Report for 2003ND21B: Hydrological Modeling of the Spatial and Temporal Variation of Prairie Potholes at the Basin Level

- Other Publications:
  - Chris Laveau, 2003, Using GIS and Digital Terrain Data to Model Groundwater Interaction in Prairie Wetlands, 4th Biennial ND/SD Joint EPSCoR Conference,Poster Presentation
  - Chris Laveau, 2003, Using GIS and Digital Terrain Data to Model Groundwater Interaction in Prairie Wetlands, University of North Dakota RNEST Biocomplexity Workshop, Presentation

Report Follows

HYDROLOGICAL MODELING OF THE SPATIAL AND TEMPORAL VARIATION OF PRAIRIE POTHOLES AT THE BASIN LEVEL

ND WRRI Graduate Research Fellowship Project
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DESCRIPTION OF WATER PROBLEM

Water resources and aquatic ecosystems in the prairies have great economic importance for water supply, flood control, and waterfowl breeding and habitat. Previous studies related to the hydrology of these wetlands (e.g. Woo and Roswell, 1992; Winter and Rosenberry, 1998) have focused on the hydrodynamics and climatic response of prairie potholes in small areas. These studies provide valuable information on the hydrology of select high-relief areas of the prairie pothole province. Information on the general hydrodynamic conditions of the entire region, however, is often needed by wildlife and wetland managers.

This proposal forms part of a larger research project funded through NSF's Biocomplexity seed grant to UND's Department of Biology. As part of their work with host - parasite / pathogen interactions on a spatially heterogeneous and temporally dynamic landscape, our portion focuses on the hydrological modeling of grassland-wetland linkages in natural and human-dominated landscapes. Dr. Brad Rundquist and graduate student Paul Sethre of UND's Department of Geography are quantifying the dynamics of wetland and open water extent using historical remote sensing imagery. Their results will complement our research component, which will provide a conceptual framework and model that describes the spatial and temporal variation of hydrologic features at Newman's amphibian study site in eastern Nelson County, North Dakota.

OBJECTIVE

The objective of this research is to provide a conceptual framework and model that describes the spatial and temporal variation of hydrologic features within the upper Turtle River drainage basin in Grand Forks and Nelson counties, North Dakota. This characterization will be conducted at the watershed level as this is a fundamental spatial unit in which to (1) estimate groundwater and surface water budget, (2) relate all surface water channels, sub-basins, and their interconnection, and (3) recognize the relationship of soil catena to geomorphology, hydrology, and land use.

Research tasks of the study include

(1) Use existing data to map the surficial geology of the area.

(2) Make a spring and fall inventory of electrical conductivity and pH of wetlands, lakes, and ponds in the watershed study area, and, if possible, establish a correlation to the classification (Cowardin and others, 1979) used in the U.S. Fish and Wildlife Service National Wetland Inventory. (Completed for Fall 2002).

(3) Identify greater-than-annual periodicities in the precipitation record, if any exist, by computing autocorrelation for precipitation recorded for nearby weather stations. Precipitation constitutes the largest input to the prairie pothole water budget, and may therefore be the best component to use.

(4) If greater-than-annual periodicities exist, then cross-correlation techniques (Davis, 1986) will be used to characterize the relationship between precipitation and the extent of wetlands. (Work now underway by Sethre and Rundquist will quantify the temporal and spatial changes in wetland and open-water extent).

(5) Modify and apply a water budget method to model the effect of climate variability on the expansion and contraction of wetlands. Wigley and Jones (1986) used time interval, historic stream flow, precipitation, and potential evapotranspiration parameters to model changes in stream and river flow. We will test the application of a similar approach to predicting the dynamics of wetland hydrology.

(6) Use the groundwater – DEM-based surface model of Gerla (1999) to map the distribution of recharge and discharge areas in the watershed study area. Using a DEM and a map of hydraulic conductivity, the model uses raster-based water balance constraints to predict the variation of recharge and discharge across the landscape. Calibration is performed using maps of surface water and shallow groundwater (based on NWI wetlands). Soils maps, which are now being digitized, will be used to provide a spatially varying estimate of hydraulic conductivity.

Effort Planned For Summer 2003 under this Fellowship: Current funding for the Graduate Fellow, Chris Laveau ends on 30 April 2003. At this point, Chris and I have made good progress on the easier tasks, 1 – 4. Chris' thesis will focus on the methods and limitations of the spatial and temporal analysis described in tasks 5 and 6. I anticipated that the work associated with modeling would not be finished by May. To meet the goal of the biocomplexity grant, Chris and I will produce digital maps of the watershed that show how recharge, discharge, and wetlands expand and contract with observed climate variability. The data and results of Rundquist's work will be used to help calibrate and verify hydrological models.

METHODS, PROCEDURES, AND FACILITIES

The research will be conducted in an environment combining geographical information systems (ArcView 3.2), hydrological software, and field observations. Thirty-meter digital elevation models (DEMs) will be processed using flow accumulation methods developed by Jensen and Domingue (1988) to delineate a watershed that completely contains the basin and associated till plains of the upper Turtle River.

To develop an understanding of the area all available data on geology, soils, groundwater, and wetlands for the watershed have been complied as a GIS project. The data was acquired from North Dakota's Digital Data Clearinghouse, National Wetlands Inventory (NWI), Soil Conservation Services, and North Dakota Geological Survey's county studies. A spring and fall inventory of electrical conductivity and pH of randomly selected wetlands, lakes, and ponds in the watershed will be conducted and, if possible, a correlation established to the classification (Cowardin et al., 1979) used in the U.S. Fish and Wildlife Service National Wetlands Inventory.

To place our model in the largest possible context, historical records on precipitation and the Palmer Drought Severity Index (PDSI) (Palmer, 1965) will be statistically analyzed using autocorrelation techniques as presented in Davis (1986). Precipitation constitutes the largest input to the prairie pothole water budget and therefore is the most important component of the model. The PDSI is an index based on precipitation, evapotranspiration, and soil moisture that was found to have a strong relationship to wetland extent (Winter and Rosenberry, 1998). If cyclicity is found to exist, then cross-correlation techniques (Davis, 1986) will be used to characterize the relationship between precipitation, PDSI, and the extent of wetlands based on aerial photos.

A water budget model that takes into account the effect of climate variability on the expansion and contraction of wetlands will be applied. Wigley and Jones (1986) used time interval, historic streamflow, precipitation, and potential evapotranspiration parameters to model changes in stream and river flow; these methods may also work with wetland dynamics by using wetland extent as a surrogate for stream flow. Groundwater recharge and discharge areas in the watershed will be accessed using the groundwater-surface water model of Gerla (1999). Soil maps, conductivity measurements, and NWI maps of the area will be used to corroborate the results.

ANTICIPATED RESULTS AND BENEFITS

Modeling water budgets and recharge-discharge on a landscape scale constitutes a challenging problem in hydrology. The work described in this proposal will assess the ability of Gerla's (1999) model to simulate the groundwater flow in a region of low topographic relief and poorly integrated drainage. The estimation of model parameters using readily available data offers a practical method for providing the data required for meaningful hydrological analysis by wetland and wildlife managers.

Current wetland classification systems that depend on qualitative descriptions, based on fauna and physical parameters of wetlands, limit their range of applicability and validity. As noted by Brinson (1993), wetland classification schemes are useful for aggregating wetlands with similar hydrology, but they generally cannot be used to compare hydrologic variations among wetlands or to evaluate temporal and spatial variations within individual wetlands.

A numerical representation of hydrodynamics in prairie wetlands also has application in understanding the role potholes play modifying peak flow. Land drainage has been implicated as cause for the increase in streamflow over time on the tributaries of the Red River in North Dakota (Brun et al. 1981). The interaction of wetlands with adjacent ground-water and surface water systems determines its water budget components and its effect on downgradient water quantity. The role of wetlands in mitigating floods would be better understood if wetland managers could take into account hydrologic dynamics within an entire watershed.

RESULTS AND CONCLUSIONS

Prairie potholes are water-holding depressions of glacial origin in the northern portion of the Great Plains. They are significant hydrologic features because of the role they play in flood control, water supply, and biological activity of prairie communities. This role is often a function of the existing water balance within the wetland.

Hydrologic investigations (e.g. Shjeflo, 1968; Woo and Roswell, 1992) found that direct precipitation and spring runoff from snowmelt were the major sources of water supply for prairie potholes, while evapotranspiration was the major cause of water loss. Their results indicated that northern prairie potholes have a negative water balance with respect to the atmosphere.

With more water leaving than entering from the atmosphere the persistence of a prairie pothole in the landscape is directly related to its groundwater budget (Sloan, 1972). An understanding of groundwater dynamics has important applications in predicting the spatial and temporal distribution of wetlands. The thesis work is focused on working with spatial datasets and groundwater modeling (Gerla, 1999) to explain the distribution and persistence of wetlands within the upper Turtle River drainage basin in Grand Forks and Nelson counties, North Dakota.

Gerla (1999) used a method of integrating digital terrain data with groundwater modeling to estimate the local configuration of the water table. The estimation technique combines the use of digital elevation models (DEMs) with numerical modeling to solve the groundwater equation for transient, unconfined flow. The thesis is taking the next steps with this initial research. The model has been redesigned to incorporate the heterogeneity of hydraulic conductivity. The model output on groundwater conditions is being quantitatively compared to field data using a statistical program. The current goal is to incorporate the statistical program into the groundwater model. The result will be a groundwater model with input parameters derived from readily available spatial datasets and output that is immediately and quantitatively compared to field data.

KEY LITERATURE CITED

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