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Multi-Platform Decision Support System

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Abstract
The Edwards aquifer is a karstic aquifer which discharges naturally to springs that support a number of endangered aquatic species. Past and projected rates of development and urbanization are high as are the political stakes in managing regional growth and water resources in a sustainable manner. Key issues involve how can development occur or what type of development is acceptable to maintain critical spring flows, water quality, maximum pumping from the aquifer, and environmental quality with intergenerational equity. We are developing a decision support system (DSS) that links scientific and management models that incorporate community stakeholder input, optimization algorithms, and decision analysis tools. The Texas Water Development Board's groundwater availability model is the basis for the DSS. We scale the distributed parameter model (MODFLOW) into a systems dynamics model (POWERSIM©) with links to socio-economic data and stakeholder preferences. Key decision variables include: well distribution and pumping rates, impervious cover, water and sewage line distributions, and stream setbacks. Key outputs include spring flow and water table declines in drought years. Overcoming uncertainties in the relationships between land use, recharge, and aquifer performance is a significant challenge. Understanding the interconnection between systems and hypothesis testing to bracket expected changes in recharge provide valuable information for groundwater management, which we are testing through stakeholder input, including narrative elicitation. The DSS allows comparison of hypotheses about spatial recharge distributions and communication with decision makers in a timely, policy-relevant format that is compatible with Texas policy for quantifying consensus and available yields. This research is being conducted at The University of Texas at Austin and Sandia National Laboratories.

Introduction

The Barton Springs segment of the Edwards aquifer is located adjacent to the city of Austin in central Texas. A recharge zone of approximately 229.32 km^2 is overlain by a rapidly urbanizing section of the city. Primary hydrostratigraphic units are karstified limestone with discrete sinkholes and fracture-based conduits forming the significant recharge features.

Pumping and drought restrictions are determined by the Barton Springs Edwards Aquifer Conservation District (District) which began a recent initiative to evaluate sustainable yield using a Groundwater Availability Model (GAM) developed with MODFLOW, as a science-based planning tool (District, 2004). The GAM represents the results of an effort to systematically model Texas aquifers with a standardized, technically rigorous process. The resultant models are

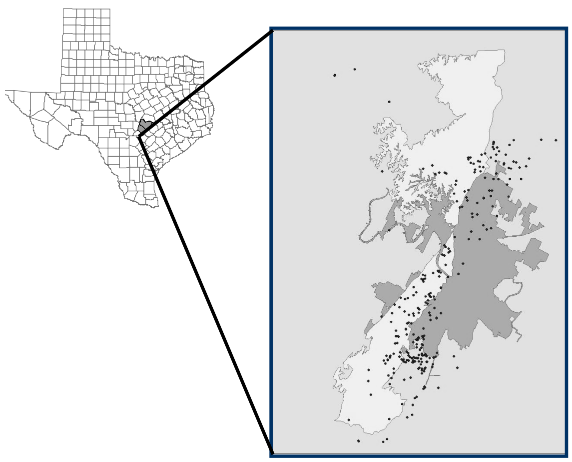

Figure 1 - General location of the Barton Springs segment of the Edwards aquifer and Austin, Texas.

approved by the Texas Water Development Board for use as an allocation and planning tool and identified by the Texas State Legislature as the mechanism for determining the available yield for communities throughout the state. The Barton Springs GAM is a two dimensional MODFLOW model that demonstrates a high sensitivity to recharge, limited response to changes in pumping, and two drains that represent drought sensitive springs. While the model is a porous media model simulating a karst system, the calibration results indicate adequate performance for use in management analyses (Scanlon et. al., 2001).

In addition, an intensive community process was convened between June 2002 and June 2005 to address regional water quality, identifying key influences, concerns, and objectives of stakeholder groups. This process established a critical list of policy actions to alleviate water quality risks in the Barton Springs segment. A sub-group of 10 stakeholders agreed to work with us to collaboratively build the decision support system (DSS), as well as participate in future testing and mediation work.

Model Construction

The DSS establishes two levels of information for model interactions, implementation, and scoping. Implementation level information begins with the spatially explicit model and a description of an aquifer. This is the information that can be used to develop minimum spring flow policies, pumping restrictions, drought definitions, and other policy level decisions that are appropriate for a science-driven management agency. Typically, the considerations within this implementation level are limited to the domain of physical system behavior and can be adequately modeled using MODFLOW. However, the influences of anthropic activities must be recognized and can be best addressed at the scoping level with decision variables that are defined in a social context. Scoping level decisions reflect the preferences and vision that a community, or stakeholder group, may share for a region. The physical system may demonstrate sensitivities to the scoping level elements, but the role of defining social elements is outside the traditional realm of hydrogeologic models. Thus, a systems dynamics (SD) model is used to relate socio-economic influences with the physical system, to define possible community growth scenarios, and to constrain the policies implemented to control the physical system.

Previous studies by Scanlon et al. (2003) have shown that the Barton Springs segment of the Edwards aquifer can be successfully modeled using either equivalent porous media models or lumped parameter models. A lumped parameter model is best suited to address both non-hydrogeologic, or socio-economic issues, while also providing the ability to run real-time model scenarios to aid a negotiation process. At the same time, permitting policies and drought management strategies are best assessed using the spatially explicit GAM model that was approved for planning purposes by state and local agencies through a rigorous technical process.

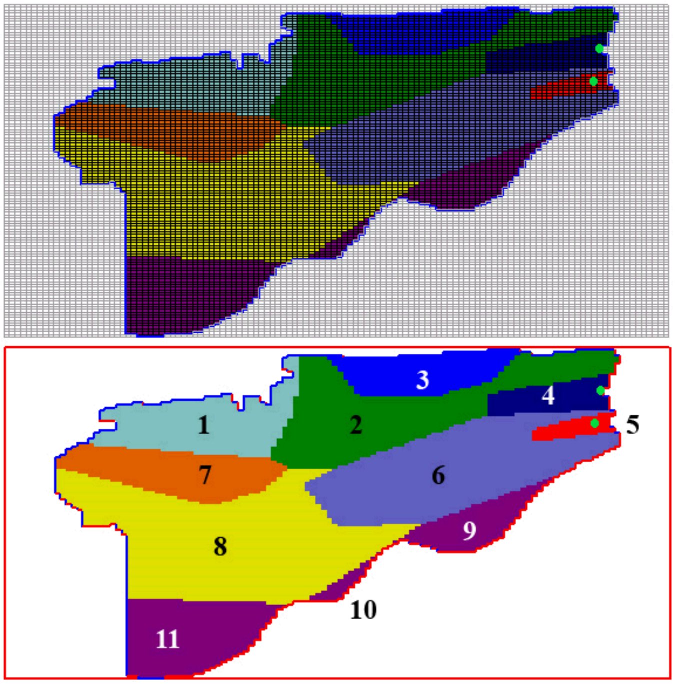

Figure 3 - The top figure shows the discretization of the GAM, which is 120x120 cells. The colored regions show cells with similar conductivity values. The bottom figure illustrates the 11 zones used in the SD model.

Therefore, the original GAM model became the template for designing a lumped-parameter, systems dynamics model.

For this study, we developed a systems dynamics (SD) groundwater model that consists of flow and matrix components, allowing semi-distributed flow modeling within the broader context of socio-economic conditions. The SD model is based on the GAM, but utilizes the 11 irregular shaped conductivity zones of the GAM as finite difference cells (Figure 2). Within the SD model, each zone is represented as a homogeneous, isotropic volume of the aquifer where a 'communication matrix' is used to indicate what zones are capable of communication with each other. Inter-zonal flows, potentiometric surfaces, and drain discharge rates (i.e. flows from the springs) were used to calibrate the SD model to the GAM by adjusting the effective conductivity and storativity of each zone as well as the conductance values for each of the two drains in the model (Barton Springs and Cold Springs). Figure 3 illustrates that the transient discharge rates for Barton Springs in the MODFLOW model are successfully reproduced by the systems dynamics model. Initial inter-model calibration was completed using a steady state version of the GAM allowing for minimal adjustments to fit the transient model flows.

The SD model includes sub-models to calculate recharge rates to the aquifer, relative property values, and a 'sprawl index' as a function of land-use distributions. Development of the SD model is a critical feature in the DSS because it allows for simplified hypothesis testing, real-time feedback, and rapid scenario building.

Stakeholder Interaction

The successful representation of hydrogeologic components within a systems dynamics framework provided the opportunity to link science information with stakeholder values. Building on the previous Regional Water Quality Planning initiative, stakeholder representatives for property rights, governmental agencies, development interests, environmental concerns, and concerned citizens were invited to participate in the conceptual design of the value attributes for the systems dynamics model.

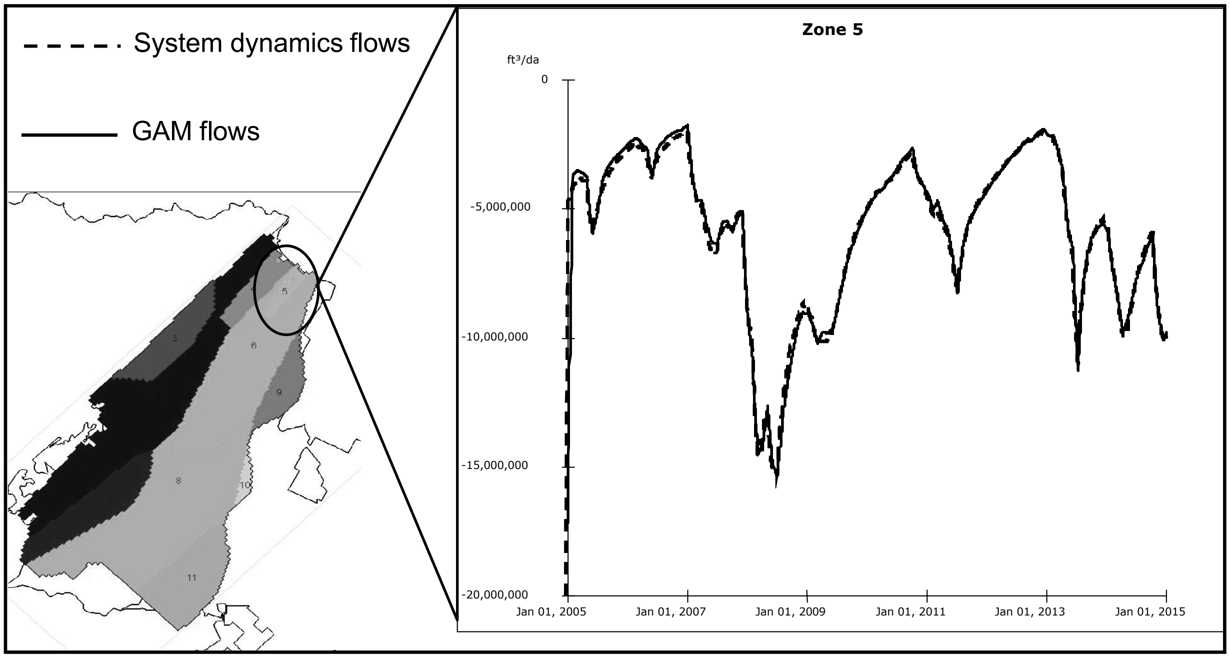

Figure 3 - Barton Springs discharge inter-model calibration graphs.

The stakeholders expressed varying personal perceptions of the aquifer and city growth. While one stakeholder referred to Austin as the "the Barton-centric city of ideas" another emphasized the implications of "unseen threats" and still another focused on the "importance of building connected communities". Each of these stated themes reflect the reasons and motivations for each stakeholder's involvement in the conflict surrounding urban growth and water management in the region. While the reasons are fairly distinct and important from a facilitation perspective, the resulting measurable concerns that emerged from elicitive interviews with all stakeholders are surprisingly similar. In particular, impervious cover levels were consistently ranked as a critical concern that linked both the emotive motivation for involvement with a physical metric that can be readily incorporated into a hydrologic model.

Results

After elicitation and model building sessions with stakeholders, a set of scenario settings and model outputs were identified. These model elements link measurable hydrogeologic parameters to key issues of concern and preferences stated by the stakeholder participants. Linking these aspects of a complex problem aids the consensus building process by engaging stakeholders in meaningful, science-based dialogue.

Specific scenario generation elements include options for setting the land use distribution, or impervious cover levels (% by watershed zone), urban expansion rates (as a function of areal extent), demand projections (pumping rates), and anticipated climate conditions (wet, normal or dry).

Initial model outputs are focused on measurable quantities from the physical system with relevance to specific stakeholder concerns. Computed natural attributes include spring flow performance, water budget parameters, saturated thickness, change in recharge, drought trigger frequency, the effect of conservation measures, and infrastructure leakage rates.

Model runs indicate that water quantity would increase with impervious cover due to the recharge dynamics from urban infrastructure. However, these results do not yet address another principle element of stakeholder concerns; degrading water quality, which will be addressed in future studies.

The integrated model was developed with the intent to use it in support of live, rapid dispute prevention sessions. Model sessions can be used for either community consensus or setting policy strategies within the feasible ranges of social preference sets. The DSS system may be used as a platform to test a series of multi-disciplinary hypotheses and method comparisons, within areas of inquiry ranging from hydrogeology, economics, operational research, decision analysis, behavioral psychology, and public affairs.

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