REVIEW AND INTERPRETATION OF THE HUECO BOLSON GROUNDWATER MODEL

Prepared For EL PASO WATER UTILITIES

John Bredehoeft, Ph.D. The Hydrodynamics Group
Jon Ford, P.E., C.P.G. Leonard Rice Engineers, Inc.
Bob Harden, P.E. R.W. Harden & Associates, Inc.
Robert Mace, Ph.D., P.G. Texas Water Development Board
James Rumbaugh, III, P.G. Environmental Simulations, Inc.

March 04

EXECUTIVE SUMMARY

In 2003, the U.S. Geological Survey (USGS) released its report ***Simulated Groundwater Flow in the Hueco Bolson, an Alluvial Basin Aquifer system beneath El Paso, Texas*** that documents the groundwater flow model of the Hueco Bolson aquifers (Heywood and Yager, 2003). The El Paso Water Utilities (EPWU) has been using this model to interpret historic and current groundwater flow conditions and flow patterns, including the influence of induced inflow caused by pumping both in El Paso and Juarez. EPWU has also been using the model to simulate a variety of potential groundwater management strategies. Among these strategies are: enhanced aquifer recharge; strategic sites for new wells; and simulation of the existing and new wells associated with a groundwater desalination facility, the design of which is currently underway.

The EPWU charged the Review Team, working both as individuals and as a group, to review the model development, the interpretations of the model results, and the current uses of the model. The Team was also asked to identify limitations of the model and suggest updates and enhancements. While the Review Team assessed the model with respect to its use by EPWU; the Team did not conduct a detailed review of all the model inputs. This report contains our peer review; it is organized to answer specific questions posed to the Team by EPWU.

Introduction

There have been a number of groundwater studies of the Hueco Bolson dating back to a USGS investigation done by Sayre and Livingston (1945). There have been a number of model studies, the first by Leggat and Davis (1966) followed by Meyer (1976), Lee Wilson and Associates (1985, and 1991), Groshen (1994), and now Heywood and Yager (2003). All of the various studies used flow models except for the Groshen investigation that included a flow and transport model. Each of these studies increased the hydrogeologic understanding of the Hueco Bolson. The Review Team concluded that the Heywood/Yager (2003) model study is a reasonably good representation of the hydraulics of the regional groundwater system in the Hueco Bolson. These investigations provide EPWU a good understanding of the regional hydrogeology of the Hueco Bolson.

System Response

Before groundwater development, groundwater that was mostly recharged in the northern parts of the aquifer moved southward through the Hueco Bolson and discharged 1) into the Rio Grande in the vicinity of downtown El Paso and Cuidad Juarez, and 2) through evapotranspiration to riparian vegetation along the river. Initially the Rio Grande was a gaining river through the downtown area. The magnitude of both the groundwater recharge and the discharge to the river was small, estimated to be less than 7,000 ac-ft/yr. One of the principles of groundwater hydrology is that under predevelopment conditions (prior to pumping) recharge is balanced by discharge.

Once groundwater pumping started, mostly in El Paso, the groundwater system responded. A cone of depression was created. Once this cone reached the vicinity of the Rio Grande the original discharge was captured and diverted toward pumping wells. As pumping continued, the discharge from the groundwater system to the river declined, eventually the discharge was stopped and then the flow direction was reversed. At this point, the Rio Grande became a losing stream through the downtown reach. Subsequently portions of the river and canals were lined. Despite these linings, the overall surface water system of the river that includes the various canals and laterals, loses water that recharges the groundwater system beneath the reach. As pumping continued more and more surface water from the river and the associated distribution system flowed into the groundwater system.

The Heywood/Yager (2003) model indicates that in 1996, surface water associated with the Rio Grande recharged the deeper groundwater system at a rate of approximately 50,000 ac-ft/yr. The model analysis indicates that much of the current deeper recharge from the Rio Grande flows toward the groundwater pumping centered in the Juarez area of Mexico.

A number of measures were undertaken by the El Paso Water Utilities (EPWU) to decrease the pumping of groundwater. Among these measures are: 1) conservation that reduced the per capita use of water to 150 gallons per day per individual—a comparatively low amount; and 2) increased reliance on surface water—water treatment facilities were built to enable the use of the surface water. These measures decreased the use of groundwater to well below projections made in the 1970s and 1980s. The conservation measures served to preserve fresh groundwater in the El Paso portion of the Hueco Bolson.

Current Availability of Groundwater

The Hueco Bolson contains both fresh and brackish groundwater. To provide perspective on the available groundwater one can divide that fraction of the total fresh groundwater in storage that is recoverable by the rate at which fresh groundwater is removed from storage. The rate at which freshwater is removed from storage is not given by the groundwater pumping. There is an analogy between groundwater and one's checking account. A certain amount of money flows in each month, and a certain amount flows out to pay bills, etc. How long one remains solvent depends on how fast one is depleting his/her savings. Groundwater in storage is analogous to one's savings. Unfortunately, unlike our bank account all the fresh groundwater in storage cannot be economically recovered. How long the fresh groundwater remains a viable source depends upon two factors: 1) how fast the fresh groundwater in storage is being depleted; and 2) what fraction of the fresh groundwater can be economically recovered.

(One would not divide his/her savings by the amount of spending in order to estimate the length of time he/she remains solvent; such a calculation would totally neglect one's income. The analogy holds true for groundwater. Dividing the total recoverable groundwater storage by the pumping totally neglects the water coming into the aquifer.)

The Heywood/Yager (2003) model is a flow model; it does not distinguish between fresh and brackish groundwater. While the model provides estimates of how much water is being removed from storage in the system, the model does not differentiate whether the water is fresh or brackish. The model has the capability of providing water budgets on specific portions of the model domain. By judiciously selecting parts of the basin to be analyzed that only contain fresh groundwater, we can use the model to make estimates of how much fresh groundwater is being removed from storage. This can be done by adding the change in storage in the El Paso area to the inflow of brackish groundwater from the East (assuming all the flow from the north is fresh groundwater, which not all of it is). Doing this the Heywood/Yager (2003) model indicates that the fresh groundwater currently being removed from storage in the El Paso portion of the Bolson is between 18,000 and 33,000 ac-ft/yr. While the flow modeling yields a single number, the uncertainty in the estimate arises from the lack of distinction in the flow model between fresh and brackish water. One is not sure from the flow model results alone how much fresh groundwater is being replaced by brackish groundwater.

EPWU recently estimated the fresh groundwater in the Texas portion of the Hueco Bolson; their estimate of the fresh groundwater is 9 million ac-ft. Using 1) the current EPWU estimate of freshwater in storage, 2) reducing this estimate to the fraction that can be readily recovered, say 25% to 50% of the total, and 3) then dividing by the rates of depletion of fresh groundwater storage during the 1990s suggests that there could be an adequate fresh groundwater supply for 70 years, or more. However, future demands for groundwater could grow over this period; the actual useful life of the fresh groundwater is highly dependent upon the future rates of use. Ciudad Juarez also pumps groundwater from the Hueco Bolson; it is the only municipal supply for Juarez.

Besides the fresh water portion of the aquifer, there are large quantities of brackish groundwater present in the Hueco Bolson. Recently the EPWU has begun work on a desalination project to utilize this brackish water resource and to protect the fresh groundwater. Future EPWU water development scenarios require predicting the movement of brackish groundwater, which the current Heywood/Yager USGS model cannot do. Therefore developing a water quality transport model of the aquifer should be a high priority. There seems to be several options with regard to developing a transport model: 1) resurrect the Groshen (1994) 4-layer flow and transport model; 2) attach a transport code to the Heywood/Yager model even though it will probably be uncalibrated; or 3) develop a simplified flow and transport model using the Heywood/Yager flow model as the conceptual framework for the flow model. Each of these options has its pros and cons. Option 3, developing a new transport model, will require more time; however, in the end it may be the most satisfying option. In addition to the issues of model architecture, there is a need to develop the supporting data that can be used both to calibrate the model and in interpreting the model results.

Conclusions and Recommendations

The Review Team came to the following conclusions and recommendations:

- We found the Heywood/Yager (2003) model to be a reasonably good representation of the Hueco Bolson regional groundwater system. Several members of the team ran the model; we concluded that the model is reasonably calibrated. The model can be used, at a regional scale, to predict the future hydraulic response of the system. It can be used to compare various scenarios of development at a regional scale.
- With continued reliance on surface water when it is available along with continued conservation there is an adequate supply of fresh groundwater for 70 years, or more.

- Several scenarios of future groundwater management involve predicting the movement of brackish groundwater. The current Heywood/Yager USGS model does not include transport—the model is lacking in this regard. The EPWU needs a transport model capability to assess the movement of salty water that will occur as a consequence of further groundwater pumping from the Hueco Bolson. There seems to be several options with regard to developing a transport model.
- Model studies generate data analysis and new information. Often this information is lost because there are not good methods, or funds to archive the information. We would urge EPWU to try and extract from Heywood/Yager and the USGS all of the information used in both constructing and calibrating the current model. Heywood and Yager wrote a good report that describes in general terms their model study; however, the information that backs up their analyses and conclusions is not in the report.
- Data collection is an important facet of aquifer development; there needs to be continued diligence in collecting and archiving relevant information.
- It is important that EPWU have a good system to assimilate and archive hydrologic information in its broadest context—such systems cost money.

QUESTIONS AND ANSWERS

The following questions were posed to the Review Team by EPWU (Hutchison, 2003). Answers to these questions are as follows:

*1. **Will El Paso run out of fresh groundwater by 2030?***

To provide EPWU a water planning perspective much more analysis is required than the model review that the Review Team was charged to conduct. Much more information including future demands on the aquifer, alternative water sources, development costs, City distribution issues and numerous other items must be integrated into an analysis to provide a firm answer to this question.

Within the Hueco Bolson determining the rate of removal of groundwater from freshwater storage is not an easy analysis to make. Groundwater flow models are created in an effort to investigate the dynamics of groundwater systems. There have been a series of groundwater models of the Hueco Bolson; the most recent of these models is the Heywood/Yager (2003) USGS flow model. Among other things the flow models indicate the amount of groundwater that is removed over time from storage; it is the quantity of groundwater taken from storage that is one of the more relevant quantities to examine. How fast groundwater storage is being depleted provides a measure of how long the aquifer can continue to supply fresh groundwater.

However groundwater flow models do not distinguish between fresh and brackish groundwater. While the model provides estimates of how much water is being removed from storage in the system, the model does not differentiate whether the water is fresh or brackish. The model has the capability of providing water budgets on specific portions of the model domain. By judiciously selecting parts of the basin to be analyzed that only contain fresh groundwater the model can be used to make estimates of how much fresh groundwater is being removed from storage. This can be done by adding the change in storage in the El Paso area to the inflow of brackish groundwater from the East (assuming all the flow from the north is fresh groundwater, which not all of it is). Doing this the Heywood/Yager (2003) model indicates that the fresh groundwater currently being removed from storage in the El Paso portion of the Bolson is between 18,000 and 33,000 ac-ft/yr. While the modeling yields a single number, the uncertainty in the estimate arises from the lack of distinction in the flow model between fresh and brackish water. One is not sure how much fresh groundwater is being replaced by brackish groundwater.

Recent analyses by EPWU indicate that there is a large quantity of fresh groundwater in the Texas part of the Hueco Bolson—approximately 9 million ac-ft. Using 1) the current EPWU estimate of freshwater in storage, 2) reducing this estimate to the fraction that can be readily recovered, say 25% to 50% of the total, and 3) then dividing by the rates of depletion of fresh groundwater storage during the 1990s suggests that there could be 70 years, or more of supply. However, future demands on the aquifer could easily grow over this timeframe. The actual useful life of the freshwater portions of the aquifer could be less. Ciudad Juarez also pumps groundwater from the Hueco Bolson; it is the only municipal supply for Juarez.

2. Have the actions taken by EPWU caused a change in conditions sufficient to make the 2030 date invalid?

In 1979, the Texas Water Development Board projected that El Paso would run out of fresh groundwater by 2031. At that time, EPWU was expected to rely almost exclusively on groundwater from the Hueco Bolson for its water supply. In addition, the projected per capita use of water was high. Since the 1979 study, EPWU pursued other water sources including a wellfield in the Mesilla Bolson and surface water from the Rio Grande. At the same time they encouraged water conservation. These actions greatly reduced El Paso's reliance on groundwater from the Hueco Bolson. The dependence on groundwater has decreased in recent years because of 1) conservation, and 2) the increased use of surface water. Pumping has also caused an increased inflow of water to the Hueco Bolson aquifers from 1) the area to the north, and 2) inflow from the Rio Grande and its associated surface water facilities. The water use activities along with the hydraulic response of the aquifer system extended the life of the fresh groundwater resource well beyond the 2030 date.

3. Is dividing total storage by annual pumping in order to estimate "life of the basin" appropriate?

Estimating the "life of the basin" by dividing total storage by annual pumping does not consider the entire dynamics of the groundwater system. Pumping within the Hueco Bolson has caused increased groundwater inflow from the north, and increased recharge from the Rio Grande and its associated canals.

A more appropriate method to provide a perspective on the potential life of the resource is to divide the total recoverable storage of groundwater by the rate at which groundwater is removed from storage. The rate of groundwater removed from storage is not equal to the pumping. There is an analogy between groundwater and one's checking account. A certain amount of money flows in each month, and a certain amount flows out to pay bills, etc. How long one remains solvent depends on how fast one is depleting his/her savings. Groundwater in storage is analogous to one's savings, recharge and induced inflow are analogous to income, pumping and other discharges are analogous to expenses. How long the fresh groundwater remains a viable source depends upon two factors: 1) how fast the fresh groundwater in storage is being depleted, and 2) what fraction of the fresh groundwater in storage can be economically removed.

(One would not divide his/her savings by the amount of spending in order to estimate the length of time he/she will remain solvent; such a calculation would totally neglect one's income. The analogy holds true for groundwater. Dividing the total fresh groundwater in storage by the pumping totally neglects the water coming into the aquifer and the water coming out of the aquifer other than the pumping by wells.)

Estimating the rate of groundwater storage depletion is typically not a simple analysis. Groundwater flow models are used often today to indicate the rate of storage depletion. The flow models can predict future changes in storage created by future demand scenarios.

There is also a large body of brackish water in the Hueco Bolson. This is an additional groundwater resource that can be used through desalination. It too needs to be factored into the life of the resource because desalination technology has become cost competitive in recent years.

4. Is the recharge to the Hueco Bolson fixed?

The term *'recharge'* is often applied to the natural infiltration of precipitation into the ground water system. *Recharge* generally refers to the virgin rate of recharge prior to development. This type of recharge is usually considered fixed because, over the long term, it is relatively constant.

However, a broader concept of groundwater inflow includes all other sources of water that enter the ground water system. These other sources in the El Paso area include seepage out of the Rio Grande and associated irrigation canals, infiltration of irrigation water applied to agricultural lands, and ground water inflow across the study area's northern boundary that resulted from pumping in Texas and Mexico. These other sources of inflow are not fixed and they vary in response to groundwater levels in the aquifer that are in turn determined by the dynamics of the aquifer system, especially the response of the system to pumping.

The water budget for the Texas part of the Hueco Bolson includes mountain-front recharge, flow from the north, and flow into and out of the Rio Grande. Mountain-front recharge has likely remained nearly the same over time with only small variations due to precipitation. Under predevelopment conditions the recharge was probably less than 10,000 ac-ft/yr. Before the development of groundwater the Rio Grande was a gaining stream in the El Paso/Juarez reach.

Pumping caused dynamic changes in the aquifer system; pumping increased the inflow of water into the groundwater system. Irrigation recharged groundwater. Pumping in both Texas and Mexico increased the groundwater flow from the north. Pumping also induced inflow from the Rio Grande and its associated canals; the Rio Grande is now a losing stream in the El Paso/Juarez reach. The recent modeling suggests that the current recharge to the deeper aquifer from the Rio Grande is approximately 50,000 ac-ft/yr in the El Paso/Juarez reach.

5. Does pumping cause induced recharge?

Pumping causes the water level in an aquifer to decline around a pumping center (either an individual well or a group of wells). This phenomenon is called a cone of depression because the decline is greatest at the center and it decreases radially away from the pumping center. The cone of depression enlarges over time as a function of pumping rate, pumping duration, and aquifer properties (transmissivity and storativity).

When the expanding cone of depression encounters a body of surface water (Rio Grande or unlined irrigation canal) it lowers the water level beneath the body of water. This in turn can cause a downward gradient that induces water to flow from the river or canal into the aquifer. The volume or rate of induced inflow is a function of the size of the cone of depression, the resulting gradient, the permeability of the material between the river/canal bottom and the aquifer, and the width and depth of flow in the river/canal. Usually, the induced inflow rate increases over time as the cone of depression enlarges—assuming of course that there is adequate surface water to supply the recharge. The inflow from surface water can decrease if the flow in the river/canal is insufficient to provide the potential recharge.

As suggested above, pumping in both El Paso and Juarez caused an increase in the groundwater inflow from the north, and caused the Rio Grande and its associated canals to lose water to the underlying aquifers. This induced inflow to the Hueco Bolson aquifers is a major component of the overall groundwater budget of the aquifer system. In the immediate El Paso/Juarez area, induced inflow to the deeper aquifer has increased over time from zero in about 1936 (Meyer, 1976) to more than 50,000 ac-ft/yr today (EPWU recent estimate using the current USGS model).

6. Does pumping capture natural discharge?

Prior to well development, every aquifer system has some level of natural discharge to springs, seep, rivers, or evapotranspiration. One of the principles of groundwater hydrology is that recharge is balanced by discharge under predevelopment conditions. Pumping from wells results in lowering the water table that in turn can intercept some or all of the natural discharge. In the El Paso area, the Hueco Bolson groundwater historically discharged to the Rio Grande. The USGS estimates that the natural discharge prior to 1920 was approximately 6,800 acre-feet per year (Meyer, 1976). As described in our response to Question 5 above, this discharge has been captured by well pumping, so that the Rio Grande in the El Paso/Juarez reach is a losing stream; surface water now flows to the aquifer rather than from the aquifer into the river as it did in the 1920s.

7. Does the USGS model adequately simulate past induced recharge/captured recharge?

Based upon our review of the model, we conclude that it does. However, we believe that because the measured water levels in wells in the vicinity of the Rio Grande are slightly higher than the model predicts; the model may underestimate slightly the current amount of induced inflow. If this trend continues in the future, the model parameters that control the rate of induced inflow may need to be adjusted slightly to improve the model's ability to simulate water levels in wells near the River. An alternative explanation is that an overestimate of pumping in the area was input into the model.

8. Is the USGS model consistent in its treatment of induced recharge with previous investigations and models?

Because of time constraints, we did not have an opportunity to become familiar with or adequately review all previous investigations and models. However, it does seem that at times the magnitude and the significance of induced groundwater inflow from the Rio Grande has been under appreciated. Other studies, for example, the USGS 1976 aquifer model (WRI 75-58), included and recognized the significance of induced inflow. In our view, the current USGS model takes advantage of both the improved modeling technology that has evolved over the years along with more complete data; it provides the best simulation to date of the aquifer system in the Hueco Bolson, including induced inflow.

9. Is the approach to estimate volumes of freshwater appropriate?

The approach of mapping the groundwater quality in each of the 10 layers in the Heywood/Yager (2003) model seems good. There are uncertainties in data because many of the wells are open through multiple model layers. This leaves one dependent upon the electrical conductivity of the native groundwater determined from the wells.

While the method and its application seem reasonable we have insufficient information to judge how good the estimates of the volume of fresh groundwater are. This is probably the best one can do with the existing data. One might try to utilize the electric logs of wells in an effort to estimate the water quality of the groundwater to gain more information. These maps can serve as the initial salinity distribution for a transport model.

Even though there is some uncertainty regarding the estimates of fresh groundwater in storage in Texas, the numbers are large. The numbers are large especially when compared to the rate at which fresh groundwater is being removed from storage. Under almost any reasonable scenario of future groundwater use one is assured a supply of groundwater for a long period—at least 70 years, or more.

10. Are the estimates of volumes of various classes of water reasonable given the approach and limitations?

The volumes of classes of groundwater based upon quality are taken from the maps of water quality interpreted for the 10 layers in the USGS (2003) model. Again this seems like a reasonable approach—perhaps the only reasonable approach with the data available. Using this approach leads to large estimates of freshwater. It should be remembered that only a portion of the amount of the freshwater can be economically recovered—perhaps 50% or so. The recoverable freshwater could be higher in this instance if in addition one is willing to pump a mixture of brackish and fresh groundwater.

11. Is running a base case appropriate?

In general, it is good to run a base case. By comparing model results to the base case, it helps to isolate the scenario being analyzed. This process of comparing results to a base case also facilitates comparison of different potential resource management scenarios to determine which are better than others.

Absolute model predictions are not usually very precise due to uncertainties in model parameters and boundary conditions. While model calibration helps make model predictions more reasonable, we cannot predict future droughts and the details of future water needs. Therefore, use of a base case provides a mechanism to evaluate different management options under a common set of assumptions about future events.

12. Is the choice of "normal" and "drought" conditions appropriate?

In general use of normal and drought conditions allows the modeler to understand the impact of a drought on the response of the aquifer. If the drought modeled is an extreme one compared to past droughts, then the results will be conservative, which can be useful from a future planning perspective. The Review Team does not have enough detailed knowledge of the El Paso area to know whether the normal and drought conditions simulated are appropriate.

Another approach that might be useful is to simulate a 50-year period of record from the past that includes a drought. Since these data on surface water flows have already been collected and used in the USGS model, it would not be difficult to run this type of scenario in combination with the 10-year drought already simulated. This would provide another useful comparison to the base case and other scenarios.

13. Is a no EPWU pumping option (except for drought) viable (in terms of dormant wells, brackish water intrusion, and groundwater level recovery)?

We would prefer to change the word 'viable' to 'desirable.' As long as water can be obtained from other sources, it would be viable to turn off the EPWU wells. Wells would not have to be completely dormant; they could be pumped periodically to make sure that all equipment is operational. The question is one of economics, which is beyond the purview of the Review Team.

However, if we ask the question using 'desirable' instead of 'viable', then the answer may be different. It appears that at normal pumping rates, somewhere between 18,000 and 33,000 ac-ft/yr of fresh groundwater is being lost from storage in the El Paso portion of the aquifer. Thus, there is a very large supply of fresh water that can be obtained that would undoubtedly be less costly than obtaining water from other sources.

Another consideration is that if El Paso stops pumping, Juarez will keep pumping and so the fresh water on the U.S. side of the border will eventually flow into Mexico. While there would be recovery of water levels in the El Paso area, the large cones of depression in Juarez would continue the process of brackish water intrusion even in El Paso. The process of saline water intrusion while it is a slow process will not stop even if El Paso stops pumping.

14. Will brackish water intrusion be reduced by concentrating the pumping as shown?

Concentrating groundwater pumping near the JDF will reduce brackish water intrusion to areas west of the JDF and accelerate brackish water intrusion from the east. As long as concentrations do not become uneconomic in the JDF wells; this approach should be a good method of preserving fresh water supplies south and west of the JDF and reducing the amount of fresh water removed from storage. The JDF pumping should protect fresh groundwater both for the City of El Paso and for Fort Bliss.

There are two potential areas where brackish water may continue to move even with the JDF. Brackish water north of El Paso near the New Mexico border will move to the south in response to pumping in El Paso. This area may not be as large as depicted on the EPWU maps; this is an area where there is a lack of data. The second area is to the southeast of the JDF. It appears that brackish water may move around the southern end of the JDF and impact wells in that area. It is not possible to estimate the brackish water concentrations with only the flow model results. Once a transport model is developed, it will help to answer how fast the brackish water will move and how serious is the threat to fresh groundwater.

15. ***Is it appropriate to use the model to investigate an artificial recharge project in this manner?***

Yes, it is appropriate to use a computer model to investigate long-term changes in regional aquifer conditions resulting from an artificial recharge project. The model will simulate a multitude of options for artificial recharge and the long-term results can be quantified to help in assessing the value of such a program.

Care should be taken in the use of the model to evaluate such a program. The model will only simulate the aquifer response due to recharge water that reaches the water table. Other operational issues associated with a recharge program, such as evaporation, infiltration rates, increased silting over time, water quality distributions, etc. are not simulated by a groundwater flow model but are important hydrologic considerations in assessing the viability of an artificial recharge program.

In considering artificial recharge it should be kept in mind that the Rio Grande and its associated canals are very effective in recharging the aquifer in the El Paso/Juarez reach. The current modeling indicates that the river system is losing more than 50,000 ac-ft/yr to the deeper underlying aquifer through this reach.

16. ***Should EPWU pursue an artificial recharge program to mitigate groundwater storage declines?***

From a strict interpretation of the question, in many cases typically it is not cost-effective to mitigate groundwater storage declines with an artificial recharge program at early stages of an aquifer's life. It is usually more cost-effective to construct additional wells to maintain capacity and incur additional water level declines. Capital costs for additional wells and increased operation costs for additional lift are typically nominal compared to costs associated with an artificial recharge program and the actual net benefit of the recharge program on mitigating water level declines.

It is probably more appropriate to consider an artificial recharge program from a variety of operational perspectives. Only one of these is water level declines. Other important issues can include aspects of the EPWU's distribution system, water quality, the nature and availability of water for recharge, relative costs to implement such a program, and long-term water policy issues. The panel does not have enough information with these issues as they specifically relate to the EPWU's situation to form an opinion on the suitability of application at this time. An elaboration of these issues for the EPWU's consideration is as follows:

One of the most cost-effective applications of artificial recharge involves optimization of a distribution system. This involves distribution pipelines in conjunction with an underlying aquifer that has naturally poor water quality but has reasonable production characteristics. If a utility's distribution system is a constraint during peak demand periods, then the distribution system can be used during off peak periods (typically late fall/winter) to deliver fresh water to the poor quality aquifer area. In such a case, a fresh water zone can be created within the poor water quality aquifer and utilized during a subsequent peak demand period. Development of such a system can realize significant cost savings in the delay and/or elimination of the need to construct additional pipeline capacity to meet peak demands.

Another example of the application of artificial recharge is the use of the aquifer itself as a distribution system. If recharge water is available at one extent of the aquifer and there is a desire to use this water at another edge of the aquifer, then the cost of a pipeline can be saved by using the aquifer as a distribution system. Typically, the aquifer would need to be highly transmissive to be able to transmit the water to the more distant location in reasonable time frames.

Long-term policy and comparative artificial recharge costs can also sometimes be used to justify an artificial recharge program. In some cases, the realization of benefit of an artificial recharge program can be many, many decades or even centuries into the future. Provided the cost to implement the program is minimal compared to the unit water cost paid by customers, than a long-term investment in the supply may be justified. Care must be exercised in an analysis of the aquifer system to ensure unacceptable amounts of the recharged waters are not lost via natural discharge mechanisms or captured by other water users. This type of analysis is most suited for the application of a computer model.

17. Are the simulations appropriate given the model development and limitations?

The model was used to investigate four major scenarios:

- Continue EPWU pumping at present rates;
- Pumping with JDF;
- Saving fresh groundwater by only pumping during droughts, and
- Artificial recharge in the northern part of the El Paso portion of the Hueco Bolson.

The model is useful as a tool to study the hydraulic response of the regional groundwater system to various projections of future operations. Evaluating the scenarios of development, mentioned above, is an appropriate use of the model.

The Heywood/Yager (2003) model only provides the hydraulic response of the aquifer system. The hydraulic response of the aquifer is only one piece of data within a larger set of information that is necessary in making decisions on how to operate and manage the aquifer. Other important factors that go into decisions include detailed analysis of the cost effectiveness of a particular action, as well as social and political considerations that surround that action. The model results are only one part of the bigger picture.

In the case of the Hueco Bolson, there are considerations of how the water quality will change under various scenarios of development. A transport model can be used to predict the changes in groundwater quality associated with development. The present hydraulic model can be used to plot groundwater flow vectors. These give an indication of how poorer quality groundwater will move; however, these are at best, only an indication of how the brackish water might move. The flow model will not provide information on the actual water quality.

18. ***Are there other simulations that we should run?***

- ***i. Wellfield optimization?***
- ***ii. Operations scenarios?***

The regional model is just that "regional" in scope. It was not intended to be used at a small scale. It is inappropriate in both scale and detail to use the present model to attempt wellfield optimization—for example, how much to pump individual wells within a field to minimize pumping levels. Wellfield optimization requires additional data at the scale of the field, well characteristics, and different analyses.

The current model is an appropriate tool to investigate broader regional scale questions—for example, what would be the impact on the regional hydrology of greatly increased pumping near the Rio Grande in the central part of El Paso?

Juarez also pumps from the Hueco Bolson aquifers; groundwater is the only supply for the city. Juarez may wish to increase their pumping in the future; this will have impacts within the Texas portion of the Bolson. The EPWU scenarios used the planned pumping for Juarez of 120,000 ac-ft/yr.

The regional groundwater flow model is a tool to investigate the entire system response to pumping throughout the Hueco Bolson, both in Texas and Mexico.

19. ***Is there a consensus (among the Review Team) regarding the reasonableness of the conclusions?***

There are a number of conclusions stated in the EPWU presentation to us starting with slide 260 continuing through slide 263. Based upon our review we conclude the following:

- Both conservation and the use of surface water have reduced the pumping of groundwater in the El Paso portion of the Hueco Bolson. Pumping brackish groundwater as part of the JDF will further reduce the use of fresh groundwater. A prolonged drought might increase the groundwater pumping significantly for the period of the drought. The scenarios analyzed using the flow model included both continued normal pumping and pumping that included a period of assumed drought.
- The modeling indicates that within the El Paso portion of the Hueco Bolson the current rate of fresh groundwater storage depletion is between 18,000 and 33,000 ac-ft/yr. Using

either the low or high rate of freshwater depletion suggests that there is an adequate groundwater supply for 70 years, or more assuming the current rate of groundwater use.

- The planned JDF will create an elongate drawdown cone that will capture a significant amount of brackish water from the eastern parts of the Hueco Bolson that includes a large part of Fort Bliss. The pumping for the JDF will serve to protect fresh groundwater in the central part of the Bolson within both Fort Bliss and El Paso. The JDF pumping will not eliminate all the brackish water migration; there will be continued brackish water movement both to the north and to the south of the capture zone created by JDF pumping. However, total elimination of brackish water migration is probably not critical for successful management of the fresh groundwater.
- The water recharge facility to the north in El Paso has impacts in raising groundwater levels locally. The decision whether to recharge groundwater in this northern area depends on other factors, especially the economics of the project. The modeling indicates that the surface water canals and distribution system associated with the Rio Grande in the vicinity of the El Paso and Ciudad Juarez are very effective in recharging the Hueco Bolson aquifer. One should weigh the tradeoff between 1) allowing surface recharge as it currently occurs, and 2) artificially recharging in the northern part of El Paso, or other areas of the aquifer.
- The modeling indicates that between 30,000 to 40,000 ac-ft/yr of groundwater moves from the vicinity of the recharge area in Texas associated with the Rio Grande River in the Hueco Bolson to the cone of depression beneath Juarez. None of the groundwater management scenarios under consideration by El Paso change significantly this flow of groundwater to Juarez.

20. ***Is the recommendation of transport model development appropriate?***

Some of the important groundwater management scenarios under consideration by EPWU involve the movement of brackish water. For example, the flow model yields a number either globally, or for a restricted area, of how much groundwater is either being stored or removed from storage. However, the flow model does not tell us how much freshwater is being replaced by brackish water—how much freshwater are we losing at any given time. This leaves uncertainties in the estimate of fresh groundwater removed from storage in the Texas portion of the Bolson—our estimate is 18,000 to 33,000 ac-ft/yr. Even given the uncertainty, this estimate is useful because it is so much smaller that the estimate of the quantity of freshwater in storage.

One way groundwater hydrologists attempt to reduce the uncertainty in this estimate is through the use of a well-calibrated water quality model—a transport model. Just as a groundwater flow model allows for more detailed analysis of all groundwater flow, a transport model can be used to predict the movement of salty water. We understand that the USGS attempted to calibrate a transport model to accompany their recent flow model; they were unsuccessful. There is no question that calibrating a transport modeling is considerably more difficult than calibrating a flow model. However EPWU should develop the capability to make management decisions in which predicting the movement of brackish water is an issue.

In our opinion there are two or three options to develop a transport model: 1) attach a transport model to the USGS/2003 flow model without attempting a detailed calibration—in this case use literature values as input transport parameter values; 2) build a greatly simplified flow and transport model using the USGS 10-layer model as a conceptual model for a the simplified model; 3) Groshen (1994) published a 4-layer flow and transport model for the basin—perhaps it is possible to resurrect the Groshen model. There are pros and cons to each approach.

Using the current USGS flow model with transport could be done quickly, but the model will be uncalibrated. The uncalibrated transport model could be used to compare a base case against other management alternatives. You would want to do various model experiments to test the sensitivity of the results to the transport model parameters. Even though the transport part of the model is uncalibrated the results may not be overly sensitive to the transport model parameters. In this case the transport results may be quite useful.

Creating a simplified model will take more time: 1) in constructing another model, 2) in assembling the data to calibrate it, and 3) in calibration. However, this approach may enhance the model's usability. Which approach to take depends in part how quickly EPWU needs results.

The importance of evaluating the movement of brackish water to EPWU's water development efforts cannot be ignored. Predictions using a transport model are only as good as the data that goes into the model. EPWU needs to evaluate the available water quality data in an effort to determine the uncertainty in transport model results.

John Bredehoeft, *Ph.D., NAE*

Jon Ford, *P.G, C.P.G.*

Robert Harden, *P.E.*

Robert Mace, *Ph.D., P.G..*

James Rumbaugh, III*, P.G.*

REFERENCES

Groschen, G.E., 1994, *Simulation of ground-water flow and the movement of saline water in the Hueco Bolson aquifer, El paso Texas, and adjacent areas:* U.S. Geological Survey Open-File Report 92-171, 87p.

Heywood, C.E. and R.M. Yager, 2003, *Simulated ground-water flow in the Hueco Bolson, an alluvial-basin aquifer system near El Paso, Texas:* U.S. Geological Survey Water-Resources Investigations Report 02-4108, 55p.

Hutchison, W., 2003, *Review of the Hueco Bolson groundwater model:* El Paso Water Utilities.

Lee Wilson and Associates, 1985, *Report 3—Hydrogeology of the Hueco Basin:* Prepared for the Public Services Board, City of El Paso, Texas.

Leggat, E.R. and M.E. Davis, 1966, *Analog model study of the Hueco Bolson near El Paso, Texas:*Texas Water Development Board Report 28, 26p.

Meyer, W.R., 1976, *Digital model for simulated effects of groundwater pumping in the Hueco Bolson, El Paso area, Texas:* U.S. Geological Survey Water-Resources Investigations 58-75, 31p.

Sayre, A.N. and P. Livingston, 1945, *Ground-water resources of the El Paso area, Texas:* U.S. Geological Survey Water-Supply Paper 1423, 84p.