Groundwater Availability Modeling

Groundwater availability models help Texas plan for the future.

By James Beach

Groundwater continues to be a major water source for domestic, industrial, and agricultural users in Texas. In 2000, groundwater supplies provided almost 60 percent of the approximately 17 million acre-feet of water used throughout the state. This usage is expected to continue—albeit at slightly decreasing levels—to the year 2050. However, a projected doubling of the state's population during that same time period, coupled with the constant threat of drought, have made it imperative for Texas to develop effective plans to make sure it can meet the future water needs of its residents.

To provide stakeholders with the necessary data to manage resources effectively, the Texas Water Development Board (TWDB) in 2000 embarked upon a comprehensive research project that will provide Groundwater Availability Models (GAM) for every aquifer in the state. This is a huge undertaking considering that in order to provide full coverage of the nine major aquifers, 17 different models had to be developed.

These groundwater models are designed to anticipate upcoming water demands, forecast how much groundwater will be available under certain usage conditions and regulations, and determine whether water will need to be imported from other areas to sustain future development within a particular region. For TWDB these groundwater models are "living tools," i.e., once constructed, they are not just shelved away, but rather revisited regularly and updated with new information to ensure they continue to provide accurate data to help plan, manage, and regulate groundwater use.

Creating the Model

A groundwater availability model is the mathematical representation of an aquifer with the help of specialized computer software, in this case the U. S. Geological Survey code known as MODFLOW (See box.) Using the basic laws of physics that govern groundwater flow, the computer model is prompted to consider the physical boundaries of the aquifer, recharge, pumping, and interaction with rivers and other characteristics to model the behavior of the aquifer over time.

Constructing an accurate groundwater model requires gathering a tremendous amount of detailed information on the hydrogeologic characteristics of the aquifer, its water quality, and its connection with the environment and other aquifers. It also involves compiling data on recharge, river interaction, water lev-

View of the Concho River, which runs through the Lipan aquifer in central Texas.

els, hydraulic properties, and pumping levels. To collect this data, input is provided from a variety of sources, including groundwater conservation districts, regional water planning groups, and governmental agencies—as well as representatives of local industry, water utilities, universities, and private landowners.

Once the model has been calibrated to accurately reproduce water levels measured in the past, it can be used to make reasonable predictions on how water levels will change over time. Factors that need to be considered include changes in pumping and recharge, and, given the state of Texas' historical drought record, extended periods without rainfall.

What follows is a closer look at what was involved in creating groundwater availability models for three of the aquifers that were part of the TWBD initiative.

The West Texas Bolsons and Igneous Aquifer—The West Texan border city of El Paso has purchased land and water rights in an area known as Ryan Flat, and intends to use the aquifer for water supply to support future needs. Constructing an accurate groundwater availability model for the aquifer was therefore of great importance for urban planners in the region, as well as groundwater conservation districts, which have some authority to regulate groundwater use in the area.

Located in a desert terrain with rain levels of eight to ten in. per year, the Bolson aquifer receives limited recharge from the surrounding mountains that recharge the sand and gravel aquifer of the valley, which contains a large volume of water in storage. Since the valley effectively receives no recharge from rainfall, accurate estimates of the water flow it would derive from the mountains are crucial in determining how long groundwater supplies will last under certain demand conditions.

Using data collected from hydrogeologic studies, well drilling records, and geophysical logs, a detailed conceptual model was developed for the groundwater flow system of the Igneous and Bolson aquifers. The model simulates flow in the Igneous aquifer system, which consists of a series of water-bearing lava and ash flows that are in varying degrees of hydrologic communication. To spatially estimate the hydraulic properties of the aquifer, aquifer test and specific capacity data were collected. Six predictive runs were performed using the calibrated model. Model predictions included an estimate of water decline, an aquifer impact analysis for pumping projections, and projected drought conditions to the year 2050.

The Lipan Aquifer—While relatively small, the Lipan aquifer in central Texas is of great importance to this largely agricultural part of the state. Due to the fact that groundwater was easily accessible for irrigation during the 1990s, local farmers began to install wells and pivot irrigation systems to water their crops. As a result, demand on the aquifer increased three to four times, ultimately decreasing water levels, driving up pumping costs, and causing some of the wells to run dry.

Because most of the demand from the aquifer is agricultural, properties derived from standard tests employed to characterize aquifers were not available. To make up for this lack of information, an alternative approach was developed to estimate spatial changes in aquifer productivity by evaluating well production estimates from drillers. Calibrating the model to groundwater/surface water interaction also increased the reliability of the model.

The groundwater availability model was designed to help estimate the recharge to the aquifer from precipita-

MODFLOW

MODFLOW is a three-dimensional finite-difference groundwater model that was first published in 1984. It has a modular structure that allows it to be easily modified to adapt the code for a particular application. Many new capabilities have been added to the original model.

MODFLOW-2000 simulates steady and nonsteady flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined. Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through river beds, can be simulated. Hydraulic conductivities or transmissivities for any layer may differ spatially and be anisotropic (restricted to having the principal directions aligned with the grid axes), and the storage coefficient may be heterogeneous. Specified head and specified flux boundaries can be simulated as can a head dependent flux across the model's outer boundary that allows water to be supplied to a boundary block in the modeled area at a rate proportional to the current head difference between a "source" of water outside the modeled area and the boundary block. MODFLOW is currently the most used numerical model in the U. S. Geological Survey for groundwater flow problems.

The groundwater flow equation is solved using the finite-difference approximation. The flow region is subdivided into blocks in which the medium properties are assumed to be uniform. In plan view the blocks are made from a grid of mutually perpendicular lines that may be variably spaced. Model layers can have varying thickness. A flow equation is written for each block, called a cell. Several solvers are provided for solving the resulting matrix problem; the user can choose the best solver for the particular problem. Flow-rate and cumulative-volume balances from each type of inflow and outflow are computed for each time step.

In addition to simulating groundwater flow, the scope of MODFLOW-2000 has been expanded to incorporate related capabilities such as solute transport and parameter estimation.

For further information, go to http://water.usgs.gov/nrp/gwsoftware/modflow2000/Mf2k.txt.

tion to provide authorities with the necessary data to manage and limit pumping, if necessary.

The Northern Trinity and Woodbine Aquifer—The groundwater availability model covers all or parts of 46 counties within Texas as well as nine counties in Oklahoma and five in Arkansas. It encompasses seven major river basins as well as the metropolitan areas of Dallas-Fort Worth and Waco. Historically, the aquifer was characterized by its flowing artesian wells.

Groundwater pumpage over the past 100 years has caused water levels to decline hundreds of feet in some areas. To support this development, dams and reservoirs were established to provide surface water supplies. However, groundwater from the aquifer continues to be used by smaller communities and irrigators in the area.

Based on a collection of water level data from the 1800s onwards, historic water level maps were created that assisted with model calibration. In addition, all available pumping test data was gathered, evaluated, and statistically analyzed for use in the flow model.

The models that have been completed have proven to be valuable tools for water planning. The GAMs are commonly used to evaluate the possible effects of increased pumping, new development, and drought on water levels. The model of the northern part of the Ogallala aquifer has been used to help planners assess water-level declines and future groundwater availability based on projected irrigation demands and municipal needs. In addition, the TWDB intends to update the models regularly as new information becomes available and as modeling techniques improve.

As the Texas examples demonstrate, groundwater availability modeling has proven to be an invaluable tool for assessing future groundwater availability, aquifer impact, and the longevity of aquifers. The effort provides local and state government entities with a means of planning for and managing water resources effectively to accommodate future growth. GE

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