Drought Triggers in the Barton Springs Segment of the Edwards Aquifer

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Introduction

The Barton Springs segment of the Edwards Aquifer provides drinking water to than 50,000 people, provides water for irrigation purposes, and serves as a habitat for many species, including the endangered Barton Springs salamander.[1],[2] Meeting current and future needs will prove more difficult with a limited amount of groundwater available due to climatic stressors and increased demand on the Barton Springs Aquifer. The combination of prolonged drought and substantial pumping can have significant impacts on aquifer spring flow and water levels. To provide better management of the limited and often stressed supplies in the aquifer, the Barton Springs/Edwards Aquifer Conservation District implements a drought management program using water levels and discharge from different locations. These measurements trigger different stages of drought, after which, mandatory and voluntary water conservation policies kick in. Droughts have only been triggered by two of these five locations, Barton Springs and the Lovelady monitoring well. Implementation of drought trigger methods has been confusing to the public and the fairness of district wide pumping restrictions on localized drought has been questioned. The question now is if there are any alternative methods of drought determination and what alternative pumping restrictions could be once drought is triggered.

Objective

The objective of this project is to reexamine the conditions of drought indicators in the Barton Springs segment of the Edwards aquifer using flow simulations during standard conditions and drought conditions, comparing spring flow, water level, and total storage to pumping over the area of the aquifer. The end goal is to create a visual tool displaying these effects that can be used in determining the best methods determining drought triggers and restricting pumping during different drought stages.

Background

Barton Springs segment of the Edwards Aquifer

The Barton Springs Aquifer is a karst aquifer that is part of the larger Edwards Aquifer system. It is located in Travis and Hays County, bounded in the north by the Colorado River and in the south by a groundwater divide in the City of Kyle.[3] The map below shows the extent of the

[1] Barton Springs/Edwards Aquifer Conservation District. *About the Aquifer.* Website <www.bseacd.org/aquifer-science/about-the-aquifers/>

[2] Barton Springs/Edwards Aquifer Conservation District. 2004. “Evaluation of Sustainable Yield of the Barton Springs Segment of the Edwards Aquifer, Hays and Travis Counties, Central Texas.” Report. Available online <www.bseacd.org/uploads/AquiferScience/HR_SustYield_BSEACD_report_2004_web.pdf>

[3] *Ibid.*

Barton Springs segment along with the contribution zone. Including the contributing, recharge, and artesian zones, the area of the system is 916 km^2.[4]

Figure 1 Barton Springs segment of the Edwards Aquifer. The artesian and recharge zones are part of the aquifer. The contributing zone is the watershed containing streams that contribute to the aquifer when they pass the recharge zone.

The aquifer discharges to many springs, but Barton Springs is the primary point of discharge, averaging 53 cubic feet per second (cfs). The lowest recorded discharge was 11 cfs during the 1950s. In September 2011, a period of extreme drought, Barton Springs experienced daily fluctuations up to 30% of flow as spring flow approached 20 cfs.[5] During average flow conditions, pumping from is about 10-12 cfs[6]. The drought in 2011 was the most intense Texas drought in recorded history. Flow during this time did not reach or dip below the value recorded in the 1950s likely due to the mandate to manage and conserve groundwater resources. The pumping restrictions put in place given certain levels of discharge or water levels attempt to provide a solution to this low supply and consistent demand.

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[4] Budge, T., and Sharp, J.M., Jr. (2008). "Delineating contributing areas in two Texas karst aquifers using NEXRAD rainfall estimates." Water Down Under: 2008.
[5] Hunt, B.B., Smith, B.A., and Hauwert, N. (2012). "Real and Apparent Daily Springflow Fluctuations during Drought Conditions in a Karst Aquifer, Barton Springs Segment of the Edwards Aquifer, Central Texas." Gulf Coast Association of Geological Societies Transactions: 62, pp189-204.
[6] Scanlon, et al. (2001) "Groundwater availability of the Barton Springs segment of the Edwards Aquifer, Texas: Numerical simulations through 2050." Bureau of Economic Geology, University of Texas at Austin, UTA99-0.

The Barton Springs Aquifer experiences rapid fluctuations in spring flow and water levels in response to changes in pumping and precipitation because it is a limestone full of faults, fractures, and conduits that allow water to easily flow through the system. This characteristic leaves a large amount of scientific uncertainty in the aquifer conditions.

Societal Impact

With increasing population and increasing urbanization in central Texas, the amount of water demanded increases. Increasing population will require more water, and, depending on whether this water comes from the Barton Springs Aquifer, will change the way the aquifer is managed. The contributing zone in Figure 1 becomes important when thinking about development; the nature of development in the contributing zone, whether done in a sustainable way or not, will have an impact on recharge into the aquifer.

Multiple stakeholders have an interest in how the aquifer is managed, including urban developers, environmentalists, and other water users (private well owners, irrigators, farmers, etc.). The question is whether or not this uncertainty is important when making management decisions in light of multiple users and drought conditions, and how all of these factors can be incorporated to communicate the story of the Barton Springs Aquifer that can be used to effectively manage central Texas's groundwater resources.

Data

The dataset used in this project is based on a Groundwater Availability Model developed for the Barton Springs segment of the Edwards Aquifer as reported by Scanlon, et al., 2001. The model was based on a MODFLOW96 model calibrating using observed data from a 10-year period (1988-1998). The dataset includes 10,256 simulation runs and are used as a preliminary dataset for experimental analysis. There are other sets of simulations that alter variables within the model, but this initial set of original simulations is used as a baseline scenario against which additional simulations can be compared in the future.

The model area in relation to the aquifer and its contributing zone are shown in Figure 2. The model divides the Barton Springs Aquifer into eleven zones based on conductivity, shown in Figure 3. The model zones overlap the recharge zone and artesian zone. Activities in zone 8 has the potential to have interesting impacts on the two indicators that have triggered droughts in the past because it spans about equally over the recharge zone and artesian zone; these two indicators are shown on Figure 3, the Lovelady monitoring well and Barton Springs.

Figure 2 Extent of MODFLOW model active cells in the Barton Springs segment of the Edwards Aquifer. The model contains 7036 active cells at 500 feet by 1000 feet per cell.

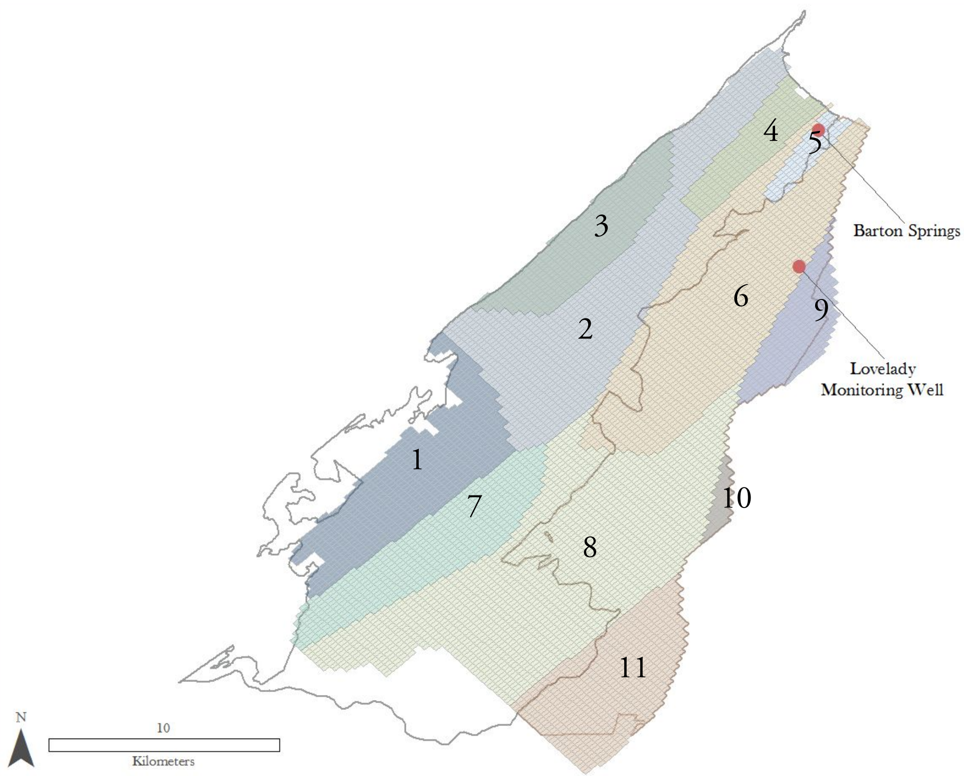

Figure 3 Extent of MODFLOW model divided into eleven zones based on hydraulic conductivity. Barton Springs and the Lovelady monitoring well are located in two different zones out of the eleven.

Model parameters include recharge averaged over all cells at monthly intervals and monthly total volume of recharge. Attributes of the model include monthly spring flow rates for Barton Springs, minimum spring flow for Barton Springs in the modeled period, total pumping rate for each period, and average head by model zone. Management variables were formulated to allow variation in pumping rate by zone and rate at the beginning of each model run.

A preliminary uncertainty analysis was performed on the data to evaluate the sensitivity of particular variables as a result of changes in management variables. Several methods of uncertainty analysis are still underway, but this project uses the preliminary analysis with a statistical distribution of all variables cross-correlated with the median value to determine the relative influence on simulation performance by each variable.

The Texas Water Development Board updates these models every so often. The latest models were obtained that include a steady-state model, transient flow model, drought condition model based on the 1950s drought, and several other conditional droughts. These were not used in this project due to software issues explained in the next section.

Methods

ArcHydro Groundwater was developed to specifically examine groundwater data. The MODFLOW Analyst was developed to analyze MODFLOW model simulations and visualize the results. It is the ideal tool to tell the story of aquifers, visualizing groundwater flow, its interaction with surface water flow, and response to stressors like pumping, urban development, and climatic conditions. The ArcHydro Groundwater data model can also represent aquifer characteristics in 3D, which can be especially beneficial in this project to communicate the Barton Springs aquifer in a scientific and policy-making setting.

Unfortunately, there is a bug in the process used to import MODFLOW models that is being worked out at the moment. This posed some serious limitations in this project analysis, so the following alternative steps were used on the dataset to display pumping in each zone and spring flow from Barton Springs in a given simulation with the preliminary uncertainty analysis and are still in development.

Combining Data

MODFLOW Data Characteristics (Fields of interest)

- Shapefile of MODFLOW model extent – active cells
  - Row & Column (identifying individual cells of the model)
- ActiveCell Spreadsheet
  - Row & Column (identifying individual cells of the model)
  - Conductivity Zone (1-11)
  - Land Elevation
  - Bottom Elevation

Results from uncertainty data analysis

- Pumping rate multipliers by zone
- Median monthly spring flow – Barton Springs

Barton Springs location from well and gage shapefile (State Well ID#: 5842920)

To display the individual conductivity zones, row and column were concatenated within the GIS attribute table and also within the ActiveCell spreadsheet. These two were joined based on a new ROWCOL field (Figure 4) and displayed by conductivity zone, the results of which are displayed in Figure 3.

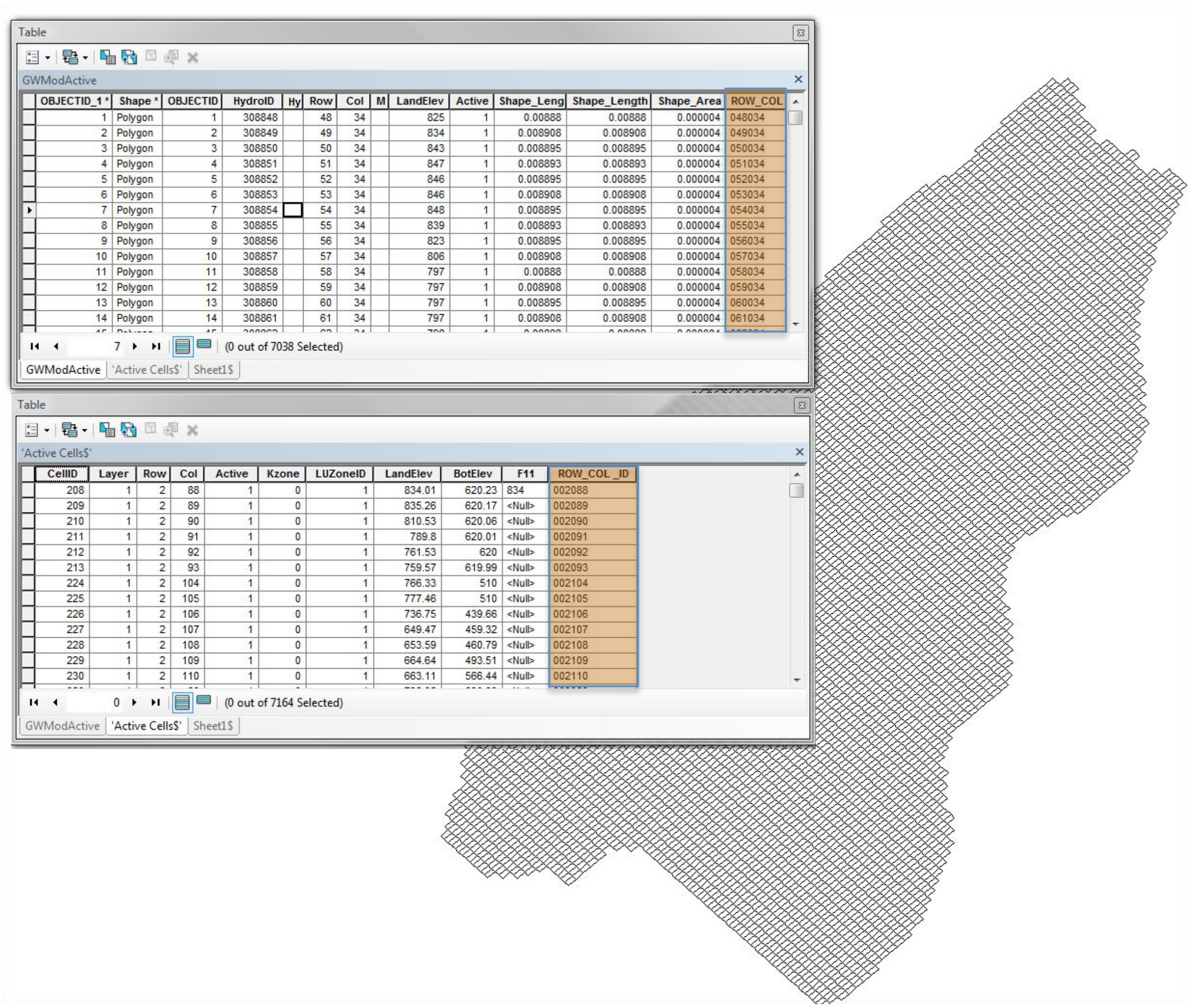

Figure 4 Join to display conductivity zones identified in MODFLOW model.

The polygon zone feature was then converted to raster to more easily display average pumping over each zone.

A portion of the results from the uncertainty analysis are displayed in Figure 5.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	top 80	alias	hashcode	VOLUME V	MIN DRAI	Zone1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Total Pum	A1 Median Monthly
2	0	954	179e5fc02	2.18E+09	18.01	1.9	1.8	1.9	1.9	1.9	1.9	1.9	0.6	1.9	2	1.9	19.6	57.32
3	134	729	11cd530d	2.2E+09	18	1	1	1	1	1	1	1	1	1	1	1	11	58.62
4	162	1947	31b03c50f	2.2E+09	18	1.9	1.5	2	1.9	2	1.1	1.8	0.6	1.8	1.9	1.9	18.4	57.94
5	350	1141	1c3d8fbe	2.2E+09	18	2	1.5	1.9	2	1.9	2	1.9	0.7	2	2	1.9	19.8	57.16
6	615	8244	ccd6ff3b0	2.2E+09	18	1.9	1.5	2	2	2	1.9	2	1.7	1.9	1.9	1.9	20.7	54.99
7	959	9052	e1b3e562	2.2E+09	18	2	1.5	1.9	2	2	1.6	1.8	0.8	2	2	1.5	19.1	57.66
8	1089	2112	3647eef03	2.2E+09	18	2	1.5	1.9	2	2	1.9	2	0.6	1.9	2	1.8	19.6	57.48
9	1106	9467	ebd8ff645	2.2E+09	18	1.9	1.9	2	1.9	1.9	2	2	1.3	2	1.9	1.9	20.7	55.89
10	1238	9208	e5383843	2.2E+09	18	1.9	1.5	2	2	1.3	2	1.9	0.7	2	1.9	1.9	19.1	57.17
11	1482	5179	81c6ba1ac	2.2E+09	18.01	2	1.9	1.9	2	1.9	1.4	2	0.6	2	2	1.9	19.6	57.66
12	1667	10127	fcda8e04f	2.2E+09	18	1.9	1.9	2	2	2	2	1.9	0.9	1.9	1.9	1.8	20.2	56.77
13	1755	6040	966a4a1e	2.2E+09	18.01	2	1.9	1.9	2	1.3	2	2	0.7	1.9	2	1.9	19.6	57.07
14	1814	1782	2cfe65c21	2.2E+09	18.01	1.9	1.8	1.9	2	1.9	1.9	2	0.6	1.9	0.9	2	18.8	57.23
15	1874	1910	30aa8947c	2.19E+09	18.01	2	1.7	1.9	1.9	2	2	2	0.7	1.9	2	1.9	20	57.11
16	2075	9158	e41fac3b8	2.19E+09	18.01	2	1.5	2	1.3	1.9	1.9	2	0.7	2	2	1.9	19.2	57.2

Figure 5 Excel spreadsheet of uncertainty analysis information. Each row contains information for one simulation; there are more than 10,000 total runs in the spreadsheet.

The values for each zone are multipliers of pumping rates set in the MODFLOW model. Given the time limitations of completing this project, only 40 simulations were imported into GIS. The table above was joined to the raster of conductivity zones and displayed by pumping rate multiplier (this means increased or decreased pumping) for each zone. Figure 6 displays the results; green represents decreased pumping and red represents increased pumping.

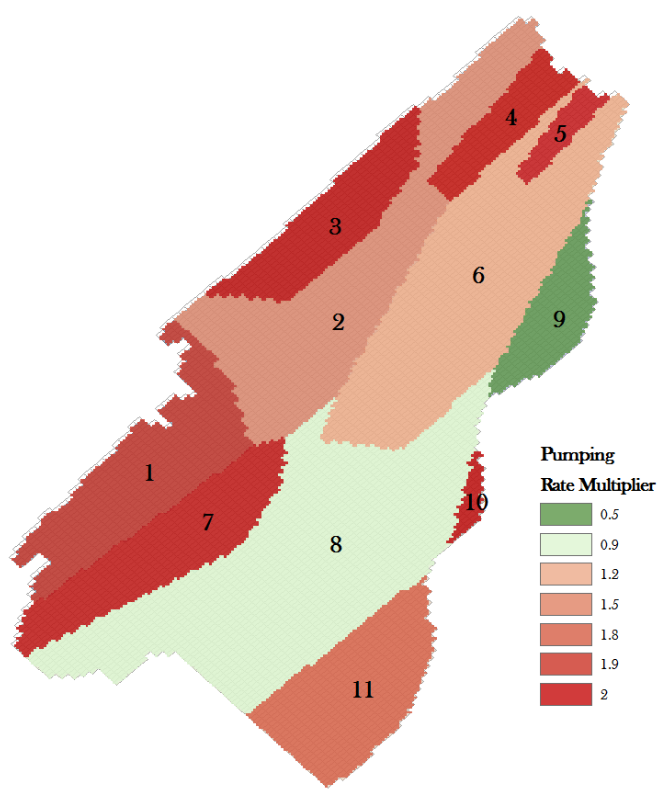

Figure 6 MODFLOW zones displayed by increased or decreased pumping for *one* simulation run.

The idea was then to add on the discharge from Barton Springs by joining median monthly spring flow from Figure 5 to the well information and displaying the symbol proportional to a run with no modifications to pumping in any of the zones. This proved unsuccessful.

Certainly there is a way to add or manipulate all of the data runs such that they could be viewed as a time series, but doing this was outside the time limits of this project.

Results and Discussion

The results of this project have limited current utility because they only show one variable of one MODFLOW model run. Ideally, two displayed variables would have been the result of the above efforts. A number showing spring flow at the point of display would have been sufficient in showing this information, though does not fulfill the objective of creating visual connections between pumping and spring flow.

With further time, additional variables of total aquifer storage and average water level in each zone could have been displayed, incorporating multiple variables into one image to get an overall sense of how pumping changes impact each. Spatially viewing these relationships would be useful in estimating vulnerability and risk to particular areas during drought conditions. It would also be interesting to examine the spatial relationships of water demand, water volume demanded, urban density, land use, and projected development, particularly when thinking of making a tool to be used in groundwater planning.

The question proposed in this project is whether or not the current methods of drought determination are the most effective and the most efficient given varied stakeholder interest and highly variable climatic conditions. Using the results of uncertainty analysis and analyzing the results visually could potentially reveal that there are other options that should be considered in determining drought and restricting pumping in localized areas.

The best method to view and present this information, incorporating all desired variables, is undoubtedly with ArcHydro Groundwater MODFLOW analyst. A full analysis with this method is intended in the future when the issues with the software are worked out.

References

Budge, T., and Sharp, J.M., Jr. (2008). "Delineating contributing areas in two Texas karst aquifers using NEXRAD rainfall estimates." Water Down Under: 2008.

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