Northern Prairie Wetlands and Climate Change

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ABSTRACT

The Prairie Pothole Region (PPR) of North America contains millions of wetlands that provide abundant ecological services that are highly sensitive to climate change. We explored the broad spatial and temporal patterns across the PPR between climate and wetland water levels and vegetation by “moving” a wetland model (WETSIM 3.1) among 18 stations with 95-year weather records. Ecoregions were used as the spatial framework to select weather stations and to compare and contrast model outputs. A critical component to WETSIM 3.1 was an accurate digital elevation model (DEM) for the wetland basin. Spatial analysis was performed on model outputs in ArcGIS. Simulations suggest that optimum wetland conditions would shift under a drier climate from the center of the PPR (Dakotas and southeastern Saskatchewan) to the wetter eastern and northern fringes, areas currently less productive and where most wetlands have been drained.

1.0 INTRODUCTION

1.1 Study Area

The Prairie Pothole Region (PPR) of North America covers approximately 715,000 km^2 (Euliss et al. 1999), 770,000 km^2 (Dahl 1993) or 875,902 km^2 (Millett 2004) (Figure 1). It is bounded on the south and southwest by the limits of the Laurentide ice sheet of the Wisconsinan glaciation and on the west by the ice-marginal Missouri River. The northern limit of the PPR is the southern boundary of the Canadian boreal forests of Alberta, Saskatchewan, and Manitoba, and the eastern limit is the prairie-deciduous forest transition zone. This transition zone shifts eastward when climate conditions become dry and westward when conditions become wetter (Anderson 1983).

Figure 1. Prairie Pothole Region (PPR) shaded in gray (Omernik 1987, 1995).

These wetlands were formed during the Pleistocene Epoch, approximately 18,000 years ago. The mid-continental ice sheets retreated and left behind water filled depressions called potholes, kettle holes, or sloughs scattered across the landscape. These prairie wetlands support numerous waterfowl and aquatic plant species. The fossil pollen record indicates that vegetation of the Great Plains of North America also has undergone dramatic changes since the Late Pleistocene (Wells 1970).

There are millions of basins within the PPR. Cowardin et al. (1995) estimated that about 3.1 million wetland basins occur in MN, MT, ND and SD; estimated mean wetland-basin sizes were 2.7 ha in MN, 1.2 ha in MT, 0.6 ha in ND, and 1.1 ha in SD. The number of wetlands with water varies from year to year, depending primarily on the amount of precipitation and runoff. The Canadian Prairie Provinces have between 2 and 7 million wetlands. May pond long-term averages (1961-2001) showed Alberta with 728,000, Manitoba with 1,992,000, and Saskatchewan with 687,000 basins that resulted in a total of 3.4 million wetlands (Wilkins et al. 2002).

The wetlands of the glaciated prairies of the north central United States and south central Canada are highly sensitive to weather extremes and changes in climate (Poiani et al. 1991, Halsey et al. 1997, Hurd et al. 1999, LaBaugh et al. 1996, Meyer et al. 1999, Fritz et al. 2000, Johnson et al. 2005).

Previous studies focused on a semi-permanent wetland at one location (Poiani et al. 1991, 1993a, 1993b, 1995, 1996). They developed and used the model WETland SIMulation (WETSIM) to simulate the vegetation and hydrology in semi-permanent prairie wetlands. Their results indicated that warmer temperatures, similar to those predicted by various climate models, caused drier conditions, despite increases in precipitation. The overall result was less open water and greater emergent cover in nine out of ten climate scenarios. When the cover ratio became unbalanced, either toward more open water periods or emergent vegetation, productivity of waterfowl declined (Weller and Spatcher 1965).

This research used a revised version of the simulation model WETland SIMulation (WETSIM) 3.1, weather data, and analyzed model outputs using Geographic Information Systems (GIS) to better understand the spatial and temporal sensitivity of PPR wetlands to climate variability.

1.2 OBJECTIVES

Objective 1. Build accurate Digital Elevation Model (DEM).

An accurate DEM was required for wetland model simulations. A DEM for bathymetry of Wetland P1 and the surrounding topography of the Cottonwood Lake study area was created from elevation point data files and required numerous modifications. The DEM for wetland P1 basin was constructed using the Topogrid model included in ESRI in ArcGIS 8.1 software. Topogrid generates a hydrologically correct grid of elevation from point, line and polygon coverages.

Objective 2. Divide the PPR into Ecoregions.

A geographic classification system was sought to define the patterns of ecological variation across the PPR. Tansley (1935) coined the word "ecosystem" to capture the regional array of biological and physical forces shaping organisms in nature. The ecoregion concept is one of the most important in landscape ecology, both for management and understanding ecological components (Omernik and Bailey 1997, Omernik 1995). Ecological regions are identified through the analysis of the patterns and the composition of biotic and abiotic phenomena that affect or reflect the differences in ecosystem quality and integrity (Omernik 1987 and 1995). These often include geology, hydrology, vegetation, climate, soils, land use, wildlife, and physiography. The relative importance of each characteristic varies from one ecological region to another regardless of the hierarchical level (Omernik 1987).

Objective 3. Characterize the historic climate of ecoregions and identify long-term climate trends across ecoregions.

Weather station data were used to characterize the climate of PPR ecoregions and for WETSIM 3.1 modeling experiments. Criteria for selecting stations included: their length of record, and geographic location within an ecoregion. It was important to select weather stations with long and complete records to accurately represent the weather throughout the twentieth century. Stations were geographically selected to encompass the widest range of climatic variation within an ecoregion. Historic normal climate variation among ecoregions within the PPR was determined from weather station data. Precipitation and temperature trends were determined from the appropriate 95-year record from each station.

Objective 4. Develop and use WETSIM 3.1 model outputs in GIS to map areas of optimum wetland conditions derived from historic and modified climate model simulations.

The effect of historic and modified climate scenarios on wetland hydrology and vegetation dynamics was evaluated through simulation of WETSIM 3.1 for the wetland P1 basin moved among weather stations. Cover ratio and return time were used in

WETSIM 3.1 to compare model results across the PPR. The cover ratio is the proportion of open water to vegetation cover for a wetland. The return time is the length of time for a wetland to return to a specific phase of the cover cycle.

2.0 DATA AND METHODS

2.1 Brief Description of WETland SIMulation (WETSIM) 3.1

WETSIM 3.1 is a next generation hydrologic model based on WETSIM 2.0 (Poiani and Johnson 1991, 1993a, 1993b, Poiani et al 1995 and 1996). It is a deterministic model based on watershed and wetland processes. These include watershed surface processes, watershed groundwater, wetland surface processes, and wetland vegetation dynamics. The model uses daily precipitation and temperature to calculate daily wetland water balance, estimate wetland stage, and simulate wetland vegetation from May through September. Model simulations used weather station data for each ecoregion. Model parameters that varied geographically among weather stations were maximum temperature, minimum temperature, precipitation, initial starting volume, and latitude.

The WETSIM 3.1 vegetation sub-model calculated spatial distribution of vegetation cover types and open water in the wetland. A grid of uniform cells represented the wetland and upland margin. Cell size for initial model simulations was 25 m^2. The elevation data used in the hydrology sub-model were applied to simulate vegetation dynamics. Calibration stage levels were provided by Tom Winter, USGS.

The approach used in this study was to “move” the P1 model wetland to each of the 18 weather stations to examine the effect of climate variation on wetland processes. In effect, this approach “excised” the P1 watershed and all of its characteristics (soils, topography, upland vegetation) and subjected it to the full range of PPR climates.

Cover ratio and return time were two indices developed for the WETSIM 3.1 output to determine optimum wetland conditions. Wetland cover ratio conditions were divided into three categories; closed marsh phase (0 to 25 percent open water), hemi-marsh phase (>25 to <75 percent open water), and open-water phase (>75 percent open water). The return time represents the length of time for a wetland to return to a specific phase of the cover cycle. This value was determined by the number of times the model wetland completed the cover cycle during the 95-year simulations at each weather station.

2.2 Prairie Wetland Ecoregion Boundary Delineation

The method used to delineate ecoregions was based on the premise that ecological regions can be identified through the analysis of patterns of biotic and abiotic phenomena that reflect differences in ecosystem quality and integrity (Wilken 1986, Omernik 1987, 1995). Level I and Level II divide the North American continent into 15 and 51 regions, respectively. At Level III, the continental United States contains 98 regions (United States Environmental Protection Agency [USEPA] 1996). Level IV regions are more detailed ecoregions for state level applications; Level V regions are the most detailed and used for landscape-level or local-level projects.

Canada uses a similar hierarchical approach for delineating ecoregions. It has 15 ecozones, 53 terrestrial ecoprovinces, 194 ecoregions, and 1021 ecodistricts (Marshall and Schut 1999). The prairie ecozone delineates the Canadian portion of the PPR. In 1991 a collaborative project was undertaken by a number of federal agencies in cooperation with provincial and territorial governments, all under the auspices of the Ecological Stratification Working Group. The working group focused on three priority levels of stratification: ecozones, ecoregions, and ecodistricts (Ecological Stratification Working Group 1996). The Canadian ecoregions tended to be more finely defined than the U.S. ecoregions at the same level. The prairie ecozone was divided into nine ecoregions.

A relatively small number of ecoregions was sought because the analysis planned for each ecoregion required a large amount of climate data. The US Level IV ecoregions and Canadian ecodistricts provided the most detail with 198 subregions (Figure 2A). Some of these could be merged at the US-Canadian border. However, due to the large number of divisions, it was impractical for the scope of this project to use this many subdivisions. The Level III ecoregions provided only four large ecoregions, referred to as the Lake Agassiz Plain, Mixed Grassland, Moist Mixed Grassland, and Western Corn Belt Plains. In addition these were a few small regions near the Cypress Hills that border Alberta and Saskatchewan and the isolated peaks near the foothills of the Rocky Mountains (Figure 2B). Since these relatively small areas were not to be a focus of this study, they were incorporated into the much larger ecoregion that surrounded them. Further subdivision was still sought to show more physiographic detail within the PPR. Two more ecoregions were defined. The first was an important physical feature called the

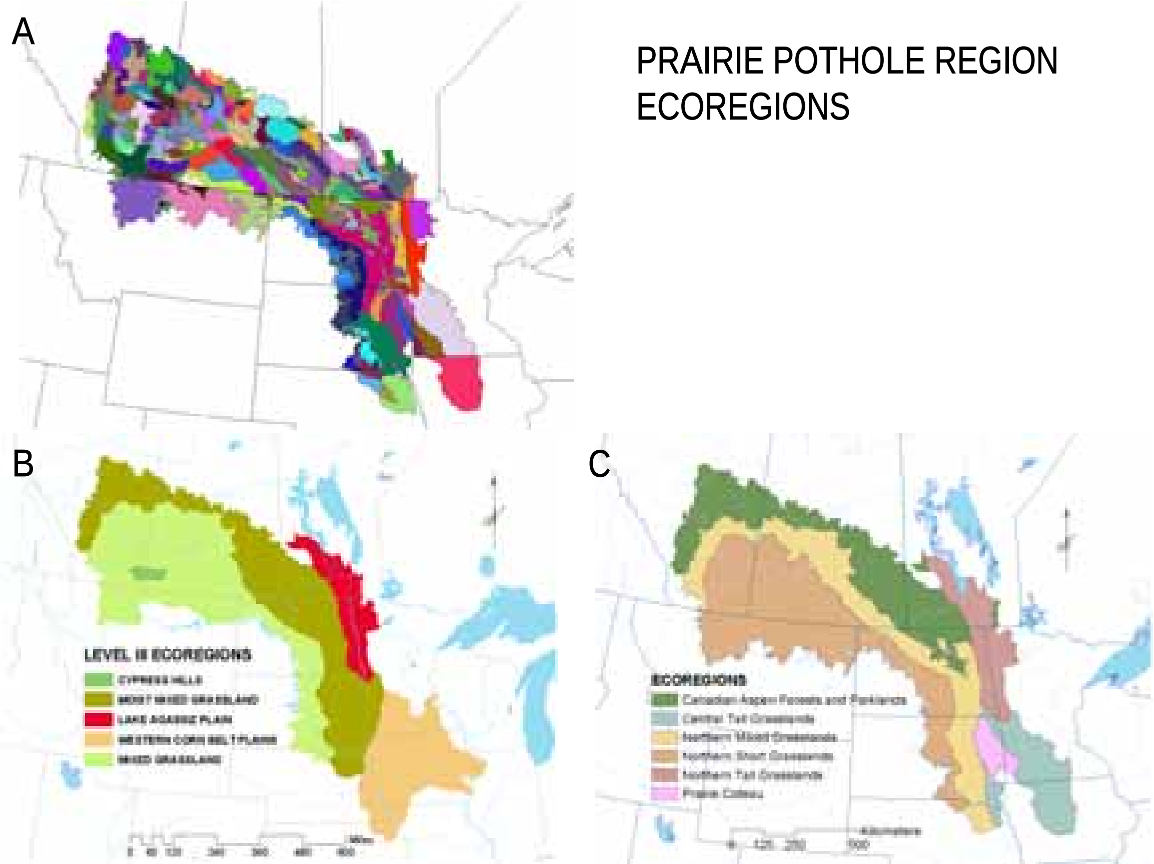

Figure 2 A. PPR US Level IV ecoregions and Canadian ecodistricts form 358 subregions.
B. PPR Level III ecoregions are the Lake Agassiz Plain, Mixed Grassland, Moist Mixed Grassland, and Western Corn Belt Plains.
C. Modified version of PPR ecoregions with the Prairie Coteau and Aspen Parkland added to the Level III ecoregions.

2.3 Weather Station Data Selection and Preparation

Prairie Coteau located in eastern South Dakota and southwestern Minnesota. The second division was the Canadian Aspen Forests and Parklands, which forms an arc along the northern portion of the PPR (Figure 2C). This ecoregion represents the transition between the boreal forest to the north and the grasslands to the south. It is characterized by aspen, oak groves, mixed tall shrubs, and grasslands.

Three weather stations were selected to characterize the climate of each ecoregion, comprising 18 total stations. These stations were chosen based on their longevity of record, geographic location within each ecoregion, and completeness of record. Records of 95 years were desired to encompass the widest range of climatic variation. For example, most ecoregions in the PPR have a north-south orientation, thus weather stations were selected from northern, central, and southern locations to represent this environmental gradient. A GIS database for the PPR was created to facilitate weather station selection. The database contained station latitude, longitude, elevation, and the start and end data collection dates. The widest separation of stations was sought to provide the most complete representation for the ecoregion, while maintaining those stations with long records. Weather stations with at least some temperature and precipitation data prior to 1932 are highlighted in yellow (Figure 3). All weather stations had at least some breaks in their period of record. Some stations collected only partial weather data such as temperature and then collected precipitation many years later. Other stations may have collected data only seasonally with little or no data during the winter months. Another common problem involved long gaps in the data record. These were stations where collection was interrupted for several months or years before recording resumed. Missing data were replaced by extrapolating from three nearby stations where possible. Occasionally one or two stations were used for extrapolation when there were no stations nearby with data during the missing data period. It was more common to find only one nearby station during the early part of the twentieth century because there were fewer stations collecting data.

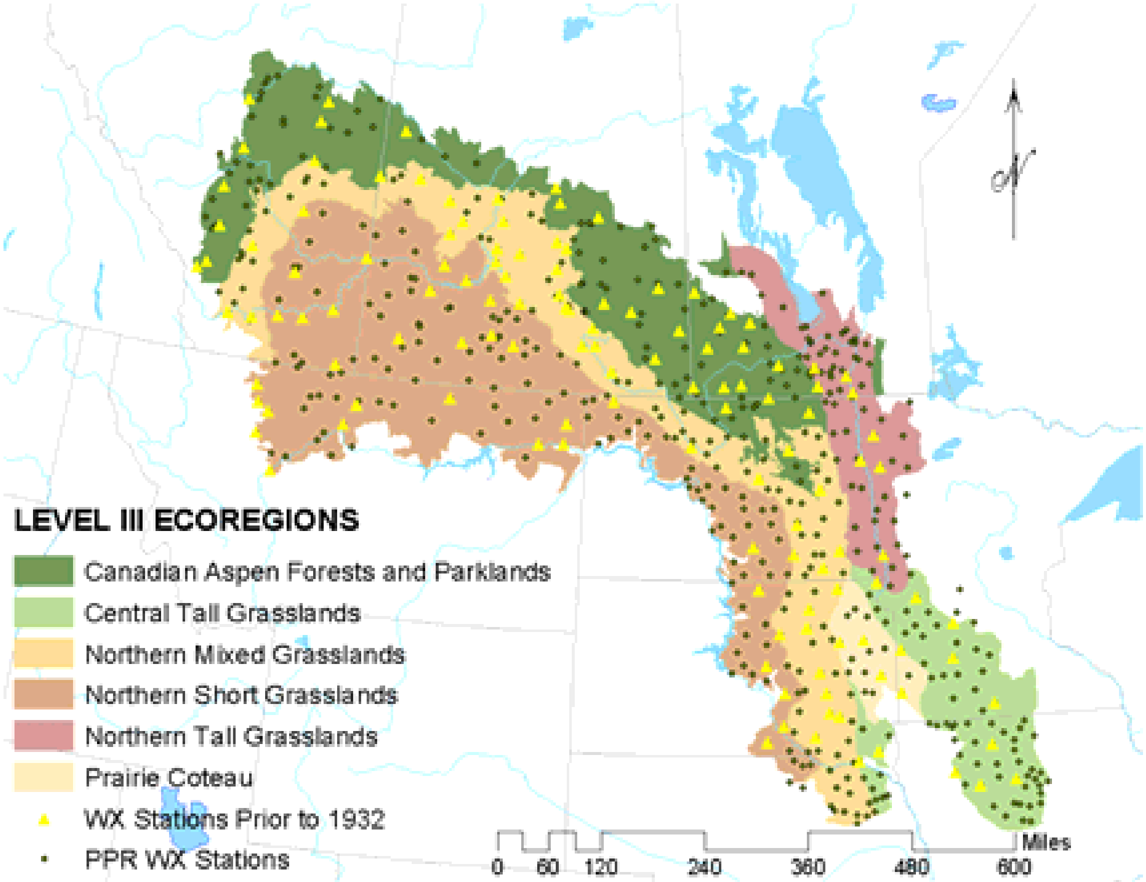

Figure 3. Weather stations with data records prior to 1932 are highlighted in yellow.

The large climate datasets were managed using Microsoft EXCEL and ArcView software. They were reduced to three variables: daily precipitation, maximum daily temperature, and minimum daily temperature. Missing records, in the actual columns were designated as –99999, and replaced with estimated values. Data files were checked for outliers. After all the –99999 (missing data) and erroneous data were replaced with the estimated values, the table was exported to a tab delimited text file. Files from some of these weather stations exceeded 100 years but it was more desirable to trim these datasets to 95 years so they were all of equal size.

The input format for WETSIM 3.1 required columns for years, months, days, precipitation, minimum daily temperature, and maximum daily temperature. The United States weather station temperatures were then converted in Excel to degrees Celsius and precipitation records were converted to millimeters. Each of the 18 weather stations had 34,699 records for the 95 years of daily weather data. The total number of records for daily precipitation, maximum daily temperature, and minimum daily temperature resulted in 104,097 records for each weather station. The total for all elements and stations was 1,873,746 records to use as inputs to WETSIM 3.1 and to use in the analysis of weather trends.

2.4 Digital Elevation Model (DEM)

2.4.1 Point Data Preparation

The semi-permanent wetland chosen to model was the Wetland P1 located at the Cottonwood Lake study area, Stutsman County, North Dakota (Figure 4). A DEM for bathymetry of Wetland P1and the surrounding topography of the Cottonwood Lake study area was created in the following way. Elevation point data files were provided by Tom Winter (U. S. Geological Survey). These raw data files required numerous modifications before they could be used in GIS applications. Normally the first step would involve converting the format of the .dig files into ARC/INFO coverage’s, but this could not be accomplished because each file contained points that were in a Cartesian coordinate system and there were no geographic coordinates to use for a reference. This meant that each point was positioned correctly in relation to the other points but the points needed to be transformed into a geographic coordinate system.

There were 117 small files containing 87,031 points. These small files of elevation point data were put together into a single large file. Point data were extracted from the files and put into a Microsoft EXCEL file. The data entered into EXCEL consisted of the X coordinate, Y coordinate, Z value (elevation), and unique identification number for each point. Data were added until they reached the limit of EXCEL’s row capacity of 65,000. Another EXCEL file was created for the remaining points. The EXCEL files were then saved as tab delimited text files. These text files were imported into ArcView assigning the X and Y coordinates appropriately. The file was then converted into a shapefile and then into ARC/INFO coverage.

Elevation contours were interpolated from the point data and overlaid onto a Digital Raster Graphic (DRG) and a Digital Orthophoto Quadrangle (DOQ). A DRG is a scanned image of a U.S. Geological Survey (USGS) standard series topographic map, including all map collar information. The image inside the map neatline is georeferenced to the surface of the earth and fit to the Universal Transverse Mercator projection. A DOQ is a uniform-scale aerial photograph. It is georeferenced and is able to serve as a base map on which other map information may be overlaid. The DRG and DOQ were used as a visual reference to position the survey contours. Positioning the contours required numerous trial and error steps until a best fit was found. Once this step was completed a point file was then geographically registered in Universal Transverse Mercator (UTM) North American Datum 1983. These data were then used to construct the DEM.

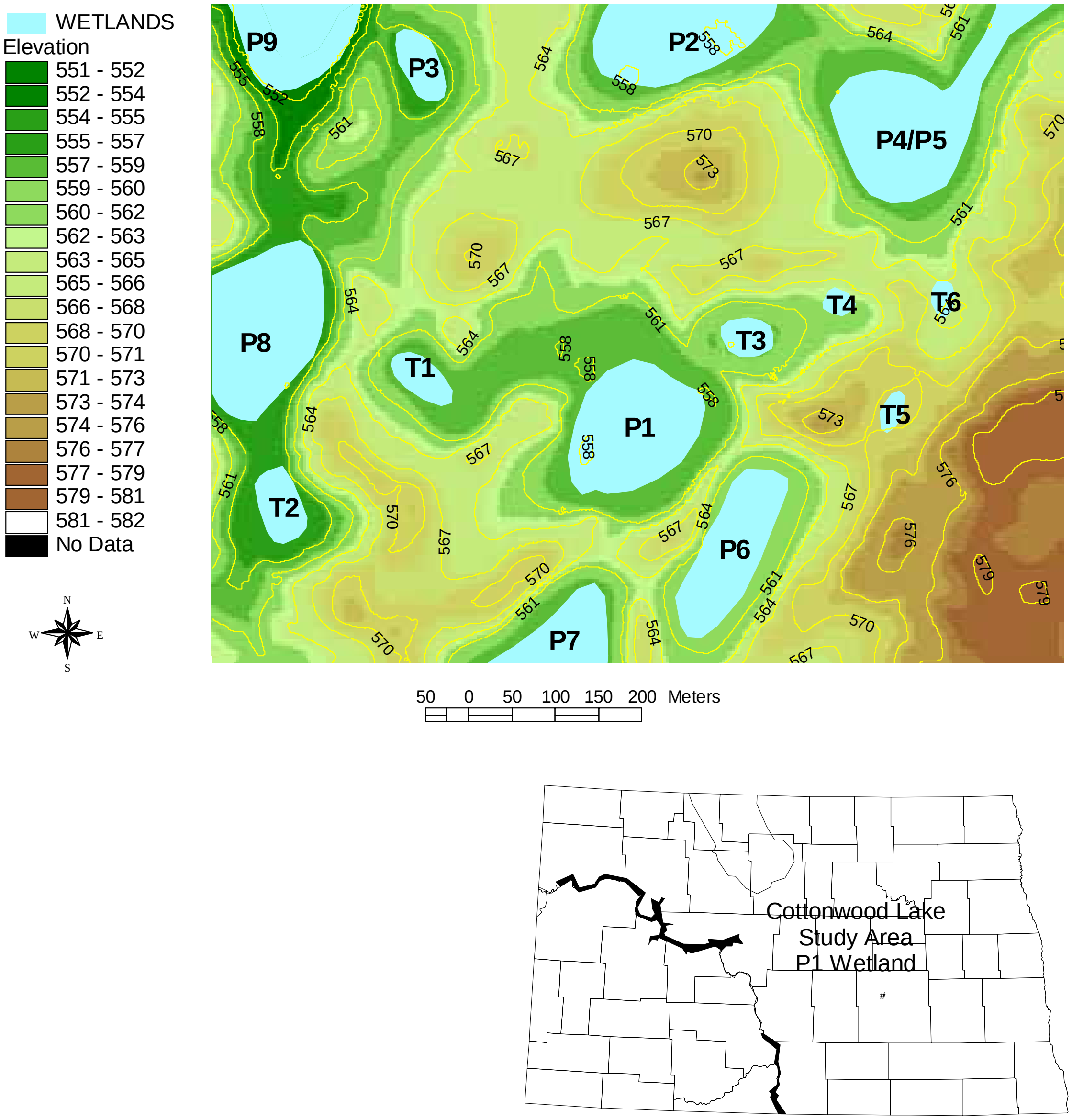

Figure 4. Cottonwood Lake study area is located in Stutsman County, North Dakota. Wetland P1 is located in the south-central portion of the study area.

2.4.2 DEM Construction

The PPR is a difficult area to map for hydrological purposes because many areas do not have a functional surface drainage network. The landscape is dotted with small depressions that require very detailed elevation surveys. Some of these water-filled depressions may or may not be hydrologically connected at the surface. In many instances these wetlands have subsurface connections via the water table.

The DEM for wetland P1 basin was constructed using the Topogrid model included in ESRI in ArcGIS 8.1 software. Topogrid generates a hydrologically correct grid of elevation from point, line and polygon coverages. The Topogrid command is an interpolation method specifically designed for the creation of hydrologically correct digital elevation models (DEMs) from comparatively small, but well selected elevation and stream coverages. It is based upon the ANUDEM program developed by Michael Hutchinson (1988, 1989).

Construction of a DEM was needed to support the vegetation dynamics portion of the WETSIM 3.1 model. A 5x5-meter grid was created for the P1 wetland basin using Topogrid. The program imposes a global drainage condition that automatically removes most errors in the data. However, the DEM required numerous modifications, these included the removal of spurious peaks and sinks. There were several topographic anomalies within the bottom of the basin that resulted from limited bathymetric data. Points were added to adjust the elevation values and to remove problematic peaks and sinks.

2.4.3 Watershed delineation

Drainage boundaries may be delineated manually from a topographic map, digitized from Digital Raster Graphic map (DRG), or determined through the use of raster data from Digital Elevation Models. An early version of Arc Hydro tools for ArcView 3.3 was used to derive several data sets to describe the drainage patterns of the watershed from the P1 semi-permanent wetland DEM. Raster analysis was performed to generate data on flow direction, flow accumulation, stream definition, stream segmentation, and watershed delineation.

Three wetlands are contained in the P1 semi-permanent watershed: P1, T1, and T3. T1 and T3 wetlands coalesce with P1 at high stage levels. Temporary wetland T1 along with semi-permanent wetland P1 form a single wetland when the water level is above an elevation of 558.5 meters or when water depth exceeds 0.8 meters. This study used the combined watersheds of T1 and P1 as the base watershed. There were two pour points used to determine two watersheds. A pour point is the point at which water flows out of an area. It is the lowest point along the boundary of a drainage basin. The first pour point was used to calculate the P1 semi-permanent wetland and T1 temporary wetland watershed. A second pour point was positioned between T3 temporary wetland and P1 semi-permanent wetland. At an elevation 559.65 meters or at water depth of approximately 1.65 meters the ponds coalesce. The location of the pour points was determined by creating contour lines from the DEM and finding the lowest elevation that would allow for water to escape in the event that the basin were to fill with water. The area of the watershed for P1 semi-permanent wetland is 163,383 m^2 and the T3 watershed is 57,866 m^2 (Figure 5).

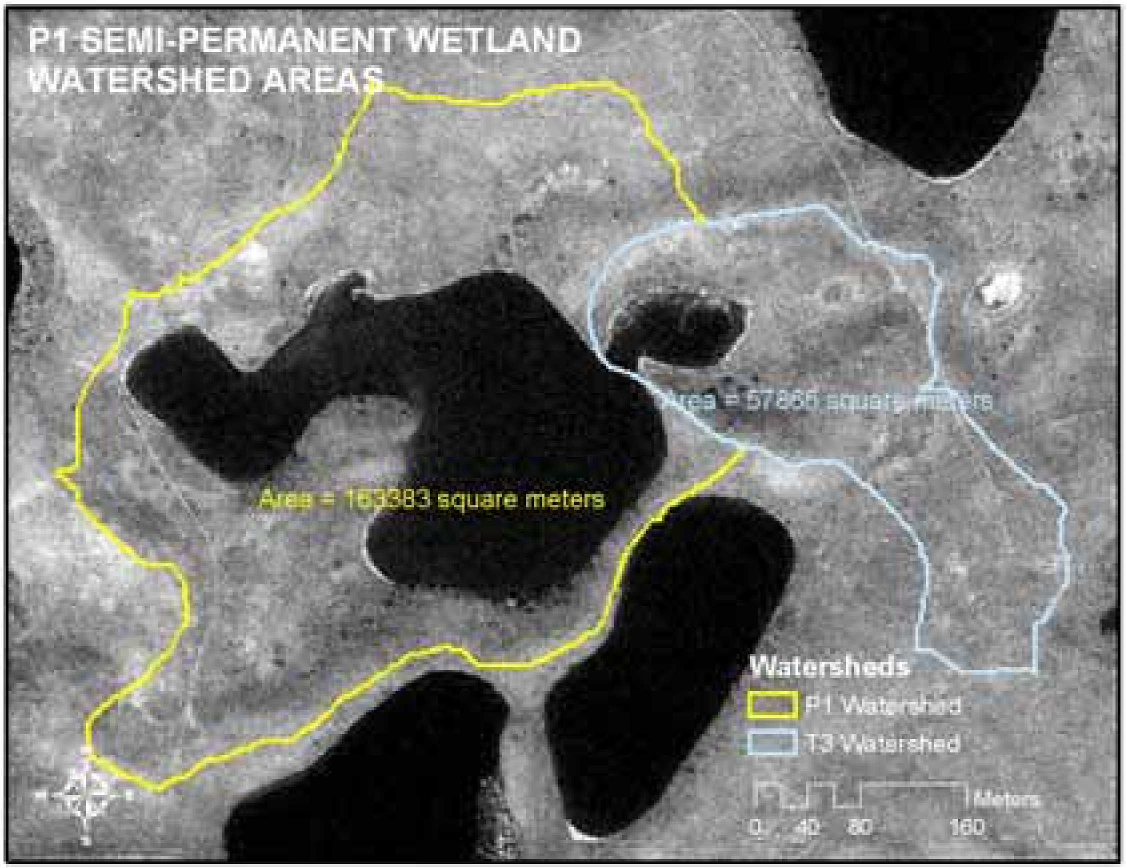

Figure 5. P1 and T3 watershed areas.

3.0 RESULTS

3.1 Ecoregion Delineation

The classification process resulted in six modified level III ecoregions (Figure 6). The Canadian Aspen Forests and Parklands ecoregion extends in a broad arc from southwestern Manitoba, northwestward through Saskatchewan to its northern limit in central Alberta. The parkland is a transitional region between the boreal forest to the north and the grasslands to the south. The Central Tall Grasslands was once covered with

Figure 6. Six ecoregions and 18 selected weather stations for the PPR.

tallgrass prairie; more than 75 percent of the region is now used for cropland agriculture and much of the remainder is in forage for livestock. The landscape varies from nearly level to gently rolling glaciated till plains and hilly loess plains. The Northern Mixed Grasslands comprises the northern extension of open grasslands in the Interior Plains of Canada and extends southward into the Dakotas. The Northern Short Grasslands is a semiarid grassland ecoregion in southwestern Saskatchewan, southeastern Alberta, northern Montana and central Dakotas. The Northern Tall Grasslands was formed by Glacial Lake Agassiz. It produced an extremely flat landscape with beds of lake sediments on top of glacial till. In the U.S. this region is known as the Red River Valley and in Canada it is called the Lake Manitoba Plain. The Prairie Coteau is the result of stagnant glacial ice melting beneath a sediment layer. The hummocky landscape has poorly developed drainage networks and possesses many semi-permanent and seasonal wetlands. The area of each ecoregion was calculated for each ecoregion and summed for the PPR (Table 4).

Table 1. Ecoregion areas and PPR area based on digitized GIS coverages.

ECOREGION	AREA KM^2	ACRES	HECTARES
Canadian Aspen Forests and Parklands	208,274	51,465,854	20,827,575
Central Tall Grasslands	84,178	20,801,007	8,417,902
Northern Mixed Grasslands	191,684	47,366,358	19,168,561
Northern Short Grasslands	295,516	73,023,771	29,551,789
Northern Tall Grasslands	73,430	18,145,064	7,343,076
Prairie Coteau	22,816	56,381,97	2,281,706
PPR Total	875,902	216,440,254	87,590,611

3.2 PPR Precipitation and Temperature Spatial Trends 1906 to 2000

The number of missing data records were determined for each station variable. There were 34,699 total days from January, 1906 through December, 2000, yielding a total record count of 1,873,746 for the 18 weather stations. Most weather stations were missing fewer than 694 days (less than 2.0%) of the total records for each weather element.

Two stations required extensive supplemental data. Graysville, MB was missing data for some 13,095 days (37.7%). The two longest periods of missing data were from January 1, 1906 to August 1, 1925 (7,152 days) and from November 1, 1988 to December 31, 2000 (4,444 days). Watertown, SD was missing an average of 11,406 days (32.9%). The longest gap in the missing data occurred between January 1, 1906 and December 31, 1931 (9,496 days). A second smaller gap occurred between January 1, 1996 and December 31, 2000 (1,827 days).

Precipitation and temperature trends varied across the PPR (Figure 7). Three areas that became drier occurred in the northwestern, central, and southeastern portion of the PPR. Areas of increased precipitation surrounded these drier regions. Precipitation at eastern stations tended to increase more than western stations. The statistical results indicated that the areas on the map ranging from green to lighter blue were not statistically significant. Dark blue indicated areas with the greatest increases in precipitation and were statistically significant.

The greatest increase in minimum temperatures occurred in the central and northern portions of the PPR (Figure 7). Maximum temperature increased in the west central and northeastern portions of the PPR. Cooling occurred in the southern and very western PPR. Northern stations tended to warm more than southern stations for both minimum and maximum temperatures. Statistical analysis indicated that the mid spectrum colors (Figure 7) for temperatures (green-light yellow range) were not statistically significant. However, the bolder colors (blue and bright yellow – red) were significant.

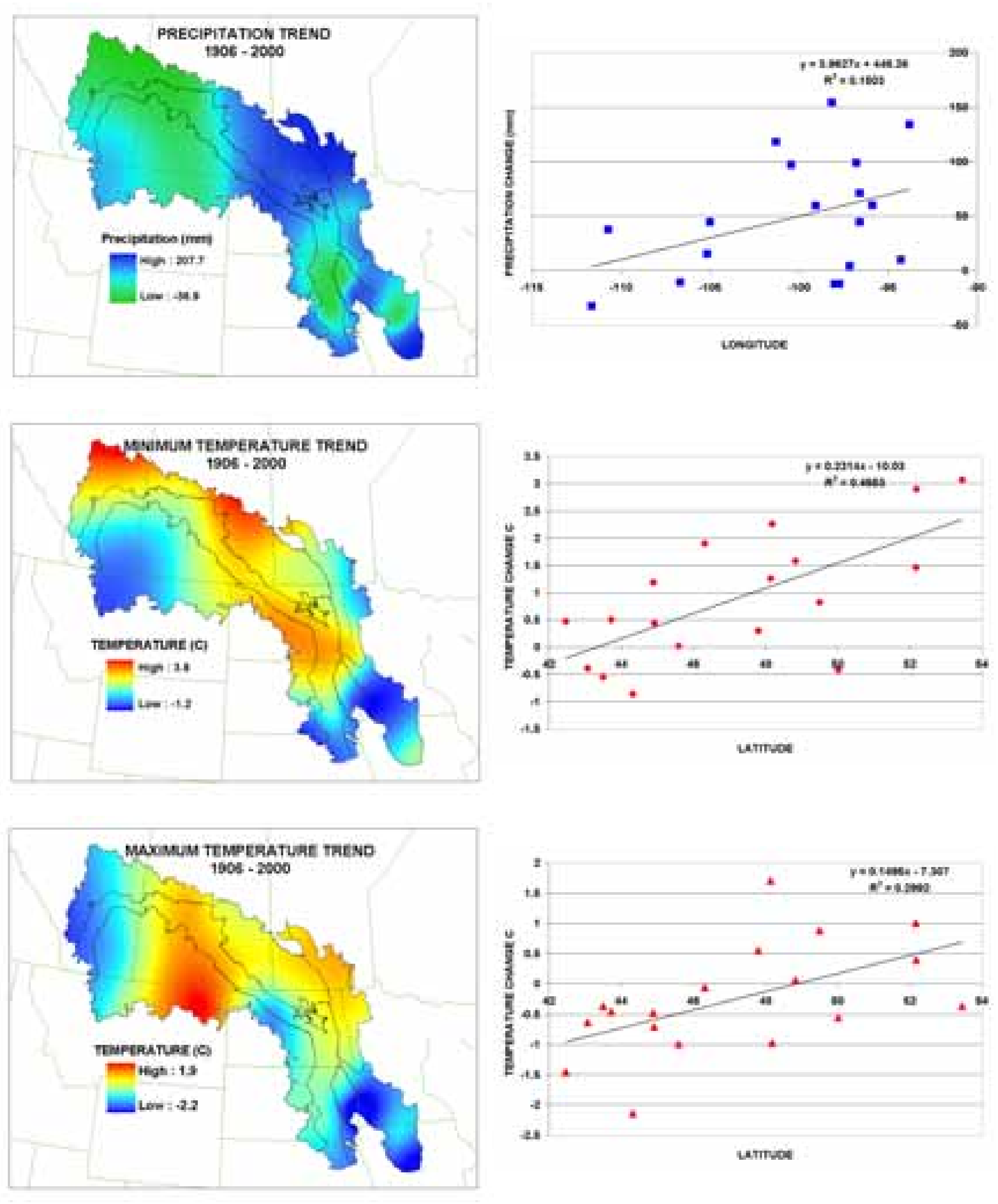

Figure 7. Historic precipitation, minimum and maximum daily temperature trends for the Prairie Pothole Region from 1906-2001. Graphs illustrate longitudinal gradient for precipitation trend and latitudinal gradient for minimum and maximum temperature trends.

3.3 *Optimum Wetland*

Historic and climate change simulations were mapped and shaded to show areas with >30% hemi-marsh conditions and the occurrence of at least one return time during the 95-year period. These conditions represented optimum wetland conditions (Figure 8).

Figure 8. Shaded areas represent at least one return time and hemi-marsh conditions occurring greater than 30% of the 95-year period from 1906 to 2000. Results are based on six weather stations: Algona, IA, Crookston, MN, Medicine Hat, AB, Minot, ND, Muenster, SK, and Watertown, SD. Hemi-marsh conditions were classified as >25% and <75% vegetation cover.

Optimum wetland conditions shifted geographically as climate was varied. The historic simulation showed that at least a portion of all six ecoregions experienced optimum wetland conditions during the 95-year simulations. The temperature +3^{o}C simulation shifted optimum conditions northward and eastward and eliminated the optimum conditions in the Northern Mixed Grasslands, Northern Short Grasslands, and almost all of the Canadian Aspen Forests and Parklands (Figure 9).

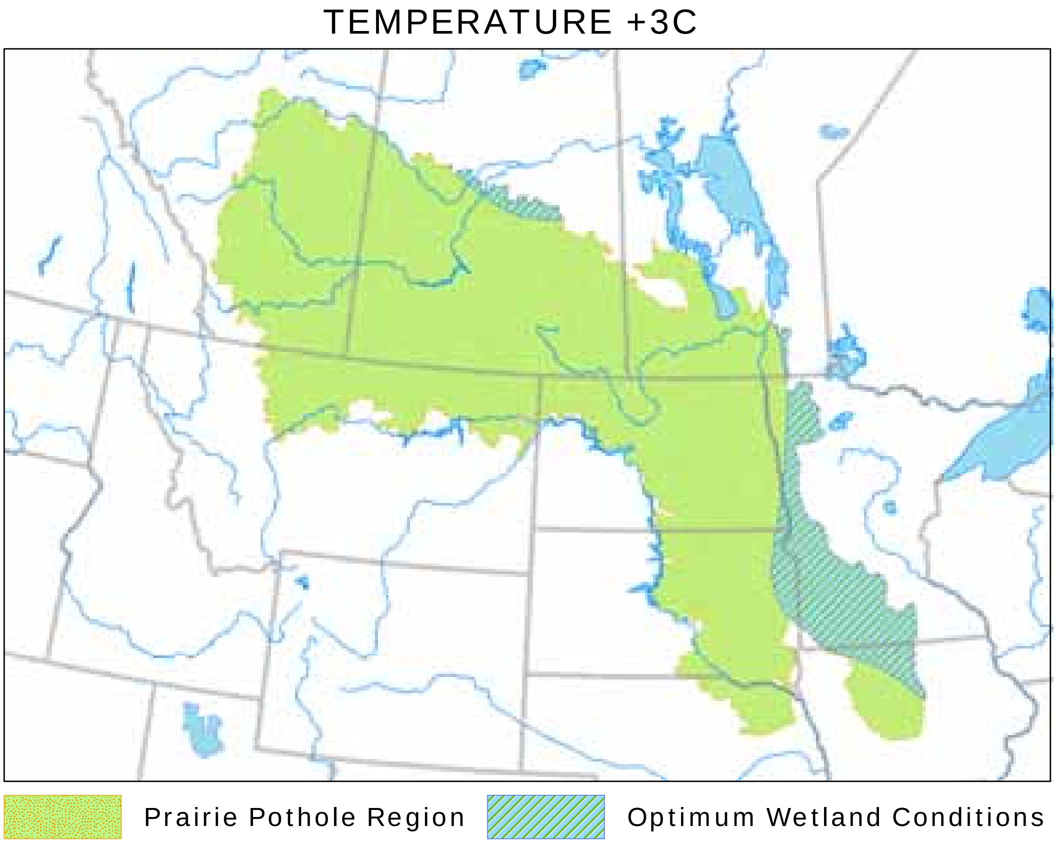

Figure 9. Shaded areas represent at least one return time and hemi-marsh conditions occurring greater than 30% of the 95-year period from 1906 to 2000. Results are based on six weather stations: Algona, IA, Crookston, MN, Medicine Hat, AB, Minot, ND, Muenster, SK, and Watertown, SD. Hemi-marsh conditions were classified as >25% and <75% vegetation cover.

The precipitation -20%/ temperature +3^{o}C simulation posed the greatest threat to optimum semi-permanent wetland conditions. The southern Central Tall Grasslands was the only area of the PPR to exhibit optimum conditions (Figure 10).

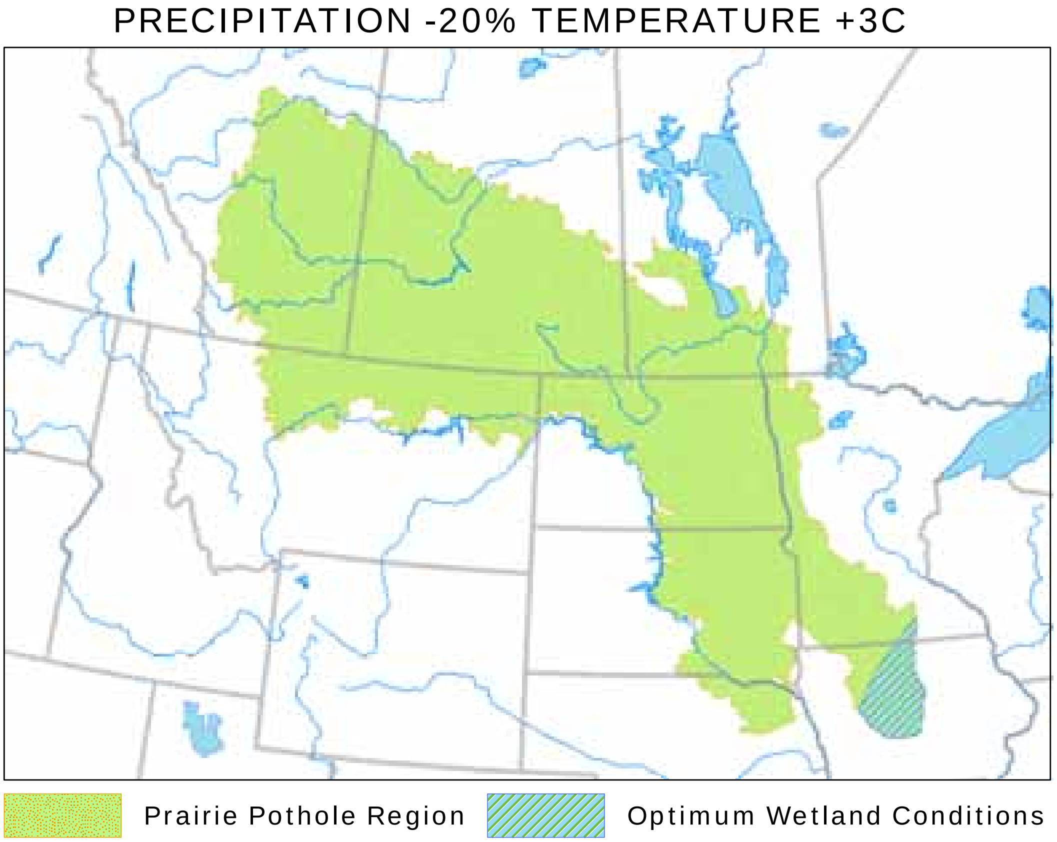

Figure 10. Shaded areas represent at least one return time and hemi-marsh conditions occurring greater than 30% of the 95-year period from 1906 to 2000. Results are based on six weather stations: Algona, IA, Crookston, MN, Medicine Hat, AB, Minot, ND, Muenster, SK, and Watertown, SD. Hemi-marsh conditions were classified as >25% and <75% vegetation cover.

Future climate changes will affect wetlands in two fundamental ways: the number of functioning wetlands within most ecoregions will decline and the geographic location of optimum wetlands will shift. Wetland simulations in this study indicated that the Northern Short Grasslands were the most vulnerable portion of the PPR to increases in temperature. Semi-permanent wetlands in this ecoregion have historically functioned on the margin, and any increase in temperature would result in decreases in water levels and increases in vegetation cover. The central portion of the PPR is currently the most ecologically diverse and productive. Model simulations indicate that this area could shift eastward and northward with warmer temperatures, although precipitation increases would offset this shift. The least vulnerable areas were the eastern and southeastern portions of the PPR. These areas currently have stable wetlands. Warmer temperatures would tend to improve wetland conditions. Wetlands in this region currently function more like lakes.

Prairie wetlands have been shown to be very sensitive to climate change. They have also proven their ability to adapt to the wide variety of weather extremes that occur within the PPR. As climate continues to change the boundaries of the PPR and its associated ecoregions will to shift to new locations. The shift in optimum wetland conditions will reduce the number of existing prairie wetlands. Semi-permanent wetlands functioning on the margins of the PPR would be the most vulnerable to climate change. Wetlands in the western portion of the PPR would be more vulnerable to warming temperatures and lower rainfall. This study showed that only a small portion of the PPR would benefit from warming temperatures and lower rainfall.

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