ENVIRONMENTAL AND ECONOMIC RESEARCH AND DEVELOPMENT PROGRAM

Potential Effects of Climate Change on Inland Glacial Lakes and Implications for Lake Dependent Biota in Wisconsin

Executive Summary
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Executive Summary

Overview

The economic vitality and quality of life of many northern Wisconsin communities is closely associated with the ecological condition of the abundant water resources in the region. Climate change models predict warmer temperatures, changes to precipitation patterns, and increased evapotranspiration in the Great Lakes region. Recently (1950-2006), many regions of Wisconsin have experienced warming, and precipitation has generally increased except in far northern Wisconsin. Modeling conducted by the University of Wisconsin Nelson Environmental Institute Center for Climate Research predicts an increase in annual temperature by the middle of the 21st century of approximately 6^{o}F statewide, and an increase in precipitation of 1"–2". However, summer precipitation in the northern part of the state is expected to be less and winter precipitation will be greater. By the end of the 21st century, the magnitude of changes in temperature and precipitation are expected to intensify.

Such climatic changes have altered, and would further alter hydrological, chemical, and physical properties of inland lakes. Lake-dependent wildlife sensitive to changes in water quality, are particularly susceptible to lake quality-associated habitat changes and are likely to suffer restrictions to current breeding distributions under some climate change scenarios. We have selected the common loon (*Gavia immer*) to serve as a sentinel lake-dependent piscivorous species to be used in the development of a template for linking primary lake-dependent biota endpoints (e.g., decline in productivity and/or breeding range contraction) to important lake quality indicators. In the current project, we evaluate how changes in freshwater habitat quality (specifically lake clarity) may impact common loon lake occupancy in Wisconsin under detailed climate-change scenarios. In addition, we employ simple land-use/land cover and habitat scenarios to illustrate the potential interaction of climate and land-use/land cover effects. The methods employed here provide a template for studies where integration of physical and biotic models is used to project future conditions under various climate and land use change scenarios. Findings presented here project the future conditions of lakes and loons within an important watershed in northern Wisconsin – of importance to water resource managers and state citizens alike.

Projecting Future Lake Conditions in the Trout Lake basin of Northern Wisconsin

We used a coupled ground-water/surface-water model with the capability of incorporating predictions of temperature and precipitation from physical climate models to predict changes in the hydrologic cycling within the Trout Lake basin in Vilas County. The Trout Lake basin has been the focus of numerous modeling studies that represent stages in the development and refinement of a coupled groundwater/surface-water model using the U.S. Geological Survey's GSFLOW code. The basin also lies within the heart of the current common loon breeding range in Wisconsin. The GSFLOW model, which is driven by precipitation and temperature inputs, was calibrated using the Parameter ESTimation (PEST) suite of calibration software.

A lake water quality model, adapted from a simple lake carbon cycling equilibrium model, was used to predict the consequences of changing climate to in-lake dissolved carbon concentrations and resulting changes to water clarity. The model is the steady state solution to a relatively simple differential equation. The load to a lake is the sum of areal input from the lake perimeter, groundwater (GW) inflow, precipitation and surface water (SW) inflow. The mass load of carbon from GW and SW is the product of their respective concentrations and their inflow volumes described below. The areal load is assumed to be the sum of shoreline with canopy and shoreline without canopy.

Given the uncertainty in climate modeling, it is desirable to use more than one global climate model (GCM) in order to obtain a range of potential future climatic conditions. Daily precipitation and temperature output from six GCMs were considered for one current and three future emissions scenarios. The GCM output from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Special Report on Emission Scenarios was downscaled for the Trout Lake area by the Wisconsin Initiative on Climate Change Impacts. The downscaled climate data for the period 1961-2100 was used as input to the GSFLOW model, and the corresponding lake budgets from the GSFLOW runs were used as input for the Lake Model.

Changes in Lake Levels

According to the model results, lowland drainage lakes in the watershed show relatively minor changes due to the future climate, in part because drainage lakes are relatively low in the watershed, and have large contributing areas relative to the lake area. Headwater drainage lakes, however, may be more impacted (see Historic Changes in Lake Condition). Seepage lakes show a gradual decline in net precipitation (precipitation minus evaporation) with time, a slight increase in net groundwater, and variable net surface-water inputs, resulting in a relatively steady to moderate decline in water levels with time. In almost all cases the variability of the various components increases in the later part of the 21st century. Beginning around 2060, there appears to be an increase in variability and relatively large changes in the net groundwater, which are reflected in the increase in variability in the lake stages. Because the predicted increase in net groundwater is less than the decrease in net precipitation, the result is a declining water level.

Changes in Water Clarity

The general trend in lakes was toward slightly higher water clarity, as indicated in model results by increased Secchi depth. In all lakes, except Allequash and Edith, dissolved organic carbon (DOC) concentrations decreased. Decreases in DOC had commensurate increases in clarity for these lakes, even under conditions of elevated total phosphorus. The competing effect on clarity, from DOC and chlorophyll, is the result of light extinction due to DOC which is 3 times greater than the light extinction due to chlorophyll. Given the log relationship between total phosphorus and chlorophyll, the scenario with a 25% increase in total phosphorus translates to approximately a 40% increase in chlorophyll for these lakes. The ensuing decrease in water clarity was offset by a concurrent decrease in DOC of 15% or more.

Historic Changes in Lake Condition

To further illustrate the potential impact of a warmer and drier climate, a sediment core was extracted from Max Lake, Vilas County, WI to assess the ecological changes experienced during the mid-Holocene dry period. During the mid-Holocene (5,000-7,000 years ago) the climate in the Great Lakes region was warmer and effectively drier than at the present. During this time the climate was similar to that predicted by climate change models. The sediment core encompassed the entire 13,000 year history of the lake since the retreat of the glaciers. The sediment was examined for charcoal to assess the general climate of the region. An increase in the frequency of wildfires indicates a drier and perhaps warmer climate. The diatom community was examined to determine changes in pH and phosphorus levels. These variables provide an estimate of the hydrologic regime of the lake.

Our results indicated that during the first few centuries following the establishment of Max Lake, it functioned as a drainage lake that was likely part of a much larger lake. The pH levels were consistent with those found at the present time in headwater drainage lakes. Charcoal levels were relatively low indicating a cool, moist climate. Around 7,000 years ago, the frequency of wildfires greatly increased, signally the beginning of the mid-Holocene warming period. At that time, effective reduction in precipitation caused the lake to change from a drainage lake to a seepage lake. The change in the hydrologic regime resulted in a decline in the pH values of about 0.5 units. Around 6,000 years ago, low charcoal levels indicate a return to moist conditions and the lake briefly returned to a drainage lake. This was short lived and for the last 6,000 years the lake has been a seepage lake with lower pH values and lower phosphorus concentrations. Even though the charcoal indicates a drier climate during the last four millennia, Max Lake has remained a seepage lake. This work demonstrates that if the future climate becomes warmer and effectively drier as predicted, there may be substantial changes in the ecology of headwater drainage lakes. These lakes may become seepage lakes resulting in potentially lower pH and nutrient levels which may result in a simplification of the fish community and a reduction in the lake's overall productivity.

Historic Range Contraction of the Common Loon in Wisconsin

The breeding range of the common loon has shifted northward in the Great Lakes states from former southern range limits that are known to once extend throughout southern Minnesota to northern Iowa, throughout southern Wisconsin to northern Illinois, and throughout southern Michigan to northern Indiana and Ohio. A review was conducted of historical and recent water quality data for Wisconsin lakes that formerly supported but no longer support breeding loons. Historical phosphorus concentrations inferred from paleolimnological data, and land use change that occurred within the drainage basins of former loon nesting lakes were considered in the analysis. The review indicated that the landscape of southern Wisconsin has changed dramatically since Common Loons last nested in this part of Wisconsin. A number of factors have likely contributed to the decreased appeal of southern Wisconsin lakes to breeding Common Loons, including changes to water quality, altered trophic status resulting from nutrient enrichment, and reductions in suitable nesting habitat stemming from shoreline development and altered water levels. Increased nutrient and sediment inputs from agricultural and developed areas likely contributed to a reduction in habitat quality. We contemplated whether similar shifts in trophic state of lakes across Wisconsin might occur under a warming climate pattern accompanied with increased evapotranspiration rates and have negative consequences on loon occupancy.

Projecting Future Loon Occurrence in the Trout Lake Basin of Northern Wisconsin

Wisconsin Loon Habitat Model

Research across North America has shown that common loons select breeding territories as a function of lake physical and chemical characteristics. We developed a predictive regional common loon breeding habitat suitability model based on loon populations in northern and central Wisconsin, and assessed the potential effects of future climate change on loon habitat quality and breeding pair occupancy of lakes within the Trout Lake basin in northern Wisconsin.

We used presence or absence of loon territorial pairs as the response variable in logistic regression analyses with multiple habitat predictor variables. Water quality data including Secchi depth, color, total phosphorus, temperature, pH, conductivity, and dissolved oxygen, nest habitat quality, and land cover within 150 m and 500 m of each lake or reservoir were considered in the analysis. The best fitting logistic regression model included as predictor variables nest habitat, number of waterbodies within 10 km, Secchi depth, log of lake area, and the interaction between Secchi depth and log of lake area. The two next best models included these same variables plus proportion of forest within either the 500 m or 150 m buffer.

Future Loon Occurrence in the Trout Lake Basin

We used the best-fitting loon habitat model to predict loon occurrence for 27 of the lakes in the Trout Lake basin under projected future climatic conditions. Linked climate and lake hydrology model (described above) were used to simulate lake conditions for all years from 1962 to 2100 under three emissions scenarios and six general circulation models. The results of hydrology and lake modeling of the Trout Lake basin in northern Wisconsin indicates that these lakes have the potential to become clearer under future climate conditions. This is due to the fact that DOC, not total phosphorus , is the parameter most closely associated with lake clarity in the watershed that is likely to change under future climate scenarios, and DOC levels are predicted to be lower. Secchi depth estimates from the linked climate and hydrology models for the period between 2010 and 2090 are predicted to increase slightly in the 27 lakes in the Trout Lake basin. Considering water clarity as a primary factor in loon habitat suitability, estimated probabilities of loon occurrence are expected to stay the same or increase very slightly between 2010 and 2090 for all 27 lakes as Secchi depth slowly increases over time. Changes in nest habitat can have large effects on the probability of loon occurrence in lakes. Lake stage is predicted to be lower at Trout basin seepage lakes under future climate scenarios, potentially altering nest habitat quality. Step changes in nest habitat generally overwhelm the effect of estimated changes in Secchi depth or possible changes in total phosphorus. These results point to the critical need to conserve and enhance common loon nest habitat within the Trout Lake basin, and throughout the current breeding range of loons in Wisconsin. Adaptation strategies to reduce potential negative consequences of a changing climate should include preserving existing critical nest habitat by managing shoreline development and habitat loss.

Acronyms used in the report

AIC	Akaike's Information Criterion
AUC	Area under the ROC curve
Chl	Chlorophyl-a concentration
COOP	National Weather Service Cooperative
DEM	Digital elevation model
DOC	Dissolved organic carbon
EPA Legacy STORET	U.S. Environmental Protection Agency Legacy STOrage and RETrieval Data Warehouse
GCM	Global Climate Model
GHB	MODFLOW General Head Boundary condition
GIS	Geographic Information System
GPS	Geographical Positioning System

Acronyms used in the report (continued)

GRTS	Generalized Random-Tesselation Stratified
GSFLOW	USGS coupled groundwater/surface-water model
HRU	Hydrologic response units
IPCC	Intergovernmental Panel on Climate Change
LAK	MODFLOW Lake Package
LEC	Light extinction coefficient of water
LU/LC	Land use and land cover
MODFLOW	USGS Modular Groundwater Flow Model
NLDC	National Land Cover Database
PEST	Software used for parameter estimation
PRMS	USGS precipitation-runoff modeling system
ROC	Receiver operating characteristic
Secchi	Secchi depth in the lake
SFR2	MODFLOW Streamflow Routing Package
SRES	Special Report on Emission Scenarios
SWIMS	Wisconsin Surface Water Integrated Monitoring System
TIGER/Line files	Topologically Integrated Geographic Encoding and Referencing Database Line Shapefiles
TP	Total phosphorus concentration
UMESC	U.S. Geological Survey Upper Midwest Environmental Sciences Center
USEPA	U.S. Environmental Protection Agency
USEPA STAR	U.S. Environmental Protection Agency Science to Achieve Results Research Grants program
USGS	U.S. Geological Survey

Acronyms used in the report (continued)

UZF	MODFLOW Unsaturated Zone Flow Package
WDNR	Wisconsin Department of Natural Resources
Wisconsin DNR	Wisconsin Department of Natural Resources