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Technical Memorandum

To:	Kathy Arnold	**From:**	Grady O'Brien, Project Manager
Company:	Rosemont Copper Company	**Date:**	July 30, 2010
Re:	Steady-State Sensitivity Analyses	**Doc #:**	202/10-320874-5.3
CC:	David Krizek, P.E. (Tetra Tech)		

1.0 Introduction

This Technical Memorandum provides an update on the status of the sensitivity analyses performed to date on the groundwater flow models prepared by Tetra Tech for the proposed Rosemont Copper Project (Project). The Project is located on the east side of the Santa Rita Mountains, approximately 30 miles southeast of Tucson, Arizona in Pima County. The regional groundwater flow models prepared for the Project represent pre-mining steady state conditions, active mining conditions, and post-closure mining conditions. The groundwater flow model construction process, calibration results, and flow-model predictions have been documented in previous technical memoranda (Tetra Tech [2010a] and Tetra Tech [2010b]).

2.0 Scope, Objective, and Approach

Sensitivity analyses have been completed on the steady-state groundwater flow model. The objective of the sensitivity analyses was to identify the model inputs that have the most impact on the calibration (model fit) and on the conclusions of the modeling analyses (ASTM, 2008). The model results evaluated during the steady-state sensitivity analyses were limited to the effect on the sum of square weighted residuals (SOSWR). The SOSWR is a measure of how well the model matches the target water levels. During the calibration process, the SOSWR was minimized to the greatest extent possible without creating unrealistic conditions, such as water-levels above land surface. The analysis provided the SOSWR for each parameter change to determine whether the change improved the numerical model fit.

The most sensitive parameters in the steady-state model were identified and then varied to determine the impact on the SOSWR. Hydraulic conductivity, recharge, stream-bed conductance, and the western model boundary were evaluated. The steady-state flow model had ten (10) hydrogeologic units that were defined as parameters (Table 1).

Table 1. Hydrogeologic Units used in the Steady-State Flow Model

Unit Abbreviation	Description
Qal	Quaternary and Recent alluvium
QTg	Late Tertiary to Early Quaternary basin-fill deposits - higher permeability
QTg1	Late Tertiary to Early Quaternary basin-fill deposits - lower permeability
QTg2	Late Tertiary to Early Quaternary basin-fill deposits - lowest permeability
Tsp	Early to Mid-Tertiary sedimentary and volcanic units (Pantano Formation)

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Resourceful.

Memorandum

To: Bev Everson

Cc: Tom Furgason

From: Kathy Arnold

Doc #: 033/10 – 15.3.2

Subject: **Transmittal of Groundwater Modeling Technical Memoranda**

Date: July 30, 2010

Rosemont is pleased to transmit the following documents related to the groundwater modeling work that has been undertaken by Tetra Tech:

- *Predictive Groundwater Flow Modeling Results,* Tetra Tech, July 2010
- *Steady-State Sensitivity Analyses,* Tetra Tech, July 2010

Rosemont is providing three hardcopies and two disk copies for the Forest and two hardcopies and one disk copy for SWCA.

Table 1. Hydrogeologic Units used in the Steady-State Flow Model (continued)

Unit Abbreviation	Description
KTi	Upper Cretaceous and Early Tertiary intrusive rocks
Kv	Upper Cretaceous volcanic rocks
Ksd	Lower Cretaceous sedimentary units (Bisbee Group)
Pz	Paleozoic sedimentary and metamorphic formations
pCb	Precambrian igneous and metamorphic crystalline formations

The 13 parameters with the highest composite scaled sensitivity values, plus the horizontal flow barrier (HFB) hydraulic conductivity and the streambed hydraulic conductivity, are provided in Table 2. Parameters were also normalized to the highest composite scaled sensitivity (CSS; defined in Section 3.1) value (Recharge zone 2) to simplify comparing CSS values. The most sensitive parameters were the six (6) recharge zones and the hydraulic conductivity of seven (7) hydrogeologic units (HGU). The bedrock HGU parameters include the "backbone fault", Kv, Ksd, and Pz. Paleozoic units were subdivided to create a "backbone fault" zone parameter to simulate the steeply dipping beds and influence of the Backbone fault in the western pit area. The basin–fill parameters were QTg1 and QTg_TB.

Table 2. Steady-State Model Composite Scaled Sensitivities for the Most Sensitive Parameters

PEST Parameter Name[1]	HGU (Zone)	Calibrated Parameter Value	Composite Sensitivity	Composite Scaled Sensitivity	Normalized CSS
r2	Recharge	2.30E-05	1.30E+01	6.03E+01	1.00
r5	Recharge	3.70E-05	5.63E+00	2.49E+01	0.41
kz6	Kv (6)	4.00E-04	6.83E+00	2.32E+01	0.38
r4	Recharge	2.90E-05	4.87E+00	2.21E+01	0.37
kz11	Backbone (11)	1.00E-04	5.43E+00	2.17E+01	0.36
r7	Recharge	9.14E-05	3.40E+00	1.37E+01	0.23
kz8	Ksd (8)	1.20E-03	4.57E+00	1.33E+01	0.22
kx3	QTg1(3)	5.30E-02	8.80E+00	1.12E+01	0.19
r6	Recharge	4.70E-05	2.20E+00	9.51E+00	0.16
kx15	QTg_TB (15)	1.10E-01	9.24E+00	8.85E+00	0.15
kz9	Pz(9)	3.30E-03	3.55E+00	8.81E+00	0.15
r3	Recharge	2.60E-05	1.75E+00	8.03E+00	0.13
kx11	Backbone (11)	1.00E-03	2.36E+00	7.08E+00	0.12
Hf1	HFB	1.00E-06	7.83E-01	4.70E+00	0.08
St1	Streambed	2.00E+00	1.41E-01	4.25E-02	0.001

[1]r = recharge; kz = vertical hydraulic conductivity; kx = horizontal hydraulic conductivity; Hf = horizontal flow barrier

3.0 Steady-State Sensitivity Results

The sensitivity analyses confirmed that the steady-state calibration resulted in nearly optimal parameter values for matching water levels in the model. However, different values for a few model parameters did result in an improvement in the SOSWR. However, these parameter values would have resulted in either water levels above land surface in the PCb southwest of the pit or a lowering of water levels at the pit area. However, simulated water levels in the calibrated model were already lower than observed. While changing parameter-values would improve the calculated model fit, the model's representation of the overall groundwater system would also be degraded.

3.1 Parameter Sensitivity

Parameter sensitivities measure how changes in model parameters impact the computed water levels at the measured water levels locations. The PEST (Parameter ESTimation) software (Doherty, 2010), provides an overall quantification of the parameter sensitivities through a variable referred to as a composite sensitivity.

Parameter sensitivity is defined as the derivative of a predicted value, in this case groundwater level, relative to a model parameter, such as hydraulic conductivity. The sensitivity is the change in the groundwater level caused by a change in a model parameter value divided by the change in the parameter value. In the case of the hydraulic conductivity parameter, the sensitivity would have units of feet divided by the units of hydraulic conductivity, such as feet per day. As a result, the units for composite sensitivity will be different depending on which model parameter is considered. Comparing composite sensitivities among parameters requires normalized values by multiplying the sensitivity by the parameter value. If the model parameter is log transformed in PEST, the log of the parameter value is multiplied by the composite sensitivity. The resulting composite scaled sensitivity has the units of feet regardless of which model parameter is being considered.

Composite parameter sensitivities are useful in identifying those parameters which may be degrading the performance of the parameter estimation process through lack of sensitivity to model outcomes. The use of composite scaled sensitivities, in addition to normal sensitivities, assists in comparing the effects that different parameters have on the parameter estimation process when these parameters are of a different type, and possibly of very different magnitudes.

3.2 Sensitivity Simulations

A series of sensitivity runs were conducted by increasing and decreasing parameter values identified in Table 2 in addition to others that will be sensitive in the mining and post-mining runs. Results of the sensitivity simulations are presented on figures where the percent difference of the SOSWR value from the calibrated model is plotted versus the multiplier used to modify the calibrated parameter value. A negative percent difference value means a change in parameter value decreases the SOSWR and a positive percent difference value means a change in parameter value increases the SOSWR. Most changes in Kh result in a higher SOSWR indicating near optimal parameter values were chosen during calibration. The results of these modeling simulations are discussed below.

3.2.1 Horizontal Hydraulic Conductivity by Zone

Figure 1 shows the sensitivity of horizontal hydraulic conductivity (Kh) parameter on zones 3 (QTg1), 11 (Backbone), and 15 (QTb_TB) on SOSWR. Increasing these parameter values increases the SOSWR, which indicates a decrease in model fit. Decreasing the Kh of the backbone parameter (Kx11) results in a 2.9% reduction in SOSWR compared to the calibrated steady-state model. However, this reduction in Kh causes water levels in the Santa Rita Mountains (PCb HGU) to rise above land surface.

3.2.2 Horizontal Hydraulic Conductivity by Rock Type

Figure 2 shows the sensitivity of varying Kh of all basin fill HGUs (zones 1 – 4 and 15) at the same time and the sensitivity of varying Kh of all bedrock HGUs (zones 5 – 11) at the same time. An increase or decrease in Kh by 30% (i.e., a multiplier of 0.7 or 1.3) for basin fill HGUs results in a higher SOWSR indicating that near optimal parameter values were obtained during calibration. Reducing the bedrock Kh values by 10 percent (i.e., a multiplier of 0.9) results in a reduction of the SOSWR by approximately 5 percent. However, this reduction in Kh causes water levels in the Santa Rita Mountains (PCb HGU) to rise above land surface.

3.2.3 Vertical Hydraulic Conductivity by Zone

Figure 3 shows the sensitivity of vertical hydraulic conductivity (Kv) parameter on zones 6, 8, 9, and 11 on SOSWR. Reduction in Kv values for zones 6 (Kv or volcanic units) and 11 (backbone fault) produce up to a 1.9 percent reduction in SOSWR. Reducing the zone 6 causes water levels at the pit to drop by over 10 feet. Reducing zone 11 Kv causes water levels in the PCb southwest of the pit to rise above land surface. Increasing Kv for zones 8 (Ksd) and zone 9 (Pz) produce up to a 3.8 percent reduction in SOSWR. Increasing either zone by these multipliers would lead to a reduction of water levels at the pit by over 10 feet.

3.2.4 Vertical Hydraulic Conductivity by Rock Type

Figure 4 shows the sensitivity of varying Kv of basin fill HGUs at the same time and the sensitivity of varying Kv of bedrock HGUs at the same time similar to Kh described above. An increase in Kv by 30 percent for basin fill HGUs results in a minor reduction (0.2 percent) of SOWSR. Reducing the bedrock Kh values by 30 percent results in a reduction of the SOSWR by approximately 2 percent. However, this reduction in Kv causes water levels in the Santa Rita Mountains (PCb HGU) to rise above land surface.

3.2.5 Recharge

Figure 5 shows the sensitivity of changing the recharge globally in the model. Increasing recharge by 20 percent in the model reduces SOSWR by approximately 2 percent. However, this increase in recharge will cause water levels in the Santa Rita Mountains (PCb HGU) to rise above land surface. Decreasing recharge by 20 percent or increasing recharge by 40 percent results in a significant increase (>20 percent) in SOSWR.

3.2.6 Streambed Hydraulic Conductivity and Horizontal Flow Barrier

Figure 6 shows the sensitivity of the streambed and HFB (quartz-porphyry dike) hydraulic conductivity on SOSWR. Due to their low CSS values, there is little change in SOSWR with an increase or decrease of these parameter values by an order of magnitude. However, it is expected that these parameters will have an effect on drawdown extent and potential stream flow impacts.

3.2.7 West Model Boundary Changed to No Flow

Due to the proximity of the western model boundary to the pit, a sensitivity run was conducted to convert the western boundary in all model layers to a no flow boundary. The SOSWR value increased by 264 percent, indicating the steady-state model calibration is extremely sensitive to that boundary and requires groundwater flow in and out of that boundary to produce a good model calibration.

4.0 Predictive Model Sensitivity Simulations

The steady-state sensitivity results will be updated and included with the results from the predictive model sensitivity analyses. The impact of parameter changes on predictions of the lateral and vertical extent of the drawdown cone, and changes in stream flow, evapotranspiration, and water levels are currently being evaluated using the predictive models. This on-going analysis is a continuation of the steady-state sensitivity analyses. A companion Technical Memorandum will document the results of sensitivity analyses performed on the predictive, mining-phase and post-closure/post-mining phase flow models. These simulations are currently underway and it is anticipated that these simulations will be completed by Friday, August 6. Documentation will follow within about three (3) business days of completing the model simulations. Documentation will include electronic modeling files.

5.0 References

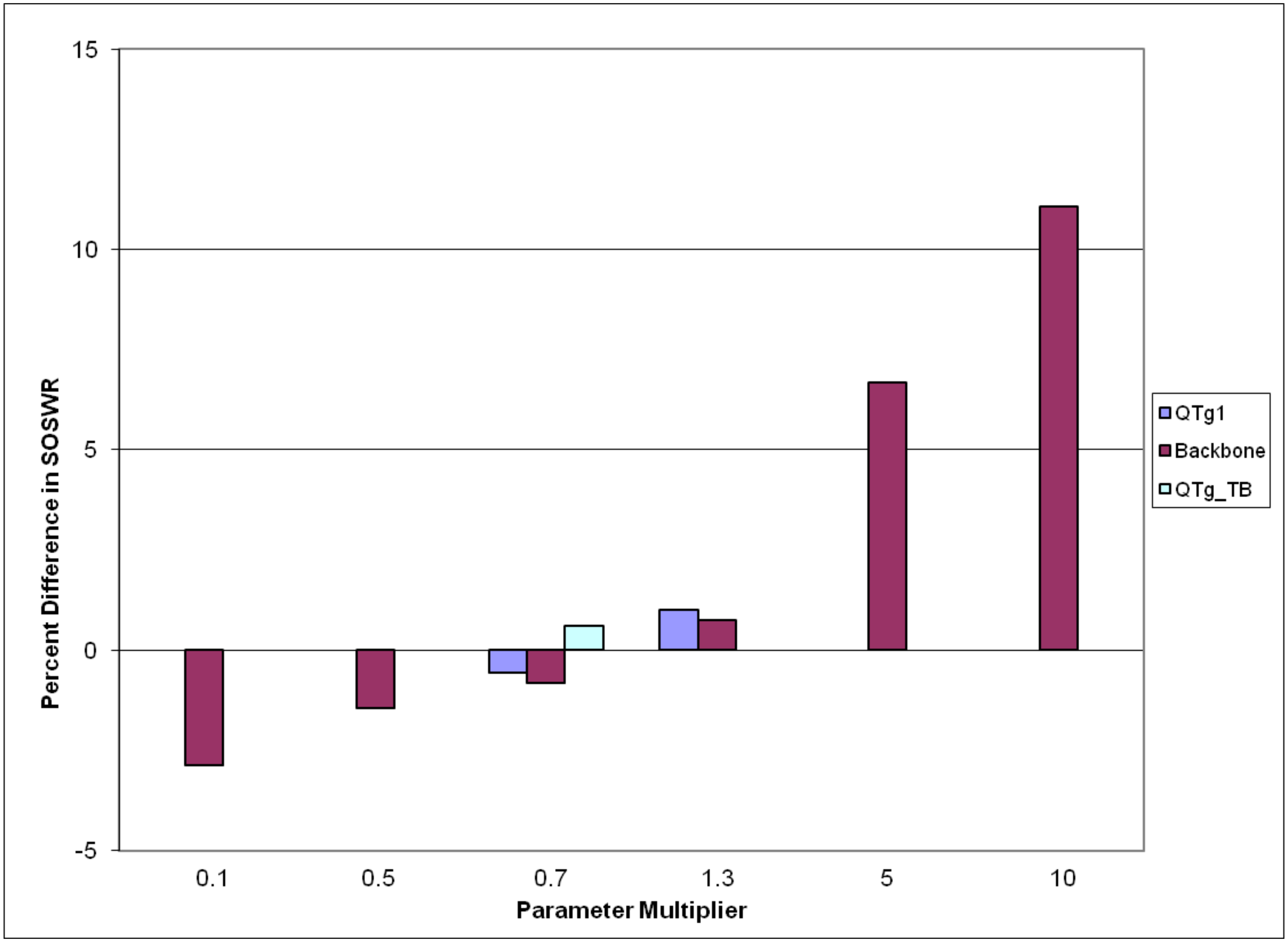
ASTM (2008), Standard Guide for Conducting a Sensitivity Analysis for a Ground-Water Flow Model Application, ASTM D5611-94(2008).

Doherty (2010), PEST, Model-Independent Parameter Estimation and Uncertainty Analysis

Tetra Tech (2010a), *Groundwater Flow Model Construction and Calibration* ,Technical Memorandum to Kathy Arnold (Rosemont Copper Company), Technical Memorandum dated July 26, 2010.

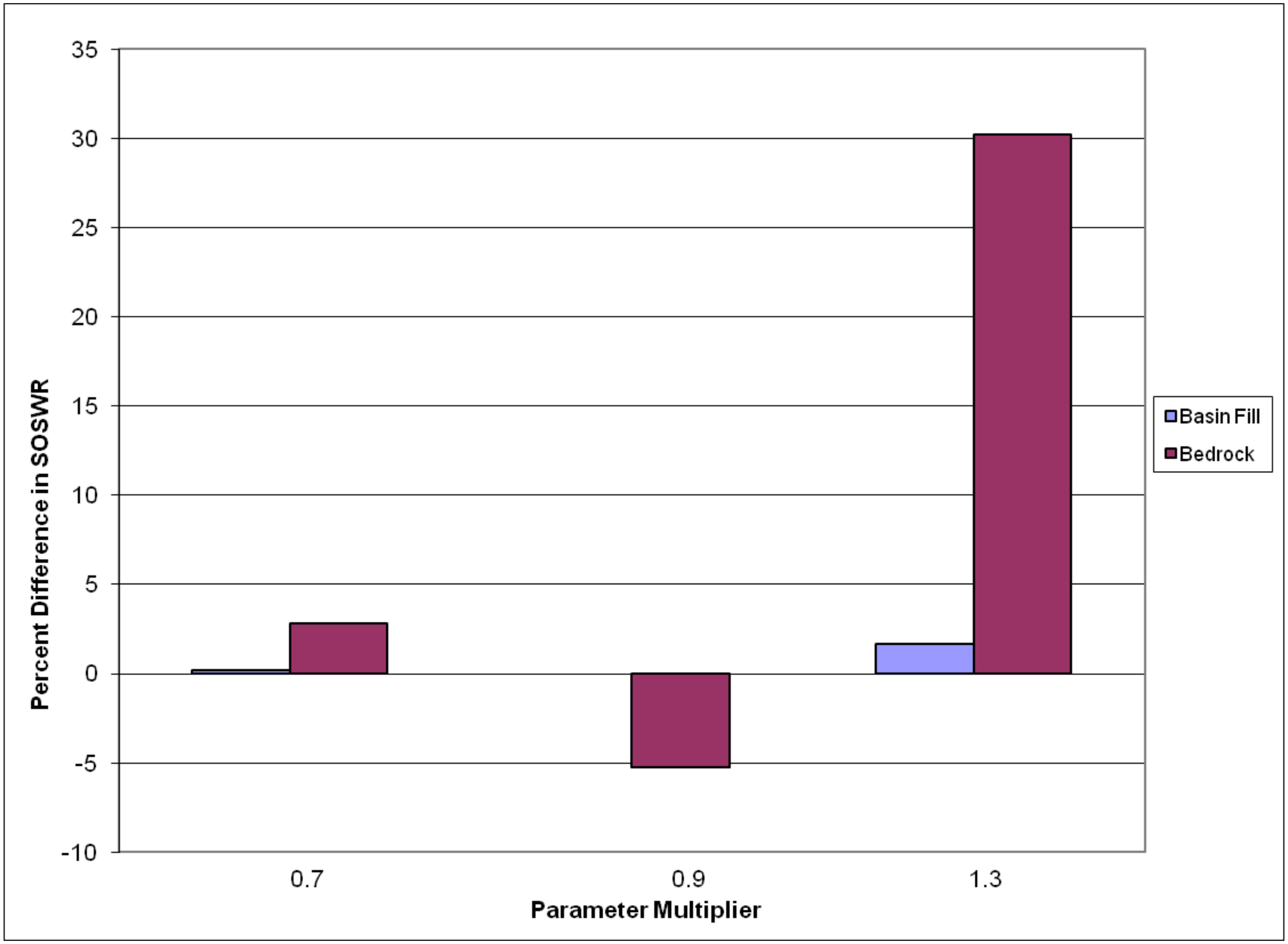
Tetra Tech (2010b), *Predictive Groundwater Flow Modeling Results*. Technical Memorandum to Kathy Arnold (Rosemont Copper Company). Technical Memorandum dated July 30, 2010.

FIGURES



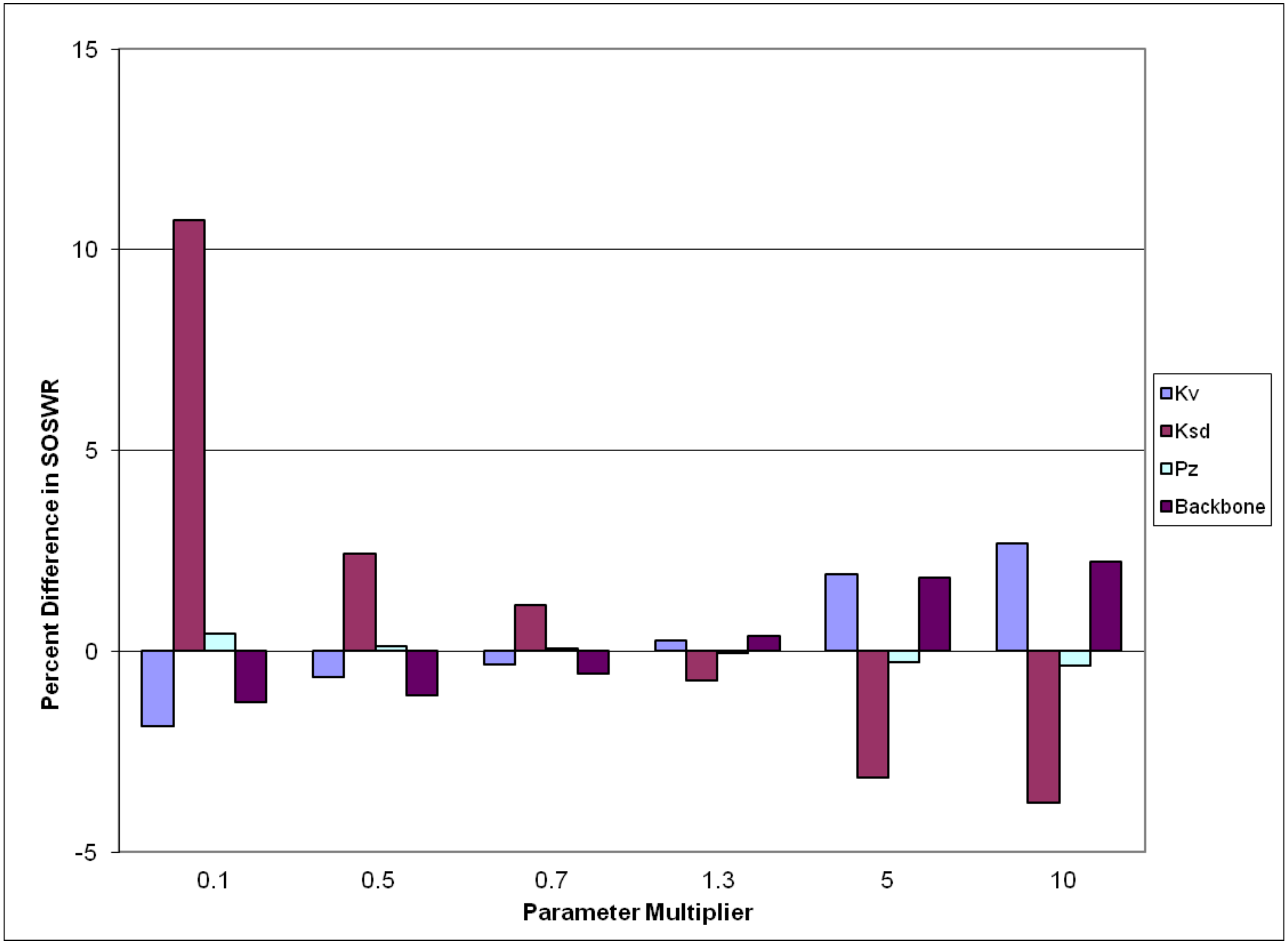
SOSWR: Sum of squared weighted residuals

Figure 1
Horizontal Hydraulic Conductivity
Sensitivity by Zone



SOSWR: Sum of squared weighted residuals

Figure 2
Horizontal Hydraulic Conductivity
Sensitivity by Rock Type



SOSWR: Sum of squared weighted residuals

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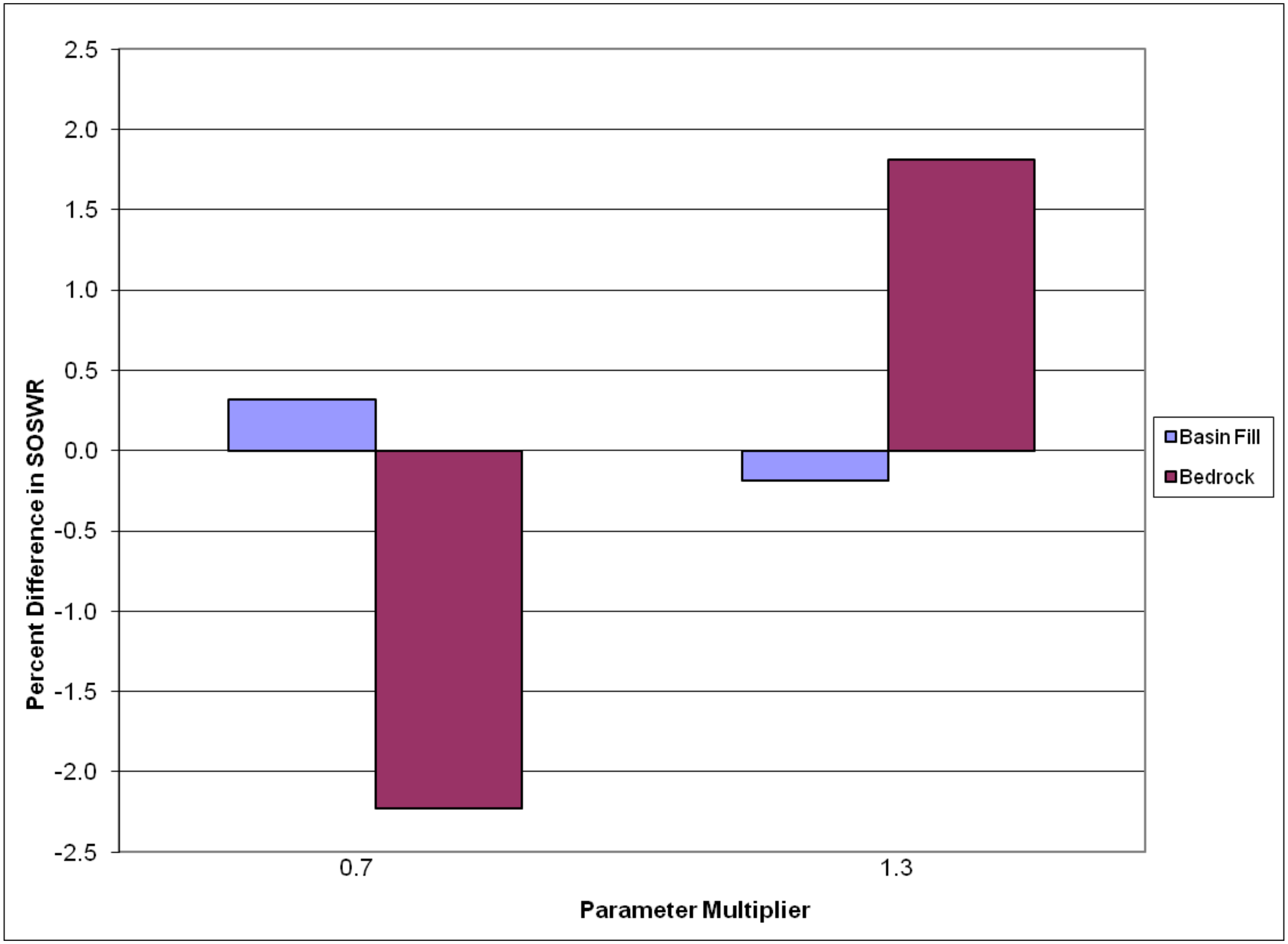
Figure 3
Vertical Hydraulic Conductivity
Sensitivity by Zone



SOSWR: Sum of squared weighted residuals

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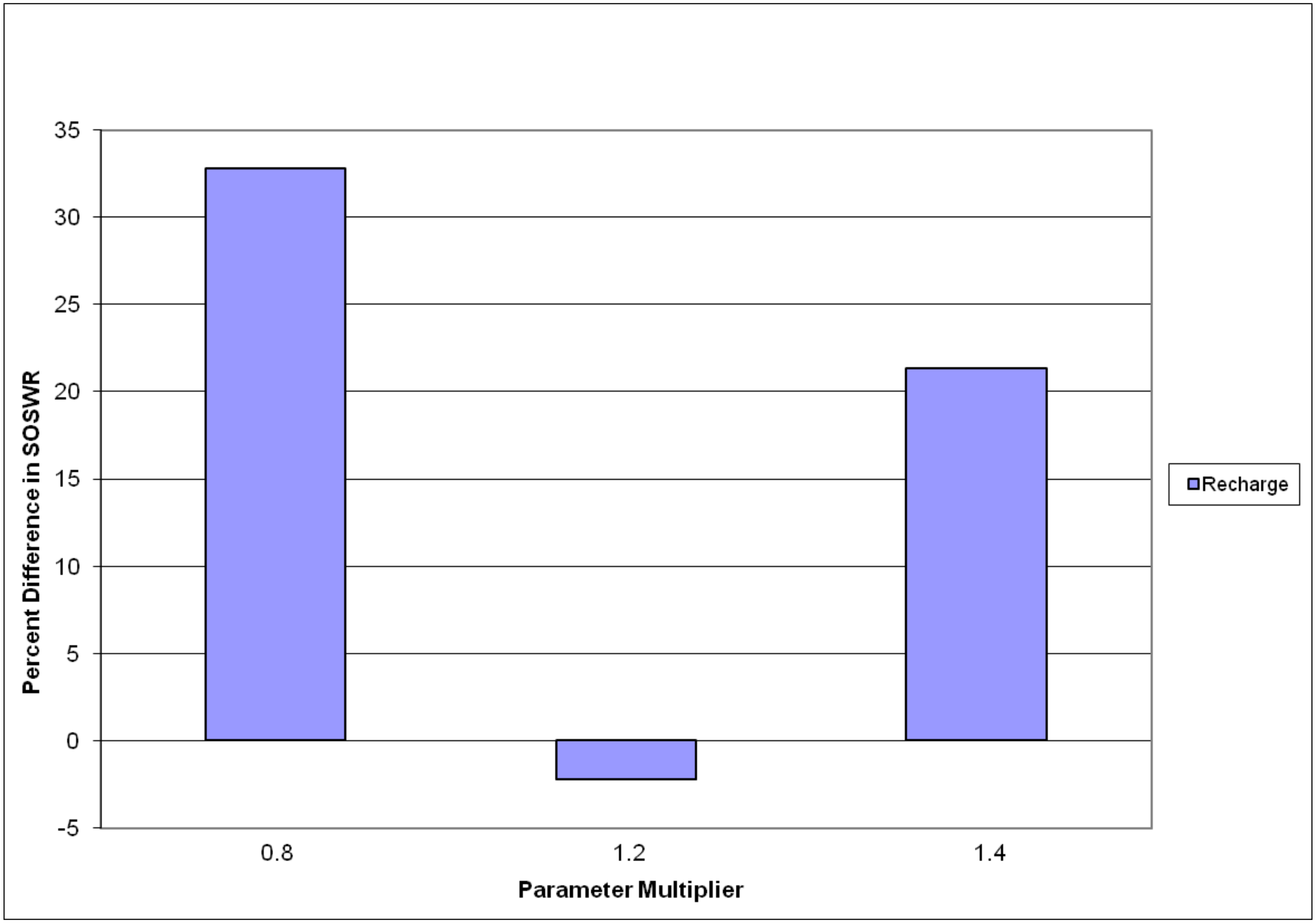
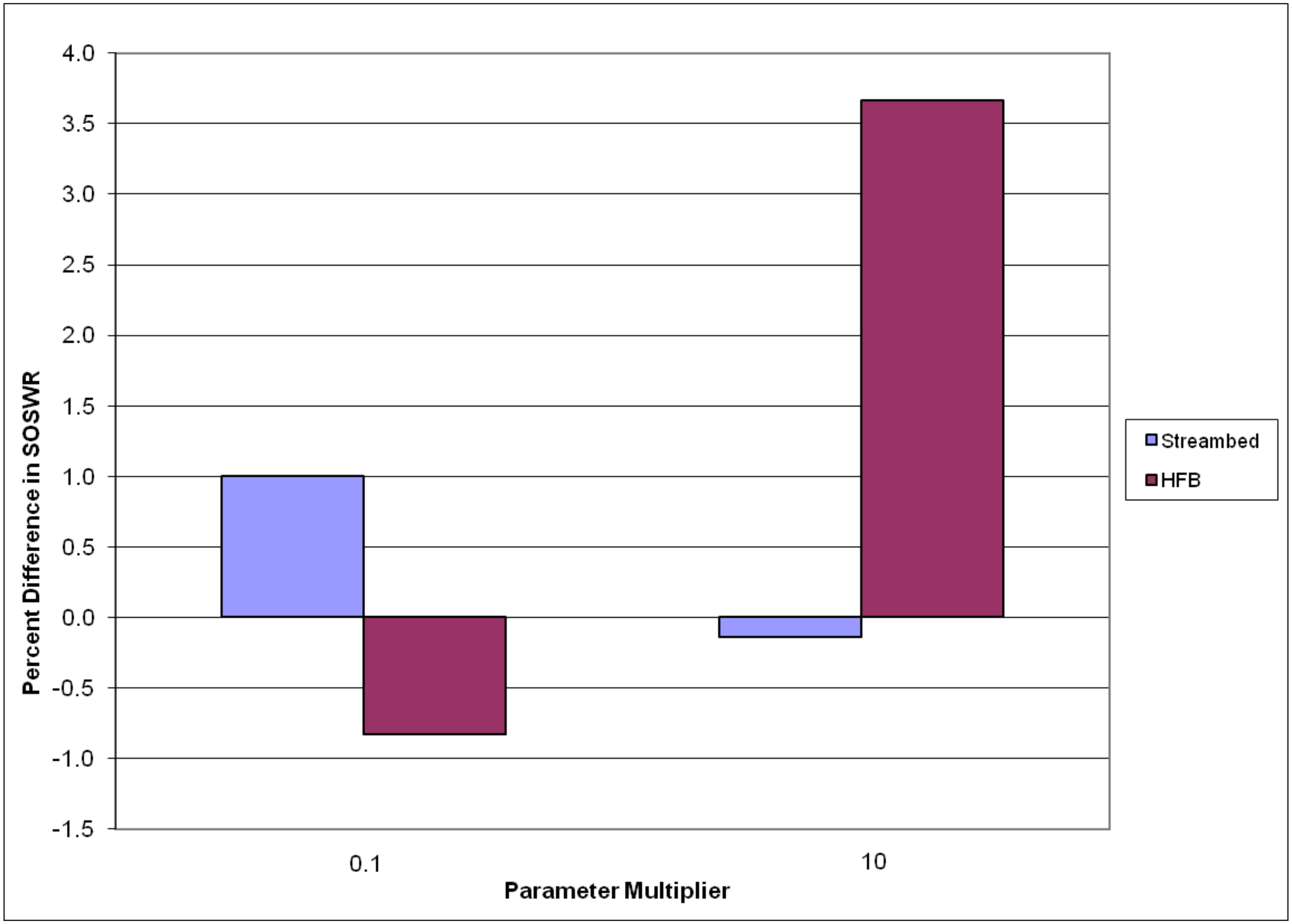
Figure 4
Vertical Hydraulic Conductivity Sensitivity by Rock Type



SOSWR: Sum of squared weighted residuals

Figure 5
Recharge Sensitivity



SOSWR: Sum of squared weighted residuals

Figure 6
Streambed Hydraulic Conductivity and Horizontal Flow Barrier Sensitivity