Geology 208

A Groundwater Flow Model of the California State University, Sacramento, Subsurface

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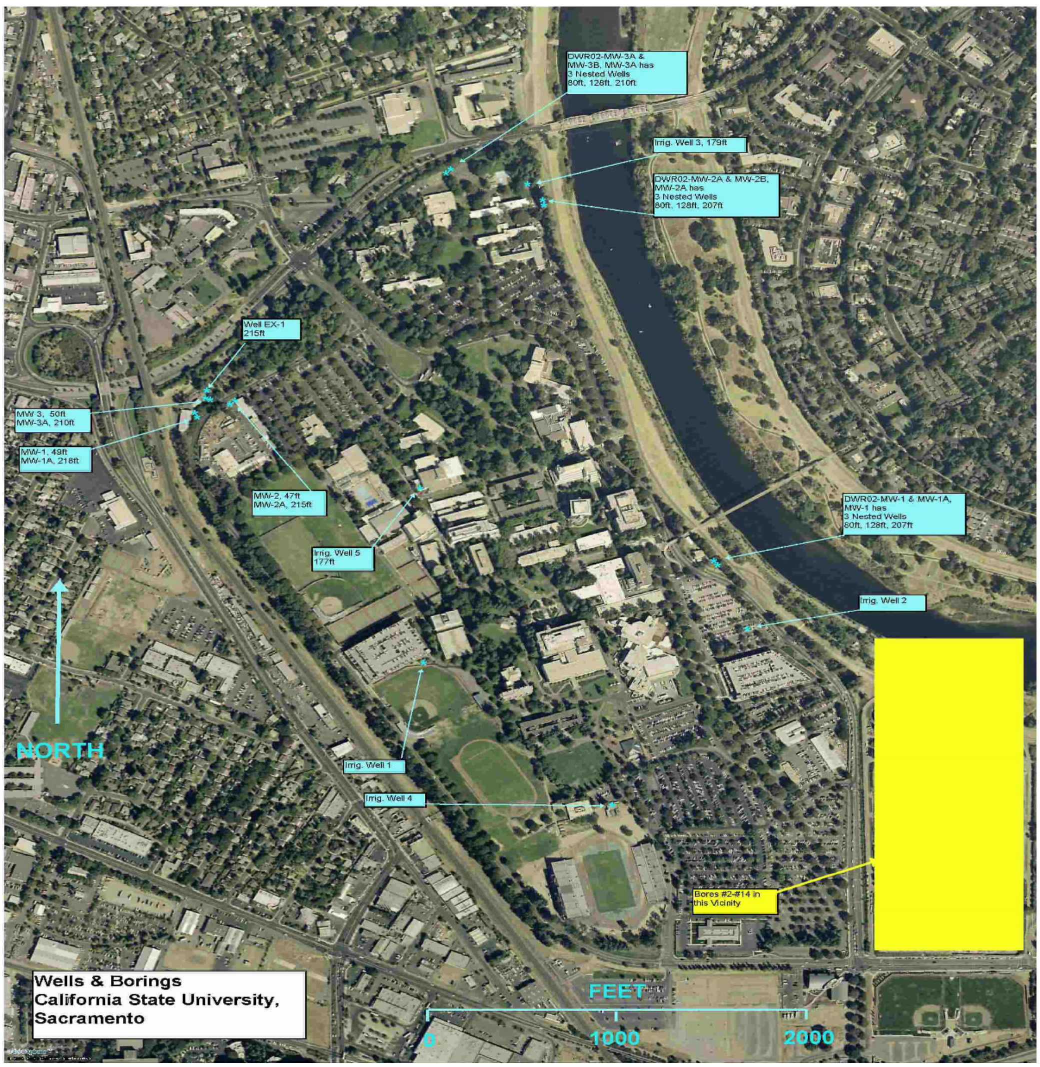


Table of Contents

Introduction

The objective of this project is to develop a model of an aquifer that exists in the area of the California State University, Sacramento. Once proven to be a useful tool, this model is intended to be of assistance in the research necessary to develop a modified instantaneous pulse slug test that may enable hydrogeologists to better evaluate the hydrology of the subsurface.

This project is also for the purpose of meeting the requirements Geology 208, Groundwater Modeling, of the California State University, California, Geology Department, and for the purpose of becoming more proficient at groundwater modeling.

I want to express my appreciation to my future step daughter, Meghan Anderson, for doing much of the necessary “leg work” in finding the State agencies and the CSUS departments that maintain information on the existing campus wells, and for her help in taking the series of depth-to-water measurements needed for the initial conceptualization and history matching.

Section II

Conceptual Model

The subsurface in the area of the California State University, Sacramento (CSUS), has been the site of operating wells for at least forty-five years. Since the first CSUS irrigation well was put into service in 1957, there have been approximately seventeen additional borings penetrating from forty to over three hundred feet below the surface (see appendix 6 for well locations). All of these wells are in excellent condition, and most are available to further examine the properties of the strata through which they are cased and screened. Additionally, there are numerous interpretations available on the geology and hydrology of the subsurface (Chamberlain, 1994 – appendix 25). In view of this, it is easy to conclude that there is enough data available to produce a groundwater model of this site.

The site is located adjacent to and south of the American River between US Highway 50 and the Sacramento California City 'H' Street (see appendix 5 for area and local topographic maps). It is on the flood plane of the American River and is protected from high river stages by a human-made levee system. Surface elevations at the site range from approximately 40 feet MSL near the river to 30 feet MSL on the west and south sides of the campus.

The site is located in a temperate climatic zone which averages approximatyely18 inches of rain per year, which almost exclusively falls in the "winter" months. It has an average annual temperature of approximately 67 degrees Fahrenheit. This model is being based in the month of May, which averages 0.3 inches of rainfall and temperatures ranging from highs in the mid eighties to lows in the mid fifties. Landscaping on campus requires and receives irrigation with water pumped from wells on campus during this month. The quantity of water pumped per month is summarized in appendix 23.

The geology of the shallow subsurface is Pliocene to Recent fluvial sediments . On-campus borings show a complex system of interbedded sands, silts, gravels, clays, and combinations of these materials. Attempts have been made to correlate beds between wells, but a generalized pattern is probably all that can be made of most of the beds. One bed that does have good communication across the site is at a depth of approximately 190 feet to 200 feet below the surface. This is the "aquifer of interest" for this model. It generally consists of fine to coarse sands including sands from 1.5 to 2 mm in size, high resistivity, and a description in the borings logs that enable it to be correlated in each of the available boring logs. Thickness of this bed varies from 10 feet in the area of wells EX-1 and DWR02-MW-1A, 15 feet at well DWR02-MW-2A, 20 feet at DWR02-MW-3A, and 12 feet at Irrigation well no. 5 (see fence diagram in appendix 4). From a recent pumping test done at well EX-1, results for transmissivity and hydraulic conductivity were 4200 ft^2/day and 210 ft/day respectively and a value of 2.2×10^{-4} was obtained for storativity. The test was conducted for approximately three hours and, during that time, there was no evidence of leakage from the upper aquifer which is screened in well MW-3A from 27 feet to 47 feet. There was drawdown and associated decay at a distance of approximately 2000 ft in well DWR02-3A which is screened from 175 ft to 195 ft. This is good indication that the "aquifer of interest" is a confined aquifer, is relatively homogeneous, and extends throughout the area of the model.

From initial measurements of hydraulic head, groundwater flow in the "aquifer of interest" appears to be from the northeast to the southwest. Perimeter boundaries on all sides are 'General Head Boundaries' with inflow coming from a distant source to the northeast and flowing to a distant sink in the southwest. Recharge from overlying aquifers appear to be negligible and therefore recharge from the surface is also negligible. Outflow also exists from pumping at the five irrigation wells. During the month of May, this averages 30,156 ft^3/day, which normally occurs during the night while the campus is unoccupied.

Section III

Description of the numerical groundwater model

In deciding the type of model to use, three things were considered: 1) The subsurface in this area was complex enough to require a numerical model, 2) due to the presence of operating extraction wells, the model must be at least two-dimensional, and 3) the model must be one that the author was already trained to use. Visual Modflow (VMod) from Waterloo Hydrogeologic was chosen because it met all three requirements.

After entering the required model default values (see appendix 7), an aerial photo was chosen for the model background. Using a photo as a background would not only give the user interface a more agreeable backdrop, it would also make it easier to place existing wells for which georeferencing coordinates were not available. To get adequate coverage of CSUS and the surrounding area, four photos were obtained from GlobeXplorer and then 'stitched' together using photo software. The area covered is larger than necessary for this report but was chosen in the event enlarging the geographical scope of the model became necessary in the future. The photo was imported into VMod and then georeferenced using coordinates that were available from observation wells DWR02-MW-1 and DWR02-MW-3A.

Information used to 'build' the subsurface layers was found in boring logs that were obtained from the CSUS Geology Department and from the State of California Department of Water Resources (see appendices 10 thru 23). Four logs were used predominately; EX-1, DWR02-MW-3A, DWR02-MW-1, and Irrigation well #5. The same information from these four wells that was used to build the model, was also used to produce the 'fence diagram' found in appendix 4. X, Y, and Z coordinates for each layer from each well were entered into

Microsoft Excel, imported into Surfer, and then imported into VMod to produce interpolated surfaces at each interface.

The layers were defined hydrologically. Layer 1 was defined as the earth's surface down to the water table (based on May 6, 2004). Layer 2 was defined by a layer of sand and gravel that was identifiable in most borings. Layer 4 was defined by the easily identified coarse and volcanic sand strata that was found in all borings. And, layer 3 was defined as that layer of interbedded sands, silts, and clays between the layer 2 gravels and the layer 4 sands. As a result of an aquifer pumping test done by the CSUS Geology 210 class on April 17, 2004 and the available well logs, layers 1 and 3 were assigned low conductivity values, layer 2 was assigned a higher value, and layer 4 was given the highest (see appendix 7 for initial settings). The values of conductivity and storage for layer 4 were based on data from the pumping test, while values for the remaining layers were assigned based on well logs and standard values.

There are five pumping wells on the CSUS campus. No information was found on the placement of the screens in these wells. The depths of two of the wells are known and from their logs, it is likely these two are screened in layer 4. It will be assumed for this report that the other three irrigation wells are also screened in layer 4. Monthly discharge rates were obtained from the CSUS Grounds Office. Since irrigation is done at night, the individual rates for the month of May were adjusted and entered into the model to simulate each pump operating from midnight to 6:00AM daily for the seven day model period.

Recharge and evapotranspiration rates were entered but, since the target of this model is layer 4 and layer 4 appears to be a confined aquifer, no exhaustive effort was made to develop multiple zones with varying rates.

A record of the values used to build the model is summarized in table form in the appendix 7. Logging of initial entries were not made for the initial model building due to the extensive amount of trial and error in the calibration process. Once the model was accepted, all settings were recorded and placed in appendix 7 for future reference. Logging of entries was done after the historical matching during the sensitivity analysis so a record would exist of how the model varied from the initial settings. This method was used so it would be easier to review what values were used initially. These tables will be updated after additional historical matching is completed.

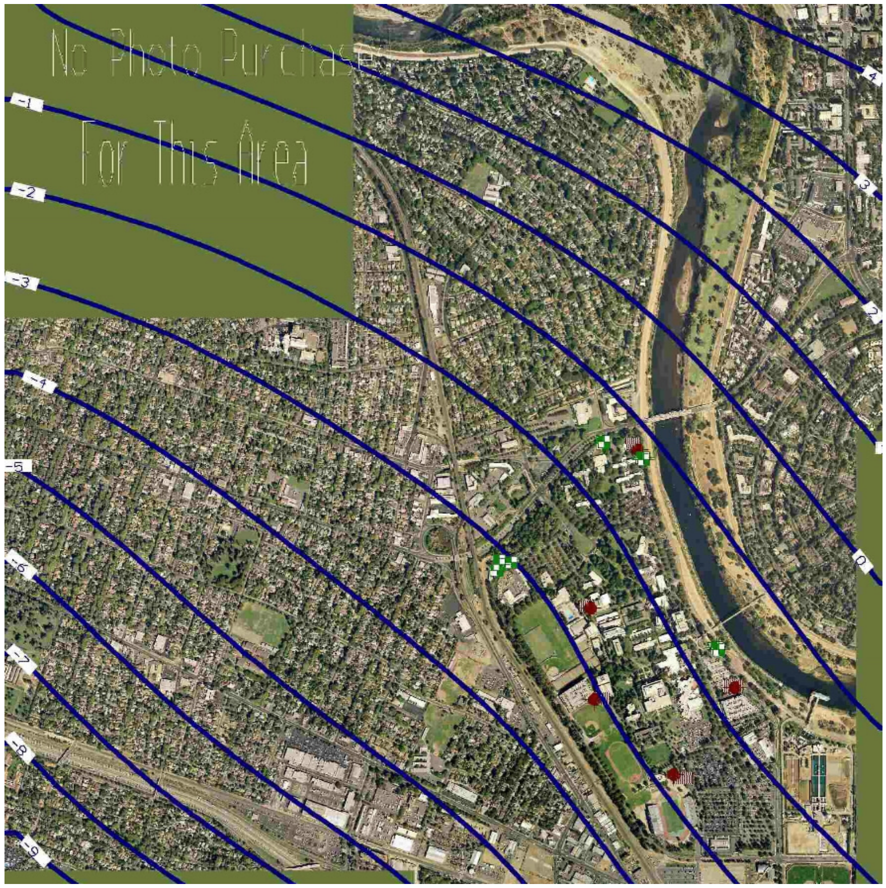
Calibration during the initial building process consisted of making numerous small changes in the gradient, head, and conductivity of the ‘general head boundaries’ combined with changes in layer 4 conductivity. These small changes continued until;

1) Equipotentials became uniform and relatively straight during non-pumping periods,
2) Realistic cones of depression formed during periods of irrigation pump operation,
3) History matching showed close correlations between the head at the observations wells and the model’s predictions,
4) The model converged when run in ‘transient flow’ mode, and
5) The ‘normalized RMS’ was in the range of 10% or less.

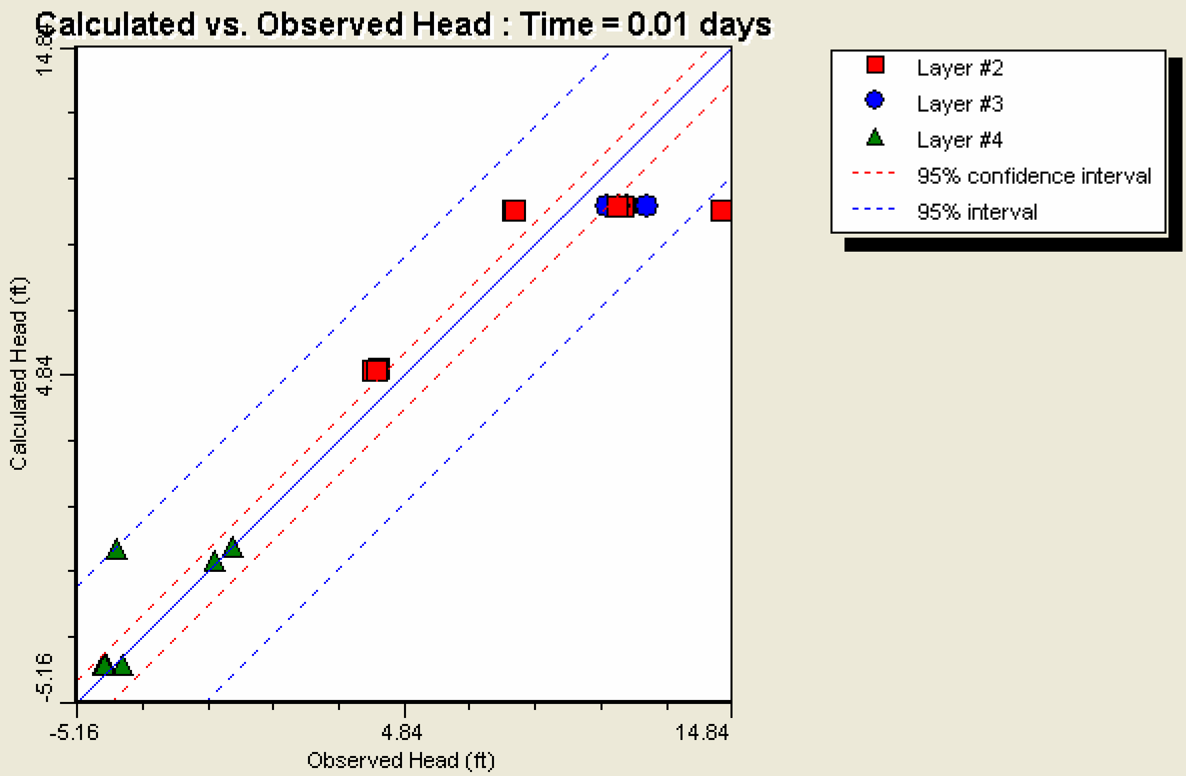
Maps showing layer 4 lines of equipotential during “pump on” and “pump off” periods are on the following page, and the head calibration graph showing the Normalized RMS under 10% is on the page that follows the equipotential maps.

At this point the model was ready for history matching.

Layer 4, Time Step 1, Irrigation Pumps ‘on’



Layer 4, Time Step 2, Irrigation Pumps ‘off’



Num. of Data Points : 19
Max. Residual: -4.642 (ft) at DWR02-MW-1A SHALLOW/SHALLOW
Min. Residual: 0.01 (ft) at DWR02-MW-3A-DEEP/DEEP
Residual Mean : -0.161 (ft)
Abs. Residual Mean : 1.315 (ft)

Standard Error of the Estimate : 0.409 (ft)
Root Mean Squared : 1.743 (ft)
Normalized RMS : 9.253 (%)
Correlation Coefficient : 0.972

Section IV

History Matching

Initial water level measurements were taken in all wells for use in the numerical model as “initial head observations” for the start of the 7 day run period. Water levels were then taken and recorded twice a day (with the exception of only one measurement on day 3) for the same 7 day period that was being used for the numerical model. The graphs of observed head and the graphs of calculated head for each of the observation wells are shown on the two following pages. These graphs were used to match the head predictions of the model with the actual history of the aquifer over the 7 day run.

The observed head graph indicates that the daily fluctuations in water level as a result of pumping from the irrigation wells was seen in both deep and shallow wells but was more pronounced in the shallow wells It also showed the existence of a steady decline in the average water level over the 7 day period. The calculated head graph predicted that the cyclical fluctuations from the pumping would only be observed in the deep wells and there would be a steady increase in water level over time.

Since the observed daily fluctuations are occurring in both the lower and upper layers and the calculated daily fluctuations only occur in the deep wells, there must be incorrect setting in the numerical model. There apparently is: 1) much more leakage thru the confining layer than predicted, 2) the irrigation wells are not screened in only the lower layer, or 3) a combination of both of these.

Taking this discrepancy into account, model settings were adjusted to give the irrigations wells screened intervals that included the upper layers and to give layers 2 and layer

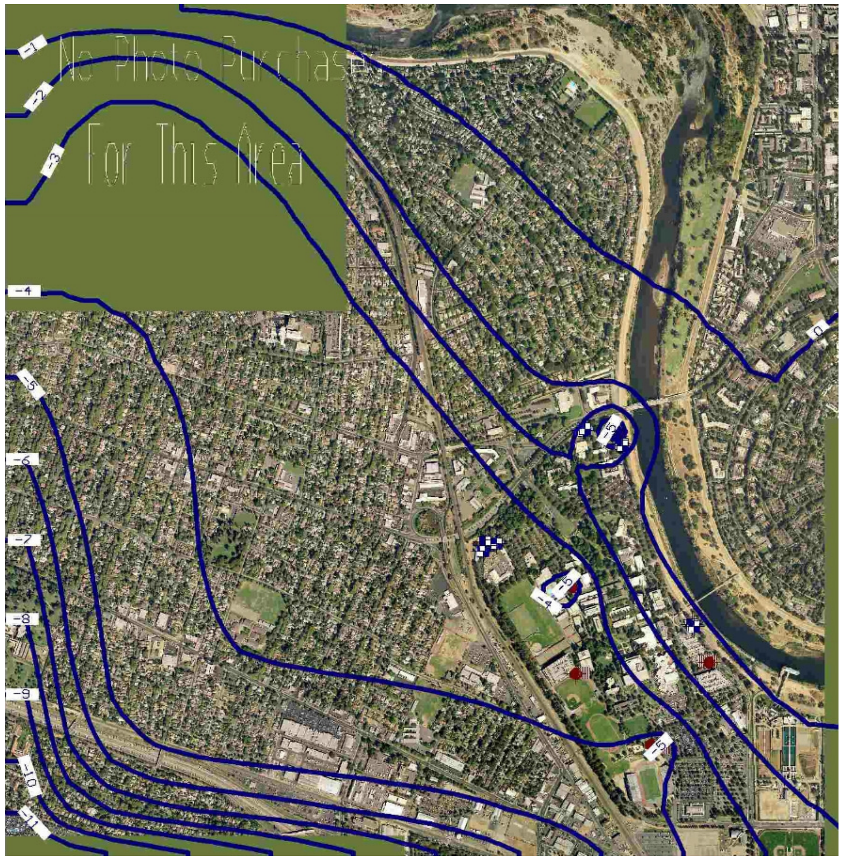
3 (the confining layer) higher conductivities. The log of these changes are included in appendix 7 along with tables of the initial settings.

It was found that modifying the screen elevations worked well for distributing the daily cyclical fluctuations between layer 2 and layer 4. Obviously more research is needed to find exactly where these wells are screened. It was also found that water levels in layers 2 and 4 are sensitive to changes in the hydraulic head at the model boundaries, and the conductivity of both the boundaries and the layer itself. By decreasing the conductivity of the boundaries, less water was entering the layer and then the model was able to simulate the gradual average decrease in water level that appeared in the observed well measurements in both the shallow and deep layers. There is also clearly a need to perform long duration aquifer pumping tests to accurately determine the amount of leakage in the confining layer, and more accurately determine the conductivity of the transmissive layers.

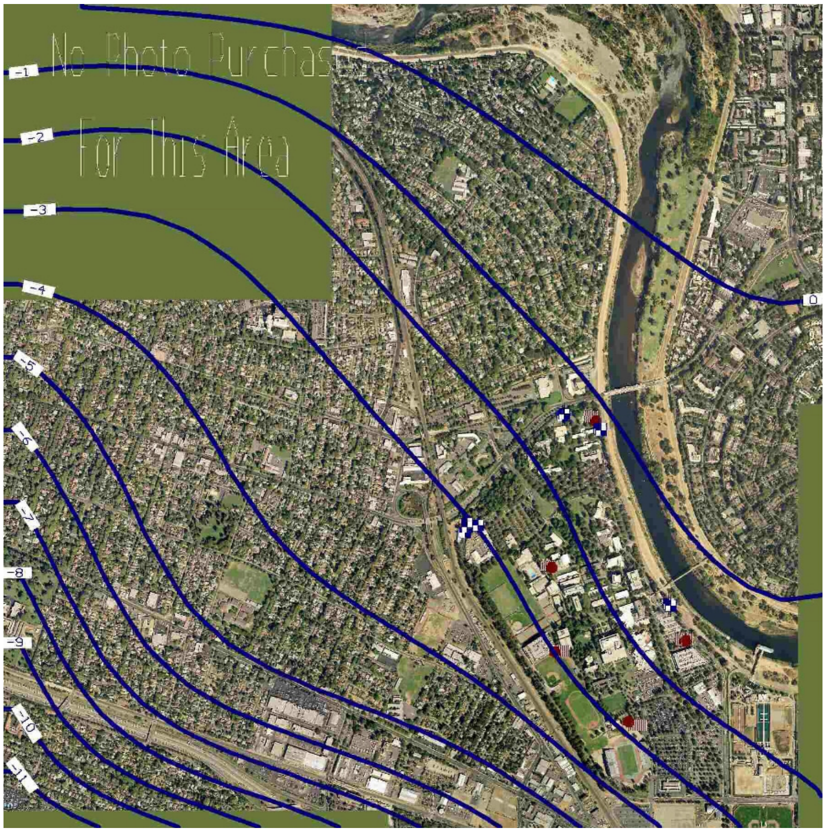
Graphs of calculated heads after the history matching corrections, and maps showing lines of equipotential, also after the history matching corrections, are shown on the following pages.

Layer 2 Time Step 1, Irrigation Pumps ‘on’
(after history matching & sensitivity analysis)

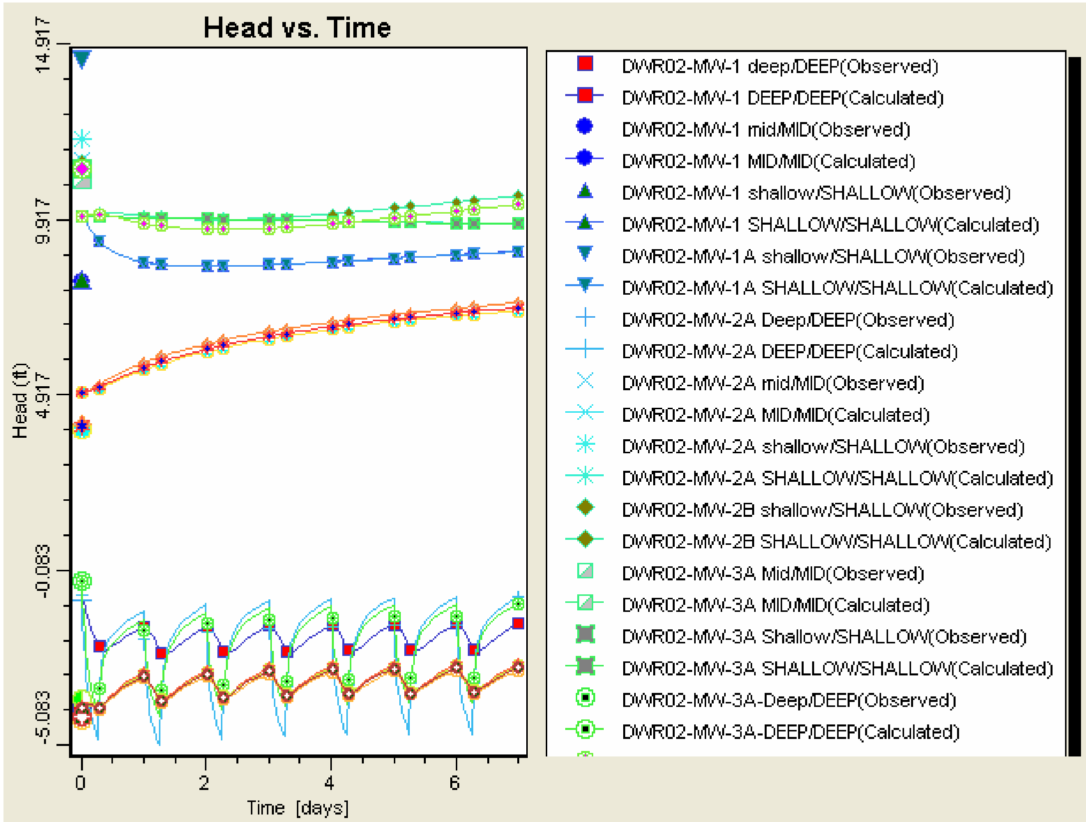
Layer 2 Time Step 2, Irrigation Pumps ‘off’
(after history matching & sensitivity analysis)



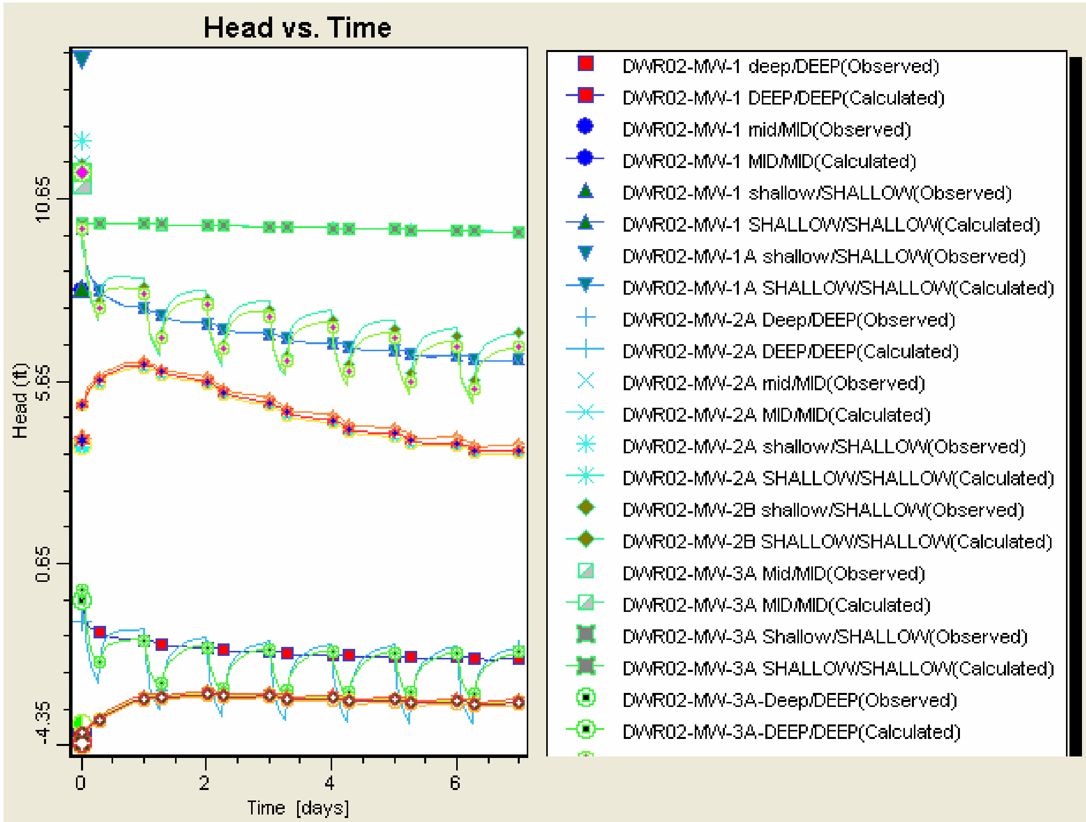
Layer 4 Time Step 1, Irrigation Pumps ‘on’
(after history matching & sensitivity analysis)



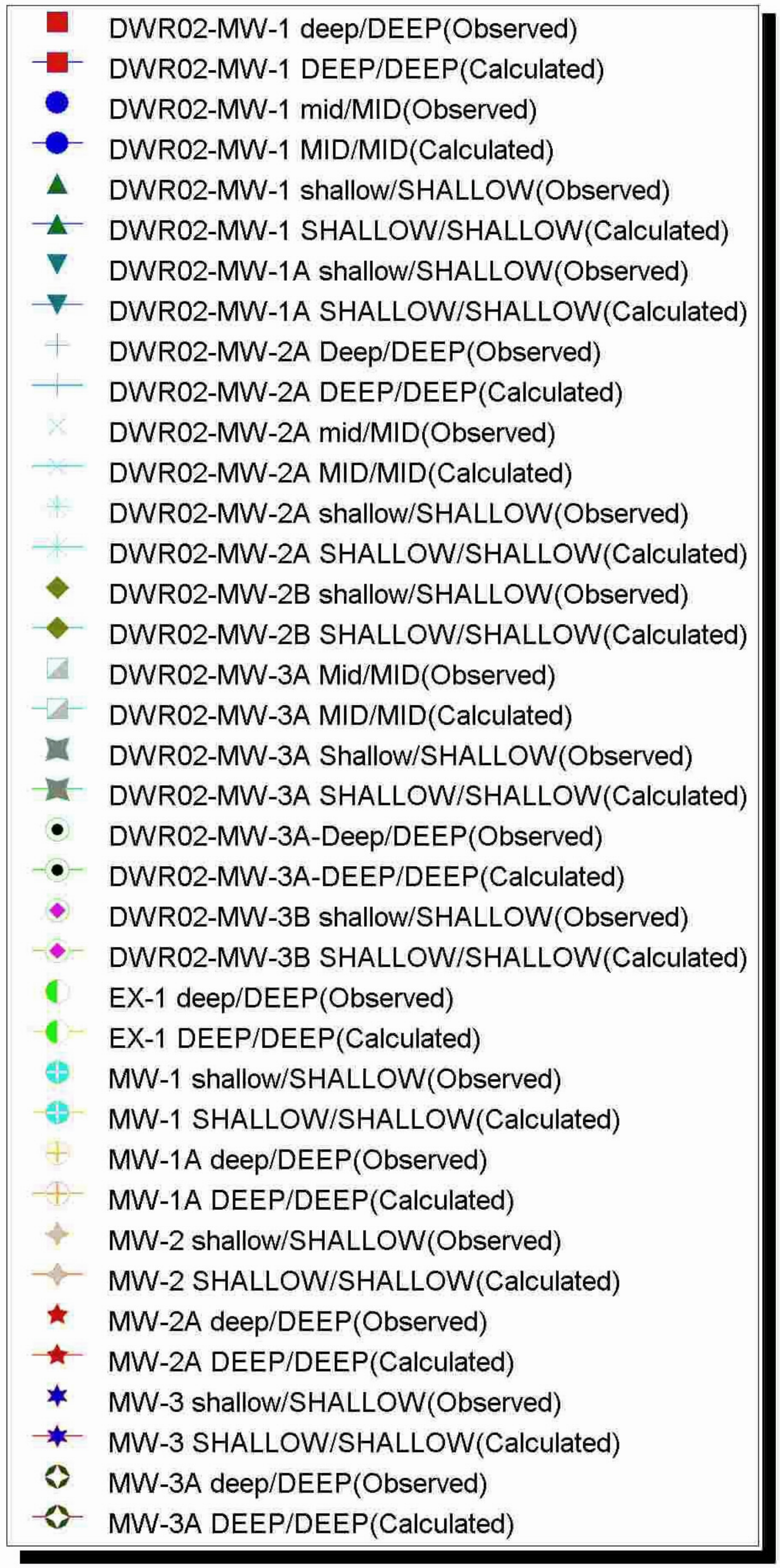
Layer 4 Time Step 2, Irrigation Pumps ‘off’
(after history matching & sensitivity analysis)



Calculated Heads
(before history matching and sensitivity analysis)



Calculated Heads
(after history matching and sensitivity analysis)
(see complete legend on next page)

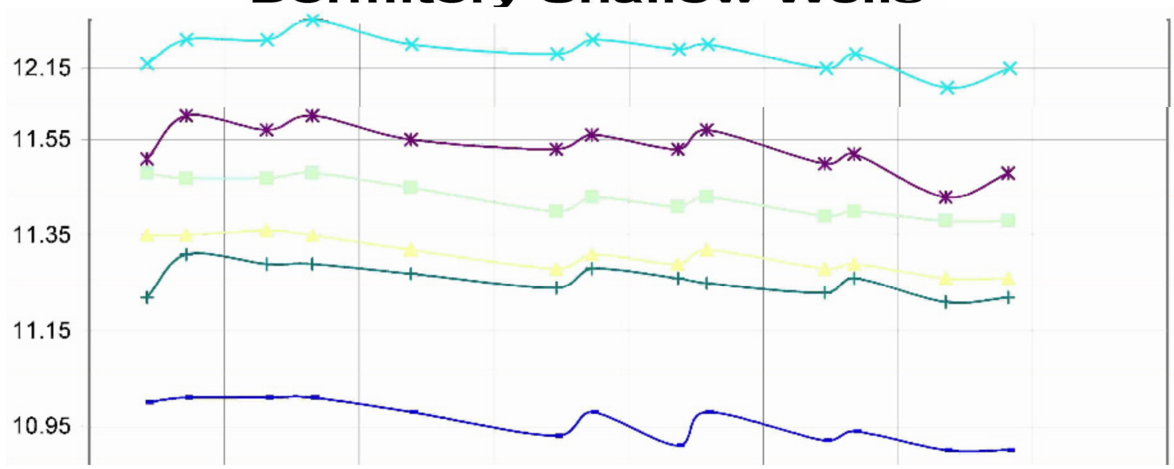


Complete legend for graphs on previous page

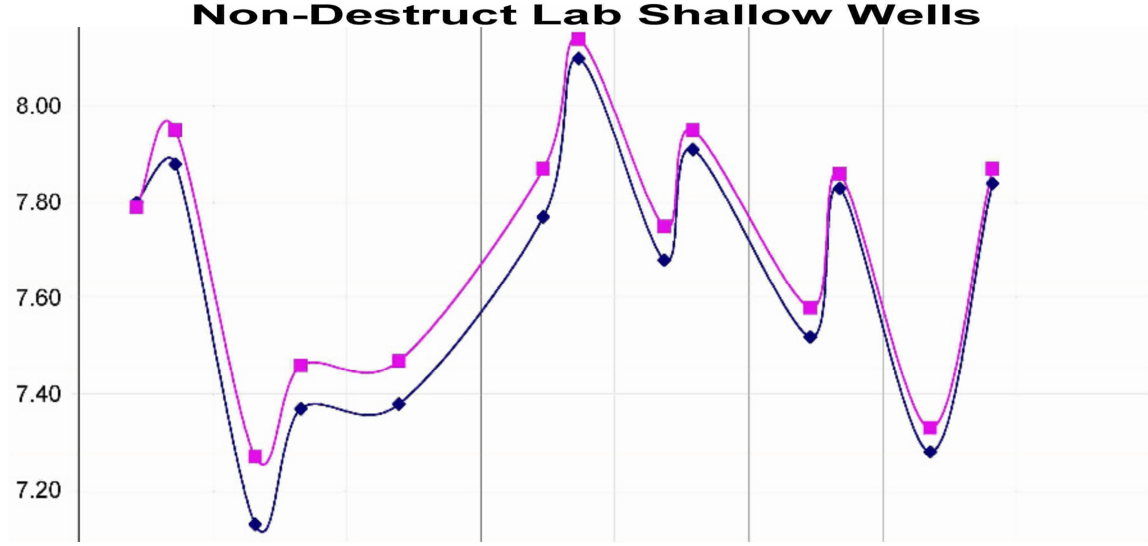
(legend follows)
(feet MSL)

Summary of Measured Well Water Levels
During 7-day Model Period

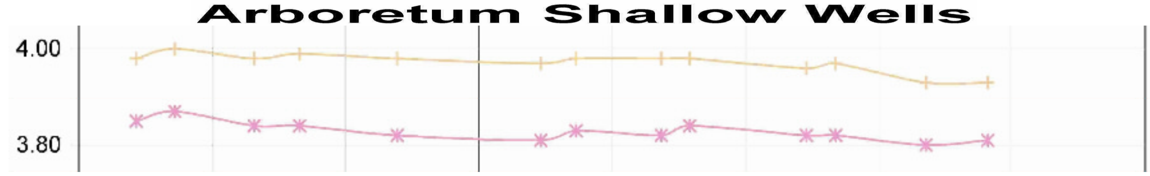
Dormitory Shallow Wells



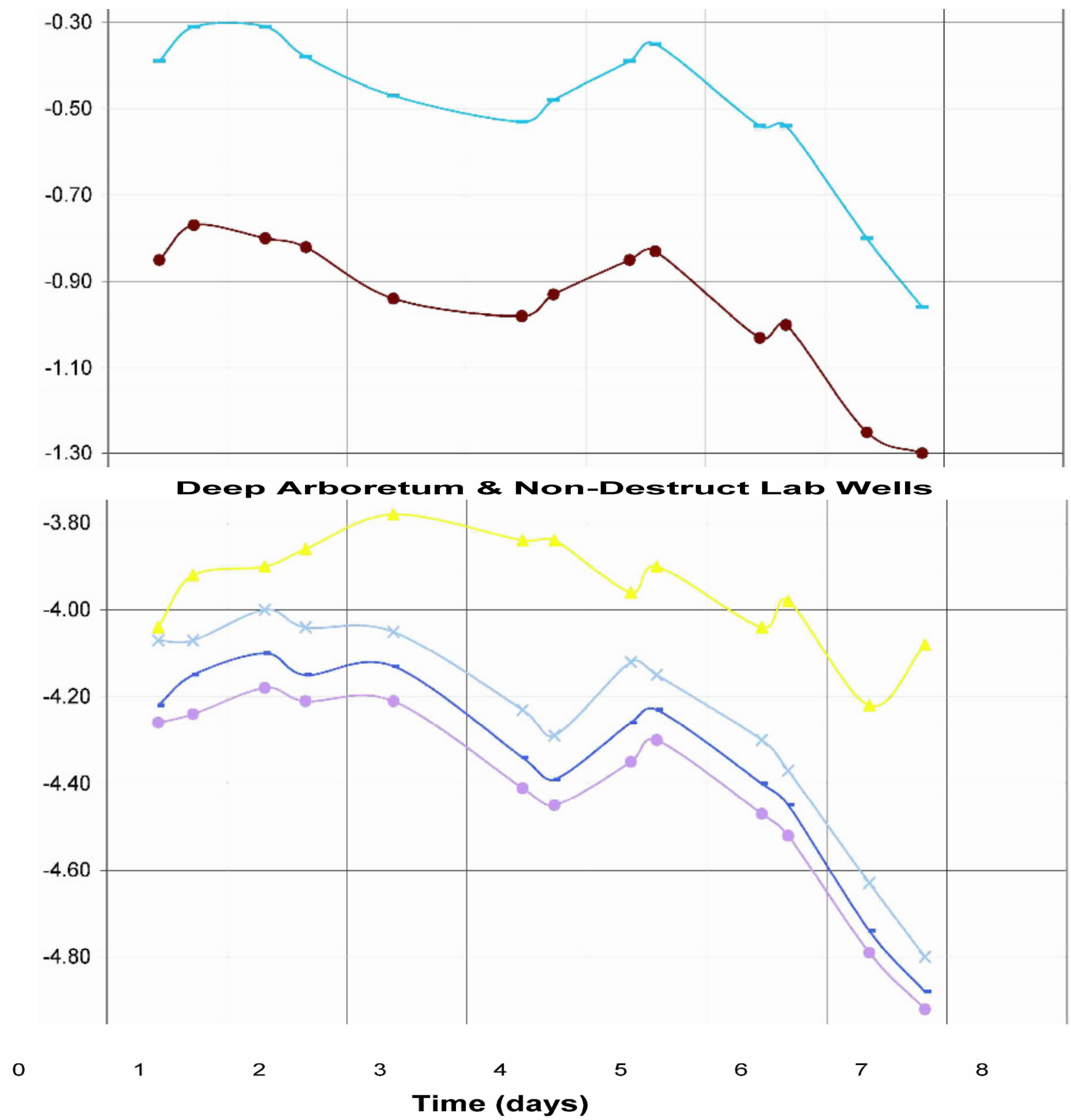
Non-Destruct Lab Shallow Wells



Arboretum Shallow Wells

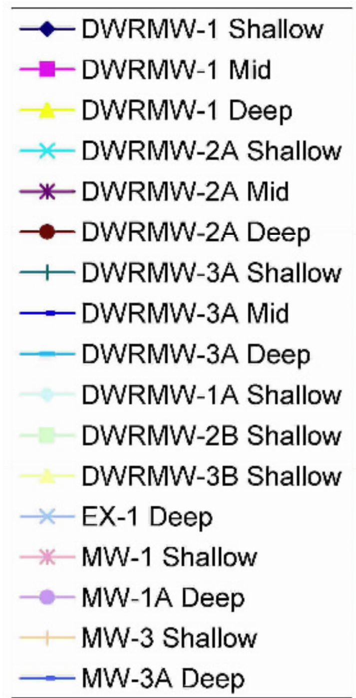


Deep Dormitory Wells



-0.30
-0.50
-0.70
-0.90
-1.10
-1.30
Deep Arboretum & Non-Destruct Lab Wells
-3.80
-4.00
-4.20
-4.40
-4.60
-4.80
0
1
2
3
4
5
6
7
8
Time (days)

LEGEND
For Graphs of CSUS Wellfield



Section V

Conclusion

This project was started with evidence indicating there was very little leakage between layer 2 and layer 4. There was also evidence suggesting that the campus irrigation wells were screened in the layer 4 aquifer. It is clear now that either one or both of these hypothesis is not correct.

Within the scope of this project, though, it was possible to achieve in the numerical model the general trends that existed in the actual well observations. The model showed very smooth and predictable responses to changes made in the parameters during the calibration and history matching process. It seems clear that with access to all relevant subsurface information, the numerical model would be an excellent tool in helping to understand the subsurface hydrology in this area. More extensive subsurface investigation was not within the scope of this project, though, so a general understanding of how a conceptual model, limited physical observations, and a numerical model built on this information, can all work in a complimentary fashion to help achieve the first step in the investigation process is the most important result of this project.

While this model is clearly not ready to suitably analyze the subsurface hydrology in the CSUS area, it clearly demonstrates that with good data it is capable of doing so.

Log of Setting Changes Made After Initial Calibration

(Only Changes are Listed. Refer to Previous Table of Settings for Complete Setting Details)

Date	Modification
5-14-04	Changed Irrigation Well #2 screen to 14’ to –158’
“	Changed Irrigation Well #1 screen to 7’ to –143’
“	Changed Irrigation Well #5 screen to 5’ to –145’
“	Changed Irrigation Well #4 screen to 12’ to –143’
“	Changed layer 2 conductivity to x & y 200ft/day, z 100ft/day
5-15-04	Changed layer 4 conductivity to 150ft/day
“	Changed layer 4 west boundary to 0’/-12’ head and 650 ft/day conductivity
“	Changed layer 4 south boundary to –12’/-2’ head and 650ft/day conductivity
“	Changed layer 4 north boundary to 0’/1’ head
“	Changed layer 4 east boundary to 1’/-2’
5-16-04	Changed layer 4 north boundary gradient to 3’ / 0’, & conductivity to 100ft/day,
“	Changed layer 4 conductivity to 200ft/day
“	Changed layer 4 east boundary gradient to 3’/ -2, & conductivity to 100ft/day
“	Changed Irrigation Well #3 screen to 11’ to –164’

References:

Chamberlain, L., 1994, Pliocene to Recent Geology Beneath the CSUS Campus and the Fairbain Water Treatment Plant: CSUS Senior Report

Garcia, Ruben, CSUS Manager, 2004, Grounds & landscaping Services, information on campus irrigation wells

Horner, Tim, 2004, CSUS Geology Department wellfield well logs

Roth, Anne, 2004, State of California, Department of Water Resources, CSUS irrigation well logs

TSSB Geologic Support Region 1, 1990, well logs, legends, and cross section