Brianna Svoboda **Hydrogeology Student**

1310 Maple Street
Golden CO 80401

brsvobod@mines.edu
Phone: 303-234-5678

January 30, 2014

City of Golden
911 10th Street
Golden, CO 80401
303-384-8000

Subject: Analysis of Pump Test Data from Golden, CO

Dear Dave:

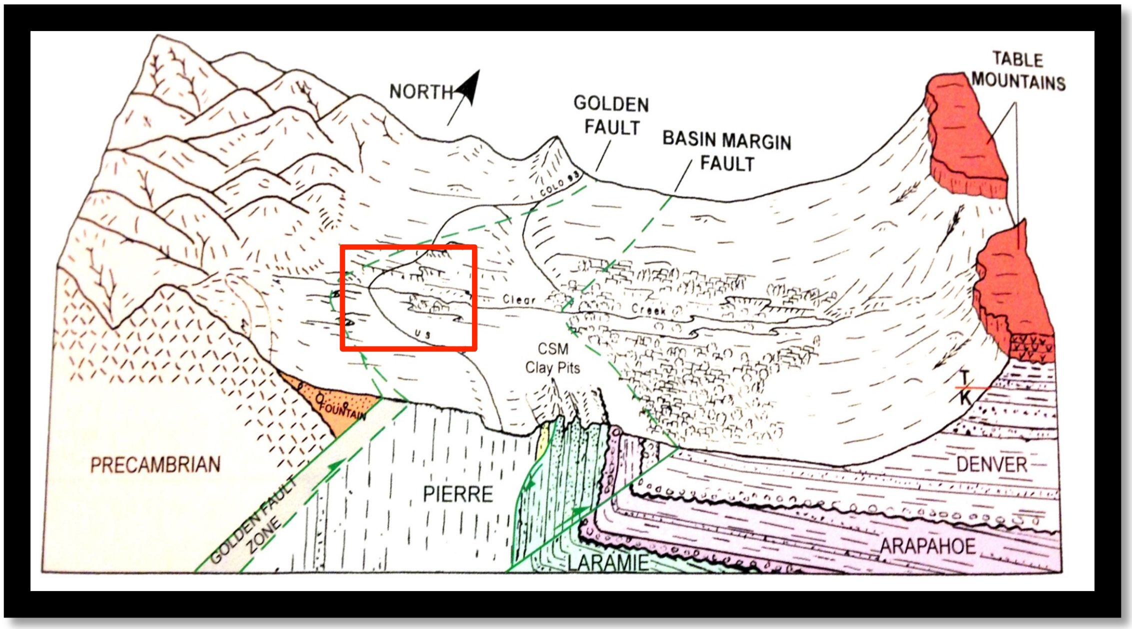
The City of Golden requested data analysis of pump tests performed near 6th Avenue and Clear Creek, just north of the Colorado School of Mines campus. The data was collected by another company. The following report contains information about the local geology and hydrology of the site, a Cooper-Jacob analysis, motivation for modeling, and modeling methods and results. Conclusions and recommendations are also included for your consideration.

1.0 Local Geology and Hydrology

1.1 Local Geology

The site is characterized by well-drained soils consisting of fine to coarse grained sand and clay (WebSoilSurvey Staff, 2014). The unconfined aquifer at the site is approximately six to seven feet below the ground surface, located in the well-drained soils (WebSoilSurvey Staff, 2014). Additionally, the Golden Fault runs through the study area (refer to Figure 1) (Weimer et al., 2011).

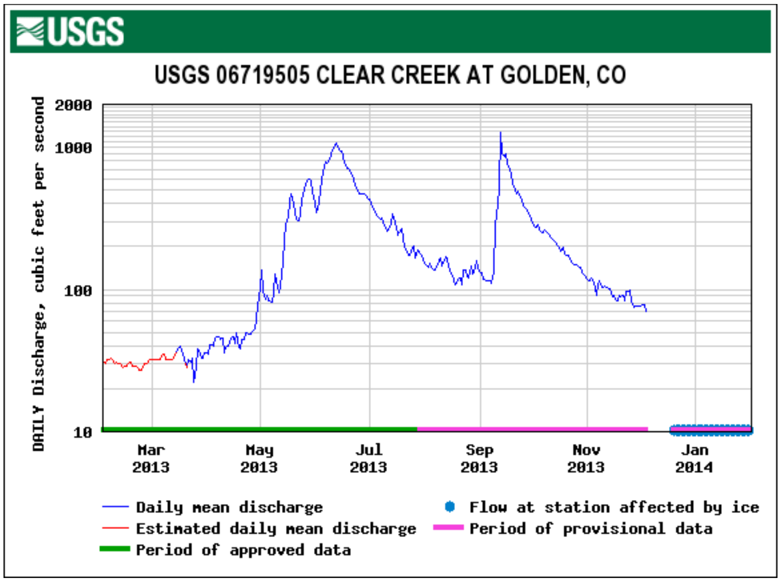
Figure 1. *"Sketch of geology of Golden area with Golden, Basin Margin, and Clay Pits faults (After F.E. Moore)" (Weimer et al., 2011*
Note: Red box designates an approximation of the site area for the pump tests completed near 6th Avenue and Clear Creek.



1.2 Clear Creek Watershed

Surface water from Clear Creek is located within 300 feet of the observation wells one and two. The Clear Creek drainage area is 394 square miles (USGS staff, 2014). The daily discharge of Clear Creek, in cubic feet per seconds (cfs), ranges between approximately 30 cfs to over 1000 cfs in a given water year due to variable seasonal runoff rates (refer to Figure 2).

Figure 2. *Daily Discharge of Clear Creek (2013 WY) (USGS Staff, 2014)*



2.0 Initial Analysis by Cooper-Jacob

2.1 Method and Results

The Cooper-Jacob method was used for the initial analysis of the unconfined aquifer within the site area. Storativity and transmissivity of the aquifer were evaluated by plotting drawdown (ft.) v. the log of time (days) (Refer to Figure 3). The hydraulic conductivity was also approximated by dividing the calculated transmissivity by the aquifer thickness of 30ft (refer to Table 1).

Table 1. *Results from the Cooper-Jacob Method*

Observation Well	Q (ft^3/d)	s (ft.)	t_o (days)	r (ft.)	r^2 (ft^2)	T (ft^2/d)	S (dimensionless)	K (ft./d)
1	4000	0.74	0.23	150	22500	989.34	2.28E-02	32.98
2	4000	0.365	0.45	250	62500	2005.79	3.25E-02	66.86
3	4000	0.72	0.9	300	90000	1016.82	2.29E-02	33.89

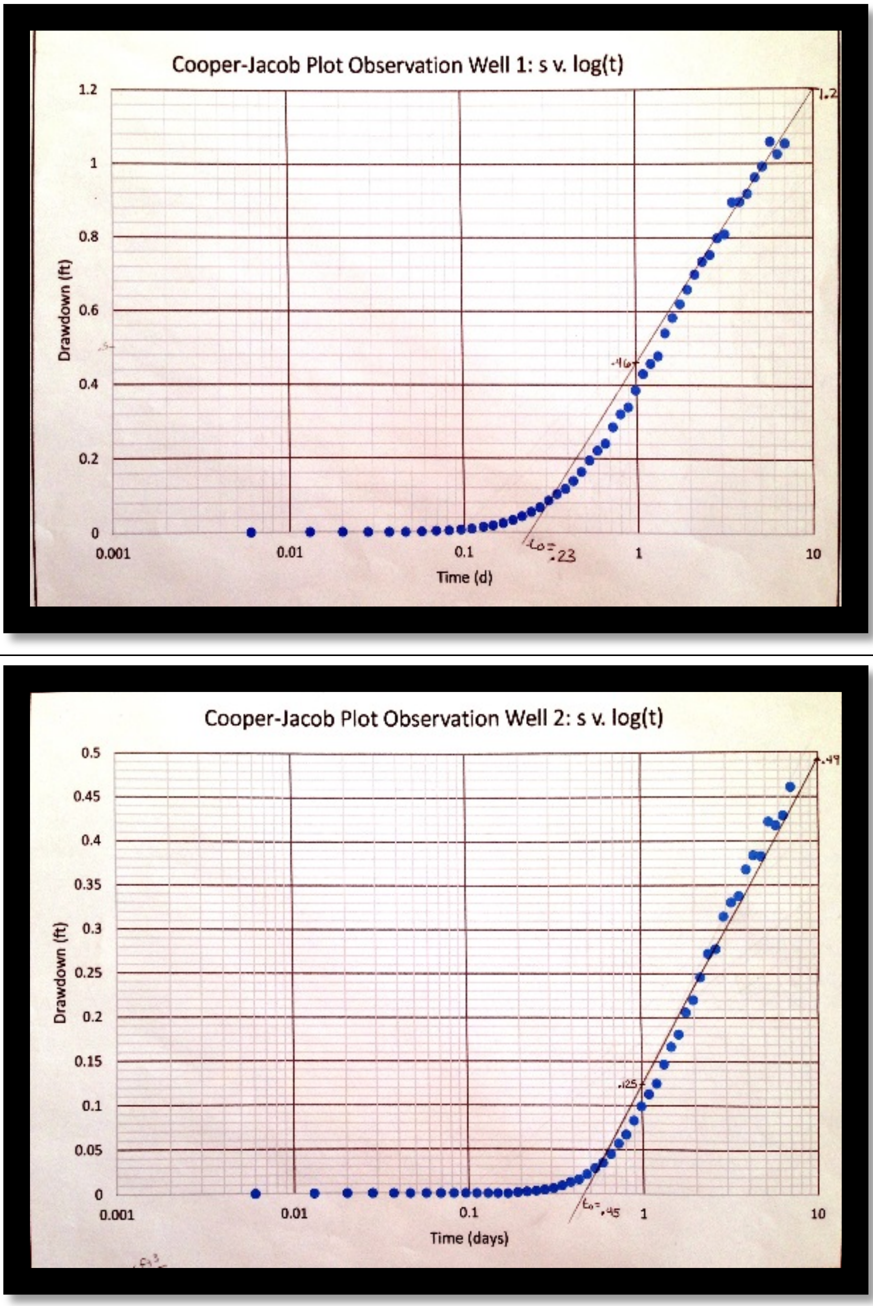
Note:

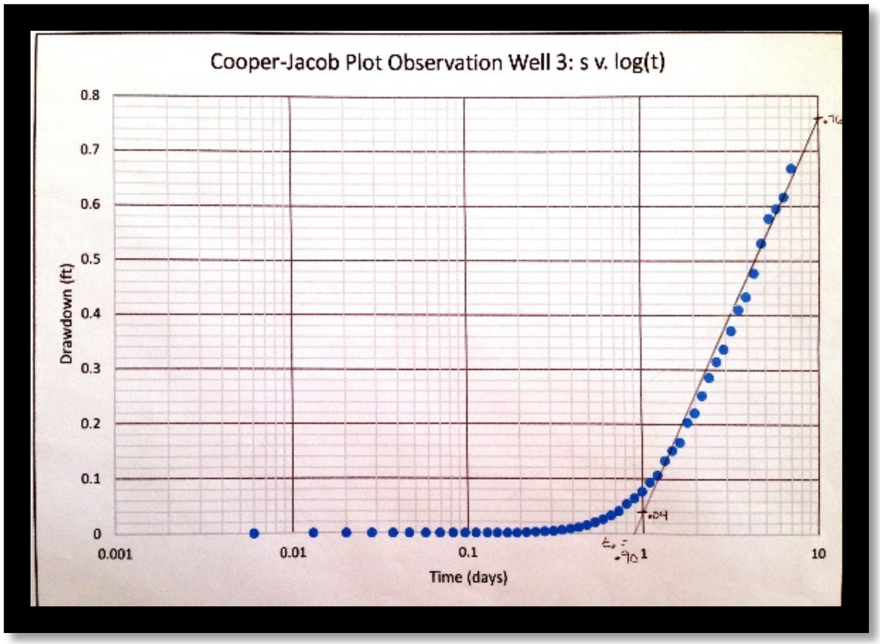
Q: Pumping rate, s: Drawdown, t_o: time at zero drawdown, r: radius between pumping well and observation well, T: Transmissivity, S: Storativity, K: Hydraulic Conductivity, b: aquifer thickness

Equations used in the Cooper-Jacob Analysis:
$T= (2.3Q) / (4\pi (h_0-h))$
$S= (2.25Tt_0) / (r^2)$
$T= Kb$

In general, the Cooper-Jacob results approximate the hydraulic conductivity in wells one and three to be around 33 ft. /day. Well two resulted in a much higher hydraulic conductivity rate of 66 ft. /day. The storativity of wells one and three were similar at a value of 0.02. Well two slightly deviated with a storativity value of 0.03.

Figure 3. *Cooper-Jacob Plots for Wells 1, 2, and 3 (Note the linear drawdown approximation)*





2.2 Potential Errors

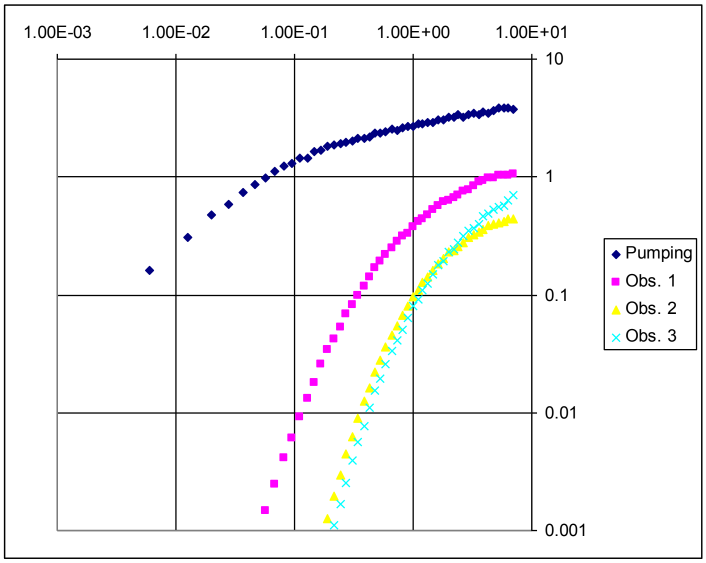
The Cooper-Jacob method assumes that the drawdown in the aquifer is linear. There are several potential errors associated with this assumption including that the recharge and no-flow boundaries are not accounted for in the calculations. The Golden Fault creates a no-flow boundary, which may influence the drawdown in well three that has the closest proximity to the fault. Well two is the closest in proximity to Clear Creek and both the hydraulic conductivity as well as the drawdown of the well are significantly influenced by the creek.

Additionally, the variability in the heterogeneity of the soils was not accounted for in the Cooper-Jacob method. This could influence the transmissivity and hydraulic conductivity near the three monitoring wells. Overall, the Cooper-Jacob results are a linear estimation which do not account for any non-linear behavior in the system.

3.0 Motivation for Modeling Work

The unconfined aquifer at the site is characterized by non-ideal aquifer behavior, where recharge and no-flow boundaries influence the drawdown in the observation wells (refer to Figure 4). In order to more accurately represent the physical system and to better evaluate the parameters of the unconfined aquifer, modeling work was completed.

Figure 4. *Non-ideal aquifer behavior (Benson, 2014)*



Note: Drawdown in observation wells 2 and 3 cross each other, which illustrates the presence of recharge and/or no-flow boundaries in the area.

4.0 Methodology

4.1 Development of the Model

The modeling program MODFLOW was used to model the aquifer system. The provided pump test data was used to calibrate the model. The model used designated no-flow boundaries where bedrock and faulting were present in the site. Constant head boundaries were assigned to Clear Creek and were set at 30 cfs to simulate the lowest daily discharge of the stream. The model was run at a transient state in order to observe a cone of depression over time for the drawdown in each well. Model parameters of hydraulic conductivity and storativity were adjusted to fit the model results with the measured data.

4.2 Potential Modeling Errors

Sources of error in developing the model reside in approximating the placement of the pumping well and observation wells in the site. Placement of no-flow boundaries, particularly the Golden Fault, in the site area are also sources for error. If they were placed inaccurately it could influence the data produced by the model. The designation of Clear Creek as a constant head boundary may have contributed to some error in the model because in the field the discharge rates of Clear Creek are variable from approximately 30 cfs to over 1000 cfs depending on the time of year and seasonal runoff (USGS Staff, 2014).

5.0 Results

After completing calibration of the model, it was determined that the aquifer parameters that best fit the measured data include the following:

Hydraulic Conductivity (K) (ft./d)	Storativity (S) (dimensionless)
25	0.04

The calibration results of the model data, along with the measured data, are graphically represented in Figures 5 and 6 below.

Figure 5. *Drawdown v. Log Time of Measured and Model Data (Note: The red model line coincides with the green model line at the beginning of the model drawdown time.)*

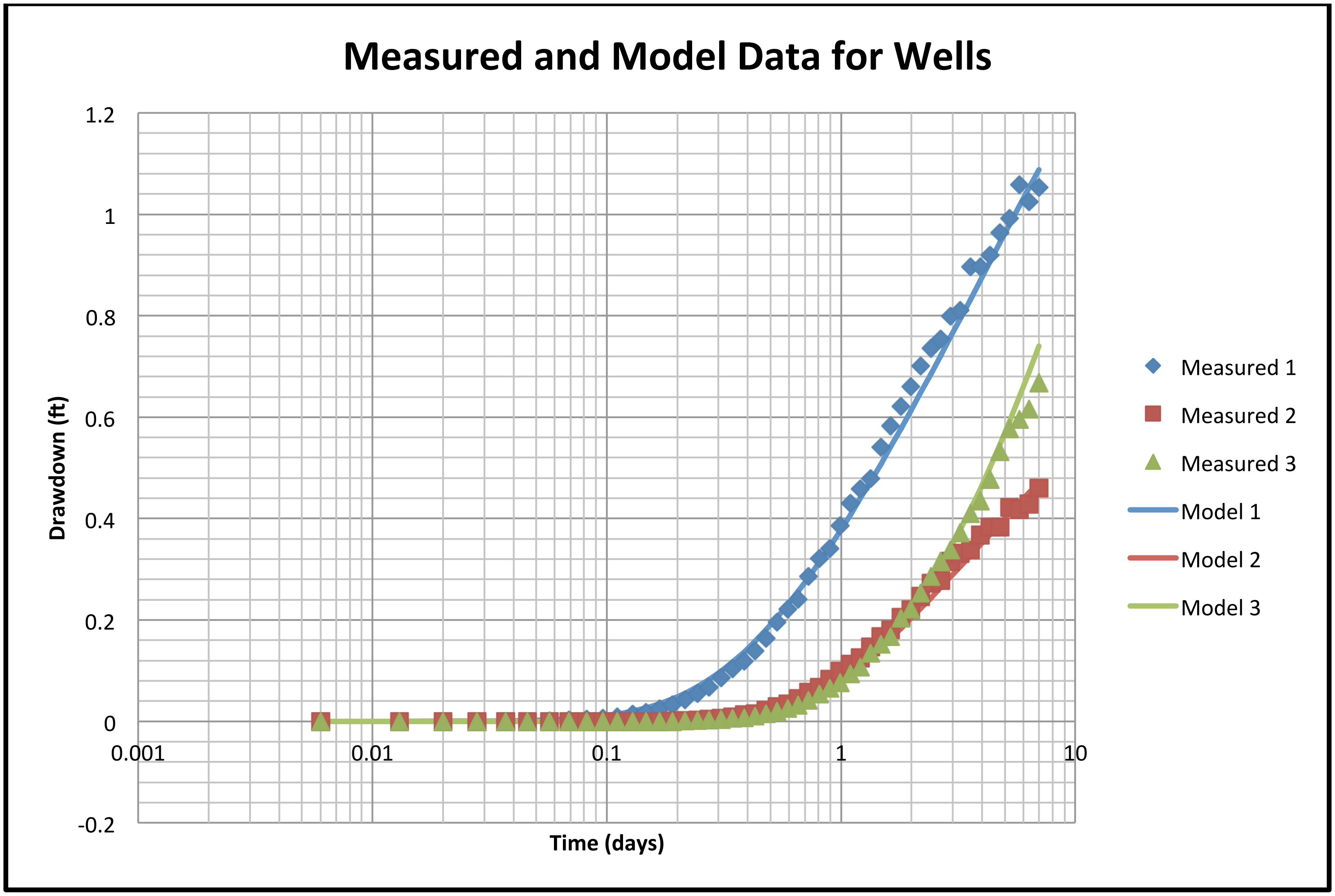
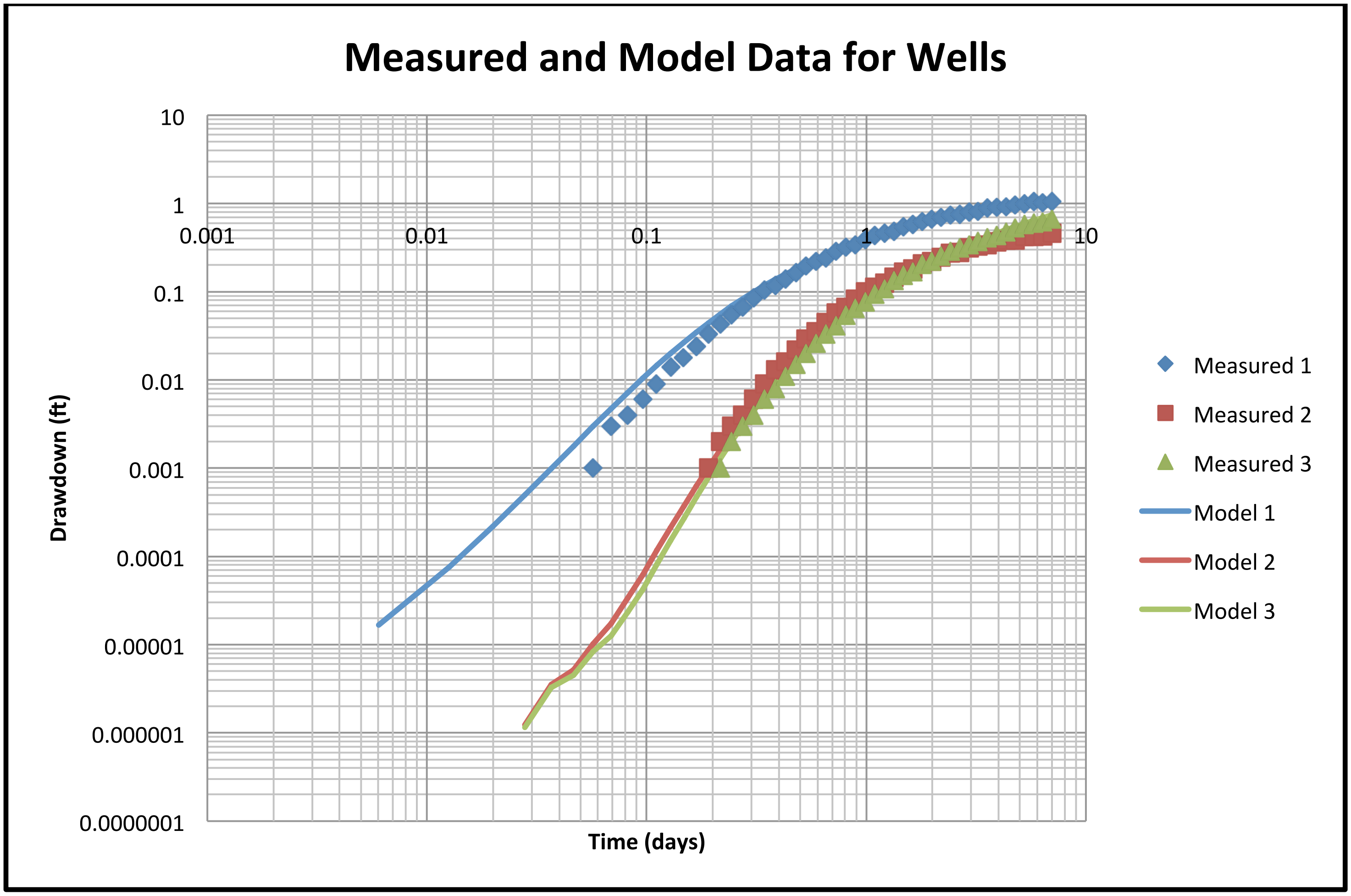


Figure 6. *Log of Drawdown v. Log of Time Plot for Visualization of Measured and Model Data Fit*



6.0 Conclusions & Recommendations

- The calibration of the model data with measured data displays that the best fit parameters for the unconfined aquifer in the field has a hydraulic conductivity that is approximately 25 ft./day and a storativity of 0.04.
- Typical hydraulic conductivities for soils that contain mostly coarse grain sand to gravel are around 50 ft. /day (EVS Staff, 2014). Soils with a mixture of grain sizes of sand and clay typically have hydraulic conductivities in the range of 10 to 40 ft. /day (EVS Staff, 2014). Relatively, the hydraulic conductivity in the model was an average to lower value of typical hydraulic conductivity ranges for soils composed of sand and clay.
- The storativity for an unconfined aquifer typically ranges from 0.02 to 0.30 (Zhang, 2014). In comparison, the storativity of the unconfined aquifer at the site is relatively low at a value of 0.04.
- The deviation of the end drawdown behavior in observation well one in the model may be explained by a no-flow boundary near the well, resulting in more drawdown than measured in the field.

- The model data and the Cooper-Jacob method result in different parameters for the aquifer. The linear estimation of the Cooper-Jacob model does not account for recharge boundaries (Clear Creek) or for no-flow boundaries that impact the drawdown of the wells.
- The constant head boundary for Clear Creek does not reflect the variability in discharge throughout the year and the varying impact the flow rate may have on the hydraulic conductivity of well two.
- Additional site investigation and soil testing is recommended to better understand the materials present at the site and to obtain a more specific location of the Golden Fault.
- For more accurate modeling, surveying data for well and pump placement is suggested for future studies.

If you have any questions or concerns, please do not hesitate to contact me directly at brsvobod@mines.edu or at 303-234-5678.

Sincerely,

Brianna Svoboda
Hydrogeology Student
Colorado School of Mines

References

Benson, D. 2014 “GEGN470 Class Notes,” Colorado School of Mines.

EVS Staff, 2014, “5 Hydraulic Conductivity,” Environmental Science Division, Argonne National Laboratory, Accessed on 2/4/14 at http://web.ead.anl.gov/resrad/datacoll/conuct.htm

USGS Staff, 2014, “National Water Information System: USGS 06719505 Clear Creek at Golden, CO,” Accessed on 2/2/14 at http://nwis.waterdata.usgs.gov/nwis/nwismap/?site_no=06719505&agency_cd=USGS

WebSoilSurvey Staff, 2014, “AOI: Golden, CO,” USDA Natural Resources Conservation Services. Accessed on 2/2/14 at http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Weimer, R., Sonnenberg, S., & Martin, L. 2011, “A Guide to Mines Geology Trail, Colorado School of Mines,” Geology Museum Special Publication, No. 3

Zhang, P., 2014, “EAS44600 Groundwater Hydrology Lecture 8: Storage Properties of Aquifers,” Accessed on 2/4/14 at mail.sci.ccny.cuny.edu/~pzhang/EAS44600/EAS446lec8.pdf