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**Groundwater-Lake Interaction: Response to Climate Change
Vilas County, Wisconsin**

Mary P. Anderson

2002

**Groundwater-Lake Interaction: Response to Climate Change
Vilas County, Wisconsin**

Final Report
to the
Water Resources Institute
University of Wisconsin

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PROJECT SUMMARY

Title: Groundwater-Lake Interaction: Response to Climate Change, Vilas County, Wisconsin

Project ID: R/UW-GSI-004

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Period of Contract: July 1, 2001 – June 30, 2002

Background/Need: There are numerous lakes and wetlands in Wisconsin and most have some connection with the groundwater system. Groundwater fluxes, while difficult to measure, may be important to the hydrology and chemistry of lakes. Stresses on the groundwater system and changes in groundwater fluxes affect surface water levels, which in turn affect groundwater levels in a dynamic feedback process. Problems in Wisconsin that critically depend on recognition and quantification of this feedback mechanism include predicting the effects of land use and proposed mining operations on groundwater and lake levels, urbanization on groundwater/surface water systems, agricultural drainage systems on wetlands, and potential global climate change on hydrologic systems.

Standard groundwater models assume that surface water levels are known inputs, and therefore do not recognize the true nature of the connection between surface water and groundwater. Recognition of the need for improvement in the way in which groundwater models handle surface water inputs led to development of specialized software packages for MODFLOW (the industry's standard code for groundwater flow modeling) that address the dynamic exchange of groundwater with rivers and reservoirs. Watersheds containing important lake and stream systems require models that include consideration of the dynamic exchange of waters among groundwater, lakes and streams.

The Trout Lake Basin study site is ideal for addressing issues related to groundwater-surface water interaction inasmuch as long-standing and on-going hydrological research with accompanying data collection and monitoring occurs at this site through the National Science Foundation's Long Term Ecological Research (LTER) program and the U.S. Geological Survey's Water, Energy, Biogeochemical Budgets (WEBB) program.

Objectives: (1) to determine effects on water levels of potential climate change in the Trout Lake Basin, Vilas County, Wisconsin and (2) to define the contributing groundwater basins and travel times to lakes within the Trout Lake Basin.

Methods: A regional groundwater-based watershed model of the Trout Lake Basin was calibrated under both steady-state and transient conditions and used to delineate lake capture areas and to assess the effects of potential climate change on surface water and groundwater

levels. The industry standard groundwater flow code, MODFLOW, including the newly developed LAK3 package for simulating groundwater exchange with lakes and a beta version of the Streamflow Routing Package for simulating groundwater exchange with streams and routing of streamflow, was used to simulate groundwater flow in the watershed. The flow model was calibrated using a parameter estimation code, UCODE. Results from the flow simulation were input to a particle tracking code, MODPATH, and used to delineate steady-state capture areas for 30 lakes in the basin as well as three streams. MODPATH also calculated travel times within the capture areas for selected lakes.

Results and Discussion. The large lakes tend to have large capture zones; Trout Lake has the largest. Many lakes receive water that underflows or flows through another lake. Travel times range from 200 years within the Trout Lake capture area to less than 20 years within the Crystal Lake capture area.

Sensitivity of the model to changed climate conditions, simulated by “wet” and “dry” recharge scenarios, showed that in general, capture zones are smaller under the “wet” conditions, corresponding to lower groundwater inflow rates for most of the lakes. All lakes had increased rates of groundwater discharge during the “wet” scenario and decreased rates during the “dry” scenario. Crystal Lake, a small lake located near the regional groundwater divide, showed the most dramatic change in capture zone size between the two scenarios. Lake levels in the large drainage lakes were insensitive to changes in recharge since lake level is controlled by the outlet streams. Seepage lakes showed, on average, a half-meter stage change under both “dry” and “wet” conditions.

Conclusions/Implications/Recommendations: Calibration of the complex three-dimensional groundwater model demonstrated the importance of using multiple calibration targets including groundwater heads and fluxes as well as additional non-traditional targets. Delineation of lake capture areas verified the importance of three-dimensional flow in this watershed; capture areas clearly show the occurrence of underflow of water beneath lakes. In effect, the system of lakes acts as a conveyor of water moving water down gradient to Trout Lake. Simulations designed to test the sensitivity of the model to potential global climate change demonstrated that lake capture areas, lake stages and groundwater fluxes to/from lakes in the Trout Lake Basin are sensitive to changes in precipitation, evaporation and recharge rates.

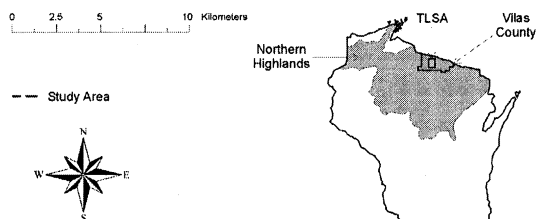
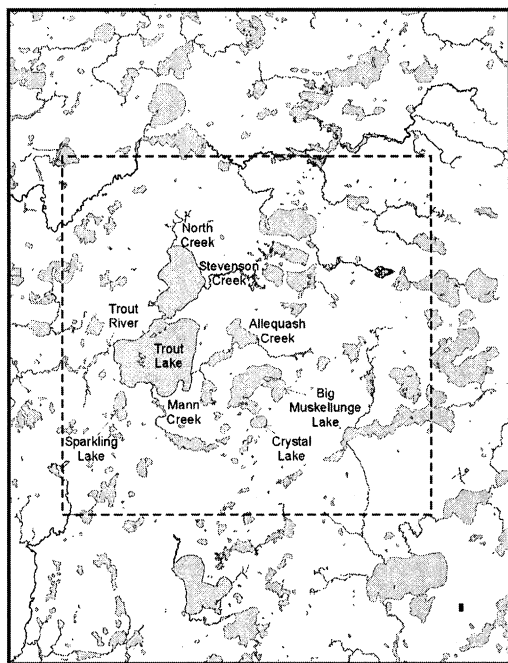
The results of the climate change simulations will be of interest to water managers and to scientists interested in the hydrologic effects of changes in groundwater recharge at a watershed scale. The delineation of lake capture areas will be helpful in addressing questions related to potential impacts on lakes as a result of land use change. Travel times of water flow to the lakes are needed for on-going studies of the geochemical evolution of groundwater in the Trout Lake Basin and could be used in transport studies related to possible introduction of solutes from certain kinds of land use.

Key Words: Groundwater, modeling, climate change, lake capture area, travel time, groundwater age.

INTRODUCTION

There are numerous lakes and wetlands in Wisconsin and most have some connection with the groundwater system. Groundwater fluxes, while difficult to measure, may be important to the hydrology and chemistry of lakes. Stresses on the groundwater system and changes in groundwater fluxes affect surface water levels, which in turn affect groundwater levels in a dynamic feedback process. Problems in Wisconsin that critically depend on recognition and quantification of this feedback mechanism include predicting the effects of land use changes and proposed mining operations on groundwater and lake levels, urbanization on groundwater/surface water systems, agricultural drainage systems on wetlands, and potential global climate change on hydrologic systems.

Standard groundwater models assume that surface water levels are known inputs, and therefore do not recognize the true nature of the connection between surface water and groundwater. Recognition of the need for improvement in the way in which groundwater models handle surface water inputs led to development of specialized software packages for the industry's standard code for groundwater flow modeling, MODFLOW (McDonald and Harbaugh, 1988), that address the dynamic exchange of groundwater with rivers and reservoirs.



Under the auspices of NSF's Long Term Ecological Research program, we have conducted hydrological studies in the Trout Lake Basin, Vilas County, Wisconsin (Figure 1), for over ten years. We developed a groundwater flow model of the basin at a regional scale (Cheng, 1994), building it from smaller scale sub-basin studies (e.g., Kenoyer and Anderson, 1989; Krabbenhoft et al., 1990). As part of this research Cheng (1994) and Cheng and Anderson (1993) developed a new module (the Lake Package, LAK1) for MODFLOW that calculates lake levels in response to changes in precipitation, evaporation and surface water and groundwater fluxes. Cheng (1994) applied MODFLOW with the Lake Package to solve a three-dimensional steady-state finite difference model of the Trout Lake Basin.

Figure 1. Lakes and streams in the Trout Lake Basin. The study area is delineated by the dashed line. Inset shows location of the Trout Lake Study Area (TLSA) in Wisconsin.

Geotrans (1995) revised and improved Cheng's Lake Package (also see Council, 1997, 1998). Merritt and Konikow (2000) recently developed a new version of the Lake Package (LAK3), which follows the original structure of the Anderson/Cheng package but includes some of the

features in GeoTrans' LAK2 that are designed to facilitate steady-state solutions, as well as other improvements. In LAK3, the routing of water to lakes through streams is handled by the Streamflow Routing Package (Prudic, in preparation).

We calibrated a three-dimensional, transient model of the Trout Lake Basin using MODFLOW with the LAK3 Package and a beta version of the Streamflow Routing Package. We used the model to delineate lake capture areas and to assess the hydrological effects of changed groundwater recharge rates that might occur under potential global climate change. To our knowledge, our application of MODFLOW with the LAK3 and Streamflow Routing packages is the first application of these two new packages to a field site. The hydrological effects of global climate change is an area of active research that may have important implications for water supply and management issues. In many areas of Wisconsin, effects of climate change are important for addressing potential effects on ecosystems, as well as sports and tourist industries that utilize our water resources. We used the Trout Lake Basin as a representative watershed to assess hydrological effects of potential climate change.

PROCEDURES AND METHODS

Design and Calibration of the Groundwater Flow Model

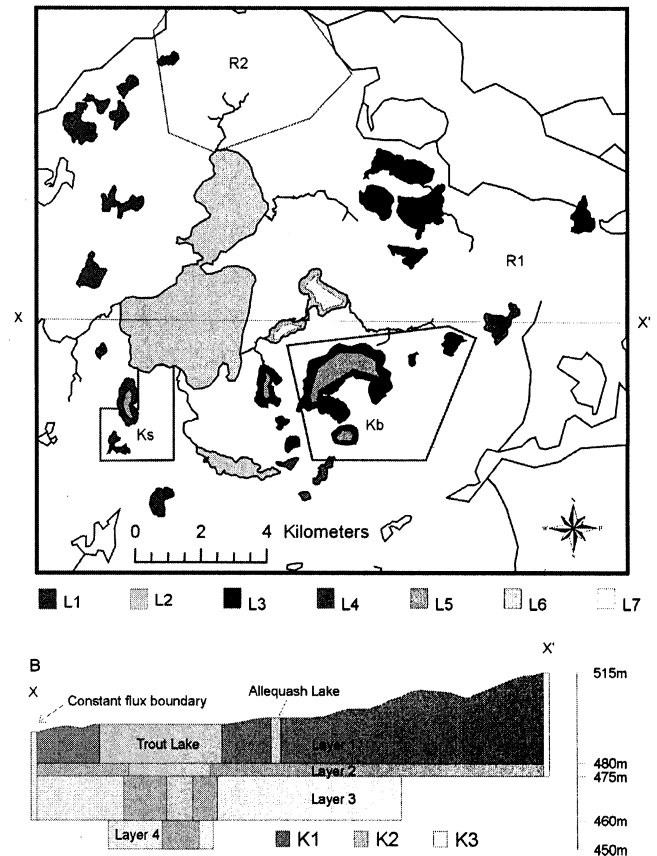
A three-dimensional model using MODFLOW2000 (Harbaugh et al. 2000) was constructed for the 310 square kilometer area that includes the greater Trout Lake basin (Figure 1). The model area was discretized into 240 rows and 230 columns with a uniform nodal spacing of 75 m. There are four model layers (Figure 2), which range in thickness between 5 and 15 m for the bottom three layers and between 8 and 35 m for the upper layer. Thirty lakes within the Trout Lake basin or near its boundary were simulated using the LAK3 Lake Package (Merritt and Konikow 2000), which calculates steady-state lake stages based on volumetric water budgets. Streams within the Trout Lake basin were simulated using the recently revised Streamflow Routing Package (Prudic, personal communication 2001). Porosity used in particle tracking was set equal to 0.29 (Dripps, personal communication). The model was run using the pre- and post-processor MODFLOW GUI (Shapiro et al. 1997) within Argus Open Numerical Environments, or Argus ONE (Argus Interware Inc. 1997). Particle tracking was performed using MODPATH (Pollock 1994).

A two-dimensional analytic element model of the region (Hunt et al. 1998a) was modified and used to extract boundary conditions for the finite difference model. MODFLOW input files were extracted from the analytic element code GFLOW (Haitjema 1995) using an automated routine (Hunt et al. 1998b) based on heads and fluxes calculated by the analytic element model. Groundwater fluxes across the boundary of the grid were distributed to the four model layers based on the layer thickness and input to the MODFLOW well package. The crystalline bedrock, which is assumed to be impervious, forms the bottom boundary of the model.

The MODFLOW model was calibrated using the parameter estimation code UCODE (Poeter and Hill 1998). UCODE calculates parameter sensitivity as well as parameter values that are a quantified best fit between simulated model output and head and flux targets. UCODE is a universal parameter estimation code, which allows the flexibility of including different data types as targets. Six different data types were used as targets for the steady-state calibration including

groundwater heads and fluxes, which are typical targets in calibration of groundwater flow models, as well as nontraditional targets, which included information on flow paths in the basin. Information on each target is given below.

Figure 2. Areal view of the model domain and cross section along line X-X' showing model layers. Parameter zones for recharge (R1 and R2), hydraulic conductivity (Ks, Kb, K1, K2, K3), and lakebed leakance (L1-L7) are also shown.



Heads. July 2001 water levels in 51 wells were used as head targets. July 2001 water level measurements represent near average conditions in the basin during the period of record 1985-2001. The UCODE weight assigned to these data was based on a standard deviation of 0.3 m, which represents 25% of the average annual water level fluctuation observed in wells with long-term data sets. In order to gain better spatial coverage, seven additional water level measurements from piezometers located between Allequash Lake and Big Muskellunge Lake, measured during the spring of 1999, were added as head targets and given the same weight (SD = 0.3 m) as the other head targets.

Lake levels. Measured lake stages for five lakes that are measured by the LTER program and 20 lakes stages estimated from topographic maps were used as lake stage targets. The LTER lakes were given a relatively small standard deviation (0.5 m for seepage lakes and 0.25 m for drainage lakes) based on the seventeen year measured range (1984-2001) (LTER database). The 20 estimated lake stages were given a larger standard deviation (1.0 m), which reflects the large amount of uncertainty associated with the estimates.

Baseflow. Average base flows measured during the period 1991-2000 for four streams, Allequash Creek, North Creek, Stevenson Creek and Trout River (Figure 1), were used as flux targets. The discharge records for Allequash Creek and Trout River are of higher quality than those from North Creek and Stevenson Creek. Hence, Allequash Creek and Trout River were assigned coefficients of variation (CV) equal to 0.02 and North Creek and Stevenson Creek were assigned CVs equal to 0.05.

Groundwater fluxes. Groundwater inflow rates were calculated for eleven of the lakes in the basin by Ackerman (1992) using a stable-isotope mass balance method (Krabbenhoft et al., 1994). Because of the inherent uncertainties associated with this methodology and the inability of a regional model to simulated lake specific hydrology, a relatively low weight was assigned to

these values (CV equal to 0.3). Groundwater outflow rates calculated by Ackerman (1992) have more associated uncertainty than the inflow rate calculations and were assigned a larger coefficients of variation (CV equal to 0.7). Additionally, a groundwater inflow rate for Trout Lake based on a water budget analysis (Champion, 1998) was used with an assigned coefficient of variation equal to 0.3.

Isotopes. Oxygen isotopes were used at two nested well sites to determine the top elevation of a plume of water emanating from Big Muskellunge Lake. These targets were assigned weights using a standard deviation of 0.5 m.

Travel time. CFC and tritium sampling in the basin provided an estimate for the time of travel between two well nests located between Big Muskellunge and Allequash Lakes (Walker et al., in review). The location of the flow path was identified using the Hunt et al.(1998a) analytic element model. The travel time target was given a standard deviation of 1 year. Periodically throughout the calibration process, simulated flow paths were visually compared to the flow paths determined by Walker et al. (in review). Although not directly used in the automated calibration of the model, this qualitative analysis was used to check overall model fit and to identify possible sources of error.

Three different data types were used as targets in the transient model calibration: lake stage, water level from observation wells, and stream flow.

Lake Levels. The average monthly lake stage measured for each of the five LTER lakes was compared to the lake stage simulated at the midpoint of the corresponding stress period. Two hundred and sixty-one lake stages from 1994 to 2001 were used as targets and given a standard deviation of 0.025m, which represents 25% of the average monthly lake stage fluctuation.

Groundwater Levels. Water level measurements in 42 wells were used as head targets (LTER database). In the area around Crystal Lake (Figure 1) where there are numerous wells with long-term water level records, only one well was used as a target. Five of the target wells had long-term data sets with water level measurements available from 1994 to 2001. Each measurement made during this period was used as a head target and compared to the equivalent simulated head. Eight additional wells had hourly measurements from late 1999 to July 2001. For these wells, the median monthly water level was used as a target and was compared to the simulated head at the midpoint of the corresponding stress period. Forty-eight additional water levels measured in 29 wells were used as head targets. Each of these measurements was compared to the equivalent simulated head. All water level targets were given a standard deviation of 0.05 m, which represents 25% of the monthly variation in head observed in wells with long-term records.

Stream flow. Median monthly stream flows for four streams were used as flux targets. Allequash Creek, Stevenson Creek, and Trout River (Figure 1) each had 81 flux targets from 1994 to 2000. North Creek had 48 targets from 1996 to 2000. Data were not available for 2001 for all streams or from 1994 to 1996 for North Creek. Mann Creek, also located in the basin, does not have a gaging station. Stream flow targets were compared to simulated flow at the midpoint of the corresponding stress period. The stream flow targets were assigned a coefficient of variation of 0.05, which represents measurement error.

Fourteen model parameters (Figure 2) were optimized during the steady state calibration; specific storage for layers 2-4 and specific yield in layer 1 were optimized during the transient calibration. A sensitivity analysis (Pint, 2002) showed that the steady state model was most sensitive to the recharge parameter R1 while the transient model was most sensitive to L5, K3 and to the value of specific storage.

Particle Tracking Analysis for Lake Capture Areas and Travel Times

Lake capture areas were delineated for thirty lakes in the Trout Lake Basin using the steady state groundwater flow model. One particle was introduced at the water table in the center of every active node in layer one. These particles were tracked forward in time to their points of discharge: lake cell, stream cell, river cell, or boundary well. Each lake, stream, and river in the model was assigned a unique zone number for use in MODPATH. Capture zones were then delineated based on the discharge zone number for water starting in each cell in layer one. A commonly used method for delineating capture zones, particularly for wells, is to use backward particle tracking (Anderson and Woessner, 1992). In this method, particles are introduced at the discharge point and tracked backwards in time to their source. Initial tests using this method to delineate capture zones in the Trout Lake Basin were unsuccessful. However, backward tracking was used for a pathline analysis in the Allequash Basin. Particles were started beneath Allequash Lake and Allequash Creek and tracked backwards in time to their recharge locations. MODPATH also calculates the travel time for each particle. Output from MODPATH was used to delineate the capture areas for selected lakes along with contours showing lines of equal travel time.

RESULTS AND DISCUSSION

Model Calibration

Calibrated parameter values as optimized by calibration with UCODE are shown in Table 1.

Table 1. Final optimized parameter values used in the groundwater flow model.

Parameter	Calibrated Value	Parameter	Calibrated Value
R1 (cm/yr)	24.9	L1 (d ⁻¹)	0.004
R2 (cm/yr)	25.8	L2 (d ⁻¹)	0.1
K1 (m/d)	9.67	L3 (d ⁻¹)	0.0043
Kb (m/d)	37	L4 (d ⁻¹)	0.023
Ks (m/d)	26.2	L5 (d ⁻¹)	0.00037
K2 (m/d)	3.44	L6 (d ⁻¹)	0.7
K3 (m/d)	38.2	L7 (d ⁻¹)	0.1
Sy	0.23	Ss	0.0005

The average residual and mean absolute error (MAE) for the 58 head measurements in the steady state model were -0.07m and 0.46m, respectively. Lake stages were simulated within the 95% confidence interval of the measured stage. The MAE was 0.10 m for the five LTER lakes and 0.67 m for the other twenty lakes used as targets. All four streams were simulated within the

estimated 95% confidence interval of each measured stream flow. Groundwater inflow rates to lakes also matched field estimates, although fluxes to lakes with small inflow rates showed higher discrepancies. Simulated groundwater outflow rates all fell within the uncertainty of the measured value although it should be noted that the uncertainty in the outflow measurements is much larger than for inflow rates.

The simulated steady state flow paths matched measured flow path targets that were explicitly included in the steady-state calibration. The depth of the plume of water emanating from Big Muskellunge Lake as simulated by the model was very similar to that estimated from isotope measurements. Furthermore, the simulated time of travel was within 10% of the time estimated by the CFC dating. A steady-state flow path analysis performed in the Allequash Creek basin compared well with results from Walker et al. (in review) who made deductions about the source of water discharging to Allequash Lake and Creek (Pint et al., 2002). The model also performed well during the transient calibration. Additional details regarding both the steady-state and transient calibrations are provided in Pint (2002).

Lake Capture Areas and Travel Times

While a capture zone is a three-dimensional surface (e.g., Townley and Trefry 2000), for our purposes a lake capture area is defined as the land surface area that contributes flow that discharges directly into the relevant lake or stream. It should be noted, however, that in effect, the system of lakes acts as a conveyor moving water down gradient toward Trout Lake, so that water anywhere in the basin may ultimately originate at the groundwater divide of the Trout Lake Basin, or anywhere in between. For example, Big Muskellunge Lake receives water from within its lake capture area (Figure 3) but also from flow paths that originate from upgradient lakes (e.g., Crystal Lake) and that water may have originated in another upgradient lake or at a terrestrial source.

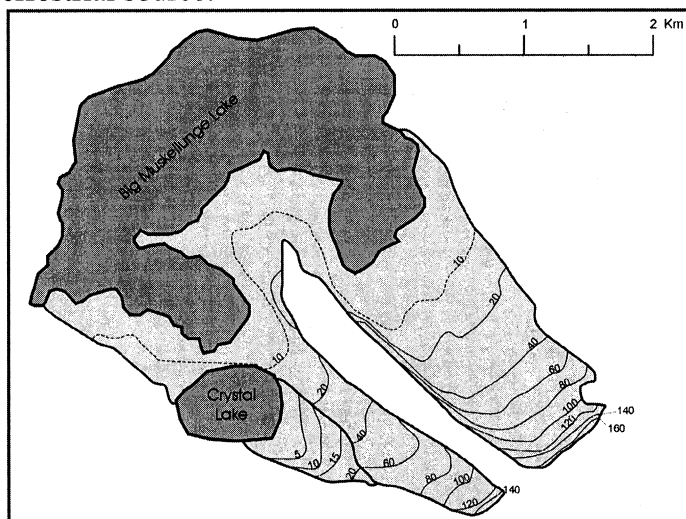


Figure 3. Lake capture areas for Big Muskellunge Lake and Crystal Lake, with contours showing travel times required for water to travel from recharge location to the lake.

Water over 160 years old is found in the Big Muskellunge capture area while all water within the Crystal Lake capture area is less than 25 years old (Figure 3).

All of the lakes in the model area are flow-through lakes, with groundwater entering and exiting through parts of the lakebed. While Trout Lake and Allequash Lake are predominantly discharge lakes, they both lose water to the aquifer in regions surrounding their outlet streams. The large lakes tend to have large capture zones, with Trout Lake having the largest (Figure 4, Lake 23). Many of these lakes receive water that underflows or flows through another lake. For

example, Allequash Lake (Figure 4, Lake 1) receives water that originates upgradient of Big Muskellunge Lake (Figure 4, Lake 2) and flows under Big Muskellunge Lake before discharging to Allequash Lake. Travel times range from 200 years within the Trout Lake capture area to less than 25 years within the Crystal Lake capture area (Figure 3). The travel time contours also provide relative information on the velocities throughout the basin. Contours that are closely spaced represent areas with low velocities, and contours that are far apart indicate areas with high velocities. The slowest water velocities in the basin occur near groundwater divides, e.g., the upgradient end of the Crystal Lake capture area (Figure 3).

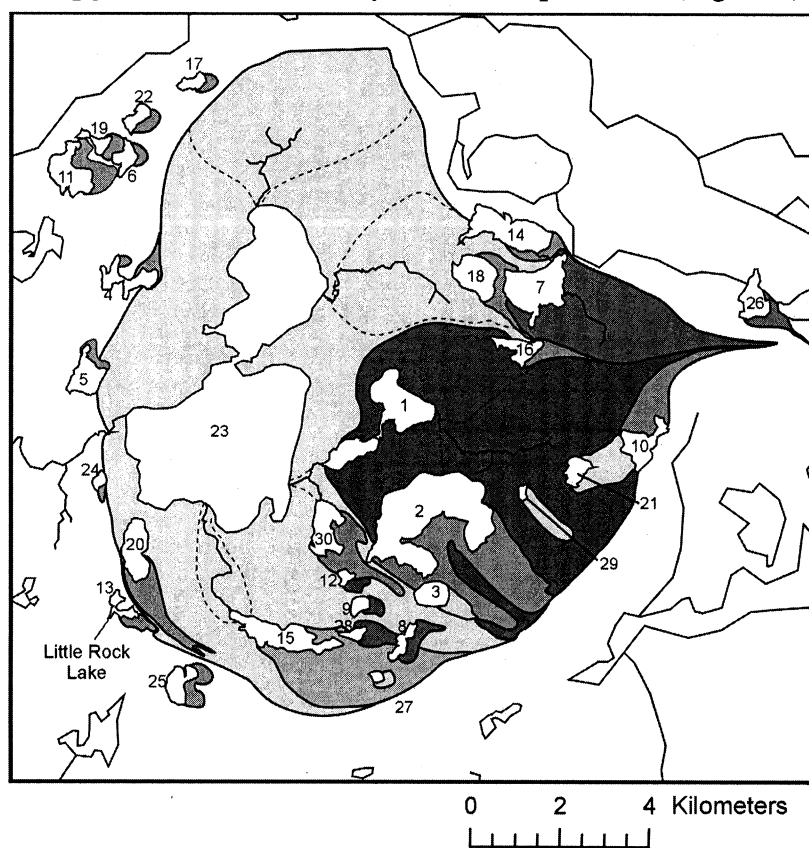


Figure 4. Capture areas for lakes in the Trout Lake Basin. 1 Allequash; 2 Big Muskellunge; 3 Crystal; 4 Day; 5 Diamond; 6 Edith; 7 Escanaba; 8 Fallison; 9 Firefly; 10 Frank; 11 Jag; 12 Little John Jr.; 13 Little Rock; 14 Lost Canoe; 15 Mann; 16 Nebish; 17 Nichols; 18 Palette; 19 Rudolph; 20 Sparkling; 21 Starrett; 22 Streat; 23 Trout; 24 Unnamed; 25 Vandercook; 26 White Birch; 27 Emerald; 28 Blueberry; 29 Little John.

Pint (2002) presented maps of capture areas and travel times similar to Figure 3 for Allequash Creek, North Creek, and Stevenson Creek and for the following lakes: Trout, Allequash, Sparkling, Little Rock, and Mann.

Response to Climate Change

The sensitivity of the model to changes in precipitation, lake evaporation, and groundwater recharge rate, such as might occur during potential global climate change, was tested by running the model under changed climate scenarios (Table 2). A drier climatic condition was simulated by decreasing recharge and precipitation to lakes by 10% and increasing lake evaporation by 10%. A wetter climate was simulated by increasing recharge and precipitation to lakes by 10% and decreasing lake evaporation by 10%. These simulations were not designed to model potential climate change, but only to test the sensitivity of the lake capture areas and lake levels to changes in hydrologic stresses that might accompany climate change.

Table 2. Recharge, precipitation, and evaporation rates used in the climate change scenarios.

	Wet Scenario	Dry Scenario	Average Conditions
Recharge Rate-R1 (cm/yr)	27.4	22.4	24.9
Recharge Rate-R2 (cm/yr)	28.4	23.2	25.8
Precipitation (cm/yr)	86.9	71.2	78.8
Lake Evaporation (cm/yr)	48.5	59.5	54.0

Capture zones were smaller under the “wet” conditions, corresponding to lower groundwater inflow rates for most of the lakes, except for the down gradient drainage lakes, which showed increased groundwater inflow rates under the “wet” conditions. Crystal Lake (Figure 4, Lake 3) showed the most dramatic change in capture zone size between the two scenarios. During the “wet” scenario, a large portion of the water that flows into Crystal Lake under average conditions is lost down gradient to Big Muskellunge Lake and Trout Lake (Pint, 2002). Lake levels in Allequash Lake and Trout Lake were insensitive to changes in recharge; in these drainage lakes lake level is controlled by the outlet streams. The remaining 28 lakes had, on average, a half-meter stage change under both “dry” and “wet” conditions (Figure 5). All lakes had increased rates of groundwater discharge during the “wet” scenario and decreased rates during the “dry” scenario (Pint, 2002).

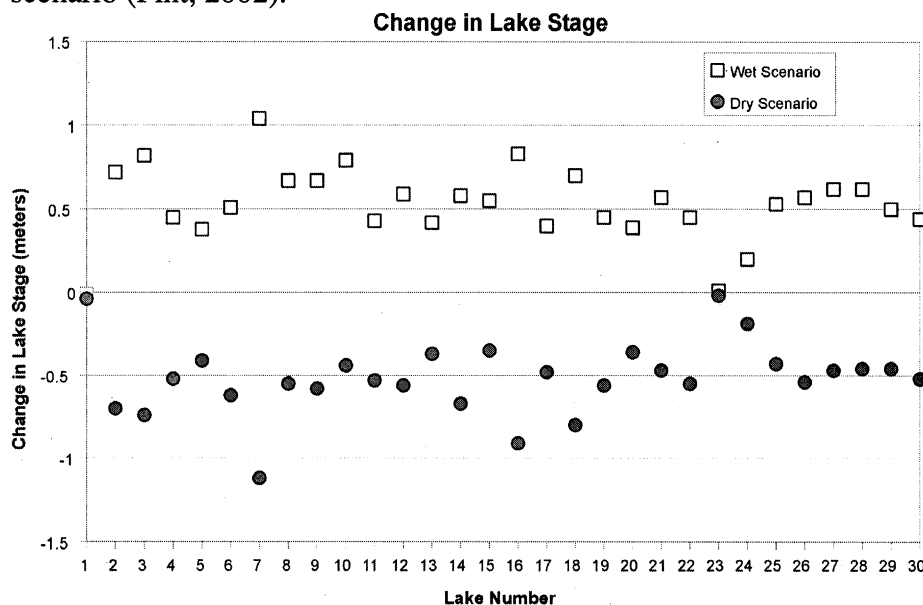


Figure 5. Change in lake level for 30 lakes in the Trout Lake Basin calculated from simulations of climate change. See Figure 4 for the key to lake numbers.

CONCLUSIONS AND RECOMMENDATIONS

Calibration of the complex three-dimensional groundwater watershed model of the Trout Lake Basin demonstrated the importance of using multiple calibration targets including groundwater heads and fluxes as well as additional non-traditional targets. Delineation of lake capture areas verified the importance of three-dimensional flow in this watershed; capture areas clearly show the occurrence of underflow of water beneath lakes. In effect, the system of lakes acts as a conveyor of water moving water down gradient to Trout Lake. Simulations designed to test the sensitivity of the model to changes in hydrologic stresses that might occur as a result of potential global climate change demonstrated that lake capture areas, lake stages and groundwater fluxes to/from lakes in the Trout Lake Basin are sensitive to changes in precipitation, evaporation and recharge rates.

The results of the climate change simulations will be of interest to water managers and to scientists interested in the hydrologic effects of changes in groundwater recharge at a watershed scale. The delineation of lake capture areas will be helpful in addressing questions related to potential impacts on lakes as a result of land use change. Travel times of water flow to the lakes are needed for on-going studies of the geochemical evolution of groundwater in the Trout Lake Basin and could be used in transport studies related to possible introduction of solutes from certain kinds of land use.

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APPENDIX A. Publications and Presentations

Abstracts/Presentations

Pint, C.D., M.P. Anderson, and R.J. Hunt, 2001, Groundwater-Lake Interactions: A modeling study of the Trout Lake Basin, Northern Wisconsin, Proceedings of the Amer. Water Resources Association, Wisconsin Sectional Meeting, Wisconsin Dells, WI, March 2001, oral presentation, p. 29-30.

Pint, C.D., M.P. Anderson, and R.J. Hunt, 2001, Assessment of Calibration and Prediction Reliability of a Groundwater-Lake Model, Poster presentation at ModelCARE 2002 Conference, Prague, Czech Republic, 17-20 June 2002.

Papers

Pint, C.D., R.J. Hunt, and M.P. Anderson, 2002, Flow Path Delineation and Ground Water Age, Allequash Basin, Wisconsin, *Ground Water*, special issue on Hydrogeology of Small Watersheds, in review.

Pint, C.D., R.J. Hunt, and M.P. Anderson, in preparation, Calibration using multiple targets: Trout Lake Basin, Wisconsin.

Abstract for AWRA Sectional Meeting, Wisconsin Dells, WI, March 2001.

Groundwater-Lake Interactions: A Modeling Study of the Trout Lake Basin, Northern Wisconsin

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Many of the numerous lakes and wetlands in Wisconsin are connected to the groundwater system in a dynamic feedback process, such that changes in groundwater fluxes affect lake levels, which in turn affect groundwater levels. Recognition of this process is critical when assessing the effects that potential climate change may have on a watershed. In order to gain a better understanding of lake-aquifer relationships and the effects of potential climate change, a three-dimensional finite difference MODFLOW model was constructed for the Trout Lake Basin in northern Wisconsin. Boundary conditions for the model were extracted from a regional scale analytic element model. Both transient and steady state models of the basin were calibrated with the use of the inverse modeling code UCODE, allowing parameters such as hydraulic conductivity, lakebed conductance and storage coefficient to be selected so that modeled heads and fluxes best match measured lake and groundwater levels, stream flow and groundwater fluxes to lakes. The use of UCODE significantly improved the calibration compared to earlier attempts using trial-and-error calibration methods. The calibrated model was then used to predict the effects of potential climate change as reflected in changes in lake and groundwater levels.

Abstract for ModelCARE Conference, Prague, Czech Republic, June 2002

Assessment of Calibration and Prediction Reliability of a Groundwater-Lake Model

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Groundwater flow models traditionally use head and stream flow data as calibration targets. However, these data often do not provide enough information to constrain complex problems, such as in many groundwater/lake systems. The use of additional, nontraditional targets provides a more robust calibration with increased reliability. A universal inverse modeling code such as UCODE allows for the inclusion of a wide variety of observation data to be used as calibration targets. A groundwater flow model of the Trout Lake Basin in Northern Wisconsin utilized UCODE in a steady state calibration. Targets for the model included head, lake stage, and base flow estimates, as well as nontraditional targets such as groundwater flux into and out of lakes, depth of flow paths, and travel time. The use of these data as calibration targets resulted in an improved understanding to the system and increased confidence in the model.

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