

Historic/Prehistoric Hydrographic Model for Minnesota

MnModel Phase 4

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Introduction

The first MnModel hydrographic modeling procedures were developed in 2008 (Stark et al. 2008) utilizing modern hydrographic data, digital soils data, and geomorphic data to model locations of historic and prehistoric surface water. MnDOT updated the hydrographic model in 2018 to take advantage of the newly digitized data from the Public Land Survey maps, more comprehensive digital soils data (gSSURGO), statewide geomorphic data from the MnModel Phase 4 Landscape Model, and wetland distributions as modeled by the MnModel Phase 4 Historic Vegetation Model. The updated procedures produce two models, one for historic hydrography and one for prehistoric hydrography. The historic hydrographic model approximates surface water features (lakes, rivers, varied types of wetlands, and floodplains) at the time of the Public Land Survey. The prehistoric hydrographic model approximates surface water features over a time period exceeding thirteen thousand years, using historic hydrographic data, soils data, geomorphic data, and modern hydrographic data to identify areas that provide evidence of having been lakes, wetlands, shores, and floodplains at some time in the more distant past.

Research Need

Modern surface hydrography does not adequately reflect the location of surface water during the early Historic (1650 CE – 1837 CE) and Prehistoric (12,000 BCE – 1650 CE) Periods. In the past 100-150 years humans have altered the surface water of Minnesota dramatically by damming and diverting streams, draining wetlands, and creating artificial lakes. Since the location of natural water is an important factor for predicting the location of archaeological sites, we needed to create a model of where water was likely to have been prior to these disturbances. This model is the MnModel Phase 4 Historic/Prehistoric Hydrographic Model.

Background

The first historic/prehistoric hydrographic model for MnModel was developed in 2008 by researchers at the University of Minnesota, Duluth (Stark et al. 2008). This model was developed from National Wetlands Inventory (NWI), MnDNR streams, Landform Sediment Assemblages (LfSA), and USDA Natural Resource Conservation Service County Soil Surveys (pre-gSSURGO) digital data. In particular, this project defined the characteristics of soils that are indicative of past wetlands. The modelers also experimented with the use of surface water polygons digitized from GLO maps and with Restorable Depressional Wetland Inventory (RDWI) data from the Minnesota Department of Natural Resources (DNR), but neither of these was widely available at the time. This model was run for every county that had digital soils data available in 2009. Most of these counties were missing digitized GLO plat maps and RDWI, but the model was designed to be run without those datasets if necessary.

The shortcomings of the models produced by these procedures were that there was no way to distinguish types of water bodies or to distinguish between historic and prehistoric water bodies. Because the model depends heavily on soil characteristics, it is best interpreted as an estimate of the maximum post-glacial extent of surface water and wetlands. Moreover, since the original hydrographic model was developed in 2008 new data have

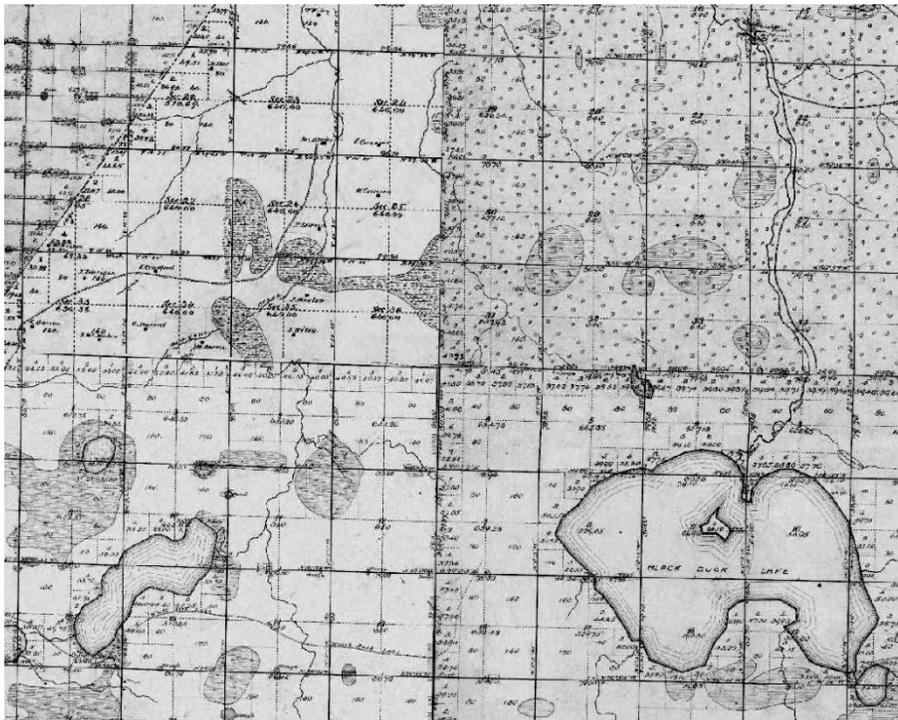
become available, and the gSSURGO tables have been re-formatted in such a way as to require modifications of the original modeling tools.

Data Sources

Historic Data

The best primary source for the distribution of vegetation types in Minnesota prior to extensive Euro-American settlement is the Public Land Survey (PLS) conducted by the U.S. Surveyor General's Office (GLO). These surveys were conducted in Minnesota between 1848 and 1907. The surveyors' line notes and field sketch maps were used as the source material for the creation of the [Public Land Survey plat maps](#). These are maps of each township surveyed showing section lines, water bodies, wetlands, and other features observed. In general, the locations of small lakes and wetlands are accurate along the section lines where they correspond to the line note. They are also accurate for large lakes and rivers, as surveyors typically surveyed these shorelines. Figure 1 shows an example of a plat map. The small lake and tamarack swamp are correctly located along the line, but their shapes and extents away from the line may not be reliable.

Figure 1: Surveyor's Plat Map Example



[PLS plat maps were scanned](#) in a collaborative effort by several Minnesota State Agencies and were later georeferenced by MnGeo. In 2012, MnDOT contracted to have the georeferenced plats mosaicked into a statewide image and to digitize polygons represented on those maps. The contractor initially classified the digitized polygons based on the map symbols and annotation, though not all symbols were interpretable.

Subsequently, MnDOT overlaid the digitized polygons with MnDNR point and line data extracted from the surveyors' notes and used these to refine the polygon classifications.

Lakes and rivers from PLS plat maps are valuable in the construction of an early historic hydrographic model because these data were collected before many significant human alterations to Minnesota water bodies and wetlands took place. Wetland polygons, on the other hand, are not accurately delineated, so are not helpful.

Historic Vegetation Model

Public Land Survey records include surveyors field notes as well as plat maps. [Vegetation observations](#) and species of [bearing trees](#) made by the surveyors were extracted to section and quarter section corner points and published by MnDNR in 1997. More recently, John Almendinger (MnDNR) made available surveyor line notes extracted to section lines for the northern half of the state. MnDOT reclassified the vegetation point data using a classification system developed by MnDNR (Aaseng 1993). The line and bearing tree data were used as needed to help make decisions for classifying the corner points. The classified point data were used to develop a high resolution statistical model of historic vegetation (Hobbs 2019a). At best, the MnModel Phase 4 Historic Vegetation Model is an approximation of potential natural vegetation at the time of the Public Land Survey. It is limited by the surveyors' vocabulary and familiarity with Minnesota vegetation, by the environmental data used to develop the predictive variables, and by the lack of information about historic disturbances, particularly fire, that helped shape vegetation patterns. Nevertheless, we found it to be a more reliable than modern hydrographic data for mapping historic wetland locations (see below).

Geomorphic Data

Geomorphic data for Minnesota are available in digital format from MnDOT, Minnesota Geological Survey, and MnDNR at scales ranging from 1:24,000 to 1:100,000 and for varying geographic extents. In 2014, MnDOT initiated development of a statewide geomorphology model from the best available digital data for any given part of the state (Hobbs 2019b). This MnModel Phase 4 Landscape Model utilized a consistent statewide classification of geomorphic regions, subregions, landscapes, and landforms to facilitate analysis. The geomorphic model was used to help identify historic and prehistoric lake beds, river channels, and floodplains.

Soils Data

At the time this model was developed, gSSURGO data were available for all of 83 of Minnesota's 87 counties and parts of the four counties that gSSURGO data does not cover completely (Cook, Lake, Pine, and St. Louis). Using logic developed for the original MnModel hydrographic model (Stark et al. 2008), potential wetland soils were identified based on soil taxonomy, soil drainage, and hydric status. Soil taxonomy was aggregated for each mapunit from the gSSURGO *component* table. The soil taxa with the largest representative proportion within each mapunit was selected to represent the mapunit. Soil drainage and hydric status were extracted from the gSSURGO *mapunit* table (Hobbs et al. 2019). Soils data are the primary source of wetland locations in the prehistoric hydrographic model.

Modern Hydrographic Data

Several sources of modern hydrographic data were combined to create MnModel Phase 4's modern water polygon feature class. A Minnesota Surface Water Inventory (SWI) derived from the [National Wetlands Inventory](#) (NWI) data were acquired from USFWS and reclassified to wetland types consistent with Aaseng (1993) to the extent possible. No other available data sources provided sufficient attribute information to support this level of classification, so NWI was considered the most authoritative source. These made up about 91 percent of the final feature class. However, other data sources mapped bodies of water, some of them quite significant, that were missing from NWI. To make sure that we were working with the most comprehensive data possible, MnDNR water and wetlands (about two percent of the total) and [National Hydrography Dataset](#) (NHD) polygons (about six percent of the total) were combined and used to supplement NWI. The data sources were found to be inconsistent with each other in their classification of water and wetlands. Some useful attributes were extracted from gSSURGO and used to incorporate additional information into the dataset to support classification of non-NWI features. Finally, MnDNR's [Native Plant Communities](#) dataset (NPC) was found to contain wetland areas not mapped by other sources, so it was also incorporated into the feature class. For this model, modern water polygons or portions thereof were eliminated if they were artificial or if they exhibited a combination of soil drainage and topographic characteristics implying they were in improbable locations for historic hydrographic features.

All of this work was done prior to developing the Historic Vegetation Model. At that time, we did not know whether modern wetlands or the model would provide the best representation of historic hydrographic features. Although we subsequently determined that the Historic Vegetation Model would be the most reliable source, we found the modern data useful to fill in features missing from PLS plat maps and to replace hydrographic features from the plat maps that appear to be erroneous when compared to digital elevation models and other data.

In addition, linear streams data were acquired both to provide additional information about rivers that were also mapped as polygons as well as to supplement the dataset with stream courses not mapped as polygons. Linear features were acquired from [MnDNR](#), [National Hydrography Dataset](#), and Minnesota's [Alter Watercourses](#) project.

Data Preparation

Preparation of data for the Hydrographic Model is documented in Appendix B (Brown et al. 2019) of the MnModel Phase 4 Archaeological Predictive Modeling Guide (Landrum et al. 2019). Specific decisions made regarding data for this model are discussed below.

Determination of Reliable Sources

The original MnModel Hydrographic Model (Stark et al. 2008) focused on the use of soil taxonomic classes to identify soils that were saturated for long periods at some time in the past. Soils data were considered the most reliable source of information in determining the locations of prehistoric wetlands because of soils' slower alteration over time than surface expression of wet lands. However, there is no way to determine when or for

how long these soils were saturated. These polygons provide us with what we must assume to be a model of the maximum extent of surface water in the post-glacial period. For predicting archaeological site locations, it would also be useful to have a model of the extent of water in the historic/late prehistoric period. For this, we needed to determine which of our historic and modern sources were most reliable.

Public Land Survey plat map wetland boundaries are poorly defined when compared to other source material, including a LiDAR-derived Digital Elevation Model (DEM). It appears that the surveyors accurately located wetland margins where they crossed section lines, then approximated polygons around these, often connecting wetlands across unsuitable upland terrain. Modern wetland data are missing many of the historic wetlands that have been drained for agriculture and urbanization. Soils data allows us to identify soil polygons that were saturated at some time in the past, but not to separate historic from prehistoric features.

When the first iteration of the Historic Vegetation Model was completed for one region in the state, we compared its depiction of wetlands to that of the modern hydrographic data to determine which was most reliable. This comparison involved sampling both the vegetation model and the modern wetland data with a set of points for which vegetation types observed by the Public Land surveyors had been extracted from the digitized line notes data from MnDNR. These points had not been used to build the vegetation model, but overlapped a portion of the area modeled. The vegetation model did a much better job of predicting the wetland types than did the modern data (Table 1). We therefore determined to use wetlands from the Historic Vegetation model to represent historic wetlands in the Historic Hydrographic model. It was apparent, however, that though the vegetation model predicted lake and river locations well, it did a poor job of depicting their outlines. Since shorelines are important locations for archaeological sites, we decided to use lakes and rivers from plat maps, supplemented by modern data where necessary (see below), to represent historic features.

Table 1: Preliminary Historic Vegetation Model vs. Modern Hydrographic Data for Predicting Historic Wetland Types

Wetland Type	Floodplain Forest	Lake	Marsh	Wet Meadow/Fen	River	Swamp
Predicted by Vegetation Model	75%	89%	75%	67%	82%	74%
Predicted by Modern Data	20%	54%	32%	1%	11%	14%

Selection of Features

To facilitate the selection of hydrographic features from the various source data, a 'USE' field was added to each feature class and calculated to indicate whether or not a feature would be used in the hydrographic model.

Plat Map Polygons

Lakes digitized from the PLS plat maps took precedence over any modern lakes they intersected. The only exception to this rule was when the digital elevation model clearly showed that the plat map lakes were inaccurately mapped. We are aware that some of these lakes were already reservoirs, but there is no earlier depiction of their boundaries available.

Plat maps vary in their ability to accurately depict river courses. Shores of very large rivers (for example the Mississippi and Minnesota) were surveyed, at least in part, and are relatively accurately depicted. Smaller rivers tended to be drawn free-hand. Rivers selected for use were those that fit within the floodplain and appeared to follow a natural path, particularly those with a course similar to incised meanders in the terrain model and those with a course different than or narrower than that of the corresponding altered modern river. Plat map polygons were most often used for larger rivers, such as the Minnesota and Mississippi Rivers, which were actually surveyed, for cases where modern data represented streams as reservoirs, diversions, or ditches, or where the stream was missing altogether from the modern data. In cases where rivers from the plat maps were nearly identical to those in the modern data, modern rivers were chosen due to the more precise delineation of their boundaries.

Historic Vegetation Model

After an Historic Vegetation Model was completed for each modeling region, all wetland categories were exported for inclusion in the Historic Hydrographic Model. Lake and river categories were recoded to a new value, 'Wet Land', so that predictions from the vegetation model could be distinguished from lakes and rivers added to the Historic Hydrographic Model from other sources.

Soils Data

Soils data were determined to be the most reliable source of information in determining the locations of prehistoric wetlands because of soils' slower alteration over time than surface expression of wet lands.

Soils selected for inclusion in the model include:

- Histosols, soils in the aquic soil suborders (Aquerts, Aquolls, etc.), Albolls, and Fluvents. These are further subselected to include only soils in these classes that are both 75% hydric and either poorly drained or very poorly drained. Albolls and some aquic soil orders were omitted from the original hydrographic model developed by UMD, probably because they did not occur in the counties for which we had soils data at the time the model was developed. They have been included in the current definition of potential historic wetland soils.
- Udalfs may have fragipans and their ability to hold water varies with the depth to that horizon. There is one Udalf mapunit in Minnesota gSSURGO data that is characterized as poorly drained and 90 percent hydric. gSSURGO rates it as 90 percent potential soil wetland landscape. It also corresponds to a number of modern wetlands. For this reason, the model was refined to include Udalfs with poor to very poor drainage that are greater than or equal to than 85 percent hydric, which is the same criteria for all other wetland soils.

- Soils identified as having a wet substratum. The assumption is that these are filled wetlands.

In the original model, soil polygons indicative of former wetlands were extracted by a series of queries from county soils datasets. Because we now have gSSURGO data in a statewide geodatabase, it was simplest to perform the queries once on the soil tables for the state and code a new variable to indicate which mapunits qualified for inclusion in the model. This variable would need to be updated whenever the statewide gSSURGO data are updated.

Geomorphic Data

A version of the MnModel Phase 4 Landscape Model was created with additional fields for coding features by time periods. The time period fields are:

- MODERN: post-agricultural features.
- HISTORIC: features extant only during the last 200 years
- PREHISTORIC: post-glacial features (local ice evidence through 200 BP)
- GLACIAL: evidence of local ice.

Naturally, many older features are not recorded as they are overlain by younger features. One concession to this dilemma was to code historic floodplains also as glacial floodplains. The Landscape Model uses 'Lake Basin' to designate lake beds containing water at present and 'Lake Bed' to designate lake beds that are dry or contain wetlands. Lake beds from the landscape model were used only in the prehistoric model, as we considered lakes from the PLS plat maps and modern data to be better indicators of historic lakes.

Modern Hydrographic Data

All modern sources included artificial water bodies – sewage disposal ponds, quarries, tailing basins and such – and these were automatically excluded from modeling. Most were coded in the source data as artificial, but others were not identifiable as such without visual examination and comparison to aerial photographs. Artificial lakes were sometimes recognizable by their context as 'amenities' in a modern subdivision, as farm utility ponds, or in industrial areas. Wetland polygons were also excluded if they were mapped on improbably steep slopes.

Likewise, river polygons were evaluated based on their attribute data in the sources mentioned as well as attributes taken from linear streams data (including the statewide [Altered Watercourse](#) dataset). If they were coded as 'impounded,' 'altered,' 'channeled,' or 'ditched' they were excluded from the model. Additional altered rivers were identified and coded for exclusion if they appeared more like a lake than a river, occupied a very different course from that depicted on the plat maps, or were unnaturally straight.

Modern water bodies that appeared to be natural were coded for use only in specific situations:

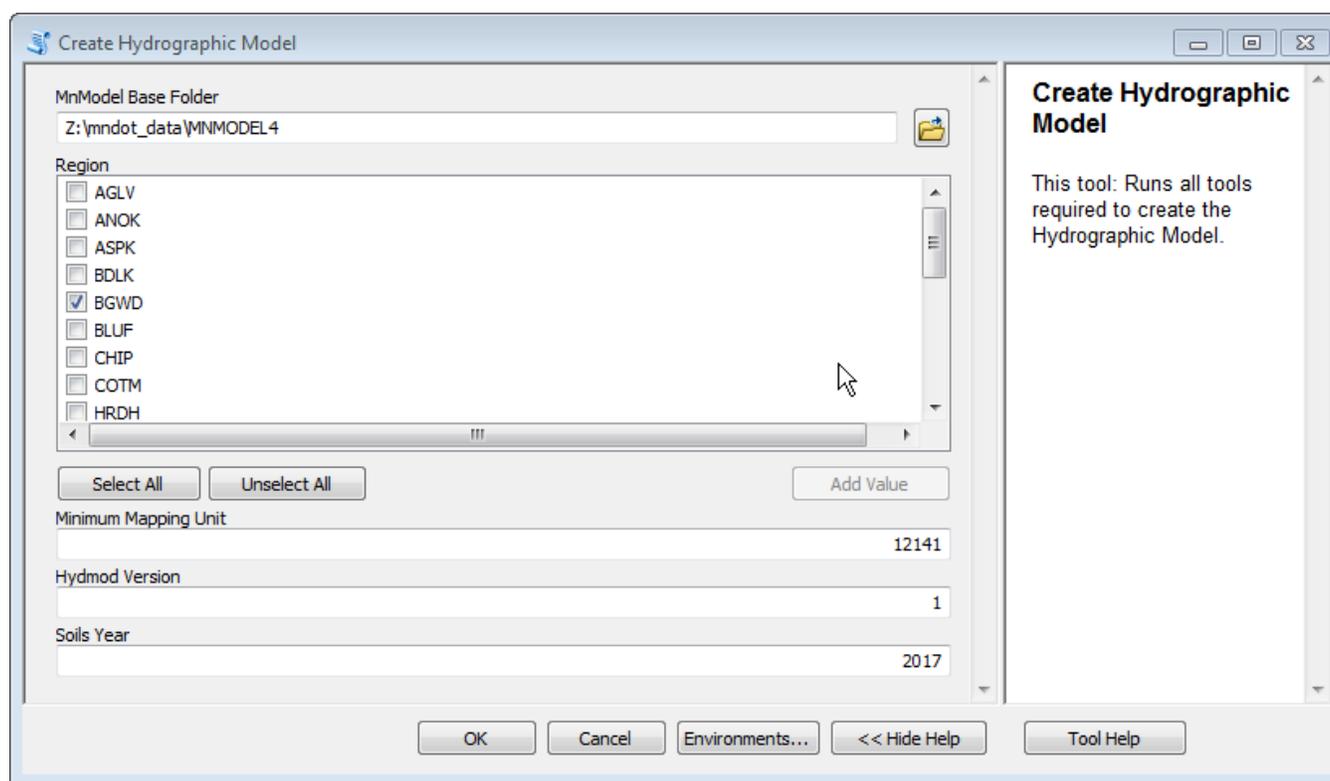
- Lakes that were completely within a single section and would not have been observed by the Public Land surveyor. Surveyors did not stray from section lines, which are organized in one-mile square grids. It is likely they did not see many small lakes.

- Lakes needed to replace plat map lakes that were inaccurately mapped.
- Rivers that appeared to be naturally flowing, not dammed or diverted, within the historic floodplain, similar to the course depicted on the plat maps, and/or with deeply incised meanders.

Hydrographic Modeling

The hydrographic model is developed in ArcGIS by running one custom Python tool (Brown et al. 2019), with some manual quality control suggested following a successful tool run. This single tool (Figure 2) creates regional MnModel Phase 4 Historic and Prehistoric Hydrographic Models. It also creates feature classes of historic and prehistoric floodplains. The actions implemented by the ‘Create Hydrographic Model’ tool (Figure 2) are documented in Appendix A of this report (Figure A1) and summarized in the next section.

Figure 2: ‘Create Hydrographic Model’ Tool



For additional information on how this tool is successfully run see the MnModel Phase 4 Tool Handbook.

Modeling Procedures

Step 1: Extract Historic Lakes and Rivers

This tool clips the Public Land Survey polygons by the region boundary and extracts all rivers and lakes to a new feature class. It adds a new field (HISTHYD) to the attribute table, selects and codes lakes and rivers in this field, then deletes all fields except HISTHYD.

Step 2: Extract Modern Lakes and Rivers

The tool clips the modern surface hydrography polygons by region, then selects those previously coded for use. It then dissolves the polygons based on water body type, eliminates polygons smaller than the user-selected minimum mapping unit (12,141 sq m for this project) by merging them with their neighbors, deletes any small polygons that were not merged, and deletes any artificial water bodies that might remain. It selects river and lake polygons and creates a separate layer to be combined with wetland soils.

Step 3. Extract Features from Landscape Model

The MnModel Phase 4 Landscape Model was prepared for use by creating a separate feature class (LANDCHRON) and coding features as either modern, historic, or prehistoric. These decisions were based on guidance by the project geomorphologist. The modeling tool clips this statewide feature class by the region boundary, then selects and codes features as documented in Table 5. These coded features are extracted to new feature class and provide the model with several new lake and river polygons as well as historic and prehistoric floodplains.

Table 2: Floodplain Selection from Landscape Model

Model Type	Selected Landform Values
Historic Lake	<ul style="list-style-type: none"> • Does not intersect a modern lake selected by the previous tool. • Coded in LANDCHRON as HISTORIC = 'LAKE BASIN'
Historic River	<ul style="list-style-type: none"> • Does not intersect a modern river selected by the previous tool. • Coded in LANDCHRON as MODERN = 'RIVER BED'
Historic Floodplain	<ul style="list-style-type: none"> • Not already coded as 'LAKE' or 'RIVER' in a previous step. • Coded in LANDCHRON as HISTORIC = 'FLOODPLAIN'. These include: <ul style="list-style-type: none"> ○ Paleo river channels if they are on floodplains and not in catastrophic flood, galciofluvial, or terrace landscapes. ○ Reservoirs on floodplains ○ Alluvial Fans
Prehistoric Lake	<ul style="list-style-type: none"> • Coded in LANDCHRON as PREHISTORIC = 'LAKE BASIN' or 'LAKE BED'
Prehistoric Floodplain	<ul style="list-style-type: none"> • Coded in LANDCHRON as PREHISTORIC = 'FLOODPLAIN'. These include: <ul style="list-style-type: none"> ○ All historic floodplains ○ River terraces • Coded in LANDCHRON as PREHISTORIC = 'RIVER BED'. These include: <ul style="list-style-type: none"> ○ Paleochannels on terraces and tributary fans

Step 4: Extract Potential Wetlands from gSSURGO STATEWIDE

Soil polygons were previously coded for use in the hydrographic model. The codes are recorded in the 'HYDMODGRP' variable in the MM_Mapunit_Interpreted table, a custom table, created for this project, that can be joined to gSSURGO mapunit keys. Values for HYDMODGRP are detailed in Table 2.

Table 3: HYDMODGRP Values

HYDMODGRP	Definition	Includes
-999	No taxonomic data	<ul style="list-style-type: none">• Areas with no published gSSURGO data• Water bodies, intermittent water, disturbed areas, some beaches, some flooded areas
1	Potential wetland soils, filtered by hydric status & drainage	<ul style="list-style-type: none">• Taxonomic order is Histosols or taxonomic suborders include Albolls, Aqualfs, Aquents, Aquepts, Aquerts, Aquolls, Fluvents, Fluvaquents, Histosols, and Udalfs.• Soils with a wet substratum (mostly Orthents)• Except for soils with a wet substratum, soils are at least 75 percent hydric.• Except for soils with a wet substratum and soils that are more than 85 percent hydric, soils are all poorly or very poorly drained.
0	Not wetland soils	<ul style="list-style-type: none">• Soils less than 75 percent hydric and neither poorly nor very poorly drained.• If 'manipulated materials', there is no wet substratum

The modeling tool selects polygons coded for use (HYDMODGRP = 1) and codes these polygons to distinguish between wetland soils and soils with wet substrata.

Step 5: Combine Modern Water Polygons and Wetland Soils

In this step, lakes and rivers from the modern hydrographic data are combined with the wetland soil and wet substrate polygons extracted from gSSURGO. They are combined so that the lakes and rivers take precedence over the soil features. This step is an apparent dead-end, and its end product is not used in subsequent procedures.

Step 6: Combine Historic Floodplains

Historic and prehistoric floodplains were identified by types of landforms in the gSSURGO soils data. Decision rules for distinguishing between historic and prehistoric floodplain features are documented in Table 3. We

decided not to use alluvium as recorded in soils data to represent floodplains, as too many alluvial features are identified on outwash plains, hillslopes, depressions, beach ridges, and other non-floodplain landforms.

Table 4: Floodplain Selection from gSSURGO

Model Type	Selected Landform Values
Historic	Alluvial flats, backswamps, bars, flood-plain splays, flood-plain steps, levees, natural levees
Prehistoric	Alluvial flats, backswamps, bars, flood-plain splays, floodplain-steps, flood plains, levees, natural levees, benches, alluvial fans, fans, strath terraces, stream terraces, terraces

Historic floodplains from the gSSURGO soils data and the Landscape Model (Step 3) are then combined.

Step 7: Prepare Streams Line Data

Natural streams mapped as lines were processed to create three separate feature classes:

- Buffered streams, to create polygons for supplementing rivers mapped as polygons for the historic hydrographic model.
- Perennial streams, to serve as source data for deriving a ‘distance from perennial stream’ variable for the archaeological predictive model.
- Intermittent streams, to serve as source data for deriving a ‘distance from intermittent stream’ variable for the archaeological predictive model.

Step 8: Combine Historic and Modern Water

This step combines historic lakes and rivers extracted from the Public Land Survey data with non-intersecting lakes and rivers from the modern natural water feature class. It then adds the buffered stream polygons if they do not overlap a river polygon already in the feature class. Finally, it incorporates historic floodplains from the landscape model and gSSURGO source. In addition, it exports a combined ‘Major Rivers’ feature class.

Step 9: Create Final Historic Vegetation and Hydrographic Models

In this step, the historic lake, river, and floodplain polygon feature class is converted to a raster. The vegetation model is updated with more accurately mapped lakes and rivers from the historic hydrography data. Finally, wetlands are extracted from the preliminary Historic Vegetation Model for the region and combined with the lakes, rivers, wetlands and floodplains so that lakes and rivers take precedence over wetlands, and wetlands take precedence over floodplains.

Step 10: Create Prehistoric Hydrographic Model

Select Shores from gSSURGO Soils Data

Beaches and shores may be important features for archaeological site locations. These were selected from gSSURGO data on the basis of the landform classification. Shores included landforms classed as beaches,

lakeshores, and shorelines where the landscape is not 'lake plain.' It should be noted that some of these shores are mapped at some distance from historic and prehistoric water bodies, though it is clear from the terrain data that they are on the margins of basins.

Extract Prehistoric Floodplains

Prehistoric floodplains from both the gSSURGO data and the Landscape Model are selected and combined into a new feature class. Modern rivers are combined with these, and coded as floodplains, to prevent NULL values in the subsequent model.

Combine Prehistoric Water Features

The prehistoric floodplain feature class is combined with the wetland soils extracted in Step 4 so that wetland soils take precedence over floodplains. Prehistoric Lakes are combined with these so that they take precedence over all others. Shores are incorporated where no other features are present. Finally, the polygons are converted to rasters and, where soils data are missing, wetlands from the vegetation model are incorporated to represent prehistoric wetlands.

Final Model Classification

The model creates two raster layers: HISTHYD to hold features for the historic hydrographic model and PREHYD to hold features for the prehistoric hydrographic model. These features are segregated based on decision rules documented in Table 5.

Table 5: Final Features Classes and Categories for the Hydrographic Model

Feature Class	Valid Values	Includes
HISTHYD	<ul style="list-style-type: none"> • LAKE • RIVER • BOG • FLOODPLAIN • FLOODPLAIN FOREST • MARSH • WET MEADOW/FEN • SWAMP • WET LAND 	<ul style="list-style-type: none"> • Natural lakes and rivers from modern water sources • PLS plat maps lakes and rivers • Wetlands from the Historic Vegetation Model • Floodplains from gSSURGO and the landscape model ONLY where there are no wetlands on the floodplain
PREHYD	<ul style="list-style-type: none"> • FLOODPLAIN • LAKE • SHORE • WETLAND 	<ul style="list-style-type: none"> • All floodplains except those that were glacial • Beaches & shores extracted from modern water sources,

Feature Class	Valid Values	Includes
		gSSURGO and the Landscape Model <ul style="list-style-type: none"> • All lake basins and lake beds except glacial • River beds and paleochannels are classified as floodplains • Wetland soils, except where soils data are not available • Wetlands from the Historic Vegetation Model where soils data are missing.

Quality Control

To facilitate quality control, separate model layers were created. These layers were compared to their source data and to the scanned PLS plat maps to check for valid values and completeness. In particular, the order of features was checked; for example, where wetlands are present they should supercede floodplains. It was important not to assume that automated procedures that ran correctly in one modeling region would run correctly in other regions.

Checklists were developed to insure that quality control procedures were systematic and to help correct the Python code accordingly. The procedures for checking the Historic Hydrographic Model (HISTHYD) involved:

- Comparing the model to the region’s boundary to make sure it covered the entire region.
- Examining the raster attribute table to verify that all expected cell values were present.
- Confirming that water body type classifications (MODTYPE field) matched the corresponding numeric values matched (Table 7).
- Confirming that PLS plat map lakes and rivers were classified as such and not as WET LAND.
- Verifying that lakes and rivers took precedence over WET LAND, FLOODPLAIN, and other wetland types.
- Verifying that HISTHYD’s FLOODPLAIN values were present only where other wetlands were absent by comparing to the wetland values from the Historic Vegetation Model.

Table 6: Valid Values for Historic Hydrographic Model (HISTHYD) Attribute Table

VALUE	MODTYPE	DEFINITION
-999	NO DATA	No historic surface hydrographic features present
100	LAKE	Historic lakes from PLS plat maps, supplemented by modern lakes (derived from NHD, DNR, and NWI data) that are not artificial and are not water bodies accurately depicted on PLS plat maps.
150	WET LAND	Areas classified as lakes or rivers by the Historic Vegetation Model that were not occupied by lakes or rivers mapped by other sources. These may have been wetlands or intermittent water historically.
200	RIVER	Historic river courses from PLS plat maps and modern rivers (derived from NHD, DNR, and NWI data) that are not as accurately depicted on PLS plat maps and are not reservoirs or part of historically constructed channels.
210	BOG	Open sphagnum and conifer bogs, from the Historic Vegetation Model
230	MARSH	Marshes, from the Historic Vegetation Model
240	FLOODPLAIN FOREST	Floodplain forests, from the Historic Vegetation Model
270	WET MEADOW/FEN	Wet meadows, wet prairies, and fens from the Historic Vegetation Model
280	FLOODPLAIN	Historic floodplains, from gSSURGO and geomorphic data sources, which were not otherwise occupied by wetlands.
290	SWAMP	Conifer, hardwood, and shrub swamps from the Historic Vegetation Model

Procedures for checking the Prehistoric Hydrographic Model (PREHYD) involved:

- Comparing the model to the region’s boundary to make sure it covered the entire region.
- Confirming that only valid values (Table 8) were present in the attribute table.

- Verifying that lake basins and lake beds from the Landscape Model and lake beds from the gSSURGO, are depicted as lakes.
- Verifying that wetlands and lakes took precedence over cells classified as floodplains. This can be done by observing lakes and wetlands on the raster that appear to be present on floodplains (engulfed by floodplains, but still present).
- Verifying that wetlands from the gSSURGO data are present.
- Verifying that wetlands from the Historic Vegetation Model were used where gSSURGO data were unavailable.

Table 7: Valid Values for the Prehistoric Hydrographic Model (PREHYD) Attribute Table

VALUE	MODTYPE	DEFINITION
-999	NO DATA	No prehistoric hydrographic features present
100	LAKE	Prehistoric lakes, including historic lakes from HISTHYD and lake beds as mapped by gSSURGO and geomorphic data.
110	SHORE	Lake (mostly) and river shores mapped from modern water, gSSURGO and geomorphic data.
150	WETLAND	Prehistoric wetlands, mapped from gSSURGO wetland soils where available and from the Historic Vegetation Model where soils data are absent.
280	FLOODPLAIN	Prehistoric floodplains, as mapped from gSSURGO and geomorphic data.

If a regional PREHYD or HISTHYD raster violated any of the rules, the modeling tool was revised to correct the identified flaws and the raster was regenerated.

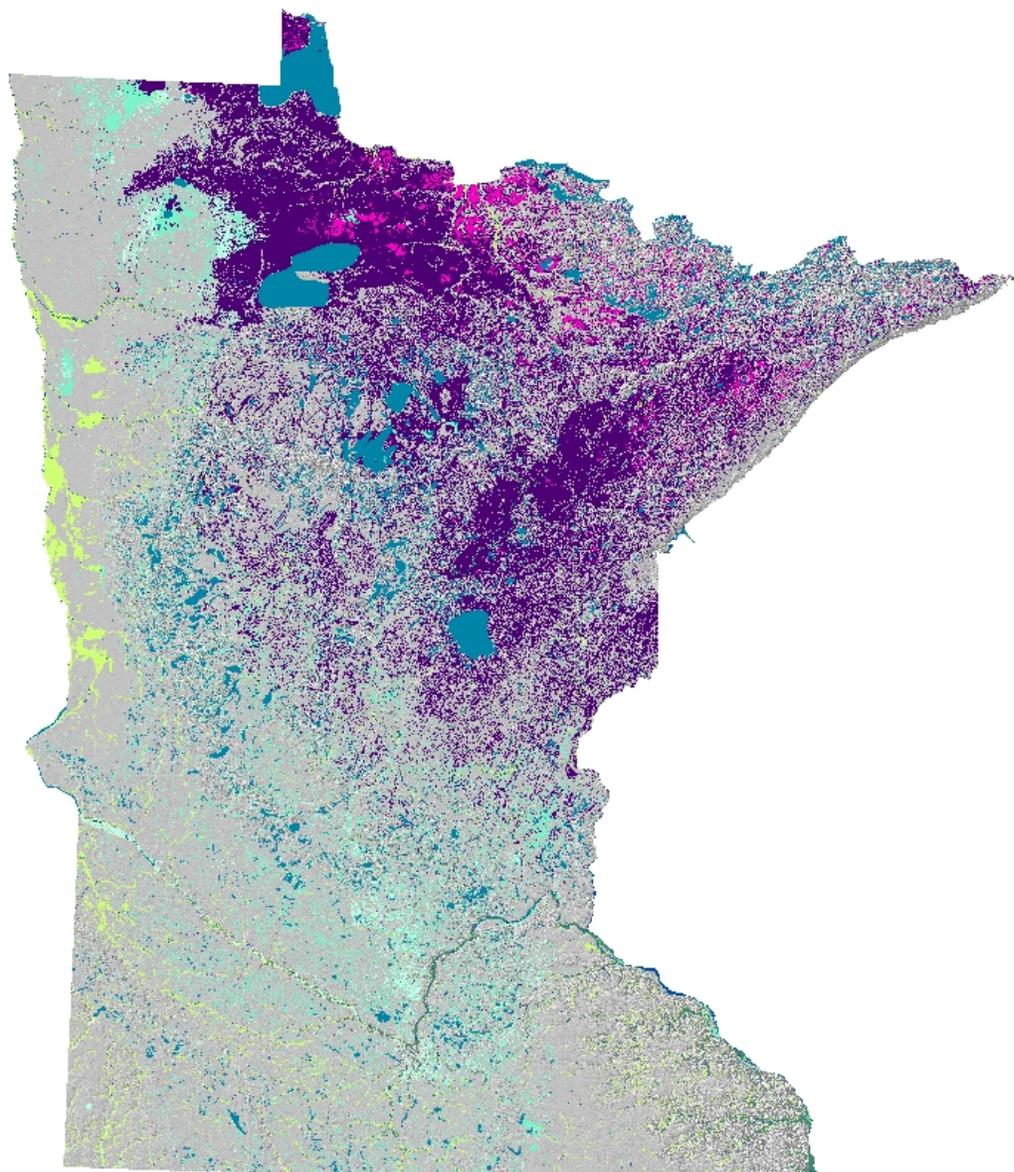
Results

Historic Hydrographic Model

The Historic Hydrographic Model represents potential surface water distribution in the late prehistoric and early historic periods (Figure 3). Although distinctions between different types of wetlands are certainly biased by researchers' interpretations of the vocabulary used by the Public Land Surveyors, overall patterns are as

expected. Marshes and wet prairies dominate the southwestern part of the state and swamps dominate in the north.

Figure 3: MnModel Phase 4 Historic Hydrographic Model

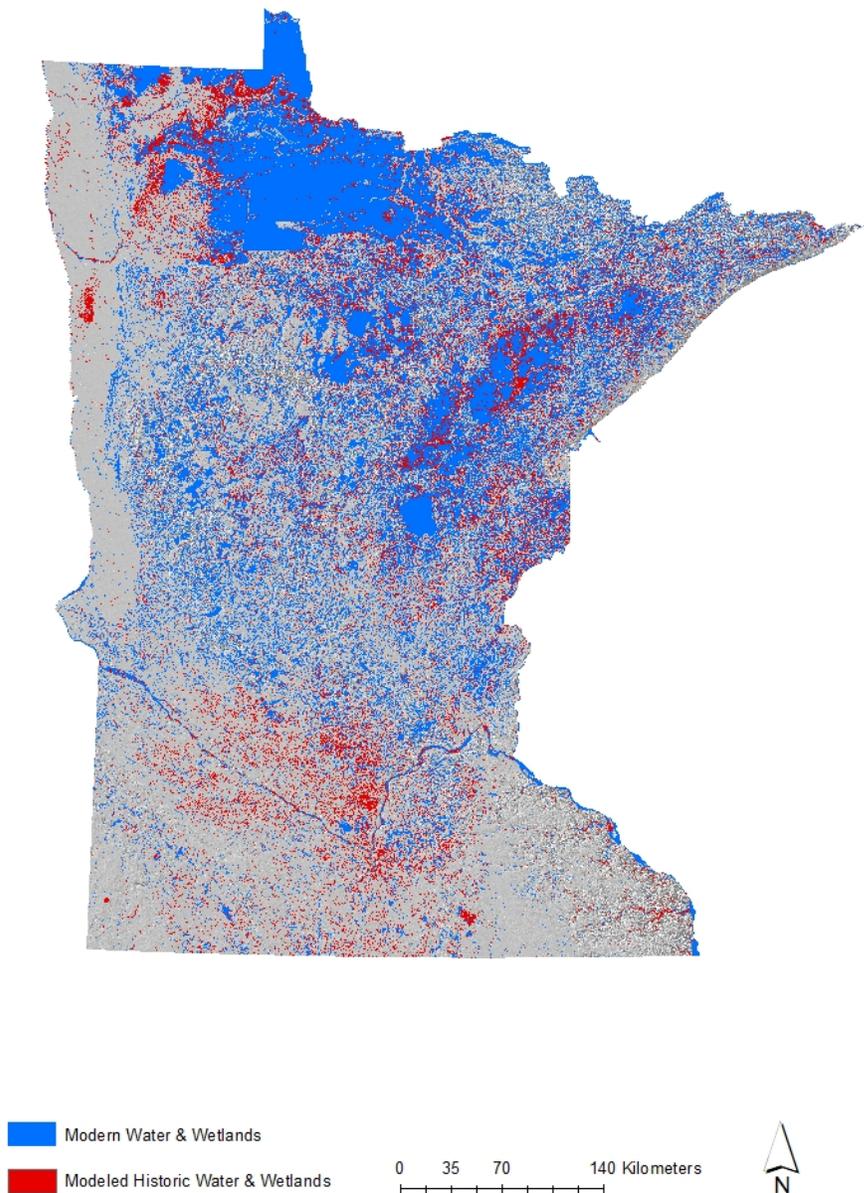


This model categorizes 35 percent of Minnesota as covered by permanent or intermittent water historically (Table 9). This compares to the present when contemporary data categorize 27 percent of the state as natural water features and reservoirs. In the modern data, the area of lakes as declined only slightly (to 5.5 percent of the state), the area of rivers has not changed, and the area of wetlands has decreased to 20.7 percent of the state from the historic model’s combined total of 26.3 percent (excluding floodplains with no mapped wetlands). In Figure 4, historic wetlands are visible only where they are not overlain by modern water and wetlands. Wetland loss is apparent throughout the state.

Table 8: Statewide Extent of Hydrographic Categories in Historic Hydrographic Model

VALUE	MODTYPE	HECTARES	PERCENT OF STATE
-999	NO DATA (Not water or wetland)	14,224,725	65.0
100	LAKE	1,239,495	5.7
150	WET LAND	164,316	0.8
200	RIVER	91,816	0.4
210	BOG	264,649	1.2
230	MARSH	1,047,914	4.8
240	FLOODPLAIN FOREST	181,845	0.8
270	WET MEADOW/FEN	245,890	1.1
280	FLOODPLAIN	562,908	2.6
290	SWAMP	3,845,315	17.6

Figure 4: Extent of Modern Water and Wetlands Compared to Historic Water and Wetlands



To test the accuracy of the model, all points classified in the Public Land Survey data as wetlands, lakes, and rivers were overlain on the model. This evaluation model results is based on a sample of 72,002 points statewide. Table 10 details the percent of the sample represented by each wetland type and the accuracy, as measured by the correct percentage of predictions, for each. The model is best at predicting historic lakes, which stands to reason since these were taken primarily from the PLS plat maps. It also does an excellent job of predicting swamps, which are the most common wetland type. It does a poor job predicting bogs, which are

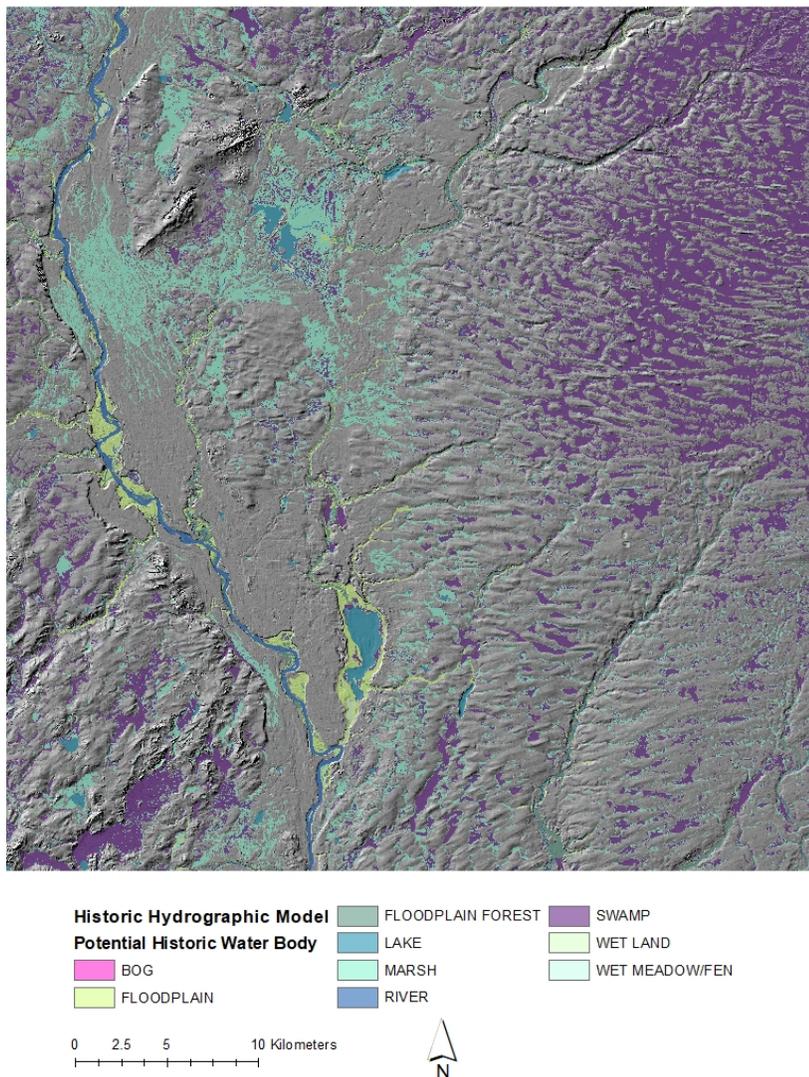
most often erroneously predicted as swamps, and wet meadows/fens (primarily wet prairie in the southwestern part of the state), which are most often erroneously predicted as non-wetland.

Table 9: Accuracy of Historic Hydrographic Model Predictions

MODTYPE	SAMPLE	ACCURACY
LAKE	13.8%	93%
RIVER	0.8%	50%
BOG	8.1%	42%
SWAMP	45.5%	86%
MARSH	19.7%	57%
FLOODPLAIN FOREST	3.6%	55%
WET MEADOW/FEN	8.5%	39%

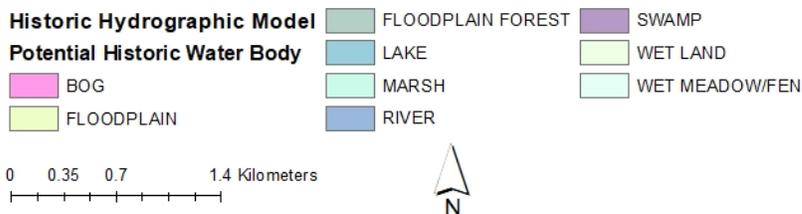
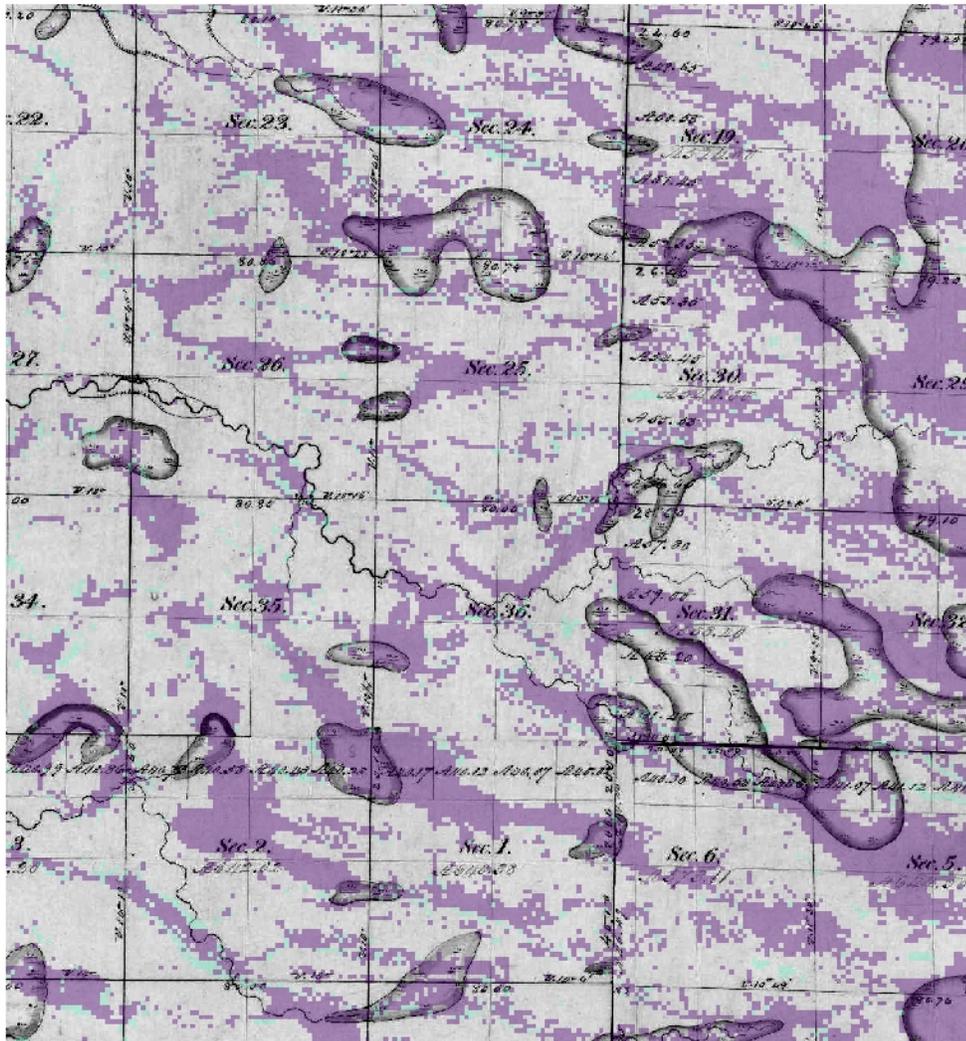
Less formal tests of the Historic Hydrographic Model include visual comparisons of its results to the digital terrain model and the scanned Public Land Survey plat maps. The modeled water and wetlands correspond very well to terrain in a variety of landscapes (Figure 5). Much of this is by design. Lake and river polygons were selected from whichever available source provided the best fit with the digital terrain model. The Historic Vegetation Model, the source of all wetlands, relies on a number of terrain variables as predictors.

Figure 5: Sensitivity of Historic Hydrographic Model to Terrain



By comparison, the fit to the PLS plat maps is far from exact (Figure 6). This is to be expected, since the surveyors' observations are accurate only along the section lines and around meandered lakes and rivers. Wetland boundaries, in particular, were imaginative interpolations from the surveyed section lines. What is striking, though, is the extent to which the model corresponds to wetlands where they are crossed by section lines. This is a good indication that the model is doing a decent job of representing the landscape the surveyors observed.

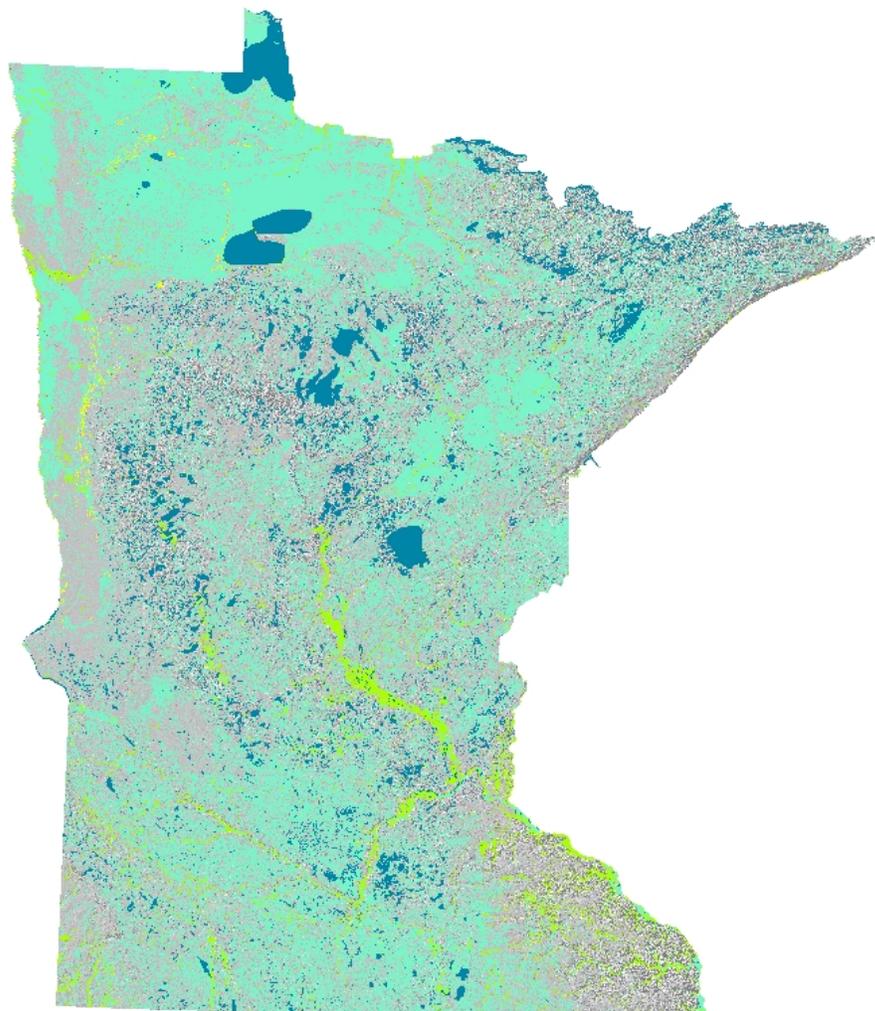
Figure 6: Comparison of Historic Hydrographic Model to PLS Plat Maps



Prehistoric Hydrographic Model

The Prehistoric Hydrographic Model represents potential maximum post-glacial surface water distribution in the prehistoric period (Figure 7). What is notable is that both lakes and wetlands were more extensive than in the historic period (Table 11). Prehistorically, approximately 47 percent of the state was permanently or intermittently wet.

Figure 7: MnModel Phase 4 Prehistoric Hydrographic Model



Prehistoric Hydrographic Model

Prehistoric Feature

-  WETLAND
-  SHORE
-  LAKE
-  FLOODPLAIN

0 35 70 140 Kilometers

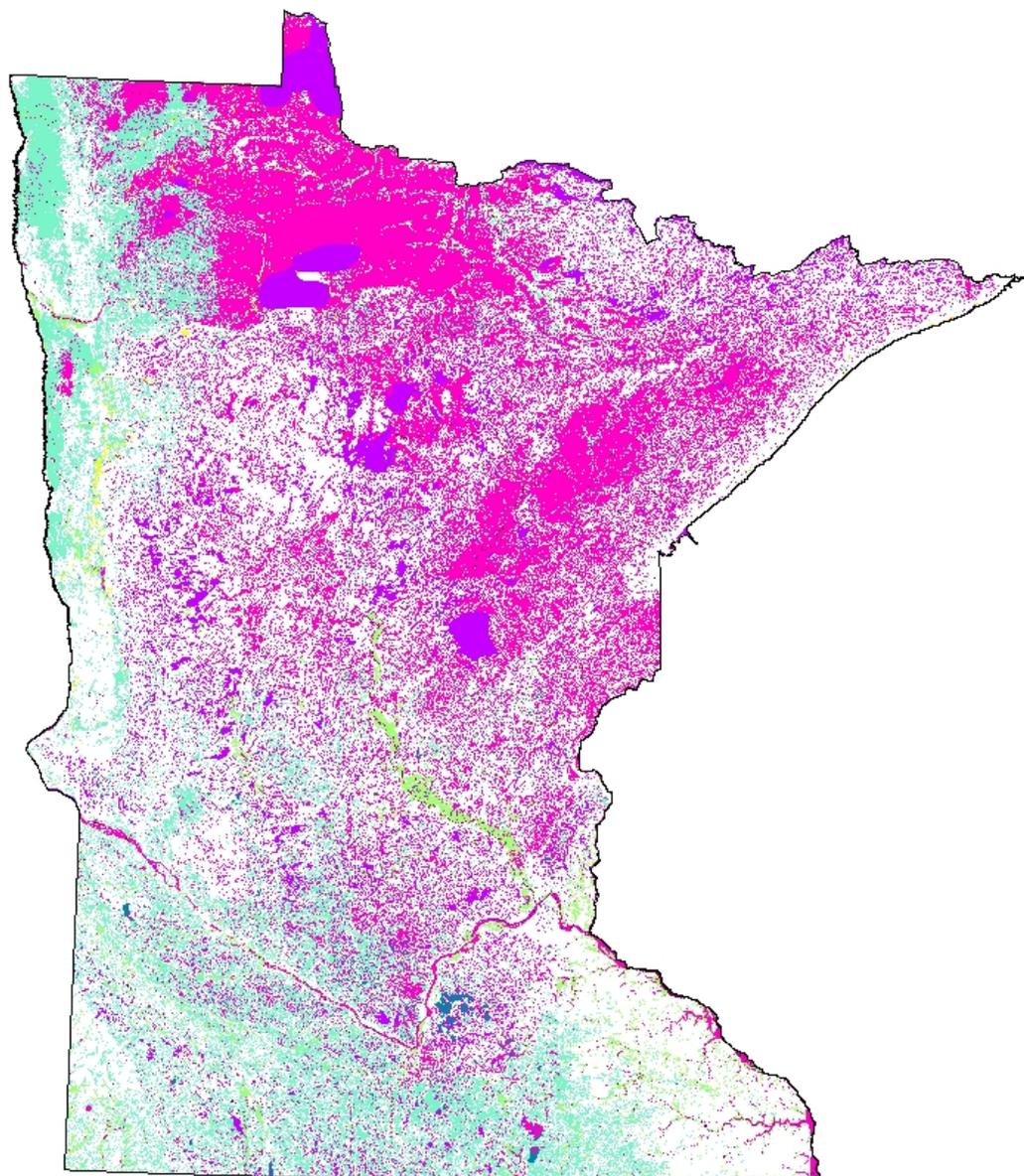


Table 10: Statewide Extent of Hydrographic Categories in Prehistoric Hydrographic Model

VALUE	MODTYPE	HECTARES	PERCENT OF STATE (Prehistoric)	PERCENT OF STATE (Historic)
-999	NO DATA	11,498,920	52.6	65.0
100	LAKE	1,427,809	6.5	5.7
110	SHORE	48,406	0.2	N/A
150	WETLAND	8,214,703	37.6	26.3
280	FLOODPLAIN	679,035	3.1	1.2 (includes rivers)

For comparison, an overlay of the historic model on the prehistoric model shows where wetlands have been lost due to climate change in the post-glacial period. The prehistoric model differs little from the historic model in the cooler, forested north-eastern part of the state (Figure 8). Southeastern Minnesota was not recently glaciated and has steep terrain, so prehistoric wetlands were more extensive only on the floodplains. Evidence of more extensive prehistoric wetlands in the prairie regions of western, southwestern, and south-central Minnesota, however, is striking (Figure 9). The northwestern portion was the bed of Glacial Lake Agassiz, while most of the southwestern area was covered by the Des Moines Lobe, where wetlands there were remnants of melting ice embedded in ground moraines. Even before extensive agriculture, these areas experienced a significant post-glacial wetland loss as the climate became progressively drier.

Figure 8: Comparison of Historic and Prehistoric Hydrographic Models



Historic Lakes and Wetlands Prehistoric Lakes and Wetlands

Historic Feature

-  HISTORIC LAKE
-  HISTORIC RIVER
-  HISTORIC WETLAND
-  NOT HISTORIC WETLAND

Prehistoric Feature

-  PREHISTORIC WETLAND
-  PREHISTORIC SHORE
-  PREHISTORIC LAKE
-  PREHISTORIC FLOODPLAIN



0 35 70 140 Kilometers

Conclusions

One of the goals of updating the previous Hydrographic Model was to distinguish between the ‘maximum extent’ of post-glacial surface water, as represented primarily by soils evidence, and the conditions at the other end of the prehistoric period when Euro-American settlers began altering the landscape. These models seem to do this well. The Prehistoric Hydrographic Model is quite similar to our original model (Stark et al. 2008) in the extent of wetland mapped, while the Historic Hydrographic Model maps less surface water and compares favorably to the observations of the Public Land Surveyors. Thus these two models bracket the time period of interest to archaeologists in Minnesota. The actual conditions on the ground at any specific prehistoric time can be expected to be somewhere in between them.

When used to predict archaeological site locations for MnModel Phase 4, these hydrographic models performed very well (Hobbs 2019b). Hydrographic variables derived from these models appeared frequently in statistical models for determining probable locations for archaeological sites (Hobbs, Walsh, and Hudak 2019). Least-cost path distances to large historic lakes, prehistoric large lakes, historic ‘wet’ land, and historic wetlands are the most significant hydrographic variables. Least-cost path distance to rivers, perennial streams, and intermittent streams all performed well. Individual types of wetlands (bogs, marshes, swamps, wet meadows) seemed to matter less than proximity to a basin filled with some type of water. However, *Path distance to historic surface water* (a variable that includes lakes, ‘wet land’, rivers, bogs, swamps, and marshes as source cells) did not perform well. It seems important to the models that distances to lakes, rivers, and wetlands be distinguished as these contribute different and useful information.

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Appendix A: Hydrographic Modeling Process

The MnModel Phase 4 historic/prehistoric hydrographic modeling procedures, as implemented in the 'Create Hydrographic Model Tool', are illustrated in Figure A1.

Figure A1: MnModel Phase 4 Historic and Prehistoric Hydrographic Modeling Process

