Numerical Modeling Aids Evaluation of Pumping Impacts

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As the western half of the United States faces increasing population, its problems with water shortages are becoming headline news. Population growth, protection of endangered species, recognition of federal and tribal water rights, and aesthetic preferences all put pressure on both the water resources and the water-administration system in the West. Currently, some states, such as Arizona, Colorado, Nebraska, and Texas, apply different legal doctrines to surface water and groundwater. In contrast, states such as Washington, Oregon, Kansas, and New Mexico apply prior appropriation, or the "first in time, first in right" doctrine, to both surface water and groundwater.

Scientific reality shows that the stream-aquifer system is often not two separate entities, but is an interconnected system. As decision-makers face this physical reality, they realize that current policy and political boundaries are not well-suited to the intricacies of nature. Regardless of how the rights are managed, most states have stipulations for wells capturing surface flows – such as the regulations that apply to Colorado's "tributary waters" and Texas's "underflow," or the regulatory agencies require the establishment of hydraulic continuity and no well impairment to surface flows, such as in Washington.

Many state regulatory agencies are turning to numerical models to aid in determining if impairment to a stream by a pumping well exists, if the pumped water in question can be legally considered underflow, or if the cone of depression reaches a "subflow" zone. The following examples illustrate applications of numerical modeling in evaluating potential impacts of groundwater pumping on surface-water resources.

The Hydrologic Institutional Model (Kansas v. Colorado)

The Hydrologic Institutional Model (HI Model) was developed by the State of Kansas to determine the quantity of water depleted from the Arkansas River by groundwater pumping. After the signing of the Arkansas River Compact between Colorado and Kansas in 1948, Colorado experienced extensive well development in the Arkansas River basin. Almost forty years later, Kansas filed a complaint against Colorado alleging that groundwater pumping had depleted the Arkansas River, resulting in depleted flows at the Kansas state line, and that Colorado was in violation of the compact.

The HI Model was designed to simulate both ground and surface-water processes and their effects upon each other. The original and sequential versions of the model extend from Pueblo, Colorado, to the Kansas border and contain 18 river reaches and 89 water rights for 23 canal companies. The model is designed to receive input as both direct data and generated output from other models/analyses. Two model runs are made to calculate groundwater depletion to the river. First, the model is run with actual historical conditions, then a second run simulates all historic conditions except groundwater pumping occurring after the 1948 compact. The difference between the flows at the Kansas state line in the two runs is the depletion due to groundwater pumping (Littleworth, 1994).

The HI Model has undergone multiple revisions by both the Kansas and Colorado expert teams. During trial, several concerns about the model were raised. The main criticisms revolved around calibration technique, model accuracy over short versus long time periods, and lack of model documentation for adequate peer review. Currently, the model is being used by the court to determine groundwater pumping depletion to the Kansas state line.

Colorado's Decision Support Systems

The Colorado Water Conservation Board (CWCB) and the Colorado Department of Water Resources (CDWR) are developing five Decision Support Systems (DSS) for the state of Colorado. The DSSs combine several hydrologic models, a Geographic Information System (GIS), and a Graphical User Interface and are being used to assess interstate compacts and to aid water-resources planning and administration.

The Rio Grande DSS, which has a significant focus on groundwater/surface water interactions, consists of a consumptive use model, a surface water model, a groundwater model, a geographic information system, the Colorado Water Rights Administration Tool (CWRAT), and a water budget. The consumptive use model estimates evapotranspiration, supplemental or primary pumping, and the amount of applied water that is available for recharge in the basin (Wilson, 2002). The surface water model predicts the amount of water available for each user through incorporation of hydrologic principles, legal constraints, and reservoir operation data as it simulates the effect of both aquifer recharge and pumping on a stream (Armbruster, 2002). The groundwater model evaluates groundwater pumping depletions to rivers and streams, potential for the drying up of wet areas due to groundwater pumping in an unconfined aquifer, and the potential for land subsidence due to concentrated aquifer pumping. Together, the DSS components allow large-scale evaluations of pumping effects on streams (Riverside Technology, Inc. and others, 1998).

ADWR's Determination of the "Subflow" Zone

The third case study presents the Arizona Department of Water Resources's (ADWR) determination of the jurisdictional "subflow" zone. Arizona's bifurcated system allows a subflow zone of groundwater to be governed under the prior appropriation doctrine rather than the applied groundwater doctrine of reasonable use. The Arizona Supreme Court's *Gila IV* (2002) decision defined this zone as the saturated floodplain Holocene alluvium. The declaration of subflow recognizes that pumping wells can have a significant impact on stream flow. In addition, the Court determined that any well with a cone of depression intercepting the subflow zone would also be subject to prior appropriation.

In response to the Court's request, ADWR published what it determined to be a suitable methodology for delineating the subflow zone in the San Pedro Watershed in its "Subflow Technical Report, San Pedro River Watershed: In Re the General Adjudication of the Gila River System and Source." ADWR concluded that the entire Holocene alluvium extent should be considered saturated since the thickness of the floodplain Holocene alluvium and the depth to the water table beneath the floodplain vary both spatially and temporally. ADWR plans to determine whether a well's cone of depression intercepts the subflow zone by using the program THWELLS or MODFLOW to map drawdown from the water table. Furthermore, ADWR stipulates two conditions for a well outside the technical subflow zone to be considered pumping subflow. First, the cone of depression must reach the edge of the subflow zone and have drawdown of more than 0.1 foot in that zone. Second, the water table outside the subflow zone must be lower in elevation than the water table inside the subflow zone. If these conditions are met, the well will be deemed to be pumping subflow and subject to appropriation (ADWR, 2002).

Conclusion

Numerical models are being applied in various ways to aid decision-makers in applying water policy. Although there is a movement to use complex models for evaluating water rights, most state water-right permitting agencies determine the need for a model on a case-by-case basis. Many times the agency decides that only a conceptual or simple water budget model is required. The use of models is also limited by the lack of hydrological information; if accurate information is not available to use as input, accurate outcomes will not be predicted.

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