THE NEED FOR REGIONAL ASSESSMENTS OF GROUNDWATER AVAILABILITY

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ABSTRACT
Regional assessments of groundwater availability provide a necessary framework for policy makers, resource managers, scientists, and the general public to understand the possibilities and implications of groundwater withdrawals. The need for regional assessments is highlighted by recent issues, such as competition for groundwater in water-rich areas of North America, groundwater/surface-water linkages in the Great Lakes Charter Annex, and concerns regarding climate change. Regional groundwater assessments in the United States were completed in the 1980s and 1990s as part of the U.S. Geological Survey Regional Aquifer-System Analysis (RASA) Program. Recent regional groundwater assessments make use of advances in geophysics, flow models, and model-calibration techniques. Regional groundwater assessments cannot be conducted solely by hydrogeologists. More frequent and structured communication and collaboration among hydrologists, geologists, biologists, and geographers are needed so scientists understand interrelationships of principles and processes in the various disciplines.

RÉSUMÉ
Les évaluations régionales de la disponibilité d'eaux souterraines fournissent un cadre nécessaire pour des décisionnaires, des directeurs de ressource, des scientifiques, et le grand public pour comprendre les possibilités et les implications des retraits d'eaux souterraines. Le besoin d'évaluations régionales est accentué par les issues récentes, telles que la concurrence des eaux souterraines dans les régions eau-riches de l'Amérique du Nord, tringleries de eaux souterraines/ eaux de ruissellement à l'annexe de charte de Great Lakes, et les soucis concernant le climat changent. Des évaluations régionales d'eaux souterraines aux Etats-Unis ont été accomplies dans les années 80 et les années 90 en tant qu'élément du programme régional de l'analyse de Couche-Système d'enquête géologique des ETATS-UNIS (RASA). Les évaluations régionales récentes d'eaux souterraines se servent des avances dans la géophysique, les modèles d'écoulement, et les techniques de modèle-calibrage. Des évaluations régionales d'eaux souterraines ne peuvent pas être conduites seulement par des hydrogeologists. Une communication et une collaboration plus fréquentes et plus structurées parmi des hydrologistes, des géologues, des biologistes, et des géographes sont nécessaires ainsi les scientifiques comprennent des corrélations entre les principes et des processus dans les diverses disciplines.

1. INTRODUCTION

As water availability looms as a world-wide issue, the need for regional assessments of groundwater availability has never been greater. Population growth, land-surface transformation, and climate change are all major drivers of this need. Local issues of groundwater supply and demand and of restoration and protection of aquatic ecosystems almost always require a regional perspective of groundwater-flow systems to achieve resolution.

Regional assessments of groundwater availability require more information than simply the amount of potable groundwater in the subsurface. Necessary information includes:

- 3-dimensional geologic mapping
- distribution of aquifer-system hydraulic properties
- historical and current flows into and out of the region of interest
- historical changes in groundwater levels
- forecasts of future groundwater use
- projected land uses
- potential climate change

This paper briefly describes U.S. Geological Survey (USGS) regional assessments of groundwater availability from 1978 to the mid-1990s, discusses data and information needs using recent studies as examples, and points to future needs for groundwater research. Where possible, examples are drawn from studies in the northern glaciated area of the United States.

2. THE REGIONAL AQUIFER-SYSTEM ANALYSIS PROGRAM

The Regional Aquifer-System Analysis (RASA) Program began in 1978 in response to a Congressional directive to develop quantitative appraisals of the major groundwater systems in the United States. During the next 15 to 20 years, the RASA Program studied 25 regional aquifer systems using geologic, hydrologic, and geochemical information. This information, together with numerical groundwater-flow models, was used to analyze and develop an understanding of each system. The RASA Program developed new concepts of regional groundwater flow and sources of recharge for some aquifer systems, assembled a large amount of existing data and information, and provided new numerical techniques applicable to modeling regional flow systems. An excellent compilation and summary of the program is given by Sun and Johnston (1994).

A major strength of the RASA Program was the vision of a national set of regional assessments and the long-term commitment of resources to achieving that vision. Through the RASA Program, a very large amount of geologic, hydrologic, and geochemical data were collected and analyzed. Relatively new field and analytical techniques, at least within the scientific field of hydrogeology, were developed and applied. The use of straddle-packers to measure transmissivity and to collect hydraulic-head data and water samples became common practice. Borehole-geophysical techniques became a well-accepted and efficient method to develop a 3-dimensional understanding of the distribution of aquifers and confining units. Geochemical data, already understood to be related to groundwater residence time and flow paths, became a critical part of developing conceptual models of the groundwater-flow system. During the RASA Program, isotopic data were routinely used to understand the age and mixing of groundwater. Finally, the national-scale need for simulation of groundwater flow, and the concurrent growth in the development of computers, resulted in the development of MODFLOW and other numerical groundwater-flow models and their widespread application. The use and application of these models by scores of hydrogeologists across the United States resulted in significant advances in our national understanding of regional groundwater-flow systems. These models also allowed for greatly improved advances in predicting the response of regional aquifer systems to future pumping and changes in other stresses.

The RASA Program, of course, did not have the advantage of major recent advances in information, tools, and technology. The availability of geographic information systems coupled with very large geographic-data sets and remotely sensed data allows for significant improvements in modeling land-use transformation and groundwater flow. Large-scale climatic models provide information with which to estimate future changes in recharge and water demand. Model parameter-estimation procedures reduce the trial-and-error approaches to model calibration, and aquifer-management models provide a scientific basis for groundwater-resource management decisions.

Two important topics went largely unexplored during the RASA Program. The first topic is groundwater flow in glacial deposits. Glacial aquifer systems generally are not regional flow systems. Therefore they were the focus of only one RASA study, the glacial-fill deposits in the bedrock valleys of the northeastern United States. In the Great Lakes region, glacial deposits cover most of the area and are an important source of water to wells, yet in RASA models they were treated either as an upper boundary condition in a groundwater-flow model or as a simplified single model layer. A major recommendation resulting from the RASA Program (Sun and Johnston, 1994) was to develop “a detailed analysis of the important shallow, unconfined aquifers…on a regional basis.” The second topic that was largely unexplored during the RASA Program is groundwater-flow needs of aquatic ecosystems. The RASA Program was designed to provide an understanding of regional aquifer systems, and not necessarily to evaluate groundwater availability for human and ecological uses. At its inception, there was not a general appreciation of the linkages between groundwater and aquatic ecosystems. Groundwater/surface-water interactions mostly were considered in the context of model calibration needs.

3. EXAMPLES OF RECENT REGIONAL GROUNDWATER ASSESSMENTS

A few examples of recent groundwater studies are briefly cited below to illustrate the types of information that are broadly applicable to current regional groundwater assessments. These studies include non-traditional approaches to defining the hydrogeologic framework in the Middle Rio Grande Basin in New Mexico and in glacial deposits in Michigan and Indiana, applications of long-term monitoring in southeastern Wisconsin, and understanding recharge in the Great Lakes region.

A 3-dimensional understanding of the geologic framework is fundamental to regional assessments of groundwater availability. Geologic and geophysical studies of the Middle Rio Grande Basin in New Mexico over a 6-year period provided a new framework for a groundwater-flow model of the region (summarized by Bartolino and Cole, 2002). Regional gravity data were used to identify deep faults that constrain the flow system, and aeromagnetic data provided detailed information about faults that offset aquifer units. These data led to a better understanding of the depositional environment of the basin-fill sediments that form the principal aquifers and confining units in the basin.

In glacial deposits, the distribution of lithologies and associated hydraulic conductivities generally is extremely heterogeneous. The lateral continuity of these may be very short compared to that of bedrock units. Consequently, mapping the 3-dimensional distribution of glacial deposits using traditional approaches is time-consuming and expensive. Typically, however, a large number of water-well logs are available in glaciated areas. Although these logs are made by drillers and contain some errors and generalities, these logs are a potential data set for understanding the hydrogeologic framework. In southwestern Michigan and northwestern Indiana, about 28,000 water-well logs are being used to develop a 3-dimensional model of sediment texture and associated hydraulic conductivities. Various geostatistical techniques are being applied to the data to develop alternative models which, in turn, will be evaluated by geologists for comparison to their understanding of the depositional environment of the region (Howard Reeves, U.S. Geological Survey, written commun., 2004).

The value of long-term monitoring in regional assessments of groundwater availability cannot be overstated. Ideally, long-term monitoring data include flows into and out of an aquifer system and the response of the system to stress. The monitoring should encompass predevelopment conditions through the present. As a recent example, Feinstein and others (2004) describe how a groundwater-flow model useful for forecasting long-term groundwater availability in southeastern Wisconsin could be constructed with increased confidence because long-term streamflow, water use, and groundwater-level data were available. Records from 8 streamflow-gaging stations, with long-term records and drainage areas covering most of the modeled area, were available to calibrate flows from the groundwater-flow system into streams. Historical pumping rates for 794 high-capacity wells in the central model area and 508 high-capacity wells in surrounding areas allowed for simulation of 16 sequential pumping conditions averaging about 10 years in length. Lastly, about 50 wells in southeastern Wisconsin had long-term levels suitable for model calibration. The resulting model simulates the stresses on and response of the groundwater-flow system from 1864 to 2000.

The regional distribution of recharge to a groundwater-flow system is not directly measured and is difficult to estimate. Usually it is problematic to verify the estimate. A common surrogate for estimation of the regional distribution of recharge is to calculate the base-flow component of streamflow from long-term records at streamflow-gaging stations (Holtschlag, 1996). This approach incorporates two important assumptions that usually cannot be independently tested. The first is that the calculated base flow is derived from a recharge area that is similar to the drainage area for the streamflow-gaging station. The second is that changes in base flow over time represent changes in recharge, rather than a change in some other stress to the system, such as groundwater pumpage. Consideration of this latter assumption led hydrologists to hold recharge constant over the simulation period of the southeastern Wisconsin groundwater-flow model. Despite these assumptions, streamflow data are often available over many of the spatial and temporal scales needed for calibration of groundwater-flow models and other data applicable to estimating recharge are not. Currently, USGS and National Water Research Institute researchers are estimating the groundwater component of streamflow for the entire watershed of the Great Lakes.

4. FUTURE NEEDS OF REGIONAL ASSESSMENTS OF GROUNDWATER AVAILABILITY

Groundwater withdrawals, their effect on surface-water flow, and the related effects on aquatic ecosystems are becoming an increasingly important issue. Understanding in-stream flow requirements for various biota is an area that requires an interdisciplinary approach among hydrologists and biologists. In some parts of the world, aquatic ecosystems and humans are viewed to be equally important users of water (Postel and Richter, 2003). This viewpoint is an impetus for restoring and protecting the natural flow regimes of streams.

Geochemistry and age-dating show promise as indicators of the regional distribution of recharge, particularly when used iteratively in the model calibration procedure (Bartolino and Cole, 2002). Another potential approach is linkage of groundwater-flow and rainfall-runoff models. Remote sensing of precipitation, temperature, and plant growth, coupled with digital elevation models, provide an opportunity for regional calibration of rainfall-runoff models, with a resulting estimate of water lost to the groundwater-flow system.

The need to manage regional groundwater withdrawals to meet both human and ecosystem needs is motivating the development of conjunctive-use modeling in humid northern regions of the United States. Previously in the United States, this has been an issue mostly in semi-arid western regions. In Rhode Island, a simulation-optimization approach was implemented to address issues of conjunctive use (Galloway and others, 2003). A model of the groundwater-flow system first was developed to accurately simulate flow in the shallow unconsolidated aquifers that are well-connected hydraulically to the surface-water-flow system. Second, an optimization model was developed to address water-resources management objectives, which are to maximize groundwater withdrawals while minimizing impacts on streamflow. The linked simulation-optimization model was used to explore management alternatives and evaluate trade-offs between these alternatives.

Land-use transformation modeling is a geographic science used to forecast changes in land use (for example, Brown and Duh, 2003). Results may be applicable to forecasting changes in recharge and water demand. Land-use changes that increase runoff to surface water reduce the potential for recharge. Land-use changes that increase population, manufacturing, or agriculture may increase water demand. Application of land-use transformation modeling to regional assessments of groundwater availability requires an interdisciplinary approach that includes geography, social science, and hydrology.

The earth's climate is variable, and recent research indicates that future long-term changes in climate may result from human activities. General Circulation Models (GCMs) are being widely applied to this issue. In the Great Lakes region, GCMs have been developed to forecast changes in Great Lakes water levels and the factors that affect them, including streamflow and precipitation. In Michigan, the results of a GCM were used in a groundwater-flow simulation to forecast the long-term effects of reduced recharge on groundwater levels in a major metropolitan area that is dependent upon groundwater (Croley and Luukkonen, 2003).

Despite the well-known need among scientists for the collection of basic geologic and hydrologic data and long-term monitoring of water-resources, this need is not widely understood among the general public and legislative bodies. Many regions lack the geologic data needed to develop geologic models that can serve as the framework for hydrogeologic and simulation models. Critical long-term streamflow-gaging stations (U.S. Geological Survey, 1999) and groundwater-level observation wells (Taylor and Alley, 2001) have been discontinued in some areas and never established in others. Water-use data are extremely variable in quantity and quality from one state to another, and consumptive-use coefficients have not been developed for many regions and use-sectors.

5. REFERENCES

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