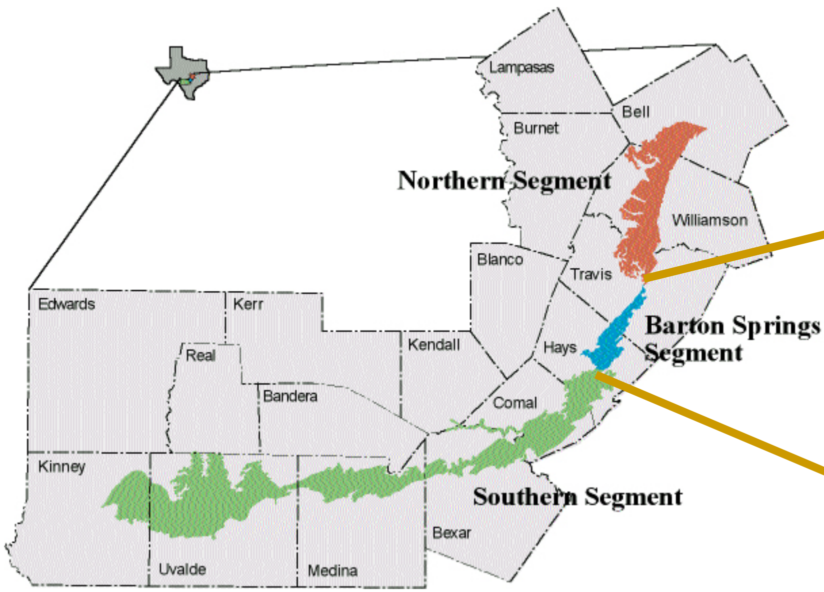
Updating the Barton Springs Groundwater Availability Model

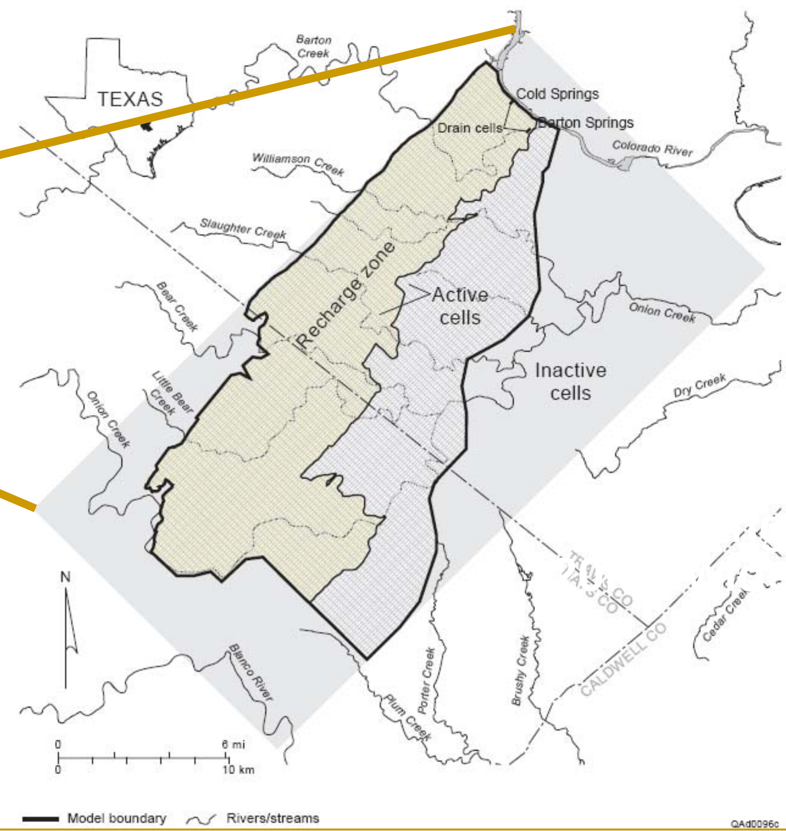
Jim Winterle, Scott Painter, Ron Green
Geosciences and Engineering Division
Southwest Research Institute®

Outline

- Overview of Barton Springs segment GAM update project
- MODFLOW-DCM
- Project Accomplishments
  - Extend model domain
  - Convert to MODFLOW-DCM
  - Steady-state calibration
  - Transient model calibration using recharge as a function of averaged monthly precipitation data
- GAM Requirements
- Conclusions

Barton Springs Segment
Edwards Aquifer





(Scanlon et al., 2003; BSEACD,2003)

Scanlon et al., 2001, *Groundwater availability of the Barton Springs segment of the Edwards Aquifer, Texas: Numerical simulations through 2050.*

Barton Springs Segment GAM Update Motivation

- Initial Barton Springs Segment GAM (Scanlon et al., 2001) calibrated to normal spring flow conditions
- BSEACD developed alternative GAM, calibrated to low spring flow conditions
- Matching both normal and low spring flow using a single standard MODFLOW model was not achieved
- Instigated interest in exploring innovative karst modeling technology

GAM Update Project Timeline

- TWDB issued RFQ in summer of 2007
- "Research grants for improvements and updates to existing groundwater availability models with matching fund contributions"
- SwRI was approached by BSEACD to respond to the RFQ
- SwRI teamed with BSEACD to submit a proposal to TWDB in September 2007
- Contract finalized on March 31, 2008
- Terms: 12 months, jointly funded by TWDB & BSEACD

GAM Update Project Objectives

- Develop the conceptual model
- Define the model architecture
- Calibrate the model
- Conduct sensitivity analysis

GAM Update Project Tasks

- Task 1: Develop an Improved and Updated Barton Springs GAM Model using MODFLOW-DCM package
- Task 2: Fulfill the TWDB GAM Requirements
- Task 3. Identify the Transient Calibration Period
- Task 4. Prepare Documentation
- Task 5. Conduct an Outreach and Technical Transfer Program
- Task 6. Prepare Status Reports and Final Report

GAM Update Project Deliverables

Deliverable	**Date**
Kickoff Meeting	April 25, 2008
1st Stakeholders Advisory Forum	May 28, 2008
2nd Stakeholders Advisory Forum	January 8, 2008
Final Project Report Presentation	January 22, 2009
Draft Final Report	January 30, 2009
Final Report	March 31, 2009

DCM input parameters

- Conduit conductivity
  - Effective grid-scale property
  - Implicitly incorporates geometrical properties
  - Input for laminar conditions
- Critical gradient for onset of turbulence
- Conduit storage parameters
- Conduit-matrix exchange term
  - Depends on matrix conductivity and conduit surface area
  - Implicitly incorporates geometrical properties
  - Input for filled conduit – calculated for partially filled conduit

Project Accomplishments:

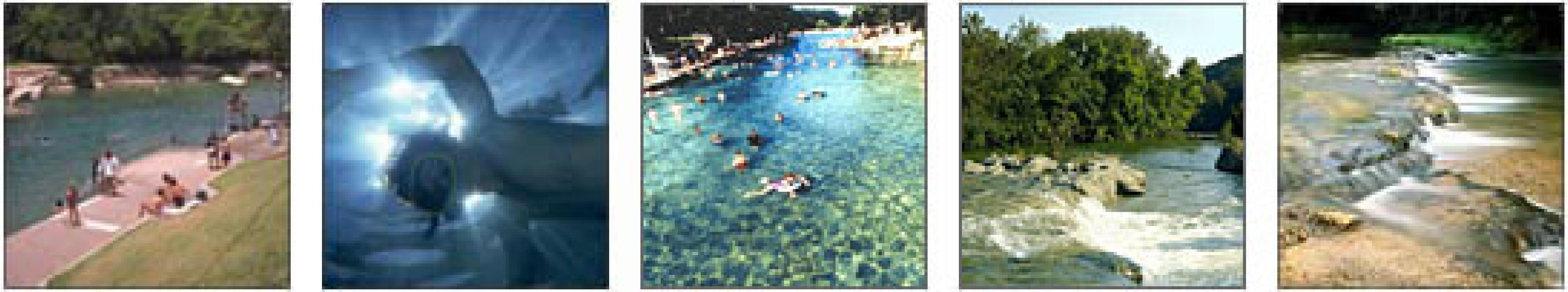
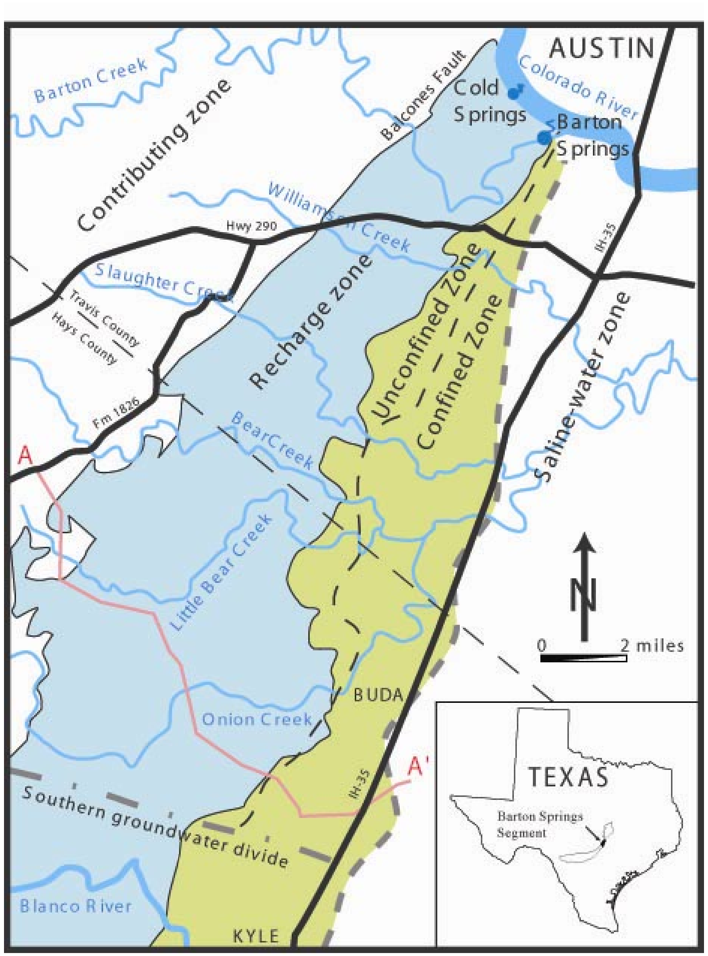


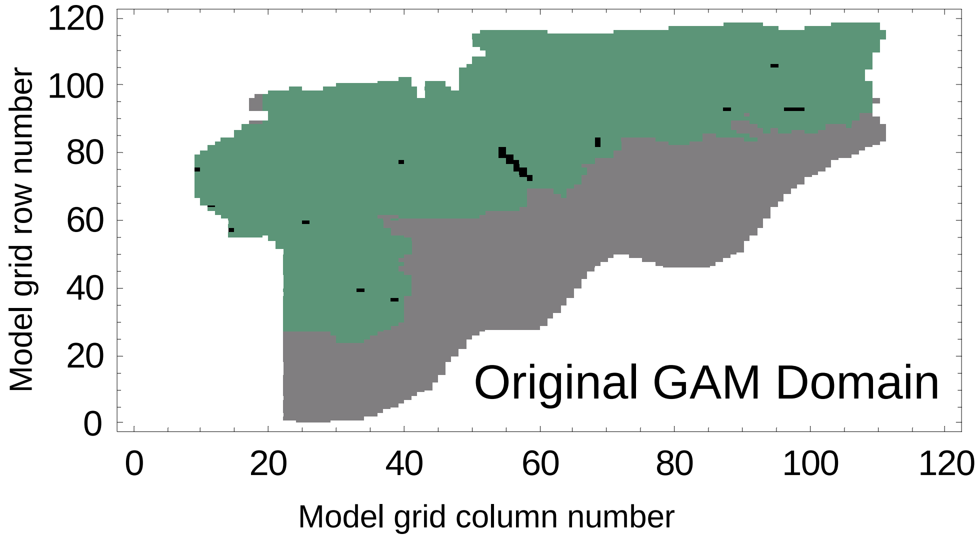
Image Source
http://www.ci.austin.tx.us/parks/bartonsprings.htm

Model for Barton Springs segment of Edwards Aquifer

- Started with existing GAM
- Extended Boundary Domain
- Added conduit layer
  - Conduit locations provided by BSEACD (dye tracing, sediment in wells, troughs)
  - Conduit recharge concentrated in small number of known features
  - Conduit elevations coincide with top of Kirshberg member
  - Conduits are 20 feet thick
- Recalibrated



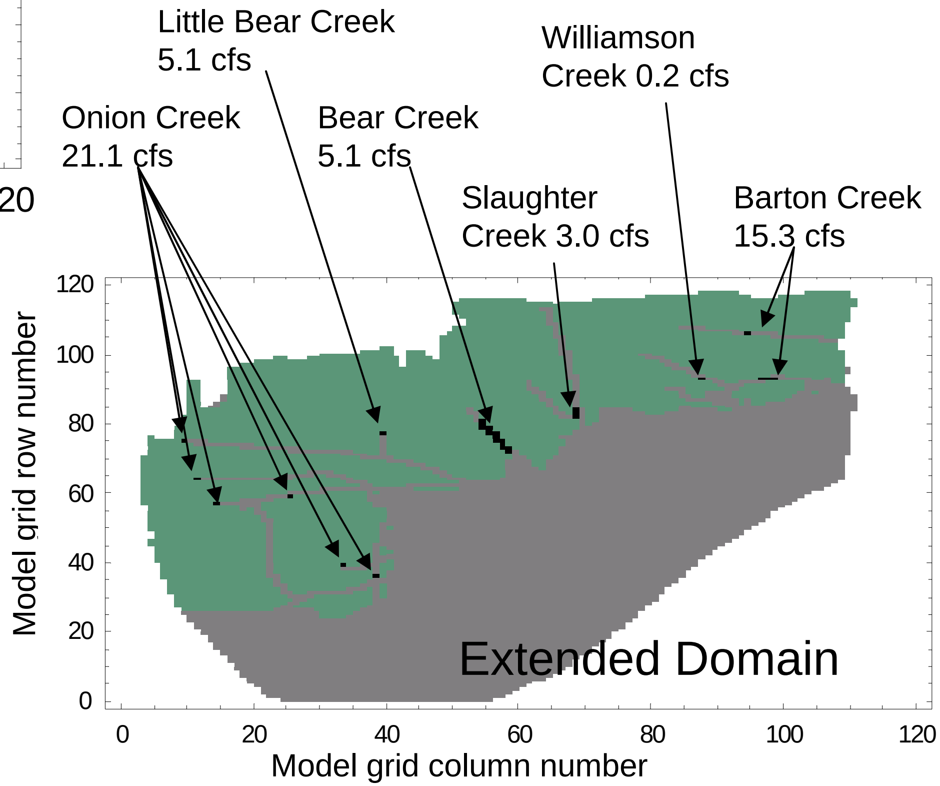
Extended Model Domain and Recharge



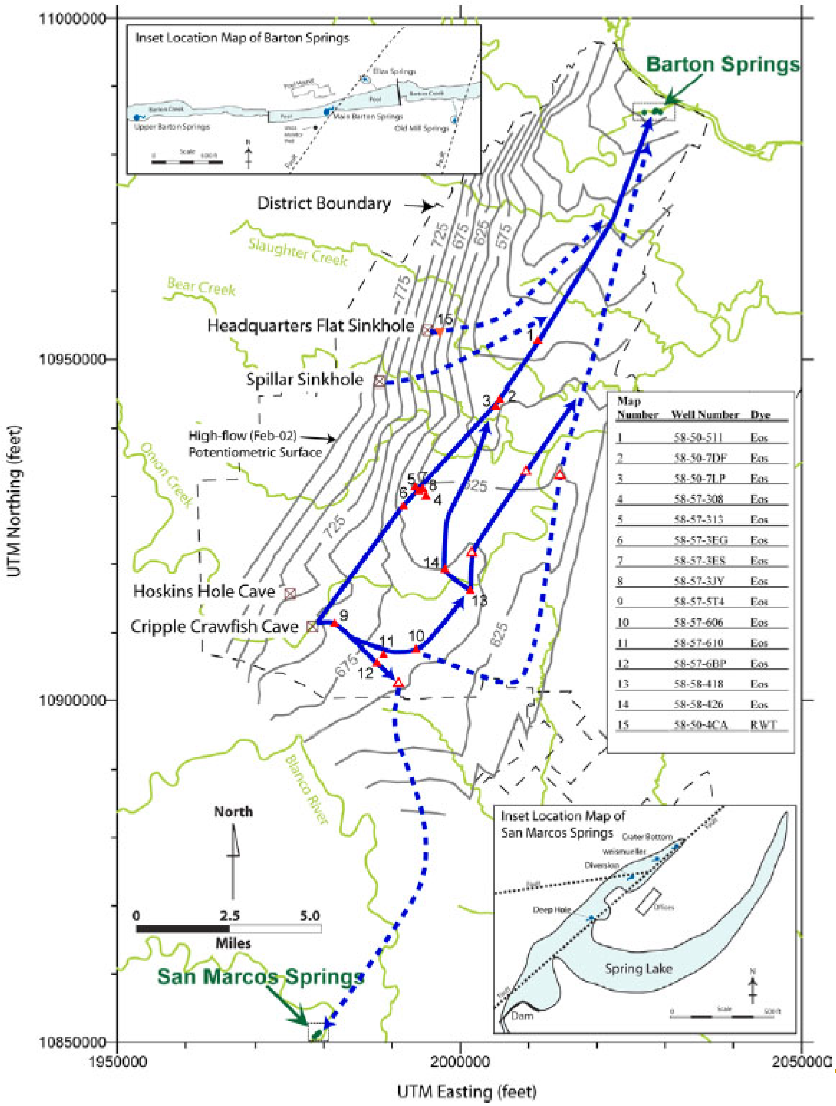
Total Recharge = 61 cfs

Green = Distributed Recharge Zone (15%)

Black = Focused Recharge Locations (85%)



Conduits Based on Dye Trace Map

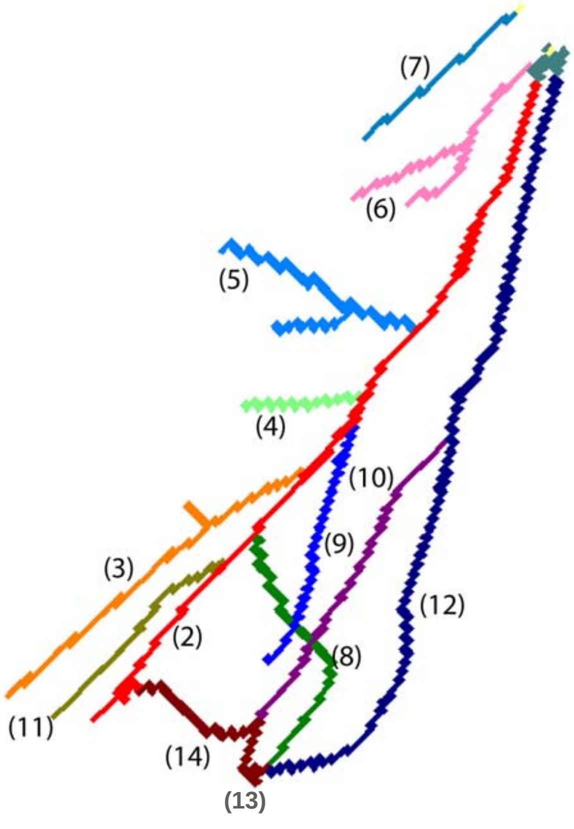


Map Number	Well Number	Dye
1	58-50-511	Eos
2	58-50-7DF	Eos
3	58-50-7LP	Eos
4	58-57-308	Eos
5	58-57-313	Eos
6	58-57-3EG	Eos
7	58-57-3ES	Eos
8	58-57-3JY	Eos
0	58-57-5T4	Eos
10	58-57-606	Eos
11	58-57-610	Eos
12	58-57-6BP	Eos
13	58-58-418	Eos
14	58-58-426	Eos
15	58-50-4CA	RWT

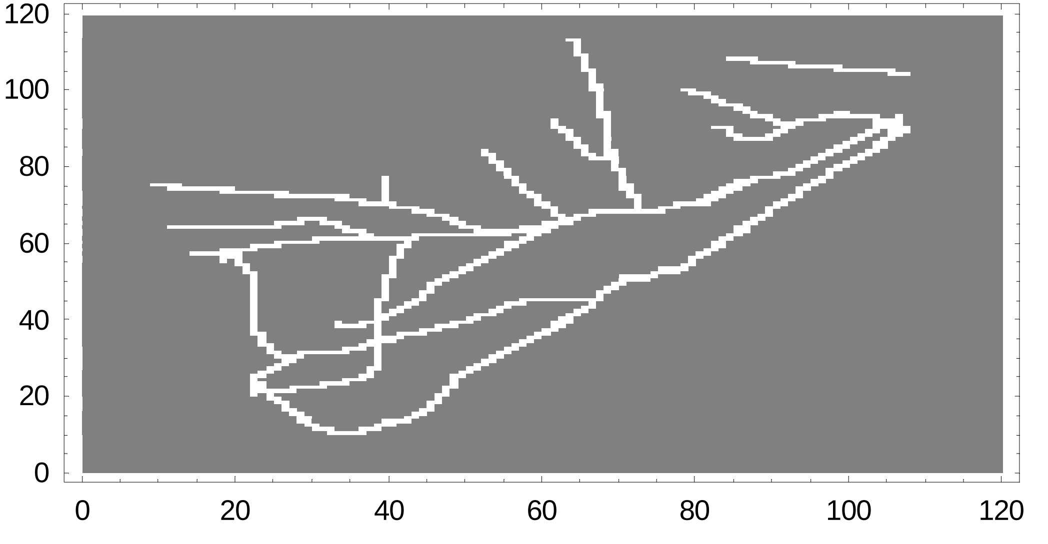
Source: http://www.ci.austin.tx.us/watershed/dyetrace.htm

Source: Hauwert et al. (2001)

Conduit Network in MODFLOW-DCM

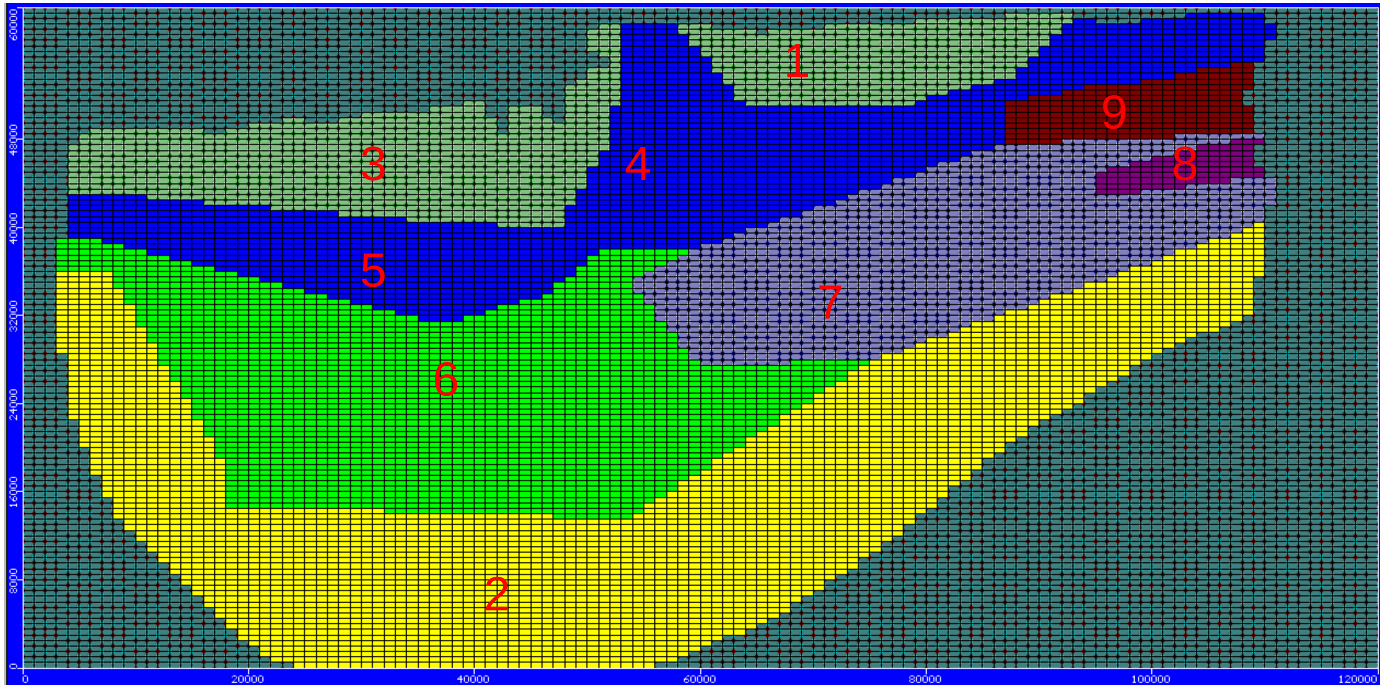


- 13 distinct conduit zones specified
- - Transmissivity adjusted during steady-state calibration



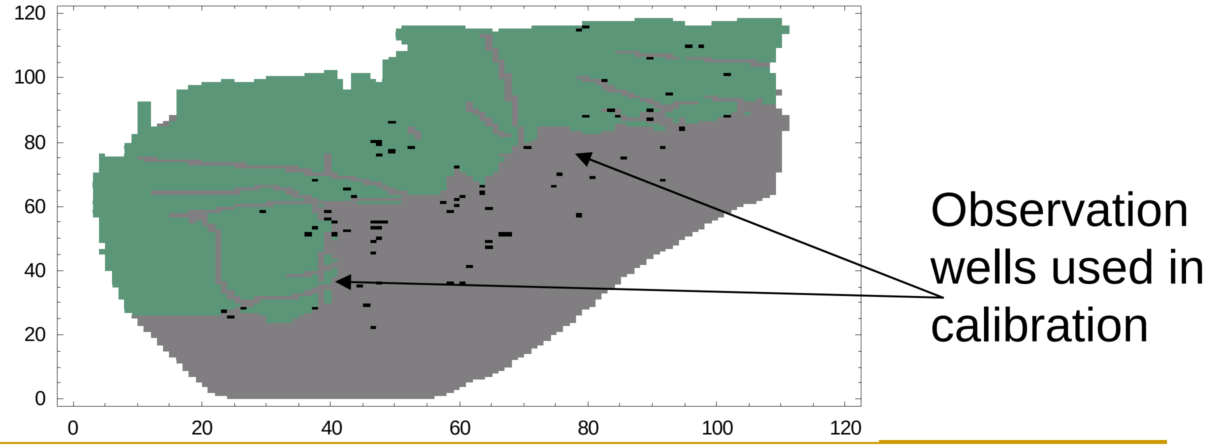
Diffuse Layer Zones

- Nine distinct zones specified
- Transmissivity adjusted during steady-state calibration

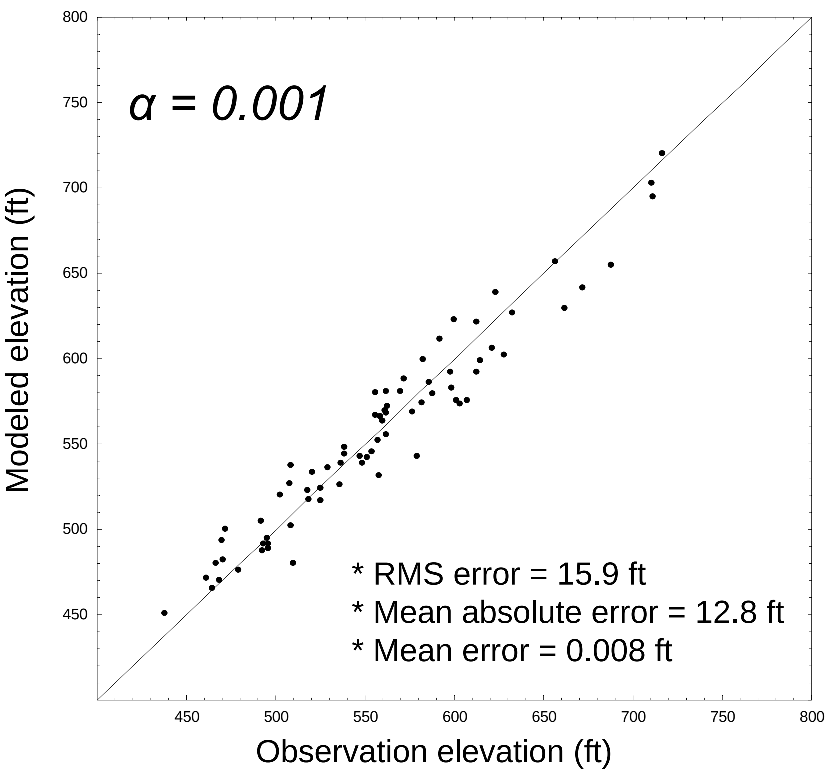


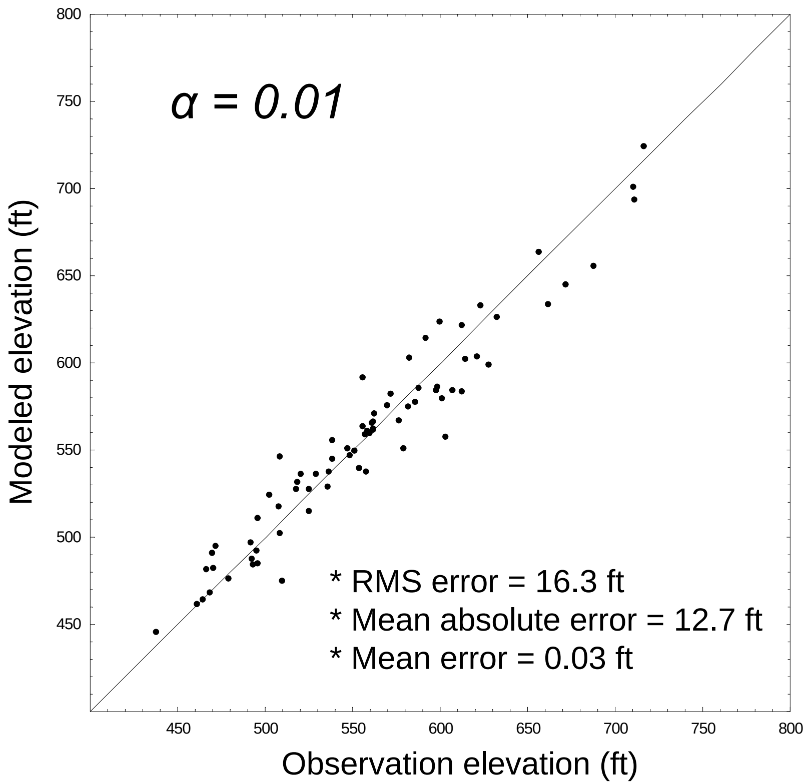
Steady-State Calibration

- Used average pumping and spring discharge estimates for years 1976 to 1998
- Recharge set equal to sum of pumping plus spring discharge
- Transmissivity of diffuse and conduit layers adjusted to observed best fit to water levels in 74 observation wells averaged for years 1976 to 1998
- Obtained steady state calibrations for two alternative values for diffuse conduit exchange parameter (α) to facilitate analysis of sensitivity of transient simulation to the exchange term
  - $\alpha = 0.001$
  - $\alpha = 0.01$



Comparison with observed head





- Head range in the observation set: 278 feet
- RMS residual <10% of head range: considered acceptable for calibration by Texas State rules for Groundwater Availability Models
- Improvement over previous steady-state calibrations

Recharge as a Function of Precipitation

- Developed simple transfer function for estimating fraction of recharge that become precipitation
- Developed utility to quickly generate MODFLOW input files for recharge based on monthly precipitation record

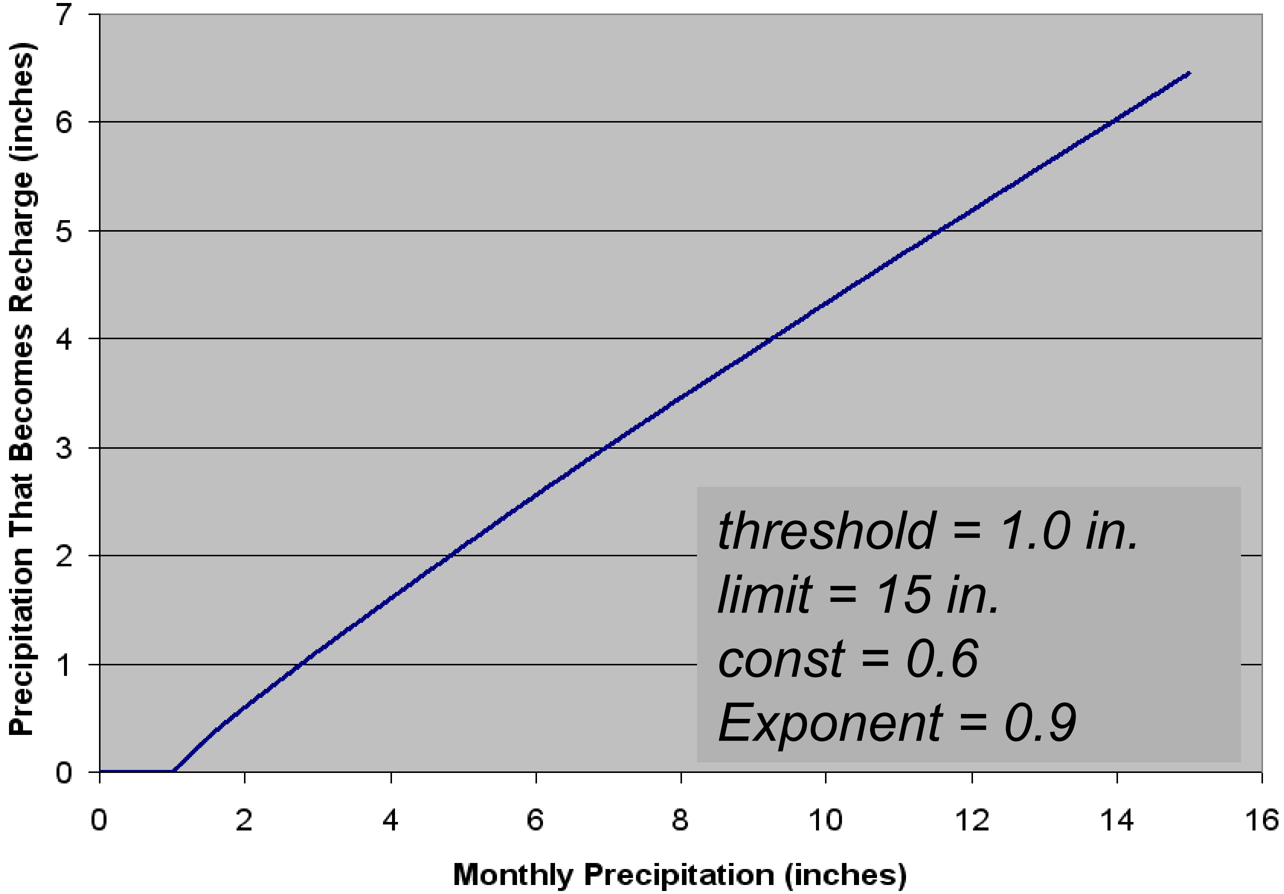
If (*Precipitation* < *threshold*) *Recharge* = *zero*

If (*Precipitation* > *limit*) *Recharge* = *limit*

Else Recharge = $const * Precipitation^{Exponent}$

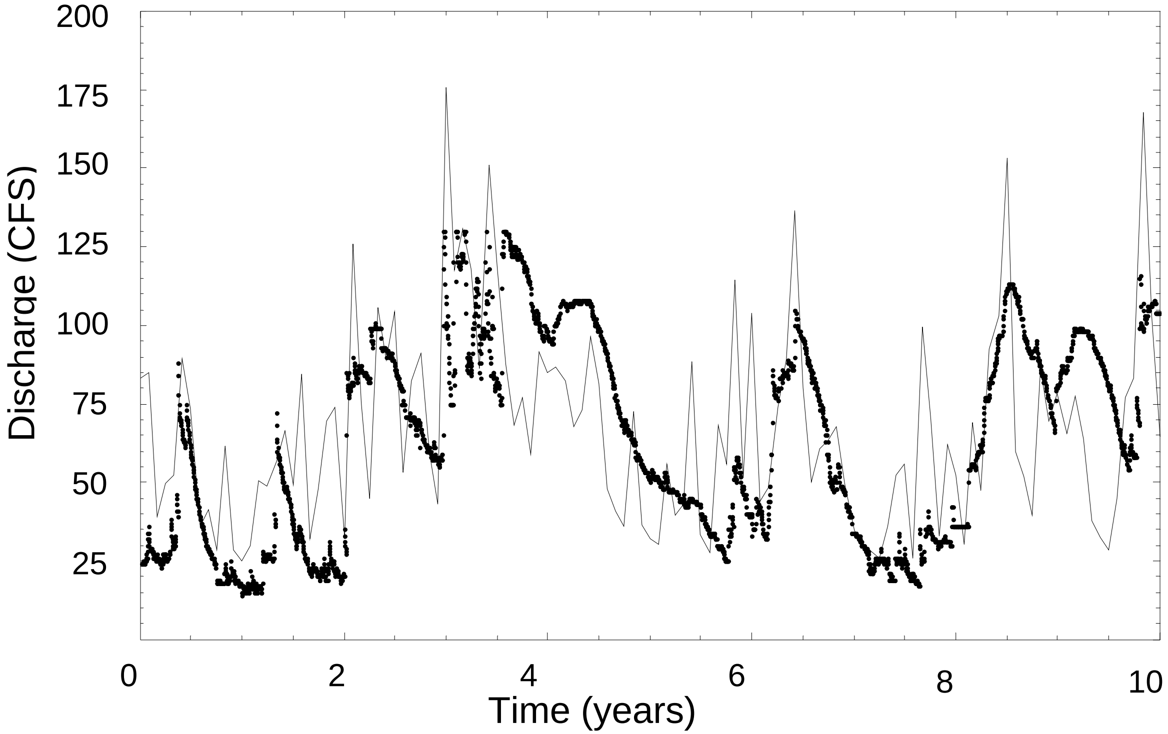
Recharge as a Function of Precipitation

- Transient calibration used monthly precipitation averages from January 1989 to December 1998

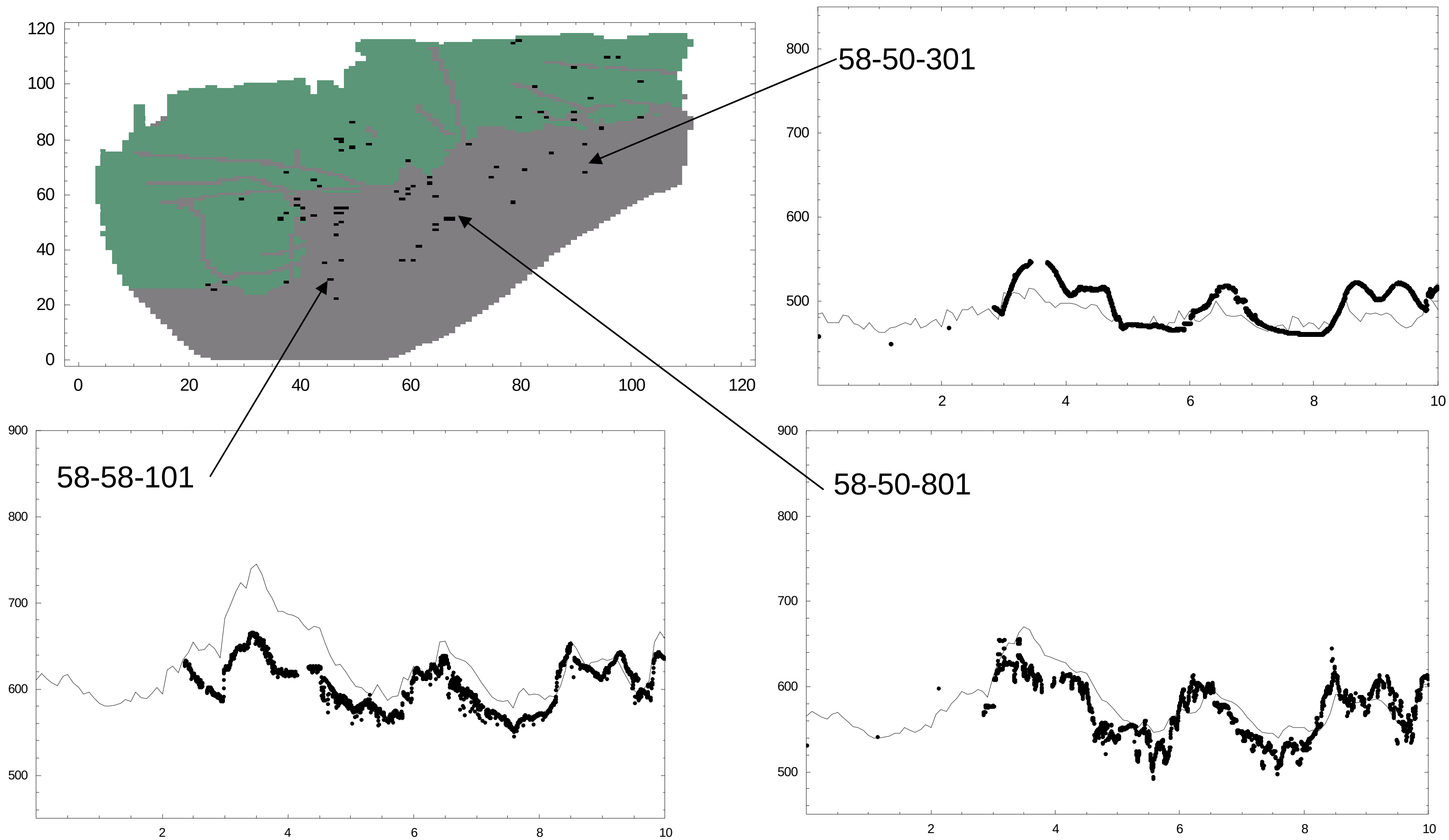


Transient Calibration

- Adjusted recharge and storage parameters to obtain best qualitative fit two calibration targets
  - Spring discharges from 1/1989 to 12/1998
  - Water-level responses from selected observation wells
    - Well #58-50-801
    - Well #58-50-301
    - Well #58-58-101

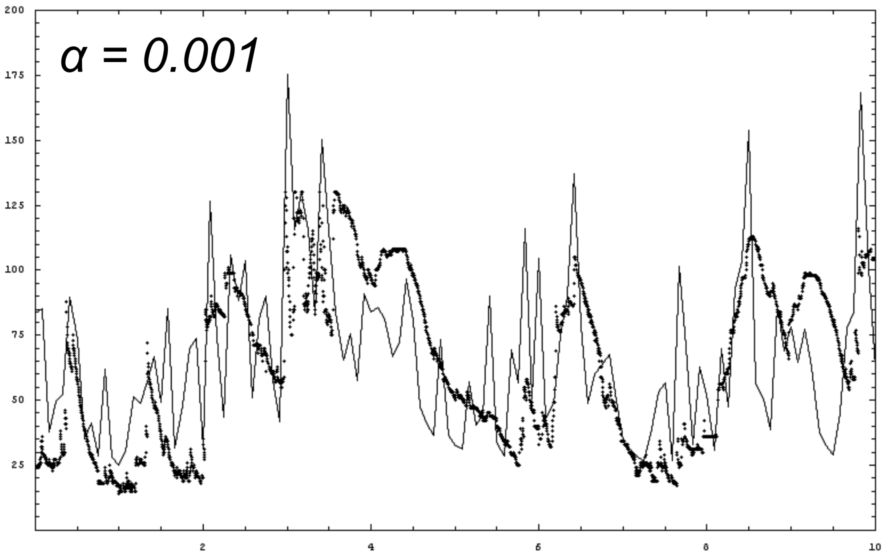


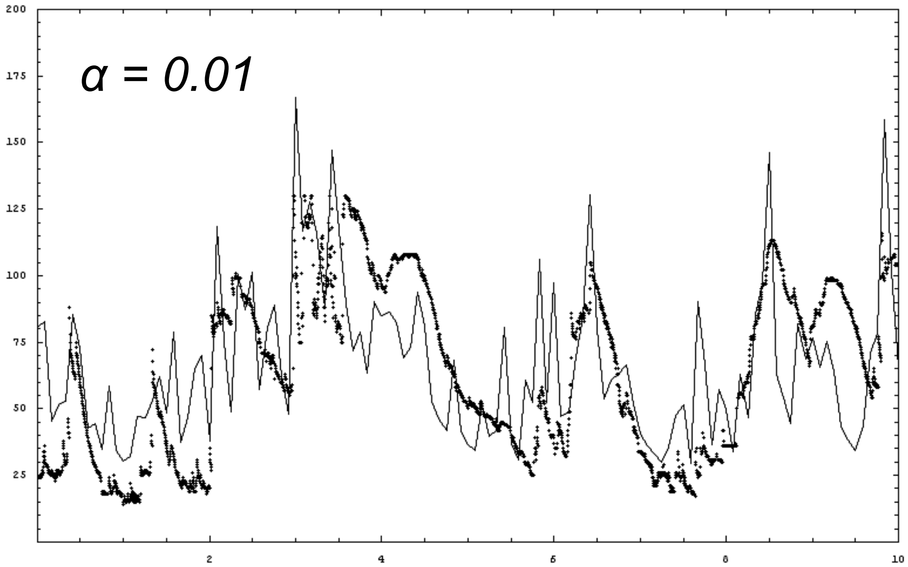
Transient Calibration



Sensitivity Analyses

- Sensitivity to conduit-diffuse layer exchange rate
  - Increasing *α* by a factor of 10 from 0.001 to 0.01 slightly reduces peaks and increases troughs

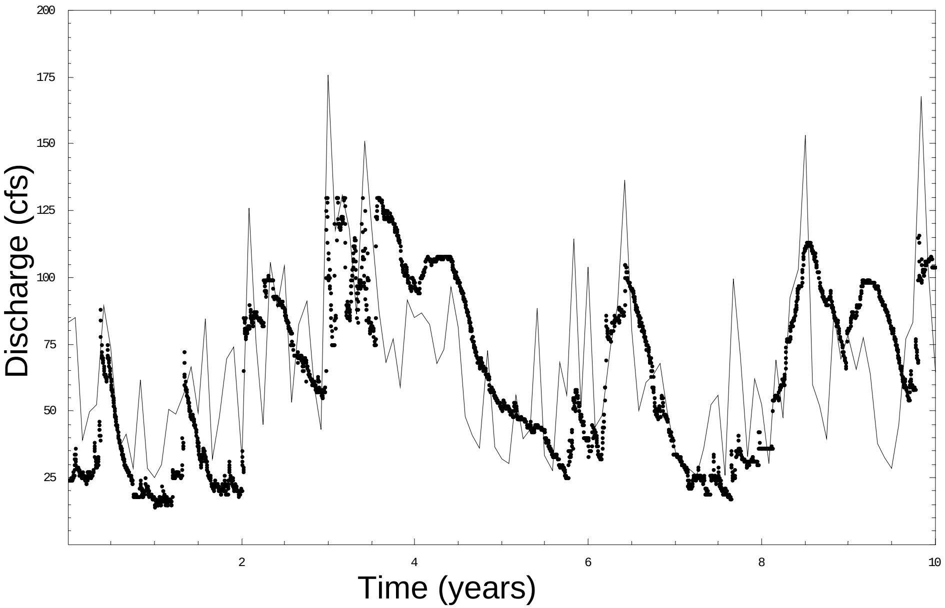




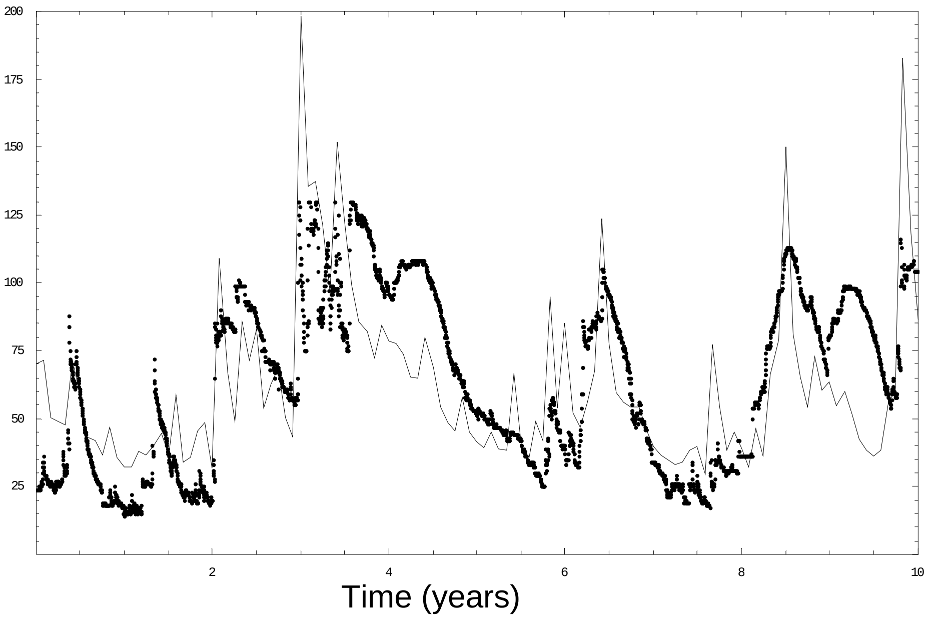
Sensitivity Analyses

- Sensitivity to Precipitation-Recharge Parameters
  - Increasing α by a factor of 10 from 0.001 to 0.01 slightly reduces peaks and increases troughs

Threshold = 1.0 in.
Const. = 0.6
Exp. = 0.9
Limit = no limit



Threshold = no threshold
Const. = 0.0714
Exp. = 2.0
Limit = no limit



Discussion of Results

- Algorithm for estimating recharge from precipitation generally reproduces high- and low-flow spring discharge conditions but response is “flashy” compared to observations, especially on trailing edges of discharge peaks
- Increasing parameter values for specific storage and specific yield results in improved match to observed spring discharge response, but diminishes match to well water-level response
- A potential explanation for this behavior is a secondary storage capacity in between the precipitation and recharge stages. For example, storage and slow drainage from watershed subsurface or epikarst features
- This secondary storage could be incorporated in a more complex algorithm for converting precipitation to recharge
  - Account for antecedent precipitation
  - Account for secondary storage fraction
  - Account for response time of secondary storage
- Existing signal processing techniques could be applied and linked to the physical basis for input parameters

Conclusions: Barton Springs modeling

- Achieved steady-state calibration that meets GAM requirements
  - Residual errors slightly improved from previous efforts
  - Not unique
- Transient calibration based on actual precipitation record
  - Previous calibrations were based on setting recharge equal to discharge + pumping, which limits predictive ability
  - Improved match to water level hydrographs over current GAM
  - Match to spring discharge is “flashy” but able to capture low flow conditions
- Model can be improved by accounting for secondary storage in the precipitation-to-recharge transfer function (beyond the scope of this effort)

Barton Springs Segment of the Edwards Aquifer GAM
2nd Stakeholder Advisory Forum
January 8, 2009
Austin, Texas

NAME	AFFILIATION
Jim Winterle	SwRI
Brian Smith	BSEACD
Trevor Budge	URS
Melissa Hill	TWDB
Ron Green	SwRI
Cindy Ridgeway	TWDB
Joe Beery	BSEACD
John Mikels	GEOS Consulting
James Beach	LBG-Guyton Associates

Second Barton Springs Segment of the Edwards Aquifer Groundwater Availability Model (GAM) Stakeholder Advisory Forum (SAF)

January 8, 2009

Barton Springs Edwards Aquifer Conservation District (BSEACD) Office
Manchaca, Texas

The second Stakeholder Advisory Forum (SAF) for the Barton Springs Segment of the Edwards Aquifer Groundwater Availability Model (GAM) was held on January 8th from 10:00 am until 12:00 pm at the Barton Springs Edwards Aquifer Conservation District (BSEACD) Office, Manchaca, Texas.

The purpose of the fourth SAF was to present the draft final results of the groundwater flow model for the Barton Springs segment of the Edwards Aquifer. The presentation material is available at the TWDB's GAM website (www.twdb.state.tx.us/gam).

Meeting Introduction: Ms. Cindy Ridgeway, TWDB.

The meeting was opened by Ms. Cindy Ridgeway of the Texas Water Development Board (TWDB), who introduced the Barton Springs Segment of the Edwards Aquifer GAM team personnel giving the presentation.

SAF Presentation: Dr. Ron Green and Mr. Jim Winterle, Southwest Research Institute.

After the introduction by Ms. Cindy Ridgeway, Dr. Ron Green gave a review of the GAM project, which was followed by Mr. Winterle who summarized how the new GAM differs from the existing GAM and provided the model results. During and following the presentation, questions were asked by the stakeholders, which are summarized below.

Questions and Answers: Open Forum:

Q: Are conduits connected where they cross?

A: Yes, the conduit network in the DCM model is limited to one layer.

Q. Are velocities of conduits different?

A. Yes. Velocities are dependent on the hydraulic properties assigned to the conduits.

Q. What is the total recharge?

A. Approximately 60 cfs for steady-state conditions.

Q. Are RMS values required for transient simulations?

A. No, although RMS (root-mean square) residual error calculations are required for steady-state simulations, they are not required for transient simulations.

Q. Any thoughts on what can be addressed to improve agreement between the basecase model and steady state conditions?

A. The hydraulic effect of the epikarst may not be sufficiently included in the model.

Q. Do you mean vadose zone storage?

A. Yes.

Q. Were there differences during summer and winter in the fraction of precipitation that becomes recharge?

A. No. The recharge function does not account for seasonal changes (i.e., winter versus summer recharge). In the transient simulations, recharge is varied over time.

Q. What precipitation values were used?

A. Roger Glick provided weighed values calculated from 12 separate measurement locations. One value was assigned to the entire model domain for each one-month stress period in the transient simulations.

Q. There is sufficient precipitation information to assign separate values to each sub-watershed.

A. Yes, that would be beneficial.

Q. Was any limit imposed on recharge?

A. No, setting a limit on the fraction of precipitation that becomes recharge in the recharge algorithm was assessed in the transient simulations and found to not have a noticeable effect on the calibration.

Q. Is DCM a single-layer model?

A. Yes.

Q. Is there a limitation to determining vadose zone storage?

A. Yes. The current one-layer model does not handle vadose zone storage.

Comment. The USGS has a multi-layer karst model, however the USGS model does not have a robust fix for the dry-cell problem and would not be appropriate for the Barton Springs GAM because of the large gradients in the recharge zone.

Q. It appears that this problem could be addressed either with additional layers or with a storage term.

A. SwRI is exploring ways to account for effects of storage outside the main aquifer layer.

Comment: Including a flow restriction in downstream conduits might remove some of the peaks in the simulations.

Comment: Including a more complex storage term could also remove the peaks in the simulations.

Q. Was Cold Spring separately considered?

A. Cold Spring is assigned its own drain cell in the model. However, the spring discharges shown in the presentation are for Barton Springs only. Cold Springs is assumed to account for 6% of the total spring discharge and this is approximately reproduced by the model.

Q. How close was the simulation to the actual low flow discharge values?

A. We don’t have that number available, but will include it in the final report.

Comment: This comparison should be included in the final report to be able to justify the new GAM model.

Q. The DCM is an improvement over the existing GAM, but may not be enough of an improvement at this time to justify becoming the official GAM and that the original GAM may still be preferred.

A. In the existing GAM, recharge is set by manipulating measured discharge. Although that approach is successful at matching historical discharge, it is not possible to make a meaningful forward projection of discharge with that approach. The DCM version of the GAM uses recharge calculated from measured precipitation. This is a significant improvement in terms of predictive capability because we can use measured and projected precipitation to estimate future discharge.

Q. Has total simulated discharge over time been calculated and compared with the actual?

A. No, but adjusting the constant in the precipitation algorithm would help make the simulated match the actual values. This will be included in the final report.

Q. How did groundwater elevations at specific index wells in the existing GAM compare with actual values?

A. The existing GAM matches water-level elevations fairly well, but significantly overestimates peak water elevations.

Q. Does the District still focus on the low end of spring discharge?

A. Yes, low spring discharge is the focus and high spring discharge rates of less importance and interest,

Q. Could the drought of record be checked?

A. No, precipitation data from the drought of record are not available. However, well established methodology is available for generating synthetic precipitation data that can be used to assess potential drought scenarios.

Q. Having a predictive simulation would be beneficial.

A. Pumping and recharge data after 1998 are available, but predictive simulations are not required for GAM demonstrations. Predictive runs are only used in state planning.

Q. The report should contain a recommendation section.

A. Yes. A recommendation section will be included in the final report.