A DIGITAL METHOD to INVENTORY CONVERTED WETLANDS

Minnesota
Department of Natural Resources
Division of Waters

June 1997

A Digital Method to Inventory Converted Wetlands

by
Kara M. Dunning
and
LLoyd P. Queen

St. Paul, MN
June 1997

Minnesota
Department of Natural Resources
Division of Waters

This information is available in an alternative format upon request.

Equal opportunity to participate in and benefit from programs of the Minnesota Department of Natural Resources is available to all individuals regardless of race, color, national origin, sex, sexual orientation, marital status, status with regard to public assistance, age or disability. Discrimination inquiries should be sent to: MN/DNR, 500 Lafayette Road, St. Paul, MN 55155-4031; or the Equal Opportunity Office, Department of the Interior, Washington, D.C. 20240.

The DNR Information Center phone numbers:
Twin Cities: (612) 296-6157
MN Toll Free: 1-800-766-6000
Telecommunication Device for the Deaf:
(612) 296-5484
MN Toll Free: 1-800-657-3929

Department of
Natural Resources
Division of Waters

Printed on Recycled Paper

Kara M. Dunning, Boise Cascade Corporation, 400-3rd Avenue East, International Falls, MN, 56649.
phone: (218) 285-5650 email: Kmdunning@aol.com

LLoyd P. Queen. University of Montana, School of Forestry, Missoula, MT, 59812.
phone: (406) 243-2709 email: lpqueen@ntsg.umt.edu

A Digital Method to Inventory Converted Wetlands

Kara M. Dunning and LLoyd P. Queen
Respectively, former Research Assistant and Research Associate
University of Minnesota, St. Paul, MN

Current Addresses: Boise Cascade Corporation, 400 3rd Avenue East, International Falls, MN 56649;
School of Forestry, University of Montana, Missoula, MT 59812

This report summarizes the results of a three year project entitled, "*Pilot Project for a Statewide Inventory of Drained Wetlands*", funded by the U.S. Environmental Protection Agency Clean Waters Act Section 104(b) grant (CD995592501) for the development of state wetland protection programs through the Minnesota Department of Natural Resources, Divisions of Fish & Wildlife and Waters. The goal of this project was to define a method of inventory for converted wetlands and explore data requirements and availability.

Abstract

A digital method was developed for the inventory of converted wetlands using geographic information system (GIS) technologies. There is a heightened interest in wetland restoration and a growing need for resource managers to assess wetland losses and select appropriate wetland restoration sites. This method uses digital GIS coverages of hydric soils, the National Wetlands Inventory, and artificial drainage to identify presettlement wetlands. Each basin identified as a converted wetland is assigned a likelihood value indicating the level of confidence that the basin really was a converted wetland.

The method was tested in three Minnesota study areas. Wetland extent determined by the digital method was verified with converted wetland inventories derived from aerial photographs in the Chisago County and Kittson County study areas. The correspondence between the converted wetland inventory data and the verification data set was 64 percent for the Chisago County study area and over 90 percent for the Kittson County study area. It was not possible to verify the results of the Cottonwood County study area because virtually all wetlands in this area were converted to agricultural land uses prior to the earliest available aerial photographs. The greatest challenge to landscape-level GIS inventories is the limited availability of digital data due to the large commitment of resources needed to develop them.

Introduction

There has been an increase in public awareness of the beneficial functions and values of wetland ecosystems for several decades. This awareness has led to wetland protection legislation and a heightened interest in wetland restoration and conservation across the United States (National Research Council 1995). The availability of digital databases and geographic information systems (GIS) technology has greatly improved the ability to accurately collect and manage data for natural resource management.

Like any decision-making process, it is important that wetland conservation practices are based on accurate and timely information. One critical information void in the United States is the lack of spatial data indicating the location and extent of converted wetlands. Converted wetlands are wetlands that have been artificially drained, cultivated, filled, or otherwise seriously disturbed such that they no longer meet the three parameter wetland criteria (ie.presence of hydric soil, hydrophytic vegetation, and wetland hydrology) (Cowardin et al. 1979). While broad estimates of wetland losses are available (Tiner 1984; Dahl 1990), a detailed and spatially explicit inventory of converted wetlands is critically needed to assess wetland losses, select appropriate restoration sites, and provide information for natural resource decision-makers. No widely accepted method of landscape-level inventory for converted wetlands is currently available.

With approximately 50 percent of presettlement wetlands remaining (Minnesota Department of Natural Resources 1988; Johnston 1989; Dahl 1990), Minnesota is an excellent choice for a pilot implementation of a digital method of inventory of converted wetlands. In Minnesota, the percentage of remaining presettlement wetlands range from virtually none in the southern and western parts of the state to over 95 percent in the north and northeast (Anderson and Craig 1984). Minnesota was one of the first states to have complete coverage of digital National Wetlands Inventory (NWI) data. Also, with the enactment of the Wetland Conservation Act (WCA) in 1991, Minnesota became a leader in wetland protection with detailed wetland replacement and mitigation banking standards (Minnesota Wetland Conservation Act 1991).

The WCA requires replacement of newly impacted wetland basins at ratios determined by the percentage of remaining presettlement wetlands in the impacted county or watershed. Anderson and Craig's (1984) report on the energy potential of Minnesota's peatlands is the current source of information on percentages of remaining presettlement wetlands for the State of Minnesota. This report used data derived from analysis of the 1:250,000 scale Minnesota Soils Atlas County Series Maps (University of Minnesota circa 1970). The data were developed as a forty-acre resolution raster GIS layer within the Minnesota Land Management Information System (MLMIS). Hydric soils data were summarized only at the county level, resulting in only one remaining presettlement wetland value per county in Minnesota. Distribution of remaining presettlement wetlands within counties or by ecological land units or watersheds cannot presently be determined. It is clear that Minnesota resource managers and resource policy makers need converted wetlands data that is more precise and can be analyzed by units defined by ecological criteria.

Three primary sources of data are used to assess presettlement landscape characteristics (including presettlement wetland extent): 1) public land survey notes, 2) aerial photograph interpretation, and 3) soil survey data. First, surveyor notes from the original public land survey (PLS) are commonly used to characterize presettlement vegetation (Marschner 1930; Lorimer 1977; Noss 1985). This method was recently used by Cromer et al. (1993) to map historical wetlands of the Saginaw Bay Watershed in Michigan. One substantial problem with this method is that PLS notes only contain information about conditions along survey section lines and near section corners. To establish presettlement conditions for converted wetland inventories, boundaries of wetlands must be interpolated from those point data. The General Land Office required surveyors to record the quantity and location of swamps in states affected by the Swamp Acts of 1849, 1850, and 1860. Since the Swamp Act granted federally-owned wetland areas over 40-acres in size to states, there may have been bias in land descriptions leading to an overestimation of presettlement wetland extent. Additionally, possible inconsistencies between surveyors, anomalous precipitation during the survey years, and fraudulent surveys must also be considered (Galatowitsch 1990).

Second, aerial photographs have been used to assess changes in presettlement conditions (assuming information on presettlement conditions is available) occurring in the recent past. The earliest available photographs usually date to the 1930s. Vaughn (1994, personal communication) used aerial photographs to map wetland conversions in Chisago County, Minnesota. Williams and Lyon (1995) used aerial photographs from seven dates to map wetland changes in the St. Mary's River Basin in Michigan. This method may have limited utility in conversion analyses for some areas where a large number of wetlands were converted before the 1930s.

Third, soils data may be a reliable reference to presettlement wetland and hydrologic conditions. Soil morphology does not change quickly with changes in hydrology (Bell 1994, personal communication; Tiner 1996) and thus can be useful in the mapping of converted wetlands. Hewes (1951) mapped the extent of the northern wet prairie using soil survey data. Burns (1954) used soil survey data to make inferences about artificial drainage in Blue Earth County, Minnesota. Galatowitsch and van der Valk (1994) stated that soil survey maps are often the only way to obtain essential information such as size, shape, boundaries, and type of wetland formerly present on a tract of land. Hydric soils are used to identify wetlands in Connecticut and New Hampshire (Tiner 1996). Connecticut considers all poorly-drained and very poorly-drained alluvial and floodplain soils as wetlands. Many municipalities in New Hampshire use hydric soils to identify wetlands (Tiner 1996).

Two limitations of using soil data to predict wetland extent include: 1) precision and resolution of existing soil maps and 2) probable overestimation of the extent of converted-wetlands. Mapped soil units often contain inclusions of hydric soil that are too small to be mapped as distinct soil polygons (Natural Resources Conservation Service 1995). These inclusions would be missed by an automated mapping process based solely on soil data. Since hydric soils often extend slightly past the wetland boundary where wetland vegetation and wetland hydrologic conditions are present, the area of converted wetlands defined by hydric soil boundaries may be slightly overestimated (Bell 1994, personal communication; Tiner 1997).

Several researchers have overlaid NWI and soil survey data to determine wetland losses (Moorhead 1991; Moorhead and Cook 1992; Bailey 1994). Moorhead mapped converted wetlands at the landscape scale in two coastal counties of North Carolina and found that a significant percentage of historic wetlands were lost (65 percent and 38 percent) and one third of remaining wetlands had been ditched. Bailey created a GIS layer of presettlement wetland extent for a 30 square mile study area in central Florida using 1916 soil data and 1938 aerial photographs. By comparing the presettlement wetland extent to current wetland extent he was able to map converted wetlands.

The objective of this study was to develop and test a method of inventory for converted wetlands that could potentially be used statewide. A method was developed describing the data requirements for GIS analyses summarizing the results of trial implementations at three study areas in Minnesota (Figure 1), and identifying the percentage of existing wetlands with altered hydrology in each of the study areas. A description of the verification process used to assess accuracy at two of the sites and the results are provided, along with a discussion on the limitations of the method and recommendations for implementation of the method at larger scales.

Existing Data

Based on the literature, three primary data layers were identified to be used in the digital method of inventory for converted-wetlands: 1) existing wetland inventory, 2) soil data, and 3) artificial

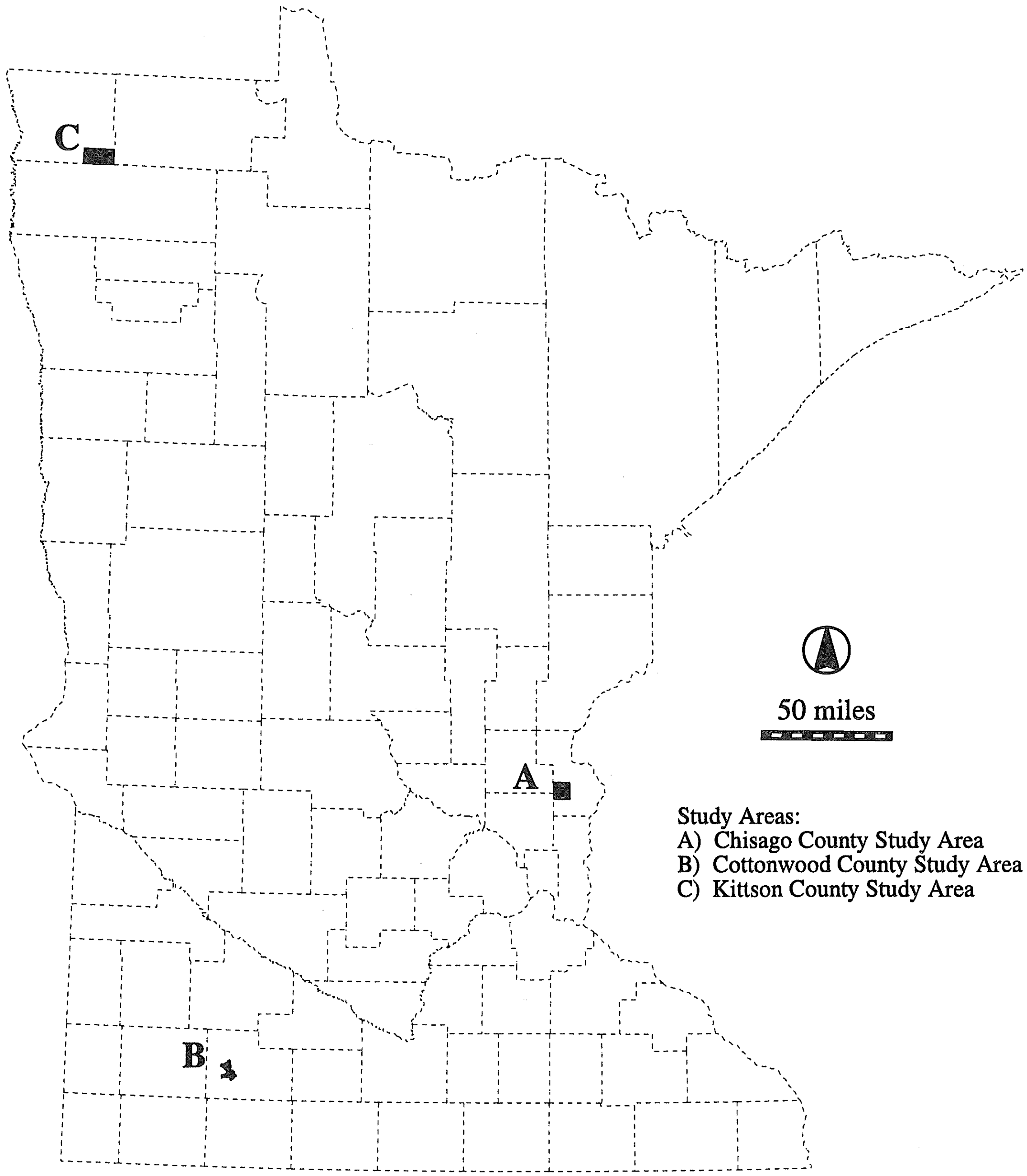


Figure 1. Location of the three converted wetland inventory study areas within the state of Minnesota.

drainage including both ditches and tile lines. In the mid-1970's, the U.S. Fish and Wildlife Service initiated the National Wetlands Inventory (NWI) project, a nationwide effort to map and classify wetlands for resource assessment. Minnesota has been completed. The NWI mapping process relies heavily on interpretation of National High Altitude Aerial Photography and some field verification (Santos 1994). Minnesota photos had a 1:58,000 to 1:80,000 scale and 1974 to 1984 source dates. NWI maps and digital NWI GIS data are currently available to the public for all of Minnesota from the Minnesota Land Management Information Center (LMIC) and via the Internet from U.S. Fish and Wildlife Service (http://www.nwi.fws.gov).

Most counties in Minnesota have a published modern soil survey produced by the USDA Natural Resources Conservation Service (NRCS) with over half having these data in a digital format as SSIS, EPPL7, or vector coverages potentially suitable for use in GIS analyses. Minnesota county soil surveys also use a soil classification protocol that includes a natural drainage classification (Appendix A). Natural drainage class is defined as follows: Drainage class refers to the frequency and duration of periods of saturation or partial saturation during soil formation, as opposed to altered drainage, which is commonly the result of artificial drainage or irrigation but may be caused by sudden deepening of channels or the blocking of drainage outlets (Natural Resources Conservation Service 1995). The state of Connecticut uses natural soil drainage classes to identify wetlands (Tiner 1996). Natural soil drainage classes are used in this automated converted wetland inventory method.

Open drainage ditches and underground tile lines have been widely used to drain and convert wetlands across the eastern half of the United States (United States Department of the Interior 1909; LeBarron 1942; Burns 1954; Johnston 1989; Smith et al. 1989; Wilen and Tiner 1993). Water table drawdown around open ditches has also been well documented (Averell and McGrew 1929; Boelter 1972; Boelter and Close 1974; and Bradof 1988). While it is known that artificial drainage causes water table drawdown, the degree to which this occurs under various soils and landscape conditions is less clear. Landowners frequently run ditches into wetlands to drain the marginal land which encircles the wetland basin. This can result in elevated wetland water elevations and adversely affect wetland margins. Surface drainage features such as grassed waterways and swales can also impact wetland areas which otherwise would have short periods of saturation or inundation.

Two areas in Minnesota have inventories of artificial drainage: Chisago County and South Central Minnesota. The Chisago County Drained Wetland Inventory Project (CCDWI) was a cooperative project between Minnesota DNR, U.S. Fish and Wildlife Service, and Ducks Unlimited. It mapped ditches and known tile lines for part of Chisago County. The Water Resources Center at Mankato State University (MSU) has created a digital inventory of major ditches and tile lines for a thirteen county area in south central Minnesota (Surface Water Hydrology Atlas Series 1993) excluding most private agricultural tile lines and designed contouring and grassed waterway drainages.

Private tile lines pose a unique problem for the development of any comprehensive converted wetland GIS because they are difficult to map. The earliest tile networks were laid by hand and were made of clay. Around mid-century, plastic tile and tile-laying machinery became available and dramatically changed the economics of laying tile. Generations of landowners have replaced and expanded original tile lines to improve drainage on their farms (Berg 1994, personal communication). Landowner's often do not have current and complete records describing the location of private tile lines and no other sources of data are available. For these reasons, tile lines are difficult to map even at a single farm scale.

The MSU Water Resources Center and the CCDWI data are the only fairly comprehensive maps of artificial drainage in Minnesota. U.S. Geological Survey 7.5' quadrangle maps contain information for some large ditches. County engineers or auditors have files for some public ditches. It is usually not possible to use these drawings for data development because the drawings are insufficiently precise and lack spatial coordinates. The drawings were generally drafted for planning purposes, and were usually not updated following ditch improvements or maintenance activities.

The best consistent source of data for mapping open drainage ditches appears to be aerial photographs. The USDA Farm Service Agency (FSA) offices maintains a series of annual aerial photographic slides for most agricultural counties in Minnesota. Typically these photos cover one square-mile. Ditches can be delineated via aerial photograph interpretation. A complete ground survey is required to verify ditch delineation because many linear features, including field lines, tree lines and fences can resemble ditches on aerial photography, and many early ditches that have not been maintained are now filled with brush and trees and have reduced potential to conduct water. Other sources of existing aerial photograph data include the University of Minnesota College of Natural Resources, University of Minnesota Map Library, Minnesota Department of Natural Resources (DNR) field offices, and the National High Altitude Photography Program.

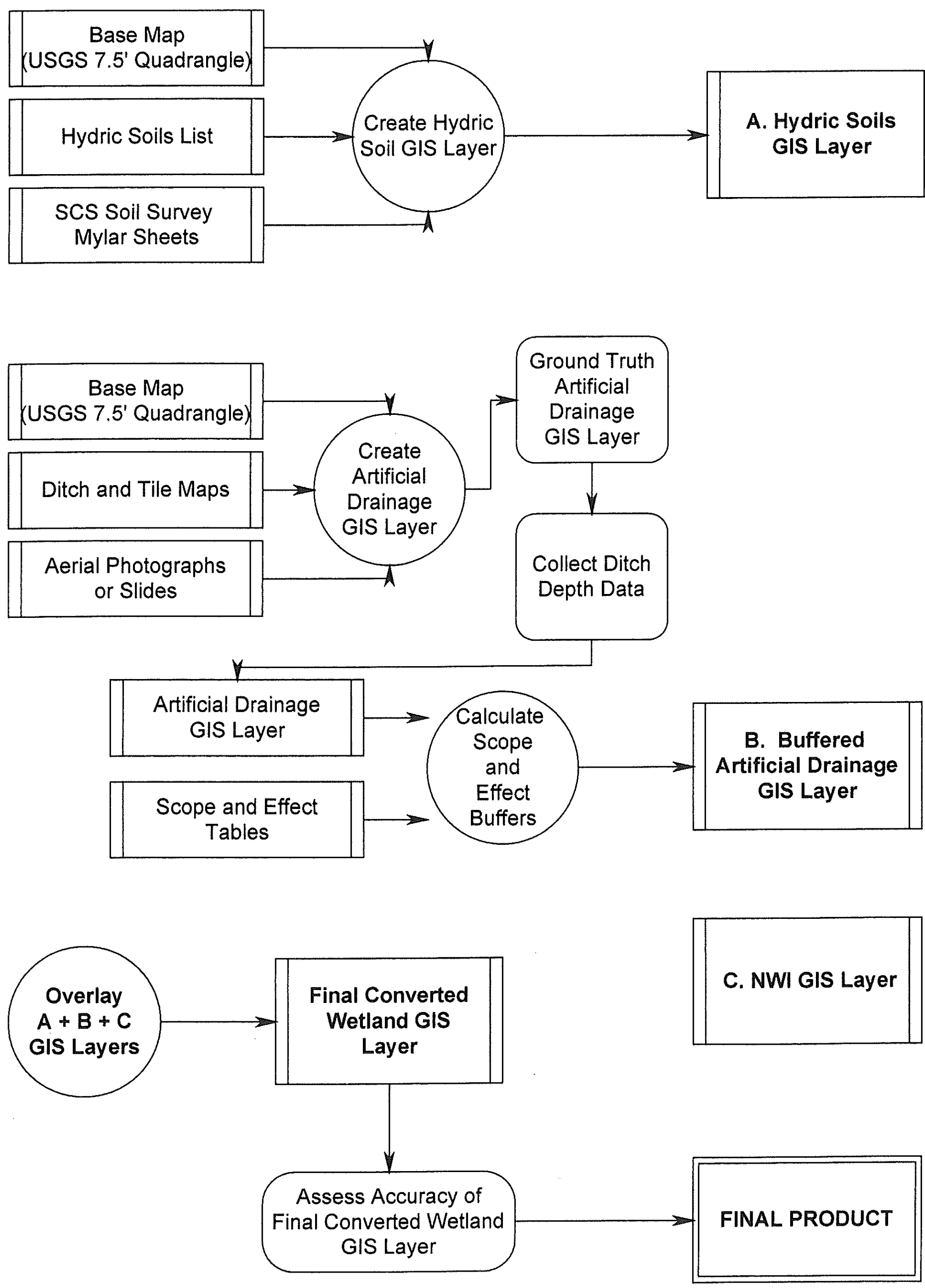
A procedure was developed to automate the determination of scope-and-effect (Jacobson 1990). Scope-and-effect is a process developed by the NRCS for estimating the lateral effect of ditches and tile lines on water table levels. Scope-and-effect was originally derived for agriculture drainage installations and has been adapted for use in converted wetland assessment. The process employs an equation to calculate lateral effect based on depth of ditch or tile and type of soil (Appendix B). Assumptions for the scope-and-effect equation include: 1) surface drainage is adequate; 2) within horizons, soil permeability is homogenous; 3) drainage ditches have adequate capacity to remove one-eighth inch of water from the area drained in twenty-four hours; and 4) if an impervious layer was not identified in the soil data, one is assumed at depth of 10 feet (Jacobson 1990).

Lord (1994, personal communication) expressed concern over the use of scope-and-effect to delineate disturbed wetland boundaries because of the associated assumptions, possible site specific conditions such as spoil bank compaction, and differences in effective growing season duration between adjacent organic and mineral soils. In spite of some concern about the use of scope-and-effect, it is commonly used in Minnesota by the NRCS, local government units, and the Minnesota Board of Water and Soil Resources to determine the extent of altered wetland hydrology on a site-specific basis.

Methods

The method used for the inventory of converted wetlands builds on Moorhead's (1991) efforts by adding an artificial drainage layer and scope-and-effect to his analytical process. All digitizing was done with PC ARC/INFO software and a minimum mapping unit of $25m^2$. All analyses were done with ARC/INFO (except where noted) on a SUN SPARC workstation. The resulting analytical process employs an overlay of three primary digital data layers. Hydric soil, NWI, and artificial drainage combined with scope-and-effect were used to identify presettlement wetlands (Figure 2).

Figure 2. This graphic is a process flow diagram of the converted wetland inventory method described in this report. It is intended to help resource managers understand the sequence of activities required to produce a converted wetland inventory and facilitate the division of data development tasks.



Non-orthorectified soils data were transferred from 1:20,000 and 1:15,840 scale soil survey mylar sheets onto 7.5' USGS topographic quadrangle maps using a Bausch and Lomb Zoom Transfer Scope. This transformation was done to bring the soil data to 1:24,000 scale and allow digitization from an orthorectified basemap. Hydric soils were identified using the national hydric soils list (Soil Conservation Service 1991). Hydric soil polygons were labeled with the unique soil survey label. Nonhydric soil polygons were collapsed into a single class. Soil data were digitized and their attributes were attached.

Chisago County study area ditch and tile line data were taken from the Chisago County Drained Wetland Inventory Project (CCDWI). The CCDWI was an existing drained wetlands inventory compiled by comparing historic aerial photographs to present day aerial photographs (Vaughn 1994). Both ditch and drained wetland data from this project were digitized to be used in this analysis and as a verification data set. The MSU Water Resources Center provided artificial drainage data in ARC/INFO format for the Cottonwood County study area. For the Kittson County study area, public and private ditches were mapped using 1993 USDA aerial photographs (8"=1 mile). Ditches were delineated on USGS 7.5' quadrangle maps and field-verified. At each 0.25-mile interval in the field, ditch depths were measured and recorded. Verified data were digitized and corresponding ditch depth attributes were attached. Collectively, the ditch and tile layers are referred to as artificial drainage coverages.

The Minnesota DNR, Division of Waters provided ARC/INFO format NWI data for the three study areas. The 1:24,000 scale NWI data are archived as individual 7.5' quadrangle coverages. NWI quadrangles for each study area were appended into a single GIS coverage of each study area.

Hydric soil and artificial drainage coverages were intersected. Jacobson provided a scope-and-effect table for soils in the study areas. This table listed the lateral effect of ditches based on ditch depth (two-foot intervals) and each hydric soil type. Lateral scope-and-effect buffer distances were determined for ditches using the ditch depth and soil type (Figure 3). These distances were used to compute buffers away from ditches in the GIS. Ditch buffers terminate either at a nonhydric soil or when they reach the extent of the ditch lateral effectiveness. Since no data were available for tile size, a standard 50-meter buffer for tile lines (Cottonwood County study area) was used. The buffered artificial drainage and soils coverages were intersected with the NWI coverage. Likelihood values were assigned to each resulting polygon via an ARC/INFO Arc Macro Language program (AML) written to implement likelihood classification decision rules (Figure 4).

The likelihood value is an ordinal classification indicating the likelihood of each polygon in the final coverage being a converted wetland based on input attribute criteria (Figure 4). There are five likelihood classes: 1) Existing Wetland, 2) Unlikely Converted Wetland, 3) Likely Converted Wetland, 4) Very Likely Converted Wetland, and 5) Extremely Likely Converted Wetland. Final coverages contain all attributes from each of the three input coverages, the scope-and-effect buffers, and the converted wetland likelihood values (Figures 5a, 5b, and 5c).

Study Areas

Three study areas were chosen that represent a range of analyses, types of drainage networks, drainage extent, and wetland and landscape characteristics (Figure 1). The presence of available artificial drainage data also influenced study area selection.

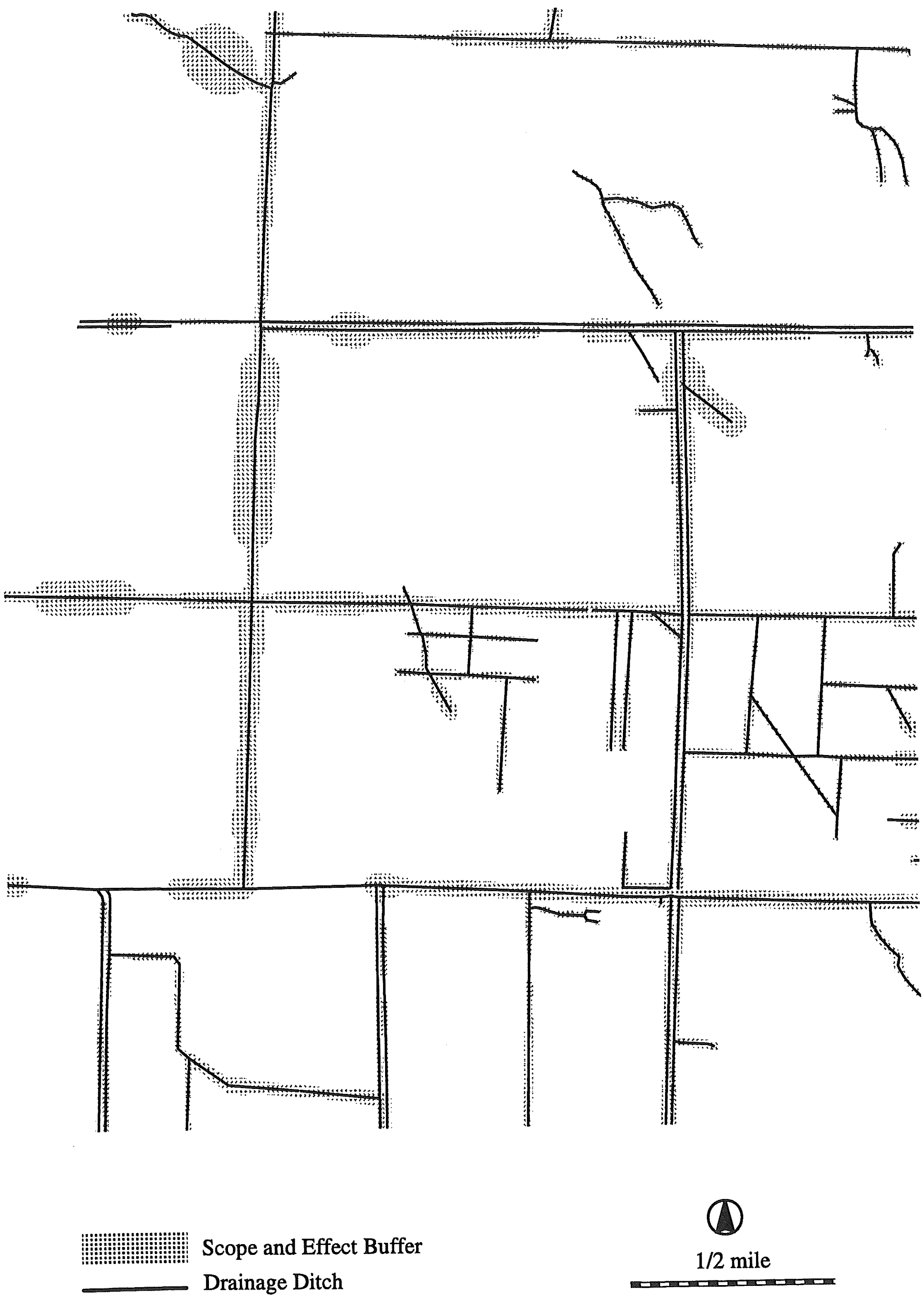


Figure 3. Sample map of ditches with scope and effect buffers from the Kittson County study area. Scope and effect buffers are used to estimate the lateral effectiveness of ditches and drainage tile using the depth of ditch and type of soil. Buffers are widest in areas with deep ditches and/or very permeable soils.

Figure 4. This flow diagram shows the decision rules that are used to assign converted wetland likelihood values.

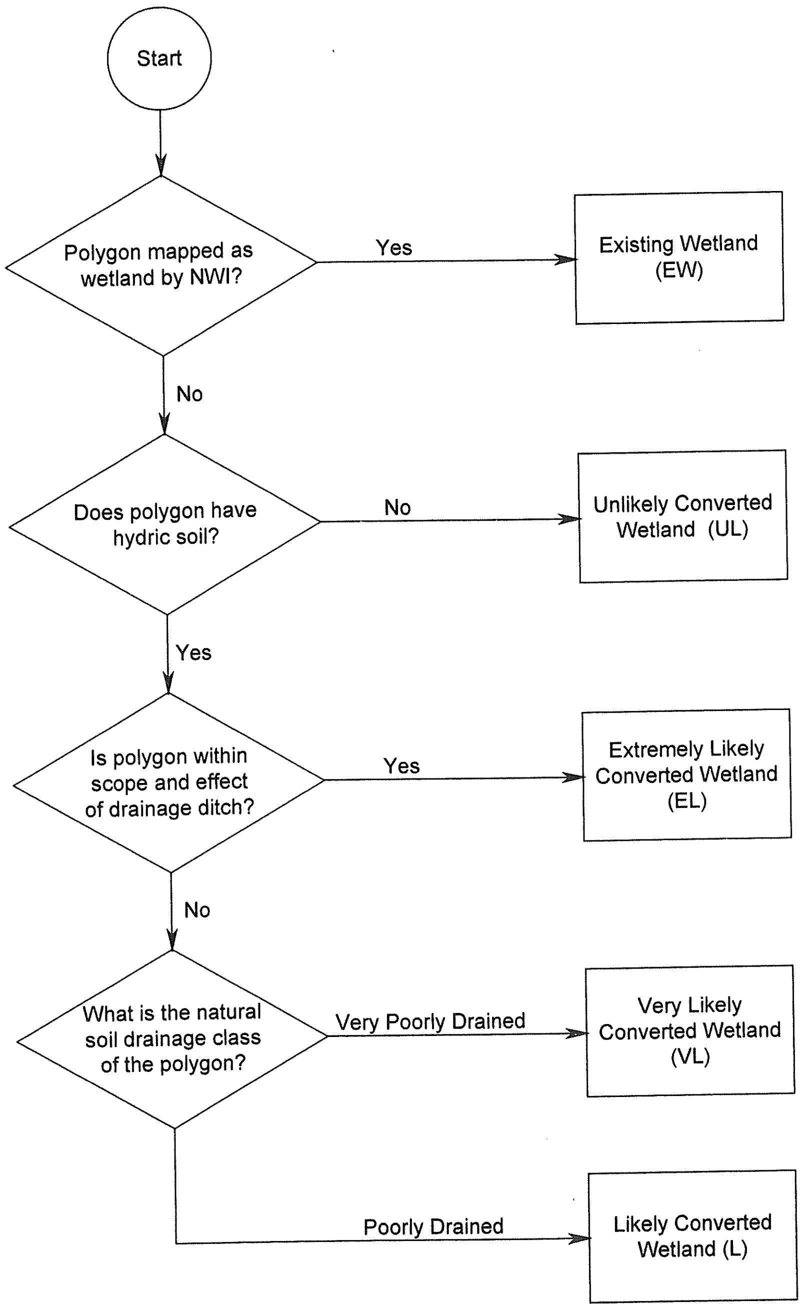


Figure 5a. Chisago County study area final converted inventory map. Note the changes in wetland spatial configuration. Presettlement wetlands were most often part of large wetland complexes. Existing wetland basins are much more likely to be isolated in our current landscape than they were at the time of European settlement.

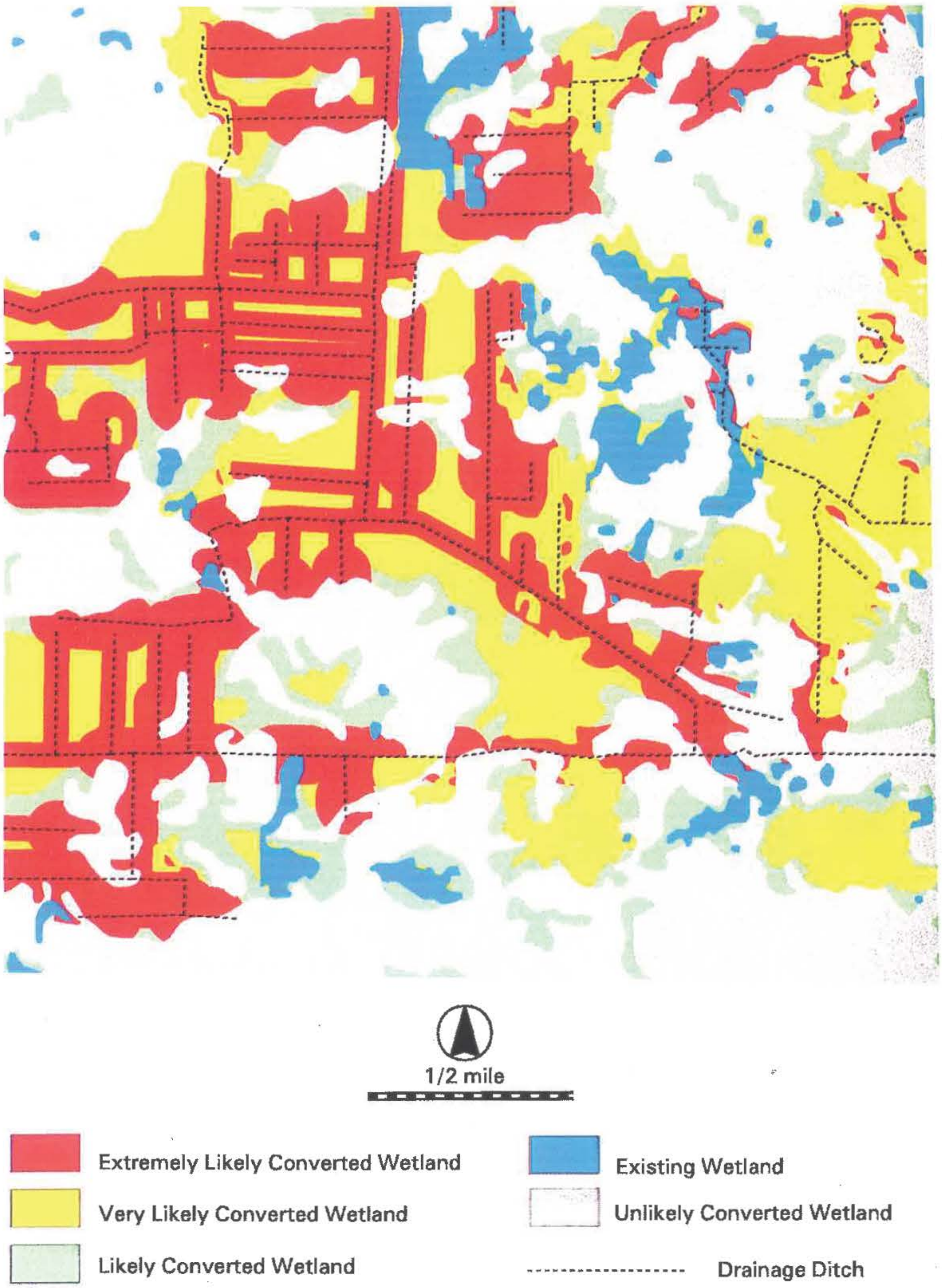
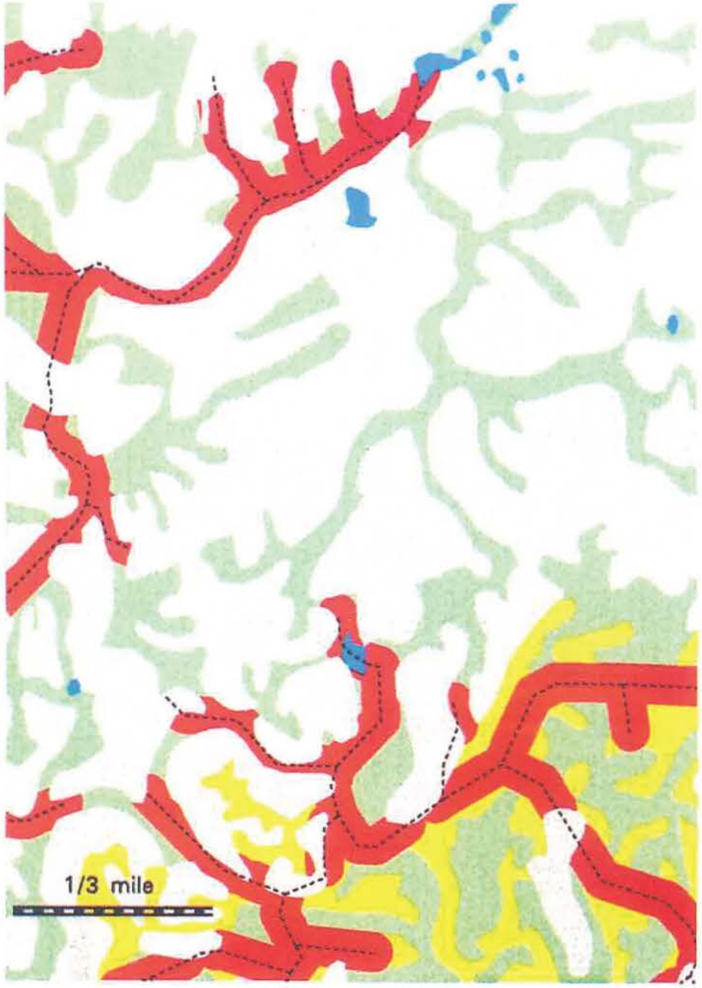
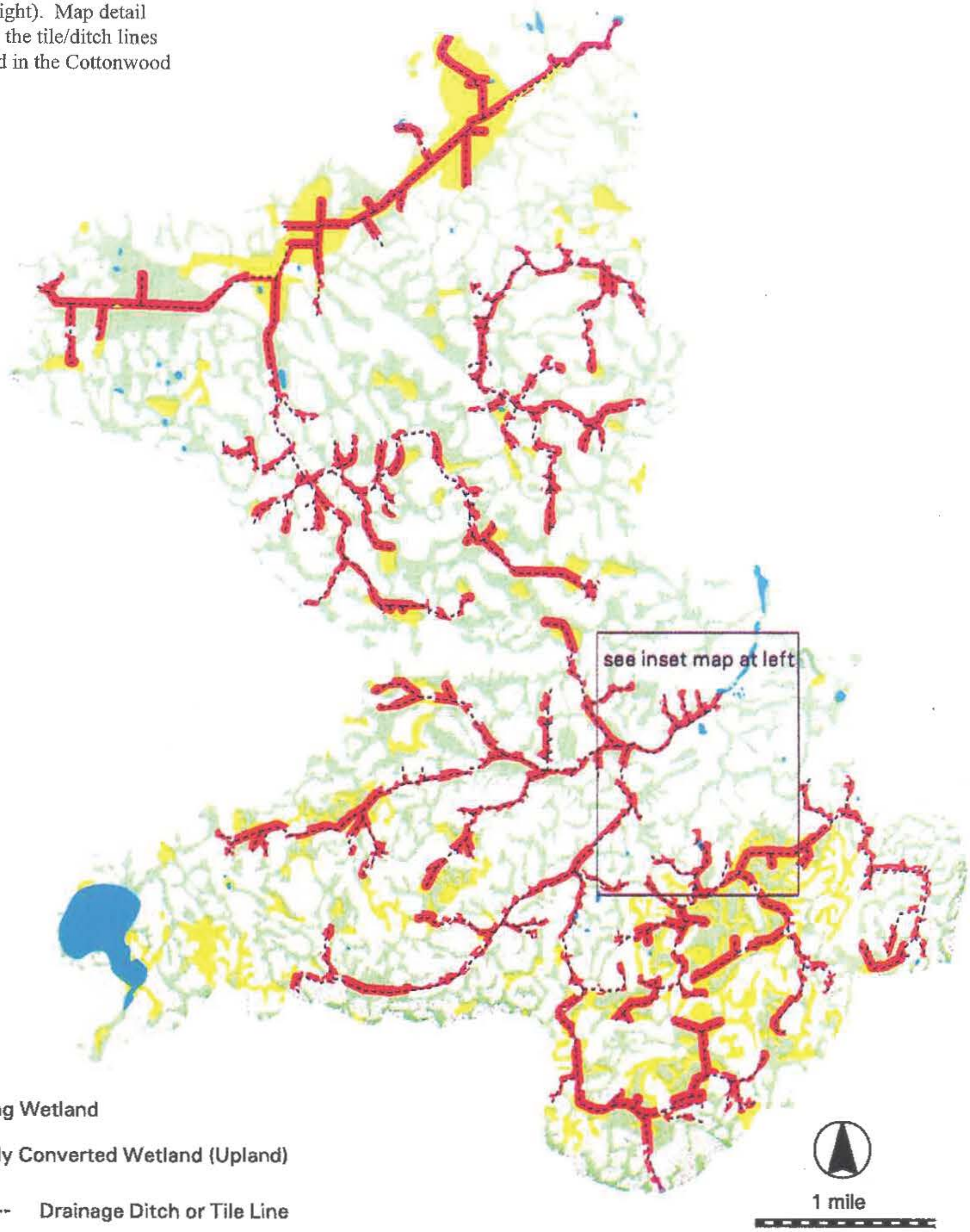


Figure 5b. Cottonwood County study area final converted wetland inventory map (right). Map detail shown on left. Note the dendritic drainage pattern of this landscape and how closely the tile/ditch lines follow these natural drainages. There are many private tile lines that are not included in the Cottonwood analysis because of the impracticality of mapping them.





Extremely Likely Converted Wetland

Very Likely Converted Wetland

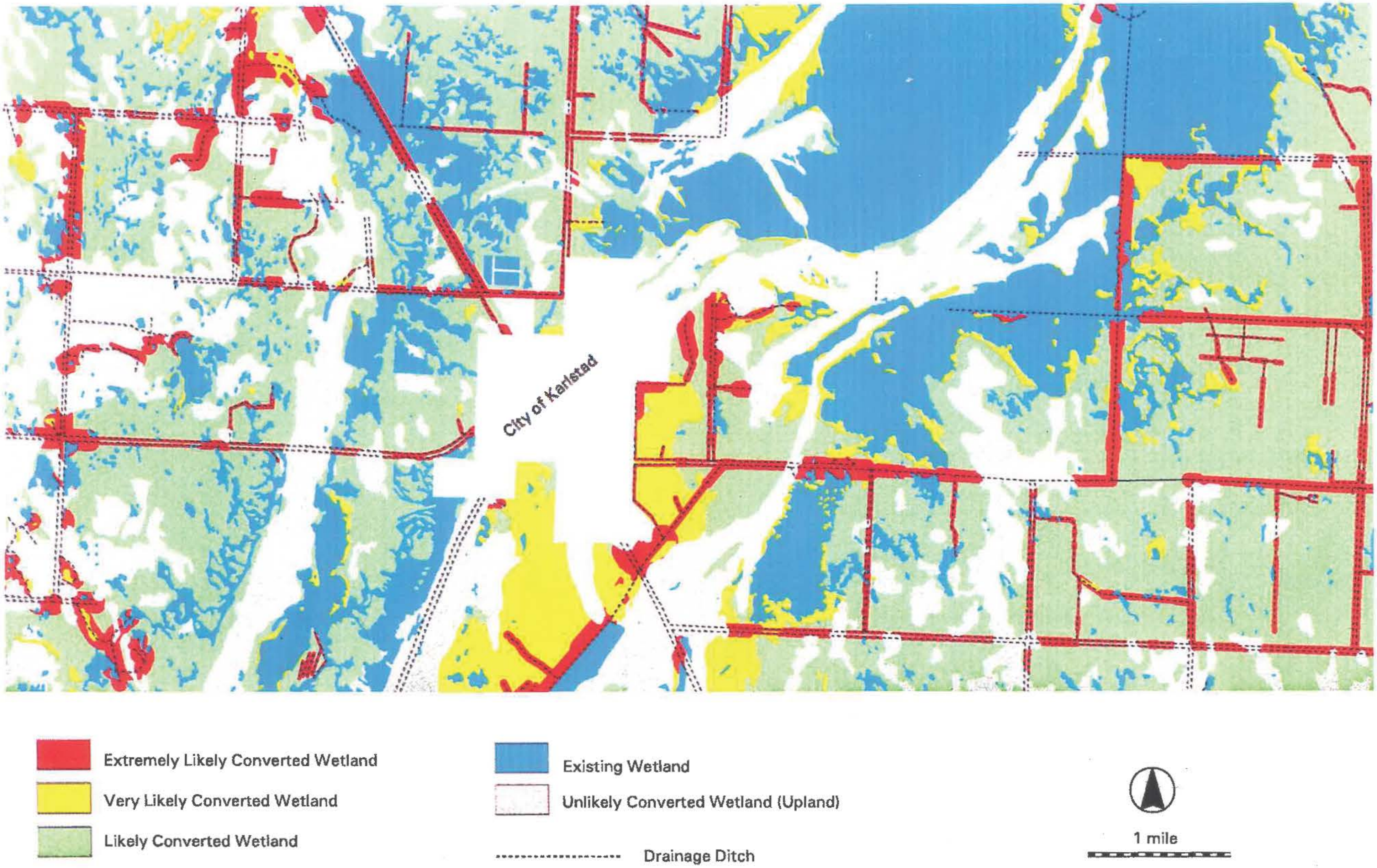
Likely Converted Wetland

Existing Wetland

Unlikely Converted Wetland (Upland)

Drainage Ditch or Tile Line

Figure 5c. Kittson County study area final converted inventory map. This study area has the greatest percentage of presettlement wetlands remaining (29%). In this flat glacial lakebed landscape wetlands cover large expanses of land. Note the remnant glacial beach ridges (linear upland features).



The Chisago County study area is in four sections (2,328 acres) of Lent Township (T34N, R21W of the 4th PM), in the southwestern part of Chisago County, Minnesota. This area is on the northern fringe of the rapidly developing Minneapolis/St. Paul metropolitan area. It is on the Anoka Sandplain left by the Wisconsin glaciation (Ojakangas and Matsch 1982) and has gently sloping topography. The soils are in the Zimmerman-Isanti Association, an association comprising 21 percent of Chisago County (Natural Resources Conservation Service 1995). Soil orders include Mollisols and Histosols with Aquoll and Saprist dominant suborders (Anderson and Grigal 1984; Natural Resources Conservation Service 1995). Approximately 6 percent of the area is classed as wetland on NWI maps. The area has an extensive system of open ditches and tile lines that is used for drainage and irrigation of sod and truck farms.

The Cottonwood County study area includes two minor watersheds (14,073 acres) located primarily in Rosehill Township (T106N, R38W) and Amo Township (T106N, R37W) in Cottonwood County in south central Minnesota. It is on the Coteau des Prairies or Ridge of Grasses which is a plateau of bedrock overlaid by glacial sediments. The physiography of the area is predominately gently undulating hills with a dendritic drainage pattern. Nearly the entire area was in agricultural land uses by 1900 and remains so today. The soils are in the Webster-Nicollet Association and the Clarion-Swanlake Association, and are predominately Mollisols with Ustoll and Udoll suborders (Soil Conservation Service 1979a; Anderson and Grigal 1984). Approximately one percent of the area is classed as wetland on NWI maps. The area is almost completely drained by a network of agricultural drainage tile lines.

The Kittson County study area is the area represented on the northern two-thirds of Karlstad and Twistal Swamp 7.5' USGS quadrangle maps. The 38,136 acre area is in the Red River Valley and within the lakebed of Glacial Lake Agassiz. The terrain is nearly flat except for several remnant glacial beach ridges that rise 10-13 feet above the surrounding plain. The area is sparsely populated and agriculture is the primary land use. The soils are in the Rockwell-Grimstad Association, the Arveson-Ulen Association, the Lohnes-Dune land association, the Percy-Fram Association, and the Deerwood-Cathro-Markey Association. A wide variety of soil orders include Mollisols, Inceptisols, Entisols, and Histosols. Aquoll, Boroll, Aquept, Aquent, Psamment, and Saprist suborders are common (Soil Conservation Service 1979b, Anderson and Grigal 1984). Approximately 21 percent of the area is classed as wetland on NWI maps. The area has an extensive network of open drainage ditches.

Discussion of Findings

In this study, digital soil survey and artificial drainage data were used to map converted wetlands. By overlaying these data using a GIS, a polygon map of the study areas was produced. Each polygon in the map was assigned an ordinal confidence value (likelihood of being a converted wetland). Polygons with the most evidence supporting the identification of a converted wetland (for example, close proximity to a ditch or with a very poorly drained natural drainage class) received the highest likelihood value. Polygons with limited evidence (for example, not in close proximity to a ditch or with a poorly drained natural drainage class) received a lower likelihood value. The resulting map product from this study can be used to address at least four questions: 1) How much wetland was there in a particular area at the time of European settlement?; 2) What percentage of presettlement wetlands remain wetland today?; 3) How many of the remaining wetlands have altered hydrology?; and 4) Is the spatial configuration of presettlement wetlands the same as it was at the time of European settlement?

How much wetland was there in a particular area at the time of European settlement?
Currently there is a great deal of public and professional interest regarding the ecological composition and distribution of our waters, wetlands, prairies, and forests at the time of European settlement. For both metaphysical and environmental planning reasons, we would like to have a clearer view of how our Minnesota landscape looked and functioned prior to development. Unfortunately, it is not possible to create a precise map of wetland presence, character, and configuration at the time of settlement because source data do not exist. However, it is possible to use existing data to make approximated inferences about the abundance and spatial distribution of pre-European settlement wetlands. This has been done in Minnesota at a statewide scale by Anderson and Craig (1984) using the coarse (1:250,000 scale) Minnesota Land Management Information System's (MLMIS) digital soil layer. These data (digitized from the Minnesota Soils Atlas, minimum mapping unit of approximately 1 square mile) are the only available soil layer that has statewide coverage. Anderson and Craig estimate the State of Minnesota was 35 percent wetland (18,583,000 acres) at the time of European settlement. For Chisago, Cottonwood, and Kittson counties they estimate that 20 percent (56,000 acres), 10 percent (40,000 acres), and 73 percent (517,000 acres) of the total county areas were wetland at the time of European settlement. Using more precise (1:20,000 scale) soil data this study estimates that our study areas in Chisago, Cottonwood, and Kittson counties were 59 percent, 44 percent, and 72 percent wetland, respectively, at the time of European settlement. These percentages represent total converted wetland acreage plus existing wetland acreage values.

It is important to note that this study only provides estimates for the specific study areas which do not comprise entire counties. Therefore, county-level estimates of wetland conversions are not provided. When considering the differences between the results of this study and those of Anderson and Craig's (1984) county-level study, both precision of source data and within-county variation must be taken into account. Most counties have variations in geomorphology and soils. As an example, the geomorphology of Kittson County changes from west to east. In the relatively flat western part of the county, the soils are rich, black Red River Valley soils. This part of the county has been more heavily ditched because the soils are valuable as farmland. In the eastern part of the county, coarse sandy glacial beaches are interspersed with organic soils and muck in the valleys. The Kittson study area described in this study is located on the eastern edge of Kittson County that is much less intensively cropped than the west.

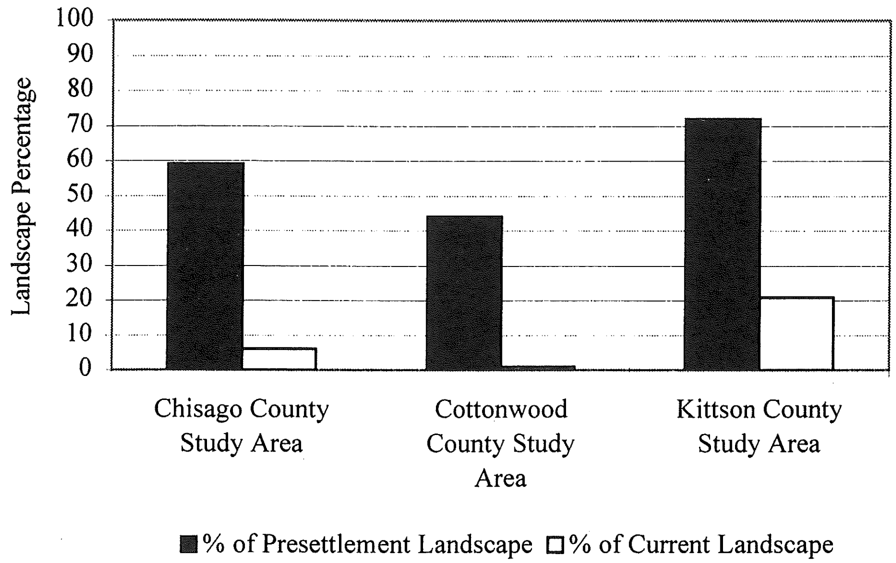
What percentage of presettlement wetlands remain wetland today?
Anderson and Craig (1984) estimated that 53 percent of the 18,583,000 acres of presettlement wetland still exist in Minnesota. Their county-specific estimates for presettlement wetlands remaining for Chisago, Cottonwood, and Kittson counties were 64 percent, 1 percent, and 19 percent., respectively. In this study it was determined that 10 percent of presettlement wetlands remain in the Chisago study area, less than 1 percent of presettlement wetlands remain in the Cottonwood study area, and 29 percent of presettlement wetlands remain in the Kittson study area. This means that substantial portions of the study areas have been converted from wetland to other land uses: Chisago (53 percent), Cottonwood (43 percent), and Kittson (51 percent). Using the likelihood values assigned by the digital converted wetland inventory it is possible to evaluate these wetland losses using three levels of certainty (Table 1, Figure 6).

How many of the remaining wetlands have altered hydrology?
Wetland ecologists have expressed concern over the degradation of existing wetlands by artificial drainage (Carter 1986; Johnston 1989; Wilen and Tiner 1993; and Johnston 1994). Moorhead and Cook (1992) found that 30 percent of existing wetlands in coastal North Carolina has been

Table 1. Summary of wetland losses by study area. Figures shown as percent of total study area (Refer to figure 4 for decision rules for likelihood values assignment).

	Chisago Area	Cottonwood Area	Kittson Area
Likely Converted Wetland (L)	9	26	38
Very Likely Converted Wetland (VL)	19	7	6
Extremely Likely Converted Wetland (XL)	25	10	7
Existing Wetland	6	1	21
Upland	41	56	28
Total Area	100	100	100
Total Converted (L)+(VL)+(XL)	53	43	51

Figure 6. This figure shows the total percentage of each study area that was wetland prior to the time of European settlement (black) and the percentage of each study area that is wetland today (white).



ditched using the NWI "d" modifier to estimate the percentage of existing wetlands with altered hydrology. Using the special modifier "d", the percentage of existing wetlands that have altered hydrology was calculated in each of the study areas (Table 2). In the Kittson County area, for example, NWI classified 5.5 percent of existing wetlands with the "d" modifier.

NWI data most likely underestimate the percentage of existing wetlands that have altered hydrology because it is difficult to identify ditches on high altitude aerial photographs (U.S. Fish and Wildlife 1990). Using the ARC/INFO *overlap* command a comparison was made between ditched existing wetlands in the Kittson County study area using the ditch inventory developed as part of this study versus the NWI "d" modifier. Results from the new ditch inventory found that 12 percent of existing wetland basins have been ditched; whereas, the NWI noted only 5.5 percent. Thus, the use of aerial photographs (8 inch = 1 mile) coupled with ground verification more than doubled the number of existing wetlands altered by ditches identified by the NWI "d" modifier. Considering this limited analysis, it appears that NWI significantly underestimates the percentage of existing wetlands that have altered hydrology.

Table 2. Summary of the study areas for acreage and National Wetland Inventory data.

	Chisago Area	Cottonwood Area	Kittson Area
Study Area Acreage	2,328	14,073	38,136
NWI Wetland Acres	140	140	8,009
Percent of Study Area	6	1	21
Number of:			
Existing Wetlands	717	60	1,284
Non-ditched Wetlands	581	49	71
Ditched Wetlands	136	11	1,213
Percent of Existing Wetlands Ditched	19	18	5.5

Is the spatial configuration the same as it was at the time of European settlement?

By visually analyzing the maps produced using this converted wetland inventory method, it is clear that the spatial configuration of wetlands today in the study areas is not the same as it was at the time of European settlement. Based on visual analysis of map products produced by this converted wetland inventory, the following statements can be made: 1) Presettlement wetlands were much less likely than current wetlands to be isolated from other wetland basins; and 2) Individual presettlement wetland basins were most commonly part of large interconnected wetland complexes. Also, it is clear that geomorphology and topography can be used to understand presettlement wetland spatial configuration. For example, presettlement wetlands in the Cottonwood study area were located along and within the complex dendritic natural drainages in this landscape of gently rolling hills while presettlement wetlands in the Kittson study area covered large expanses of the flat, glacial lakebed landscape. These fascinating observances about the changes in wetland spatial configuration since European settlement may set the stage for work that addresses the ecological responses to isolation of these previously connected communities.

Accuracy Assessment

When conducting an inventory of presettlement landscape characteristics it is difficult to follow the traditional model of inventory with accuracy assessment via field verification because field verification is not possible in converted landscapes. Converted wetlands are commonly now agricultural fields, parking lots, stormwater retention ponds, cities, and suburban subdivisions. Visiting a converted site is of little value to assessing whether the map identifications are correct or not. Presettlement inventory projects require a definable standard or record in time for comparative analyses to confirm results. Perhaps this is the reason previous presettlement mapping projects have not reported accuracy results (Marschner 1930; Hewes 1951; Anderson and Craig 1984; Moorhead 1991; Moorhead and Cook 1992; Cromer et al 1993; Vaughn 1994).

In this study, accuracy was assessed for the Chisago County and Kittson County areas by using historical aerial photographs for verification and mapping converted wetlands when they were intact on early photographs but converted in later photographs. It was not possible to compile an accuracy assessment for the Cottonwood County study area because most of the land was put into agricultural land use prior to the date of the earliest available aerial photography (circa 1930), and no other converted wetland data set was available for verification purposes.

The Chisago County Drained Wetland Inventory (CCDWI) was used as a verification data set for the digital converted wetland inventory for the Chisago County area. The CCDWI data were digitized and converted from raster, a GIS format using ARC/INFO GRID. A raster format allows the data to be easily brought into an image processing package for accuracy assessment. A matrix of correspondence was created between the verification data set and the study data set using ERDAS image processing software. To do this, the likelihood classes were collapsed from five to three classes: 1) converted wetland, 2) existing wetland, and 3) unlikely converted wetland (upland). The CCDWI data had the same classes. The correspondence matrix was derived based on the percentage of pixels in the data that corresponded with the value of the associated pixel in the CCDWI raster. The digital method of inventory mapped 36 percent more converted wetlands than the CCDWI. The extremely likely likelihood class had a correspondence rate of 79 percent (Table 3).

Table 3. Results of accuracy assessment for Chisago county and Kittson County study areas. Figures show percent correspondence between digital converted wetland inventory and verification data sets.

	Chisago	Kittson
Extremely Likely Converted Wetland	79.4%	91.2%
Very Likely Converted Wetland	52.6%	99.8%
Likely Converted Wetland	59.7%	90.8%
Total Converted Wetland	63.9%	93.9%

A verification data set for the Kittson County area was compiled from 1940, 1950, and 1993 aerial photographs. Verification sites were chosen that appeared to have pre-settlement vegetation and hydrologic conditions (i.e.: undisturbed) in the 1940 photos. Sites were excluded that appeared disturbed in the 1940 photos, eliminating the problem of identifying wetlands converted prior to 1940. Within verification sites, converted wetlands were identified on the photographs, and polygons were transferred to 7.5' USGS quadrangle base maps, digitized, and assigned attributes. The verification data set and the converted wetland inventory data set were then converted from vector to raster. Using ERDAS image processing software, a correspondence matrix was created for the two raster data sets. Correspondence between the verification data set and digital converted wetland inventory data set was over 90 percent in all likelihood classes (Table 3). The very high correspondence rates for the Kittson County study area may be in part due to the large percentage of the total area that was wetland at the time of European settlement (72 percent).

Recommendations for Future Work

Application of this method will be limited to areas with existing analog or digital, detailed (first or second order) soil surveys. Implementation will not be possible for areas that do not have such soil surveys. A further limitation is the significant amount of time required to compile the source data. It is estimated that 3-5 technician days are required for each square mile of data development and analysis. In the Kittson County study area, for example, 8 hours per square mile were invested to develop the digital ditch layer. An additional 8 hours per square mile were required to transfer, digitize and attribute the hydric soil layer from the published county soil survey. These estimates are in addition to time required for GIS analysis and accuracy assessment. Time requirements will decrease as digital soil and ditch data become more readily available making it more feasible to conduct these types of inventories over large areas.

Currently, a tool is needed by local water resource managers to assess wetland losses within their planning areas. In an effort to make this method more feasible to implement and less costly to apply, we used sensitivity analysis to explore the possibility of eliminating the artificial drainage layer from the digital method. In addition to reducing the cost of implementation, dropping the artificial drainage layer would make it practicable for areas with drainage tile. A final coverage compiled excluding the artificial drainage coverage was compared to a final coverage compiled using all three input coverages. In the analysis that excluded the artificial drainage layer, the scope-and-effect buffers were eliminated and consequently the 'extremely likely converted' likelihood class was not assigned to any polygons. Polygon complexity was reduced (polygon perimeter to area ratio was reduced by 4 percent in the Kittson County study area and 17 percent in the Chisago County study area). However, because the method's decision rules are primarily driven by soil drainage class, the total area of converted wetlands remained the same in both scenarios.

This sensitivity analysis indicates that the digital converted wetland inventory can be used with two different approaches. The approach using all three data layers is appropriate for determining the extent of converted wetlands as well as identifying and prioritizing potential restoration sites. Implementing a restoration effort often includes restoring wetland hydrology by plugging a ditch or tile line. In this situation, location of ditches is an important restoration variable. Additionally, artificial drainage information can be a powerful tool in landscape level hydrologic planning because natural hydrologic flows are strongly influenced by artificial drainage. The second, less costly approach may be appropriate when the purpose of a converted wetland inventory is solely to summarize the extent of wetland conversion for a particular area. The resulting coverage would identify the same total area of converted wetlands but would have reduced polygon complexity and be lacking the "Extremely Likely" likelihood class. In areas with many unmapped drainage tiles (such as southern Minnesota) this approach may be the only reasonable alternative. In this case, restoration sites could be chosen after a thorough onsite evaluation.

Conclusion

In summary, a statewide inventory of converted wetlands would provide important planning and decision support information to natural resource managers. In addition to the descriptive work presented here these spatial data could be used to analyze the spatial patterns and configuration of presettlement wetland complexes. A converted wetland inventory would assist resource managers in selecting and prioritizing restoration sites. Regional variation in wetland losses could be readily analyzed by ecological units. Future NWI updates could be compared to a statewide inventory of converted wetlands to monitor wetland loss trends. Future converted wetland mapping projects should include accuracy assessments where possible. Verification data sets should be developed using historic aerial photographs and should only include areas that have intact hydrology and vegetation on the earliest available photographs. Further analyses of similar studies are needed to confirm whether this method is sufficiently precise for mapping presettlement wetlands. It is our hope that this work will provide a catalyst for future projects to more fully develop our understanding and management of our complex wetland communities.

This project was supported by the U.S. Environmental Protection Agency Clean Waters Act Section 104(b) grant (CD995592501) for the development of state wetland protection programs through the Minnesota Department of Natural Resources, Divisions of Fish & Wildlife and Waters. This paper is an edited version of the thesis prepared by Kara Dunning for completion of the Master of Science degree at the University of Minnesota, College of Natural Resources, in 1996. The mention of specific brand name products implies endorsement by neither the Minnesota Department of Resources nor the United States Environmental Protection Agency.

References

Anderson, J. L., & Grigal, D. F. 1984. Soils and Landscapes of Minnesota. St. Paul: Agricultural Extension Service, University of Minnesota. AG-FO-2331.

Anderson, J. P., & Craig, W. J. 1984. Growing energy crops on Minnesota's wetlands. Minneapolis: Center for Urban and Regional Affairs. Publication No. 84-3.

Averell, J.L., & McGrew, P.C. 1929. The Reaction of Swamp Forests to Drainage in Northern Minnesota. Department of Drainage and Waters, State of Minnesota.

Bailey, J. J. 1994. Assessing long-term impacts of ditching and grazing using GIS and undisturbed reference wetlands. Masters Thesis. University of Florida, Gainesville.

Bell, J. 1994. Personal Communication. University of Minnesota, Associate Professor of Soil Science. St. Paul, MN.

Berg, C. 1994. Personal Communication. Water Resources Center, Mankato State University. Mankato, MN.

Boelter, D. H. 1972. Water table drawdown around an open ditch in organic soils. Journal of Hydrology 15: 329-340.

Boelter, D. H., & Close, G. E. 1974. Pipelines in forested wetlands: Cross drainage needed to prevent timber damage. Journal of Forestry 72: 561-563.

Bradof, K. L. 1988. Environmental impacts of drainage-ditch and road construction on the Red Lake Peatland, Northern Minnesota: Drainage history, hydrology, water chemistry, and tree growth. Masters thesis. University of Minnesota, St. Paul.

Burns, B. E. 1954. Artificial drainage in Blue Earth County, Minnesota. Ph. D. Dissertation. University of Nebraska, Lincoln.

Carter, V. 1986. An overview of hydrologic concerns related to wetlands in the United States. Canadian Journal of Botany 64: 364-374.

Cowardin, L. M., Carter, V., Goblet, F. C., & Large, E. T. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Fish and Wildlife Service Publication FWS/OBS-79/31, Washington, D. C.

Cromer, P., Dennis, A., Leibfried, T., Wells, H., & Austin, M. 1993. Historical wetlands of the Saginaw Bay Watershed. Unpublished Report. Michigan DNR, Lansing.

Dahl, T. E. 1990. Wetland losses in the United States: 1790's to 1980's. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC.

Dunning, Kara Marie. 1996. A digital method of inventory for converted wetlands. University of Minnesota, St. Paul, Masters thesis. 40 pages.

Galatowitsch, S. 1990. Using the original land survey notes to reconstruct presettlement landscapes in the American west. Great Basin Naturalist 50(2): 181-191.

Galatowitsch, S., & van der Valk, A. G. 1994. Restoring prairie wetlands: An ecological approach. Ames: Iowa State University Press.

Hewes, L. 1951. The northern wet prairie of the United States: Nature, sources of information, and extent. Annals of the Association of American Geographers 41: 307-323.

Jacobson, S. 1990. Drainage scope and effect. *In* Jurisdictional delineation of wetlands in Minnesota. Unpublished Interagency Report. Minnesota Board of Water and Soil Resources. Minnesota Association of Soil and Water Districts.

Johnston, C.A. 1994. Cumulative impacts to wetlands. Wetlands 14: 49-55.

Johnston, C. A. 1989. Human impacts to Minnesota wetlands. Journal of the Minnesota Academy of Science 55: 120-124.

LeBarron, R. & Neetzel, J. 1942. Drainage of Forested Swamps. Ecology 23: 457-465.

Lord, C. 1994. Personal Communication. Anoka County Soil and Conservation District wetland conservation technician. Blaine, MN.

Lorimer, C.G. 1977. The presettlement forest and natural disturbance cycle of northeastern Maine. Ecology 58: 139-148.

Marschner, F. J. 1930. Source material and construction of the natural vegetation map of Minnesota. Manuscript to accompany the Original Vegetation of Minnesota map. North Central Experimental Station, St. Paul, MN.

Minnesota Wetland Conservation Act. 1991. Laws of Minnesota for 1991, Chapter 354. H.F. #1.

Minnesota Department of Natural Resources. 1988. Natural vegetation of Minnesota: At the time of the public land survey. Biological Report No. 1. St. Paul, MN.

Minnesota Soil Atlas Series. 1970. St. Paul, MN. University of Minnesota.

Moorhead, K. K. 1991. Evaluating wetland losses with hydric soils. Wetlands Ecology and Management 1: 123-129.

Moorhead, K. K., & Cook, A. E. 1992. A comparison of hydric soils, wetlands, and land use in Coastal North Carolina. Wetlands 12: 99-105.

National Research Council. 1995. Wetland characteristics and boundaries. Washington, D.C.: National Academy Press.

Natural Resources Conservation Service. 1995. Soil survey of Chisago County, Minnesota. U.S. Department of Agriculture.

Noss, R. F. 1985. On characterizing presettlement vegetation: How and why. Natural Areas Journal 5: 139-148.

Ojakangas, R. W., & Matsch, C. L. 1982. Minnesota's geology. Minneapolis: University of Minnesota Press.

Santos, K. M. 1994. User's guide to the National Wetlands Inventory maps (Region 3). United States Fish and Wildlife Service. Bloomington, MN.

Smith, B. J., Browers, H. W., Dahl, T. E., Nomsen, D. E., & Higgins, K. F. 1989. Indirect wetland drainage associated with federal highway projects in the prairie pothole region. Wetlands 9: 27-39.

Soil Conservation Service. 1991. Hydric soils of the United States. U.S. Department of Agriculture. Miscellaneous Publication no. 1491.

Soil Conservation Service. 1979a. Soil survey of Cottonwood County, Minnesota. U.S. Department of Agriculture.

Soil Conservation Service. 1979b. Soil survey of Kittson County, Minnesota. U.S. Department of Agriculture.

Surface Water Hydrology Atlas Series. 1993. Water Resources Center, Mankato State University, Mankato, MN.

Tiner, R.W. 1997. NWI Maps: What they tell us. National Wetlands Newsletter. 19(2): 7-12.

Tiner, R.W. 1996. Practical considerations for wetland identification and boundary delineation. p. 113-137. *In* G. Mulamoottil, B. G. Warner, & E. A. McBean (Eds.), Wetlands: Environmental gradients, boundaries, and buffers. Boca Raton: CRC Press.

Tiner, R. W. 1984. Wetlands of the United States: Current status and recent trends. National Wetlands Inventory, U.S. Fish and Wildlife Service, Washington, D.C.

U.S. Department of Interior. 1909. Drainage survey of the ceded Chippewa lands in Minnesota. 61st Congress, 1st Session. House of Representatives Document no. 27.

U.S. Fish and Wildlife Service. 1990. Photo interpretation conventions for the National Wetlands Inventory. Unpublished Report. St. Petersburg, FL.

Vaughn, S. 1994. Personal Communication. Chisago County Drained Wetland Inventory Project. Cambridge, MN.

Wilen, B. O., & Tiner, R. W. 1993. Wetland losses in the United States. p.515-636. *In* D.F. Whigham, D. Dykyjov , & S. Hejn (Eds.), Wetlands of the World. Boston: Kluwer Academic Publishers.

Williams, D. C. & Lyon, J.G. 1995. Use of a geographic information system database to measure and evaluate wetlands changes in the St. Mary's River, Michigan. p.125-139. *In* J.G. Lyon, & J. McCarthy (eds.), Wetland and environmental applications of GIS. Boca Raton: CRC Press.

APPENDIX A. Natural Resources Conservation Service definitions for natural soil drainage classes (Soil Conservation Service 1995).

Excessively Drained – Water is removed from the soil very rapidly. Excessively drained soils are commonly very coarse textured, rocky, or shallow. Some are steep. All are free of the mottling related to wetness.

Somewhat Excessively Drained – Water is removed from the soil rapidly. Many somewhat excessively drained soils are sandy and rapidly pervious. Some are shallow. Some are so steep that much of the water they receive is lost as runoff. All are free of the mottling related to wetness.

Well Drained – Water is removed from the soil readily, but not rapidly. It is available to plants throughout most of the growing season, and wetness does not inhibit growth of roots for significant periods during most growing seasons. Well drained soils are commonly medium textured and are mainly free of mottling.

Moderately Well Drained – Water is removed from the soil somewhat slowly during some periods. Soils are wet for only a short time during the growing season, but periodically they are wet long enough that most mesophytic crops are affected. They commonly have a slowly pervious layer within or directly below the column or periodically receive high rainfall, or both.

Somewhat Poorly Drained – Water is removed slowly enough that the soil is wet for significant periods during the growing season. Wetness markedly restricts the growth of mesophytic crops unless artificial drainage is provided. Somewhat poorly drained soils commonly have a slowly pervious layer, a high water table, additional water from seepage, nearly continuous rainfall, or a combination of these.

Poorly Drained – Water is removed so slowly that the soil is saturated periodically during the growing season or remains wet for long periods. Free water is commonly at or near the surface for long enough during the growing season that most mesophytic crops cannot be grown unless the soil is artificially drained. The soil is not continuously saturated in layers directly below plow depth. Poor drainage results from a high water table, a slowly pervious layer within the profile, seepage, nearly continuous rainfall, or a combination of these.

Very Poorly Drained – Water is removed from the soil so slowly that free water remains at or on the surface during most of the growing season. Unless the soil is artificially drained, most mesophytic crops cannot be grown. Very poorly drained soils are commonly level or depressed and are frequently ponded. Yet, where rainfall is high and nearly continuous, they can have moderate or high slope gradients.

APPENDIX B. Scope and effect equation and assumptions.

$$Le = 0.5\sqrt{\frac{[8(Kb)(de)(\Delta h) + 4(Ka)(\Delta h^2)]}{q}}$$

WHERE:

L_e = Maximum lateral effect of the drain(inches/hr).

Ka = Weighted average soil permeability from the draw down level to the drain (inches/hour).

Kb = Weighted average soil permeability below the drain to an impervious barrier (inches/hour).

de = Depth from drain to an impervious layer in feet for open ditches.

h = Drainage head, the difference between the drain depth and the desired drawdown level (1 or 1.5 feet below the soil surface depending upon soil permeability) in feet.

q = drainage coefficient (inches/hr). 24 hr drainage coefficient must be converted.

Assumptions:

1. Surface drainage is assumed to be adequate.
2. Average permeability of each soil horizon was used.
3. If an impervious layer was not identified in the soil data one is assumed at depth of 10 ft.
4. It is assumed that the drainage ditch has adequate capacity to remove $1/8^{th}$ inch of water from the area drained in 24 hours.