and Richardson, 1989). Pore water solutions in saline soils will be high in magnesium and sodium sulfates (**Figure 4**).

(Insert Figure 4 here)

Soluble salts are transported by groundwater. Thus, knowledge of groundwater movement associated with Northern Prairie wetlands is essential to understand the development of wetland soil salinity. The general progression of salinity in North Prairie wetlands has been investigated by various researchers (Mills and Zwarich, 1986; Arndt and Richardson, 1988, 1989; Knuteson et al., 1989; Seelig et al., 1990; Richardson et al., 1992). In general, research indicates that soil salinity and soil development in Northern Prairie wetlands can be explained by considering a dynamic recharge-flowthrough-discharge continuum of groundwater movement within the context of evapotranspirative concentration.

1.1.4.2. Depression-focused Groundwater and Surfacewater Flow

In a groundbreaking paper on the groundwater hydrology in the Northern Prairies, Lissey (1971) found that both groundwater recharge as well as discharge are focused in depressions. Under his model the intervening uplands were found to be essentially uninvolved in water transfers to and from the water table.

These relationships become clearer when comparing groundwater recharge and discharge in hummocky till landscapes in humid versus subhumid environments (Arndt and Richardson, 1994). **Figure 5** is an example of local groundwater relationships in hummocky topography of humid regions characterized by a precipitation surplus. After a precipitation event, a portion of the water falls on the wetland itself (direct interception), a portion is received as runoff from the surrounding catchment, and a portion infiltrates the upland soil and percolates downward or laterally as long as positive hydraulic gradients exist.

(Insert Figure 5 here)

Because precipitation events in the humid region are closely spaced in time, a succession of recharge events drives deep percolation to the water table and results in groundwater recharge. If incoming water reaches the watertable faster than water is removed as discharge to low areas, groundwater mounds tend to develop under topographically elevated areas. Thus, Figure 5 illustrates the generally accepted hydrologic model for groundwater recharge. The watertable is a subdued replica of the surface topography, and all wetlands are foci of local discharge.

Figure 6 is an example of local ground water relationships in hummocky topography of subhumid regions that are characterized by a moisture deficit. Recharge events still result in water input to wetland positions via direct interception and overland flow. However, the amount of time between precipitation events and the usually intense nature of the events themselves ensures that deep percolation and ground water recharge does not regularly occur under topographically higher areas. Much of the soil water is returned to the atmosphere by evapotranspiration before the next recharge event occurs. The overall lack of precipitation coupled with high evapotranspiration further ensures that the wetlands do not usually fill to overflowing.

(Insert Figure 6 here)

However, groundwater is recharged frequently at the edges of ponded wetlands and beneath wetlands that frequently go dry because groundwater recharge occurs first where the vadose zone is thinnest (Winter, 1983). The result is a landscape dominated by closed catchments and limited or non-existent surface drainage. Because deep percolation is minimized by the lack of frequent precipitation, inter-depressional uplands are relatively uninvolved in transfers of water to and from the watertable. Thus in the subhumid Prairie Pothole region, groundwater recharge and discharge are depression-focused.

The model of depression focused flow developed by Lissey (1971) has been used to explain the relationships between wetland hydrology and salinity in hummocky areas of high relief in the Prairie Pothole region. As shown below, the concepts of depression-focused flow also explain the relationships between salinity and soils in low relief landscapes, but the relationships are more subtle.

1.1.4.3. Recharge, Flowthrough, and Discharge Wetlands and The Effects of Topography on Wetland Soil Salinity

In hummocky topography, most wetlands can be classified as distinctly recharge, flowthrough, and discharge types based on hydrology, water chemistry, and soil physical and chemical characteristics (Richardson et al., 1994). Recharge wetlands are; (1) typically located in higher positions in the landscape, (2) seasonally ponded with fresh water and (3) characterized by soils that have a morphology associated with frequent wetting and drying cycles and dominantly downward water movement (Richardson, 1989). The Tonka series (*Fine, smectitic, frigid Argiaquic Argialbolls*) is typical of recharge wetlands in the Upper Basin.

Flowthrough wetlands; (1) are located in intermediate landscape positions. (2) are typically more permanently ponded, and (3) receive more of their water from groundwater discharge and are thus generally brackish (i.e. moderately saline). A characteristic soil of the pond interior in flowthrough wetlands in the Upper Basin would be the very poorly drained phase of Parnell (*fine, smectitic, frigid Vertic Argiaquolls*) or Southam (*fine, smectitic, calcareous, frigid Cumulic Endoaquolls*) series. Edge soils in flowthrough wetlands can be saline and would be characterized by Calciaquolls similar to the Hamerly (*fine-loamy, mixed, superactive, frigid Aeric Calciaquolls*) or Vallers (*fine-loamy, mixed, superactive, frigid Typic Calciaquolls*) series.

Discharge wetlands are permanently saturated or semi-permanently-to-permanently ponded, reflecting the dominance of groundwater discharge. Soils are calcareous and are usually quite saline, especially around the wetland periphery. A typical discharge-type soil would be the Hegne saline series (*fine-silty, mixed, superactive, frigid Typic Calciaquolls*) or saline variants of Southam soils. In some soil surveys saline soils are listed as "Aquents." These relationships have been summarized by Arndt and Richardson (1988, 1989, 1994) and Richardson et al., (1994) and are illustrated in **Figures 7 and 8**

(Insert Figure 7 here)

(Insert Figure 8 here)

Much of the above described research on salinity in the Northern Prairies has been performed in hummocky till topography with relief of 15 to 20 meters where the recharge-flowthrough-discharge relationships between wetlands and salinity are distinct and easily studied. However, much of the Upper Basin has low relief on the order of 1 to 2 meters. The relationships between groundwater flow and salinity still hold in low relief landscapes but the topography and the relationships between recharge and discharge are more subtle and are dominated by localized groundwater recharge and discharge. The flowthrough zone is essentially the wetland periphery and groundwater discharge occurs in the low relief areas adjacent to the wetland. In these areas, the presence of a groundwater mound associated with recharge maintains elevated watertables in soils that are transitional between wetland and upland conditions. These elevated watertables supply a source of dissolved solids that can be concentrated by evapotranspiration in the soil profile in the somewhat poorly drained soils that are adjacent to the wetlands.

Knuteson et al. (1989) investigated the distribution of carbonates and salinity in fine-textured soils in a low relief landscape in the Red River Valley. Total relief in the area studied was on the order of 0.5 to one foot. In this very flat landscape, soils were segregated into recharge and discharge types that were separated horizontally by only a few feet. Depression-focused runoff resulted in a recharge wetland characterized by a Lindaas soil (*fine, smectitic, frigid Typic Argiaquolls*) that was strongly leached to depth. However, the recharge wetland was surrounded by Calciaquolls (Bearden series, *fine-silty, mixed, superactive, frigid Aeric Calciaquolls*) indicative of groundwater discharge. Thus the soil occupying the lowest position in the landscape was a leached soil characteristic of depressional wetlands in the Red River Valley. Uplands less than a foot higher in elevation were dominated by discharge type, non-hydric Aeric Calciaquoll soil. Several similar soil associations are common in the Upper Basin, including the Hamerly-Tonka and the Vallers (Saline Phase)-Parnell map unit complexes. The relationships between the Lindaas and Bearden soils are illustrated in **Figure 9**.

(Insert Figure 9 here)

1.1.4.4. Edge Effects and the Distribution of Salinity in Upper Basin Wetlands

Within a given wetland, wetland salinity is focused on the wetland edge because the edge maintains a watertable above a critical depth and receives groundwater elevated in dissolved solids as discharge from both the pond and the groundwater system. Water leached from recharge wetlands that discharges at the wetland edge results in the accumulation of sparingly calcium carbonate. Thus, somewhat poorly drained soils on the periphery of recharge wetlands frequently forms “rings” of Typic Calciaquolls (e.g. the Hamerly soil series). These peripheral soils are rarely saline when they are associated with temporarily to seasonally ponded wetland soils.

However, flowthrough and discharge wetlands can have quite saline edges due to the relatively high concentration of salts in both groundwater and surface water and the persistence of elevated adjacent watertables. Thus it is quite common for flowthrough and discharge type wetlands to have calcareous and gypsiferous saline soils and saline variants of non-saline soils ringing the wetland. Edge effects in wetlands have been studied and are reported in Arndt and Richardson (1993) and Steinwand and Richardson (1989). The wetland edge is also a dynamic component of the hydrologic system that accumulates and transports salinity within the wetland. The characteristics of edge-focused groundwater recharge and discharge are illustrated in **Figure 10**.

(Insert Figure 10 here)

1.1.4.5. Effects of Hydrologic Alterations on the Mobilization of Salinity

Hydrologic alterations in and around wetlands can reorganize groundwater flow patterns developed over time, resulting in a significant mobilization of existing salts. Wetland drainage by surface ditching essentially moves the edge of the wetland to the pond interior adjacent to the ditch. Skarie et al. (1986) explained the development of linear patterns of strongly saline soils adjacent to drainage ditches in the Red River Valley to be the result of roadside drainage ditches maintaining elevated watertables at sufficiently shallow depths to mobilize subsoil salts to the surface (**Figure 11**). The result was the development of strongly saline soils over a period of a few decades. This rapid salinization effect was enhanced by the presence of substantial amounts of subsoil salinity in the soils prior to ditching. Similar salinization effects were observed adjacent to drainage ditches constructed through potentially saline soils in the Upper Basin (**Figure 12**)

(Insert Figure 11 here)

(Insert Figure 12 here)

Drainage of wetlands similarly can result in an alteration of hydrologic regimes that have developed through time. Drainage of flowthrough and discharge type wetlands typically results in; (1) the mobilization of salts to the pond interior, (2) the mobilization of salts from the subsoil of the drained wetland to the surface, and (3) the desalinization of soils at the wetland edge. Arndt and Richardson (199) observed that ditch drainage of several semipermanent wetlands in north central North Dakota resulted in the constructed ditch becoming the focus of discharge as opposed to the natural wetland edge. Salts were mobilized from the edge of the drained wetland to its interior and from the subsoil to the soil surface (**Figure 13)**. Salinization of drained semipermanent wetlands is sufficiently common to be recognized as a significant salinization problem in the Prairie Pothole regions generally (Seelig and Richardson (1991) and in the Upper Basin specifically (Mr. Terry Gregoire, Pers. Comm.). It is the remobilization of these salts that is primary soil salinization issue associated with the restoration of drained wetlands in the Upper Basin.

(Insert Figure 13 here)

2. METHODS

2.1. INTRODUCTION

A quantitative, predictive assessment of salinization hazards associated with the UBS alternative is precluded by:

- the magnitude of the area to be assessed (2616 square miles),
- the large number of potential restoration candidate wetlands identified (13,457)
- the complexity of the geomorphic, sedimentary, pedologic, and geochemical factors involved; and
- the non-specific nature of the soils map units in the county soil surveys.

However, resources and technology are available that permit a qualitative/semi-quantitative assessment of salinization hazards sufficient to evaluate the salinization potential associated with restoring wetlands in the Upper Basin. The assessment is based on the following assumptions.

2.2. ASSUMPTIONS

1. The characterization of potential restoration candidates within the Upper Basin by West Consultants accurately reflects their sizes, numbers, distribution and storage volumes.

2. Partial drainage of wetlands is not considered.

3. Restoration of drained wetlands would result in the reestablishment of the original wetland dimensions and the natural pre-drainage condition. No additional acreage would be flooded.

4. Salinization hazards associated with wetland restoration involve the mobilization of existing soluble salts. Soil salinity associated with each restored wetland would be directly related to the salinity associated with soils within and adjacent to the restoration candidates as mapped in the county soil surveys. Potential restoration candidates that do not have mapped saline soils within the drained basin or within a 200-foot buffer around the identified boundary would not have a salinization hazard.

5. The presence of saline soils within or adjacent to the original basin would represent a potential salinization hazard. The magnitude of the salinization hazard would be dependent upon the percentage of the mapped saline soils within a 200-foot buffer around the identified wetland boundary and the percentage of mapped saline soils within the drained basin itself.

6. Saline soils mapped by the NRCS in the county soil surveys as consociations (a single dominant saline soil) and as major saline components of soil complexes are of sufficient detail to identify the presence and extent of saline soils associated with the restoration candidate. Included saline soils of minor extent in soil map units that are absent of major

saline soil components are not of sufficient magnitude to create a significant salinization hazard.

7. Restoration of the wetland would result in mobilization of salts from the drained wetland interior back to the wetland edge. Furthermore, the decrease in watertable depth associated with the wetland restoration would result in the mobilization of salinity from the subsoil to the soil surface in saline soils that are peripheral to the restoration candidate. Salinization of adjacent soils could be a major process resulting in a perceived salinization problem directly related to the wetland restoration.

2.2.1. Discussion of Assumptions and Limitations

The methodology used by West Consultants to identify potential restoration candidate wetlands was based on GIS technology and augmented with detailed air photo interpretation. West Consultants, Inc. identified several limitations associated with their identification of drained wetland areas.

- No field verification was conducted.
- Partial drainage was not accounted for. Depressions were categorized as intact or drained, but not partially drained.
- The classification was based on aerial photos representing one point in time.
- Depressions were difficult to recognize in some poor quality aerial photos.
- Some individual depression classifications were subject to interpretation.

Several of the wetlands indicated as restoration candidates may not be restorable and some may not be drained. In addition, the delineated boundaries represent the restoration of the wetland to the natural pour point of the basin. Many of the potential candidates would not pond to the natural pour point.

Field mapping of saline soils is dependent upon an examination of the soil profile and crop responses to salinity. The expression of salinity can be masked if the mapping was performed during periods where crop responses are not diagnostic. Thus, saline soils and especially saline variants of non-saline soils may not be mapped correctly. The exact extent of saline soils is not known, but is an estimate based on the professional judgement of the soil scientist performing the mapping. However, the scale of the county soil surveys is sufficient to estimate the overall salinization hazards associated with the restoration candidate wetlands when considered at the scale of the entire Upper Basin.

The distribution of saline minor inclusions in soil map unit complexes cannot be determined at the scale of the county survey. Thus, the presence of minor saline inclusions was not accounted for in this report. Many semipermanent wetlands have saline inclusions peripheral to the wetland; however, these inclusions are not usually extensive. For the purposes of this report, saline inclusions in non-saline soil map units have been ignored.

2.3. ASSESSMENT OF SALINITY HAZARDS ASSOCIATED WITH UPPER BASIN STORAGE

Previous work by West Consultants, Inc. identified potentially restorable drained wetlands in the upper basin using GIS methods (see West Consultants, 2001, Chapter 3 for delineation methods). Polygons representing potentially restorable wetlands were supplied in GIS (Arcview) format. West identified several categories of depressions, including drained, intact, and other. They classified 52,210 depressions as drained, with a cumulative estimated area and storage volume of 92, 429 acres and 132,729 acre-feet, respectively. However, many of the identified depressions were shallow and of limited storage volume, which precluded their inclusion in the UBS alternative. West reduced the drained wetland dataset to 13,464 viable restoration candidates by limiting the dataset to those drained depressions that had an average depth greater than 0.5 feet. This restriction resulted in a total area and storage volume of 79,762 acres and 127,835 acre-feet, respectively.

Digital soils data (SSURGO, STATSGO) were obtained from the NRCS for Ramsey, Cavalier, Walsh, Towner, and Rolette counties. Data from these counties were extrapolated to Pierce and Benson counties for which digital data was unavailable. The large number of wetlands in Benson and Pierce counties (over 1400) precluded the manual digitization of soils information in these counties.

The following procedures were used to identify salinity hazards associated with Upper Basin Storage alternative.

1. All potentially restorable wetlands identified by West Consultants, Inc. were incorporated into an Arcview GIS and Access database. Data supplied by the St. Paul District, USACE for the potential restoration candidates resulted in a slight deviation from the numbers reported West' s 2001 study. The report that follows is based on a total number of 13,457 potential restoration candidates with a total area of 79,766 acres and a total estimated storage volume of 127,853 acre-feet. The differences are unexplained, but are insignificant and would not influence the data analysis.
2. Polygons were created to represent a 200-foot buffer around each individual wetland. Each buffer was attributed with the unique polygon ID assigned to the potential restoration candidate wetland by West Consultants, Inc. In many cases restoration candidate wetlands were in close enough proximity that buffer polygons overlapped. In order to determine the salinization hazard associated with individual wetlands, polygon overlap was maintained. However, the presence of overlap complicates the determination of affected acreage within the buffer because such areas are associated with more than one wetland. Overlapping buffers would tend to over-estimate the salinization hazard of the UBS alternative somewhat.
3. GIS polygon clipping methods were employed to exclude all soils outside of the wetland and its associated 200-foot buffer.
4. Existing and historic salinity conditions were assessed using digital and hardcopy soil survey data (SSURGO and county soil surveys, respectively), combined with MUIR attribute data. Such data include texture, drainage class taxonomic classification, landscape setting, representative salinity ranges by layer, water table depths, etc.

5. Some drained wetlands were examined in the field to provide representative examples in hydrogeologic settings with soil catenas that include saline or potentially saline soil components and to verify concepts regarding wetland drainage and salinity.
6. A determination was made of all map units included within the buffer and the wetland that are saline or that have major saline components using information in map unit descriptions in the county soil surveys combined with the MUIR database. In general, map units with major soil components that had listed salinities greater than 4 dS/m were considered saline soils. Upland soils in moderately well drained or drier drainage classes are not expected to be affected by wetland restoration and were considered non-saline.
7. For the purposes of evaluation, the soil polygons contained within the buffer and the drained wetland were reduced to two categories: saline soils and non-saline soils. Saline soils consisted of somewhat poorly drained or wetter soils that were listed in the soil survey as being saline soils or saline variants of non-saline soils or that had ECspe values in the MUIR database greater than 4 dS/m. Only major map unit components were considered. Included soils of minor percentage are ignored in this report.
8. The acreage and percentage of saline soils within the wetland boundary, and within the surrounding 200-foot buffer were determined using GIS and database methods.
9. Salinization hazard classes were developed for each wetland and wetland buffer based on the percentage of saline soils included within each wetland-polygon pair. Five salinization classes were developed: 0-5%, >5-25%, >25-50%, >50-75%, and >75-100% represent None-to-Slight, Low, Moderate, High, and Severe classes respectively. Wetland and wetland buffers are analyzed separately.
10. Database methods were used to associate the potential restoration volume (in acre-feet) and wetland area calculated by West Consultants, Inc. with the salinity hazard class of individual wetlands.
11. The results are provided in Arcview format permitting the identification of potentially restorable wetlands. Each potential restoration candidate wetland was color coded to its respective wetland and buffer hazard class.
12. The potential effects of soil salinity on land use and potential mitigation measures were identified.

The basic assumption regarding the assessment of salinization hazards associated with restoration of candidate wetlands identified by West Consultants, Inc. is that salinity is not being added to the landscape by the restoration of drained wetlands, but rather may be remobilized and transported to its original or new locations. In most cases, restoration will result in the reestablishment of pre-drainage conditions; thus, it is unlikely that new lands will be salinized. However, it is also very likely that existing salinity in areas adjacent to the restored wetlands could be aggravated by water table rises mobilizing salts from the subsoil to the soil surface. Pertinent research reviewed above suggests that areas becoming desalinized under the hydrologic regime imposed by drainage could be resalinized, and salts could be mobilized from the drained pond interior to the pond edge (Arndt and Richardson, 1993a).

The approach taken in this report to assess salinization in potential restoration candidate wetlands is to determine the salinity associated with the current condition as indicated in the soil survey, and then project how the existing salinity will respond to an altered hydrologic regime imposed by restoration. Drained wetlands that are non-saline and that have non-saline adjacent soils will not have significant salinization problems subsequent to restoration because a significant salinity source is absent. Thus, restoration candidate wetlands that lack saline soils within the buffer or wetland polygons have been placed in the None-to-Slight salinity category. The presence of inclusions, uncertainties regarding accurate mapping, and the broad ranges in ECspe provided as representative of individual soil series preclude the development of a pure "None" category.

Salinization problems will increase in direct relationship to the percentage of saline soils within and immediately adjacent to the drained wetland. The most significant salinity hazards would be associated with drained wetlands dominated by soils with major saline components both within the wetland and in adjacent soils. Thus, restoration candidate wetlands that contain >75-100% soil map units with major saline components have been placed into the severe category. Soils that have intermediate amounts of soil map units with major saline components have been placed in intermediate categories (>5-25%, >25-50%, and >50-75% represent low, moderate, and high salinity hazard categories, respectively). The intermediate categories are somewhat arbitrary and were developed to represent a representative, equally spaced gradation of salinization hazards from Low to Severe.

Most soil map units incorporate minor percentages of contrasting inclusions in the map unit description. Many map units in the soil surveys of the Upper Basin include saline components as contrasting inclusions. It is beyond the scope of this report to quantify the effects of included soils. However, it should be recognized that minor amounts of saline soils could be a component of most calcareous, somewhat poorly to very poorly drained soils. However, the effects of inclusions are not considered significant due to their limited extent.

The presence of a candidate wetland in a severe category simply reflects the potential salinity hazard associated with restoration. It is quite possible that existing severe salinity has already precluded or limited agricultural use. Thus the owner may be receptive to restoring the wetland and placing it and an appropriate buffer into a conservation reserve program provided that sufficient compensation is available.

3. RESULTS: SALINIZATION HAZARDS ASSOCIATED WITH DRAINED WETLAND RESTORATION IN THE UPPER BASIN OF DEVILS LAKE

A quantitative estimate of soil salinization hazards in the Upper Basin is precluded by the complex geochemical processes involved and the limited nature of the available data. County soil surveys provide very broad ranges in surface and subsoil salinity, with the breaks being 4 dS/m (higher levels indicate a saline phase of an existing soil), and 16 dS/m (higher levels indicate a saline soil). Soil map units in the area are usually identified in the soil survey as complexes containing two or more major soils with dissimilar characteristics, and several inclusions. The listed percentage of each major soil component represents an average established by transecting several map units. Rarely will any given map unit actually have the exact composition percentages that are listed in the soil survey. In other words, the salinization hazards induced by a given wetland restoration will be strongly influenced by the existing salinity of the affected soils. However, the existing salinity of those soils is not sufficiently known to quantify the local effects.

This analysis estimates salinization hazards using database and GIS technologies and has been limited to a determination of soil map units that contain major components that have ECspe > 4 dS/m and are therefore considered by the NRCS to be saline soils.

3.1. MAJOR STATSGO SOIL ASSOCIATIONS WITH AN EMPHASIS ON THE HYDROGEOLOGIC SETTING OF ASSOCIATED WETLANDS

Surface geology (see Figure 2) and the STATSGO map unit data (see Figure 3) exhibit similar distribution patterns because of the close relationship between soil associations and geological parent material and topography. The three most extensive STATSGO soil map units include ND046 (Barnes-Svea-Hamerly, 896 square miles), ND043 (Svea-Buse-Hamerly; 765 square miles), and ND040 (Hamerly-Tonka-Svea, 223 square miles)(see Figure 3). These three soil associations comprise 1884 square miles, or just over 72% of the 2616 square mile total for the entire Upper Basin. All three associations are mapped on hummocky collapsed till and share many of the same soil components. What separates these map units from each other is relief, with ND043 including soils more representative of a higher relief landscape than ND046 or ND040.

Two additional associations comprise just under 10 percent (over 253 square miles) of the total area of the Upper Basin and are associated with water-worked glacial drift. ND005 (Bearden-Great Bend-Overly) accounts for over 127 square miles of the total basin area and is associated with relatively fine-textured lacustrine material derived from ice-walled, glacial lake sediments (Map Unit Qcoh, see Figure 2). ND041 (Hegne-Hamerly-Fargo) accounts for 126 square miles of the total Upper Basin area and is associated with wave-washed (eroded) glacial sediment (Map Unit Qcew, see Figure 2).

One additional STATSGO map unit accounts for a significant area within the Upper Basin. ND051 (Svea-Cresbard-Hamerly) comprises 198 square miles and is generally associated with hummocky collapsed till similar to ND043 (Svea-Buse-Hamerly); however, sodicity is more common in ND051, likely because of shallower depths to Pierre Shale and a more significant shale component to the local tills.

Altogether these seven soil associations comprise over 2330 square miles (89%) of the Upper Basin area. The remaining associations shown in Figure 3 are of minor extent and will not be discussed in detail. The following discussion addresses the setting and selected characteristics of the major soils in the Upper Basin, focusing on the hydrogeologic setting of wetlands. Because of their similarity in soil component composition, the till plain associations (ND046, ND043, and ND040) will be discussed together.

3.1.1. The Barnes-Svea-Hamerly (ND-046), Svea-Buse-Hamerly (ND043), and Hamerly-Tonka-Svea (ND040) Soil Associations

ND-046, ND043, and ND040 soils associations occupy nearly level to gently rolling till plains in Rolette, Towner, Benson, Cavalier, Walsh, Ramsey, and Pierce Counties. The three associations are the most extensive in the Upper Basin. The typical landforms are characterized by knolls, discontinuous ridges, numerous swales, low rises and poorly drained depressional landforms developed from medium textured, calcareous till in uplands and fine textured recent alluvium in wetlands that receive the majority of the surface runoff (**Figure 14**).

(Insert Figure 14 here.)

3.1.1.1. Upland Soils

Upland soils consist predominantly of well-drained, moderately slowly permeable Barnes soils (*fine-loamy, mixed, superactive, frigid Calcic Hapludolls*) located on side slopes and low summits, well-drained, moderately slowly permeable Buse soils (*fine-loamy, mixed, superactive, frigid Typic Calciudolls*) located on knolls and shoulders of slopes, and moderately well drained, moderately slowly permeable Svea soils (*fine-loamy, mixed, superactive, frigid Pachic Hapludolls*) located in concave swale positions. All of the upland soils developed in till and are well to moderately well drained. None of the upland soils are expected to be affected by salinity associated with wetland restoration due to the presence of deep watertables.

Minor amounts (< 2%) of excessively drained, rapidly permeable Sioux (*sandy skeletal, mixed Udorthentic Haploborolls*), moderately well drained, moderately slowly permeable Cresbard (*fine, montmorillonitic, Glossic Natriborolls*) and moderately well drained Cavour (*fine, montmorillonitic, Glossic Udic Natriborolls*) soils are found in all three associations. Sioux soils are found on outwash plain inclusions in the till plain. Cresbard and Cavour soils are on lower backslopes, footslopes, and flats on uplands.

The major difference between the three listed associations is the composition of the wetland and upland soils resulting from subtle differences in topography. Low relief and a dominance of poorly and somewhat poorly drained soils characterize ND040. Conversely, ND043 is characterized by higher relief resulting in the presence of Buse soils that are poorly developed due to being on steeper slopes and exposed summits. ND046 is intermediate and is characterized by undulating relief resulting in the presence of better-developed Barnes soils occupying the less exposed and steep sideslopes. None of these upland soils are expected to experience a salinization hazard due to the restoration of drained wetlands because they formed under moderately well drained conditions and would not experience a conversion to a wetter regime due to wetland restoration.

3.1.1.2. Wetland Soils

Barnes, Buse, and Svea soils form the primary catchment soils that direct runoff water to low depressions occupied by wetland (hydric) soils. The Tonka soil series (*Fine, smectitic, frigid Argiaquic Argialbolls*) consists of very deep, poorly drained soils that formed in local alluvium over till or glaciolacustrine deposits. Tonka soils are located in closed basins and depressions on till and glacial lake plains. The seasonal high water table is at a depth of 0.5 foot above the surface to 1 foot below the surface, at some time during the period April through June.

Tonka soils occupy depressions that recharge the watertable. Tonka soils are non-saline, are leached of carbonate and gypsum, and have soil characteristics that indicate periodic and regular wetting and drying and strong downward water movement (e.g. the presence of clay enriched argillic horizons and light-colored, leached E-horizons with platy structure). Wetlands dominated by Tonka soils are seasonally ponded and tend to be small, resulting in their being mapped in complex with other upland soils. Because of their size, Tonka wetlands are frequently thought of as "nuisance wetlands" that complicate tillage operations because the grower frequently has to plow, till, and harvest around them during spring and wet periods in the summer and fall. However, when drained, Tonka soils are among the most productive soils in the area. Drained Tonka soils produce high yields, and rarely have problems with salinity. There is a significant economic incentive to drain Tonka wetlands to simplify tillage operations and to increase overall crop yields.

The Parnell soil series (*fine, smectitic, frigid Vertic Argiaquolls*) is a common wetland soil that consists of very deep, very poorly and poorly drained soils that formed in water-sorted sediments from glacial drift. Parnell soils are located in depressions, swales and drainageways on glacial moraines. Two phases based on drainage are recognized. A seasonal high water table for the poorly drained phase is at a depth of 0.5 to 1.5 feet during the period November to June. Poorly drained variants of Parnell soils are similar to Tonka soils. The very poorly drained phase has a water table depth of one to five feet above the surface during the period January to December. Parnell soils are, in general, ponded for a longer duration when compared to Tonka soils and occupy similar recharge positions relative to the watertable. However, soil profiles are not as well developed regarding both thickness of the clay enriched argillic horizon or development of the E horizon.

The Southam (*fine, montmorillonitic (calcareous), frigid Cumulic Endoaquolls*) soils series consists of deep, very poorly drained slowly permeable soils formed in alluvium on glacial till and Lake Plains. Southam soils are characteristic of flowthrough and discharge-type, semipermanently ponded wetlands and can have soil salinity up to 8 dS/m in the subsurface soil. Until recently Southam soils have not been extensively drained.

3.1.1.3. Saline and Potentially Saline Soils of the Wetland Periphery

The Hamerly soil series (*fine-loamy, mixed, superactive, frigid Aeric Calciaquolls*) consists of very deep, somewhat poorly drained soils that formed in calcareous loamy till. These soils are on flats in lake plains, convex slopes surrounding shallow depressions and on slight rises on low till plains. The apparent seasonal high water table is at a depth of 1.5 to 3.5 feet at some time during the period April through June. This soil is classified as non-saline (ECspe = 0-4 dS/m). However, a saline phase with ECspe ranging from 4-16 dS/m is recognized. Saline phases of Hamerly soils are usually associated with adjacent Parnell and Southam soils. Non-saline Hamerly soils are frequently mapped in complex with Tonka soils. Close attention must be paid by the mapper or restoration specialist when looking at these mapping units to see if it is the saline or non-saline phase.

The poorly drained, moderately slowly permeable Vallers soil series (*fine-loamy, mixed, superactive, frigid Typic Calciaquolls*) formed in calcareous fine-loamy till on level and nearly level slight rises at the periphery of wetlands, shallow depressions, and drainageways. Vallers soils are not as well drained as Hamerly soils and are considered by the NRCS to be hydric soils characteristic of the wetland periphery. The apparent seasonal high water table is at a depth of 0.5 to 1.5 feet at some time during the period of March through July. This soil is considered non-saline (ECspe varies from 0-4 dS/m), however a saline phase (ECspe = 4-16 dS/m) is recognized so close attention must be paid by the mapper or restoration specialist when looking at these mapping units to see if it is the saline or non-saline phase.

3.1.1.4. Potential Salinization Hazards Associated with Wetland Restoration

The dominant wetland soils in soil survey areas within the ND046, ND043, and ND040 associations include Tonka, Parnell, and Southam soils with wetland peripheries dominated by non-saline and saline variants of Hamerly and Vallers soils. These soils are mapped as complexes in most of the soil surveys, and include Hamerly-Tonka, Vallers-Tonka, and Vallers (saline phase)-Parnell map units. The somewhat poorly drained to poorly drained soils on the periphery of the seasonally ponded Tonka and Parnell wetlands consist primarily of non-saline variants of Hamerly and Vallers soils that developed under a hydrologic regime where the watertables were maintained at depths and with characteristic salinity that precludes salinization of the soil surface. Restoration of seasonally ponded wetlands dominated by Tonka and poorly drained variants of Parnell soils are not expected to produce significant salinization hazards.

However, drained wetlands that have the very poorly drained phases of Parnell and very poorly drained Southam soils characteristically have wetland peripheries dominated by saline soils and are frequently mapped as a Vallers (saline)-Parnell complex. Wetlands with Southam soils also have large amounts of subsoil salinity. It is quite probable that drained wetlands dominated by Southam soils have become salinized at the soil surface, with salinization problems more evident near the ditch that is draining the wetland. However, adjacent soils that were formerly saline may have surface salts leached to the subsoils after drainage. Restoration of these wetlands could raise watertables in adjacent soils to the extent that; (1) subsoil salts are remobilized to the soil surface and (2) surface salts in the formerly drained wetland are remobilized to the pond edge creating a perceived salinization problem.

Typical landscapes representative of the association are presented in **Figures 15, 16, and 17** along with EC profiles collected with an EM-38 salinity meter and a representative portion of the soil map.

(Insert Figure 15 here)

(Insert Figure 16 here)

(Insert Figure 17 here)

3.1.2. The Bearden-Great Bend-Overly (ND005) Soil Associations

Soils in the ND005 association are found on level to undulating lake plains encompassing portions of Towner, Ramsey and Benson Counties. The landscape is characterized by broad gentle swells, swales, and gentle rises dotted by a few beaches and deep poorly drained depressions. A block diagram showing the typical distribution of common soils is provided in **Figure 18**.

(Insert Figure 18 here)

3.1.2.1. Upland Soils

Overly, Great Bend, and Gardena soils are the dominant upland soils associated with the glaciolacustrine sediments that characterize the association. Overly soils (*Fine-silty, mixed, superactive, frigid Pachic Hapludolls*) are well and moderately well drained soils formed in calcareous sediments located on swells and rises in landscape positions generally above the Bearden soil series. The Great Bend soil series (*Fine-silty, mixed, superactive, frigid Calcic Hapludolls*) consists of very deep, well-drained soils formed in glaciolacustrine sediments on lake plains. The well and moderately well drained Gardena soil series (*Coarse-silty, mixed, superactive, frigid Pachic Hapludolls*) are on terraces, deltas and glacial lake plains. Minor amounts (<3%) of well drained Zell soils (*Coarse-silty, mixed, superactive, frigid Typic Calciudolls*) are found in coarser textured glacio-lacustrine sediments.

Outcrops of till are common throughout the association. Upland soils in the till outcrops include the well and moderately well Svea and Barnes soils described above in section 3.2.1 along with the more poorly drained Tonka and Hamerly soils.

3.1.2.2. Wetland Soils

The dominant wetland soil formed in glaciolacustrine sediments is the poorly drained Hegne soil series (*Fine, smectitic, frigid Typic Calciaquerts*). Hegne soils have slightly convex to slightly concave slopes of less than two percent on glacial lake plains and in a few places these soils are on flood plains. The seasonal high water table is one foot above to 2.5 feet below the surface. Hegne soils are not typically saline, but a saline variant is recognized and mapped in this association.

The Tonka soil series consists of very deep, poorly drained soils that formed in local alluvium over till or glaciolacustrine deposits. Tonka soils are located in closed basins and depressions on till and glacial lake plains. The seasonal high water table is at a depth of 0.5 foot above the surface to 1 foot below the surface, at sometime during the period April through June. Tonka soils were previously discussed in Section 3.2.1.2.

The Lamoure soil series (*Fine-silty, mixed, superactive, calcareous, frigid Cumulic Endoaquolls*) consists of very deep, somewhat poorly or poorly drained soils formed in silty alluvium on flood plains of major drainageways. The water table is at depths of zero to 1.5 feet, at sometime during the period from October to June. Lamoure soils frequently flood from stream overflow. Lamoure soils are frequently mapped in complex with Colvin soils (*fine-silty, frigid, Typic Calciaquolls*). Colvin soils are not considered saline; however, a saline phase is recognized that has ECspe values varying from 4 to 16 dS/m in the subsoil.

3.1.2.3. Potentially Saline and Saline Soils characteristic of the Wetland Periphery

The Bearden soil series (*Fine-silty, mixed, superactive, frigid Aeric Calciaquolls*) is a somewhat poorly drained soil formed from calcareous silt loam and silty clay loam lacustrine sediments. Bearden is located on areas of higher lying flats and around wetlands. The seasonal high water table is at depths of 1.5 to 3.5 feet at some time during the period of April through June. Bearden soils are non-saline but a saline phase is recognized adjacent to wetlands (see Figure 18).

Also included in the association are minor amounts of Vallers, Parnell, and Southam soils described in Section 3.1.2.1 and 3.2.1.2.

3.1.2.4. Potential Salinization Hazards Attendant Upon Wetland Restoration

Areas of Bearden (saline) and Hamerly (saline) soils that are mapped within and adjacent to drained wetlands would have a significant salinization hazard upon restoration of the drained wetland. A salinization hazard would also be associated with drained wetlands containing Hegne (saline) soils. In some places Lamoure soils are mapped in complex with Colvin saline variant soils that could also experience a salinization hazard when restored.

3.1.3. The Hegne-Hamerly-Fargo (ND041) Soil Association

The Hegne-Hamerly-Fargo association is on a complex landscape of glacial lake plains and till plains. The landscape is characterized by broad, gentle swells and swales interrupted by glacial till ridges and relict beaches. Complex transitional areas of soils that formed in till, lacustrine material, and outwash are between the lake plains and the nearby glacial uplands. Slopes are gentle and range from 0-3 percent.

3.1.3.1. Upland Soils

Upland soils are not dominant in the association. In a few areas dominated by glacial till, moderately well drained Svea soils (discussed in Section 3.2.1.1 above) occupy till ridges and transitional areas between glacio-lacustrine and till sediments. Aberdeen (*fine, montmorillonitic*

Glossic Udic Natriborolls), Arvilla (*sandy, mixed, Udic Haploborolls*), and Bearden soils occupy higher position on the lake plains. Moderately well drained Aberdeen soils are on swells on lake plains and in better-drained lacustrine pockets in transitional areas between lake and till plains. The somewhat excessively drained Arvilla soils are on beaches and outwash. Somewhat poorly drained Bearden soils are on the lake plains but are higher than the poorly drained Fargo (*fine, montmorillonitic, frigid Vertic Haplaquolls*) and Hegne soils.

3.1.3.2. Wetland Soils

The association is dominated by poorly drained Hegne soils on broad, gentle swales on the lake plains below the somewhat poorly drained Hamerly soils that occupy footslope positions on gently sloping till ridges. Poorly drained Fargo soils are in swales and shallow depressions on the lake plains. Fargo and Hegne soils are frequently mapped in complex. Hegne soils are not considered saline, but a saline variant of Hegne soils is recognized and mapped in the association.

3.1.3.3. Potentially Saline and Saline Soils characteristic of the Wetland Periphery

Wetlands in the Hegne-Hamerly-Fargo association are typically associated with subtle depressions occupied by Hegne and Fargo soils. Saline variants of the somewhat poorly drained Bearden and Hamerly soils that are peripheral and adjacent to drained depressions are subject to salinization as are drained depressions occupied by saline variants of Hegne soils. Drained wetlands that either contain or are peripheral to saline variants of Hegne, Bearden, or Hamerly soils would have potential salinization hazards upon restoration.

A typical landscape representative of the association is provided in **Figure 19** along with an EC profile collected with an EM-38 salinity meter and a relevant portion of the soil map.

(Insert Figure 19 here)

3.1.4. The Hamerly-Cresbard-Svea (ND051) Soil Association

The Hamerly-Cresbard-Svea association is on glacial till plains characterized by broad, shallow swales, gentle ridges, and low knolls dotted by a few small, deep depressions and shallow basins (**Figure 20**).

(Insert Figure 20 here)

3.1.4.1. Upland Soils

Cresbard, Svea, and Barnes soils are dominant on the uplands. The well-drained Barnes soils occupy the sideslopes and the low summits of ridges and are generally above the moderately well drained Svea soils in swales on the upper foot slopes. The moderately well drained Cresbard soils are in swales on the lower foot slopes. Moderately well drained Aberdeen soils are in low swales and shallow basins.

3.1.4.2. Wetland Soils

Wetland soils in the association are dominated by poorly drained Hegne soils on broad, gentle swales on the lake plains and very poorly drained Parnell soils in the deeper depressions. Hegne soils are not considered saline, but a saline variant of Hegne soil is recognized and mapped in the association.

3.1.4.3. Potentially Saline and Saline Soils characteristic of the Wetland Periphery

Wetlands in the Hamerly-Cresbard-Svea association are associated with Hamerly soils on the wetland periphery. Saline variants of the somewhat poorly drained Hamerly soils adjacent to drained depressions dominated by Hegne or Parnell soils are subject to salinization, as are drained depressions occupied by saline variants of Hegne soils.

3.1.5. Additional Soils

The assessment of soil salinization hazards was restricted in this study to somewhat poorly drained to very poorly drained soils in the counties for which digital soils maps are available (Ramsey, Cavalier, Towner, Walsh, and Rolette counties). All soils that were within the 200-foot buffer polygons and the wetland polygon itself that are somewhat poorly drained or wetter were examined for soil salinity by consulting individual county soil survey and examining the listed ranges in ECspe that are provided in the NRCS soil attribute databases. Saline somewhat poorly drained and wetter soils for all counties in the Upper Basin are in **Table 1**. All somewhat poorly drained soils for all counties are in **Appendix A, Table A1** Soils that are moderately well drained or drier have not been tabulated due to the large number of potential upland soils within the 200-foot buffer polygons and the wetland polygons themselves. However, the percentage of all major map units identified within the wetland and buffer polygons are provided by soil survey area in **Tables 2 and 3**, respectively. Map units containing saline soils as major components are in bold.

(Insert Table 1 here)

(Insert Table 2 here)

Insert Table 3 here)

Because the restoration of candidate wetlands would be to their natural conditions, soils better drained than moderately poor are not expected to experience a salinization hazard (see Section 2.2, Assumption 3, above). The rise in water table in moderately well drained or drier soils on the historic wetland periphery would not be of sufficient magnitude to result in a substantial mobilization of subsoil salt (if present). Thus all soils within the 200-foot buffer polygon or the wetland polygon itself that have major soils that are moderately well drained or drier were designated non-saline.

The presence of upland soils in the designated candidate wetlands is, in part, explained by the presence of wetlands as inclusions in many upland soil map units. For example Tonka wetlands are usually too small to map separately in map units with Barnes, Buse, or Svea as dominant soils. Because most wetland inclusions in upland soil map units usually represent recharge-type wetlands that would not be associated with salinization hazards when restored, upland soils that were moderately well drained or drier in potential restoration candidate wetlands were considered to be non-saline even though they are not hydric and would not represent the included wetland soil present within the wetland polygon. In addition, because the polygon representing the restoration candidate reflects the boundary of the wetland up to the natural pour point, the acreage of wetlands that do not usually overflow may be overestimated and can include upland soil components. The 200-foot buffer polygons would naturally contain soils that would be moderately well drained or drier, especially in areas characterized by higher relief.

3.2. ACREAGE AND STORAGE VOLUME ESTIMATES OF POTENTIAL SALINIZATION HAZARDS IN THE UPPER BASIN

The assessment of soils salinization hazards associated with potential resalinization or enhanced/expanded salinization within the 200-foot buffer polygons will be considered separately from the salinzation hazards associated with the wetland polygons themselves. Salinization hazards associated with the buffer areas are expected to be of greatest concern for the following reasons:

1. Wetland restoration will not flood areas adjacent to the restored wetlands that are within the 200-foot buffer polygons. Thus these areas could reasonably be expected to remain in agricultural production.

2. Because low relief is characteristic of many areas in the Upper Basin, non-hydric, somewhat poorly drained saline soils extend for some distance beyond the delineated wetland boundary. In these situations wetland restoration could increase watertable depths for a considerable distance, significantly increasing the salinization hazard for the existing saline soils and potentially resalinizing adjacent non-saline soils.

3. Saline soils are typically associated with the wetland periphery in wetlands that are ponded for significant periods. Thus the wetland buffer area is the most logical place to assess salinization hazards in these wetlands.

A salinization hazard exists for drained candidate wetlands with significant percentages of saline soils because salts associated with the historic pond bed would be mobilized by restoration to the pond edge. However, restoration of drained wetlands with saline soils within the wetland polygon will result in the removal of productive land whether or not the pre-restoration condition was saline. Mobilization of salts from the wetland to location far from the pond edge is not expected to be significant when compared to the effects of watertable rise on mobilizing existing subsoil salts in peripheral buffer areas. Thus the salinity hazard associated with saline soils occupying the wetland interior is not as great a concern as salinization of the wetland buffer area.

3.2.1. Distribution Statistics and the Relationship between Salinity Hazard Class and Potential Storage Volume

An analysis of the storage volumes associated with individual wetlands indicated that storage volumes are strongly skewed to lower values, suggesting that the distribution of storage volumes among the wetlands are log-normally distributed. In order to confirm a log normal distribution, a dataset consisting of log transformed values of wetland storage was created. A histogram showing the distribution of storage volumes by wetland frequency confirms that storage volumes for the 13,457 wetlands considered restoration candidates are log normally distributed (**Figure 21**). The majority of the potentially restorable wetlands are extremely small with limited storage potential.

(Insert Figure 21 here)

The distribution of storage volumes among the wetlands has significant implications for restoration. Means and medians calculated on the raw values are misleading unless calculated on a log-transformed basis then transformed back into natural numbers. The majority of the storage associated with wetland restoration would come from the restoration of a few larger wetlands with higher storage volumes. The acquisition and restoration of large numbers of smaller wetlands could complicate and increase the expense of restoration efforts. The restoration of fewer large wetlands has the advantage of minimizing the acquisition of large numbers of land parcels and the expense of restoring numerous wetlands. However, the presence of majority of the storage volume in a small number of wetlands increases the importance of acquiring these larger wetlands. If the wetlands with the greatest amount of storage are unavailable for restoration, the acquisition of large numbers of smaller wetlands may not make up the difference.

These relationships are graphically presented in **Figure 22**. Data are provided for wetlands in the None/Slight Buffer Salinization Hazard and the None/Slight Wetland Salinization Hazard classes. The data represent the cumulative summation of storage volume by the cumulative percent of wetlands. Wetlands were ranked from largest to smallest. The data show that for the None/Slight Buffer Salinization Hazard class just under 50,000 acre feet of storage (75% of the total) is contained within only 10% (approximately 900) of the 9107 wetlands identified by West Consultants, Inc. as being potential restoration candidates (exclusive of wetlands in Benson and Pierce counties). Similarly the data show that approximately for the None/Slight Wetland Salinization Hazard class approximately 45,000 acre feet of storage (71% of the total) is contained within only 10% (approximately 960) of the 9625 wetlands in the None/Slight Wetland Hazard Class.

(Insert Figure 22 here)

A detailed analysis of the distribution statistics associated with potential storage volumes and buffer and wetland salinization hazard classes is in **Appendix B**, **Figures B1-B5 and B6-B10**, respectively. Probability curves are provided to indicate the distribution of wetlands within each hazard class by potential restoration volume. Distribution statistics are provided for both raw and log-transformed storage volume data for comparative purposes.

3.2.2. Salinization Hazards Associated with Wetland Restoration

Table 4 presents a breakdown of wetland acreage and potential restoration volumes by Buffer Salinization Hazard Class and county. Information on wetland counts is also presented. The data in Table 4 indicate the following.

(Insert Table 4 here)

1. The salinity hazard classification category with the largest number, acreage, and storage volume is the None/Slight category, followed by the low, moderate, high, and severe categories.

2. The lowest percentage of total storage volume in the None/Slight salinity hazard category was in Cavalier county (45.3%), followed by Ramsey (50.7%), Towner (76.4%), Rolette (87.2%), and Walsh (91%) counties. Benson and Pierce counties were not analyzed because spatial digital soils data on map unit distribution were lacking. However, based on the percentages in the five counties where salinity was assessed, a 50% value for total storage volume in the None/Slight category would be a conservative estimate for Benson and Pierce counties.

3. Even though Ramsey and Towner Counties have the smallest percentage of wetlands in the None/Slight hazard class, they have the largest number of restorable wetlands and available storage, followed by, Cavalier, Rolette, and Walsh counties.

4. Exclusive of Benson and Pierce counties, 66,861 acre-feet of storage are in the None/Slight category, representing approximately half of the total available storage of 127,853 acre-feet. The Upper Basin storage alternative assumes restoration of 50% of the available storage identified by West Consultants, Inc. (63,926 acre-feet). The data suggest that this restoration percentage is attainable with limited salinization hazards occurring within a 200-foot buffer of the restored wetlands. As indicated in Section 3.2.1 above, the majority of the potential storage is in larger wetlands.

5. If a conservative estimate of 50% of the available storage is assumed to be in the None/Slight salinity hazard category for Benson and Pierce counties, the total restorable storage would rise from 66,861 acre-feet to 71,570 acre-feet.

Table 5 presents a breakdown of wetland acreage and potential restoration volumes by Wetland Salinization Hazard Class and county. Information on wetland counts is also presented. In general, the data on wetland acreages and storage volumes associated with specific salinity hazard classes are very similar to the data discussed above for salinization hazards associated with the 200-foot buffer. The data in Table 5 indicate the following.

(Insert Table 5 here)

1. Again, the salinity hazard classification category with the largest number, acreage, and storage volume is the None/Slight category. The distribution of wetlands by Wetland Salinity Hazard category is slightly different in that the None/Slight category is followed by the moderate, then low, and severe categories.

2. The lowest percentage of total storage volume in the None/Slight salinity hazard category was in Cavalier county (40.4%), followed by Ramsey (51.3%), Walsh (54.3%), Rolette (71.7%), and Towner (71.9%) counties. Benson and Pierce counties were not analyzed because spatial digital soils data on map unit distribution were lacking. However, based on the percentages in the five counties where salinity was assessed, a 50% value for total storage volume in the None/Slight category would be a conservative estimate for Benson and Pierce counties.

3. Even though Ramsey and Towner Counties have the smaller percentage of wetlands in the None/Slight hazard class, they have the largest number of restorable wetlands and available storage, followed by, Cavalier, Rolette, and Walsh counties.

4. Exclusive of Benson and Pierce counties, 63,512 acre-feet of storage are in the None/Slight category, representing approximately half of the total available storage of 127,853 acre-feet. The Upper Basin storage alternative assumes restoration of 50% of the available storage identified by West Consultants, Inc. (63,926 acre-feet). Again the data are similar to the data for the Buffer analysis, and suggest that this restoration percentage is attainable with limited salinization hazards occurring within the restored wetlands. As indicated in Section 3.2.1 above, the majority of the potential storage is in larger wetlands.

5. If a conservative estimate of 50% of the available storage is assumed to be in the None/Slight salinity hazard category for Benson and Pierce counties, the total restorable storage would rise from 63,512 acre-feet to 68,220 acre-feet.

A correlation analysis was performed to determine the relationship between Buffer Salinity Hazard classes and Wetland Salinity Hazard classes for individual restoration candidate wetlands. As indicated above, the storage volumes predicted for the two classes are quite close, suggesting that individual restoration candidate wetlands have similar classifications. This would be expected, as candidate wetlands with saline soils in the wetland polygon would also have saline soils associated with the 200-foot buffer. The results of the regression analysis are presented in **Figure 23**. An Pearson Correlation coefficient of 0.88 indicates a strong relationship between Buffer Salinity Hazard class and Wetland Salinity Hazard class. Salinity hazards classes are associated slightly more with wetlands than with Buffers, likely due to the larger acreage associated with the Buffers of smaller wetlands incorporating more less-saline uplands in the total acreage. However, the interpretations associated with each group are essentially the same.

(Insert Figure 23 here)

3.2.3. Salinity Hazard Classification Maps

Examples of salinity hazard classification maps and soil maps are provided for Buffer and Wetland salinization hazard classes in **Figures 24 through 29** These figures represent GIS layers for both wetland hazard classes and soil maps are being provided to the St. Paul District, USACE. The Arcview themes and their associated attribute data can be used to identify potential wetland restoration candidates by location, size, geomorphic setting, and percentage of saline soils. Also included in the GIS products is a layer identifying saline soils that are adjacent to the 200-foot buffer polygons. The distribution of saline soils in areas adjacent to the 200-foot buffer polygons established for the potential restoration candidates may have to be considered to ensure that soil salinization beyond the 200-foot buffers will not become a problem. The greatest hazard of soil salinization beyond the 200-foot buffers will likely be associated with restoration of the larger wetlands that would likely affect groundwater table elevations beyond the 200-foot buffer area. Examples of the distribution of saline soils within and adjacent to wetlands and their 200-foot buffers are provided in Appendix C.

3.2.4. Management and Mitigation of Soil Salinity

Restoration of wetlands identified in this report may still result in incidental salinization and perceived salinization hazards by growers in the Upper Basin. Salt and sodium in soils can limit their use, reduce crop yields, and influence management (Bresler et al., 1982; Franzen et al., 1994; Holm and Henry, No date). Depending on crop salt tolerance, significant yield reductions of intolerant crops occur beyond an EC of 4 dS/m. Crop tolerances to soil salinity/sodicity have been quantified (Francois, 1994, 1996) and management techniques to reduce the negative impacts of soil salinity are known (Johnsgard, 1967; Franzen et al., 1994). Many of these techniques are already in general use on saline/sodic soils in the region (Bresler et al., 1982; Franzen et al., 1994; Maianu, 1983, 1984, 1985).

Secondary soil salinization associated with the Upper Basin storage alternative may have a negative economic impact that can be quantified through an assessment of increased management costs, limits to use, and reduced crop yields. Soil water compatibility issues are well documented, requiring a knowledge of applicable soil/groundwater characteristics (U.S. Salinity Laboratory Staff, 1954; Franzen et al., 1996; Scherer et al., 1996). Given knowledge of soil type and expected changes in salinization due to the alteration of groundwater flow dynamics attendant upon restoration, salinity hazards can be identified and mitigated or accounted for.

Common management techniques use adapted crops and manipulate watertables and groundwater flow to minimize soil salinization in sensitive areas. Land and water management practices that can help producers to reduce the risk of dryland salinization include but are not limited to:

- increasing minimum tillage or no-tillage
- increasing the area of forages, pastures, and tree crops
- reducing summer-fallow area
- including crops that are more salt-tolerant in rotations
- using inputs such as mineral fertilizers and animal manure more effectively
- using precision farming
- installing interceptor forage strips or strategic subsurface tile drainage. (Eilers et al., 1997; Eilers et al., 2000)

4. CONCLUSIONS

4.1. SALINITY RISKS ASSOCIATED WITH UPPER BASIN STORAGE

Restoration of wetlands will not increase the overall salt loading of potentially restored areas. Salts are transported in saturated and unsaturated groundwater flow, and the leaching and translocation of soluble salts is controlled by groundwater flow in the landscape. Wetland drainage represents a significant alteration in groundwater flow regimes that developed over time, with salts moving to different parts of the landscape and different depths in the soil profile when compared to the distribution of salinity that existed prior to drainage.

Similarly, the restoration of drained wetlands represents a reinstatement of pre-existing groundwater hydrology. Salts mobilized and translocated as a result of the alteration of groundwater movement associated with wetland drainage will be subject to remobilization once the original hydrology has been partially or wholly reestablished. Thus wetland restoration, while imposing a salinization hazard in certain hydrological settings, does not represent the addition of salt to the landscape but a remobilization of existing salt. Salts are frequently translocated to positions in the landscape that remain saline or that were saline prior to wetland drainage. When mobilized salts accumulate in locations where salinity was not common or was not a problem before, growers will perceive a salinization problem and possibly attribute the problem to the wetland restoration.

The data provided in Tables 5 and 6 and discussed in Section 3.2.2, above suggest that the restoration of 50% of the potential storage volume contained in drained candidate wetlands identified by West Consultants, Inc. (2001) is attainable. The data suggest that well over 60,000 acre-feet of storage is available with a minimum of salinization hazards to affected growers provided that the restoration focuses primarily on candidate wetlands in the None/Slight and Low salinization hazard classes. It is also probable that wetlands in higher salinization hazard classes may be available for restoration. Existing salinity in these candidate wetlands has likely already reduced crop yields to the point that placement of saline wetlands and adjacent buffers in a conservation reserve program would be an attractive alternative to the landowner, provided that equitable compensation is made available.

If the UBS alternative is to be considered viable, restoration efforts must:

1. Focus on areas where wetland restoration will not result in the significant mobilization of existing salinity to the extent that crop yields or land use in adjacent, productive agricultural lands are affected. Such areas will be characterized by a general lack of salinity both in the drained wetland and in the adjacent soils. It is suggested that the restoration emphasis be placed on wetlands in the None/Slight and Low buffer salinization hazard categories. GIS queries could be used on the Arcview data layers to identify wetlands that have None/Slight and Low salinity hazards in both buffer and wetland categories. The resulting identified wetlands could be ranked by size, storage, and location to develop the best possible mix of restoration alternatives that would maximize long term storage, grower, and wildlife concerns.

2. Avoid wetlands with intermediate salinization hazards, e.g. those wetlands in the Moderate Salinization hazard classes for both the wetland and the wetland buffer. Restoration of such wetlands would be likely to result in a perceived salinity problem associated with the existing saline land and potentially saline adjacent land. Such land would likely be productive cropland and any change in salinity would be perceived as a potential problem.

3. Focus on existing drained saline areas (Salinity hazard classes 3 and 4). Growers in the Upper Basin have commonly drained semipermanent wetlands to reclaim productive cropland only to find that the drained areas rapidly become saline and non-productive (Seelig and Richardson, 1991; Richardson and Arndt, 1989). A viable alternative to cropping drained historic wetland unsuited or marginally suited to agriculture because of salinity hazards would be to restore the saline wetland. The restored wetland and a buffer zone around the wetland could then be placed into a conservation reserve program. This would be a particularly attractive option to farmers whose land is not producing efficiently because of existing salinity problems.

4. The analysis of the distribution of wetlands in Section 3.2.1 may be somewhat misleading because of the differences in hydrology between large and small wetland systems in the Upper Basin. Large wetlands tend to be semipermanently to permanently ponded. Once restored, these wetlands will tend to maintain a significant amount of water, thus reducing subsequent available storage. Smaller, temporarily ponded wetlands with limited storage are by far the largest group of restoration candidates; however, they have limited storage volumes. While these wetlands have limited storage, their seasonally ponded nature ensures that storage will be available several times in a season because these wetlands rapidly drain to the watertable. Additional research into the hydrology of these wetlands is needed to determine how much water is actually captured by these wetlands.

Restoration of candidate wetlands will likely have to consider members of all salinization hazard groups due to uncertainties in land acquisition, the need to restore wetlands in certain locations, and the need to focus on larger wetlands with greater storage potential. Several methods are available to compensate landowners affected by wetland restoration, including the incorporation of saline land into buffers to increase available wildlife habitat. Existing programs such as the NRCS conservation set-aside program for saline lands and the Extended Storage Acreage Program (ESAP) could be combined to provide incentives for landowners to enroll in wetland restoration programs.

If the UBS alternative is found to be a viable option to reduce flooding in Devils Lake, on-site investigations by qualified professional soil scientists should be performed prior to each restoration to verify the absence of significant areas of saline soils within and near the restoration candidate and to estimate the potential soil salinization response to restoration. An on-site assessment is particularly important to identify saline soils incorrectly mapped as non-saline and to identify the presence and extent of saline inclusions.

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Soil Salinization Hazards Associated with Devils Lake Flood Damage Reduction Alternatives:

Upper Basin Storage

Report Figures

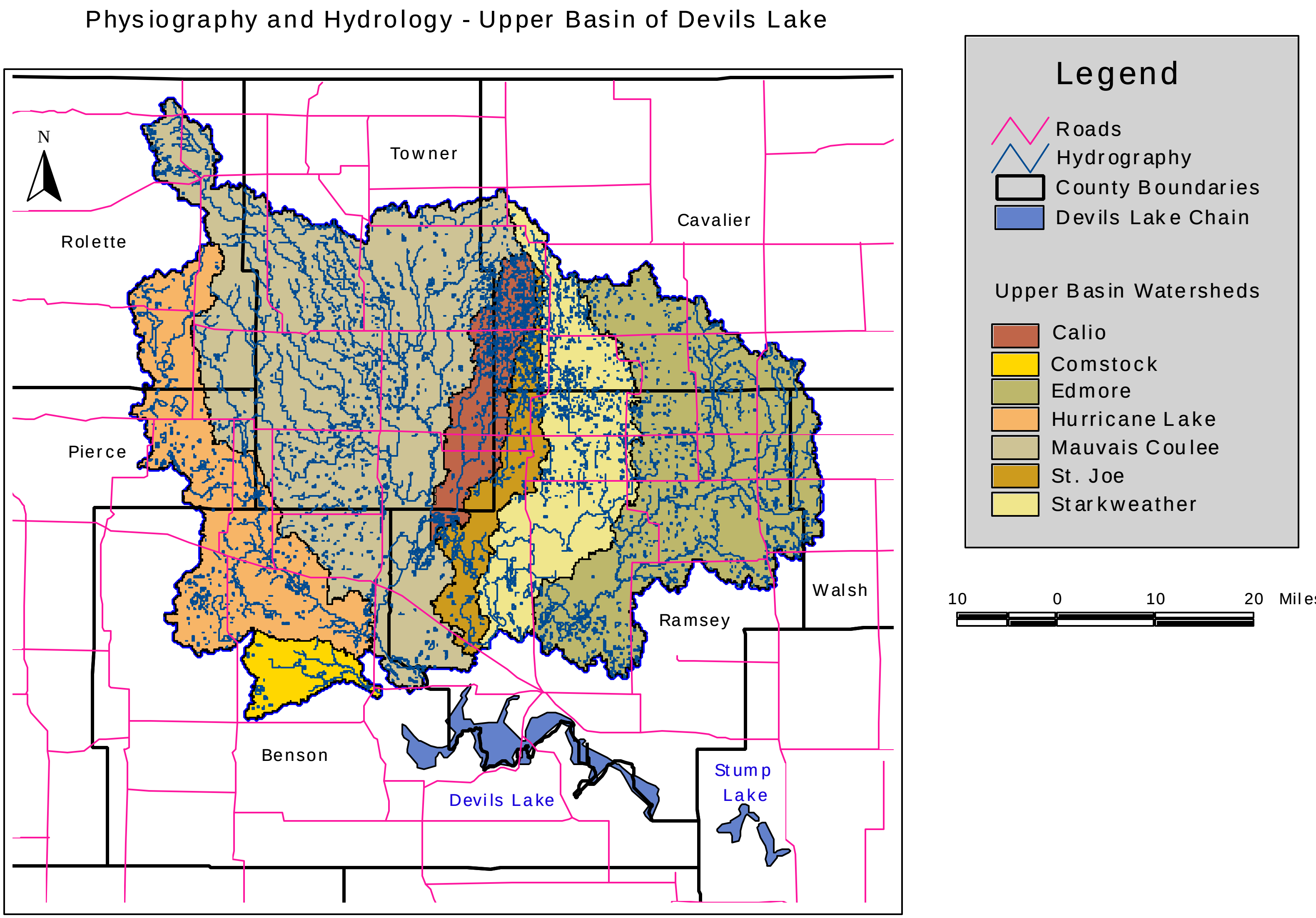


Figure 7. Physiography and hydrology of the Upper Basin of Devils Lake. The seven major watersheds are shown, along with drainages and counties.

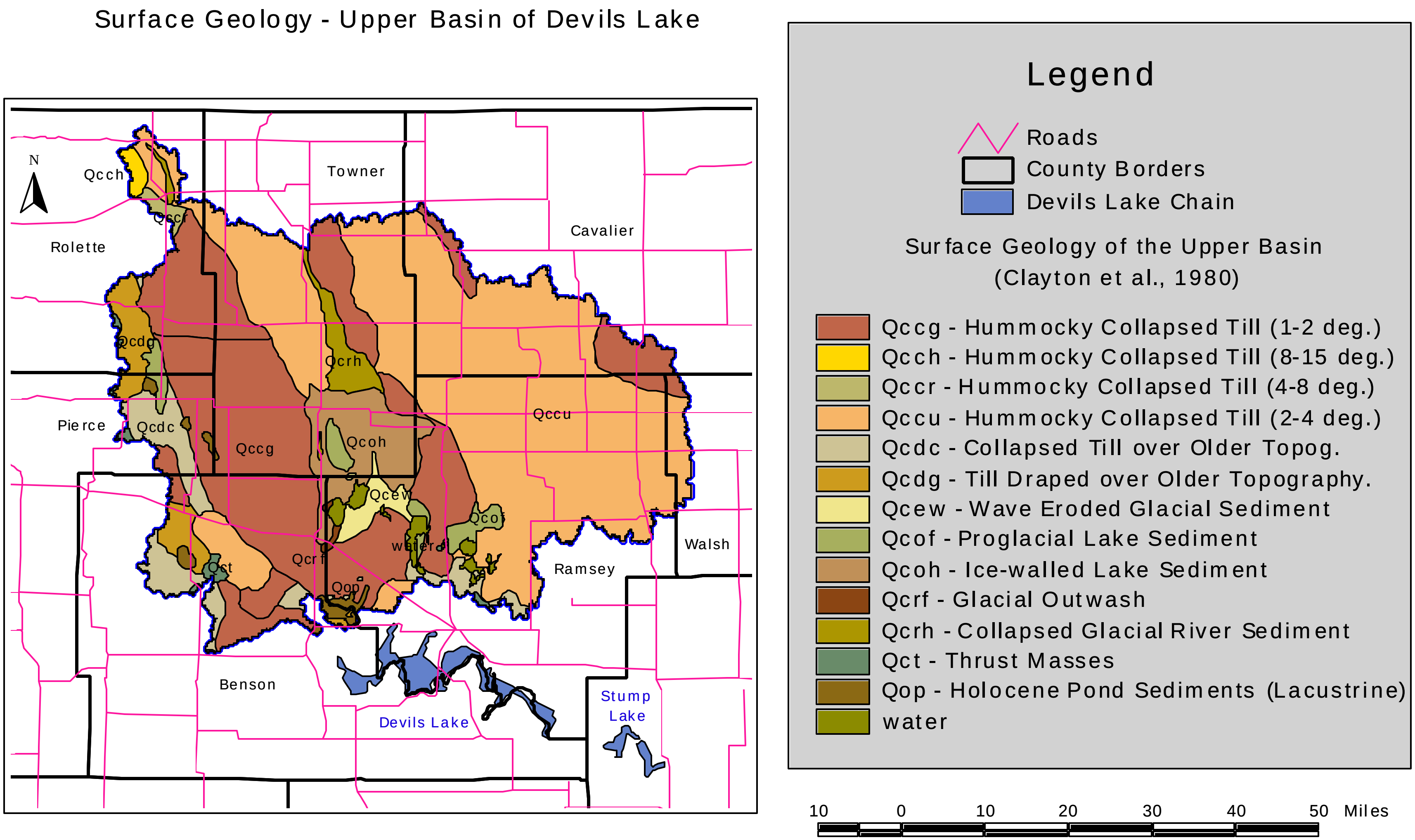


Figure 2. Surface geology of the Upper Basin of Devils Lake. The two dominant surface geological units are collapsed glacial sediment of low and gently undulating relief (Qccg and Qccu, respectively). Relatively fine-textured lake sediments are also significant units in the upper basin (Qcof and Qcoh).

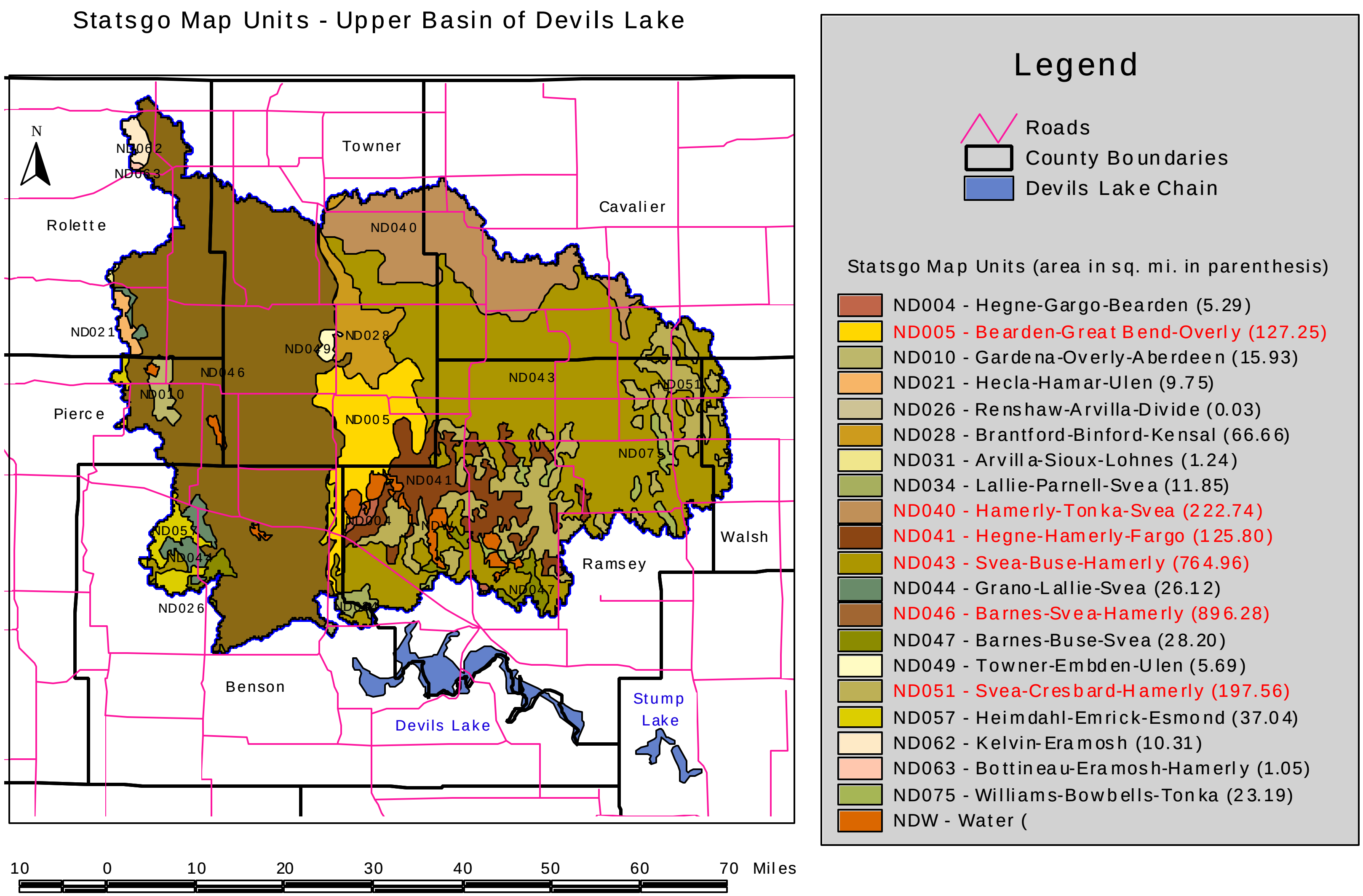


Figure 3. Major STATSGO soil associations in the upper basin. Note General similarities with the surface geology in Figure 2. Six STATSGO associations (in red) account for the majority of the land surface in the upper basin. Associations ND005 and ND041 are associated with lacustrine and wave-eroded tills Associations ND043, ND046, and ND040 are similar units that formed in a rolling till plain and vary in relative composition due to slight differences in relief.

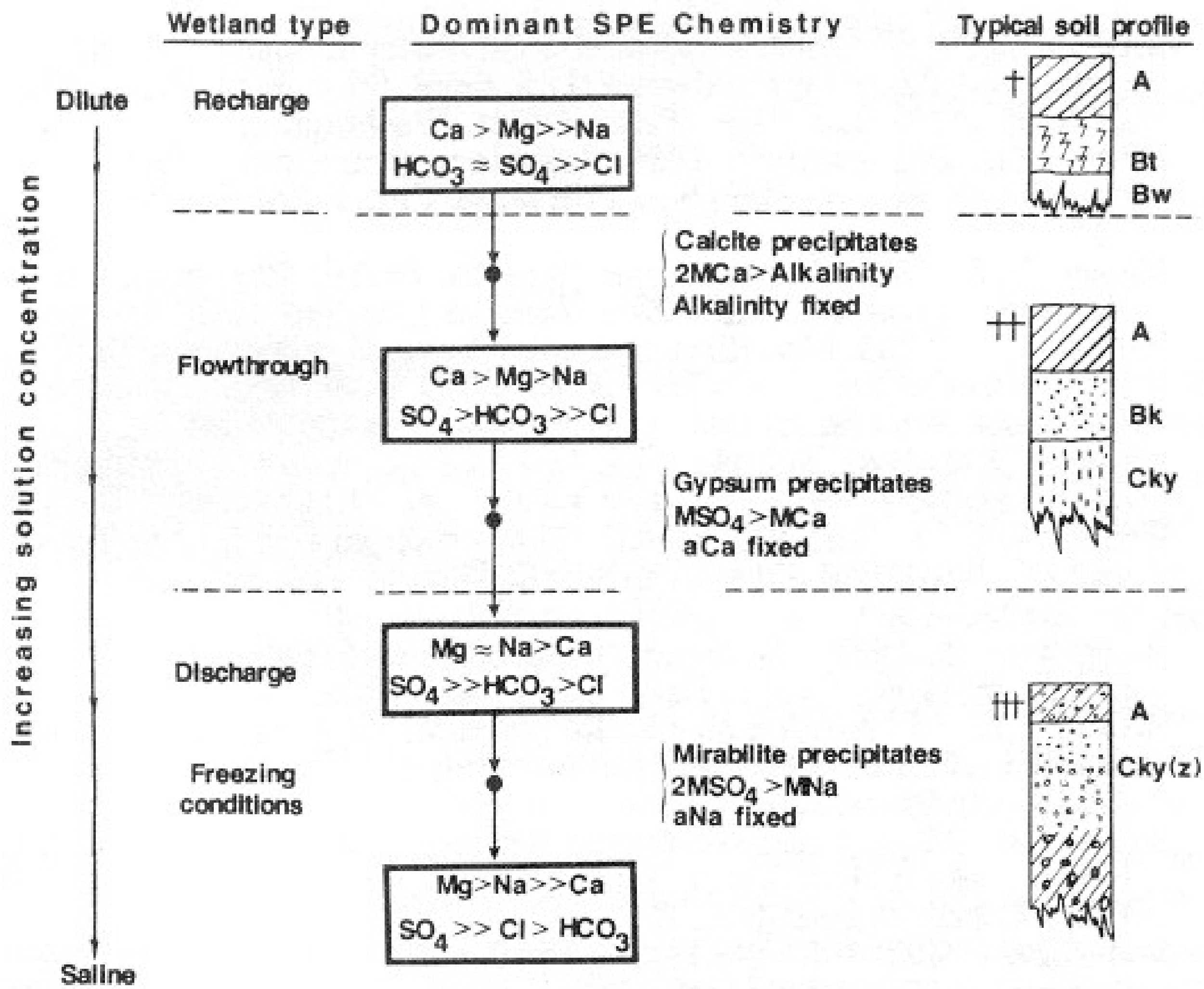


Figure 4. Summary of mineralogic controls on the development of hydric soil salinity in the saline periphery of wetlands in the Northern Plains. Alkalinity as HCO3, molarity(M) and activity (a) as designated. Typical profiles: + Typic Argiaquolls and Cumulic Endoaquolls, ++ Typic Calciaquolls and (calcareous) Cumulic Endoaquolls, +++Mollic Fluvaquents and Fluvaquentic Haplaquolls. Soil horizon subscripts t, k, y, and z indicate clay, calcium carbonate, gypsum, and salt accumulation, respectively (Arndt and Richadson, 1989).

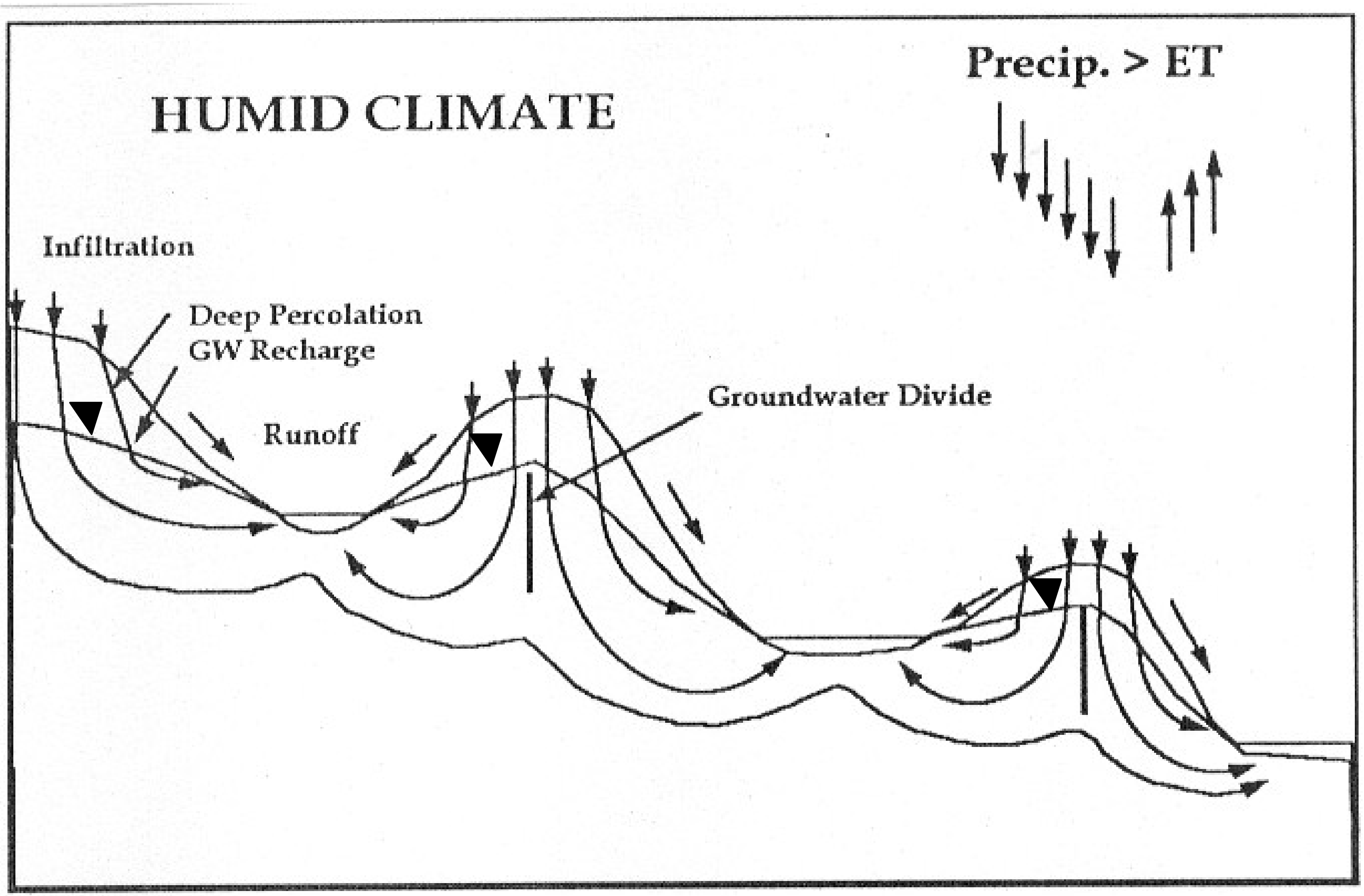


Figure 5. Groundwater flow in glaciated, hummocky, humid (precipitation > evaporation) landscapes. Note that groundwater flow is to the depressions (depression-focused discharge). Higher, upland landscape positions are recharge areas. Water table topography is a subdued image of the land surface topography (after Arndt and Richardson, 1994).

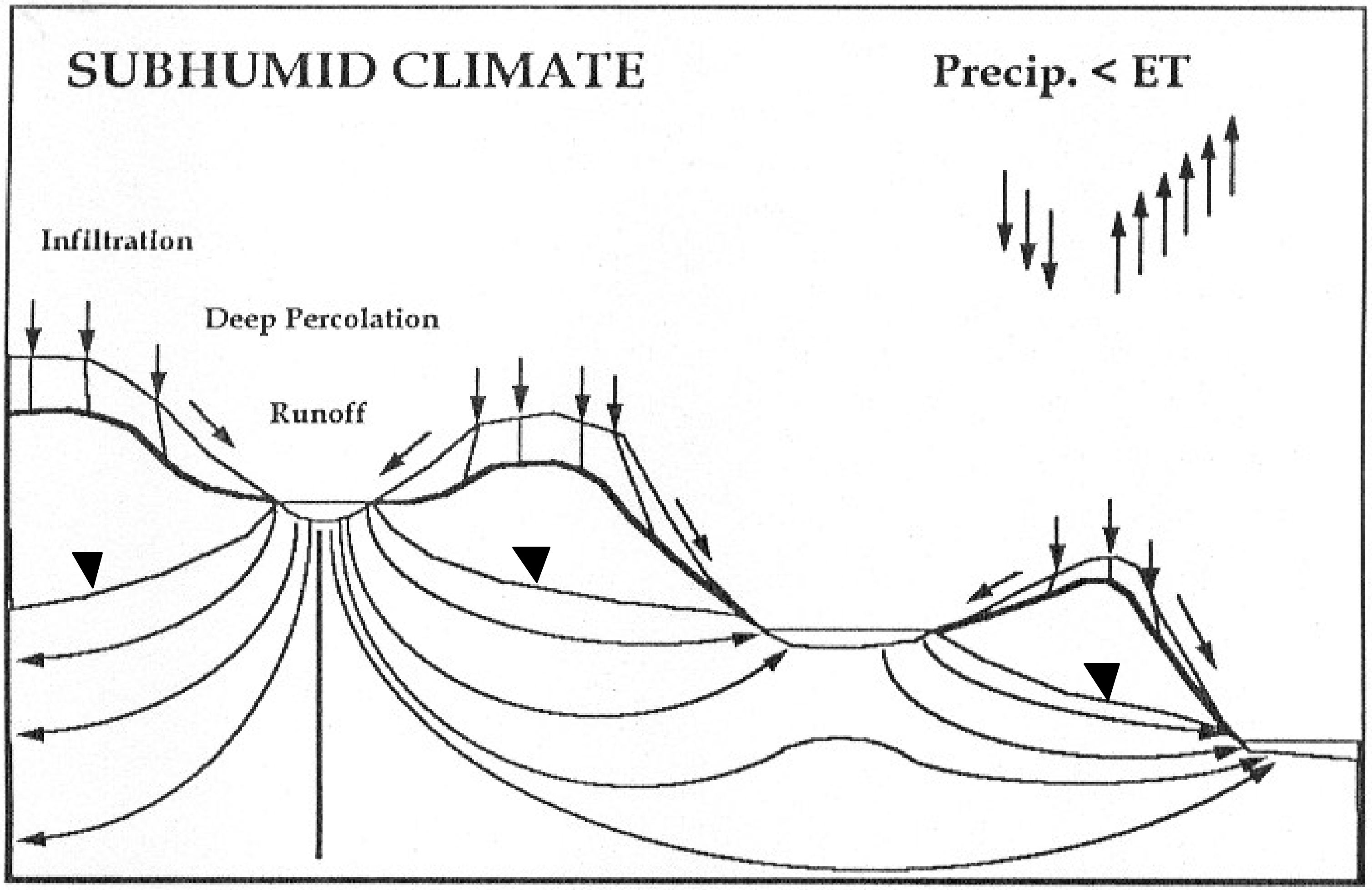


Figure 6. Groundwater flow in hummocky, sub-humid (precipitation < evaporation) glaciated landscapes. Note that surface water flow is to the depressions. Groundwater flow is away from recharge depressions, towards discharge depressions, and both towards and away from flowthrough depressions. The upland landscape areas are relatively uninvolved in transfers of water to and from the watertable. The water table does not follow the landscape topography. Wetlands in landscapes dominated by Barnes, Buse, and Svea in uplands and Vallers, Tonka, Parnell, and Southam soils in wetlands will typically have this type of hydrology (after Arndt and Richardson, 1994).

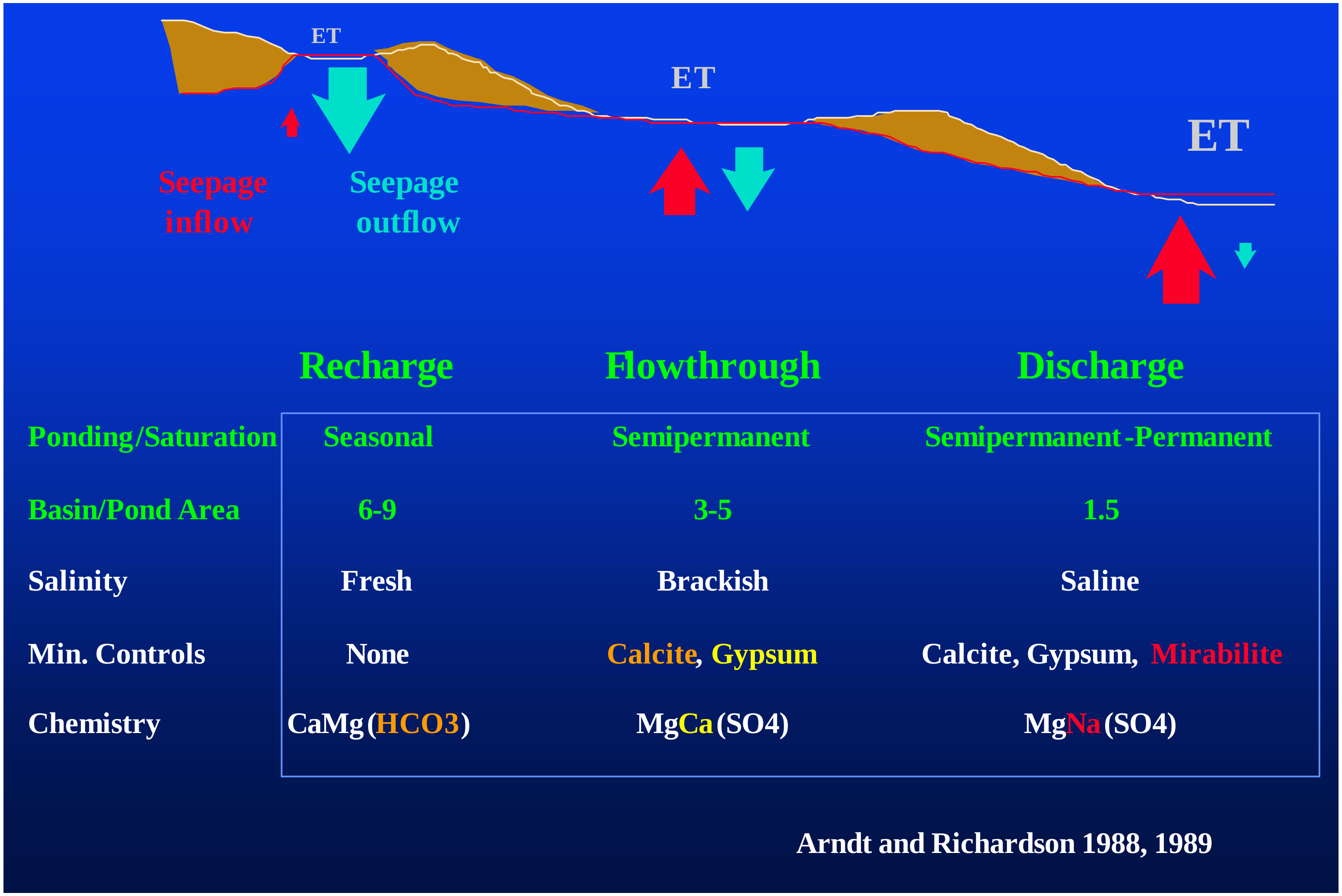


Figure 7. Selected basin characteristics and chemical parameters characteristic of recharge, flowthrough, and discharge wetlands in the Prairie Pothole Region. The relative importance of seepage inflow and seepage outflow is indicated by the size of the appropriate arrows located under the wetland positions. The relative intensity of evapotranspiration is indicated by the size of the acronym "ET" above the wetland. The basin/pond ratio indicates the ratio of the catchment basin, defined as the area capable of contributing runoff to the wetland divided by the area of the wetland. Mineralogic controls are indicated by matched colors associated with the controlling mineral and the cation or anion controlled (see also Figure 4).

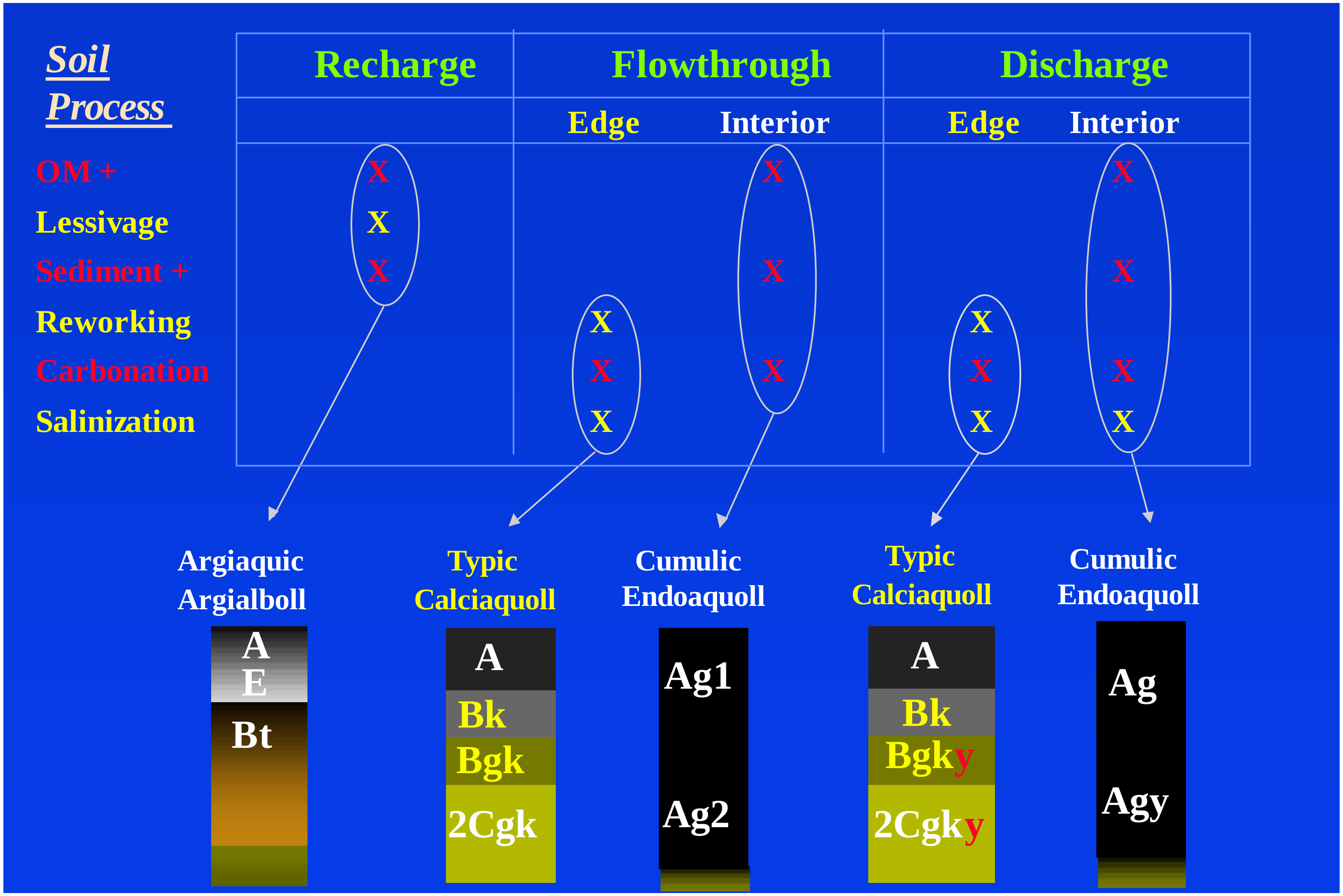


Figure 8. Characteristic hydric soils in recharge, flowthrough, and discharge wetlands in the Prairie Pothole Region, along with characteristic, dominant soil-forming processes. Organic matter and sediment accumulations are associated with all wetlands. Clay accumulation is primarily associated with recharge wetlands. Carbonation (precipitation of calcium carbonate) and salinization are associated primarily with flowthrough and discharge wetlands. Salinization is typically most intense at the wetland edge.

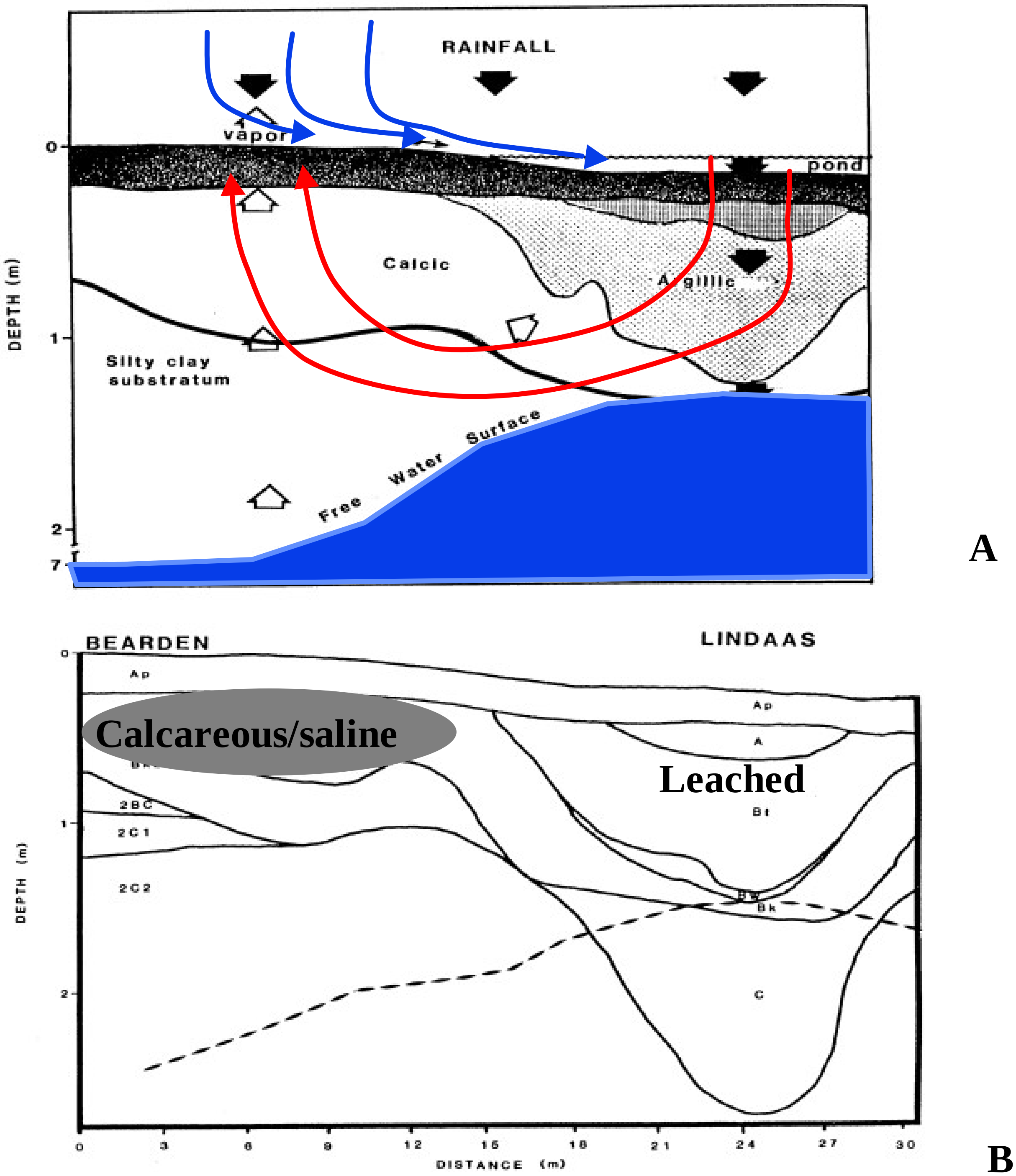
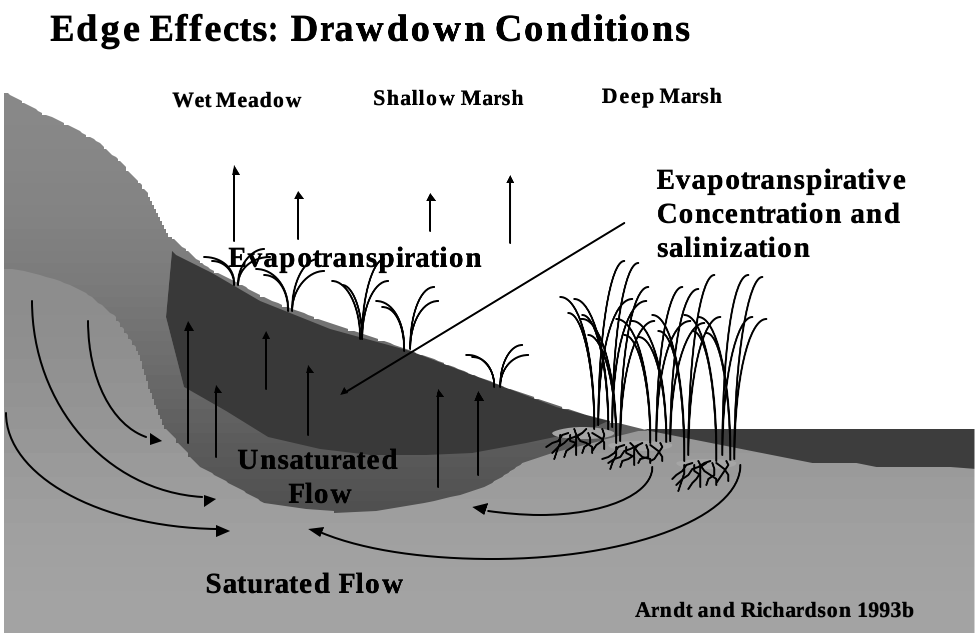


Figure 9. Depression-focused recharge in a low-relief landscape with fine-textured soils. Snowmelt and runoff seasonally/temporarily pond in the shallow depression. Ponding drives downward groundwater movement resulting in a leached, non-saline Lindaas (*fine, smectitic, frigid Typic Argiaquolls*) wetland soil. However, the resulting groundwater mound places the watertable in adjacent soils near enough to the surface for evapotranspiration to concentrate salts. The result is that the leached soil in the wetland position is surrounded by calcareous soils (Bearden series, *fine-silty, mixed, superactive, frigid Aeric Calciaquolls*). If the groundwater remains high for a sufficient period, the peripheral soils could become saline (modified from Knuteson et al, 1989)



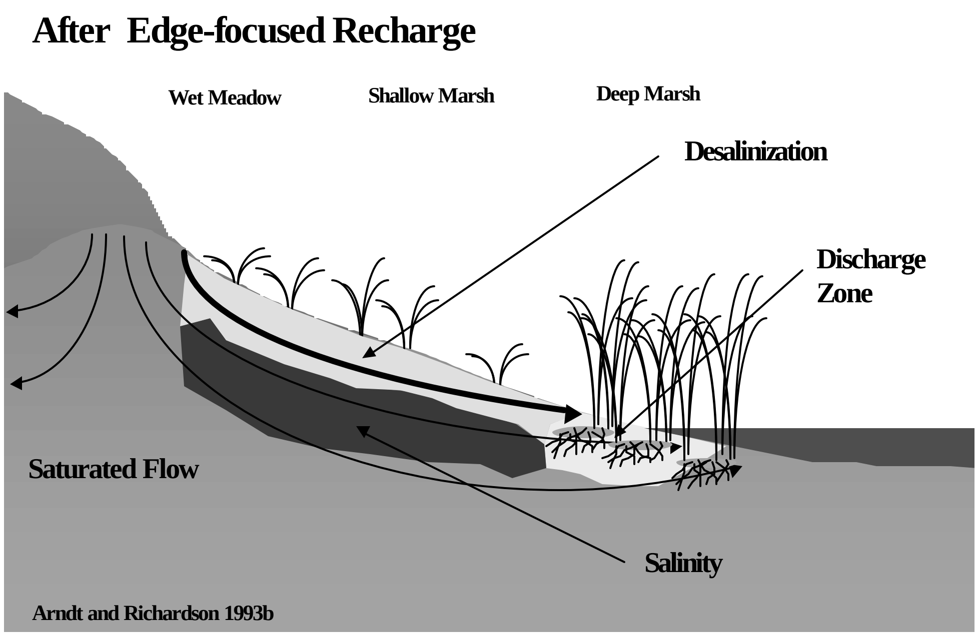
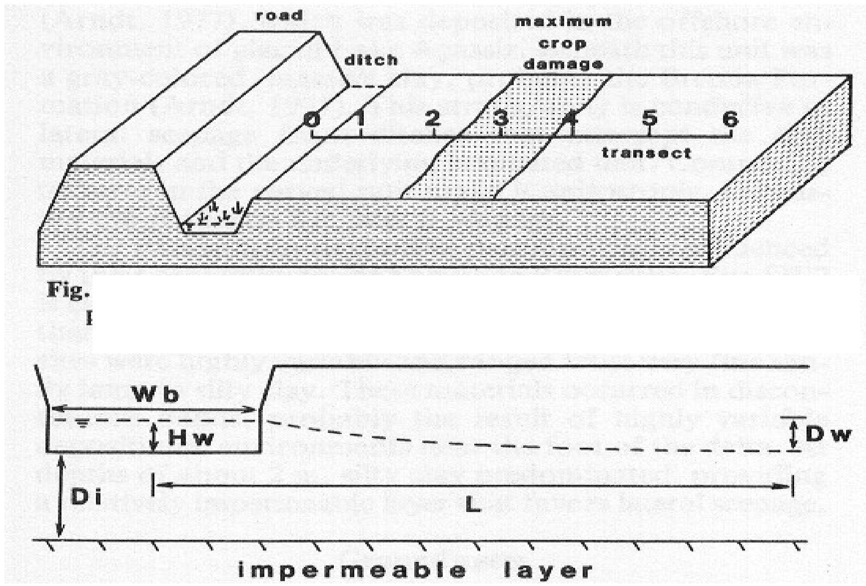
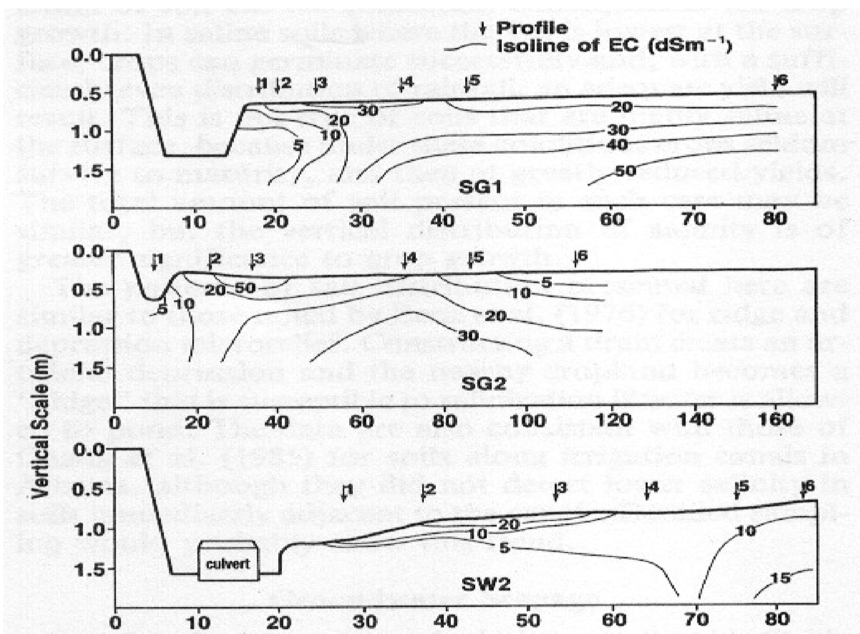


Figure 10. Salinization dynamics at the wetland edge. (A) During dry periods evapotranspiration at the pond edge results in edge-focused discharge. The wetland edge receives water from both the pond and the groundwater. Concentration and salinization of the full soil column can occur during this period if soluble salts are present in the groundwater or pondwater. (B) After significant precipitation events groundwater mounds form at the pond edge resulting in mobilization of surface salinity downslope and to the pond. Soil surfaces are desalinized at this time. Edge focused recharge and discharge acts as a "pump" that can recycle salts in the wetland (Arndt and Richardson, 1993)



(A)



(B)

Figure 11. Induced soil salinization associated with roadside ditches in the Red River Valley (modified from Skarie et al., 1986). Salinization paralleling road ditch es is common in the Red River Valley. (A) Physical and hydrologic model. Roadside ditches act as created ponds that maintain adjacent water levels at higher positions than the natural condition. (B) The distribution of salinity associated with various road ditches. Most of the salinity is found within a zone 30-60 meters from the ditch. Leaching of accumulated salts to the ditch maintains less salinity immediately adjacent to the ditch. Water table increases more distant than about 60 meters are not high enough to affect surface soil salinization due to the ditch. Rapid salinization occurs, in part, because the soils naturally have high amounts of subsoil salinity associated with them.

(A)

(B)

(C)

Figure 12. Landscape photographs. (A) Salinization of the soil surface in a semipermanent pond subsequent to drainage. (B). Ditchside salinization. (C) Drainage of a large wetland complex in the Upper Basin.

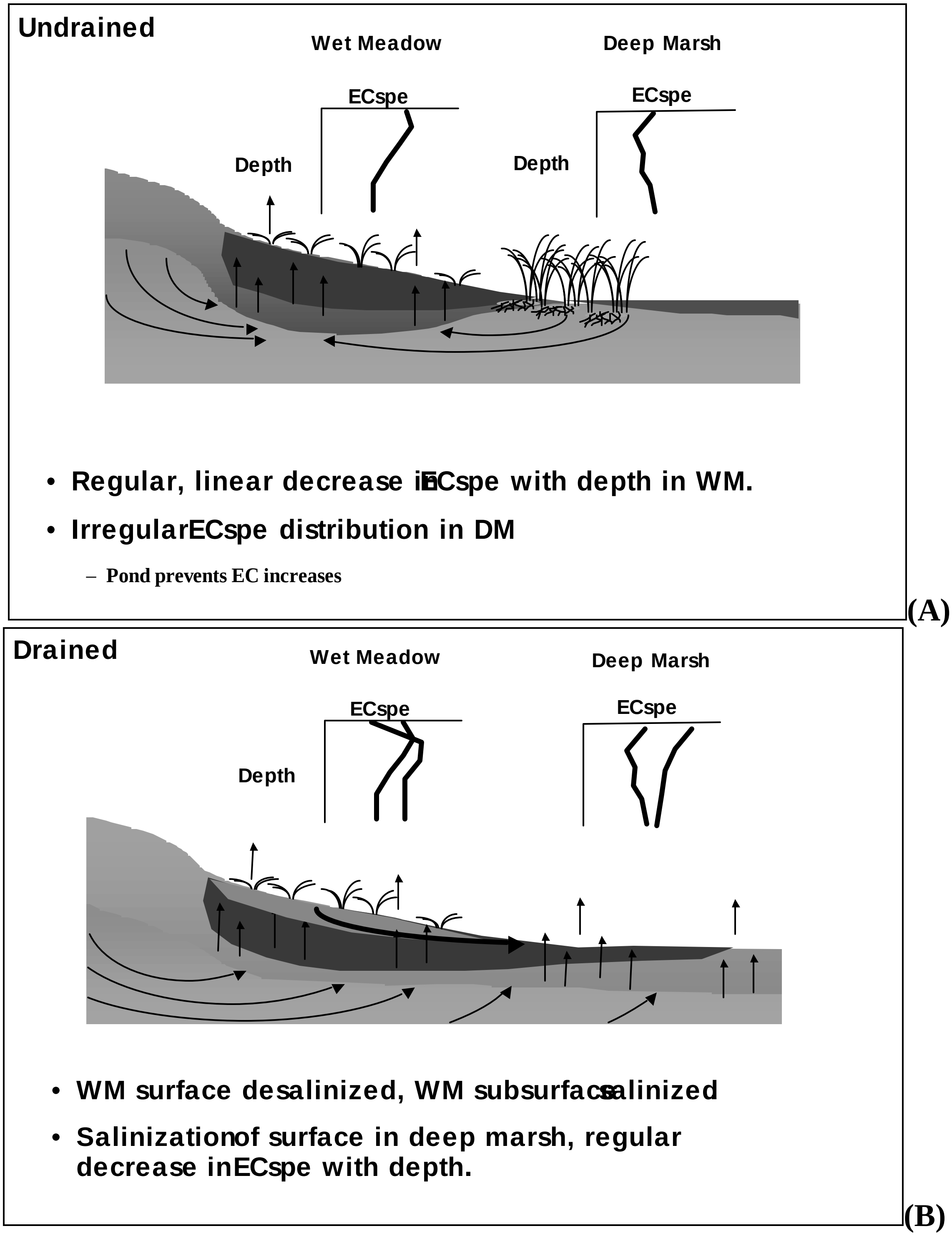


Figure 13. Induced soil salinization associated with drainage of semipermanent wetlands based on an examination of 5 paired undrained/drained wetlands (Arndt and Richardson, 1993). (A) Under the natural condition, salinization is edge-focused (see Section 1.1.4.4). The presence of surface water in the wetland basin minimizes accumulation of salts in the surface soil of the wetland. (B) After drainage, salinity moves from the edge to the pond interior and from the subsoil to the soil surface. The drainage ditch itself becomes the focus of salinization.

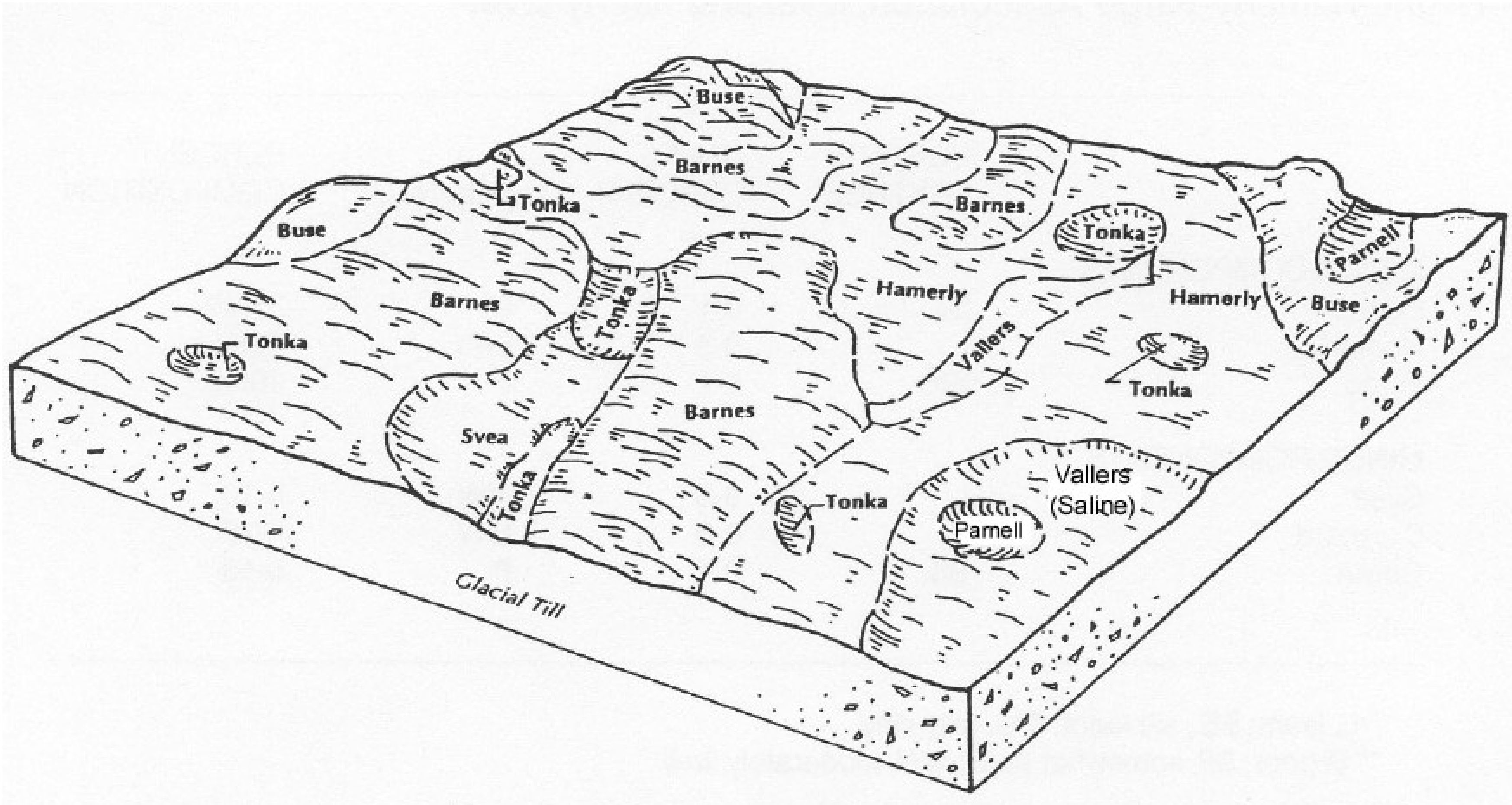
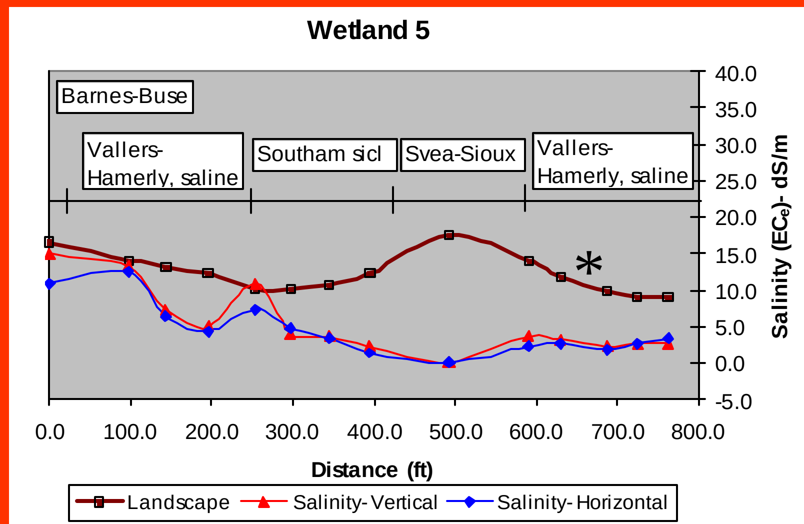
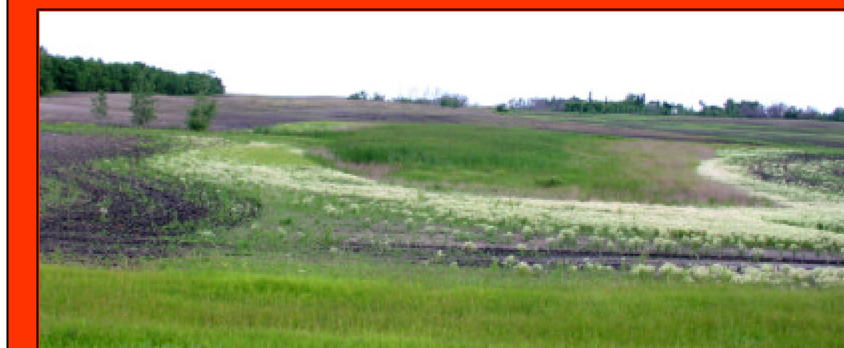
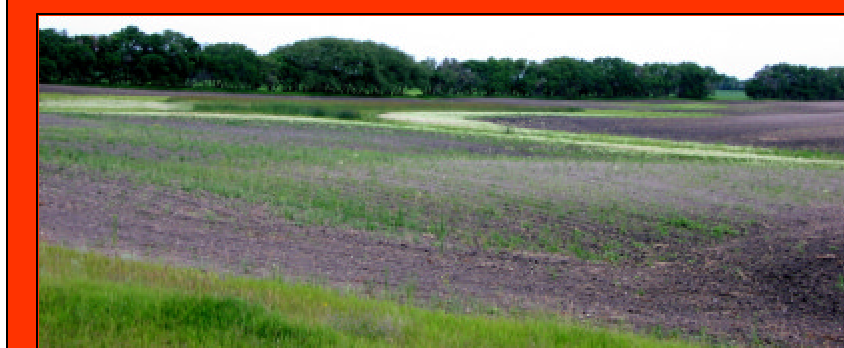


Figure 14. Generalized geomorphic settings of the major soils in the Barnes-Svea-Hamerly (ND046), Svea-Buse-Hamerly (ND043), and Hamerly-Tonka-Svea (ND040) STATSGO Soil Associations. The dominant wetland soils are Parnell and Tonka series in depressions, and Vallers soils on the periphery of the depressions. Hamerly soils are also on the periphery of depressions, but Hamerly soils are better drained than Vallers soils. Both Vallers and Hamerly soils can be saline. The Parnell depression surrounded by the Vallers (Saline) soil has a similar setting to that of a Southam soil. The major difference between the three associations is the percentage and distribution of the major soils, not their geomorphic settings. Figure modified from Soil Survey Staff, 1998.

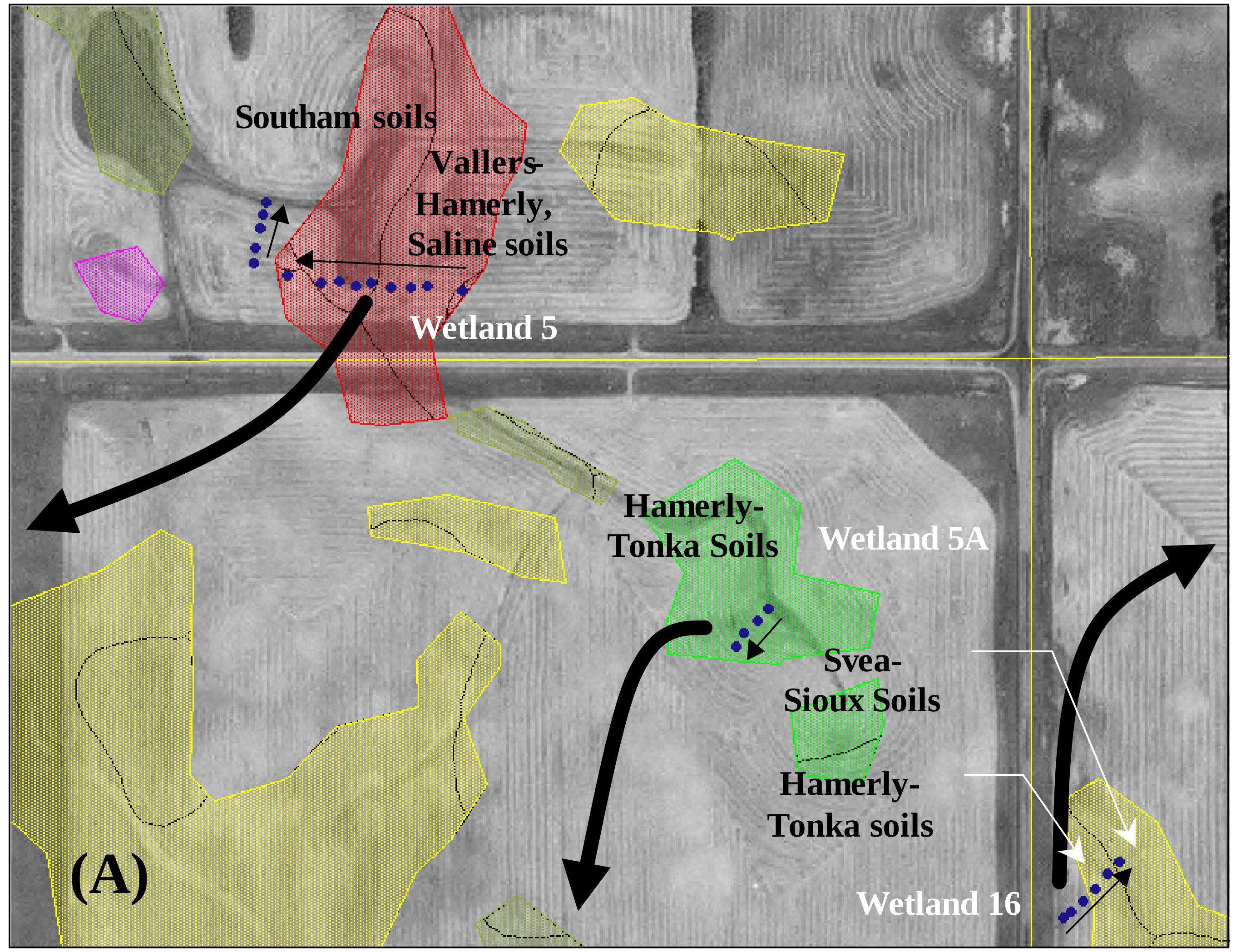
Figure 15. Selected Field Salinity Data 1

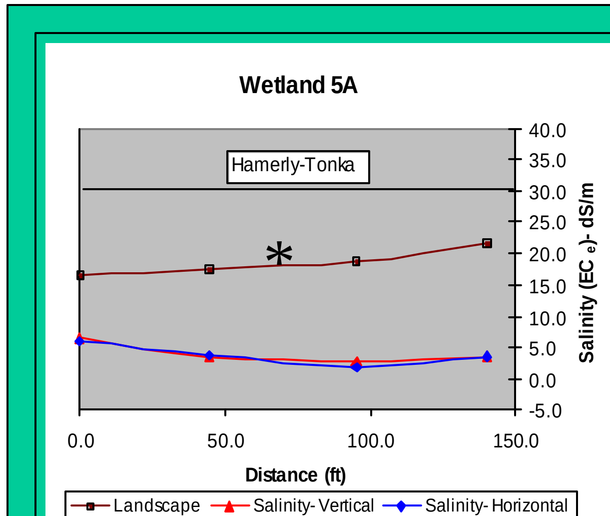




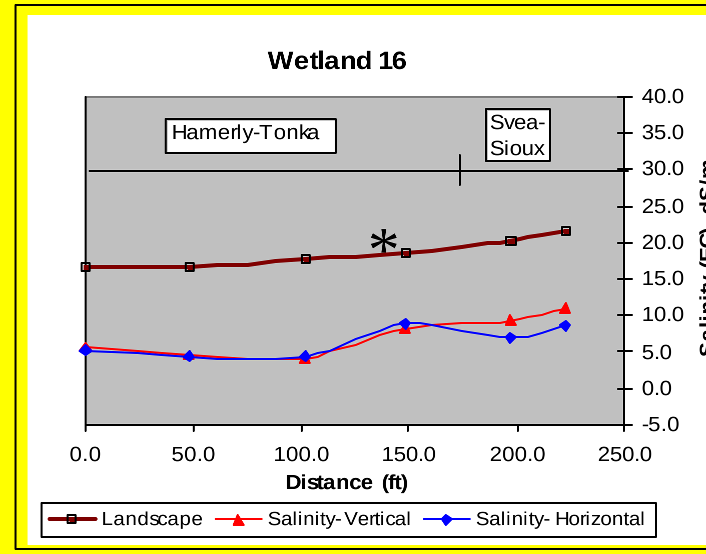


(B)





(C)



(D)

(A). Segment of Arcview GIS overlay showing transects and soil distributions. Several drained wetlands representative of typical soil conditions were present in this area. Arrows adjacent to transect points shows the direction taken during EM-38 sampling.

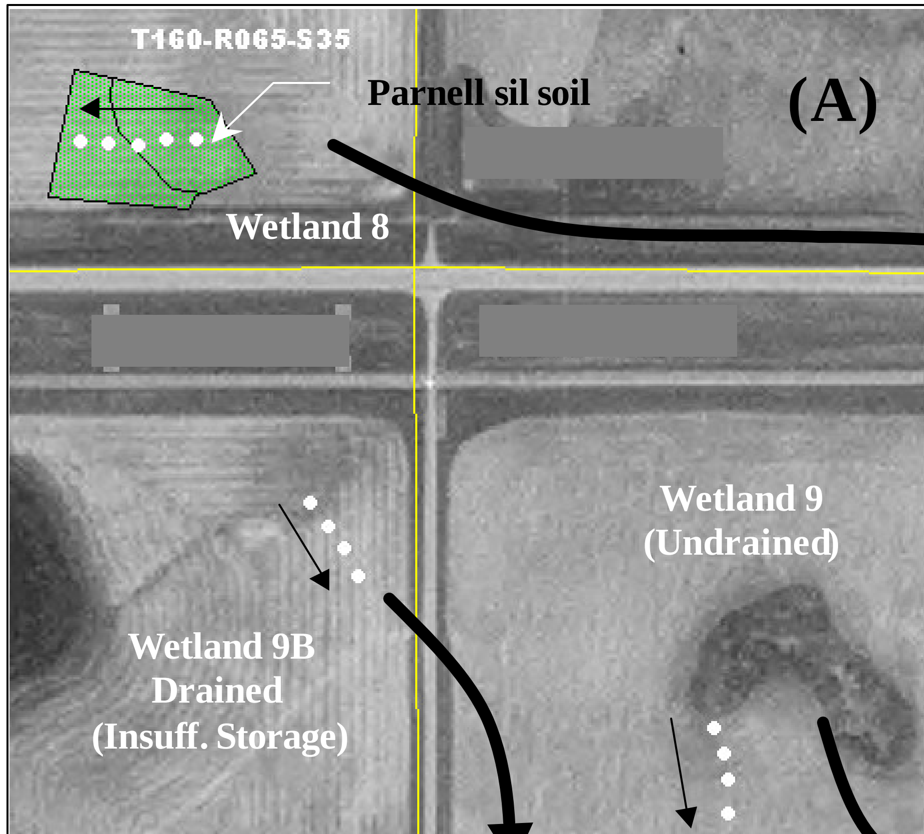
(B). Wetland 6 contains two saline/potentially saline soils, The Vallers-Hamerly (saline) shows high levels of surface and subsoil salts. The Southam soil similarly shows salinization within the imperfectly drained wetland. The typical landscape photos show that the grower was avoiding the wet Southam area. During drier periods this area may be farmed. However, soil salinity will would likely affect crop yields.

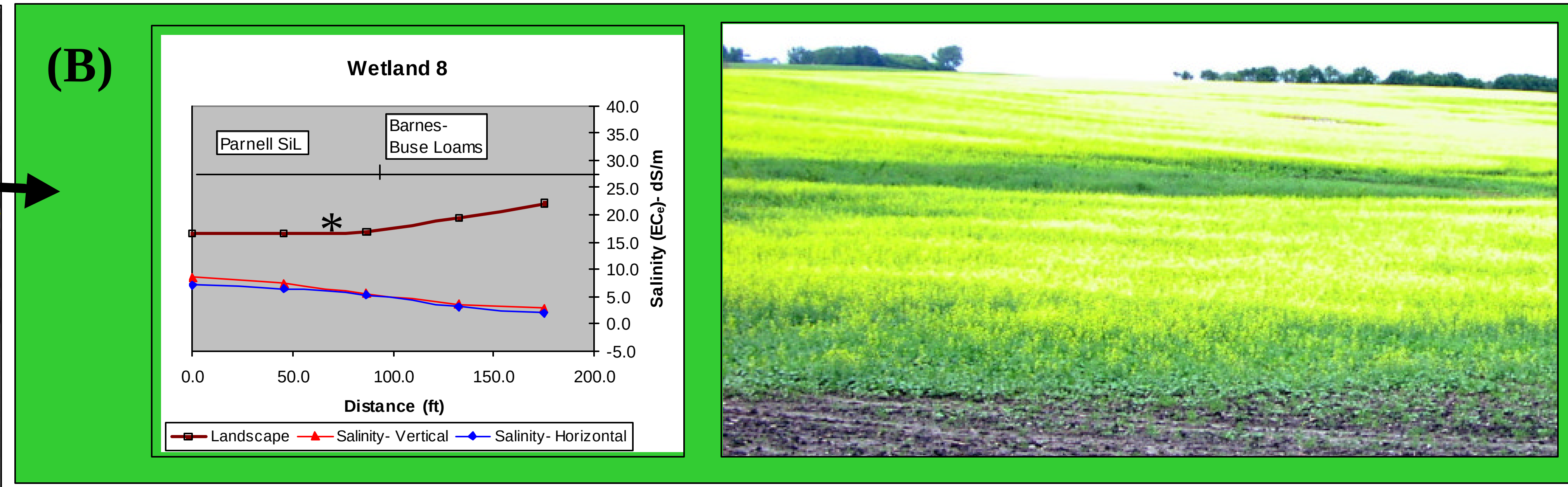
STATSGO Map Unit ND043

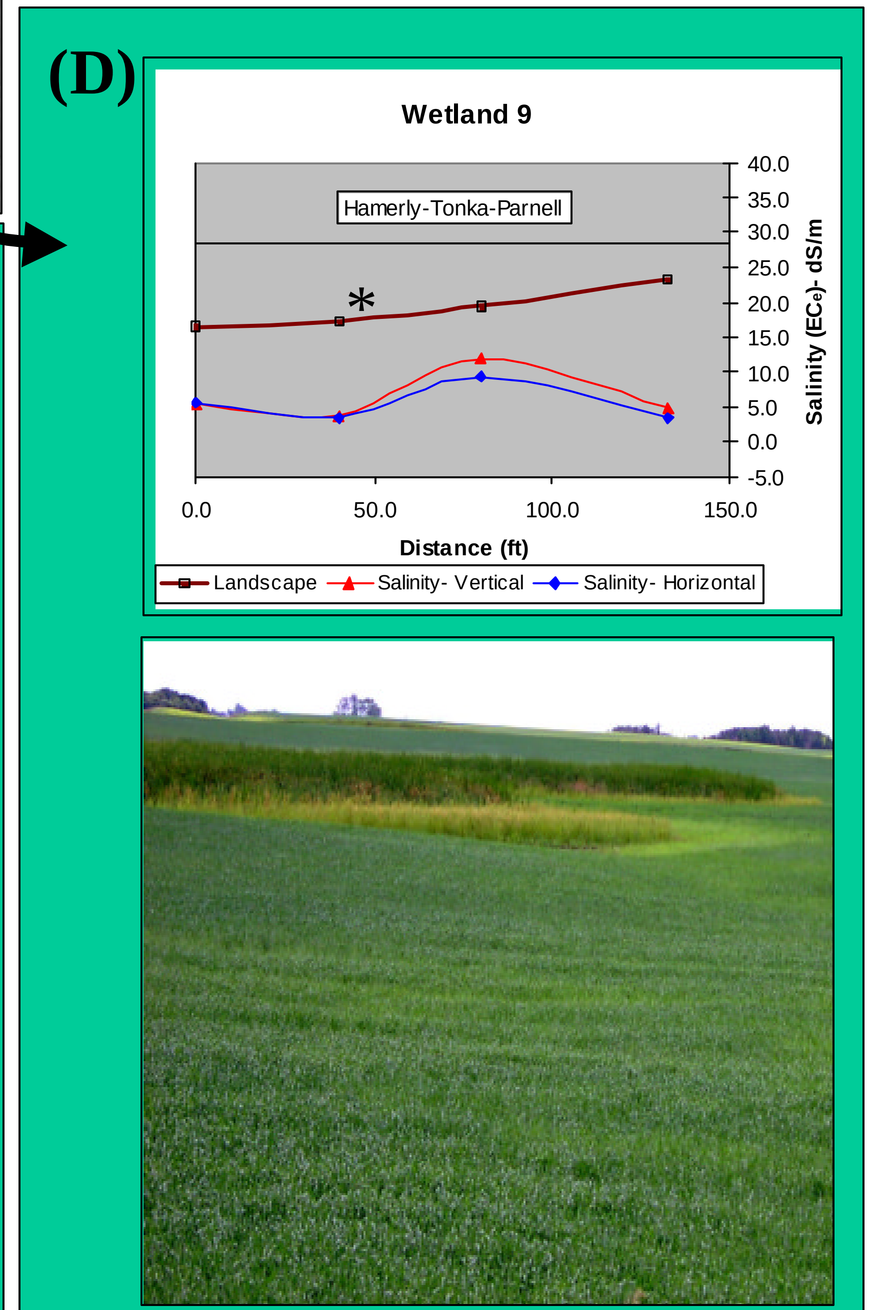
* - Relative landscape elevations (feet) are provided for reference but have not been benchmarked.

(C). Drained wetland in a Hamerly-Tonka Map Unit. The minor increase in salinity in the drained pond interior is likely due to mobilization of salts from the edge to the interior and possibly mobilization of subsoil salt to the surface. Salts are limited in distribution throughout the area. Restoration of this type of wetland would not pose significant salinization problems.

(D) Similar setting as in (C) but with slightly more soil salinity associated with the drained wetland edge. This wetland was rated as having "Low" Buffer Salinity Hazard indicating the presence of >5-25% saline soils within the 200-foot wetland buffer.







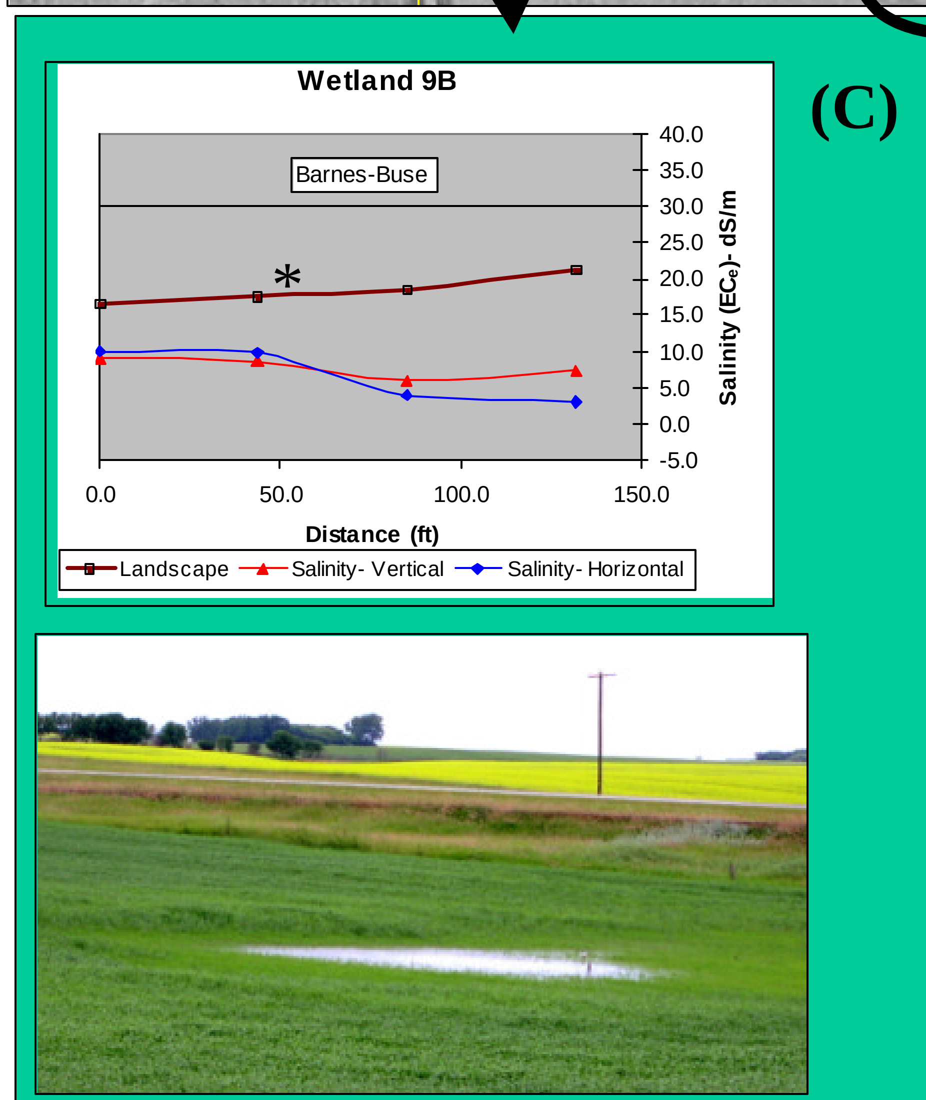


Figure 16. Selected Field Salinity Data 2

(A). Segment of GIS overlay showing transect and soil distribution. Area investigated had good examples of an intact wetland (Wetland 9) and a drained wetland of insufficient storage volume to be considered in restoration (Wetland 9B). EM-38 transects were run for both. Arrows next to transect points show the direction taken during EM-38 sampling.

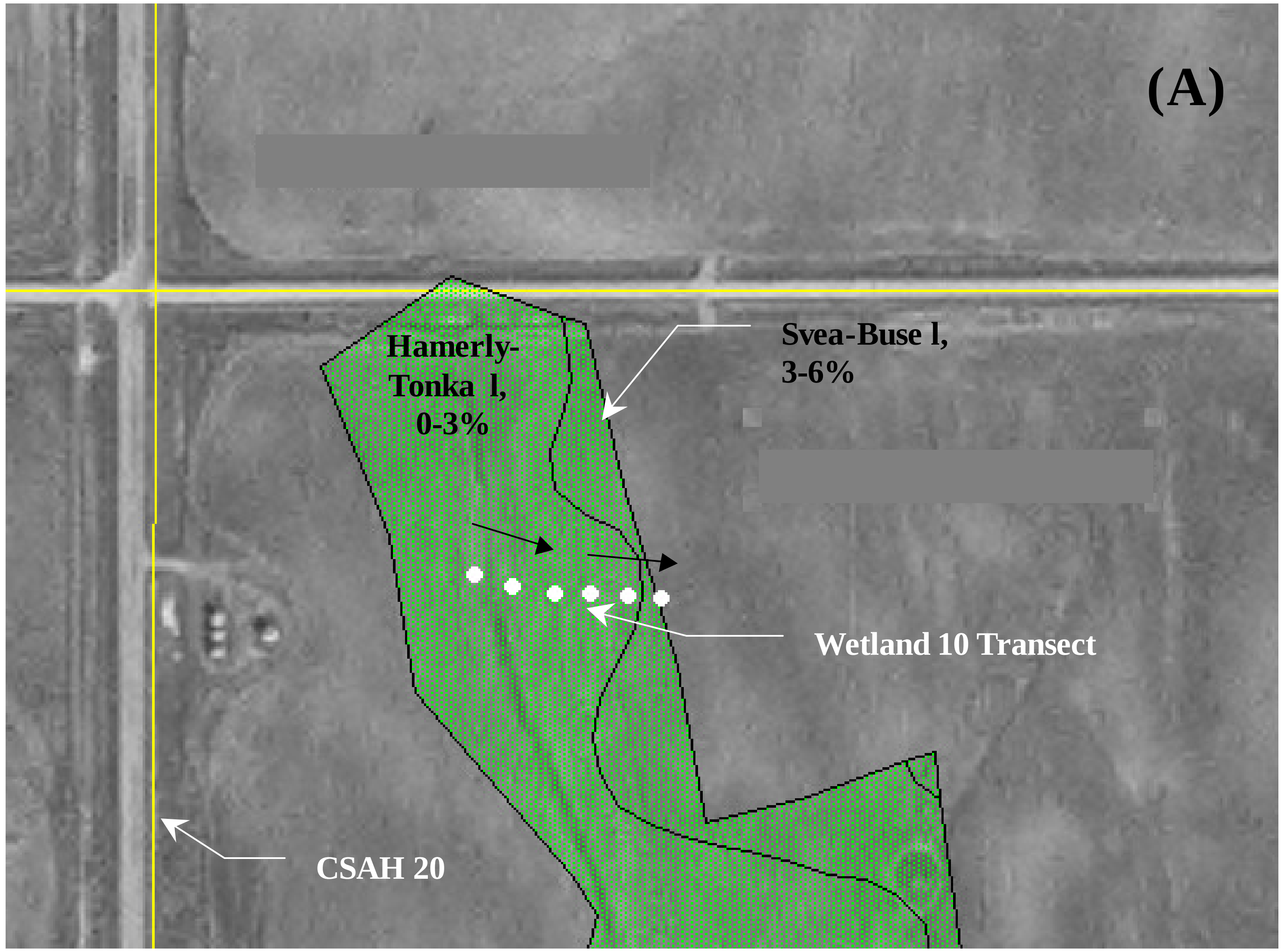
(B) Salinity within the wetland is likely the result of mobilization of salts from the subsoil to the pond surface and from the edge to the interior over time. The Edge soils (Barnes-Buse loams) are non-saline. Restoration of this wetland would not provide significant salinization hazards.

(C) Drained wetland of insufficient volume to be considered. Wetland is a probable Tonka inclusion in a Barnes-Buse soil Map Unit. Salinity in the drained wetland is likely due to movement of subsoil salts to the surface and from the edge to the wetland interior. Wetland is typical of Tonka inclusions in upland map units.

(D) Intact wetland dominated by Parnell soils in the pond interior and Hamerly soils at the periphery. Note the distinctive salinization of the edge soils. Edge soil salinization is missing or indistinct in the other drained wetlands.

STATSGO UNIT ND028

* - Relative landscape elevations (feet) are provided for reference but have not been benchmarked.



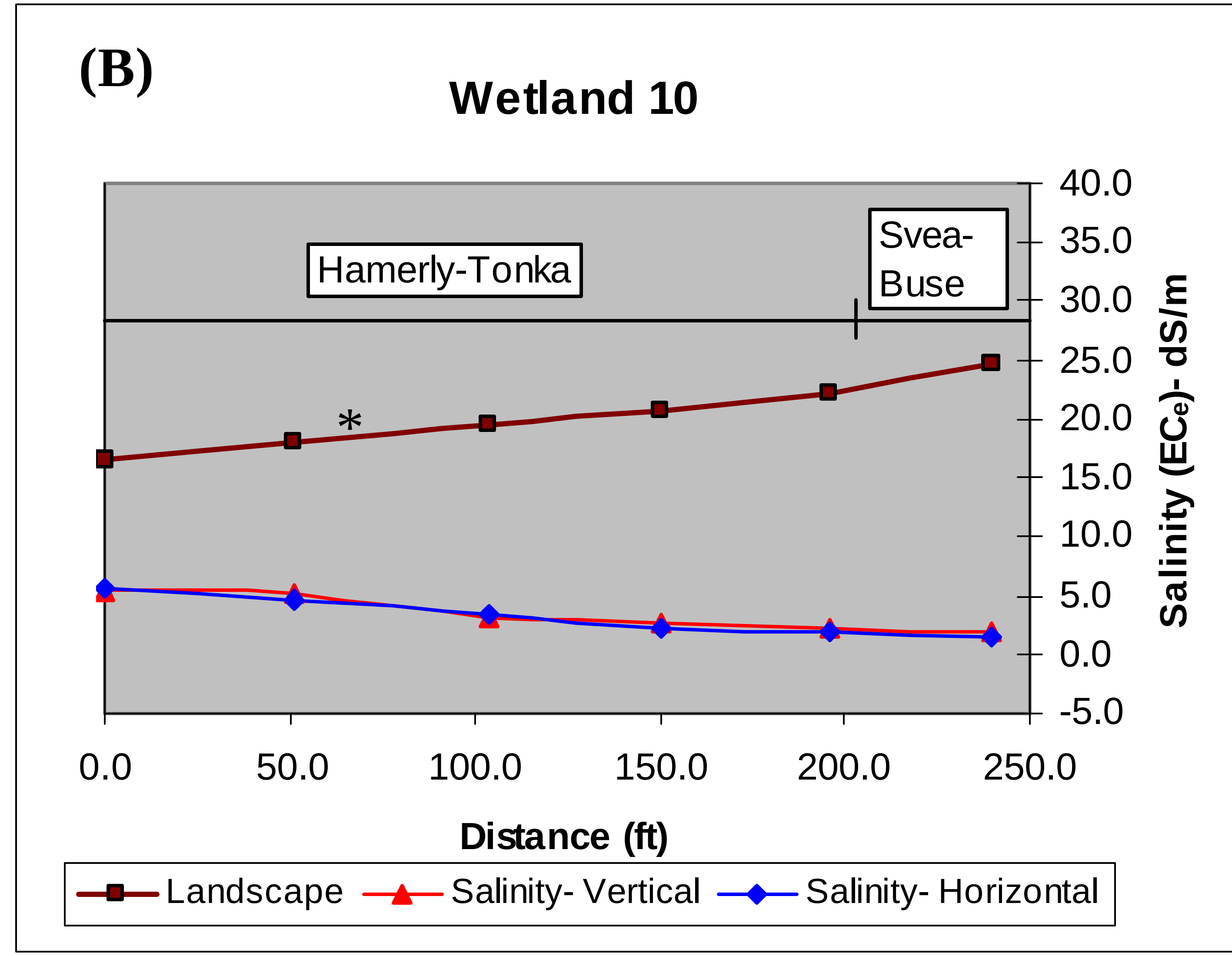


Figure 17. Selected Field Salinity Data 3

(A). Segment of GIS overlay showing transect and soil distribution. Note presence of non-saline soils (Hamerly-Tonka) in drained wetland.
(B) Salinity within the wetland is likely the result of mobilization of salts from the subsoil and edge to the pond surface over time. However, salinization is minimal and restoration should not result in significant salinization problems within the wetland edge or with buffer soils.
(C) Landscape shot. This particular wetland is fairly large and would result in a significant storage gain if restored. Several Hamerly-Tonka wetlands are drained component wetlands within this ditch system.

* - Relative landscape elevations (feet) are provided for reference but have not been benchmarked.

STATSGO Map Unit ND040

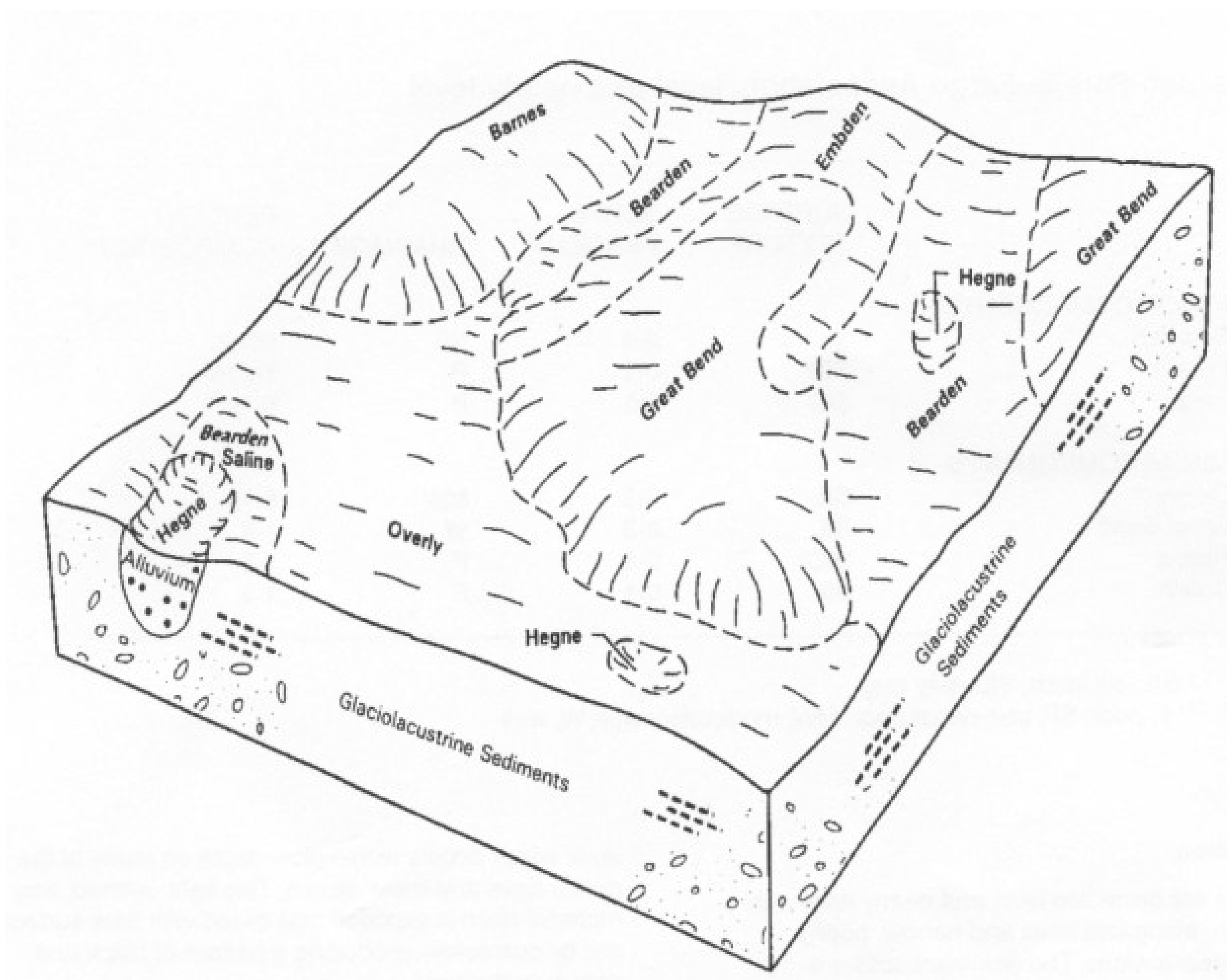
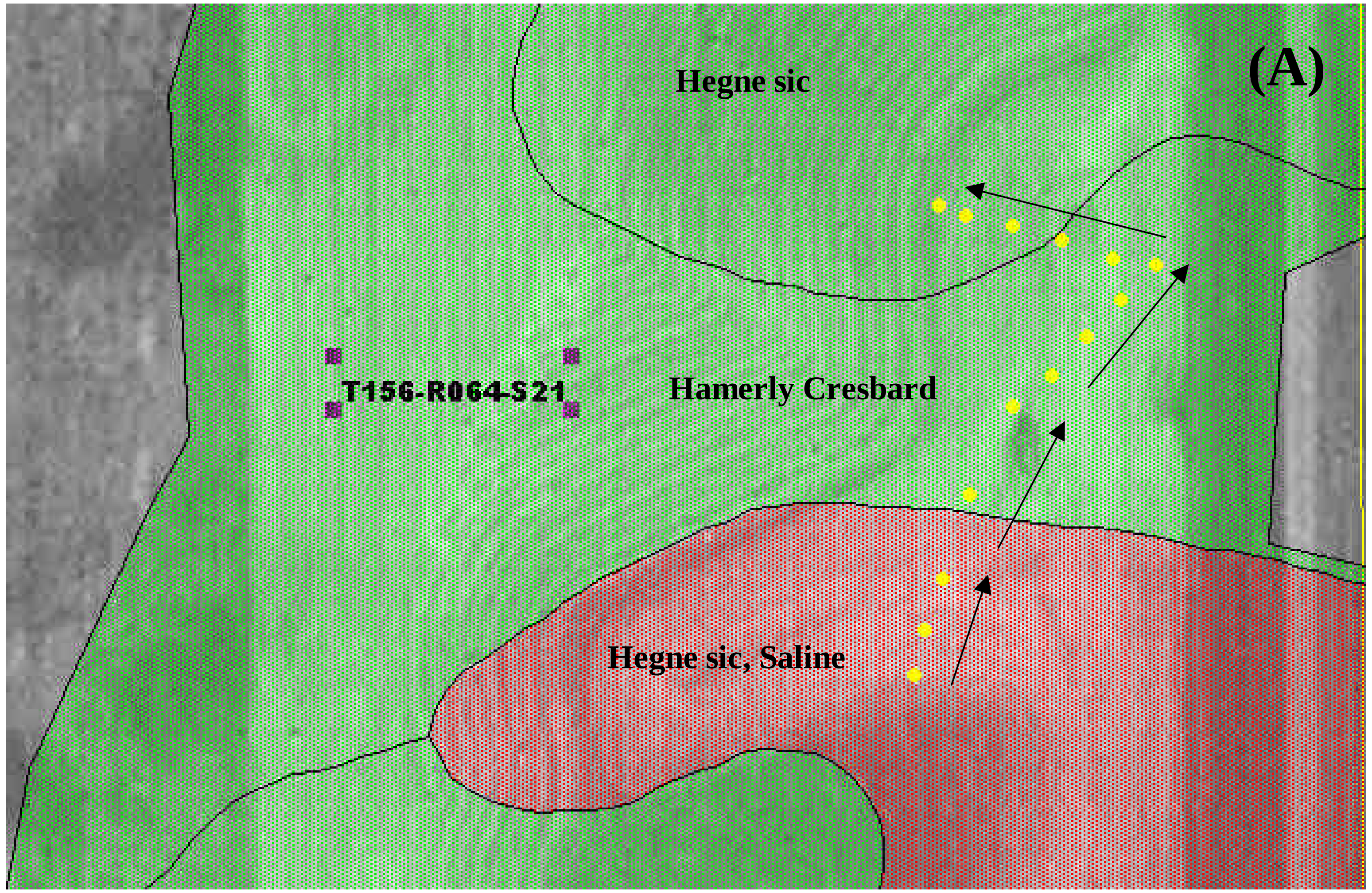
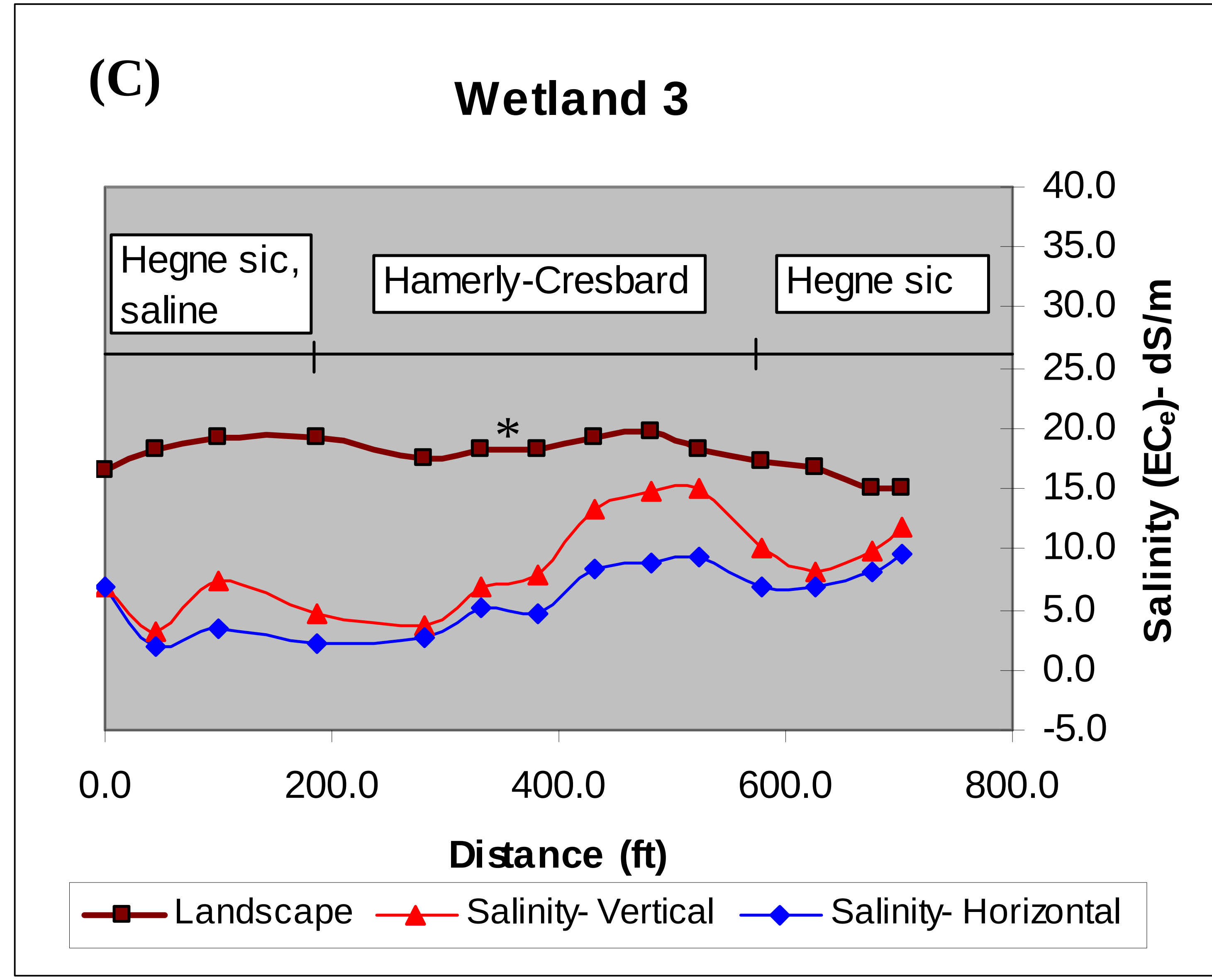


Figure 18. Generalized geomorphic setting of the major soils in the Bearden-Great Bend-Overly Association (ND005). The dominant soil parent material is glacio-lacustrine sediments punctuated by occasional till outliers. Hegne soils are the dominant wetland soils and are frequently ringed by Bearden, Overly, and Bearden (saline) soils. A saline variant of Hegne soils is also recognized. Hegne soils are primarily discharge type soils. Figure modified from Soil Survey Staff, 1998.

Figure 19. Selected Field Salinity Data 4





(A) Transect in drained wetland complex characteristics of lacustrine /till area.
(B) Beginning of transect at edge of water in Hegne Saline map unit
(C) Salinity fairly high in transect. High salinity around 500 feet is due to edge effect accumulation of salts in drained Hegne map unit.
(D) Increase in salts at 800 feet (see (C)) is due to edge accumulation of salts near of ditch where last EM-38 EC readings were taken.

A fair amount of salinity is present within this transect. Restoration of the wetlands in the immediate vicinity may result in some noticeable translocation of salts that would be perceived as a problem. This wetland was placed in the Low Salinity hazard class because of the presence of >5-25% of Hegne , saline phase soils.

STATSGO Map Unit ND041

* - Relative landscape elevations (feet) are provided for reference but have not been benchmarked.

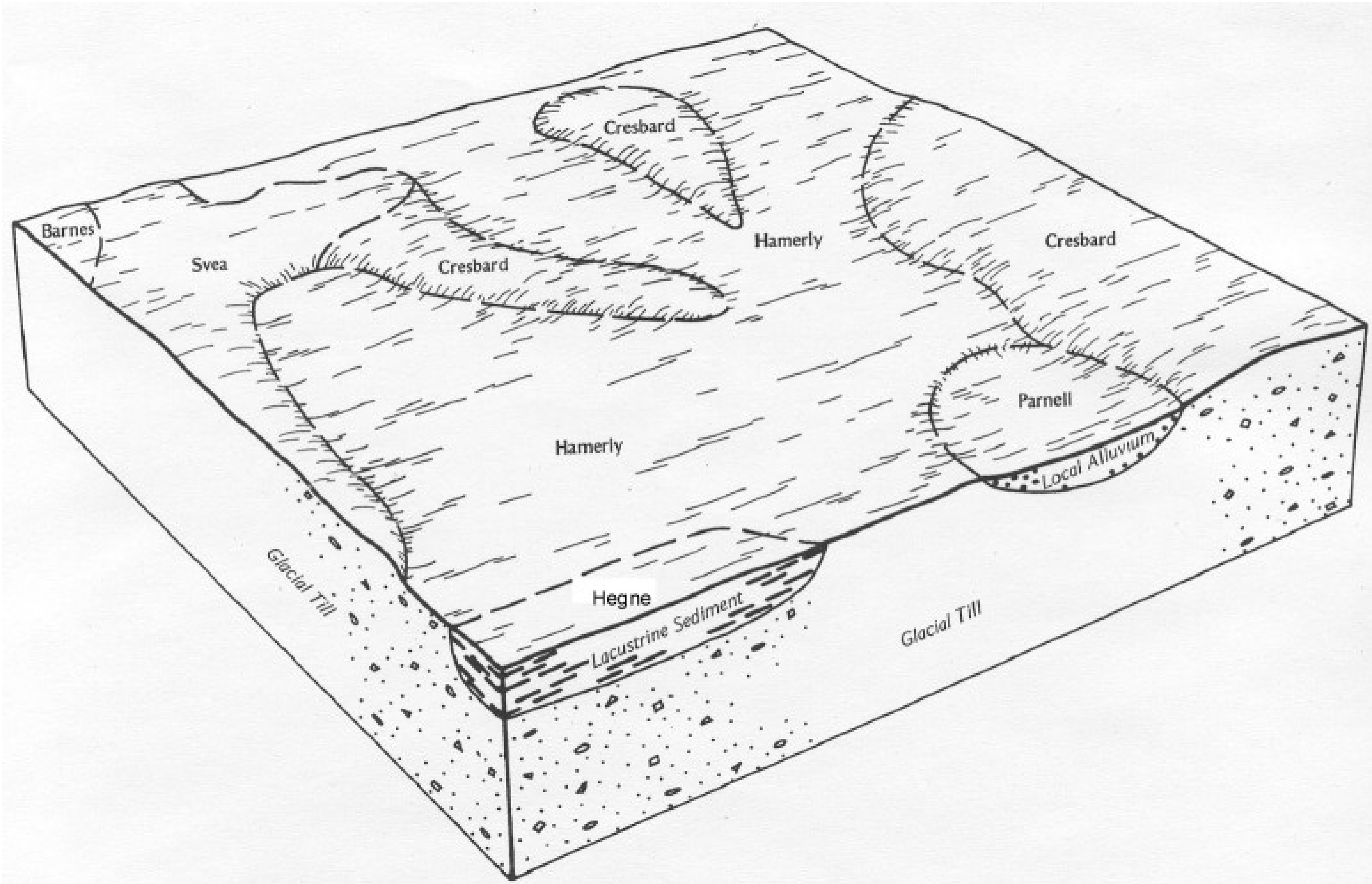


Figure 20. Generalized geomorphic setting of the major soils in the The Hamerly-Cresbard-Svea (ND051) Soil Association. The dominant soil parent material is till with occasional lacustrine inclusions. Parnell and Hegne series are the dominant wetland soils and are frequently ringed by Hamerly soils. Hamerly and Hegne soils both have saline phases found in this association. Figure modified from Bigler and Liudahl, 1986.

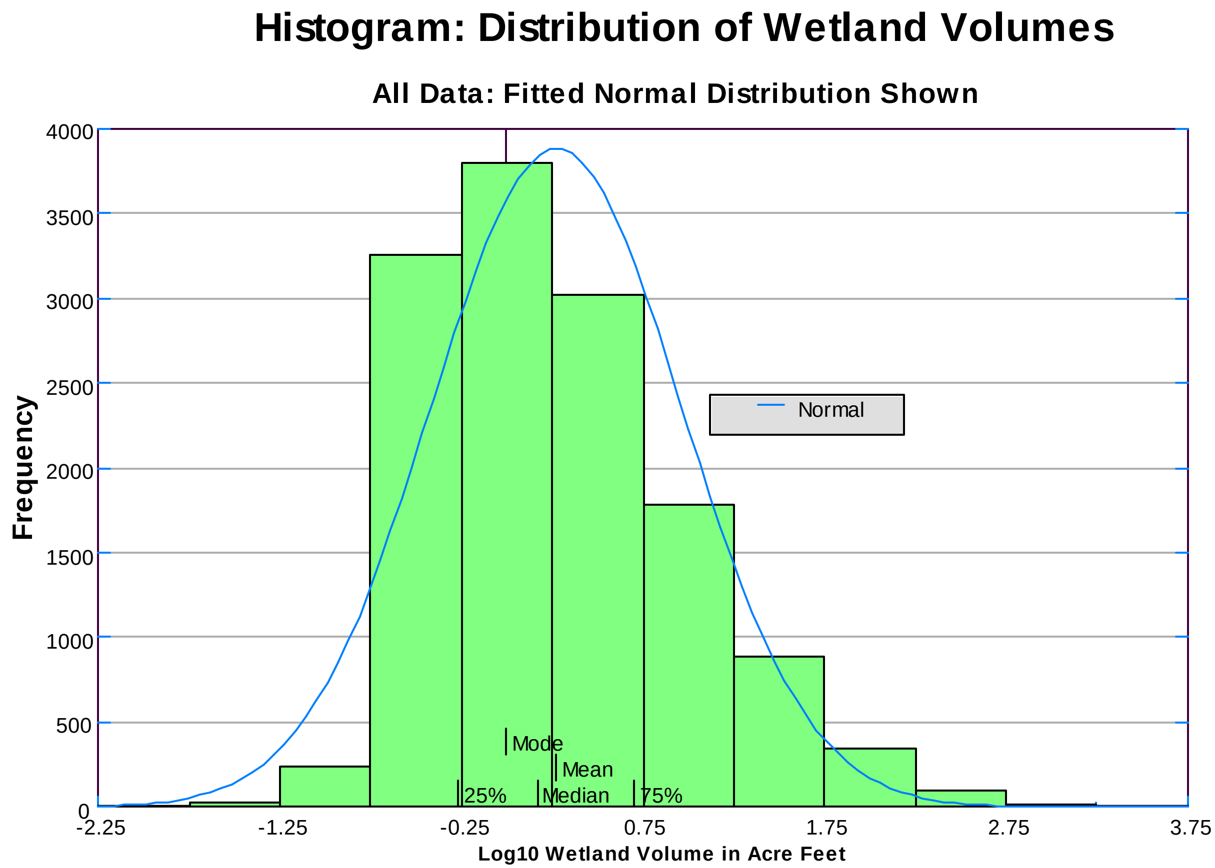
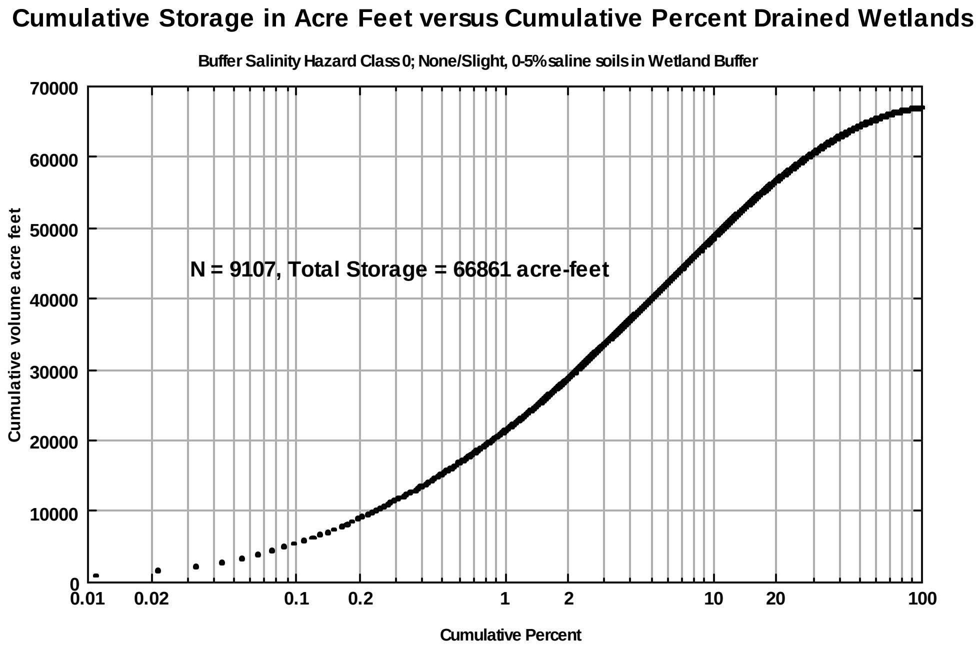
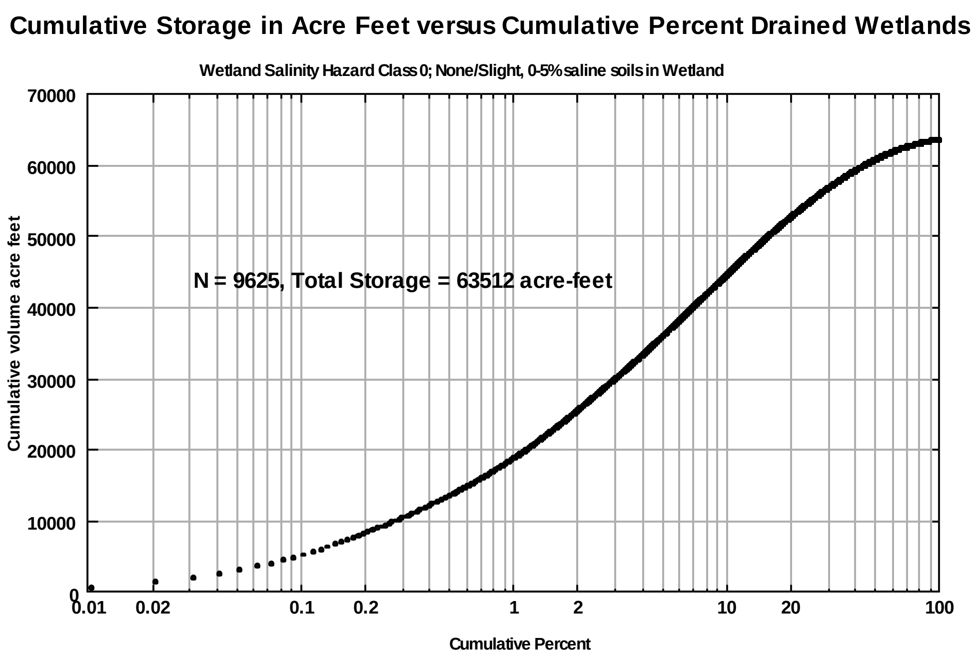


Figure 21. Histogram showing the distribution of log-transformed wetland storage values (acre-feet). Implicit in this distribution is that most of the storage associated with the wetlands is in the larger wetlands due to the overwhelming majority wetlands being small and of limited storage. The dataset used included all storage data values (13,457), including those for Benson and Pierce counties for which a salinity hazard analysis was not performed.



(A)



(B)

Figure 22. Cumulative storage in acre-feet plotted as a function of cumulative percent of wetlands in (A) Buffer Salinity Hazard Class 0, None/Slight and (B) Wetland Salinity Hazard Class 0, None/Slight. Wetlands were ranked in descending order from wetlands with the largest storage volume to wetlands with the lowest storage volumes. The data show that the greatest amount of wetland storage is associated with larger wetlands in the None/Slight hazard class for both wetlands and wetland buffer hazard classes. Just under 50,000 acre feet of storage is associated with the largest 10% of the wetlands in the Buffer Salinity Hazard Class. Approximately 45,000 acre feet of storage is associated with the largest 10% of the wetlands in the Wetland Salinity Hazard Class.

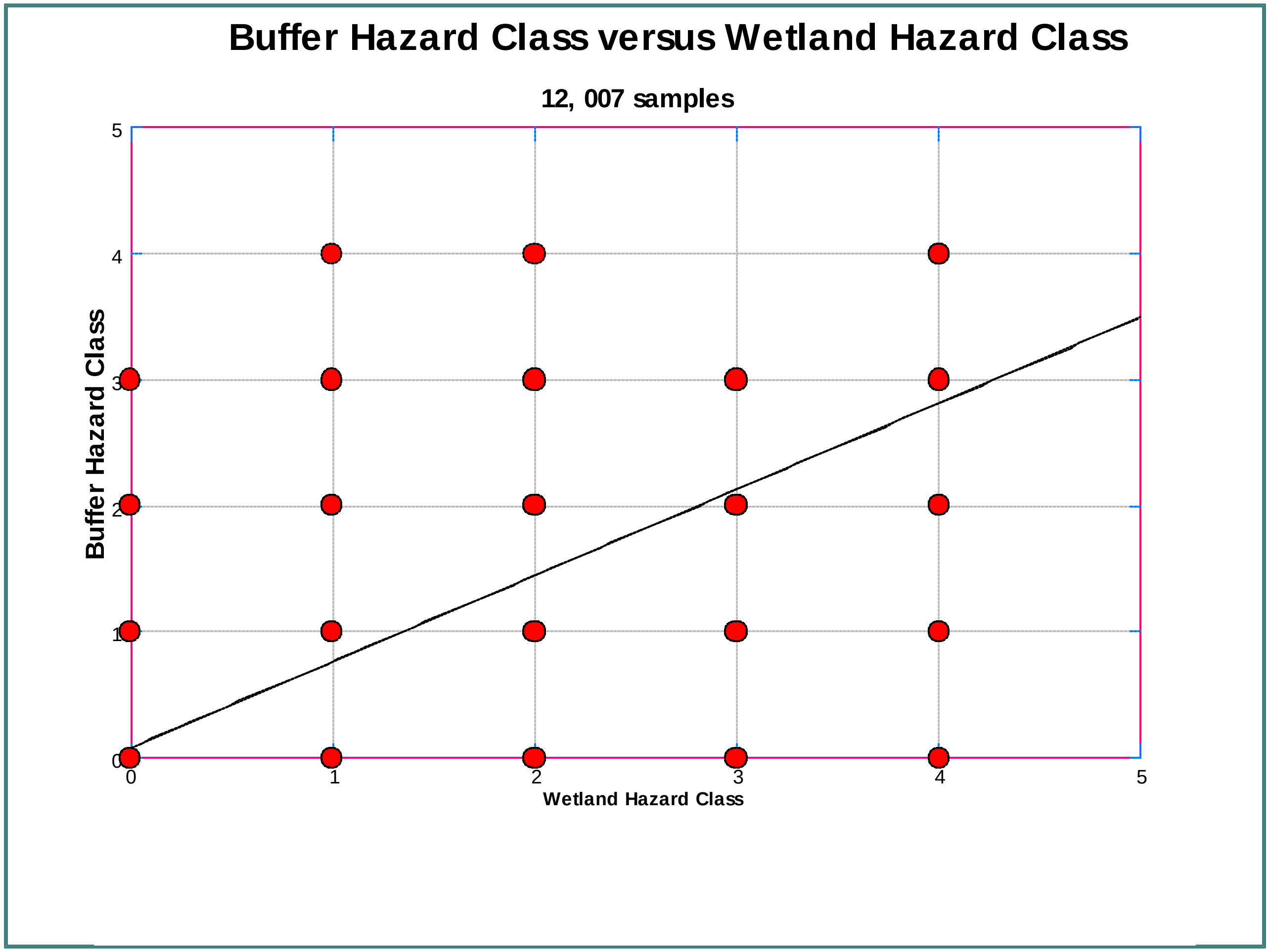


Figure 23. Plot of Buffer Salinity Hazard Class versus Wetland Salinity Hazard Class along with a best fit line. 0=None/Slight, 1=Low, 2=Moderate, 3=High, and 4=Severe. The data show that there is a close relationship between Buffer Salinity Hazard Class and Wetland Salinity Hazard Class (Pearson Correlation = 0.88). Higher salinity hazard classes are associated slightly more with wetlands than with buffers, likely due to the larger acreage associated with the buffers of smaller wetlands incorporating more acreage of non-saline uplands. Data used are exclusive of candidate wetlands in Benson and Pierce counties for which a salinization hazard analysis was not performed.

Soil Salinization Hazards Associated with Devils Lake Flood Damage Reduction Alternatives:

Upper Basin Storage

Report Tables

Table 1. Selected data for all saline, somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Cavalier	ND019	1	Southam Clay	1	61	Southam	Fine, Montmorillonitic (Calcareous), Frigid Cumulic Vertic Endoaquolls	VP	0-27	2-8	0-2
									27-44	2-8	0-2
									44-60	2-8	0-2
				2	23	Parnell	Fine, Montmorillonitic, Frigid Vertic Argiaquolls	VP	0-11	0-0	0-0
									11-32	0-0	0-0
									32-60	0-0	0-0
				3	11	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-8	4-16	0-3
									8-20	4-16	0-5
									20-60	4-16	0-10
Cavalier	ND019	17	Vallers-Hamerly Loams, Saline, 0 To 3 Percent Slopes	1	58	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-11	4-16	0-3
									11-23	4-16	0-5
									23-60	4-16	0-10
				2	29	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-8	4-16	0-0
									8-17	4-16	0-2
									17-60	4-16	0-4
Cavalier	ND019	2	Vallers, Saline-Parnell Complex	1	41	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-11	4-16	0-3
									11-23	4-16	0-5
									23-60	4-16	0-10
				2	41	Parnell	Fine, Montmorillonitic, Frigid Vertic Argiaquolls	VP	0-24	0-0	0-0
									24-43	0-0	0-0
									43-60	0-0	0-0
Cavalier	ND019	22	Miranda-Cavour Loams	1	48	Miranda	Fine-Loamy, Mixed, Frigid Leptic Natriborolls	SP	0-8	0-0	0-7
									8-15	2-8	10-25
									15-60	4-16	10-40
Cavalier	ND019	39	Hegne Silty Clay, Saline	1	71	Hegne	Fine, Montmorillonitic, Frigid Typic Calciaquerts	P	0-11	4-16	0-2
								P	11-36	4-16	0-5
								P	36-60	4-16	0-10
				2	25	Hegne, Non	Fine, Montmorillonitic, Frigid Typic Calciaquerts	P	0-11	0-0	0-0
									11-19	0-4	0-2
									19-36	0-4	0-2
									36-60	0-4	0-2
Cavalier	ND019	4	Easby Clay Loam	1	85	Easby	Fine-Loamy, Frigid Typic Calciaquolls	P	0-7	16-32	-
									7-60	8-32	-
Cavalier	ND019	5	Manfred-Vallers, Saline, Silty Clay Loams	1	53	Manfred	Fine-Loamy, Mixed, Frigid Typic Natraquolls	VP	0-7	2-4	1-5
									7-60	2-16	5-25
				2	34	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-11	4-16	0-3
									11-23	4-16	0-5
									23-60	4-16	0-10
Pierce	ND069	100	Stirum Soils, 0 To 3 Percent Slopes	1	85	Stirum	Typic Natraquolls, Coarse-Loamy, Mixed, Frigid	P	0-5	2-8	0-2
									5-14	2-16	5-15
									14-60	2-16	5-10
Pierce	ND069	104	Aquolls	1	85	Aquolls	Cumulic Vertic Endoaquolls, Fine, Montmorillonitic (Calcareous), Frigid	VP	0-16	2-8	0-2

Table 1. Selected data for all saline, somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
									16-40	2-8	0-2
									40-60	2-8	0-2
Pierce	ND069	15	Bearden Silty Clay Loam, Saline	1	80	Bearden	Aeric Calciaquolls, Fine-Silty, Frigid	SP	0-8	4-16	0-2
									8-14	4-16	0-3
									14-60	4-16	0-10
Pierce	ND069	58	Vallers Loam, Saline	1	80	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-8	4-16	0-3
									8-30	4-16	0-5
									30-60	4-16	0-10
Pierce	ND069	72	Glyndon Silt Loam, Saline, 0 To 3 Percent Slopes	1	88	Glyndon	Aeric Calciaquolls, Coarse-Silty, Frigid	MW,SP	0-7	4-16	0-0
									7-33	4-16	0-0
									33-60	4-16	0-0
Pierce	ND069	75	Borup Silt Loam, Saline	1	85	Borup	Typic Calciaquolls, Coarse-Silty, Frigid	P	0-11	4-16	0-0
									11-29	4-16	0-0
									29-60	4-16	0-0
Pierce	ND069	96	Aquents	1	85	Aquents	Vertic Fluvaquents, Fine, Montmorillonitic (Calcareous), Frigid	P	0-2	4-16	0-2
									2-60	4-16	0-5
Ramsey	ND071	131	Lowe Silty Clay Loam, Saline, 0-1% slopes	1	79	Lowe	Typic Calciaquolls, Fine-loamy, mixed		0-7	2-8	0-2
									7-34	4-16	2-4
									34-80	4-16	2-8
Ramsey	ND071	196	Bearden-Colvin Silt Loams, Saline, 0-1% slopes	1	25	Bearden	Aeric Calciaquolls, Fine-Silty, Frigid	SP	0-7	4-16	0-2
									7-22	4-16	0-3
									22-60	4-16	0-10
				2	26	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	p	0-11	4-16	0-2
									11-60	4-16	0-10
				3	17	Bearden	Aeric Calciaquolls, Fine-Silty, Frigid	SP	0-7	0-4	0-2
									7-12	0-4	0-3
									7-22	0-4	0-10
									22-60	0-8	0-10
				4	20	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	p	0-11	0-4	0-2
									11-43	0-4	0-3
									43-60	0-4	0-10
Ramsey	ND071	21	Vallers-Hamerly Loams, Saline, 0 To 3 Percent Slopes	1	48	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-8	4-16	0-3
									8-20	4-16	0-5
									20-60	4-16	0-10
				2	33	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-15	4-16	0-0
									15-28	4-16	0-2
									28-60	4-16	0-4
Ramsey	ND071	286	Aberdeen-Bearden Complex, 0-1% slopes	2	30	Bearden	Aeric Calciaquolls, Fine-Silty, Frigid	SP	0-7	4-16	0-2
									7-22	4-16	0-3
									22-60	4-16	0-10

Table 1. Selected data for all saline, somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Ramsey	ND071	38	Colvin Silty Clay Loam, Saline	1	89	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	P	0-11	4-16	0-2
									11-60	4-16	0-10
Ramsey	ND071	4	Southam Silty Clay Loam	1	75	Southam	Cumulic Vertic Endoaquolls, Fine, Montmorillonitic (Calcareous), Frigid	VP	0-16	2-8	0-2
									16-40	2-8	0-2
									40-60	2-8	0-2
Ramsey	ND071	40	Colvin-Aberdeen Silty Clay Loams	1	43	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	P	0-7	4-16	0-2
									7-60	4-16	0-10
Ramsey	ND071	44	Hegne Silty Clay, Saline	1	70	Hegne	Typic Calciaquerts, Fine, Montmorillonitic, Frigid	P	0-15	4-16	-
									15-21	4-16	-
									21-60	4-16	-
Ramsey	ND071	65	Ojata Clay Loam	1	95	Ojata	Typic Calciaquolls, Fine-Silty, Frigid	P	0-9	16-32	-
									9-60	8-32	-
Ramsey	ND071	70	Lallie Clay Loam	1	80	Lallie	Vertic Fluvaquents, Fine, Montmorillonitic (Calcareous), Frigid	P	0-5	0-8	0-2
									5-60	0-8	0-2
Ramsey	ND071	75	Lallie Clay Loam, Saline	1	97	Lallie	Vertic Fluvaquents, Fine, Montmorillonitic (Calcareous), Frigid	P	0-5	4-16	0-2
									5-60	4-16	0-5
Ramsey	ND071	81B	Mauvais Loam, 0 To 6 Percent Slopes	1	83	Mauvais	Aeric Endoaquents, Fine-Loamy, Mixed (Calcareous), Frigid	SP	0-2	0-8	0-0
									2-60	2-8	0-0
Rolette	ND079	1300	Miranda-Cavour Loams	1	65	Miranda	Fine-Loamy, Mixed, Frigid Leptic Natriborolls	SP	0-2	0-0	0-7
									2-8	2-8	10-25
									8-60	4-16	10-40
Rolette	ND079	169	Bearden Silt Loam, Saline, 0 To 3 Percent Slopes	1	67	Bearden	Fine-Silty, Frigid Aeric Calciaquolls	SP	0-11	4-16	0-2
									11-31	4-16	0-3
									31-60	4-16	0-10
Rolette	ND079	1709	Southam Silt Loam	1	82	Southam	Fine, Montmorillonitic (Calcareous), Frigid Cumulic Vertic Endoaquolls	VP	0-6	2-8	0-2
									6-26	2-8	0-2
									26-60	2-8	0-2
Rolette	ND079	1727	Stirum Fine Sandy Loam	1	81	Stirum	Coarse-Loamy, Mixed, Frigid Typic Natraquolls	P	0-7	2-8	0-2
									7-16	2-16	5-15
									16-60	2-16	5-10
				2	12	Lemert	Coarse-Loamy, Mixed, Frigid Leptic Natriborolls	SP	0-3	4-8	-
									49-60	0-8	-
									12-22	4-8	-
									22-49	0-8	-
									3-12	8-16	-
Rolette	ND079	1871	Vallers Loam, Saline	1	54	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-8	4-16	0-3
									8-30	4-16	0-5
									30-60	4-16	0-10
				2	32	Vallers, Nor	Fine-Loamy, Frigid Typic Calciaquolls	P	0-10	0-4	0-0
									10-23	0-4	0-5
									23-60	0-4	0-10
Rolette	ND079	452	Colvin Silt Loam, Saline	1	84	Colvin	Fine-Silty, Frigid Typic Calciaquolls	P	0-12	4-16	0-2

Table 1. Selected data for all saline, somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
									12-60	4-16	0-10
Rolette	ND079	864	Hamerly Loam, Saline, 0 To 3 Percent Slopes	1	64	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-7	4-16	0-0
									7-29	4-16	0-2
									29-60	4-16	0-4
Rolette	ND079	893	Harriet Silt Loam	1	49	Harriet	Fine, Montmorillonitic, Frigid Typic Natraquolls	P	0-2	0-2	0-0
									2-24	4-16	13-25
									24-60	4-16	5-20
Towner	ND095	1710	Southam Silty Clay Loam	1	92	Southam	Cumulic Vertic Endoaquolls, Fine, Montmorillonitic (Calcareous), Frigid	VP	0-5	2-8	0-2
									5-31	2-8	0-2
									31-60	2-8	0-2
Towner	ND095	1884	Vallers, Saline-Parnell Complex	1	27	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-8	4-16	0-3
									8-33	4-16	0-5
									33-60	4-16	0-10
				2	38	Parnell	Vertic Argiaquolls, Fine, Montmorillonitic, Frigid	VP	0-27	0-0	0-0
									27-45	0-0	0-0
									45-60	0-0	0-0
Towner	ND095	1886	Hamerly And Vallers Loams, Saline, 0 To 3 Percent Slopes	1	44	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-10	4-16	0-0
									10-30	4-16	0-2
									30-60	4-16	0-4
				2	24	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-8	4-16	0-3
									8-33	4-16	0-5
									33-60	4-16	0-10
Towner	ND095	2196	Bearden And Colvin Silt Loams, Saline	1	25	Bearden	Aeric Calciaquolls, Fine-Silty, Frigid	SP	0-7	4-16	0-2
									7-22	4-16	0-3
									22-60	4-16	0-10
				2	26	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	P	0-11	4-16	0-2
									11-60	4-16	0-10
Towner	ND095	966	Hegne Silty Clay, Saline	1	83	Hegne	Typic Calciaquerts, Fine, Montmorillonitic, Frigid	P	0-7	4-16	0-2
									7-32	4-16	0-5
									32-60	4-16	0-10
Walsh	ND099	Br	Bearden Silty Clay Loam, Saline	1	85	Bearden	Fine-Silty, Frigid Aeric Calciaquolls	SP	0-9	4-16	0-2
									9-20	4-16	0-3
									20-60	4-16	0-10
Walsh	ND099	Gm	Glyndon Silt Loam, Moderately Saline	1	85	Glyndon	Coarse-Silty, Frigid Aeric Calciaquolls	SP	0-8	4-16	0-0
									8-28	4-16	0-0
									28-60	4-16	0-0
Walsh	ND099	Hn	Hegne Silty Clay, Saline	1	90	Hegne	Fine, Montmorillonitic, Frigid Typic Calciaquerts	P	0-6	4-16	0-2
									6-31	4-16	0-5
									31-60	4-16	0-10

Table 1. Selected data for all saline, somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Walsh	ND099	Hs	Hegne Silty Clay, Strongly Saline-Alkali	1	85	Hegne	Fine, Montmorillonitic, Frigid Typic Natraquerts	P	0-6	0-0	0-2
									6-60	4-16	0-4
Walsh	ND099	La	Lamoure Soils, Moderately Saline	1	90	Lamoure	Fine-Silty, Mixed (Calcareous), Frigid Cumulic Endoaquolls	P	0-10	8-16	-
									10-23	8-16	-
									23-45	8-16	-
									45-60	8-16	-
Walsh	ND099	Lu	Ludden Silty Clay	1	85	Ludden	Fine, Montmorillonitic, Frigid Typic Endoaquerts	P	0-14	0-4	0-0
									14-21	0-4	0-2
									21-60	0-8	0-2
Walsh	ND099	Ly	Ludden And Ryan Soils	1	45	Ludden	Fine, Montmorillonitic, Frigid Typic Endoaquerts	P	0-14	0-4	0-0
									14-21	0-4	0-2
									21-60	0-8	0-2
				2	40	Ryan	Fine, Montmorillonitic, Frigid Typic Natraquerts	P	0-3	0-0	0-2
									3-60	4-16	0-4
Walsh	ND099	Mn	Manfred Soils	1	85	Manfred	Fine-Loamy, Mixed, Frigid Typic Natraquolls	VP	0-10	2-4	1-5
								VP	10-60	2-16	5-25
Walsh	ND099	Oa	Ojata Soils	1	85	Ojata	Fine-Silty, Frigid Typic Calciaquolls	P	0-5	16-32	-
									5-60	8-32	-
Walsh	ND099	Va	Vallers Loam, Saline	1	85	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-10	4-16	0-3
									10-33	4-16	0-5
									33-60	4-16	0-10
Benson Area	ND603	101	Lallie Loam	1	85	Lallie	Vertic Fluvaquents, Fine, Montmorillonitic (Calcareous), Frigid	P	0-2	0-8	0-2
									2-60	0-8	0-2
Benson Area	ND603	104	Lallie Loam, Saline	1	93	Lallie	Vertic Fluvaquents, Fine, Montmorillonitic (Calcareous), Frigid	P	0-2	4-16	0-2
									2-60	4-16	0-5
Benson Area	ND603	106	Lallie Loam, Wet	1	95	Lallie	Vertic Fluvaquents, Fine, Montmorillonitic (Calcareous), Frigid	VP	0-2	4-16	-
									2-60	4-16	-
Benson Area	ND603	109	Aquents	1	85	Aquents	Aeric Endoaquents, Fine-Loamy, Mixed (Calcareous), Frigid	SP	0-2	0-8	0-0
									2-60	2-8	0-0
Benson Area	ND603	126	Fram Loam, Saline	1	85	Fram	Aeric Calciaquolls, Coarse-Loamy, Frigid	SP	0-13	4-16	-
									13-60	4-16	-
Benson Area	ND603	129	Colvin And Borup Silt Loams, Saline	1	45	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	P	0-12	4-16	0-2
									12-60	4-16	0-10
				2	45	Borup	Typic Calciaquolls, Coarse-Silty, Frigid	P	0-12	4-16	0-0
									12-30	4-16	0-0
									30-60	4-16	0-0
Benson Area	ND603	135	Miranda-Larson Complex, 1 To 3 Percent Slopes	1	45	Miranda	Leptic Natriborolls, Fine-Loamy, Mixed	SP	0-5	0-0	0-7
									5-22	2-8	10-25
									22-60	4-16	10-40
Benson Area	ND603	137	Stirum Loamy Fine Sand	1	85	Stirum	Typic Natraquolls, Coarse-Loamy, Mixed, Frigid	P	0-9	2-8	0-2
									9-18	2-16	5-15
									18-60	2-16	5-10

Table 1. Selected data for all saline, somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Benson Area	ND603	145	Grano Silty Clay, Saline	1	85	Grano	Typic Endoaquerts, Fine, Montmorillonitic, Frigid	P	0-10	4-16	-
									10-60	4-16	-
Benson Area	ND603	15	Vallers Loam, Saline, 1 To 3 Percent Slopes	1	80	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-9	4-16	0-3
									9-22	4-16	0-5
									22-60	4-16	0-10
Benson Area	ND603	74B	Cavour-Miranda Complex, 1 To 6 Percent Slopes	2	35	Miranda	Leptic Natriborolls, Fine-Loamy, Mixed	SP	0-5	0-0	0-7
									5-22	2-8	10-25
									22-60	4-16	10-40
Benson Area	ND603	75	Ryan Silty Clay	1	85	Ryan	Typic Natraquerts, Fine, Montmorillonitic, Frigid	P	0-3	0-0	0-2
									3-60	4-16	0-4
Benson Area	ND603	90	Parnell And Lallie Soils, Ponded	1	50	Parnell	Cumulic Vertic Endoaquolls, Fine, Montmorillonitic (Calcareous), Frigid	VP	0-14	2-8	0-2
									14-36	2-8	0-2
									36-60	2-8	0-2
				2	44	Lallie	Vertic Fluvaquents, Fine, Montmorillonitic (Calcareous), Frigid	VP	0-2	4-16	-
									2-60	4-16	-

Table 2. Major soil map units contained within the 200-foot buffer polygons around candidate restoration wetlands. Map units with major saline components are in bold.

Soil Survey Area	Percent of Buffer Soils	Map Unit Symbol	Map Unit Name
Cavalier (ND019)	47	16	Hamerly-Tonka Loams, 0 To 3 Percent Slopes
	17	12B	Barnes- Buse Loams, 3 To 6 Percent Slopes
	14	11B	Svea-Buse Loams, 3 To 6 Percent Slopes
	8	**2**	**Vallers, Saline-Parnell Complex**
	5	11C	Svea-Buse Loams, 6 To 9 Percent Slopes
	4	**17**	**Vallers-Hamerly Loams, Saline, 0 To 3 Percent Slopes**
	1	19	Hamerly-Cresbard Loams, 1 To 3 Percent Slopes
	1	20B	Cresbard-Svea Loams, 3 To 6 Percent Slopes
	3	-	Miscellaneous Soil Map Units
Totals	100		
Ramsey (ND071)	16	20	Hamerly-Svea Loams, 1 To 3 Percent Slopes
	13	23	Hamerly-Cresbard Loams, 1 To 3 Percent Slopes
	11	19B	Svea-Buse Loams, 3 To 6 Percent Slopes
	10	**21**	**Vallers-Hamerly Loams, Saline, 0 To 3 Percent Slopes**
	6	26	Vallers-Parnell-Tonka Complex, 0 To 3 Percent Slopes
	6	42	Fargo-Hegne Silty Clays
	5	12B	Barnes- Svea Loams, 3 To 6 Percent Slopes
	5	20B	Hamerly-Svea Loams, 3 To 6 Percent Slopes
	4	13C	Barnes- Buse Loams, 6 To 9 Percent Slopes
	3	11	Svea-Barnes Loams, 1 To 3 Percent Slopes
	2	36	Bearden Silty Clay Loam
	2	146	Hamerly Tonka Complex, 0-3% slopes
	2	14C	Svea-Sioux Loams, 1 To 9 Percent
	2	45	Hegne Silty Clay
	2	24B	Barnes- Cresbard Loams, 3 To 6 Percent Slopes
	2	2	Parnell Silty Clay Loam
	1	22	Vallers Loam
	1	**38**	**Colvin Silty Clay Loam, Saline**
	1	46	Aberdeen-Fargo Silty Clay Loams
	1	24	Svea-Cresbard Loams, 1 To 3 Percent Slopes
	1	34	Aberdeen Silt Loam
	1	39	Colvin Silty Clay Loam
	1	**44**	**Hegne Silty Clay, Saline**
	1	17D	Sioux-Buse Loams, 9 To 15 Percent Slopes
	1	**40**	**Colvin-Aberdeen Silty Clay Loams**
	4	-	Miscellaneous Soil Map Units
Totals	100		

(Continued)

Table 2. Continued.

Soil Survey Area	Percent of Buffer Soils	Map Unit Symbol	Map Unit Name
Rolette (ND079)	30	118	Barnes- Buse Loams, 3 To 6 Percent Slopes
	29	137	Barnes- Hamerly Loams, 0 To 3 Percent Slopes
	22	883	Hamerly-Tonka-Parnell Complex, 0 To 3 Percent Slopes
	2	470	Cresbard-Barnes Loams, 0 To 3 Percent Slopes
	2	120	Barnes- Buse Loams, 6 To 9 Percent Slopes
	1	863	Hamerly Loam, 0 To 3 Percent Slopes
	1	167	Bearden Silt Loam
	1	846	Great Bend-Overly Silt Loams, 0 To 3 Percent Slopes
	1	1426	Parnell Silt Loam
	1	510	Divide Loam
	1	76	Arvilla Sandy Loam, 0 To 6 Percent Slopes
	1	**169**	**Bearden Silt Loam, Saline, 0 To 3 Percent Slopes**
	1	**864**	**Hamerly Loam, Saline, 0 To 3 Percent Slopes**
	1	939	Hecla-Hamar Loamy Fine Sands, 0 To 3 Percent Slopes
	1	**452**	**Colvin Silt Loam, Saline**
	1	450	Colvin Silt Loam
	5	-	Miscellaneous Soil Map Units
Totals	100		
Towner (ND095)	27	883	Hamerly-Tonka-Parnell Complex, 0 To 3 Percent Slopes
	21	118	Barnes- Buse Loams, 3 To 6 Percent Slopes
	15	2292	Hamerly-Barnes Loams, 0 To 3 Percent Slopes
	4	2287	Bearden-Lindaas Silt Loams
	3	167	Bearden Silt Loam
	3	**1886**	**Hamerly AndVallers Loams, Saline, 0 To 3 Percent Slopes**
	3	154	Barnes- Svea Loams, 0 To 3 Percent Slopes
	3	**1884**	**Vallers, Saline-Parnell Complex**
	2	511	Divide Loam, 0 To 3 Percent Slopes
	2	120	Barnes- Buse Loams, 6 To 9 Percent Slopes
	2	846	Great Bend-Overly Silt Loams, 0 To 3 Percent Slopes
	2	971	Hegne-Fargo Silty Clays
	1	2048	Wyndmere Fine Sandy Loam, 0 To 3 Percent Slopes
	1	1782	Swenoda Fine Sandy Loam, 0 To 6 Percent Slopes
	1	450	Colvin Silt Loam
	1	2208	Brantford- Coe Loams, 1 To 6 Percent Slopes
	1	1426	Parnell Silt Loam
	1	**2196**	**Bearden And Colvin Silt Loams, Saline**
	1	2293	Lamoure-Colvin Complex, Channeled
	1	1221	Maddock-Hecla Loamy Fine Sands, 1 To 6 Percent Slopes
	1	2324	Wyndmere-Tiffany Loams, Silty Substratum
	1	871	Hamerly-Cresbard Loams, 0 To 3 Percent Slopes
	1	2290	Coe-Binford Sandy Loams, 6 To 15 Percent Slopes
	3	-	Miscellaneous Soil Map Units
Totals	100		

(Continued)

Table 2. Continued.

Soil Survey Area	Percent of Buffer Soils	Map Unit Symbol	Map Unit Name
Walsh (ND099)	16	BkB2	Barnes- Svea Loams, Gently Undulating, Eroded
	15	BkB	Barnes- Svea Loams, Gently Undulating
	15	SuA	Svea-Barnes Loams, Nearly Level
	14	HgA	Hamerly-Svea Loams, Nearly Level
	14	SvA	Svea-Cresbard Loams, Nearly Level
	12	Vh	Vallers-Hamerly Loams
	3	Pa	Parnell Silty Clay Loam
	3	BaC2	Barnes Loam, Rolling, Eroded
	3	He	Hamerly-Cresbard Loams
	2	**Mn**	**Manfred Soils**
	1	VnA	Vang-Brantford Loams, Nearly Level
	1	**Va**	**Vallers Loam, Saline**
	1	BhD	Barnes-Sioux Complex, Hilly
	1	Pt	Parnell And Tonka Soils
	1	-	Miscellaneous Soil Map Units
Totals	100		

Table 3. Major soil map units contained within the West Consultants, Inc. delineated boundary of candidate restoration wetlands. Map units with major saline components are in bold.

Soil Survey Area	Percent of Wetland Soils	Map Unit Symbol	Map Unit Name
Cavalier (ND019)	54	16	Hamerly-Tonka Loams, 0 To 3 Percent Slopes
	19	**2**	**Vallers, Saline-Parnell Complex**
	7	12B	Barnes- Buse Loams, 3 To 6 Percent Slopes
	7	**17**	**Vallers-Hamerly Loams, Saline, 0 To 3 Percent Slopes**
	6	11B	Svea-Buse Loams, 3 To 6 Percent Slopes
	2	3	Parnell Silt Loam
	1	11C	Svea-Buse Loams, 6 To 9 Percent Slopes
	1	19	Hamerly-Cresbard Loams, 1 To 3 Percent Slopes
	2	-	Miscelleaneous Soil Map Units
Totals	100		
Ramsey (ND071)	**14**	**21**	**Vallers-Hamerly Loams, Saline, 0 To 3 Percent Slopes**
	12	20	Hamerly-Svea Loams, 1 To 3 Percent Slopes
	12	42	Fargo-Hegne Silty Clays
	11	23	Hamerly-Cresbard Loams, 1 To 3 Percent Slopes
	10	26	Vallers-Parnell-Tonka Complex, 0 To 3 Percent Slopes
	7	2	Parnell Silty Clay Loam
	4	45	Hegne Silty Clay
	4	19B	Svea-Buse Loams, 3 To 6 Percent Slopes
	3	20B	Hamerly-Svea Loams, 3 To 6 Percent Slopes
	2	36	Bearden Silty Clay Loam
	2	146	Hamerly-Tonka Complex, 0-3% Slopes
	2	12B	Barnes- Svea Loams, 3 To 6 Percent Slopes
	2	39	Colvin Silty Clay Loam
	2	**38**	**Colvin Silty Clay Loam, Saline**
	2	5	Grano Silty Clay
	1	22	Vallers Loam
	1	46	Aberdeen-Fargo Silty Clay Loams
	1	**44**	**Hegne Silty Clay, Saline**
	1	7	Fargo Silty Clay
	1	40	Colvin-Aberdeen Silty Clay Loams
	1	11	Svea-Barnes Loams, 1 To 3 Percent Slopes
	1	34	Aberdeen Silt Loam
	1	1	Tonka Silt Loam
	1	**4**	**Southam Silty Clay Loam**
	1	13C	Barnes- Buse Loams, 6 To 9 Percent Slopes
	1	8	Colvin Silty Clay Loam, Wet
	3	-	Miscelleaneous Soil Map Units
Totals	100		

(continued)

Table 3. Continued.

Soil Survey Area	Percent of Wetland Soils	Map Unit Symbol	Map Unit Name
Rolette (ND079)	29	883	Hamerly-Tonka-Parnell Complex, 0 To 3 Percent Slopes
	20	118	Barnes- Buse Loams, 3 To 6 Percent Slopes
	18	137	Barnes- Hamerly Loams, 0 To 3 Percent Slopes
	5	939	Hecla-Hamar Loamy Fine Sands, 0 To 3 Percent Slopes
	5	1426	Parnell Silt Loam
	4	450	Colvin Silt Loam
	2	863	Hamerly Loam, 0 To 3 Percent Slopes
	2	510	Divide Loam
	2	846	Great Bend-Overly Silt Loams, 0 To 3 Percent Slopes
	2	**1871**	**Vallers Loam, Saline**
	2	167	Bearden Silt Loam
	1	1269	Marysland Silt Loam
	1	**452**	**Colvin Silt Loam, Saline**
	1	**1709**	**Southam Silt Loam**
	1	169	Bearden Silt Loam, Saline, 0 To 3 Percent Slopes
	1	501	Dickey- Esmond Complex, 3 To 9 Percent Slopes
	1	120	Barnes- Buse Loams, 6 To 9 Percent Slopes
	1	**1727**	**Stirum Fine Sandy Loam**
	1	470	Cresbard-Barnes Loams, 0 To 3 Percent Slopes
	1	430	Claire-Lohnes Complex, 6 To 25 Percent Slopes
	1	1221	Maddock-Hecla Loamy Fine Sands, 1 To 6 Percent Slopes
	3	-	Miscelleaneous Soil Map Units
Totals	100		
Towner (ND095)	33	883	Hamerly-Tonka-Parnell Complex, 0 To 3 Percent Slopes
	12	2292	Hamerly-Barnes Loams, 0 To 3 Percent Slopes
	10	118	Barnes- Buse Loams, 3 To 6 Percent Slopes
	5	2287	Bearden-Lindaas Silt Loams
	5	**1884**	**Vallers, Saline-Parnell Complex**
	4	167	Bearden Silt Loam
	4	971	Hegne-Fargo Silty Clays
	4	**1886**	**Hamerly And Vallers Loams, Saline, 0 To 3 Percent Slopes**
	3	450	Colvin Silt Loam
	3	1426	Parnell Silt Loam
	2	511	Divide Loam, 0 To 3 Percent Slopes
	2	846	Great Bend-Overly Silt Loams, 0 To 3 Percent Slopes
	2	2324	Wyndmere-Tiffany Loams, Silty Substratum
	1	**2196**	**Bearden And Colvin Silt Loams, Saline**
	1	2048	Wyndmere Fine Sandy Loam, 0 To 3 Percent Slopes
	1	154	Barnes- Svea Loams, 0 To 3 Percent Slopes
	1	1782	Swenoda Fine Sandy Loam, 0 To 6 Percent Slopes
	1	2293	Lamoure-Colvin Complex, Channeled
	1	120	Barnes- Buse Loams, 6 To 9 Percent Slopes
	1	**1710**	**Southam Silty Clay Loam**
	4	-	Miscelleaneous Soil Map Units
Totals	100		

(continued)

Table 3. Continued.

Soil Survey Area	Percent of Wetland Soils	Map Unit Symbol	Map Unit Name
Walsh (ND099)	17	Vh	Vallers-Hamerly Loams
	14	Pa	Parnell Silty Clay Loam
	14	**Mn**	**Manfred Soils**
	12	HgA	Hamerly-Svea Loams, Nearly Level
	10	SvA	Svea-Cresbard Loams, Nearly Level
	10	SuA	Svea-Barnes Loams, Nearly Level
	6	BkB	Barnes- Svea Loams, Gently Undulating
	5	BkB2	Barnes- Svea Loams, Gently Undulating, Eroded
	4	Pt	Parnell And Tonka Soils
	3	He	Hamerly-Cresbard Loams
	1	**Va**	**Vallers Loam, Saline**
	1	BaC2	Barnes Loam, Rolling, Eroded
	1	VnA	Vang-Brantford Loams, Nearly Level
	1	-	Miscelleaneous Soil Map Units
Totals	100		

Table 4. Summary breakdown of wetland acreage and potential restoration volumes by Buffer Salinization Hazard Class and county. The last column provides a breakdown assuming that all wetlands in the None/Slight Buffer Salinity Hazard Class are restored.

COUNTY	Buffer Salinity Hazard Class	Number of Wetlands in Hazard Class	Wetland Acreage in Hazard Class (Acres)	Wetland Volume in Hazard Class (Acre Feet)	Total Volume by Hazard Class (Percent)	Restore Hazard Class None/Slight
All Counties exclusive of Benson and Pierce	None/Slight (0)	9107	44392	66861	56.5	
	Low (1)	1114	17735	32222	27.2	
	Moderate (2)	1004	9307	14546	12.3	
	High (3)	532	3060	4006	3.4	
	Severe(4)	250	785	801	0.7	
Grand Totals		***12007***	***75280***	***118436***	***100***	
County Breakdowns						
Cavalier	None/Slight (0)	1378	7935	13325	45.3	13325
	Low (1)	341	5912	12016	40.9	
	Moderate (2)	312	2523	3490	11.9	
	High (3)	135	497	490	1.7	
	Severe(4)	32	98	78	0.3	
Subtotal		2198	16966	29399	100	
Ramsey	None/Slight (0)	3587	19820	29711	50.7	29711
	Low (1)	533	9520	16694	28.5	
	Moderate (2)	488	5365	8699	14.8	
	High (3)	271	2157	3036	5.2	
	Severe(4)	116	454	449	0.8	
Subtotal		4995	37315	58589	100	
Rolette	None/Slight (0)	932	1974	2844	87.2	2844
	Low (1)	8	227	302	9.3	
	Moderate (2)	16	41	32	1.0	
	High (3)	10	21	34	1.0	
	Severe(4)	11	34	51	1.6	
Subtotal		977	2296	3263	100	
Towner	None/Slight (0)	3044	13636	19592	76.4	19592
	Low (1)	211	1974	3097	12.1	
	Moderate (2)	183	1356	2306	9.0	
	High (3)	115	382	444	1.7	
	Severe(4)	90	196	220	0.9	
Subtotal		3643	17544	25660	100	
Walsh	None/Slight (0)	166	1027	1388	91.0	1388
	Low (1)	21	102	113	7.4	
	Moderate (2)	5	23	19	1.3	
	High (3)	1	3	3	0.2	
	Severe(4)	1	3	2	0.2	
Subtotal		194	1159	1525	100	
Benson	Not Analyzed	1060	3595	8351		4175.5*
Pierce	Not Analyzed	390	891	1066		533*
Grand Total		**13457**	**79766**	**127853**		**66861**
						71570*

* - Assumes a conservative value of 50% restoration candidate wetlands in Benson and Pierce counties in the None/Slight Wetland Salinity Hazard Category.

Table 5. Summary breakdown of wetland acreage and potential restoration volumes by Wetland Salinization Hazard Class and county. The last column provides a breakdown assuming that all wetlands in the None/Slight Wetland Salinity Hazard Class are restored.

COUNTY	Wetland Salinity Hazard Class	Number of Wetlands in Hazard Class	Wetland Acreage in Hazard Class (Acres)	Wetland Volume in Hazard Class (Acre Feet)	Total Volume by Hazard Class (Percent)	Restore Hazard Class None/Slight
All Counties exclusive of Benson and Pierce	None/Slight (0)	9625	44156	63512	53.6	
	Low (1)	401	9188	16656	14.1	
	Moderate (2)	485	10583	20237	17.1	
	High (3)	500	5885	10730	9.1	
	Severe(4)	996	5467	7302	6.2	
Grand Totals		***12007***	***75280***	***118436***	*100*	
County Breakdowns						
Cavalier	None/Slight (0)	1485	7408	11877	40.4	11877
	Low (1)	92	1963	3820	13.0	
	Moderate (2)	160	3660	7376	25.1	
	High (3)	185	2182	3890	13.2	
	Severe(4)	276	1754	2436	8.3	
Subtotal		*2198*	*16966*	*29399*	*100*	
Ramsey	None/Slight (0)	3855	20705	30029	51.3	30029
	Low (1)	223	5348	9022	15.4	
	Moderate (2)	243	5813	11099	18.9	
	High (3)	224	2791	4875	8.3	
	Severe(4)	450	2657	3564	6.1	
Subtotal		*4995*	*37315*	*58589*	*100*	
Rolette	None/Slight (0)	937	1873	2339	71.7	2339
	Low (1)	4	289	684	21.0	
	Moderate (2)	7	51	112	3.4	
	High (3)	6	22	36	1.1	
	Severe(4)	23	61	92	2.8	
Subtotal		*977*	*2296*	*3263*	*100*	
Towner	None/Slight (0)	3182	13499	18438	71.9	18438
	Low (1)	76	1370	2757	10.7	
	Moderate (2)	72	889	1451	5.7	
	High (3)	76	855	1886	7.4	
	Severe(4)	237	930	1127	4.4	
Subtotal		*3643*	*17544*	*25660*	*100*	
Walsh	None/Slight (0)	166	671	828	54.3	828
	Low (1)	6	218	371	24.4	
	Moderate (2)	3	169	199	13.0	
	High (3)	9	35	44	2.9	
	Severe(4)	10	66	82	5.4	
Subtotal		*194*	*1159*	*1525*	*100*	
Benson	Not Analyzed	1060	3595	8351		4175.5*
Pierce	Not Analyzed	390	891	1066		533*
Grand Total		**13457**	**79766**	**127853**		**63512**
						68220*

* - Assumes a conservative value of 50% restoration candidate wetlands in Benson and Pierce counties in the None/Slight Wetland Salinity Hazard Category.

Soil Salinization Hazards Associated with Devils Lake Flood Damage Reduction Alternatives:

Upper Basin Storage

Appendix A

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Cavalier	ND019	1	Southam Clay	1	61	Southam	Fine, Montmorillonitic (Calcareous), Frigid Cumulic Vertic Endoaquolls	VP	0-27	2-8	0-2
								VP	27-44	2-8	0-2
								VP	44-60	2-8	0-2
				2	23	Parnell	Fine, Montmorillonitic, Frigid Vertic Argiaquolls	VP	0-11	0-0	0-0
									11-32	0-0	0-0
									32-60	0-0	0-0
				3	11	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-8	4-16	0-3
									8-20	4-16	0-5
									20-60	4-16	0-10
Cavalier	ND019	14	Divide Loam, 1 To 3 Percent Slopes	1	69	Divide	Fine-Loamy Over Sandy Or Sandy-Skeletal, Frigid Aeric Calciaquolls	SP	0-12	0-0	0-0
									12-24	0-2	0-0
									24-60	0-0	0-0
Cavalier	ND019	15	Wyard-Hamerly Loams, 0 To 3 Percent Slopes	1	57	Wyard	Fine-Loamy, Mixed, Frigid Typic Epiaquolls	SP	0-14	0-0	0-0
									14-21	0-0	0-0
									21-29	0-0	0-0
									29-60	0-0	0-0
				2	35	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-8	0-2	0-0
									8-17	0-4	0-2
									17-60	0-4	0-2
Cavalier	ND019	16	Hamerly-Tonka Loams, 0 To 3 Percent Slopes	1	52	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-8	0-2	0-0
									8-17	0-4	0-2
									17-60	0-4	0-2
				2	30	Tonka	Fine, Montmorillonitic, Frigid Argiaquic Argialbolls	P	0-13	0-0	0-0
									13-31	0-2	0-1
									31-60	0-4	0-2
Cavalier	ND019	17	Vallers-Hamerly Loams, Saline, 0 To 3 Percent Slopes	1	58	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-11	4-16	0-3
									11-23	4-16	0-5
									23-60	4-16	0-10
				2	29	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-8	4-16	0-0
									17-60	4-16	0-4
									8-17	4-16	0-2
Cavalier	ND019	19	Hamerly-Cresbard Loams, 1 To 3 Percent Slopes	2	39	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-8	0-2	0-0
									8-17	0-4	0-2
									17-60	0-4	0-2
Cavalier	ND019	2	Vallers, Saline-Parnell Complex	1	41	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-11	4-16	0-3
									11-23	4-16	0-5
									23-60	4-16	0-10
				2	41	Parnell	Fine, Montmorillonitic, Frigid Vertic Argiaquolls	VP	0-24	0-0	0-0
									24-43	0-0	0-0
									43-60	0-0	0-0

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Cavalier	ND019	22	Miranda-Cavour Loams	1	48	Miranda	Fine-Loamy, Mixed, Frigid Leptic Natriborolls	SP	0-8	0-0	0-7
									8-15	2-8	10-25
									15-60	4-16	10-40
Cavalier	ND019	3	Parnell Silt Loam	1	81	Parnell	Fine, Montmorillonitic, Frigid Vertic Argiaquolls	VP	0-24	0-0	0-0
									24-43	0-0	0-0
									43-60	0-0	0-0
Cavalier	ND019	37	Arveson Loam	1	73	Arveson	Coarse-Loamy, Frigid Typic Calciaquolls	P	0-8	0-0	-
									8-43	0-0	-
									43-60	0-0	-
				2	22	Borup	Coarse-Silty, Frigid Typic Calciaquolls	P	0-8	0-4	-
									8-41	0-4	-
									41-60	2-8	-
Cavalier	ND019	38	Hegne Silty Clay	1	81	Hegne	Fine, Montmorillonitic, Frigid Typic Calciaquerts	P	0-11	0-0	0-0
									11-19	0-4	0-2
									19-36	0-4	0-2
									36-60	0-4	0-2
				2	11	Fargo	Fine, Montmorillonitic, Frigid Typic Epiaquerts	P	0-9	0-2	0-0
									9-17	0-2	0-0
									17-60	0-2	0-0
Cavalier	ND019	39	Hegne Silty Clay, Saline	1	71	Hegne	Fine, Montmorillonitic, Frigid Typic Calciaquerts	P	0-11	4-16	0-2
									11-36	4-16	0-5
									36-60	4-16	0-10
				2	25	Hegne, Nonsalin	Fine, Montmorillonitic, Frigid Typic Calciaquerts	P	0-11	0-0	0-0
									11-19	0-4	0-2
									19-36	0-4	0-2
									36-60	0-4	0-2
Cavalier	ND019	4	Easby Clay Loam	1	85	Easby	Fine-Loamy, Frigid Typic Calciaquolls	P	0-7	16-32	-
									7-60	8-32	-
Cavalier	ND019	40	Glyndon Silt Loam	1	74	Glyndon	Coarse-Silty, Frigid Aeric Calciaquolls	SP	0-8	0-4	-
									8-28	0-4	-
									28-60	0-4	-
				2	13	Tiffany	Coarse-Loamy, Mixed, Frigid Typic Endoaquolls	P	0-60	0-0	0-0
									60-64	0-0	0-1
Cavalier	ND019	42	Suomi-Kelvin Complex, 0 To 3 Percent Slopes	1	59	Suomi	Fine, Smectitic, Frigid Aquertic Hapludalfs	SP	0-6	0-0	0-0
									6-9	0-0	0-0
									9-25	0-0	0-0
									25-60	0-0	0-0
Cavalier	ND019	48	Cashel Silty Clay	1	75	Cashel	Fine, Smectitic, Calcareous, Frigid Aquertic Udifluvents	SP	0-7	0-0	-
									7-60	0-0	-

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Cavalier	ND019	5	Manfred-Vallers, Saline, Silty Clay Loams	1	53	Manfred	Fine-Loamy, Mixed, Frigid Typic Natraquolls	VP	0-7	2-4	1-5
									7-60	2-16	5-25
				2	34	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-11	4-16	0-3
									11-23	4-16	0-5
									23-60	4-16	0-10
Cavalier	ND019	51	Colvin Silty Clay Loam	1	68	Colvin	Fine-Silty, Frigid Typic Calciaquolls	VP	0-8	0-0	0-2
									8-23	0-0	0-3
									23-60	0-0	0-10
				2	17	Roliss, Pd	Fine-Loamy, Mixed (Calcareous), Frigid Typic Endoaquolls	VP	0-19	0-0	-
									19-33	0-0	-
									33-60	0-0	-
				3	13	Parnell	Fine, Montmorillonitic, Frigid Vertic Argiaquolls	VP	0-11	0-0	0-0
									11-32	0-0	0-0
									32-60	0-0	0-0
Cavalier	ND019	53	Hamar Loamy Fine Sand	1	71	Hamar	Sandy, Mixed, Frigid Typic Endoaquolls	P	0-11	0-2	0-0
									11-19	0-2	0-0
									19-60	0-2	0-0
				2	12	Arveson	Coarse-Loamy, Frigid Typic Calciaquolls	P	0-8	0-0	-
									8-43	0-0	-
									43-60	0-0	-
				3	11	Tiffany	Coarse-Loamy, Mixed, Frigid Typic Endoaquolls	P	0-13	0-0	0-0
									13-60	0-0	0-1
Cavalier	ND019	55	Roliss Silt Loam	1	74	Roliss	Fine-Loamy, Mixed (Calcareous), Frigid Typic Endoaquolls	VP	0-19	0-0	-
									19-33	0-0	-
									33-60	0-0	-
Cavalier	ND019	8	Lamoure Silt Loam	1	72	Lamoure	Fine-Silty, Mixed (Calcareous), Frigid Cumulic Endoaquolls	P	0-16	0-4	1-2
									16-38	0-4	1-3
									38-60	0-4	1-3
				2	10	Rauville	Fine-Silty, Mixed (Calcareous), Frigid Cumulic Endoaquolls	VP	0-28	0-2	1-2
									28-40	0-4	1-3
									40-60	0-4	1-3
Pierce	ND069	1	Tonka Silt Loam	1	85	Tonka	Argiaquic Argialbolls, Fine, Montmorillonitic, Frigid	P	0-24	0-0	0-0
									24-37	0-2	0-2
									37-60	0-4	0-2
Pierce	ND069	100	Stirum Soils, 0 To 3 Percent Slopes	1	85	Stirum	Typic Natraquolls, Coarse-Loamy, Mixed, Frigid	P	0-5	2-8	0-2
									5-14	2-16	5-15
									14-60	2-16	5-10
Pierce	ND069	104	Aquolls	1	85	Aquolls	Cumulic Vertic Endoaquolls, Fine, Montmorillonitic (Calcareous), Frigid	VP	0-16	2-8	0-2
									16-40	2-8	0-2
									40-60	2-8	0-2

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Pierce	ND069	105	Aylmer-Fossum Complex, 0 To 6 Percent Slopes	2	20	Fossum	Typic Endoaquolls, Sandy, Mixed, Frigid	P	0-12	-	-
									12-22	-	-
									22-60	-	-
Pierce	ND069	12	Hegne Silty Clay	1	80	Hegne	Typic Calciaquerts, Fine, Montmorillonitic, Frigid	P	0-8	-	-
									8-32	0-4	-
									32-42	0-4	-
									42-60	0-4	-
Pierce	ND069	13	Hegne Silty Clay, Wet	1	88	Hegne	Typic Calciaquerts, Fine, Montmorillonitic, Frigid	VP	0-8	0-0	-
									8-32	0-4	-
									32-60	0-4	-
Pierce	ND069	14	Bearden Silty Clay Loam	1	85	Bearden	Aeric Calciaquolls, Fine-Silty, Frigid	SP	0-8	0-4	0-2
									8-14	0-4	0-3
									14-60	0-4	0-10
Pierce	ND069	15	Bearden Silty Clay Loam, Saline	1	80	Bearden	Aeric Calciaquolls, Fine-Silty, Frigid	SP	0-8	4-16	0-2
									8-14	4-16	0-3
									14-60	4-16	0-10
Pierce	ND069	17	Colvin Silty Clay Loam	1	90	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	P	0-8	0-4	0-2
									8-36	0-4	0-3
									36-60	0-4	0-10
Pierce	ND069	18	Colvin Soils, Channeled	1	58	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	P	0-8	0-0	0-2
									8-36	0-0	0-3
									36-60	0-0	0-10
Pierce	ND069	2	Parnell Silty Clay Loam	1	85	Parnell	Vertic Argiaquolls, Fine, Montmorillonitic, Frigid	VP	0-8	0-0	-
									8-46	0-0	-
									46-60	0-0	-
Pierce	ND069	24	Hecla-Ulen Loamy Fine Sands, 0 To 3 Percent Slopes	2	30	Ulen	Aeric Calciaquolls, Sandy, Frigid	SP,MW	0-16	0-4	-
									16-32	0-4	-
									32-60	0-4	-
Pierce	ND069	3	Colvin Silty Clay Loam, Wet	1	85	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	VP	0-8	0-0	0-2
									8-36	0-0	0-3
									36-60	0-0	0-10
Pierce	ND069	34	Tiffany Fine Sandy Loam	1	84	Tiffany	Typic Endoaquolls, Coarse-Loamy, Mixed, Frigid	P	0-21	0-0	0-0
									21-60	0-0	0-1
Pierce	ND069	43	Wyndmere Fine Sandy Loam	1	85	Wyndmere	Aeric Calciaquolls, Coarse-Loamy, Frigid	SP	0-10	0-0	0-1
									10-34	0-2	0-1
									34-60	0-2	0-3
Pierce	ND069	44	Fossum Soils	1	85	Fossum	Typic Endoaquolls, Sandy, Mixed, Frigid	P	0-12	-	-
									12-22	-	-
									22-60	-	-
Pierce	ND069	49	Hamerly Loam, 0 To 3 Percent Slopes	1	85	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-7	0-2	0-0
									7-16	0-4	0-2
									16-60	0-4	0-2

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Pierce	ND069	57	Vallers Loam	1	83	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-8	0-4	0-0
									8-30	0-4	0-5
									30-60	0-4	0-10
Pierce	ND069	58	Vallers Loam, Saline	1	80	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-8	4-16	0-3
									8-30	4-16	0-5
									30-60	4-16	0-10
Pierce	ND069	59	Hamerly-Tonka Complex, 0 To 3 Percent Slopes	1	50	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-7	0-2	0-0
									7-16	0-4	0-2
									16-60	0-4	0-2
				2	25	Tonka	Argiaquic Argialbolls, Fine, Montmorillonitic, Frigid	P	0-24	0-0	0-0
									24-37	0-2	0-2
									37-60	0-4	0-2
Pierce	ND069	65	Fram Loam, 0 To 3 Percent Slopes	1	85	Fram	Aeric Calciaquolls, Coarse-Loamy, Frigid	SP,MW	0-28	0-0	-
									28-60	0-0	-
Pierce	ND069	70	Glyndon Silt Loam, 0 To 3 Percent Slopes	1	84	Glyndon	Aeric Calciaquolls, Coarse-Silty, Frigid	MW,SP	0-7	0-4	-
									7-33	0-4	-
									33-60	0-4	-
Pierce	ND069	72	Glyndon Silt Loam, Saline, 0 To 3 Percent Slopes	1	88	Glyndon	Aeric Calciaquolls, Coarse-Silty, Frigid	MW,SP	0-7	4-16	0-0
									7-33	4-16	0-0
									33-60	4-16	0-0
Pierce	ND069	73	Borup And Fossum Soils, Wet	1	45	Borup	Typic Calciaquolls, Coarse-Silty, Frigid	VP	0-11	0-4	-
									11-29	0-4	-
									29-60	2-8	-
				2	45	Fossum	Typic Endoaquolls, Sandy, Mixed, Frigid	VP	0-12	0-0	-
									12-22	0-0	-
									22-60	0-0	-
Pierce	ND069	74	Borup Silt Loam	1	85	Borup	Typic Calciaquolls, Coarse-Silty, Frigid	P	0-11	0-4	-
									11-29	0-4	-
									29-60	2-8	-
Pierce	ND069	75	Borup Silt Loam, Saline	1	85	Borup	Typic Calciaquolls, Coarse-Silty, Frigid	P	0-11	4-16	0-0
									11-29	4-16	0-0
									29-60	4-16	0-0
Pierce	ND069	95	Divide Loam, 0 To 3 Percent Slopes	1	85	Divide	Aeric Calciaquolls, Fine-Loamy Over Sandy Or Sandy-Skeletal, Frigid	SP,MW	0-8	0-0	0-0
									8-20	0-0	0-0
									20-60	0-0	0-0
Pierce	ND069	96	Aquents	1	85	Aquents	Vertic Fluvaquents, Fine, Montmorillonitic (Calcareous), Frigid	P	0-2	4-16	0-2
									2-60	4-16	0-5
Ramsey	ND071	1	Tonka Silt Loam	1	69	Tonka	Argiaquic Argialbolls, Fine, Montmorillonitic, Frigid	P	0-9	0-0	0-0
									9-35	0-2	0-2
									35-60	0-4	0-2

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Ramsey	ND071	2	Parnell Silty Clay Loam	1	90	Parnell	Vertic Argiaquolls, Fine, Montmorillonitic, Frigid	VP	0-11	0-0	-
									11-32	0-0	-
									32-60	0-0	-
Ramsey	ND071	20	Hamerly-Svea Loams, 1 To 3 Percent Slopes	1	37	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-7	0-2	0-0
									7-28	0-4	0-2
									28-60	0-4	0-2
Ramsey	ND071	20B	Hamerly-Svea Loams, 3 To 6 Percent Slopes	1	46	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-7	0-2	0-0
									7-28	0-4	0-2
									28-60	0-4	0-2
Ramsey	ND071	21	Vallers-Hamerly Loams, Saline, 0 To 3 Percent Slopes	1	48	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-8	4-16	0-3
									8-20	4-16	0-5
									20-60	4-16	0-10
				2	33	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-15	4-16	0-0
									15-28	4-16	0-2
									28-60	4-16	0-4
Ramsey	ND071	22	Vallers Loam	1	67	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-8	0-4	0-0
									8-20	0-4	0-5
									20-60	0-4	0-10
Ramsey	ND071	23	Hamerly-Cresbard Loams, 1 To 3 Percent Slopes	1	47	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-6	0-2	0-0
									6-28	0-4	0-2
									28-60	0-4	0-2
Ramsey	ND071	26	Vallers-Parnell-Tonka Complex, 0 To 3 Percent Slopes	1	33	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-22	0-4	0-0
									22-31	0-4	0-5
									31-60	0-4	0-10
				2	27	Parnell	Vertic Argiaquolls, Fine, Montmorillonitic, Frigid	VP	0-11	0-0	-
									11-32	0-0	-
									32-60	0-0	-
				3	17	Tonka	Argiaquic Argialbolls, Fine, Montmorillonitic, Frigid	P	0-9	0-0	0-0
									9-35	0-2	0-2
									35-60	0-4	0-2
Ramsey	ND071	32	Glyndon Silt Loam, 0 To 3 Percent Slopes	1	78	Glyndon	Aeric Calciaquolls, Coarse-Silty, Frigid	MW,SP	0-8	0-4	-
									8-30	0-4	-
									30-54	0-4	-
									54-60	0-4	-
Ramsey	ND071	36	Bearden Silty Clay Loam	1	78	Bearden	Aeric Calciaquolls, Fine-Silty, Frigid	SP	0-9	0-4	0-2
									9-18	0-4	0-3
									18-40	0-4	0-10
									40-60	0-8	0-10
Ramsey	ND071	38	Colvin Silty Clay Loam, Saline	1	89	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	P	0-11	4-16	0-2
									11-60	4-16	0-10
Ramsey	ND071	39	Colvin Silty Clay Loam	1	72	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	P	0-11	0-4	0-2
									11-38	0-4	0-3
									38-60	0-4	0-10
Ramsey	ND071	4	Southam Silty Clay Loam	1	75	Southam	Cumulic Vertic Endoaquolls, Fine, Montmorillonitic (Calcareous), Frigid	VP	0-16	2-8	0-2

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
									16-40	2-8	0-2
									40-60	2-8	0-2
Ramsey	ND071	40	Colvin-Aberdeen Silty Clay Loams	1	43	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	P	0-7	4-16	0-2
									7-60	4-16	0-10
Ramsey	ND071	42	Fargo-Hegne Silty Clays	1	51	Fargo	Typic Epiaquerts, Fine, Montmorillonitic, Frigid	P	0-7	0-2	-
									7-20	0-2	-
									20-60	0-2	-
				2	46	Hegne	Typic Calciaquerts, Fine, Montmorillonitic, Frigid	P	0-8	-	-
									8-45	0-4	-
									45-60	0-4	-
Ramsey	ND071	44	Hegne Silty Clay, Saline	1	70	Hegne	Typic Calciaquerts, Fine, Montmorillonitic, Frigid	P	0-15	4-16	-
									15-21	4-16	-
									21-60	4-16	-
Ramsey	ND071	45	Hegne Silty Clay	1	73	Hegne	Typic Calciaquerts, Fine, Montmorillonitic, Frigid	P	0-8	-	-
									8-45	0-4	-
									45-60	0-4	-
Ramsey	ND071	46	Aberdeen-Fargo Silty Clay Loams	2	40	Fargo	Typic Epiaquerts, Fine, Montmorillonitic, Frigid	P	0-7	0-2	-
									7-19	0-2	-
									19-60	0-2	-
Ramsey	ND071	5	Grano Silty Clay	1	76	Grano	Typic Endoaquerts, Fine, Montmorillonitic, Frigid	P	0-14	0-0	-
									14-60	0-0	-
Ramsey	ND071	52	Wyrene Sandy Loam, Loamy Substratum, 0 To 3 Percent Slopes	1	78	Wyrene	Aeric Calciaquolls, Sandy, Frigid	SP	0-10	0-0	-
									10-49	0-0	-
									49-60	0-0	-
Ramsey	ND071	56	Hamerly-Renshaw Loams, 0 To 3 Percent Slopes	1	32	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-6	0-2	0-0
									6-16	0-4	0-2
									16-60	0-4	0-2
Ramsey	ND071	58	Divide Loam, Loamy Substratum, 1 To 3 Percent Slopes	1	73	Divide	Aeric Calciaquolls, Fine-Loamy Over Sandy Or Sandy-Skeletal, Frigid	SP,MW	0-11	0-0	-
									11-28	0-0	-
									28-46	0-0	-
									46-60	0-0	-
Ramsey	ND071	65	Ojata Clay Loam	1	95	Ojata	Typic Calciaquolls, Fine-Silty, Frigid	P	0-9	16-32	-
									9-60	8-32	-
Ramsey	ND071	7	Fargo Silty Clay	1	90	Fargo	Typic Epiaquerts, Fine, Montmorillonitic, Frigid	P	0-7	0-2	-
									7-19	0-2	-
									19-60	0-2	-
Ramsey	ND071	70	Lallie Clay Loam	1	80	Lallie	Vertic Fluvaquents, Fine, Montmorillonitic (Calcareous), Frigid	P	0-5	0-8	0-2
									5-60	0-8	0-2

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Ramsey	ND071	75	Lallie Clay Loam, Saline	1	97	Lallie	Vertic Fluvaquents, Fine, Montmorillonitic (Calcareous), Frigid	P	0-5	4-16	0-2
									5-60	4-16	0-5
Ramsey	ND071	77	Minnewaukan Loamy Fine Sand, 1 To 3 Percent Slopes	1	70	Minnewaukan	Typic Psammaquents, Mixed, Frigid	P	0-4	2-4	0-1
									4-60	2-4	0-5
Ramsey	ND071	8	Colvin Silty Clay Loam, Wet	1	77	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	VP	0-12	0-0	0-2
									12-28	0-0	0-3
									28-60	0-0	0-10
Ramsey	ND071	81B	Mauvais Loam, 0 To 6 Percent Slopes	1	83	Mauvais	Aeric Endoaquents, Fine-Loamy, Mixed (Calcareous), Frigid	SP	0-2	0-8	0-0
									2-60	2-8	0-0
Rolette	ND079	1269	Marysland Silt Loam	1	75	Marysland	Fine-Loamy Over Sandy Or Sandy-Skeletal, Frigid Typic Calciaquolls	P	0-18	0-0	0-0
									18-32	0-2	0-0
									32-60	0-0	0-0
				2	11	Colvin	Fine-Silty, Frigid Typic Calciaquolls	P	0-12	0-4	0-2
									12-33	0-4	0-3
									33-60	0-4	0-10
Rolette	ND079	1300	Miranda-Cavour Loams	1	65	Miranda	Fine-Loamy, Mixed, Frigid Leptic Natriborolls	SP	0-2	0-0	0-7
									2-8	2-8	10-25
									8-60	4-16	10-40
Rolette	ND079	137	Barnes-Hamerly Loams, 0 To 3 Percent Slopes	2	18	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-7	0-2	0-0
									7-29	0-4	0-2
									29-60	0-4	0-2
Rolette	ND079	1426	Parnell Silt Loam	1	75	Parnell	Fine, Montmorillonitic, Frigid Vertic Argiaquolls	VP	0-11	0-0	0-0
									11-37	0-0	0-0
									37-60	0-0	0-0
				2	20	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-10	0-4	0-0
									10-23	0-4	0-5
									23-60	0-4	0-10
Rolette	ND079	167	Bearden Silt Loam	1	76	Bearden	Fine-Silty, Frigid Aeric Calciaquolls	SP	0-11	0-4	0-2
									11-31	0-4	0-3
									31-60	0-4	0-10
Rolette	ND079	169	Bearden Silt Loam, Saline, 0 To 3 Percent Slopes	1	67	Bearden	Fine-Silty, Frigid Aeric Calciaquolls	SP	0-11	4-16	0-2
									11-31	4-16	0-3
									31-60	4-16	0-10
Rolette	ND079	1709	Southam Silt Loam	1	82	Southam	Fine, Montmorillonitic (Calcareous), Frigid Cumulic Vertic Endoaquolls	VP	0-6	2-8	0-2
									6-26	2-8	0-2
									26-60	2-8	0-2

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Rolette	ND079	1727	Stirum Fine Sandy Loam	1	81	Stirum	Coarse-Loamy, Mixed, Frigid Typic Natraquolls	P	0-7	2-8	0-2
									7-16	2-16	5-15
									16-60	2-16	5-10
				2	12	Lemert	Coarse-Loamy, Mixed, Frigid Leptic Natriborolls	SP	0-3	4-8	-
									3-12	8-16	-
									12-22	4-8	-
									22-49	0-8	-
									49-60	0-8	-
Rolette	ND079	1859	Ulen Fine Sandy Loam	1	72	Ulen	Sandy, Frigid Aeric Calciaquolls	SP	0-8	0-4	-
									8-20	0-4	-
									20-60	0-4	-
				2	17	Hamar Fsl, Pd	Sandy, Mixed, Frigid Typic Endoaquolls	P	0-8	0-2	0-0
									8-21	0-2	0-0
									21-60	0-2	0-0
Rolette	ND079	1871	Vallers Loam, Saline	1	54	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-8	4-16	0-3
									8-30	4-16	0-5
									30-60	4-16	0-10
				2	32	Vallers, Nonsalir	Fine-Loamy, Frigid Typic Calciaquolls	P	0-10	0-4	0-0
									10-23	0-4	0-5
									23-60	0-4	0-10
Rolette	ND079	2046	Wyndmere Fine Sandy Loam	1	62	Wyndmere	Coarse-Loamy, Frigid Aeric Calciaquolls	SP	0-7	0-0	0-1
									7-29	0-2	0-1
									29-60	0-2	0-3
				2	12	Tiffany Swpd	Coarse-Loamy, Mixed, Frigid Typic Endoaquolls	SP	0-10	0-0	0-0
									10-51	0-0	0-0
									51-60	0-0	0-0
Rolette	ND079	2059	Wyrene Sandy Loam	1	75	Wyrene	Sandy, Frigid Aeric Calciaquolls	SP	0-24	0-0	0-0
									24-60	0-0	0-0
Rolette	ND079	450	Colvin Silt Loam	1	76	Colvin	Fine-Silty, Frigid Typic Calciaquolls	P	0-12	0-4	0-2
									12-33	0-4	0-3
									33-60	0-4	0-10
Rolette	ND079	451	Colvin Silt Loam, Channeled	1	72	Colvin	Fine-Silty, Frigid Typic Calciaquolls	P	0-12	0-0	0-2
									12-33	0-0	0-3
									33-60	0-0	0-10
Rolette	ND079	452	Colvin Silt Loam, Saline	1	84	Colvin	Fine-Silty, Frigid Typic Calciaquolls	P	0-12	4-16	0-2
									12-60	4-16	0-10
Rolette	ND079	453	Colvin Silt Loam, Wet	1	93	Colvin	Fine-Silty, Frigid Typic Calciaquolls	VP	0-12	0-0	0-2
									12-33	0-0	0-3
									33-60	0-0	0-10
Rolette	ND079	510	Divide Loam	1	69	Divide	Fine-Loamy Over Sandy Or Sandy-Skeletal, Frigid Aeric Calciaquolls	SP	0-8	0-0	0-0
									8-25	0-2	0-0
									25-60	0-0	0-0
Rolette	ND079	601	Eramosh Peat	1	95	Eramosh	Fine-Silty, Mixed (Calcareous), Frigid Histic Endoaquolls	VP	0-15	0-0	-
									15-60	0-0	-

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Rolette	ND079	602	Eramosh Peat, Ponded	1	77	Eramosh	Fine-Silty, Mixed (Calcareous), Frigid Histic Endoaquolls	VP	0-15	0-0	-
									15-60	0-0	-
Rolette	ND079	64	Arveson Loam	1	67	Arveson	Coarse-Loamy, Frigid Typic Calciaquolls	P	0-16	0-0	-
									16-26	0-0	-
									26-60	0-0	-
Rolette	ND079	66	Arveson Loam, Wet	1	70	Arveson	Coarse-Loamy, Frigid Typic Calciaquolls	VP	0-16	0-0	-
									16-26	0-0	-
									26-60	0-0	-
Rolette	ND079	800	Glyndon Silt Loam	1	73	Glyndon	Coarse-Silty, Frigid Aeric Calciaquolls	SP	0-7	0-4	-
									7-29	0-4	-
									29-60	0-4	-
Rolette	ND079	863	Hamerly Loam, 0 To 3 Percent Slopes	1	81	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-7	0-2	0-0
									7-29	0-4	0-2
									29-60	0-4	0-2
Rolette	ND079	864	Hamerly Loam, Saline, 0 To 3 Percent Slopes	1	64	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-7	4-16	0-0
									7-29	4-16	0-2
									29-60	4-16	0-4
Rolette	ND079	883	Hamerly-Tonka-Parnell Complex, 0 To 3 Percent Slopes	1	44	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-7	0-2	0-0
									7-29	0-4	0-2
									29-60	0-4	0-2
				2	17	Tonka	Fine, Montmorillonitic, Frigid Argiaquic Argialbolls	P	0-14	0-0	0-0
									14-34	0-2	0-1
									34-60	0-4	0-2
				3	14	Parnell	Fine, Montmorillonitic, Frigid Vertic Argiaquolls	VP	0-11	0-0	0-0
									11-37	0-0	0-0
									37-60	0-0	0-0
Rolette	ND079	893	Harriet Silt Loam	1	49	Harriet	Fine, Montmorillonitic, Frigid Typic Natraquolls	P	0-2	0-2	0-0
									2-24	4-16	13-25
									24-60	4-16	5-20
Rolette	ND079	939	Hecla-Hamar Loamy Fine Sands, 0 To 3 Percent Slopes	2	39	Hamar	Sandy, Mixed, Frigid Typic Endoaquolls	SP	0-12	0-2	0-0
									12-17	0-2	0-0
									17-60	0-2	0-0
Towner	ND095	1267	Marysland Loam	1	77	Marysland	Typic Calciaquolls, Fine-Loamy Over Sandy Or Sandy-Skeletal, Frigid	P	0-9	0-0	0-0
									9-20	0-2	0-0
									20-60	0-0	0-0
Towner	ND095	1426	Parnell Silt Loam	1	69	Parnell	Vertic Argiaquolls, Fine, Montmorillonitic, Frigid	VP	0-27	0-0	0-0
									27-45	0-0	0-0
									45-60	0-0	0-0

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Towner	ND095	167	Bearden Silt Loam	1	70	Bearden	Aeric Calciaquolls, Fine-Silty, Frigid	SP	0-7	0-4	0-2
									7-12	0-4	0-3
									12-22	0-4	0-10
									22-60	0-8	0-10
Towner	ND095	1710	Southam Silty Clay Loam	1	92	Southam	Cumulic Vertic Endoaquolls, Fine, Montmorillonitic (Calcareous), Frigid	VP	0-5	2-8	0-2
									5-31	2-8	0-2
									31-60	2-8	0-2
Towner	ND095	1884	Vallers, Saline-Parnell Complex	1	27	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-8	4-16	0-3
									8-33	4-16	0-5
									33-60	4-16	0-10
				2	38	Parnell	Vertic Argiaquolls, Fine, Montmorillonitic, Frigid	VP	0-27	0-0	0-0
									27-45	0-0	0-0
									45-60	0-0	0-0
Towner	ND095	1886	Hamerly And Vallers Loams, Saline, 0 To 3 Percent Slopes	1	44	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-10	4-16	0-0
									10-30	4-16	0-2
									30-60	4-16	0-4
				2	24	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-8	4-16	0-3
									8-33	4-16	0-5
									33-60	4-16	0-10
Towner	ND095	2048	Wyndmere Fine Sandy Loam, 0 To 3 Percent Slopes	1	49	Wyndmere	Aeric Calciaquolls, Coarse-Loamy, Frigid	SP	0-10	0-0	0-1
									10-30	0-2	0-1
									30-60	0-2	0-3
Towner	ND095	2196	Bearden And Colvin Silt Loams, Saline	1	25	Bearden	Aeric Calciaquolls, Fine-Silty, Frigid	SP	0-7	4-16	0-2
									7-22	4-16	0-3
									22-60	4-16	0-10
				2	26	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	P	0-11	4-16	0-2
									11-60	4-16	0-10
Towner	ND095	2286	Aberdeen-Bearden Complex	2	30	Bearden	Aeric Calciaquolls, Fine-Silty, Frigid	SP	0-7	0-4	0-2
									12-22	0-4	0-10
									7-12	0-4	0-3
									22-60	0-8	0-10
Towner	ND095	2287	Bearden-Lindaas Silt Loams	1	47	Bearden	Aeric Calciaquolls, Fine-Silty, Frigid	SP	0-7	0-4	0-2
									12-22	0-4	0-10
									7-12	0-4	0-3
									22-60	0-8	0-10
				2	23	Lindaas	Typic Argiaquolls, Fine, Montmorillonitic, Frigid	P	0-12	0-0	0-0
									12-29	0-0	0-1
									29-60	0-0	0-2

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County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Towner	ND095	2288	Brantford-Divide Loams, 1 To 3 Percent Slopes	2	33	Divide	Aeric Calciaquolls, Fine-Loamy Over Sandy Or Sandy-Skeletal, Frigid	SP	0-7	0-0	0-0
									7-25	0-2	0-0
									25-60	0-0	0-0
Towner	ND095	2289	Buse-Svea-Lamoure Complex, 0 To 35 Percent Slopes	3	15	Lamoure	Cumulic Endoaquolls, Fine-Silty, Mixed (Calcareous), Frigid	P	0-10	0-4	1-2
									10-22	0-4	1-3
									22-42	0-4	1-3
									42-60	0-4	1-3
Towner	ND095	2292	Hamerly-Barnes Loams, 0 To 3 Percent Slopes	1	50	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-10	0-2	0-0
									10-30	0-4	0-2
									30-60	0-4	0-2
Towner	ND095	2293	Lamoure-Colvin Complex, Channeled	1	51	Lamoure	Cumulic Endoaquolls, Fine-Silty, Mixed (Calcareous), Frigid	P	0-10	0-4	1-2
									10-22	0-4	1-3
									22-42	0-4	1-3
									42-60	0-4	1-3
				2	31	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	P	0-11	0-0	0-2
									11-43	0-0	0-3
									43-60	0-0	0-10
Towner	ND095	2324	Wyndmere-Tiffany Loams, Silty Substratum	1	47	Wyndmere	Aeric Calciaquolls, Coarse-Loamy, Frigid	SP	0-14	0-0	0-1
									14-38	0-0	0-1
									38-44	0-0	0-3
									44-60	0-0	0-3
				2	39	Tiffany	Typic Endoaquolls, Coarse-Loamy, Mixed, Frigid	SP	0-10	0-0	0-0
									10-51	0-0	0-0
									51-60	0-0	0-0
Towner	ND095	450	Colvin Silt Loam	1	68	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	P	0-11	0-4	0-2
									11-43	0-4	0-3
									43-60	0-4	0-10
Towner	ND095	511	Divide Loam, 0 To 3 Percent Slopes	1	80	Divide	Aeric Calciaquolls, Fine-Loamy Over Sandy Or Sandy-Skeletal, Frigid	SP	0-7	0-0	0-0
									7-25	0-2	0-0
									25-60	0-0	0-0
Towner	ND095	871	Hamerly-Cresbard Loams, 0 To 3 Percent Slopes	1	41	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-10	0-2	0-0
									10-30	0-4	0-2
									30-60	0-4	0-2

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Towner	ND095	883	Hamerly-Tonka-Parnell Complex, 0 To 3 Percent Slopes	1	44	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-10	0-2	0-0
									10-30	0-4	0-2
									30-60	0-4	0-2
				2	20	Tonka	Argiaquic Argialbolls, Fine, Montmorillonitic, Frigid	P	0-14	0-0	0-0
									14-34	0-2	0-1
									34-60	0-4	0-2
				3	16	Parnell	Vertic Argiaquolls, Fine, Montmorillonitic, Frigid	VP	0-27	0-0	0-0
									27-45	0-0	0-0
									45-60	0-0	0-0
Towner	ND095	966	Hegne Silty Clay, Saline	1	83	Hegne	Typic Calciaquerts, Fine, Montmorillonitic, Frigid	P	0-7	4-16	0-2
									7-32	4-16	0-5
									32-60	4-16	0-10
Towner	ND095	971	Hegne-Fargo Silty Clays	1	59	Hegne	Typic Calciaquerts, Fine, Montmorillonitic, Frigid	P	0-7	0-0	0-0
									7-12	0-4	0-2
									12-32	0-4	0-2
									32-60	0-4	0-2
				2	22	Fargo	Typic Epiaquerts, Fine, Montmorillonitic, Frigid	P	0-8	0-2	0-0
									8-18	0-2	0-0
									18-60	0-2	0-0
Walsh	ND099	An	Antler Stony Clay Loam	1	85	Antler	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-13	0-0	-
									13-22	0-0	-
									22-24	0-0	-
									24-60	0-0	-
Walsh	ND099	Ao	Antler Clay Loam	1	85	Antler	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-13	0-2	0-0
									13-22	0-2	0-0
									22-24	0-8	0-2
									24-60	0-8	0-2
Walsh	ND099	As	Arveson-Fossum Fine Sandy Loams	1	45	Arveson	Coarse-Loamy, Frigid Typic Calciaquolls	P	0-10	0-0	-
									10-48	0-0	-
									48-60	0-0	-
				2	35	Fossum	Sandy, Mixed, Frigid Typic Endoaquolls	P	0-14	-	-
									14-54	-	-
									54-60	-	-
Walsh	ND099	At	Arveson-Fossum Loams	1	50	Arveson	Coarse-Loamy, Frigid Typic Calciaquolls	P	0-10	0-0	-
									10-48	0-0	-
									48-60	0-0	-
				2	35	Fossum	Sandy, Mixed, Frigid Typic Endoaquolls	P	0-14	-	-
									14-54	-	-
									54-60	-	-
Walsh	ND099	Bm	Bearden Silt Loam	1	85	Bearden	Fine-Silty, Frigid Aeric Calciaquolls	SP	0-9	0-4	0-2
									9-20	0-4	0-3
									20-48	0-4	0-10
									48-60	0-8	0-10
Walsh	ND099	BnA	Bearden Silty Clay Loam, Level	1	85	Bearden	Fine-Silty, Frigid Aeric Calciaquolls	SP	0-9	0-4	0-2
									9-20	0-4	0-3

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
									20-48	0-4	0-10
									48-60	0-8	0-10
Walsh	ND099	BnC	Bearden Silty Clay Loam, Sloping	1	85	Bearden	Fine-Silty, Frigid Aeric Calciaquolls	SP	0-9	0-4	0-2
									9-20	0-4	0-3
									20-48	0-4	0-10
									48-60	0-8	0-10
Walsh	ND099	Bo	Bearden Silty Clay Loam, Fans	1	85	Bearden	Fine-Silty, Frigid Aeric Calciaquolls	SP	0-9	0-4	0-2
									9-20	0-4	0-3
									20-48	0-4	0-10
									48-60	0-8	0-10
Walsh	ND099	Br	Bearden Silty Clay Loam, Saline	1	85	Bearden	Fine-Silty, Frigid Aeric Calciaquolls	SP	0-9	4-16	0-2
									9-20	4-16	0-3
									20-60	4-16	0-10
Walsh	ND099	Bs	Bearden Silty Clay Loam, Gravelly Substratum	1	80	Bearden	Fine-Silty, Frigid Aeric Calciaquolls	SP	0-9	0-4	0-2
									9-14	0-4	0-3
									14-20	0-4	0-10
									20-32	0-8	0-10
									32-60	0-8	0-10
Walsh	ND099	Bt	Bearden Silty Clay	1	90	Bearden	Fine-Silty, Frigid Aeric Calciaquolls	SP	0-9	0-4	0-2
									9-20	0-4	0-3
									20-48	0-4	0-10
									48-60	0-8	0-10
Walsh	ND099	Bu	Benoit Loam	1	90	Benoit	Fine-Loamy Over Sandy Or Sandy-Skeletal, Frigid Typic Calciaquolls	P	0-13	0-0	0-0
									13-19	0-2	0-0
									19-60	0-0	0-0
Walsh	ND099	Bv	Borup Silt Loam	1	90	Borup	Coarse-Silty, Frigid Typic Calciaquolls	P	0-8	0-4	-
									8-41	0-4	-
									41-60	2-8	-
Walsh	ND099	CaA	Cashel Silty Clay, Nearly Level	1	85	Cashel	Fine, Frigid Aquertic Udifluvents	SP	0-8	0-0	-
									8-60	0-0	-
Walsh	ND099	CaB	Cashel Silty Clay, Gently Sloping	1	85	Cashel	Fine, Frigid Aquertic Udifluvents	SP	0-8	0-0	-
									8-60	0-0	-
Walsh	ND099	CcE	Cashel Soils, Steep	1	95	Cashel	Fine, Frigid Aquertic Udifluvents	SP	0-8	0-0	-
									8-60	0-0	-
Walsh	ND099	Cf	Colvin Silt Loam	1	85	Colvin	Fine-Silty, Frigid Typic Calciaquolls	P	0-11	0-4	0-2
									11-30	0-4	0-3
									30-60	0-4	0-10
Walsh	ND099	Ch	Colvin Silty Clay Loam	1	85	Colvin	Fine-Silty, Frigid Typic Calciaquolls	P	0-11	0-4	0-2
									11-30	0-4	0-3
									30-60	0-4	0-10
Walsh	ND099	Co	Colvin Silty Clay Loam, Very Wet	1	84	Colvin	Fine-Silty, Frigid Typic Calciaquolls	VP	0-11	0-0	0-2
									11-30	0-0	0-3
									30-60	0-0	0-10

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Walsh	ND099	DdA	Divide Loam, Level	1	85	Divide	Fine-Loamy Over Sandy Or Sandy-Skeletal, Frigid Aeric Calciaquolls	SP	0-9	0-0	0-0
									9-32	0-2	0-0
									32-60	0-0	0-0
Walsh	ND099	FfA	Fargo Silty Clay, Nearly Level	1	85	Fargo	Fine, Montmorillonitic, Frigid Typic Epiaquerts	P	0-9	0-2	0-0
									9-22	0-2	0-0
									22-60	0-2	0-0
Walsh	ND099	Fg	Fargo Silty Clay, Depressional	1	95	Fargo	Fine, Montmorillonitic, Frigid Typic Epiaquerts	P	0-9	0-0	0-0
									9-22	0-0	0-0
									22-60	0-0	0-0
Walsh	ND099	FhA	Fargo-Hegne Silty Clays, Level	1	55	Fargo	Fine, Montmorillonitic, Frigid Typic Epiaquerts	P	0-9	0-2	0-0
									9-22	0-2	0-0
									22-60	0-2	0-0
				2	35	Hegne	Fine, Montmorillonitic, Frigid Typic Calciaquerts	P	0-6	0-0	0-0
									6-31	0-4	0-2
									31-41	0-4	0-2
									41-60	0-4	0-2
Walsh	ND099	FhB	Fargo-Hegne Silty Clays, Gently Sloping	1	45	Fargo	Fine, Montmorillonitic, Frigid Typic Epiaquerts	P	0-9	0-2	0-0
									9-22	0-2	0-0
									22-60	0-2	0-0
				2	40	Hegne	Fine, Montmorillonitic, Frigid Typic Calciaquerts	P	0-6	0-0	0-0
									6-31	0-4	0-2
									31-41	0-4	0-2
									41-60	0-4	0-2
Walsh	ND099	Gb	Gilby Loam	1	80	Gilby	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-10	0-0	-
									10-33	0-0	-
									33-60	0-0	-
Walsh	ND099	Ge	Gilby Loam, Wet	1	85	Gilby	Fine-Loamy, Frigid Typic Calciaquolls	P	0-10	0-4	0-0
									10-33	0-4	0-5
									33-60	0-4	0-10
Walsh	ND099	Gh	Gilby Stony Loam	1	90	Gilby	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-10	0-0	-
									10-33	0-0	-
									33-60	0-0	-
Walsh	ND099	GlA	Glyndon Silt Loam, Level	1	90	Glyndon	Coarse-Silty, Frigid Aeric Calciaquolls	SP	0-8	0-4	-
									8-28	0-4	-
									28-60	0-4	-
Walsh	ND099	GlB	Glyndon Silt Loam, Gently Sloping	1	85	Glyndon	Coarse-Silty, Frigid Aeric Calciaquolls	SP	0-8	0-4	-
									28-60	0-4	-
									8-28	0-4	-

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County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Walsh	ND099	Gm	Glyndon Silt Loam, Moderately Saline	1	85	Glyndon	Coarse-Silty, Frigid Aeric Calciaquolls	SP	0-8	4-16	0-0
									8-28	4-16	0-0
									28-60	4-16	0-0
Walsh	ND099	Gr	Grano Silty Clay, Very Wet	1	85	Grano	Fine, Montmorillonitic, Frigid Typic Endoaquerts	P	0-12	0-0	-
									12-36	0-0	-
									36-60	0-0	-
Walsh	ND099	Gs	Grano-Hegne Silty Clays	1	50	Grano	Fine, Montmorillonitic, Frigid Typic Endoaquerts	P	0-12	0-0	-
									12-36	0-0	-
									36-60	0-0	-
				2	35	Hegne	Fine, Montmorillonitic, Frigid Typic Calciaquerts	P	0-6	0-0	0-0
									6-31	0-4	0-2
									31-41	0-4	0-2
									41-60	0-4	0-2
Walsh	ND099	Ha	Hamar And Ulen Loamy Sands	1	45	Hamar	Sandy, Mixed, Frigid Typic Endoaquolls	SP	0-16	0-2	0-0
									16-28	0-2	0-0
									28-60	0-2	0-0
				2	35	Ulen	Sandy, Frigid Aeric Calciaquolls	SP	0-15	0-4	-
									15-32	0-4	-
									32-60	0-4	-
Walsh	ND099	Hd	Hamar And Ulen Sandy Loams	1	45	Hamar	Sandy, Mixed, Frigid Typic Endoaquolls	P	0-16	0-2	0-0
									16-28	0-2	0-0
									28-60	0-2	0-0
				2	35	Ulen	Sandy, Frigid Aeric Calciaquolls	SP	0-15	0-4	-
									15-32	0-4	-
									32-60	0-4	-
Walsh	ND099	He	Hamerly-Cresbard Loams	1	50	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-7	0-2	0-0
									7-31	0-4	0-2
									31-60	0-4	0-2
Walsh	ND099	HgA	Hamerly-Svea Loams, Nearly Level	1	45	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-7	0-2	0-0
									7-31	0-4	0-2
									31-60	0-4	0-2
Walsh	ND099	HgB	Hamerly-Svea Loams, Gently Undulating	1	45	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-7	0-2	0-0
									7-31	0-4	0-2
									31-60	0-4	0-2
Walsh	ND099	HmA	Hegne-Fargo Silty Clays, Nearly Level	1	55	Hegne	Fine, Montmorillonitic, Frigid Typic Calciaquerts	P	0-6	0-0	0-0
									6-31	0-4	0-2
									31-41	0-4	0-2
									41-60	0-4	0-2
				2	35	Fargo	Fine, Montmorillonitic, Frigid Typic Epiaquerts	P	0-9	0-2	0-0
									9-22	0-2	0-0
									22-60	0-2	0-0

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Walsh	ND099	HmB	Hegne-Fargo Silty Clays, Gently Sloping	1	55	Hegne	Fine, Montmorillonitic, Frigid Typic Calciaquerts	P	0-6	0-0	0-0
									31-41	0-4	0-2
									6-31	0-4	0-2
									41-60	0-4	0-2
				2	35	Fargo	Fine, Montmorillonitic, Frigid Typic Epiaquerts	P	0-9	0-2	0-0
									9-22	0-2	0-0
									22-60	0-2	0-0
Walsh	ND099	Hn	Hegne Silty Clay, Saline	1	90	Hegne	Fine, Montmorillonitic, Frigid Typic Calciaquerts	P	0-6	4-16	0-2
									6-31	4-16	0-5
									31-60	4-16	0-10
Walsh	ND099	Hs	Hegne Silty Clay, Strongly Saline-Alkali	1	85	Hegne	Fine, Montmorillonitic, Frigid Typic Natraquerts	P	0-6	0-0	0-2
									6-60	4-16	0-4
Walsh	ND099	La	Lamoure Soils, Moderately Saline	1	90	Lamoure	Fine-Silty, Mixed (Calcareous), Frigid Cumulic Endoaquolls	P	0-10	8-16	-
									10-23	8-16	-
									23-45	8-16	-
									45-60	8-16	-
Walsh	ND099	Lu	Ludden Silty Clay	1	85	Ludden	Fine, Montmorillonitic, Frigid Typic Endoaquerts	P	0-14	0-4	0-0
									14-21	0-4	0-2
									21-60	0-8	0-2
Walsh	ND099	Ly	Ludden And Ryan Soils	1	45	Ludden	Fine, Montmorillonitic, Frigid Typic Endoaquerts	P	0-14	0-4	0-0
									14-21	0-4	0-2
									21-60	0-8	0-2
				2	40	Ryan	Fine, Montmorillonitic, Frigid Typic Natraquerts	P	0-3	0-0	0-2
									3-60	4-16	0-4
Walsh	ND099	Mn	Manfred Soils	1	85	Manfred	Fine-Loamy, Mixed, Frigid Typic Natraquolls	VP	0-10	2-4	1-5
									10-60	2-16	5-25
Walsh	ND099	Oa	Ojata Soils	1	85	Ojata	Fine-Silty, Frigid Typic Calciaquolls	P	0-5	16-32	-
									5-60	8-32	-
Walsh	ND099	Pa	Parnell Silty Clay Loam	1	90	Parnell	Fine, Montmorillonitic, Frigid Vertic Argiaquolls	VP	0-19	0-0	0-0
									19-37	0-0	0-0
									37-60	0-0	0-0
Walsh	ND099	Pt	Parnell And Tonka Soils	1	45	Parnell	Fine, Montmorillonitic, Frigid Vertic Argiaquolls	VP	0-19	0-0	0-0
									19-37	0-0	0-0
									37-60	0-0	0-0
				2	40	Tonka	Fine, Montmorillonitic, Frigid Argiaquic Argialbolls	P	0-26	0-0	0-0
									26-42	0-2	0-1
									42-60	0-4	0-2
Walsh	ND099	Pu	Perella Silty Clay Loam	1	85	Perella	Fine-Silty, Mixed, Frigid Typic Epiaquolls	P	0-13	0-0	-
									13-23	0-0	-
									23-60	0-0	-
Walsh	ND099	Ra	Rauville Soils	1	85	Rauville	Fine-Silty, Mixed (Calcareous), Frigid Cumulic Endoaquolls	VP	0-20	0-2	1-2
									20-42	0-4	1-3
									42-60	0-4	1-3
Walsh	ND099	Ro	Rockwell Fine Sandy Loam	1	85	Rockwell	Coarse-Loamy, Frigid Typic Calciaquolls	P	0-8	0-0	-
									8-19	0-0	-

Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
									19-26	0-0	-
									26-60	0-0	-
Walsh	ND099	Un	Ulen Sandy Loam	1	90	Ulen	Sandy, Frigid Aeric Calciaquolls	SP	0-15	0-4	-
									15-32	0-4	-
									32-60	0-4	-
Walsh	ND099	Va	Vallers Loam, Saline	1	85	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-10	4-16	0-3
									10-33	4-16	0-5
									33-60	4-16	0-10
Walsh	ND099	Vh	Vallers-Hamerly Loams	1	50	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-10	0-4	0-0
									10-33	0-4	0-5
									33-60	0-4	0-10
				2	30	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-7	0-2	0-0
									7-31	0-4	0-2
									31-60	0-4	0-2
Walsh	ND099	Vm	Vallers-Hamerly Stony Loams	1	50	Vallers	Fine-Loamy, Frigid Typic Calciaquolls	P	0-10	0-4	0-0
									10-33	0-4	0-5
									33-60	0-4	0-10
				2	35	Hamerly	Fine-Loamy, Frigid Aeric Calciaquolls	SP	0-7	0-0	-
									7-31	0-0	-
									31-60	0-0	-
Benson Area	ND603	101	Lallie Loam	1	85	Lallie	Vertic Fluvaquents, Fine, Montmorillonitic (Calcareous), Frigid	P	0-2	0-8	0-2
									2-60	0-8	0-2
Benson Area	ND603	104	Lallie Loam, Saline	1	93	Lallie	Vertic Fluvaquents, Fine, Montmorillonitic (Calcareous), Frigid	P	0-2	4-16	0-2
									2-60	4-16	0-5
Benson Area	ND603	106	Lallie Loam, Wet	1	95	Lallie	Vertic Fluvaquents, Fine, Montmorillonitic (Calcareous), Frigid	VP	0-2	4-16	-
									2-60	4-16	-
Benson Area	ND603	107	Minnewaukan Loamy Fine Sand, 1 To 3 Percent Slopes	1	85	Minnewaukan	Typic Psammaquents, Mixed, Frigid	P	0-5	2-4	0-1
									5-60	2-4	0-5
Benson Area	ND603	109	Aquents	1	85	Aquents	Aeric Endoaquents, Fine-Loamy, Mixed (Calcareous), Frigid	SP	0-2	0-8	0-0
									2-60	2-8	0-0
Benson Area	ND603	122	Fram-Cathay Loams, 1 To 3 Percent Slopes	1	50	Fram	Aeric Calciaquolls, Coarse-Loamy, Frigid	SP	0-13	0-0	-
									13-60	0-0	-
Benson Area	ND603	126	Fram Loam, Saline	1	85	Fram	Aeric Calciaquolls, Coarse-Loamy, Frigid	SP	0-13	4-16	-
									13-60	4-16	-
Benson Area	ND603	127	Fram Loam, 1 To 3 Percent Slopes	1	85	Fram	Aeric Calciaquolls, Coarse-Loamy, Frigid	SP	0-13	0-0	-
									13-60	0-0	-

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County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Benson Area	ND603	129	Colvin And Borup Silt Loams, Saline	1	45	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	P	0-12	4-16	0-2
									12-60	4-16	0-10
				2	45	Borup	Typic Calciaquolls, Coarse-Silty, Frigid	P	0-12	4-16	0-0
									12-30	4-16	0-0
									30-60	4-16	0-0
Benson Area	ND603	134	Borup-Vallers Complex, 1 To 3 Percent Slopes	1	50	Borup	Typic Calciaquolls, Coarse-Silty, Frigid	P	0-12	0-4	-
									12-30	0-4	-
									30-60	2-8	-
				2	35	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-9	0-4	0-0
									9-22	0-4	0-5
									22-60	0-4	0-10
Benson Area	ND603	135	Miranda-Larson Complex, 1 To 3 Percent Slopes	1	45	Miranda	Leptic Natriborolls, Fine-Loamy, Mixed	SP	0-5	0-0	0-7
									5-22	2-8	10-25
									22-60	4-16	10-40
Benson Area	ND603	137	Stirum Loamy Fine Sand	1	85	Stirum	Typic Natraquolls, Coarse-Loamy, Mixed, Frigid	P	0-9	2-8	0-2
									9-18	2-16	5-15
									18-60	2-16	5-10
Benson Area	ND603	14	Svea-Hamerly Loams, 1 To 3 Percent Slopes	2	40	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-8	0-2	0-0
									8-22	0-4	0-2
									22-60	0-4	0-2
Benson Area	ND603	144	Hamerly-Cresbard Loams, 1 To 3 Percent Slopes	1	55	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-8	0-2	0-0
									8-22	0-4	0-2
									22-60	0-4	0-2
Benson Area	ND603	144B	Hamerly-Cresbard Loams, 3 To 6 Percent Slopes	1	50	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-8	0-2	0-0
									8-22	0-4	0-2
									22-60	0-4	0-2
Benson Area	ND603	145	Grano Silty Clay, Saline	1	85	Grano	Typic Endoaquerts, Fine, Montmorillonitic, Frigid	P	0-10	4-16	-
									10-60	4-16	-
Benson Area	ND603	146	Hamerly-Tonka Loams, 0 To 3 Percent Slopes	1	75	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-8	0-2	0-0
									8-22	0-4	0-2
									22-60	0-4	0-2
				2	10	Tonka	Argiaquic Argialbolls, Fine, Montmorillonitic, Frigid	P	0-22	0-0	0-0
									22-38	0-2	0-1
									38-60	0-4	0-2
Benson Area	ND603	14B	Svea-Hamerly Loams, 3 To 6 Percent Slopes	2	30	Hamerly	Aeric Calciaquolls, Fine-Loamy, Frigid	SP	0-8	0-2	0-0
									8-22	0-4	0-2
									22-60	0-4	0-2
Benson Area	ND603	15	Vallers Loam, Saline, 1 To 3 Percent Slopes	1	80	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-9	4-16	0-3
									9-22	4-16	0-5
									22-60	4-16	0-10
Benson Area	ND603	16	Vallers Loam	1	80	Vallers	Typic Calciaquolls, Fine-Loamy, Frigid	P	0-9	0-4	0-0
									9-22	0-4	0-5
									22-60	0-4	0-10
Benson Area	ND603	19	Tonka Silt Loam	1	85	Tonka	Argiaquic Argialbolls, Fine, Montmorillonitic, Frigid	P	0-22	0-0	0-0
									22-38	0-2	0-1

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									38-60	0-4	0-2
Benson Area	ND603	24	Fram-Emrick Loams, 1 To 3 Percent Slopes	1	45	Fram	Aeric Calciaquolls, Coarse-Loamy, Frigid	SP	0-13	0-0	-
									13-60	0-0	-
Benson Area	ND603	3	Parnell Silty Clay Loam	1	85	Parnell	Vertic Argiaquolls, Fine, Montmorillonitic, Frigid	VP	0-14	0-0	0-0
									14-36	0-0	0-0
									36-60	0-0	0-0
Benson Area	ND603	4	Fargo Silty Clay Loam	1	83	Fargo	Typic Epiaquerts, Fine, Montmorillonitic, Frigid	P	0-12	0-2	0-0
									12-30	0-2	0-1
									30-60	0-2	0-2
Benson Area	ND603	44	Glyndon Silt Loam	1	85	Glyndon	Aeric Calciaquolls, Coarse-Silty, Frigid	SP	0-14	0-4	-
									14-29	0-4	-
									29-46	0-4	-
									46-60	0-4	-
Benson Area	ND603	45	Bearden Silt Loam	1	85	Bearden	Aeric Calciaquolls, Fine-Silty, Frigid	SP	0-10	0-4	0-2
									10-23	0-4	0-3
									23-48	0-4	0-10
									48-60	0-8	0-10
Benson Area	ND603	46	Borup Silt Loam	1	85	Borup	Typic Calciaquolls, Coarse-Silty, Frigid	P	0-12	0-4	-
									12-30	0-4	-
									30-60	2-8	-
Benson Area	ND603	47	Fossum Fine Sandy Loam	1	90	Fossum	Typic Endoaquolls, Sandy, Mixed, Frigid	P	0-12	-	-
									12-19	-	-
									19-60	-	-
Benson Area	ND603	5	Hegne Silty Clay	1	95	Hegne	Typic Calciaquerts, Fine, Montmorillonitic, Frigid	P	0-10	0-0	0-0
									10-24	0-4	0-2
									24-42	0-4	0-2
									42-60	0-4	0-2
Benson Area	ND603	64	Divide Loam, 1 To 3 Percent Slopes	1	85	Divide	Aeric Calciaquolls, Fine-Loamy Over Sandy Or Sandy-Skeletal, Frigid	SP	0-10	0-0	0-0
									10-22	0-2	0-0
									22-60	0-0	0-0
Benson Area	ND603	66	Marysland Loam	1	90	Marysland	Typic Calciaquolls, Fine-Loamy Over Sandy Or Sandy-Skeletal, Frigid	P	0-8	0-0	0-0
									26-60	0-0	0-0
									8-26	0-2	0-0
Benson Area	ND603	67	Marysland Loam, Wet	1	85	Marysland	Typic Calciaquolls, Fine-Loamy Over Sandy Or Sandy-Skeletal, Frigid	VP	0-8	0-0	-
									8-26	0-0	-
									26-60	0-0	-

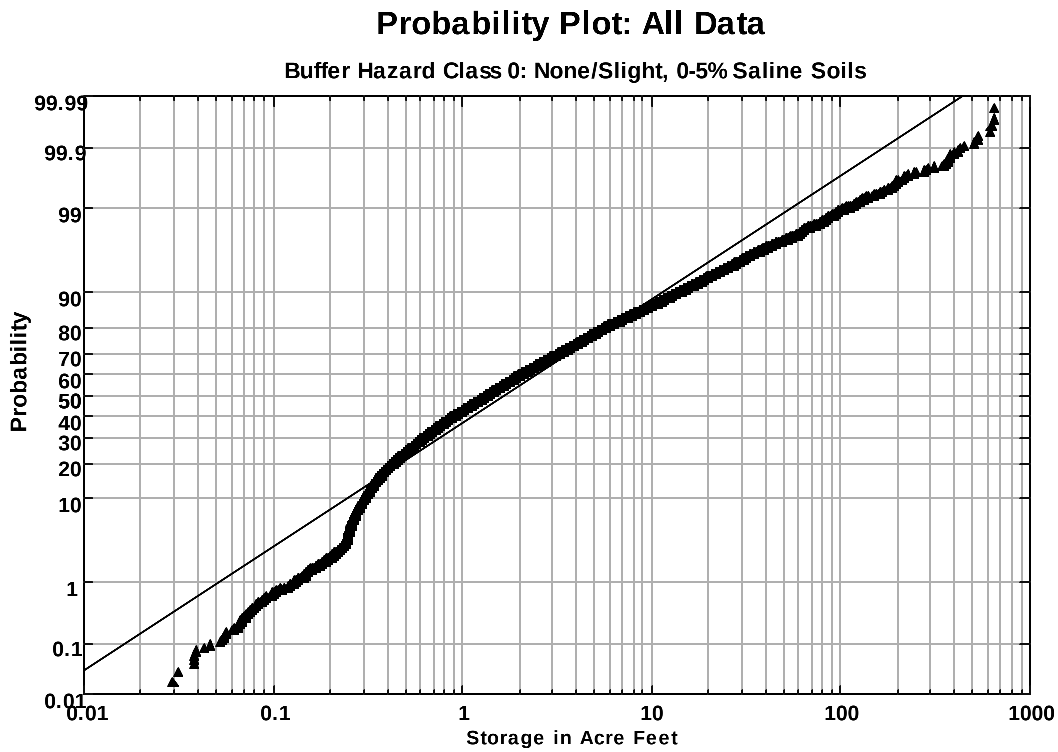
Table A1. Selected physical, chemical, and classification data for all somewhat poorly drained through very poorly drained soils in Cavalier, Pierce, Ramsey, Rolette, Towner, Walsh, and Benson Counties, North Dakota taken from the NRCS MUIR database.

County/ Survey Area	Soil Area ID	Map Unit Symbol	Map Unit Name	Component Number	Component Percent	Series Name	Series Classification	Drainage Class	Layer Depth (in)	Soil EC (dS/m)	Soil SAR
Benson Area	ND603	7	Colvin Silt Loam	1	85	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	P	0-12	0-4	0-2
									12-30	0-4	0-3
									30-60	0-4	0-10
Benson Area	ND603	74B	Cavour-Miranda Complex, 1 To 6 Percent Slopes	2	35	Miranda	Leptic Natriborolls, Fine-Loamy, Mixed	SP	0-5	0-0	0-7
									5-22	2-8	10-25
									22-60	4-16	10-40
Benson Area	ND603	75	Ryan Silty Clay	1	85	Ryan	Typic Natraquerts, Fine, Montmorillonitic, Frigid	P	0-3	0-0	0-2
									3-60	4-16	0-4
Benson Area	ND603	8	Colvin Silt Loam, Wet	1	85	Colvin	Typic Calciaquolls, Fine-Silty, Frigid	VP	0-12	0-0	0-2
									12-30	0-0	0-3
									30-60	0-0	0-10
Benson Area	ND603	85	Lamoure Silt Loam	1	85	Lamoure	Cumulic Endoaquolls, Fine-Silty, Mixed (Calcareous), Frigid	P	0-5	0-4	1-2
									5-12	0-4	1-3
									12-26	0-4	1-3
									26-60	0-4	1-3
Benson Area	ND603	89	Grano Silty Clay	1	85	Grano	Typic Endoaquerts, Fine, Montmorillonitic, Frigid	P	0-10	0-0	-
									10-42	0-0	-
									42-60	0-0	-
Benson Area	ND603	9	Rauville Silt Loam	1	90	Rauville	Cumulic Endoaquolls, Fine-Silty, Mixed (Calcareous), Frigid	VP	0-20	0-2	1-2
									20-60	0-4	1-3
Benson Area	ND603	90	Parnell And Lallie Soils, Ponded	1	50	Parnell	Cumulic Vertic Endoaquolls, Fine, Montmorillonitic (Calcareous), Frigid	VP	0-14	2-8	0-2
									14-36	2-8	0-2
									36-60	2-8	0-2
				2	44	Lallie	Vertic Fluvaquents, Fine, Montmorillonitic (Calcareous), Frigid	VP	0-2	4-16	-
									2-60	4-16	-

Soil Salinization Hazards Associated with Devils Lake Flood Damage Reduction Alternatives:

Upper Basin Storage

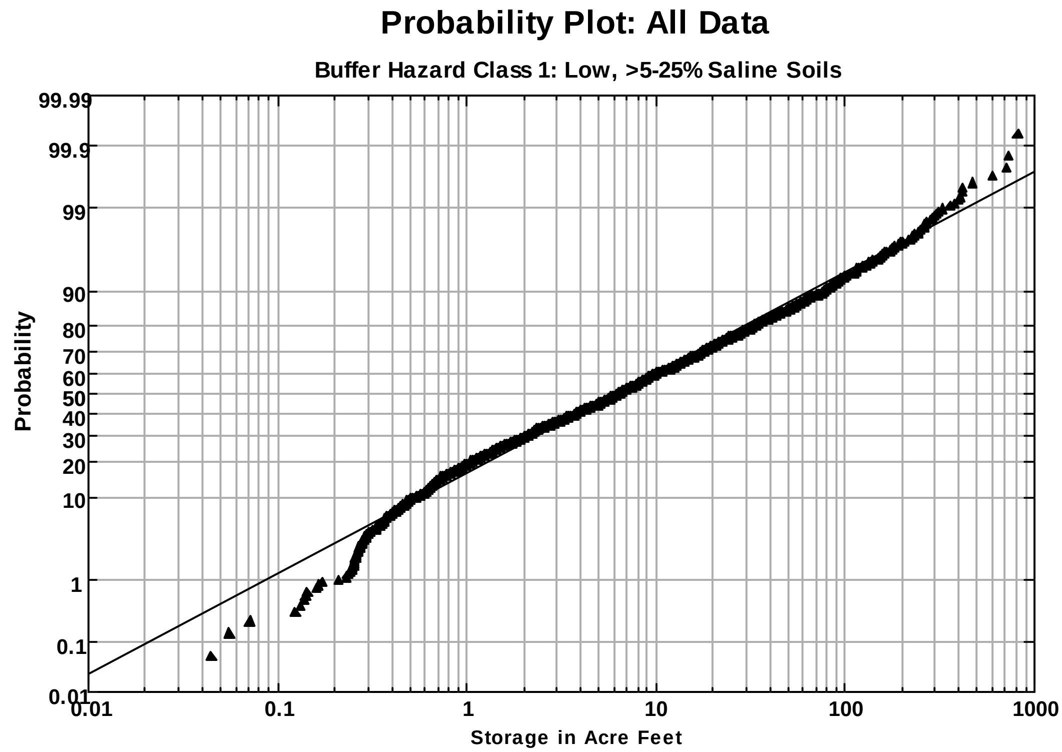
Appendix B



Distribution Statistics: Buffer Salinity Hazard Class 0, 0-5% saline soils in the 200-foot buffer

Statistic	Wetland Volume (acre feet)	Wetland Volume (Log Acre Feet)	Antilog Conversions
Valid Cases	9107	9107	
Mean	7.3417	0.2228	1.67
Median	1.3433	0.1282	1.34
Standard Deviation	29.1670	0.6515	
Standard Error	0.3056	0.0068	
Coeff of Variation	3.9728	2.9247	
Minimum	0.0217	-1.6635	
Maximum	743.4650	2.8713	
Range	743.4433	4.5348	
Lower Quartile	0.5175	-0.2861	0.52
Upper Quartile	4.2020	0.6235	4.20
Interquartile Range	3.6845	0.9095	
Skewness	12.7116	0.7190	
Kurtosis	218.2980	0.3113	

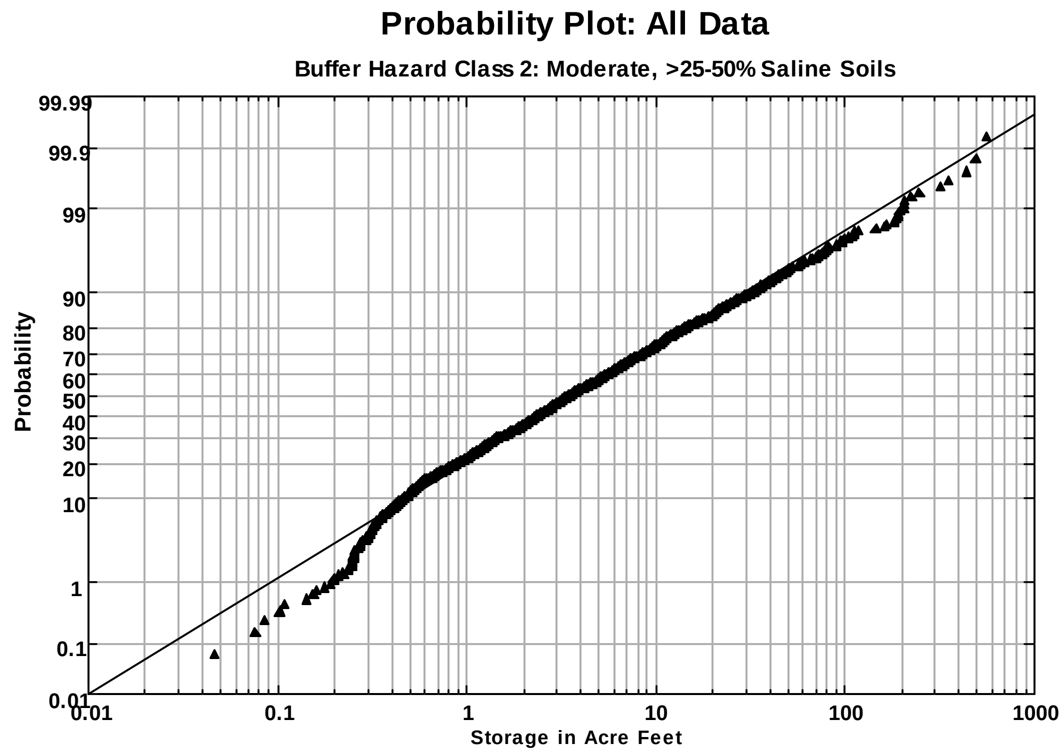
Figure B1. 9107 wetlands were placed in the None/Slight salinity hazard class based on the percentage of saline soils in the 200-foot wetland buffer. The vast majority of the wetlands are of limited storage volume. 85% of the wetlands in the None/Slight hazard category have less than 10 acre-feet of storage. The data are log normally distributed. The data are strongly skewed to the lower values (large positive skewness) with the majority of values less than the mean (high positive kurtosis). Log transformed data are normally distributed. The data suggest that most of the storage volume lies in larger wetlands. Data are exclusive of storage volumes for wetlands in Benson and Pierce counties.



Distribution Statistics: Buffer Salinity Hazard Class 1, >5-25% saline soils in the 200-foot buffer

Statistic	Wetland Volume (acre feet)	Wetland Volume (Log Acre Feet)	Antilog Conversions
Valid Cases	1114	1114	
Mean	28.9248	0.7915	6.18
Median	6.2764	0.7977	6.27
Standard Deviation	69.2524	0.7983	
Standard Error	2.0749	0.0239	
Coeff of Variation	2.3942	1.0086	
Minimum	0.0446	-1.3507	
Maximum	815.7479	2.9116	
Range	815.7033	4.2622	
Lower Quartile	1.4687	0.1669	1.4687
Upper Quartile	22.7810	1.3576	22.7810
Interquartile Range	21.3123	1.1906	
Skewness	5.6517	0.1078	
Kurtosis	43.8043	-0.6456	

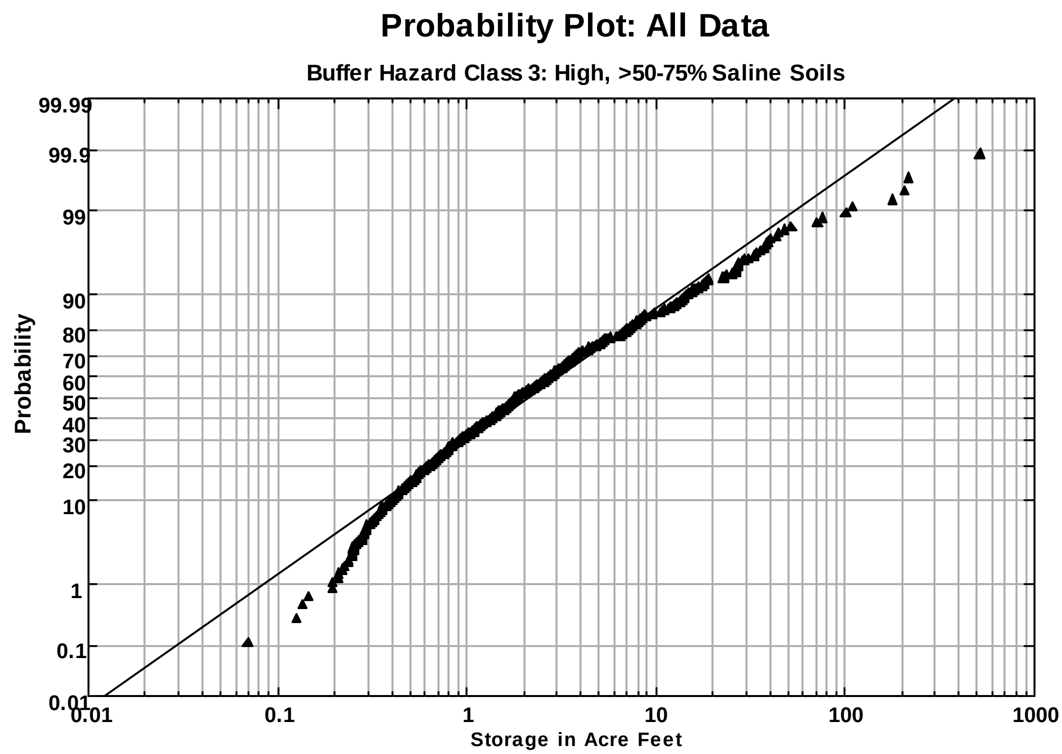
Figure B2. 1114 wetlands were placed in the Low salinity hazard class based on the percentage of saline soils in the 200-foot wetland buffer. The vast majority of the wetlands are of limited storage volume. 60% of the wetlands in the None/Slight hazard category have less than 10 acre-feet of storage. The data are log normally distributed. The data are strongly skewed to the lower values (large positive skewness) with the majority of values less than the mean (high positive kurtosis). Log transformed data are normally distributed. The data suggest that most of the storage volume lies in larger wetlands. Data are exclusive of storage volumes for wetlands in Benson and Pierce counties.



Distribution Statistics: Buffer Salinity Hazard Class 2, >25-50% saline soils in the 200-foot buffer

Statistic	Wetland Volume (acre feet)	Wetland Volume (Log Acre Feet)	Antilog Conversions
Valid Cases	1004	1004	
Mean	14.4885	0.5715	3.73
Median	3.4780	0.5413	3.48
Standard Deviation	40.7733	0.6928	
Standard Error	1.2868	0.0219	
Coeff of Variation	2.8142	1.2123	
Minimum	0.0462	-1.3354	
Maximum	562.8025	2.7504	
Range	562.7563	4.0857	
Lower Quartile	1.1655	0.0665	1.1655
Upper Quartile	10.7375	1.0309	10.7375
Interquartile Range	9.5720	0.9644	
Skewness	7.5077	0.2765	
Kurtosis	73.7932	-0.2428	

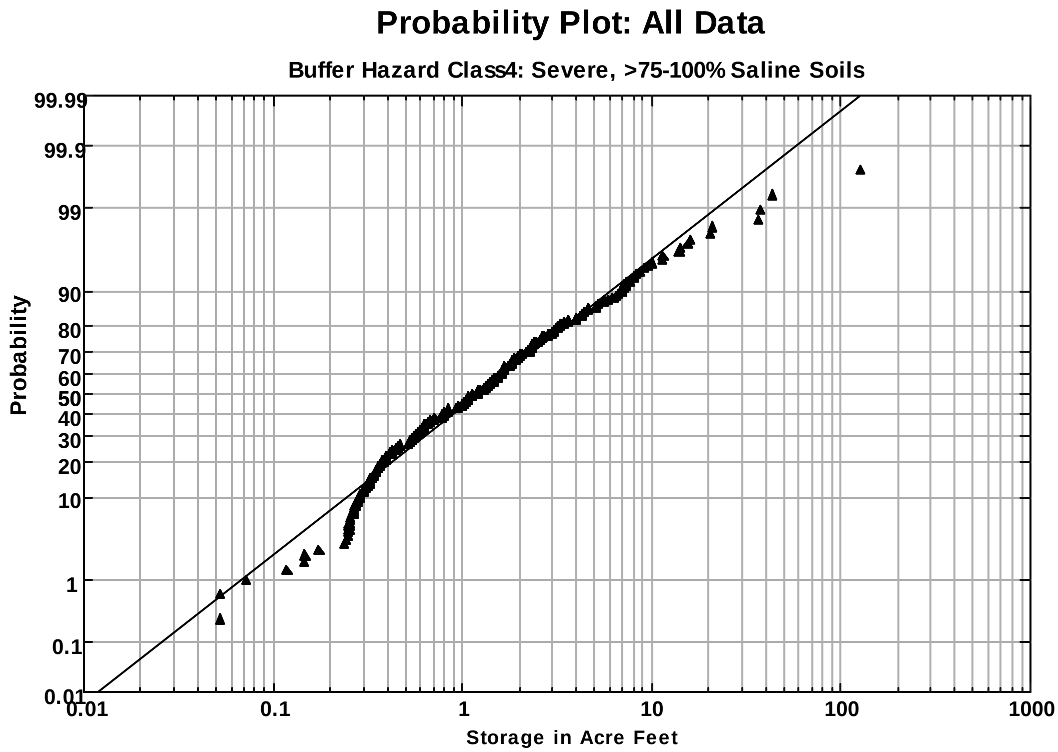
Figure B3. 1004 wetlands were placed in the Moderate salinity hazard class based on the percentage of saline soils in the 200-foot wetland buffer. The vast majority of the wetlands are of limited storage volume. 72% of the wetlands in the Moderate hazard category have less than 10 acre-feet of storage. The data are log normally distributed. The data are strongly skewed to the lower values (large positive skewness) with the majority of values less than the mean (high positive kurtosis). Log transformed data are normally distributed. The data suggest that most of the storage volume lies in larger wetlands. Data are exclusive of storage volumes for wetlands in Benson and Pierce counties.



Distribution Statistics: Buffer Salinity Hazard Class 3, >50-75% saline soils in the 200-foot buffer

Statistic	Wetland Volume (acre feet)	Wetland Volume (Log Acre Feet)	Antilog Conversions
Valid Cases	532.0000	532.0000	
Mean	7.5297	0.3330	2.15
Median	1.8046	0.2564	1.80
Standard Deviation	28.5839	0.6049	
Standard Error	1.2393	0.0262	
Coeff of Variation	3.7962	1.8163	
Minimum	0.0693	-1.1593	
Maximum	514.2028	2.7111	
Range	514.1335	3.8704	
Lower Quartile	0.7662	-0.1157	0.7662
Upper Quartile	5.0720	0.7052	5.0720
Interquartile Range	4.3059	0.8209	
Skewness	12.5604	0.5955	
Kurtosis	198.1743	0.3221	

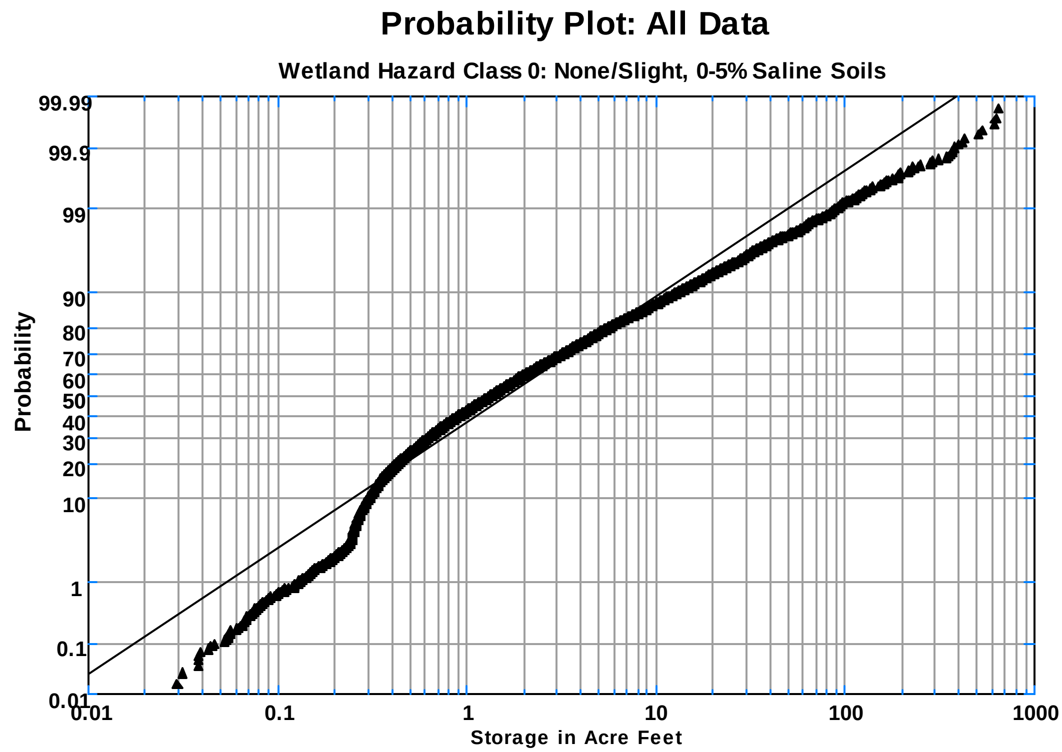
Figure B4. 532 wetlands were placed in the High salinity hazard class based on the percentage of saline soils in the 200-foot wetland buffer. The vast majority of the wetlands are of limited storage volume. 85% of the wetlands in the Moderate hazard category have less than 10 acre-feet of storage. The data are log normally distributed. The data are strongly skewed to the lower values (large positive skewness) with the majority of values less than the mean (high positive kurtosis). Log transformed data are normally distributed. The data suggest that most of the storage volume lies in larger wetlands. Data are exclusive of storage volumes for wetlands in Benson and Pierce counties.



Distribution Statistics: Buffer Salinity Hazard Class 4, >75-100% saline soils in the 200-foot buffer

Statistic	Wetland Volume (acre feet)	Wetland Volume (Log Acre Feet)	Antilog Conversions
Valid Cases	250	250	
Mean	3.2026	0.0863	1.22
Median	1.1584	0.0637	1.16
Standard Deviation	9.3422	0.5416	
Standard Error	0.5909	0.0343	
Coeff of Variation	2.9171	6.2736	
Minimum	0.0520	-1.2840	
Maximum	125.9817	2.1003	
Range	125.9297	3.3843	
Lower Quartile	0.4480	-0.3487	0.4480
Upper Quartile	2.5693	0.4098	2.5693
Interquartile Range	2.1213	0.7585	
Skewness	9.9834	0.5010	
Kurtosis	122.6743	0.4577	

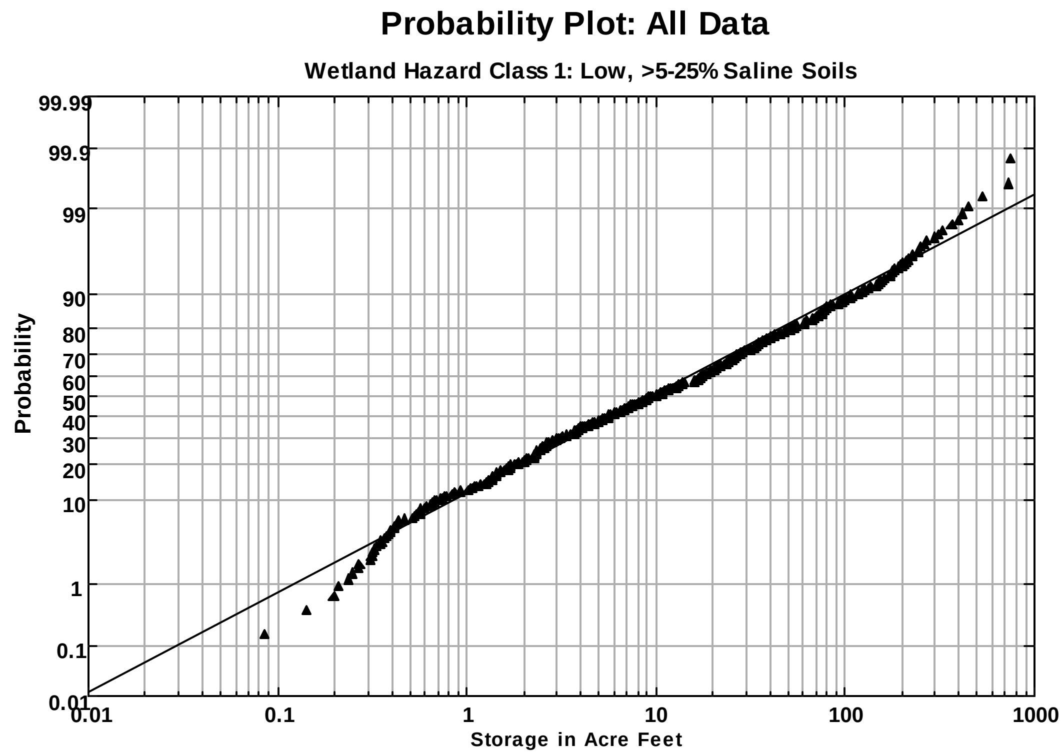
Figure B5. 250 wetlands were placed in the High salinity hazard class based on the percentage of saline soils in the 200-foot wetland buffer. The vast majority of the wetlands are of limited storage volume. 93% of the wetlands in the Severe hazard category have less than 10 acre-feet of storage. The data are log normally distributed. The data are strongly skewed to the lower values (large positive skewness) with the majority of values less than the mean (high positive kurtosis). Log transformed data are normally distributed. Data are exclusive of storage volumes for wetlands in Benson and Pierce counties.



Distribution Statistics: Wetland Salinity Hazard Class 0, 0-5% saline soils in the wetland

Statistic	Wetland Volume (acre feet)	Wetland Volume (Log Acre Feet)	Antilog Conversions
Valid Cases	9625	9625	
Mean	6.5986	0.2167	1.65
Median	1.3442	0.1285	1.34
Standard Deviation	25.1383	0.6390	
Standard Error	0.2562	0.0065	
Coeff of Variation	3.8096	2.9494	
Minimum	0.0217	-1.6635	
Maximum	650.2115	2.8131	
Range	650.1898	4.4766	
Lower Quartile	0.5199	-0.2841	0.5199
Upper Quartile	4.1611	0.6192	4.1611
Interquartile Range	3.6412	0.9033	
Skewness	13.6912	0.6669	
Kurtosis	260.1559	0.2030	

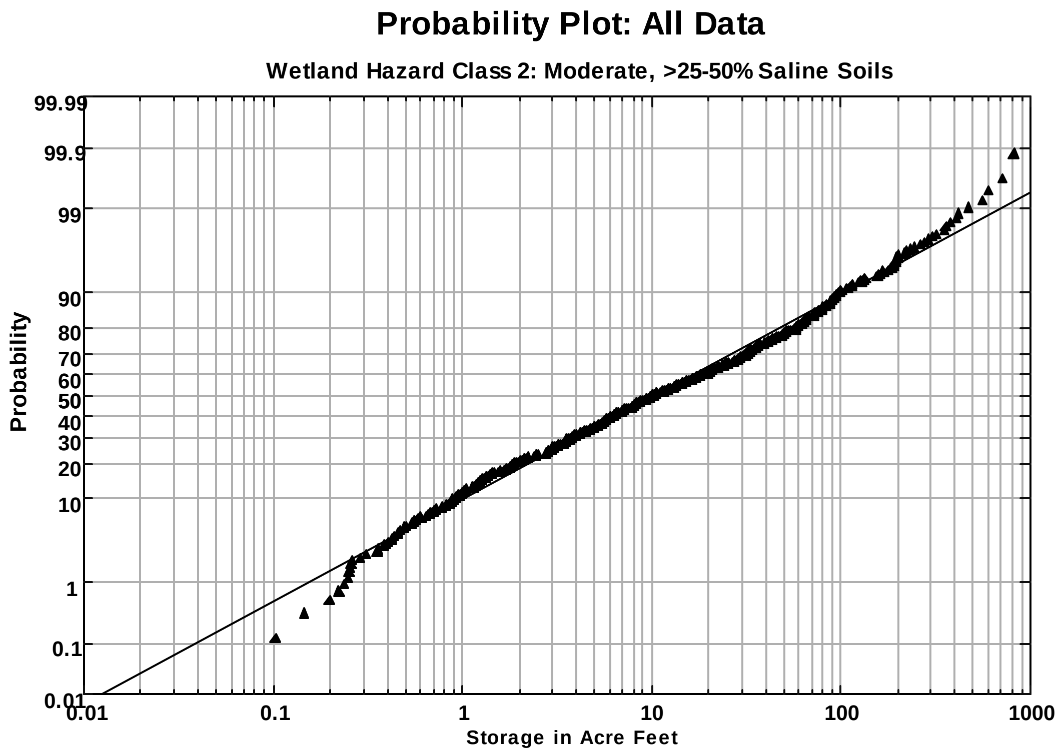
Figure B6. 9107 wetlands were placed in the None/Slight salinity hazard class based on the percentage of saline soils in the drained wetland. The vast majority of the drained wetlands are of limited storage volume. 85% of the wetlands in the None/Slight hazard category have less than 10 acre-feet of storage. The raw data are log normally distributed. The data are strongly skewed to the lower values (large positive skewness) with the majority of values less than the mean (high positive kurtosis). Log transformed data are normally distributed. The data suggest that most of the storage volume lies in larger wetlands. Data are exclusive of storage volumes for wetlands in Benson and Pierce counties.



Distribution Statistics: Wetland Salinity Hazard Class 1, >5-25% saline soils in the wetland

Statistic	Wetland Volume (acre feet)	Wetland Volume (Log Acre Feet)	Antilog Conversions
Valid Cases	401	401	
Mean	41.5349	0.9768	9.47
Median	9.4386	0.9749	9.44
Standard Deviation	87.0448	0.8083	
Standard Error	4.3468	0.0404	
Coeff of Variation	2.0957	0.8275	
Minimum	0.0856	-1.0675	
Maximum	743.4650	2.8713	
Range	743.3794	3.9388	
Lower Quartile	2.4283	0.3853	2.4283
Upper Quartile	35.9748	1.5560	35.9748
Interquartile Range	33.5465	1.1707	
Skewness	4.3965	-0.0179	
Kurtosis	25.3479	-0.6644	

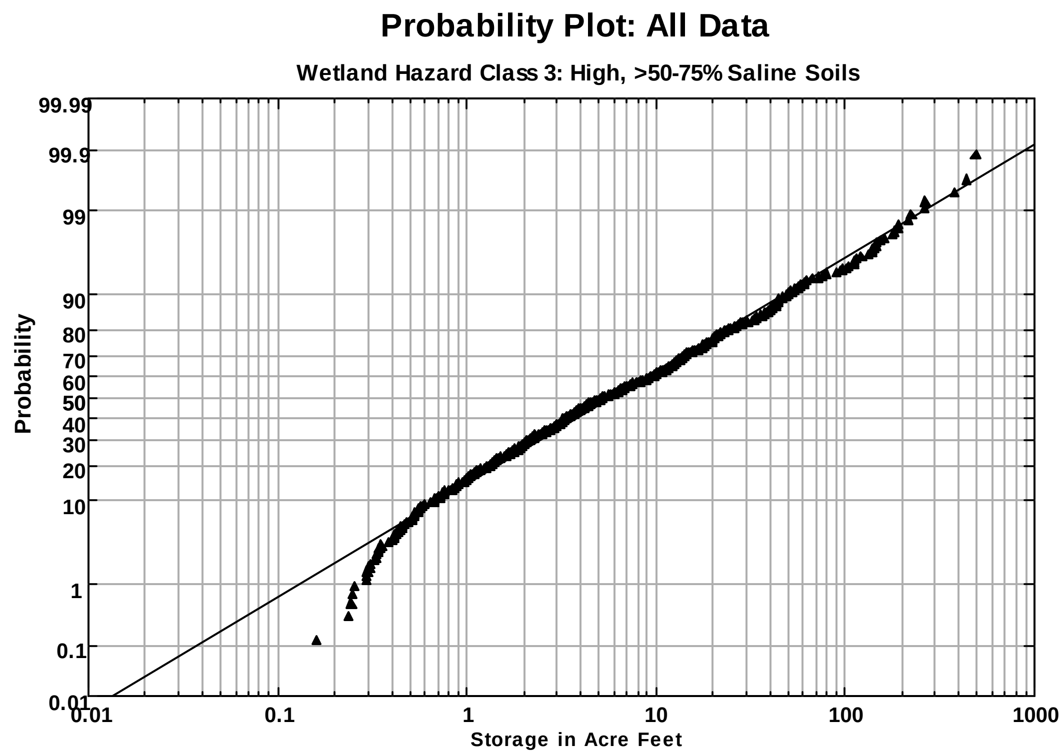
Figure B7. 401 wetlands were placed in the Low salinity hazard class based on the percentage of saline soils in the drained wetland. The vast majority of the drained wetlands are of limited storage volume. 50% of the wetlands in the Low hazard category have less than 10 acre-feet of storage. The data are log normally distributed. The raw data are strongly skewed to the lower values (large positive skewness) with the majority of values less than the mean (high positive kurtosis). Log transformed data are normally distributed. The data suggest that most of the storage volume lies in larger wetlands. Data are exclusive of storage volumes for wetlands in Benson and Pierce counties.



Distribution Statistics: Wetland Salinity Hazard Class 2, >25-50% saline soils in the wetland

Statistic	Wetland Volume (acre feet)	Wetland Volume (Log Acre Feet)	Antilog Conversions
Valid Cases	485	485	
Mean	41.7258	1.0143	10.33
Median	10.0641	1.0028	10.06
Standard Deviation	87.5566	0.7851	
Standard Error	3.9757	0.0356	
Coeff of Variation	2.0984	0.7740	
Minimum	0.1024	-0.9897	
Maximum	815.7479	2.9116	
Range	815.6455	3.9013	
Lower Quartile	2.9296	0.4668	2.9296
Upper Quartile	40.9104	1.6118	40.9104
Interquartile Range	37.9808	1.1450	
Skewness	4.6705	-0.0577	
Kurtosis	28.1538	-0.6281	

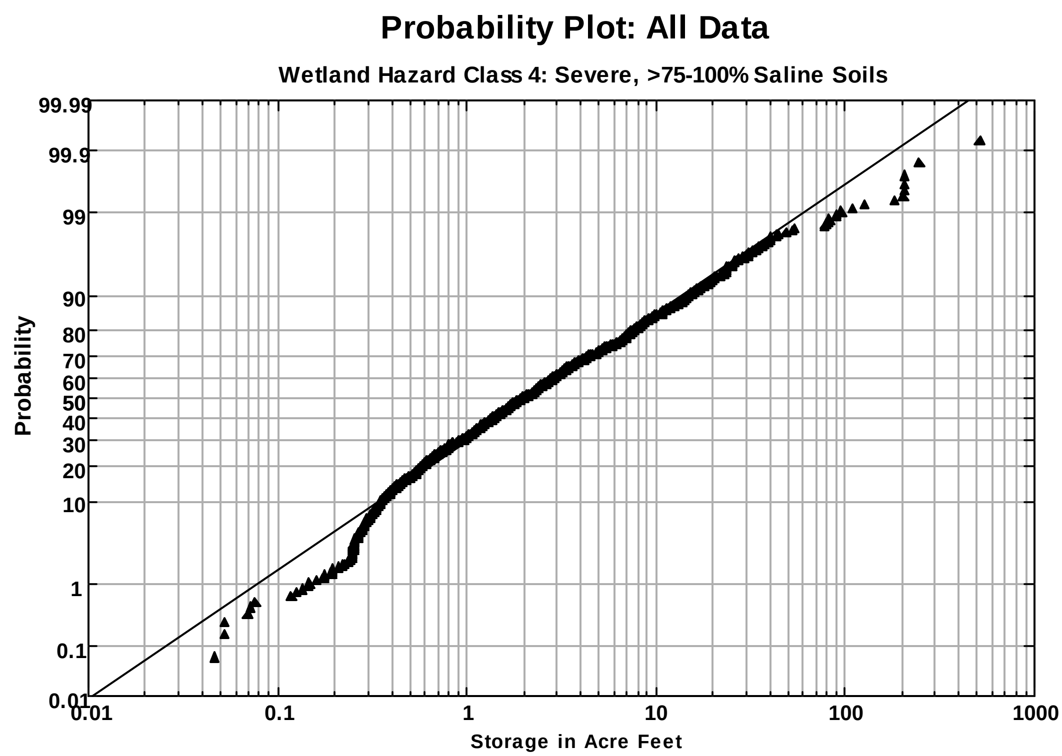
Figure B8. 401 wetlands were placed in the Moderate salinity hazard class based on the percentage of saline soils in the drained wetland. The vast majority of the drained wetlands are of limited storage volume. 50% of the wetlands in the Moderate hazard category have less than 10 acre-feet of storage. The data are log normally distributed. The raw data are strongly skewed to the lower values (large positive skewness) with the majority of values less than the mean (high positive kurtosis). Log transformed data are normally distributed. The data suggest that most of the storage volume lies in larger wetlands. Data are exclusive of storage volumes for wetlands in Benson and Pierce counties.



Distribution Statistics: Wetland Salinity Hazard Class 3, >50-75% saline soils in the wetland

Statistic	Wetland Volume (acre feet)	Wetland Volum (Log Acre Feet)	Antilog Conversions
Valid Cases	500	500	
Mean	21.4598	0.7633	5.80
Median	5.2236	0.7180	5.22
Standard Deviation	48.7150	0.7101	
Standard Error	2.1786	0.0318	
Coeff of Variation	2.2701	0.9303	
Minimum	0.1595	-0.7972	
Maximum	490.0325	2.6902	
Range	489.8730	3.4875	
Lower Quartile	1.7409	0.2408	1.7409
Upper Quartile	18.4745	1.2666	18.4745
Interquartile Range	16.7337	1.0258	
Skewness	5.2957	0.2025	
Kurtosis	36.6014	-0.5606	

Figure B9. 500 wetlands were placed in the High salinity hazard class based on the percentage of saline soils in the drained wetland. The vast majority of the drained wetlands are of limited storage volume. 60% of the wetlands in the High hazard category have less than 10 acre-feet of storage. The data are log normally distributed. The raw data are strongly skewed to the lower values (large positive skewness) with the majority of values less than the mean (high positive kurtosis). Log transformed data are normally distributed. The data suggest that most of the storage volume lies in larger wetlands. Data are exclusive of storage volumes for wetlands in Benson and Pierce counties.



Distribution Statistics: Wetland Salinity Hazard Class 4, >75-100% saline soils in the wetland

Statistic	Wetland Volume (acre feet)	Wetland Volume (Log Acre Feet)	Antilog Conversions
Valid Cases	996.0000	996.0000	
Mean	7.3312	0.3339	2.16
Median	1.9554	0.2912	1.96
Standard Deviation	25.1168	0.6227	
Standard Error	0.7959	0.0197	
Coeff of Variation	3.4260	1.8651	
Minimum	0.0462	-1.3354	
Maximum	514.2028	2.7111	
Range	514.1566	4.0465	
Lower Quartile	0.7116	-0.1478	0.7116
Upper Quartile	5.9428	0.7740	5.9428
Interquartile Range	5.2312	0.9218	
Skewness	11.8835	0.4142	
Kurtosis	192.4407	0.0624	

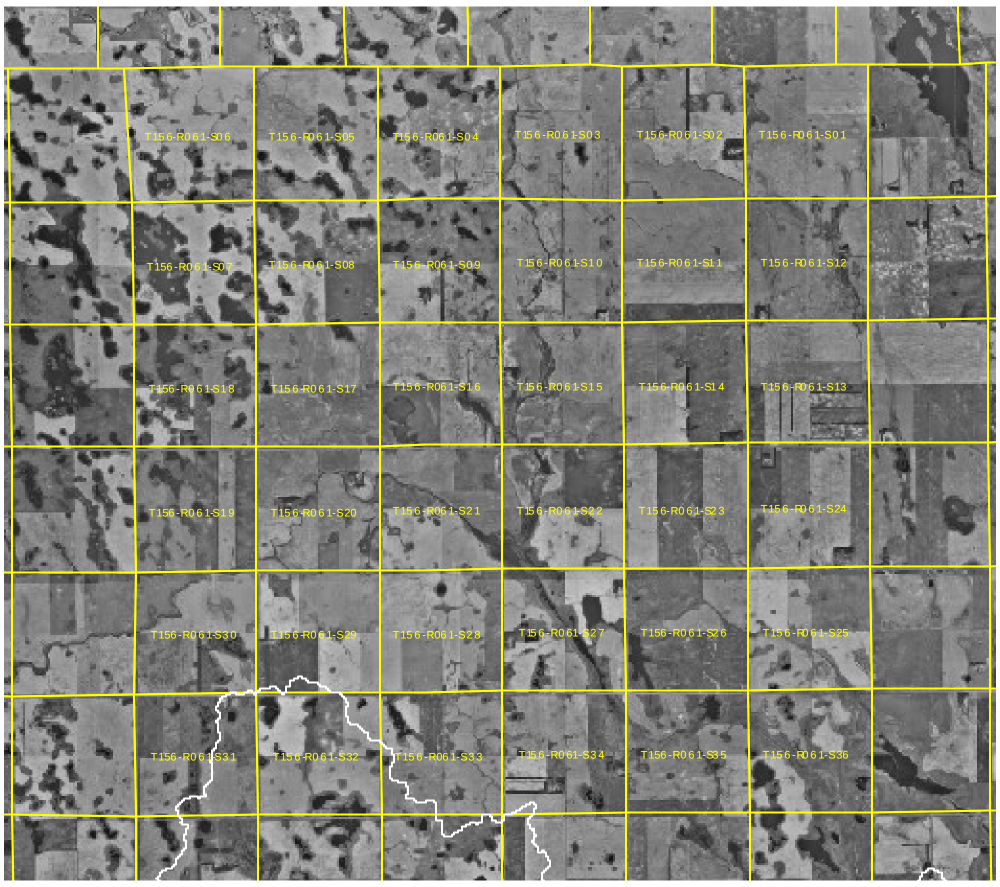
Figure B10. 996 wetlands were placed in the Severe salinity hazard class based on the percentage of saline soils in the drained wetland. The vast majority of the drained wetlands are of limited storage volume. 85% of the wetlands in the Severe hazard category have less than 10 acre-feet of storage. The data are log normally distributed. The raw data are strongly skewed to the lower values (large positive skewness) with the majority of values less than the mean (high positive kurtosis). Log transformed data are normally distributed. The data suggest that most of the storage volume lies in larger wetlands. Data are exclusive of storage volumes for wetlands in Benson and Pierce counties.

Soil Salinization Hazards Associated with Devils Lake Flood Damage Reduction Alternatives:

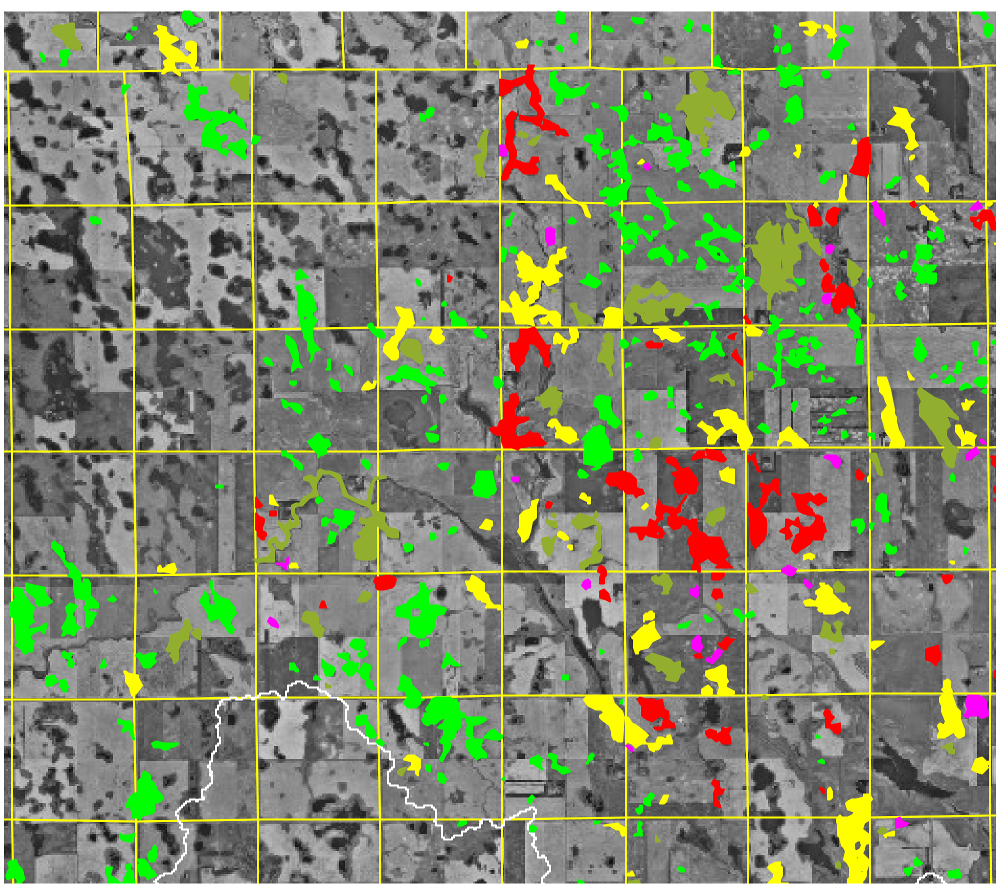
Upper Basin Storage

Appendix C

Figure C1.
Wetlands identified by Buffer and Wetland Soil Salinization Hazard classes. T156N R051W, Ramsey County, ND

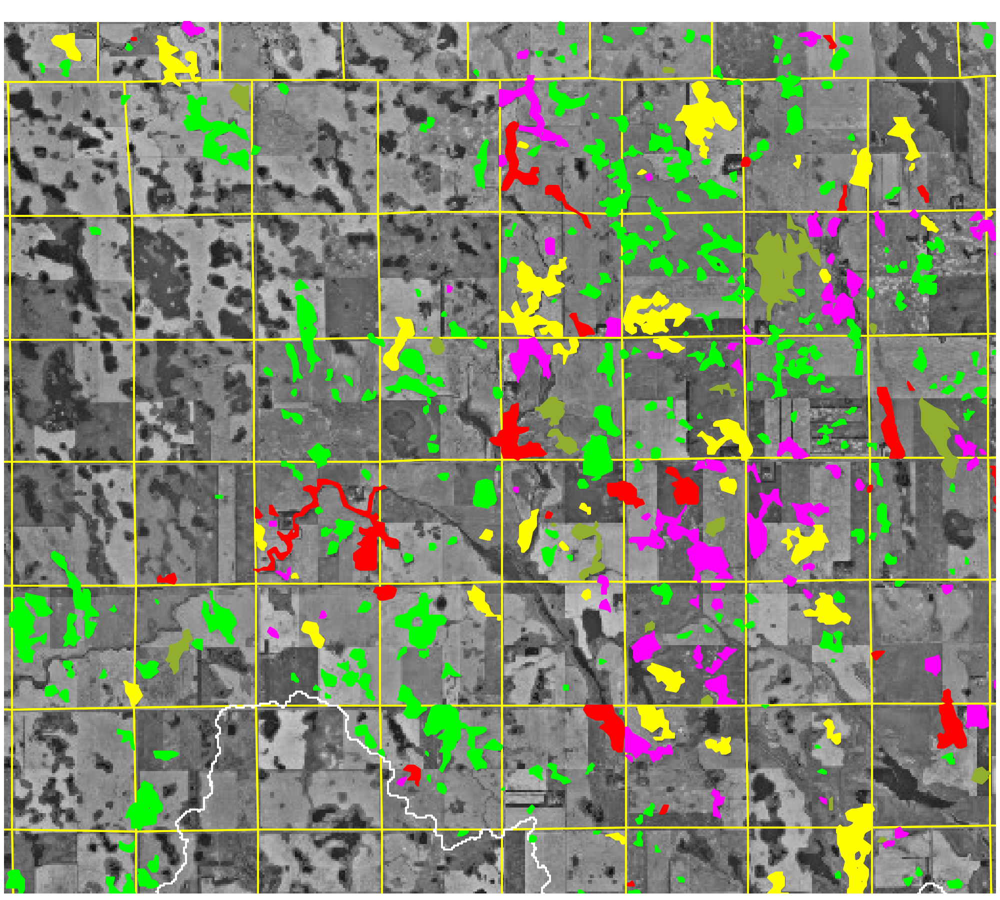


Wetland polygons from West Consultants, Inc.
Soils data from interim NRCS SSURGO GIS data.
Note that several wetlands move from Buffer Hazard Class 3 to Wetland Hazard Class 4. Buffers in Hazard Class 3 contain a smaller percentage of saline soils in these cases. See Figures C2 and C3.



Legend: Buffer Soil Salinization Hazards

- Buffer Hazard Class 0; None/Slight, 0-5% Saline Soils
- Buffer Hazard Class 1:, Low, >5 - 25% Saline Soils
- Buffer Hazard Class 2; Moderate, >25 - 50% Saline Soils
- Buffer Hazard Class 3; High, >50 - 75% Saline Soils
- Buffer Hazard Class 4; Severe; >75 - 100% Saline Soils
- Section Lines



Legend: Wetland Salinization Hazards

- Wetland Hazard Class 0; None/Slight, 0-5% Saline Soils
- Wetland Hazard Class 1:, Low, >5 - 25% Saline Soils
- Wetland Hazard Class 2; Moderate, >25 - 50% Saline Soils
- Wetland Hazard Class 3; High, >50 - 75% Saline Soils
- Wetland Hazard Class 4; Severe; >75 - 100% Saline Soils
- Section Lines

1 0 1 2 3 4 5 6 Miles

PETERSON ENVIRONMENTAL CONSULTING, INC

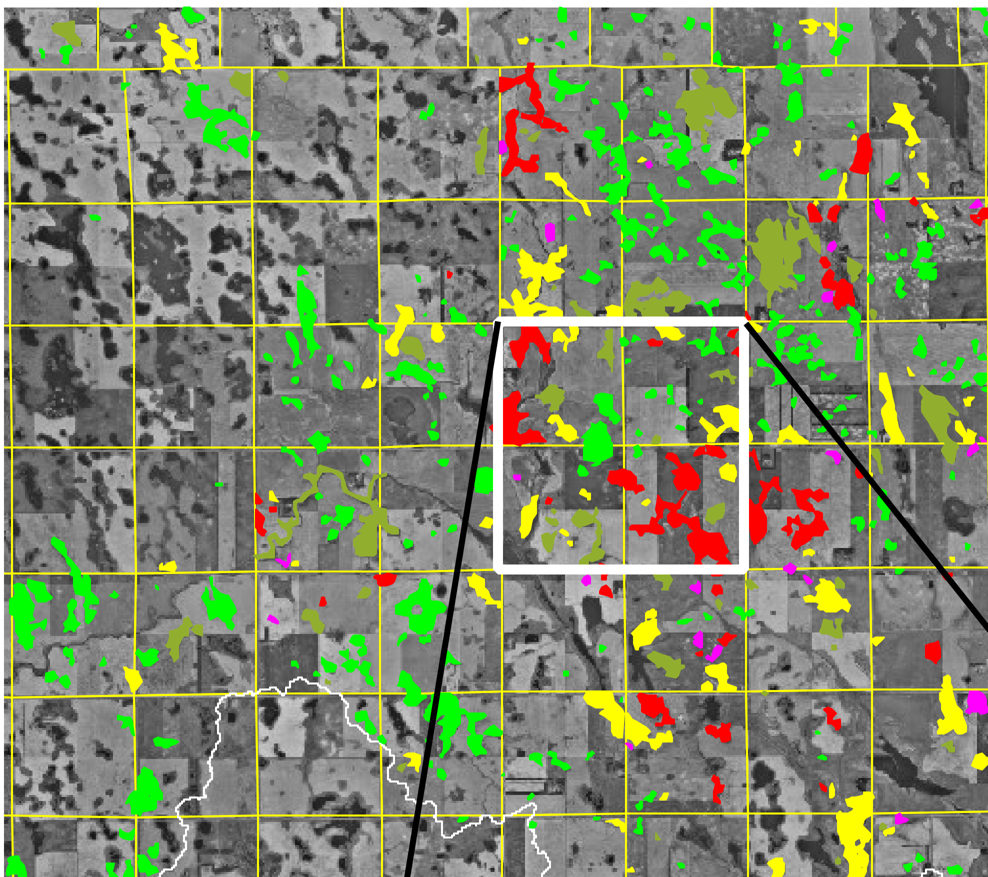
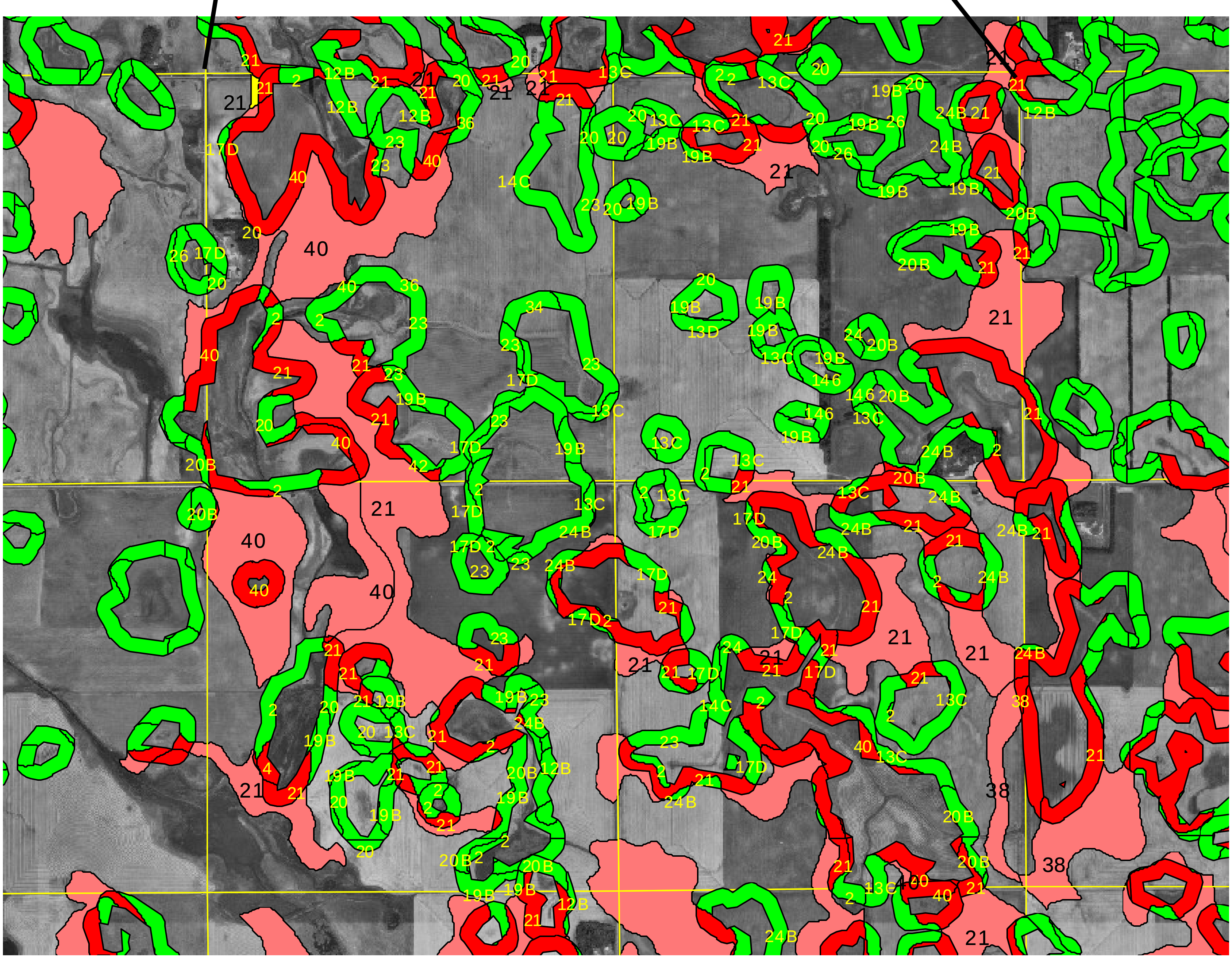


Figure C2.
Wetlands soils in Buffer Soil Salinization Hazard classes.
T156N R061W,
Sections 14, 15, 22, 23
Ramsey County, ND

Legend: Buffer Soil Salinization Hazards

- Buffer Hazard Class 0; None/Slight, 0-5% Saline Soils
- Buffer Hazard Class 1:, Low, >5 - 25% Saline Soils
- Buffer Hazard Class 2; Moderate, >25 - 50% Saline Soils
- Buffer Hazard Class 3; High, >50 - 75% Saline Soils
- Buffer Hazard Class 4; Severe; >75 - 100% Saline Soils
- Section Lines



Soil Map Unit Legend
(Map units identified only for soils within buffer polygons)

2 - Parnell sicl
12B - Barnes-Svea l, 3-6% slopes
13C - Barnes-Buse l, 6-9% slopes
14C - Svea-Sioux l, 1-9% slopes
17D - Sioux-Buse l, 9-15% slopes
19B - Svea-Buse l, 1-3% slopes
20B - Hamerly-Svea l, 3-6% slopes
21 - Vallers Hamerly l, Saline
23 - Hamerly-Cresbard l, 1-3
24B - Barnes-Cresbard l, 3-6% slopes
26 - Vallers-Parnell-Tonka Complex, 0-3% slopes
34 - Aberdeen sil
40 - Colvin-Aberdeen sil
146 - Hamerly-Tonka Complex, 0-3% slopes

Red = Saline soil or saline major component
Light Red = Saline soils adjacent to buffers
Green = Non-saline

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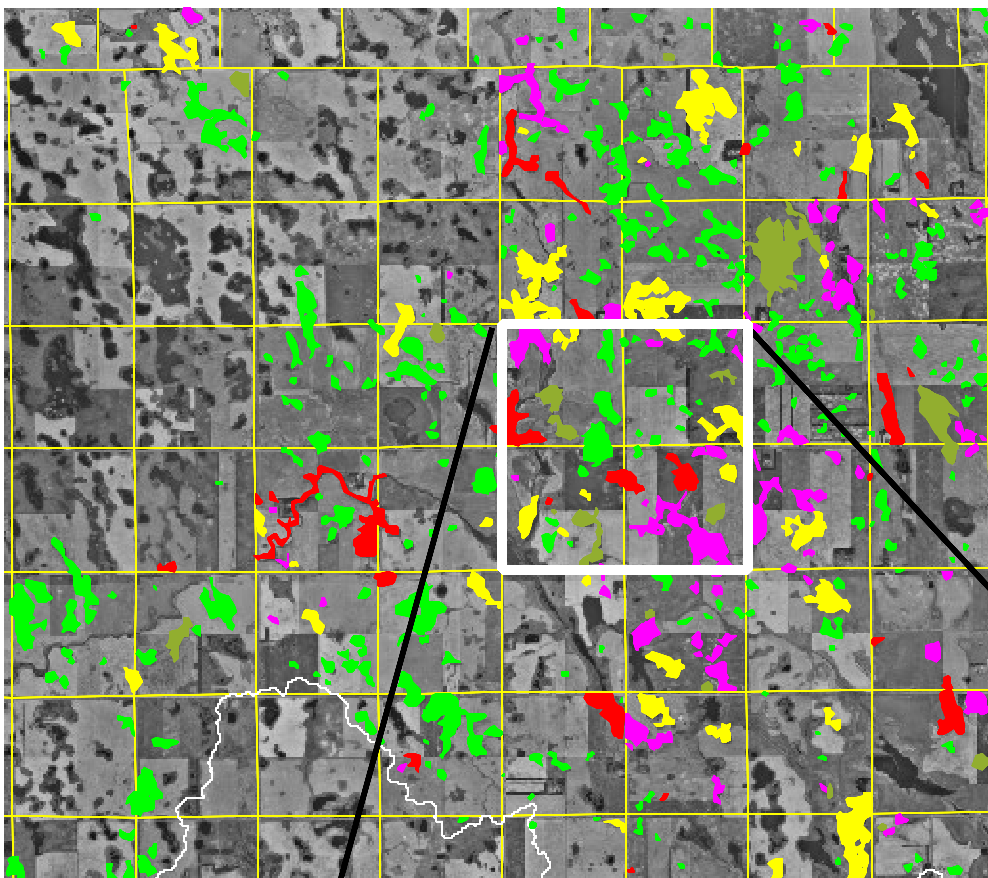
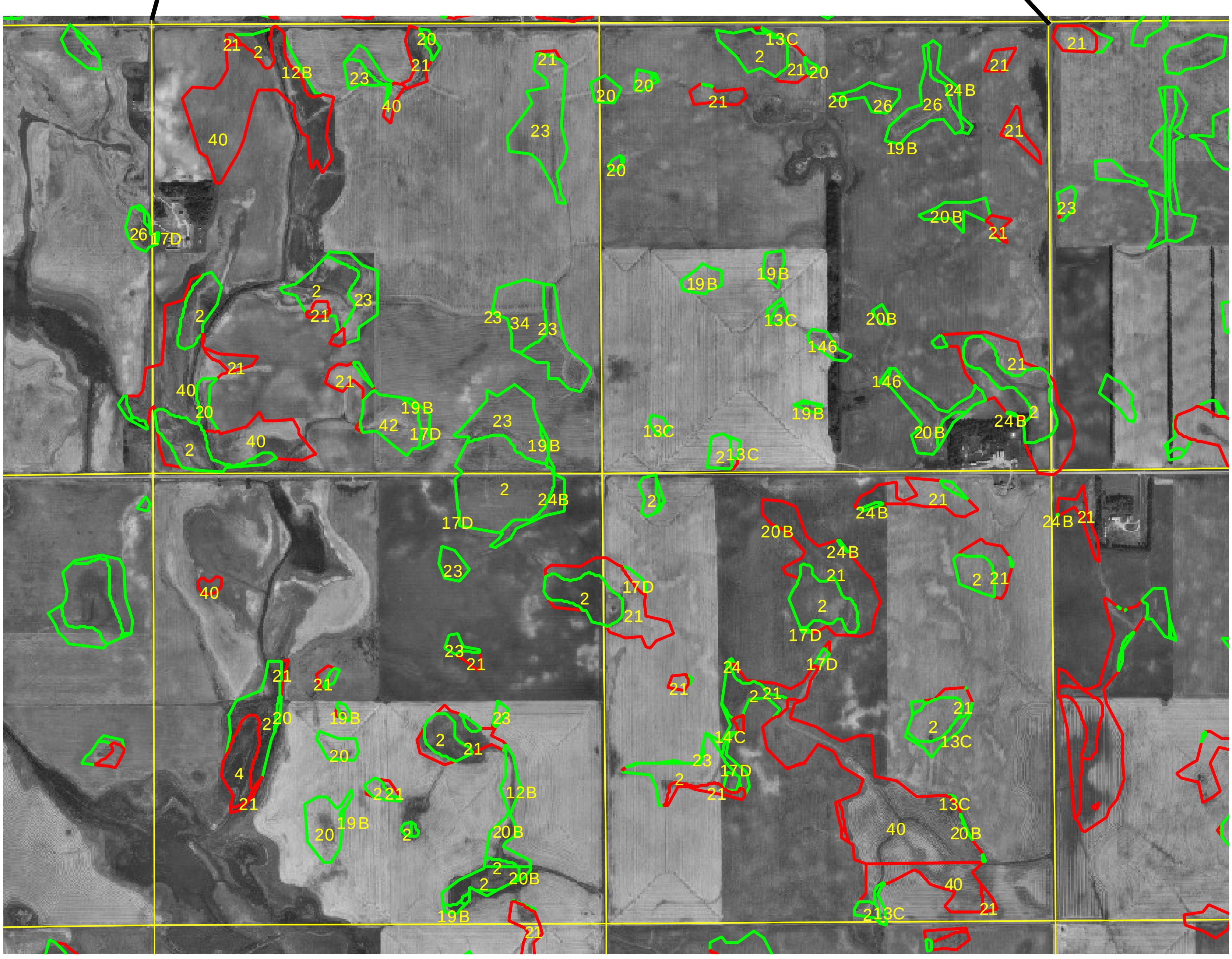


Figure C3.
Wetlands soils in Wetland Soil Salinization Hazard classes. T156N R061W, Sections 14, 15, 22, 23 Ramsey County, ND

Legend: Wetland Salinization Hazards

- Wetland Hazard Class 0; None/Slight, 0-5% Saline Soils
- Wetland Hazard Class 1:, Low, >5 - 25% Saline Soils
- Wetland Hazard Class 2; Moderate, >25 - 50% Saline Soils
- Wetland Hazard Class 3; High, >50 - 75% Saline Soils
- Wetland Hazard Class 4; Severe; >75 - 100% Saline Soils
- Section Lines



Soil Map Unit Legend
(Map units identified only for soils within wetland polygons)

2 - Parnell sicl
12B - Barnes-Svea l, 3-6% slopes
13C - Barnes-Buse l, 6-9% slopes
14C - Svea-Sioux l, 1-9% slopes
17D - Sioux-Buse l, 9-15% slopes
19B - Svea-Buse l, 1-3% slopes
20B - Hamerly-Svea l, 3-6% slopes
21 - Vallers Hamerly l, Saline
23 - Hamerly-Cresbard l, 1-3
24B - Barnes-Cresbard l, 3-6% slopes
26 - Vallers-Parnell-Tonka Complex, 0-3% slopes
34 - Aberdeen sil
40 - Colvin-Aberdeen sil
146 - Hamerly-Tonka Complex, 0-3% slopes

Red = Saline soil or saline major component

Green = Non-saline

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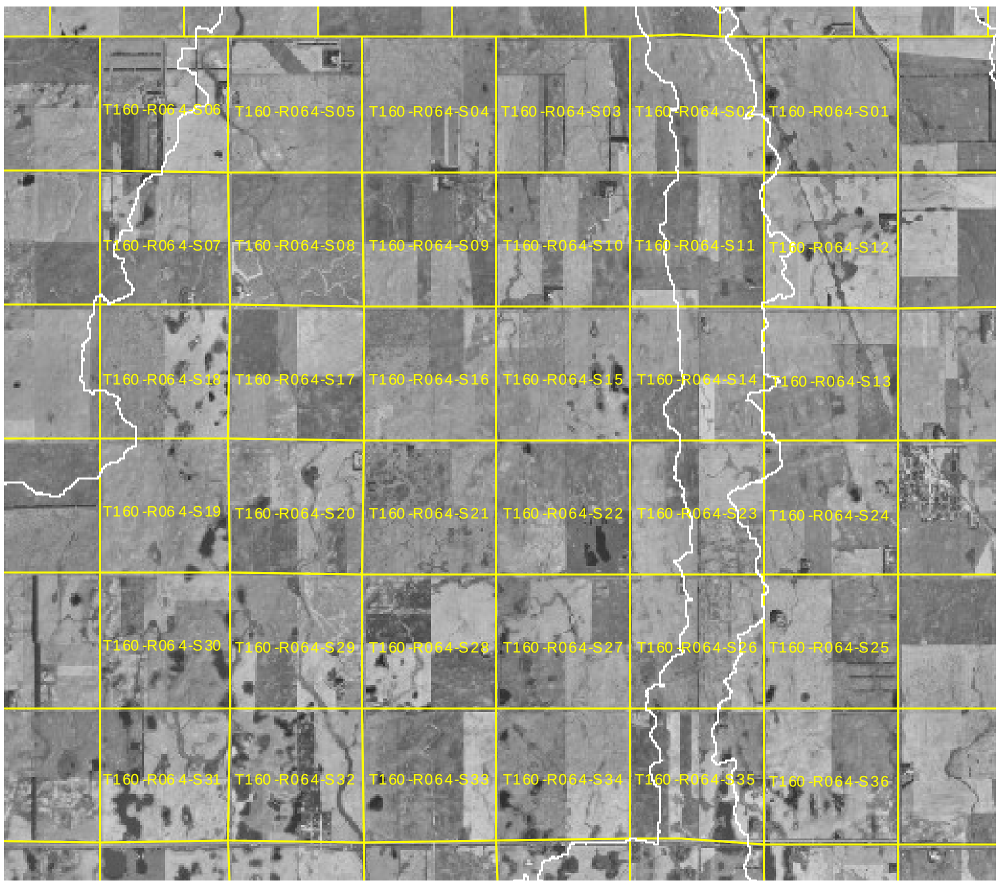
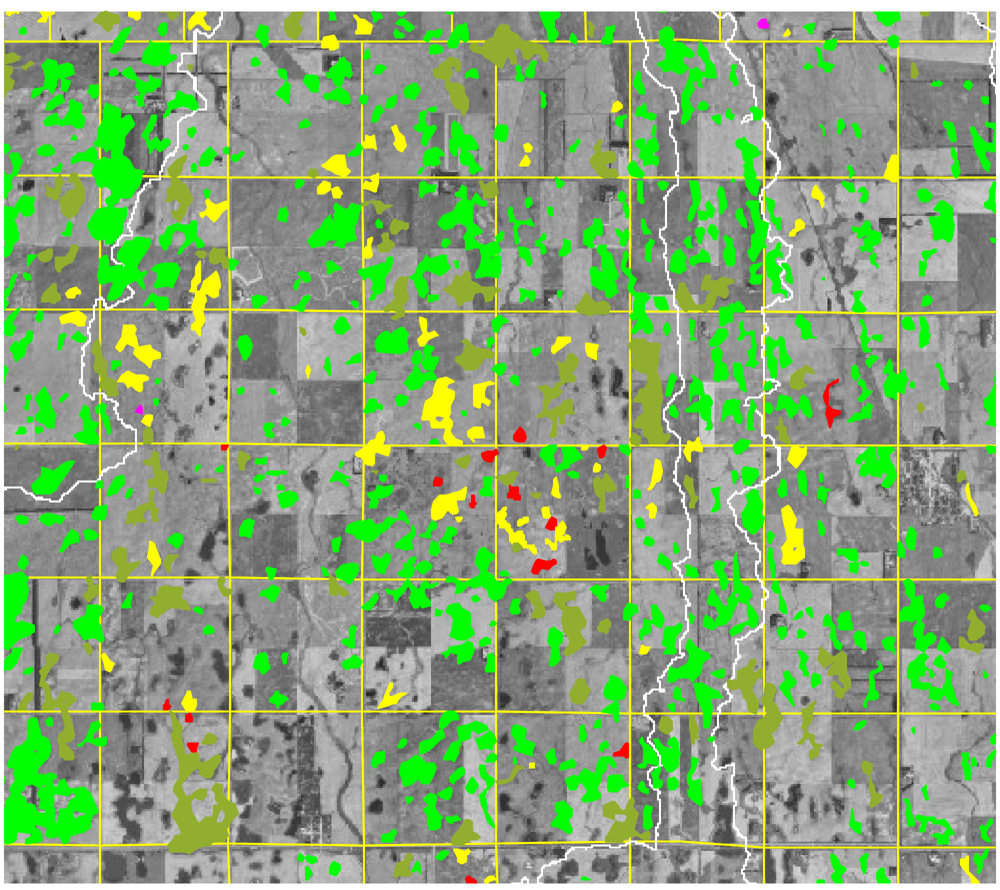


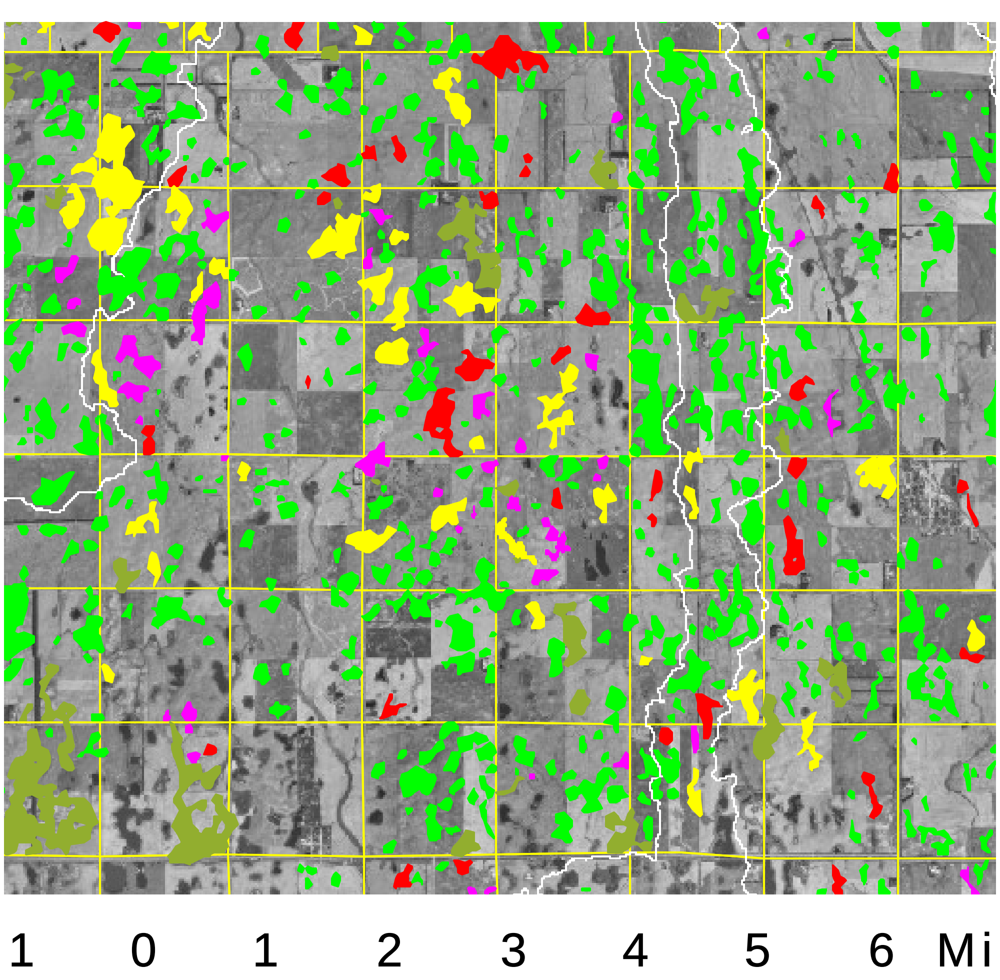
Figure C4. Wetlands identified by Buffer and Wetland Soil Salinization Hazard classes. T160N R064W, Cavalier County, ND

Wetland polygons from West Consultants, Inc. Soils data from interim NRCS SSURGO GIS data. Note that several wetlands move from Buffer Hazard Class 3 to Wetland Hazard Class 4. Buffers in Hazard Class 3 contain a smaller percentage of saline soils in these cases. See Figures C5 and C6.



Legend: Buffer Soil Salinization Hazards

- Buffer Hazard Class 0; None/Slight, 0-5% Saline Soils
- Buffer Hazard Class 1:, Low, >5 - 25% Saline Soils
- Buffer Hazard Class 2; Moderate, >25 - 50% Saline Soils
- Buffer Hazard Class 3; High, >50 - 75% Saline Soils
- Buffer Hazard Class 4; Severe; >75 - 100% Saline Soils
- Section Lines



1 0 1 2 3 4 5 6 Miles

Legend: Wetland Salinization Hazards

- Wetland Hazard Class 0; None/Slight, 0-5% Saline Soils
- Wetland Hazard Class 1:, Low, >5 - 25% Saline Soils
- Wetland Hazard Class 2; Moderate, >25 - 50% Saline Soils
- Wetland Hazard Class 3; High, >50 - 75% Saline Soils
- Wetland Hazard Class 4; Severe; >75 - 100% Saline Soils
- Section Lines

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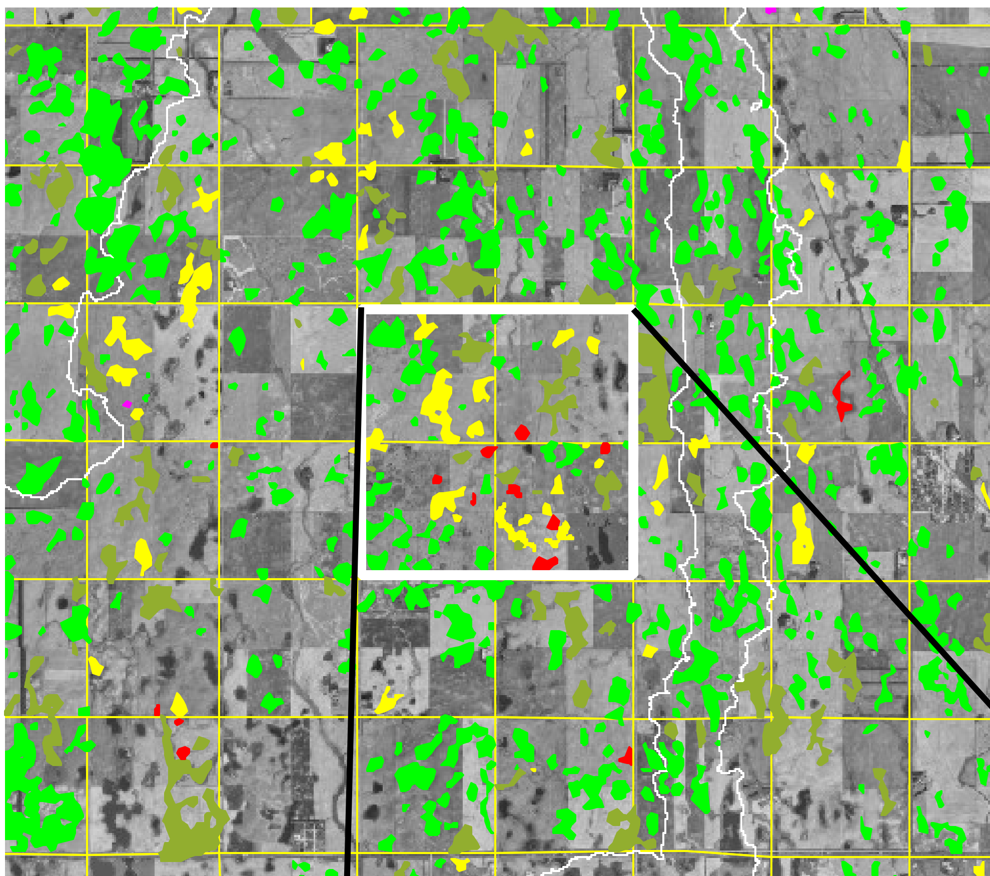
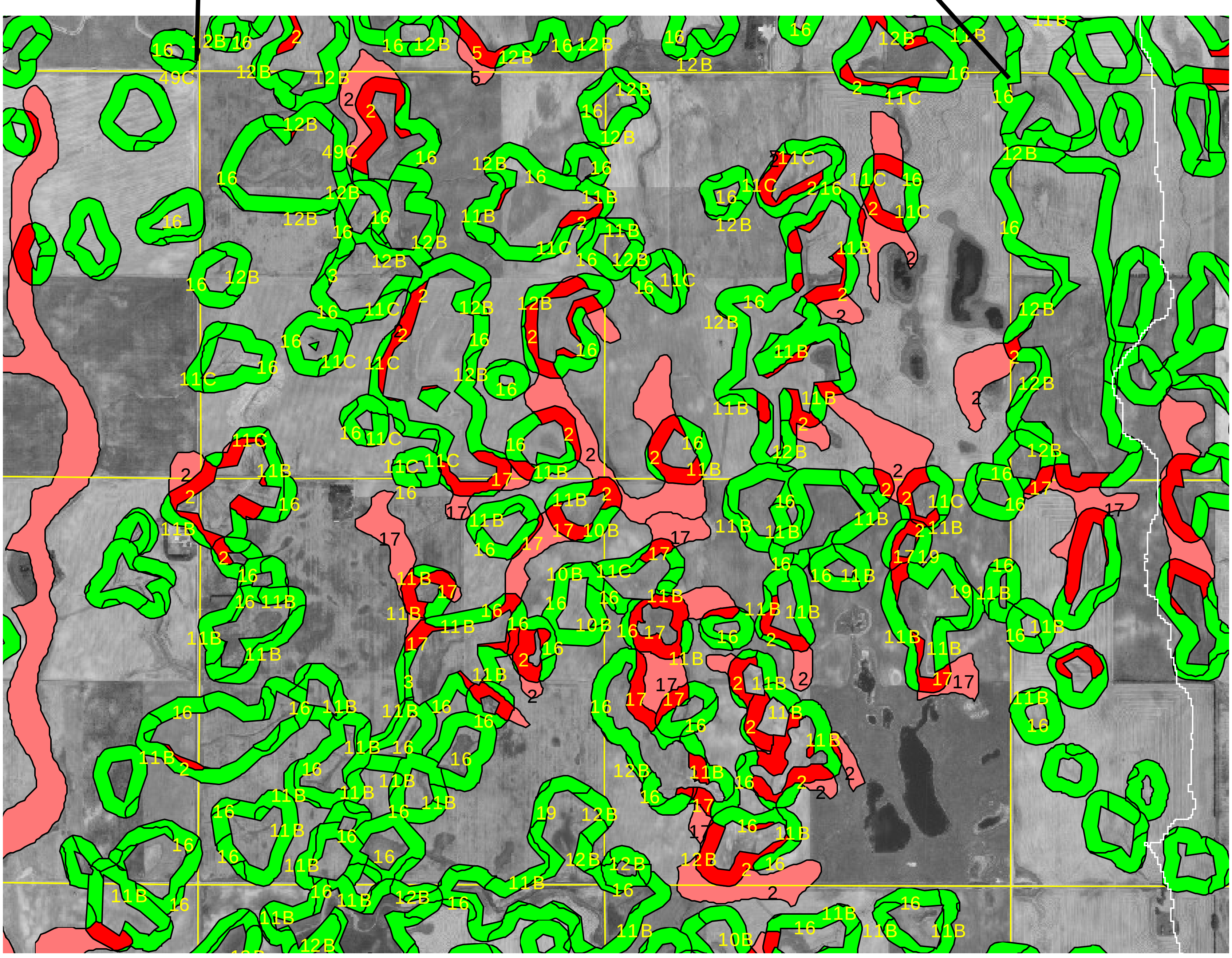


Figure C5.
Wetlands soils in Buffer Soil Salinization Hazard classes. T160N R064W, Sections 15, 16, 21, 22 Cavalier County, ND

Legend: Buffer Soil Salinization Hazards

- Buffer Hazard Class 0; None/Slight, 0-5% Saline Soils
- Buffer Hazard Class 1:, Low, >5 - 25% Saline Soils
- Buffer Hazard Class 2; Moderate, >25 - 50% Saline Soils
- Buffer Hazard Class 3; High, >50 - 75% Saline Soils
- Buffer Hazard Class 4; Severe; >75 - 100% Saline Soils
- Section Lines



Soil Map Unit Legend
(Map units identified only for soils within buffer polygons)

2 - Vallers (Saline)-Parnell Complex
11B - Svea-Buse l, 3-6% slopes
11C - Svea-Buse l, 6-9% slopes
12B - Barnes-Buse l, 3-6% slopes
16 - Hamerly-Tonka l, 0-3% slopes
17 - Vallers-Hamerly l (Saline), 0-3% slopes
19 - Hamerly-Cresbard l, 1-3% slopes
20B - Cresbard-Svea l, 3-6% slopes

Red = Saline soil or saline major component
Light Red = Saline soils adjacent to buffers
Green = Non-saline

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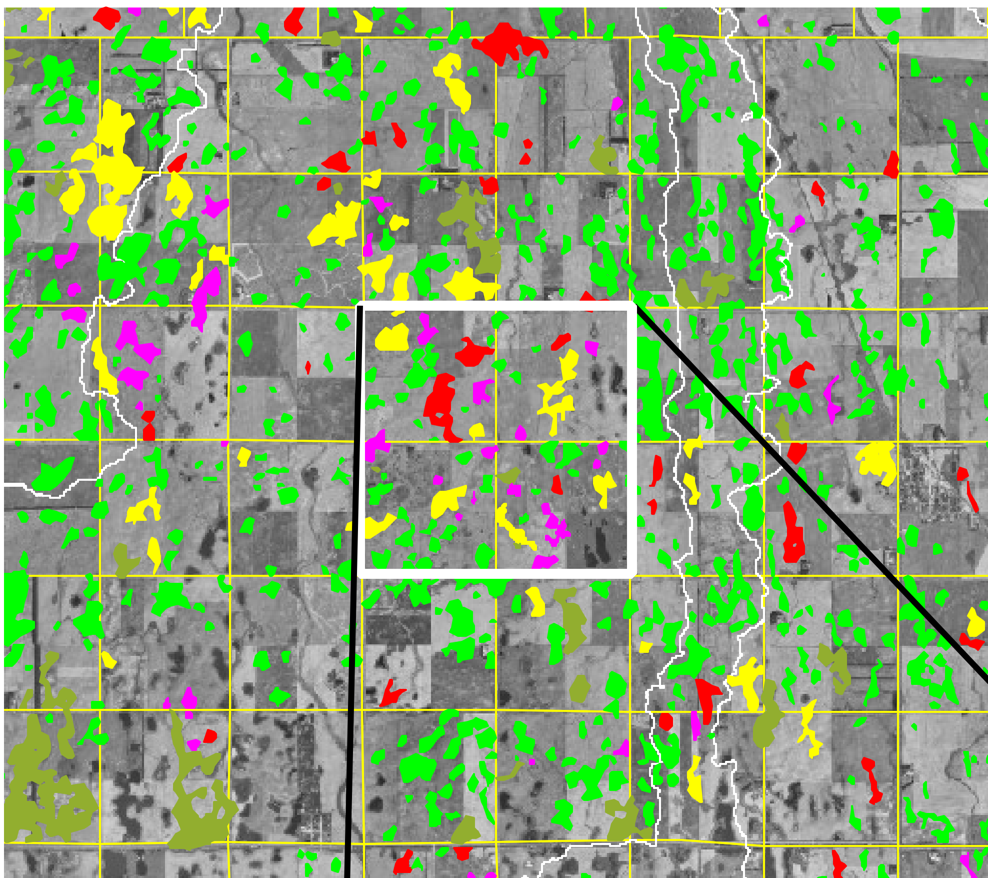
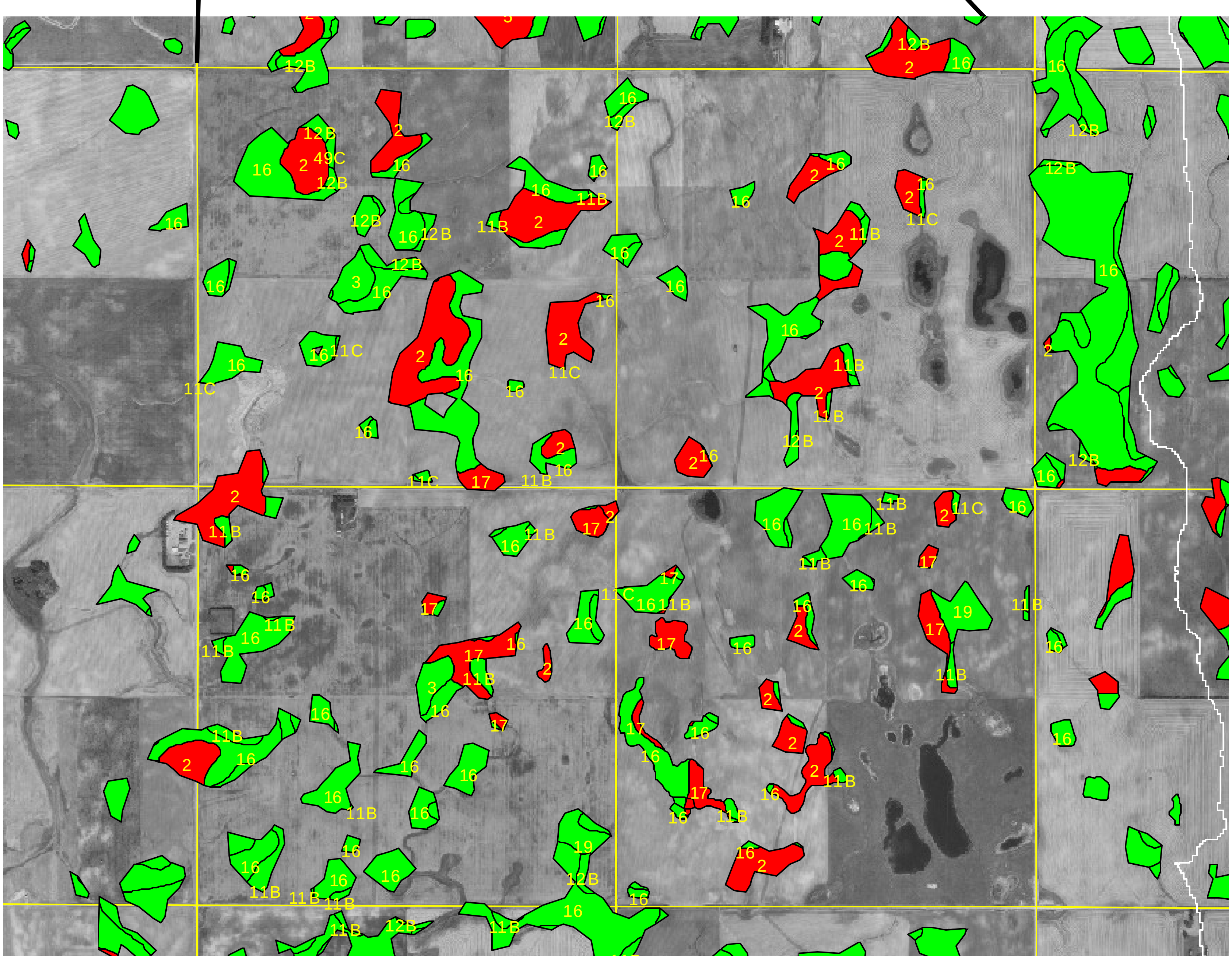
Figure C6.
Wetlands soils in Wetland Soil Salinization Hazard classes.
T113N R1123W,
Sections 15, 16, 21, 22
Cavalier County, ND



Legend: Wetland Salinization Hazards

- Wetland Hazard Class 0; None/Slight, 0-5% Saline Soils
- Wetland Hazard Class 1:, Low, >5 - 25% Saline Soils
- Wetland Hazard Class 2; Moderate, >25 - 50% Saline Soils
- Wetland Hazard Class 3; High, >50 - 75% Saline Soils
- Wetland Hazard Class 4; Severe; >75 - 100% Saline Soils
- Section Lines



Soil Map Unit Legend
(Map units identified only for soils within wetland polygons)

2 - Vallers (Saline)-Parnell Complex
11B - Svea-Buse l, 3-6% slopes
11C - Svea-Buse l, 6-9% slopes
12B - Barnes-Buse l, 3-6% slopes
16 - Hamerly-Tonka l, 0-3% slopes
17 - Vallers-Hamerly l (Saline), 0-3% slopes
19 - Hamerly-Cresbard l, 1-3% slopes
20B - Cresbard-Svea l, 3-6% slopes

Red = Saline soil or saline major component

Green = Non-saline

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