Using GIS and Digital Terrain Data to Model Groundwater Interaction in Prairie Wetlands……

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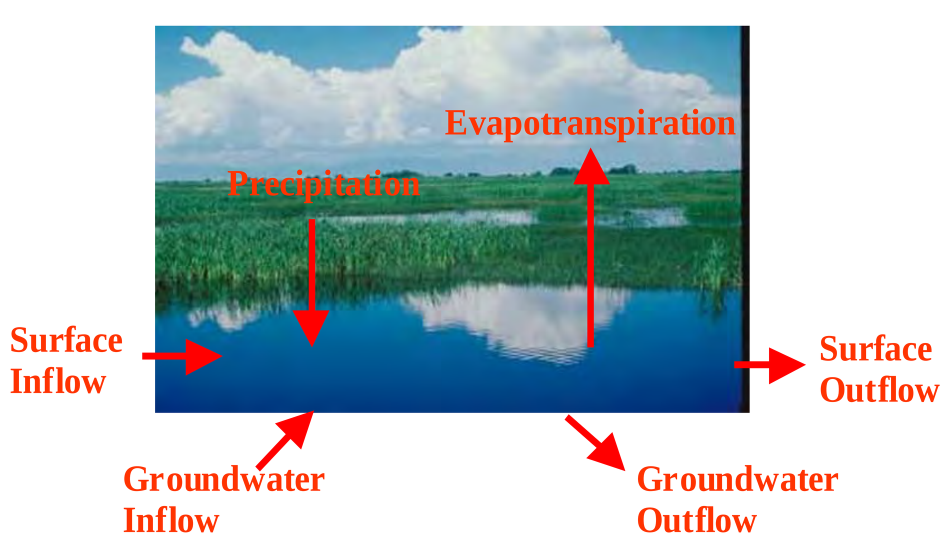
Introduction

- Prairie potholes are water-holding depressions of glacial origin in the northern portion of the Great Plains. The hydrology of these wetlands plays a role in flood control, water supply, and biological activity of prairie communities.
- Wetland classification and management often requires information on the contribution of groundwater to the water budget of these wetlands. Direct estimation of this parameter, however, is time-consuming, expensive, and can typically only be accomplished for small areas.

Prairie Pothole Region

Water Budget



Northern prairie potholes have a negative water balance with respect to the atmosphere as more water is lost to evapotranspiration than is gained by precipitation. The permanence of a wetland in the prairie region depends on its ground water budget (Sloan, 1972). An understanding of groundwater dynamics has important applications in predicting the spatial and temporal distribution, and water quality, of wetlands. 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 combined the use of digital elevation models (DEMs) with numerical modeling to solve the groundwater equation for transient, unconfined flow. The numerical solution assumes: (1) that the water table reflects the general pattern of surface topography, (2) the hydraulic gradient is equal to the slope of the water table, and (3) the gradient within the flow field is gentle and no vertical gradients exist.

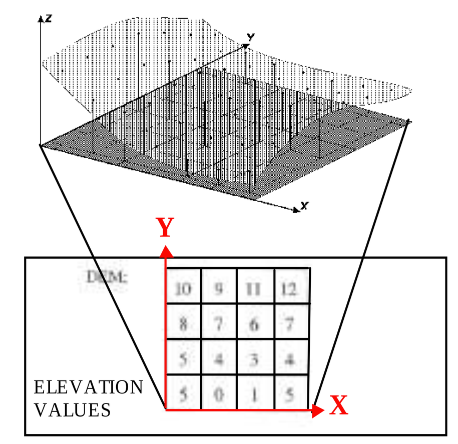
Objectives

- Estimate model variables using geographic information systems (GIS) and readily available datasets.
- Apply the model to a large prairie watershed.
- Incorporate heterogeneity of hydraulic conductivity.
- Develop and apply a statistical method of comparing the model to the observed water table.
- Apply the model during unusually dry and wet periods.

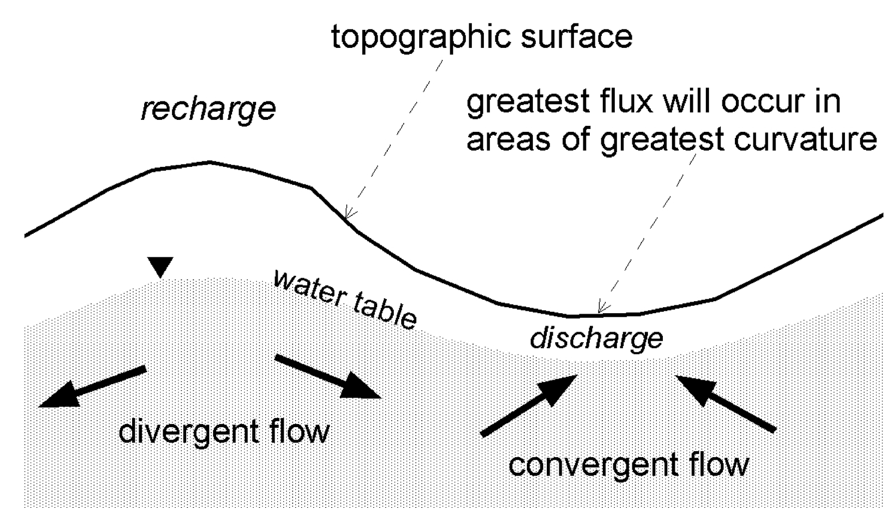
Groundwater Model

Digital Elevation Model (DEM)

- DEM's consist of an array of data representing elevation sampled at regularly spaced intervals

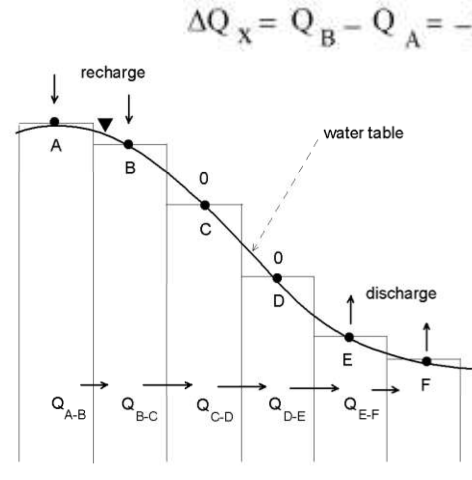


Influence of Topography on Groundwater Flow



Darcy's Law & Estimating Flow

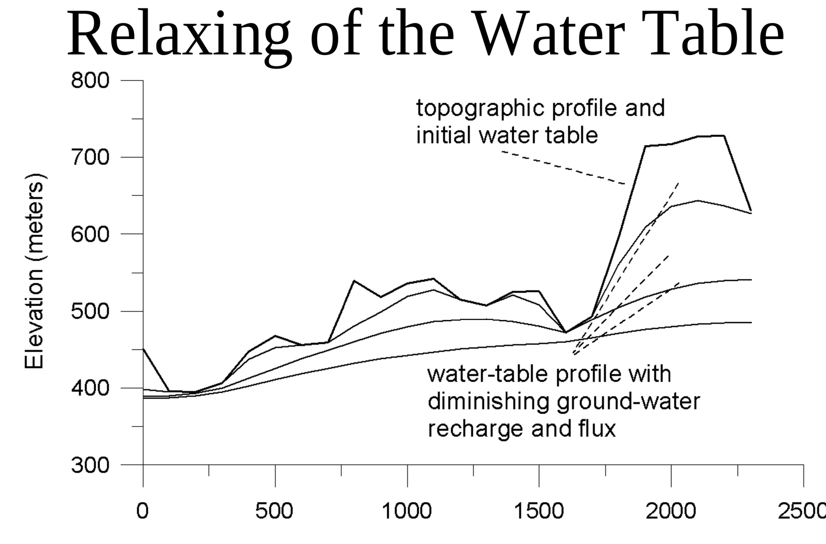
$$\Delta Q_x = Q_B - Q_A = -K\Delta y\left[h_B\left(\frac{dh}{dx}\right)_{x_B} - h_A\left(\frac{dh}{dx}\right)_{x_A}\right]$$



Q_A and Q_B represent the volumetric flow rates through the left and right faces of a nodal cell. ΔQ_x is the change in flow through the nodal cell in the x-direction.

Diagram showing the conceptual approach (in one dimension) to mapping recharge and discharge.

Relaxing of the Water Table



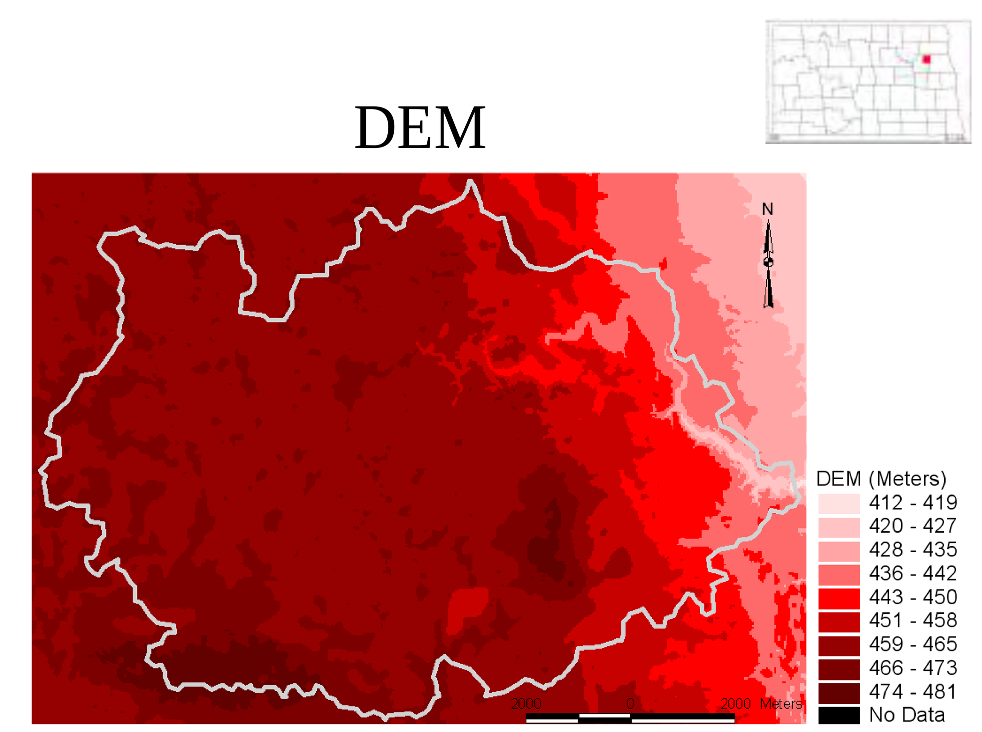
Results of a transient groundwater flow model using a DEM profile for the initial heads. An increasingly deep and smooth water table indicates decreasing groundwater recharge, flux, and discharge through the profile.

Methods & Procedures

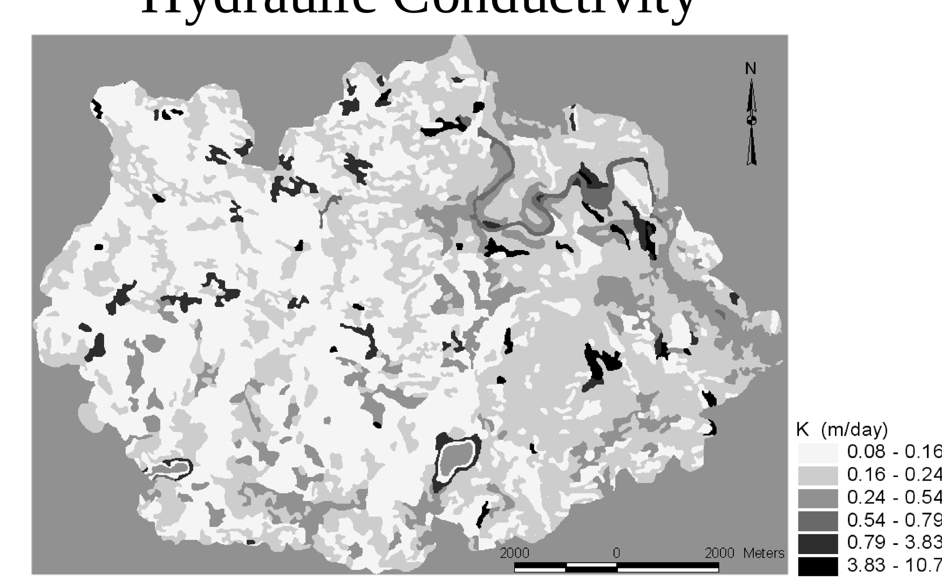
Model Variables

Specific Yield - ratio of the volume of water that drains from a saturated rock owing to gravity to the total volume of the rock. Input into the model as a single value for the entire watershed.
Hydraulic Conductivity - a measure of the ease with which a fluid will move through a medium. Input into the model as matrix to account for heterogeneity in the watershed. Values adapted from NRCS data on soils.
Elevation - derived from a DEM and applied to the model as a matrix.

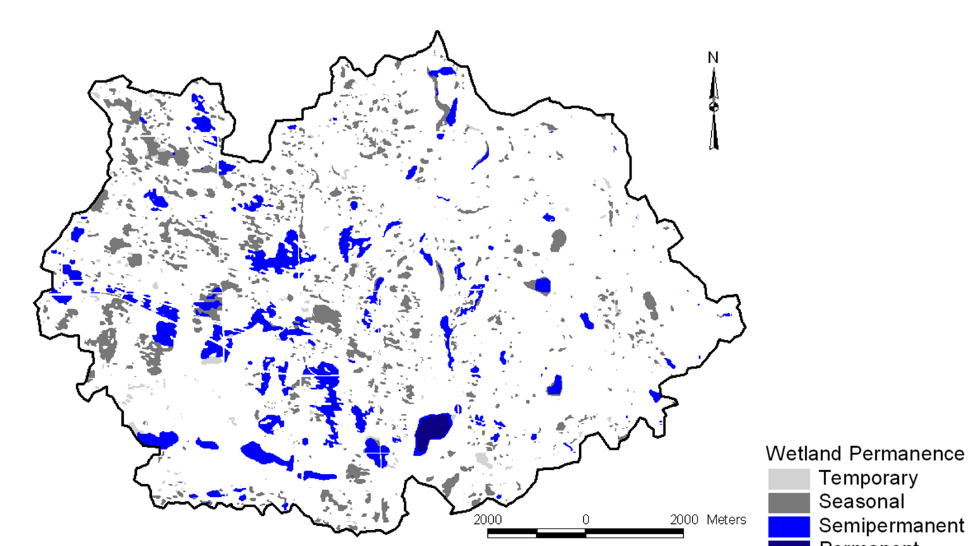
DEM



Hydraulic Conductivity



NWI Maps Provide The Observed Groundwater Table



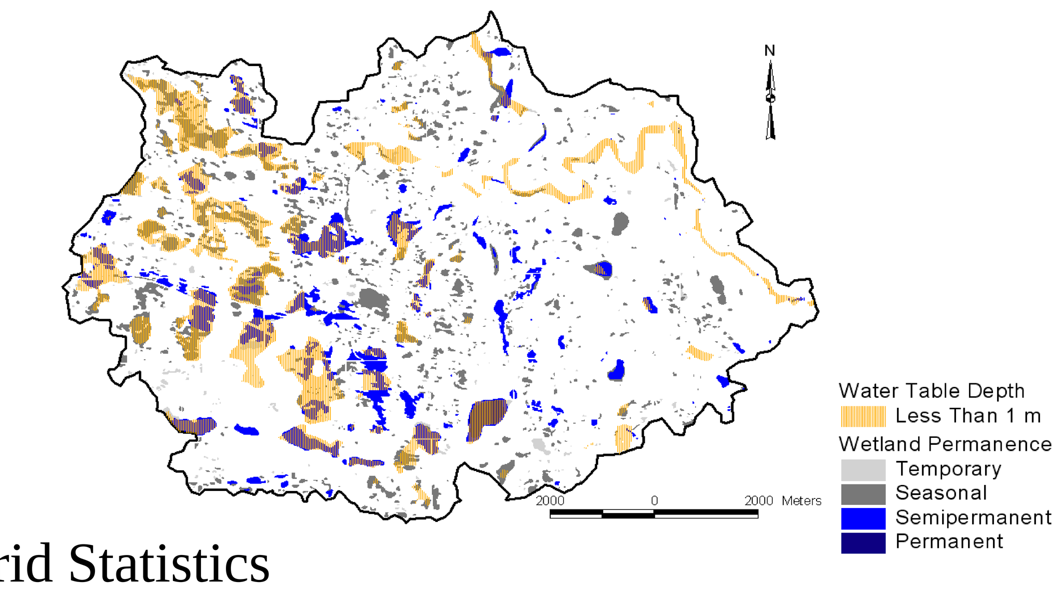
Model Output

Three Grid Arrays:
- Integer array identifying areas with a shallow water table
- Water table elevation
- Recharge/discharge flux

Grid Statistics
- Percentage area with shallow water table
- Total discharge & recharge
- Percent difference between recharge and discharge.

Preliminary Results

Model Output



Grid Statistics

% Area With Shallow Water Table = 16.20%

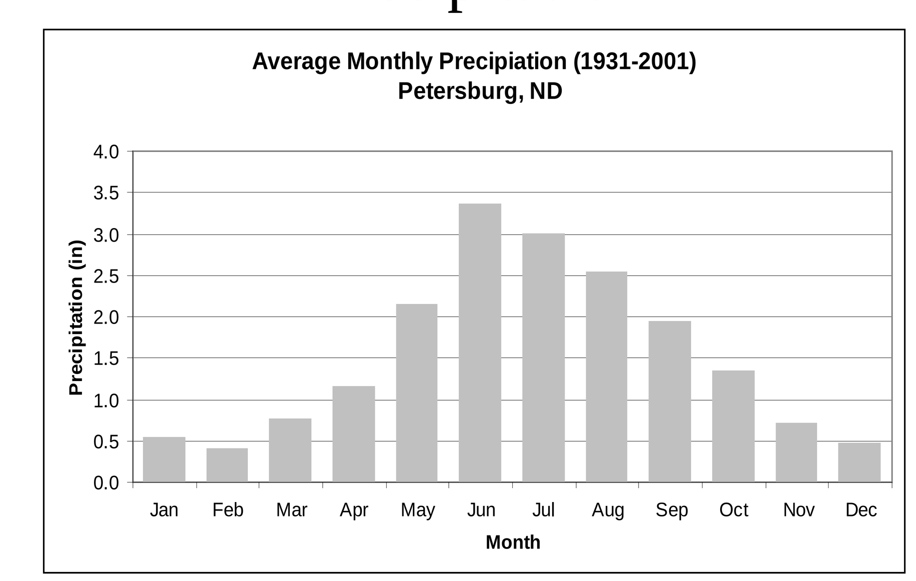
Total Recharge = 140373 m^3/day

Total Discharge = 135945 m^3/day

Percent Difference = 1.60%

Required Flux of Precipitation = 20.9 in/year

Precipitation



Application

- Modeling ground-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.
- The estimation of model parameters using readily available data offers a practical method for providing the data required for meaningful hydrological analysis.

Literature Cited

Gerla, P.J. 1999. Estimating the groundwater contribution in wetlands using modeling and digital terrain analysis. Wetlands, v.19, p.394-402.

Sloan, C.E. 1972. Ground-water hydrology of prairie potholes in North Dakota. United States Geological Survey Professional Paper 585-C, 28p.