

## **EVALUATION OF EXISTING GROUNDWATER MODELS OF THE BARTON SPRINGS SEGMENT OF THE EDWARDS AQUIFER, AUSTIN, TEXAS**

By Nico M. Hauwert, Senior Environmental Scientist

*The Barton Springs Segment of the Edwards Aquifer is a complex karst formation with a relatively well defined recharge and contributing zone and common spring discharge at points near Zilker Park in Central Austin. Due to the importance of the aquifer for public water supply, recreational opportunities at spring discharge points, and its being the only location of the endangered Barton Springs salamander, several attempts have been made to model both flow and water quality from surface recharge to discharge at Barton Springs. This short report outlines these attempts, the calibration data used, results of the simulations, advantages and disadvantages, and comparisons with the other available models. In general, each of the previous models contributes a piece of better understanding of the Barton Springs segment; however, the complexity of the hydrological system and the many influences on water quality have resulted in many limitations in the models and their applicability in planning usage.*

*Recommendations for future modeling efforts include (1) maintenance of comprehensive surface water gages upstream and downstream of the recharge zone on each creek to determine the recharge characteristics over time, (2) development of a multi-layered model to simulate the hydrogeological framework of the aquifer, (3) incorporation of complete groundwater tracing data, (4) evaluation of inflow from the Trinity Aquifer (and possibly saline water zone), (5) evaluation of the anthropogenic effects on hydrology and groundwater flow pattern, and (6) incorporation of recent aquifer test data in the model structure and simulation.*

*If these recommendations were implemented, then the resulting model could be used to (1) simulate wells placed in specific locations on Barton Springs flow path, interference on other wells, and potential drying of some areas of the aquifer, (2) evaluate different sites for recharge enhancement/flood control benefits, benefits of recharge site maintenance practices, and placement of impervious cover, (3) simulate contamination spills and point/nonpoint source pollution at specific sites, such as petroleum pipelines, and (4) simulate prevention/remediation measures to prepare or respond to major spills such as large-capacity interception wells.*

### **INTRODUCTION**

Modeling of flow and water quality in karst aquifers has been a considerably active area of hydrogeological research. In the opinion of some researchers, the intricacies of karst flow pathways, interactions with surface recharge and other aquifers, and variability in recharge water quality with runoff events make development of a deterministic model a waste of time. In addition, the data requirements to calibrate, verify, and use a detailed model of a large karst aquifer may be prohibitive in all but the most critical cases. A contrasting opinion is that the value of such efforts outweighs the investment necessary to complete them and that with more research, data gathering, dye studies, and software development, models will only improve in accuracy and ease of use. Also, the development of and investment in

modeling reveal information about the behavior of karst systems that would otherwise remain unknown, whether the complete utility of the model is realized or not.

Efforts to model the Barton Springs segment of the Edwards Aquifer demonstrate both the difficulties and the advantages of karst aquifer models. Results range from lumped-parameter large-segmentation models of flow and water quality to distributed-parameter finite-element models used predominantly for simulating flow and potentiometric surfaces to match well levels. In order to determine the best course of action for protection of Barton Springs water quality and quantity, it is still an open question whether investment in another predictive modeling framework is warranted.

In order to evaluate this question, a short comparative review of some previous attempts at modeling the Barton Springs segment of the Edwards Aquifer was completed, and recommendations for additional work were developed on the basis of this review. The models evaluated were the U.S. Geological Survey (USGS) model, the Bureau of Economic Geology model, and the University of Texas Center for Research in Water Resources model.

## **USGS FLOW MODEL**

*Model Report:* Slade, Ruiz, and Slagle, 1985, Simulation of the Flow System of Barton Springs and Associated Edwards Aquifer in the Austin Area, Texas: USGS WRI 85-4299.

*Model Type:* Two-dimensional, finite-difference porous media model with 318 active cells.

*Results:* Annual pumpage in 1981 was estimated at 3,800 acre feet per year (ac-ft/yr); only 2,900 ac-ft/yr was used in the simulation because private and irrigation well pumpage was not included.

Future projected pumpage (9,000 ac-ft/yr) was capable of drying about 5 square miles of the southwestern recharge zone during a 3-month simulation.

Simulated recharge enhancement on Onion Creek in addition to projected pumpage of 9,000 ac-ft resulted in a simulated rise in water levels of 50 ft in the southwestern portion and large water-level declines in the southeastern portion of the Barton Springs segment.

### *Limitations:*

The model could not assess the potential impact to Barton Springs. Since Barton Springs was set as a constant head elevation, the model ensured that it stayed at the same level.

The model cannot simulate groundwater flow through caves. No estimates of average groundwater travel times or flow paths were presented to compare with measured tracer travel times and destinations.

Flow loss between Lost Creek and Loop 360 on Barton Creek was attributed to Barton Springs. Now it is known that this flow recharges Cold Spring and other springs on the south bank of the Colorado River.

Only average conditions, not drought conditions, were simulated.

## **UNIVERSITY OF TEXAS CENTER FOR RESEARCH IN WATER RESOURCES FLOW AND WATER QUALITY MODEL**

*Model Report:* Barrett and Charbeneau, 1996, *A Parsimonious Model for Simulation of Flow and Transport in a Karst Aquifer*: CRWR 269.

*Model Type:* Lumped-parameter model with five cells. Each cell varied vertically in hydraulic properties to simulate stratigraphic layering. Each cell represented a major watershed and was compared to a single well with historical records.

*Results:* Intense urbanization will decrease spring flow and increase average nitrogen concentrations in the aquifer.

Several types of modeling approaches were tried to determine how well the system could be simulated. A turbulent-pipe approach simulated spring flow well but far overestimated water levels in the simulated aquifer.

### *Limitations:*

As in the other models referenced, in this model also the flow loss between Lost Creek and Loop 360 on Barton Creek was attributed to Barton Springs. Now it is known that this flow recharges Cold Spring and other springs on the south bank of the Colorado River. The flow loss downstream of Loop 360 was ignored (this may help correct for the previous error to some extent).

The model poorly simulates water levels in the recharge zone and probably other wells other than the one selected well for each cell.

Like the other existing models, it cannot simulate the fast-flowing component of groundwater moving through conduits. No estimates of average groundwater travel times or flow paths were presented to compare with measured tracer travel times and destinations.

The model cannot estimate the effects of pumpage or water quality contamination locally. No estimates of the aquifer-wide effects of pumping were included in the report.

The model poorly matched volume estimates of the aquifer from other sources, suggesting that it may not adequately predict impacts to spring flow from drought and/or pumpage. The model simulated 180,000 ac-ft of groundwater in the Barton Springs segment (at 24 cfs) compared to 275,000 to 306,000 ac-ft (10-50 cfs) estimated by Slade and others (1986), and 300,000 ac-ft (17-35 cfs) estimated by BS/EACD (1997, based on recent geologic maps). The volume of groundwater in the Barton Springs segment above the elevation of Barton Springs was estimated at 45,000 cfs, compared to 204,000 ac-ft by Slade (1986) and 94,000 ac-ft by BS/EACD (1997).

## **BUREAU OF ECONOMIC GEOLOGY FLOW MODEL**

*Model Report:* Scanlon, Mace, Dutton, and Reedy, 2000, *Predictions of Groundwater Levels and Springflow in Response to Future Pumpage and Potential Future Droughts in the Barton Springs Segment of the Edwards Aquifer*. Report prepared for the Lower Colorado River Authority by the Bureau of Economic Geology of The University of Texas at Austin.

*Model Type:* Two-dimensional, finite-difference MODFLOW porous media groundwater flow model with 7,043 active cells. A 10-year drought of the 1950's climatic cycle was simulated for current (1989-1998) and future (2041-2050) pumpage conditions.

*Results:*

After correcting for an estimated 10 cfs bias, the model predicted that under drought conditions of the 1950's, Barton Springs would decline to about 7 cfs with no pumpage, and decline to about 1 cfs under "current" estimated pumping discharges of about 4,000 ac-ft. Under future pumping of about 10,000 ac-ft/yr and drought of the 1950's climatic conditions, Barton Springs will temporarily dry.

The model verified that portions of the southwest area of the Barton Springs segment are sensitive to completely drying.

*Limitations:*

During simulated drought conditions, simulated Barton Springs flow was 10 cfs higher than measured flow. Consequently, 10 cfs was subtracted from the simulated values for the model results.

The 1950's drought of record spring flows and water levels were not used to calibrate the model or to compare with pumpage conditions of that period. Spring flows and water levels from the 1990's were used for this calibration, which were considerably higher than flows of the 1950's.

The average simulated discharge of Cold Springs was 3 cfs. An average flow loss over a 10-year period of record on the Barton Creek section that feeds Cold Springs suggests that Cold Springs and other springs on the south bank of the Colorado River average at least 14 cfs.

When the original hydraulic conductivity (the ease with which groundwater flows through a grid) of the USGS model was used, almost the entire Barton Springs segment went dry (under future pumpage of about 10,000 ac-ft/yr). The selected values of hydraulic conductivity obviously had a major influence on the simulation results. It is unclear how the final values were selected, although it is inferred that cells in the southwest side were given low hydraulic conductivity values based on the steep potentiometric (groundwater level) gradients.

Cells in the southwest section of the model, which completely dried in the USGS model, were removed from the model because they also completely dried in the BEG simulations. Some cells even dried under 1989 simulated pumpage, which was considered steady-state (background) conditions in the BEG model, requiring the lowering of cell bottoms in some areas. Some wells in these areas experienced severe lowering or drying during the 1996 drought, verifying that some of these areas are prone to dewatering.

Historical pumpage estimates by USGS were calculated differently than were estimates by BS/EACD. For undocumented domestic wells, the BEG used TWDB county-wide estimates, then divided by the percentage of area of the study area in the county. The BEG method may not accurately reflect that wells are focused in areas of sufficiently yielding potable water, and such areas are not uniformly distributed throughout the county. The BS/EACD used 1990 census data to estimate domestic pumpage and applied a growth curve. For 1995, BEG estimated a total pumpage of about 3,800 ac-ft, while BS/EACD estimated almost 5,000 ac-ft. According to BS/EACD, pumpage in the year 2000 increased to about 7,000 ac-ft.

The simulated volumes of groundwater within the aquifer and above the level of Barton Springs were not reported, so they cannot be compared to previous estimates.

This model is a porous media model, as are the other models described, and it probably would poorly simulate known tracing results (no transport simulation was described in the report that can be compared to actual groundwater tracer results). It is essentially a porous media (sand) model, which may explain why it inaccurately simulates low-flow conditions (the sand drains slower than conduits).

The model cannot simulate groundwater flow through caves.

## **RECOMMENDATIONS FOR FUTURE MODELS**

The previous models each contribute to better understanding of the Barton Springs segment. All three are porous media models that assume that the aquifer is sand and all tend to ignore its characteristic well-integrated cave conduits. A common problem with each of the previous models is that the work was done before a good understanding of the source area, (in some cases) the hydrogeologic framework, and the measured travel times were known. There are many possible nonunique variations of simulated parameters that can be made to accurately simulate a few wells and a spring within a narrow range of observed conditions. One model may look good if it is not used to simulate tracer movement, another if it represents data from only a few selected wells.

There are some professional differences in opinion about modeling approaches to karst aquifers. Some component of the Edwards Aquifer does behave as a porous medium. Some believe that at some large scale, the Edwards Aquifer can be simulated as porous media. Some believe that by predicting the basic parameters that are most important, a system can be simplified in a way that can accurately match observed data (such as the CRWR model or neural network). Although none of the porous media models constructed were presented with simulated groundwater flow path and travel time to compare with actual flow data, it is unlikely that any porous media model will ever match traced groundwater velocities of 5 miles per day. As more detailed information about the aquifer becomes available, this data should be incorporated in future models. Although these simplified models cannot simulate details of the known system, the models constructed to date may help to develop a basic hypothesis of the importance of expected parameters and can help answer critical questions now, before the aquifer framework is better known.

On the forefront of karst research, universities in Waterloo, Canada, and in Germany are experimenting with “triple porosity” models that simulate the effects of the rock matrix, the fractures, and conduits component of groundwater flow. A detailed model of this type is needed that simulates the known system, including:

- (1) Simulation of the hydrogeological framework. The effects of layer or spring elevations and fault boundaries may play an important role as the aquifer is dewatered.
- (2) Incorporation of complete groundwater tracing data to delineate the source areas under all flow conditions. The major identified preferred flow paths should be incorporated in the model framework. The model should simulate both the source area and travel times, or else the framework may be wrong.
- (3) Incorporation of the best recharge information. Better flow loss data need to be collected and incorporated, rather than assuming the maximum recharge rate is constant or disregarding the effects of upland recharge. The new lower Barton Creek flow station will help measure other Barton Creek discharges.
- (4) An evaluation of inflow from the Trinity Aquifer (and possibly the saline water zone). The TWDB Trinity model required significant simulated loss from the Trinity Aquifer to the Edwards.
- (5) An evaluation of the anthropogenic effects of groundwater diversion along trenches and utility lines, line losses from water, wastewater, and septic systems, and any changes in recharge due to impervious cover in order to determine if they are significant enough to include in a model.

- (6) Incorporation of recent aquifer test data in the model structure and simulation. A detailed model may simulate the local effects of a large pumping system.

The applicability and products of such a model could include:

- (1) Simulation of wells placed in specific locations on Barton Springs flow, interference on other wells, and potential drying of some areas of the aquifer.
- (2) Evaluation of different sites for recharge enhancement/flood control benefits, benefits of recharge site maintenance practices, and evaluation of impervious cover placement on the aquifer.
- (3) Simulation of contamination spills and point/nonpoint source pollution at specific sites, such as petroleum pipelines.
- (4) Simulation of some prevention/remediation measures to prepare for or respond to major spills such as large-capacity interception wells.

There are advantages of a more complicated but “holistic” model that considers the interaction of groundwater flow, recharge, pumpage, spring flow, and constituent transport. These benefits include greater funding opportunities due to more widespread usage, greater opportunity for public support due to immediate relevance in environmental protection, and the creation of a more accurate model for multiple purposes.