Briefing Paper

Groundwater Model - Storage Property Rationale

Background

During a meeting on March 9, 2015, the USGS raised verbal concerns about the range of the sensitivity analysis used for storage properties in the Rosemont groundwater models. Storage properties directly influence the expansion and magnitude of the cone of depression for a transient model. The purpose of this memo is to document the rationale used to select the range of storage values to use in the sensitivity analysis.

Documentation of Modeling Process

The groundwater modeling process was designed by the Forest Service as an iterative process involving Rosemont's modelers, Forest Service specialists, and outside experts contracted by the Forest Service (SRK, contracted through SWCA) to conduct peer review of the Rosemont models. The full process is documented and described in the project record[1]. Storage properties were specifically explored during the iterative peer review process. The following steps are specific to storage properties:

- Hydrologic data collection in the field was designed to provide information on storage properties by conducting aquifer tests. The first working group discussions concerning storage properties involved discussion of the aquifer tests. Including:
    - Submittal of conceptual modeling report by Montgomery with details of aquifer tests (11/30/2007, project record #012710)
    - Discussion of aquifer tests during 2-day meeting (1/15/2009 – 1/16/2009, project record #011162, 011163)
    - Peer review from SRK on the Montgomery presentation at 1/15/2009 meeting, including specific concern over lack of storage data in Paleozoic formations (1/21/2009, project record #017363)
    - Aquifer test results were included in all subsequent modeling reports as well as supporting data.

- Initial modeling was presented to the Coronado, first by Montgomery (2009), and later by Tetra Tech (2010).
    - Submittal of initial modeling report by Montgomery, including discussion/rationale for storage parameters selected for model (10/28/2009, project record #012837)
    - Submittal of initial Tetra Tech modeling memos, including one memo with estimates of hydraulic properties that includes radial flow analysis of aquifer tests and estimation of storage parameters (7/9/2010, project record #012944), one memo with model construction details including rationale for selection of storage parameters (7/26/2010,

[1] See process paper titled "Overview of Water Resource Process" dated December 6, 2013 (Project Record #047366)

project record #012944), and one memo with sensitivity analysis (8/17/2010, project record #013231).

- SRK provided peer review of the Montgomery and Tetra Tech modeling choices. Discussion of storage parameters primarily took place between initial modeling reports and final modeling reports.
    - In review of the initial Montgomery report, SRK indicated: "Storage parameters, generally, look reasonable. However, the values used do not cover the possible range of values." (2/9/2010, project record #013264) [Note that in response, Montgomery later used lower values in the final modeling report]
    - SRK peer reviewed the Tetra Tech analysis of aquifer tests (8/2/10, project record #013795)
    - SRK peer reviewed the Tetra Tech selection of storage parameters and indicated: "SRK is of the opinion that this number represents the high range of specific storage values and is not conservative enough to estimate the possible maximum extent of the cone of depression during mining and post-mining conditions. Storage parameters derived from the short stress tests tend to overestimate values. Based on SRK experience for low permeability bedrock units, a more realistic and conservative value could be $Ss=1.0 \times 10^{-6}$ ft-1, which is recommended for use in a Best Case, or, as the value for the transient sensitivity analysis." (8/17/2010, project record #013797) [Note that in response, Tetra Tech utilized a sensitivity analysis that incorporated the suggested value]
    - SRK reviewed the Tetra Tech sensitivity analysis and concluded that it was conducted properly (9/27/2010, project record #013798)

- Myers also provided unsolicited peer review (contracted by Pima County) of both models (4/21/2010, project record #013258; 1/29/2011, project record #014504). While evaluating the effects of storage parameters, Myers does not directly criticize or question the storage parameters used in either the Tetra Tech or Montgomery models.

- A series of meetings were held involving Rosemont contractors, the Forest Service, and SRK.
    - As noted earlier, a meeting to discuss aquifer testing on 2/17/2009 (project record 011176).
    - Storage parameters were discussed during a meeting 4/12/2010 (project record #047002)
    - The discussion culminated in a meeting on June 22, 2010, at which the Forest Service provided explicit direction to the Rosemont modelers about the range of sensitivity analyses to use (project record #047003).

- Final modeling reports were submitted, followed by final peer review by SRK.
    - Montgomery submitted their revised report, which included revised storage values from the initial report, and utilized the storage sensitivity range specified by the Forest (8/30/2010, project record #013310)
    - Tetra Tech followed their piecemeal modeling memos with a modeling report compiling all of the supporting technical memos together (11/29/10, project record #013794).

Storage values did not change from the initial memos, and the report utilized the storage sensitivity range specified by the Forest.

Information on Storage Values Available during the Modeling Process

There are two different storage parameters that are included in a Modflow groundwater flow model: **specific storage**, and **specific yield**. Specific storage is operative under confined conditions when a model cell is fully saturated. Specific yield is operative under unconfined conditions when water is physically draining from a model cell.

The attached figures display values for specific storage and specific yield. The figures show graphically the values used in each of the models, the range of value used for the sensitivity analysis in each of the models, and the raw data that was available to the modelers, Forest Service, and outside experts in order to reach these values. Note that only information that was explicitly documented in the modeling reports is included on these figures. This information includes:

- Results from field aquifer tests conducted by Rosemont. It needs to be noted that the values displayed are the storativity calculated during the aquifer test. "Storativity" is a more generic term that encompasses both specific storage and specific yield. For aquifer tests, the calculated storativity is a combination of the aquifer response under both unconfined and confined conditions and can't readily be separated into specific storage and specific yield components. Field tests were analyzed both by Montgomery and by Tetra Tech separately.

- Results from field aquifer tests conducted in the 1970s in the Cienega Creek basin by Harshbarger.

- Literature/studies in the area. Two specific hydrologic studies were referenced: Boggs (1980) and Bota (1997). Both of these are Masters' theses for groundwater evaluations conducted in the Cienega Creek basin.

- Other nearby groundwater models. Two published groundwater models were reviewed, one for the Tucson AMA and one for the San Pedro basin. The Tucson AMA model was constructed by the Arizona Department of Water Resources and uses a range of specific yield values (from 0.03 to 0.22) and a single specific storage value (1×10^{-4}). The San Pedro model was constructed by the USGS and uses a range of specific yield values (from 0.001 to 0.30) and a range of specific storage values (from 1×10^{-6} to 2×10^{-5}).

Stated Rationale for Selection of Model Values

- For the Montgomery model, both the specific storage and specific yield were selected using a parameter estimation procedure (the PEST package) to calibrate storage properties to the results of a 30-day pumping test. (Project record #013310, p. 73-74)

- For the Tetra Tech model, the specific storage selected was eventually based on two specific pieces of information: for bedrock, the geometric mean resulting from Tetra Tech's radial flow

analysis of the field aquifer tests was selected (9.84×10^{-6}), and for basin fill, the value used in the San Pedro model was used (6.56×10^{-5}). (Project record #013794, p. 43-44)

- For the Tetra Tech model, no specific rationale was noted in the modeling report for the specific yield that was selected.

Other Possible Ranges of Storage Values

A handful of hydrologic text books was reviewed to identify typical ranges of storage properties.

- *Groundwater*. Freeze and Cherry. Specific yield: 0.01-0.30. Specific storage: 5×10^{-5} to 5×10^{-3}
- *Groundwater and Wells*. Driscoll. Specific yield: 0.005-0.30. Specific storage: 1×10^{-5} to 1×10^{-3}
- *Specific Yield—Compilation of Specific Yields for Various Materials*. USGS Water Supply Paper 1662-D. Generally 0.01 to 0.35.

General Conclusions

- An iterative deliberative process was followed to develop both storage parameters to use in the models, and the range of sensitivity analyses to include in the modeling reports. The process involved face-to-face meetings, review of field data, and expert peer review of modeling selection. The process is fully documented in the project record.

- As a result of the iterative review process, some storage parameters were modified in the final modeling reports.

- The Forest Service dictated to the Rosemont modelers the specific range of values to use in the sensitivity analyses.

- A variety of available sources of data were used to inform the selection of storage parameters. These include literature/research in the basin, field aquifer tests, and other nearby models. (All of these sources of data were mentioned by USGS on March 9)

- The biggest concern with respect to underestimating model impacts is that the range of the storage sensitivity analysis is not sufficiently low. The range of sensitivity analysis used for the Rosemont models extends lower than any of the supporting information that was considered, including observed field data, any value obtained from literature/research, and any value used in nearby models. This is true for both specific yield and specific storage.

- Review of other sources (text books) indicates that the low end of specific storage isn't quoted below values of 1×10^{-5}. The values used in the Montgomery model extend up to two orders of magnitude lower than this range (2×10^{-7}), and are also an order of magnitude lower than the two nearby models (San Pedro and Tucson AMA). The values used in the Tetra Tech model are about equal to the low end of this range (9.8×10^{-6}), and are about equal to the values used in the two nearby models.

Table 1. Summary of Storage Properties Used During Model Development				
Source	**Unit**	**Unconfined – Specific Yield**	**Confined – Specific Storage**	**Record Source**
Montgomery interpretation of field aquifer tests	Ksd		$1.6x10^{-2}$*	012837
	Pz, KsD		$1.4x10^{-3}$*	012837
	Pz, KsD		$2.2x10^{-3}$*	012837
	Pz		$1.4x10^{-3}$*	012837
	Pz		$6.2x10^{-4}$*	012837
	Pz		$6.7x10^{-4}$*	012837
	Pz		$6.9x10^{-3}$*	012837
	KsD		$7.1x10^{-3}$*	012837
	KsD		$1.9x10^{-3}$*	012837
	KsD		$1.6x10^{-3}$*	012837
	KsD		$1.0x10^{-1}$*	012837
	pCc		$7.3x10^{-4}$*	012837
Harsbarger 1970s field tests	Not specified	0.05	$7x10^{-5}$ to $1.9x10^{-2}$	012837
Boggs 1980; Bota 1997	Basin fill	0.01-0.1		012837
Tucson AMA Model	Pantano formation	0.07-0.09		012837
	Tucson basin fill	0.10-0.13		012837
Tetra Tech Radial Flow Analysis of Well PC5	KsD		$7x10^{-7}$ – $6.6x10^{-3}$	012944
	Pz-Concha		$4x10^{-3}$	012944
	Pz-Sherrer		$1.5x10^{-7}$	012944
	Pz-Epitaph		$2.2x10^{-6}$	012944
	Pz		$1.5x10^{-7}$	012944
Tetra Tech Radial Flow Analysis of Well HC1B	Glance		$1.0x10^{-6}$	012944
Tetra Tech Radial Flow Analysis of Well HC5A	KsD		$3.3x10^{-4}$	012944
	Willow Canyon		$3.3x10^{-4}$	012944
	Pz		$3.3x10^{-4}$	012944
Tetra Tech Geometric Mean of Aquifer Test Analysis			$9.8x10^{-6}$	012944
Upper San Pedro Model	Upper Basin Fill		$6.56x10^{-5}$	013230
Tetra Tech Initial and Final Model	Basin fill	0.05 – 0.15	$6.56x10^{-5}$	013230
	Bedrock units	0.01	$9.84x10^{-6}$	013230

Table 1. Summary of Storage Properties Used During Model Development				
Source	**Unit**	**Unconfined – Specific Yield**	**Confined – Specific Storage**	**Record Source**
SRK peer review suggestion for Tetra Tech	Bedrock units		$1x10^{-6}$	013797
Tetra Tech Sensitivity Analysis	All units		± 1 order of magnitude $6.56x10^{-6}$ to $6.56x10^{-4}$ $9.84x10^{-7}$ to $9.84x10^{-5}$	013231
	Basin fill	± 50 percent 0.025 – 0.23		013231
	Bedrock	± Factor of 2 0.005 – 0.02		013231
Montgomery Initial Model	Alluvial	0.15	$5x10^{-4}$	012837
	Basin fill	0.05-0.1	$5x10^{-4}$	012837
	Bedrock	0.01-0.1	$5x10^{-5}$ to $5x10^{-6}$	012837
Montgomery Final Model	Alluvial	0.15	$2x10^{-6}$	013310
	Basin fill	0.1	$2x10^{-6}$	013310
	Bedrock	0.01	$2x10^{-7}$	013310
Montgomery Sensitivity Analysis	Basin fill	0.05 – 0.15		013310
	Bedrock	0.005 – 0.02	$2x10^{-8}$ – $2x10^{-6}$	013310

* Represents storativity, undifferentiated between specific yield and specific storage

Figure 1. Graphic Display of Specific Storage Values Used in Rosemont Modeling Process

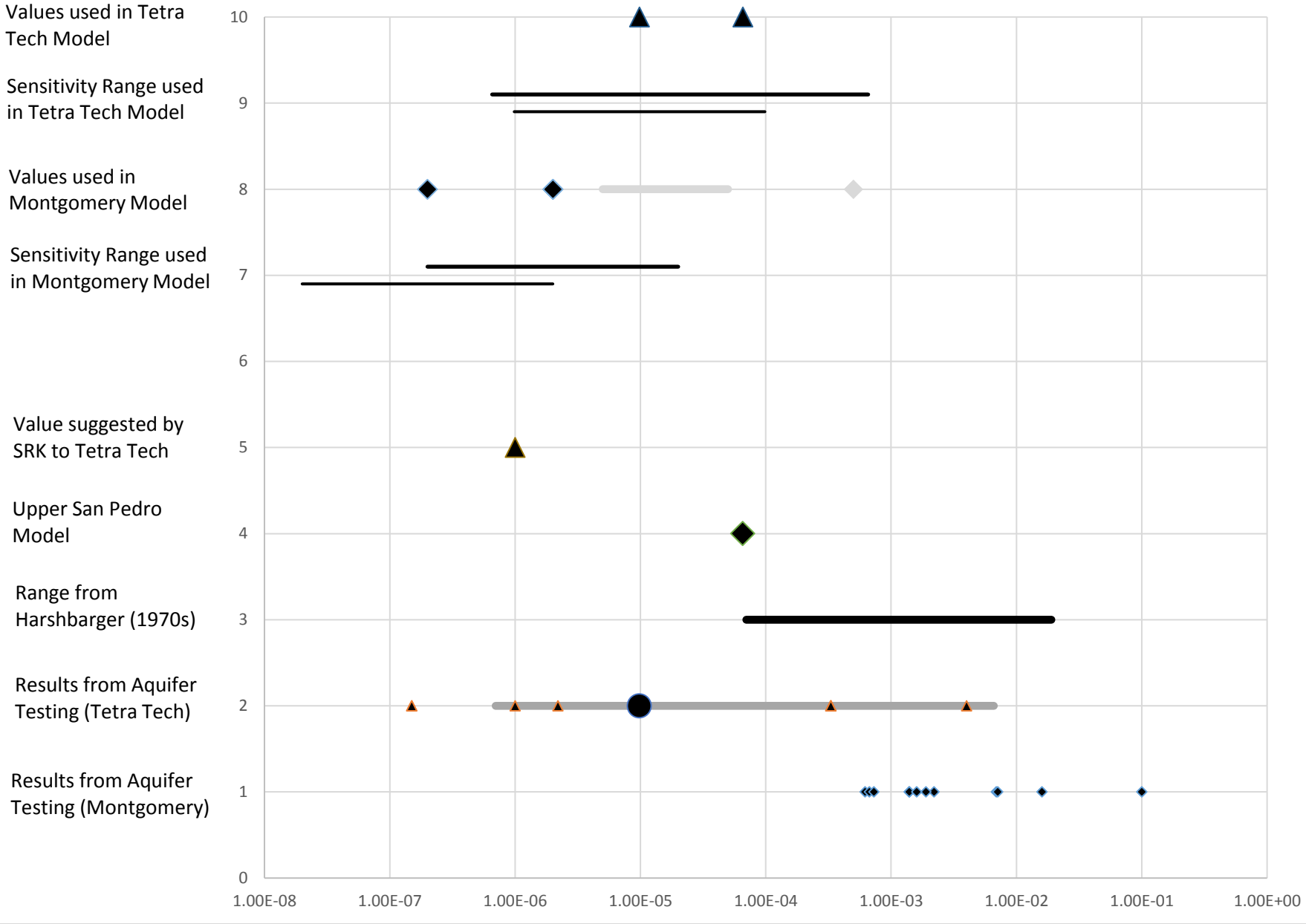

Figure 2. Graphic Display of Specific Yield Values Used in Rosemont Modeling Process