Constructing and Testing a Refined Groundwater Flow Model for the LaSalle/Gilcrest Area

Project Completion Report
Project period: July 1 2017 – June 30 2018

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1. Introduction

The Gilrest/LaSalle area is a 78 mi^2 area located northeast of Denver. In recent years, the area has experienced high groundwater levels, as depicted by the water level elevation contour map of 2013 shown in Figure 1. The source of water for the aquifer includes infiltration and recharge from surface water irrigation, groundwater irrigation, and rainfall; pumping for agricultural use and M&I use; infiltration from recharge ponds; canal seepage; groundwater lateral flow from surrounding areas; and upflux from the underlying bedrock aquifer. Figure 2 shows the location of groundwater pumps, canals, and recharge ponds, along with the crop type of each field. The principal objective for this project is to assess the impact of these individual contributions on water table elevation fluctuation, through the use of a calibrated and tested MODFLOW model. This project is an extension of previous projects that constructed a refined MODFLOW model for the LaSalle/Gilcrest area, based on data used in the state's South Platte Alluvial Groundwater Flow Model. This project (1) extended the model domain spatially to include the influence of canals to the south of Gilcrest, (2) performed model calibration and testing, and (3) performed preliminary scenario analysis to determine the groundwater sources and sinks that contribute to water table fluctuation in the area.

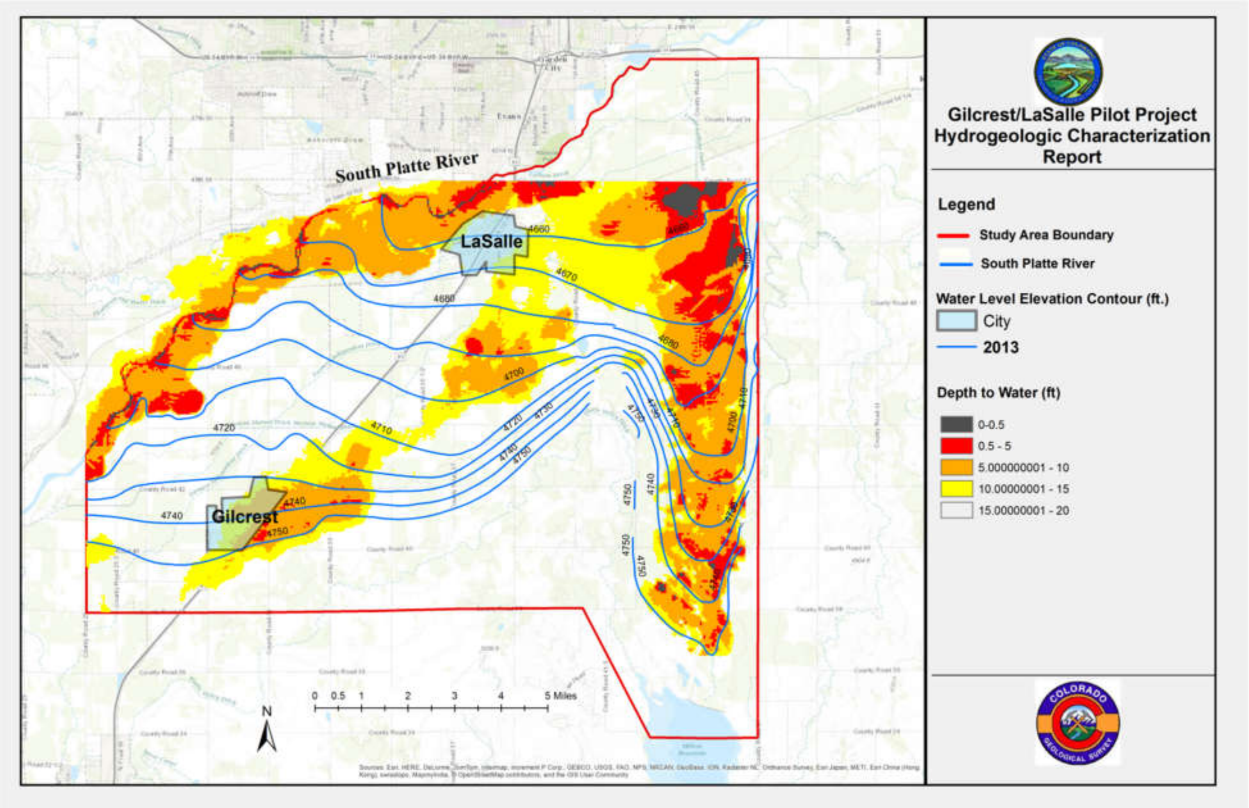


Figure 1. Gilcrest/LaSalle area depth to water table in 2013

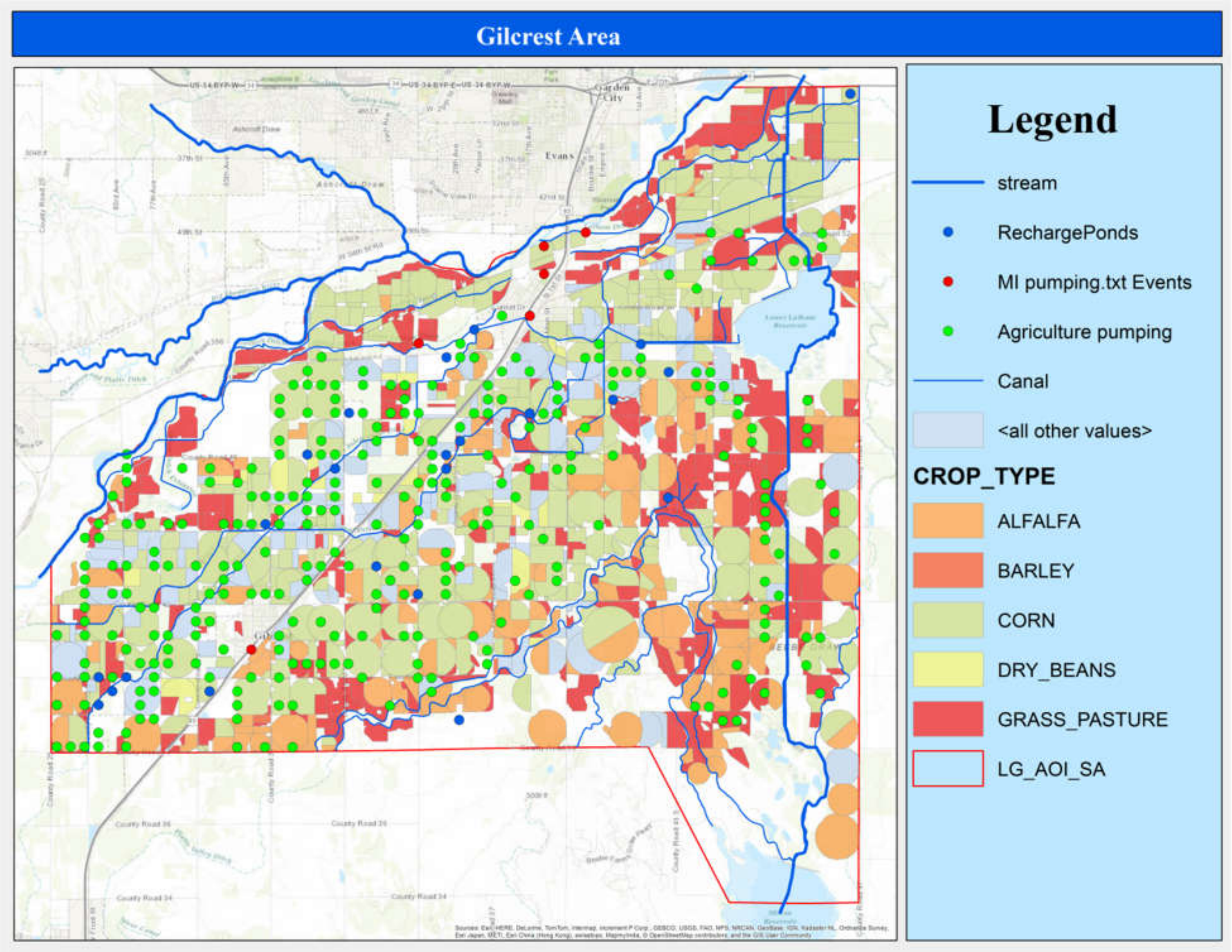


Figure 2. All the sources of water to aquifer in study area

2. Extending the MODFLOW model

The MODFLOW grid contains cells that are 500 ft on each side. The grid has 120 cells in both the north-south and west-east directions, and 10 vertical layers that represent the alluvial aquifer (6~112 ft). The new extended model includes an area to the south of Gilcrest (Figure 3). This new region was included due to the presence of canals, which likely seep large volumes of water to the aquifer, which can raise the water table and cause significant groundwater flow towards to the town of Gilcrest. However, the geological information in this area (e.g. soil type, borehole data and associated lithology) is sparse, and hence values of hydraulic conductivity and specific yield are obtained from nearby areas.

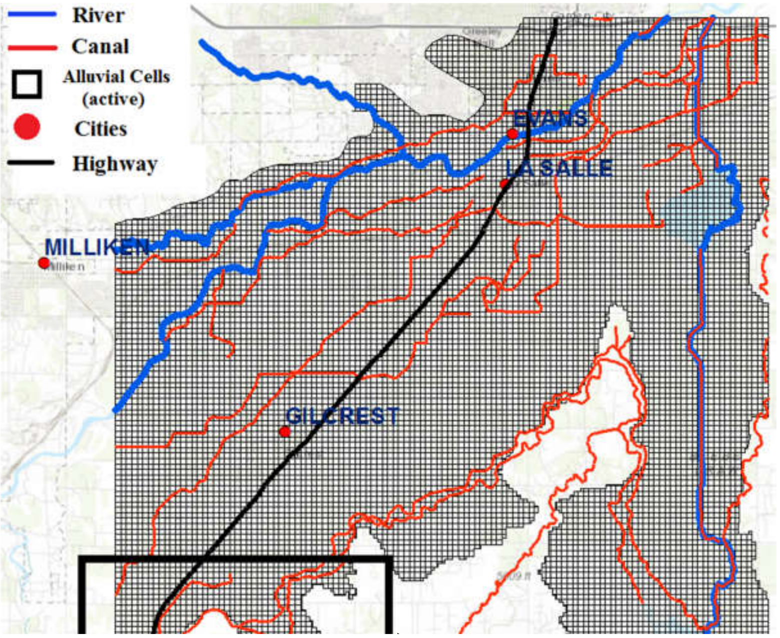


Figure 3. Finite difference grid of MODFLOW, showing the new modeled area in the southwest area of the model domain.

Besides the addition of the new area shown in Figure 3, another significant change to the model is the location of groundwater inputs. All input data are obtained from the South Platte Decision Support System (SPDSS) MODFLOW model of the South Platte River Basin (Brown and Caldwell, 2016), which is extended through the year 2012. The Gilcrest/LaSalle MODFLOW model has been discretized to be finer than the SPDSS model, resulting in cells of 500 ft on a side. The input data from the original MODFLOW model, therefore, must be mapped to the new grid cells, with one original grid cell equal in space to four cells in the new model. Figure 4 shows the spatial extent of the South Platte River Basin, the original MODFLOW grid in the Gilcrest/LaSalle area, and the refined model grid. As such, the actual location of groundwater outputs/inputs can now be more accurately defined spatially. To do so, the exact locations of the pumping wells and canals were intersected with the new grid. Figure 4 shows the location of the 427 pumping wells (Figure 4), located within the finite difference grid of the new MODFLOW model.

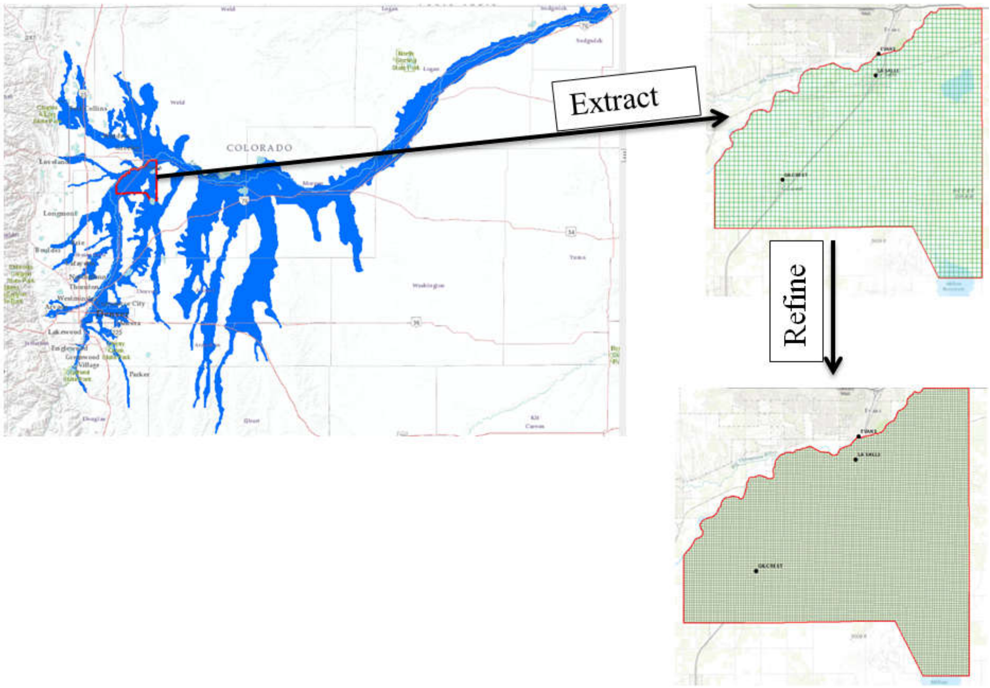


Figure 4. Location of the Gilcrest/LaSalle model domain within the South Platte River Basin, and the refinement of the original MODFLOW grid to grid cells with 500 ft sides.

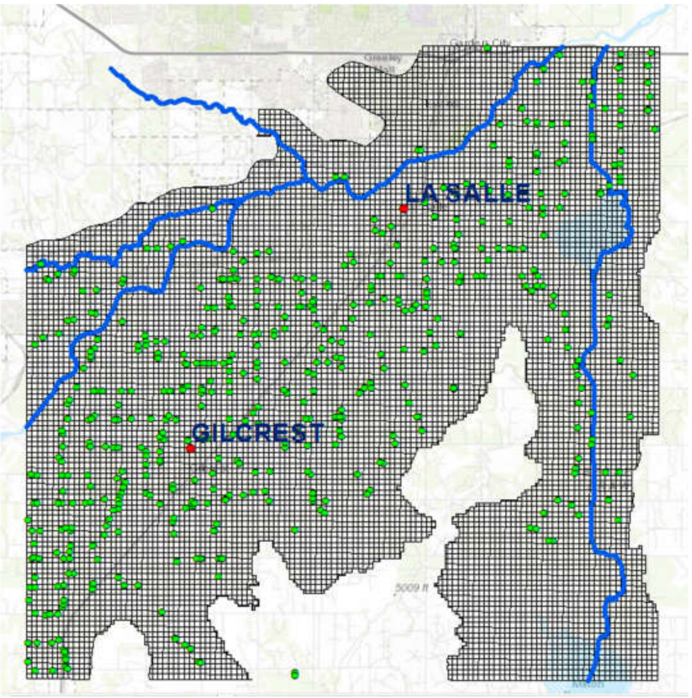


Figure 5. Location of pumping wells (green circles), located on the finite difference grid of the new MODFLOW model.

3. Model Calibration and Testing

The MODFLOW model was calibrated by estimating the values of aquifer properties throughout the model domain. The list of parameters used in the calibration process is shown in Table 1. The main parameters are horizontal hydraulic conductivity (K), the ratio of horizontal to vertical hydraulic conductivity (VANI), specific storage (S_s), specific yield (S_y). Rather than vary these parameters by zone, only the values of each material type (clay, clay/silt, silt, silt/sand, sand, gravel) are varied, according to the material types associated with the > 400 boreholes in the model domain (see Figure 6). The parameter estimation software tool used was PEST (Parameter ESTimation), which varies parameters within a prescribed range of values (see Table 1) to provide the optimal match between model-simulated hydraulic head (i.e. water table elevation) and observed hydraulic head from the network of observation wells within the model domain.

Table 1. Aquifer properties and their range of values (minimum, maximum) used in the PEST software to calibrate the MODFLOW Model.

Parameters	Minimum Value	Maximum Value
K of Clay	2.83E-06	0.36395
K of Clay & Silt	1.56E-05	2.49
K of Silt	2.83E-05	10
K of Silt & Sand	8.99E-02	189.9
K of Sand	0.899	899
K of Sand & Gravel	14.2	1420
K of Gravel	89.9	89900
S_y of Clay	2.83E-06	0.06
S_y of Clay & Silt	0.03	0.15
S_y of Silt	0.03	0.22
S_y of Silt & Sand	0.1	0.35
S_y of Sand	0.1	0.4
S_y of Sand & Gravel	0.11	0.35
S_y of Gravel	0.12	0.35
VANI (ratio of K_H to K_V)	0.5	5
S_s	1.00E-07	1.00E-03

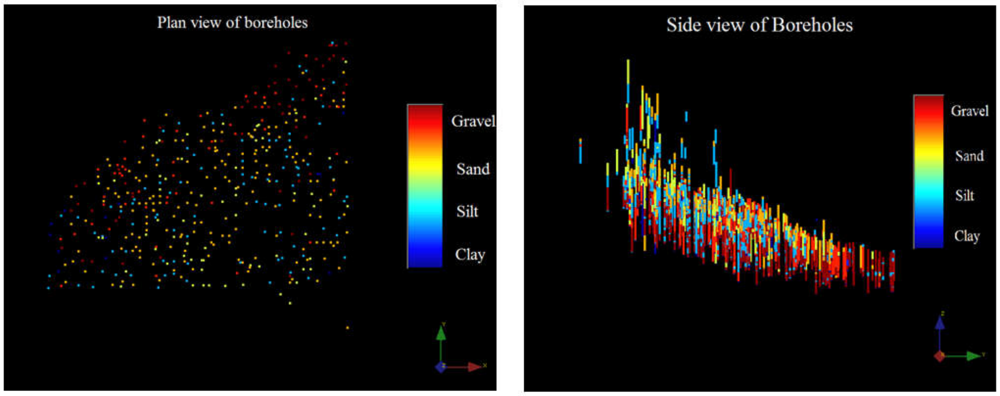


Figure 6. Plan view and side view of boreholes located in the Gilcrest/LaSalle area, showing material type (gravel, sand, silt, clay).

The model is calibrated using the monthly observed groundwater head data from 1950 to 2000 and then tested using the groundwater data from 2000 to 2012. The results are shown in Figure 7. The mean absolute error for the calibration period is about 4.0 ft, and for the testing/validation period is about 4.4 ft. A histogram of differences (residuals) between the simulated and observed values is shown on the right for both simulation periods, with most errors being less than 10 ft. To conclude, the model performs well during both the calibration and testing periods.

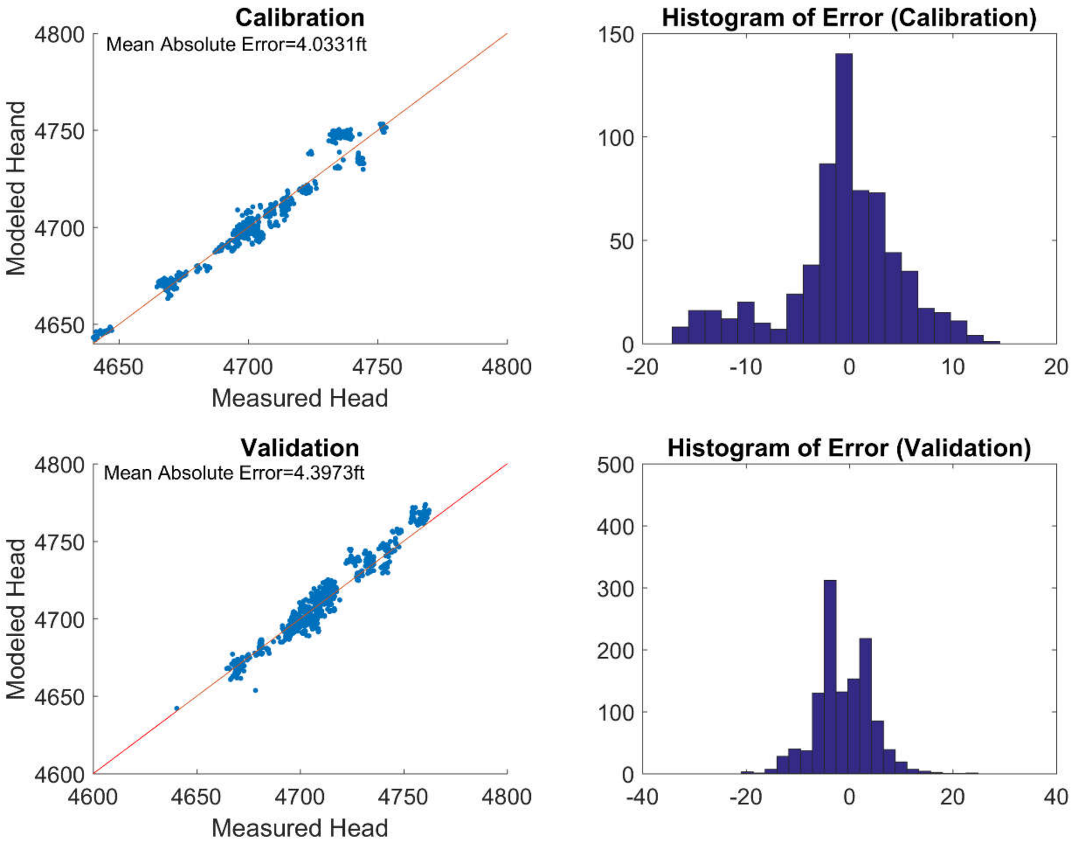


Figure 7. Comparison of simulated ("Modeled Head") and observed ("Measured Head") groundwater head for the calibration period (1950-2000) and testing/validation period (2000-2012). The charts on the right show histograms of the difference between the simulated and observed values.

Figure 8 shows the comparison water table contour plots from measured groundwater head (courtesy of the Colorado Geological Survey) and simulated groundwater head for the spring 2012 time period. A visual comparison between the two demonstrates the close match between the model results and the field data. Both plots show groundwater flowing northward towards the South Platte River.

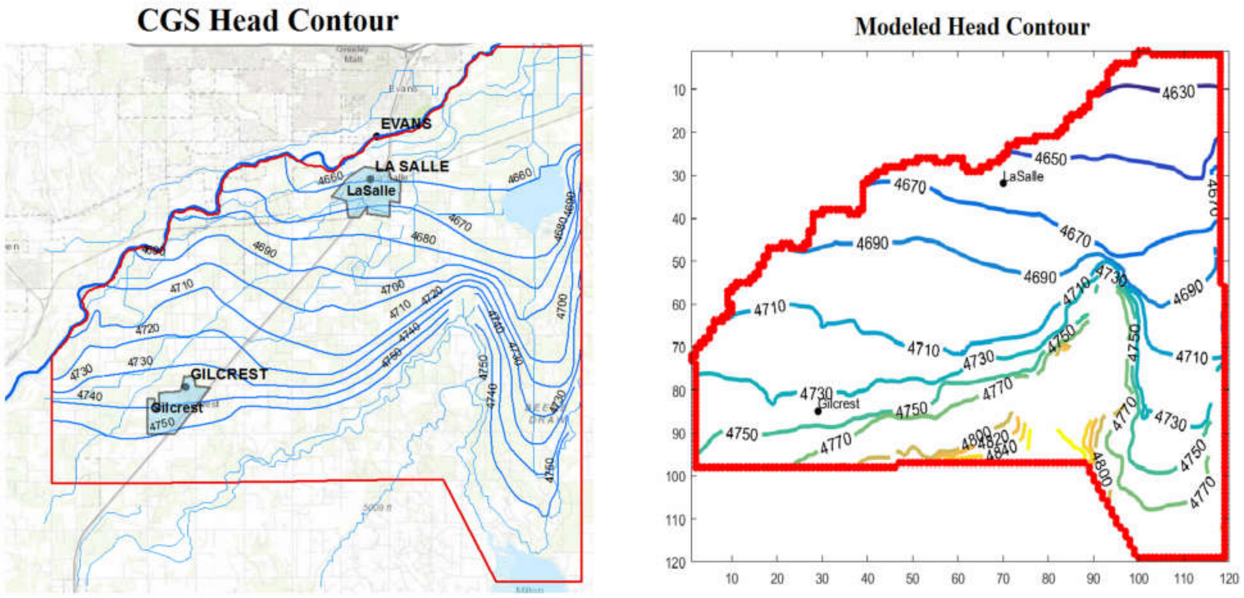


Figure 8. Groundwater head (water table) contour plot for (left) measured values in spring 2012 and (right) simulated values in spring 2012. The plots are very similar, showing a principal north direction of groundwater flow.

Figure 9 shows the measured and modeled depth to water table in spring 2012, with the field data map provided by the Colorado Geological Survey (CGS). Spatial patterns of water table depth are similar between the two plots, particularly along the South Platte River and Beebe Draw in the eastern region. The model also captures the high water table between Gilcrest and LaSalle, although the field data does not show high water tables along the south-southwest edge of the model domain. One reason for this is the lack of observation wells in this area, and therefore the depth to water table in this area is unknown. Therefore, the water table may be high as suggested by the model. More field data in this area is necessary to confirm.

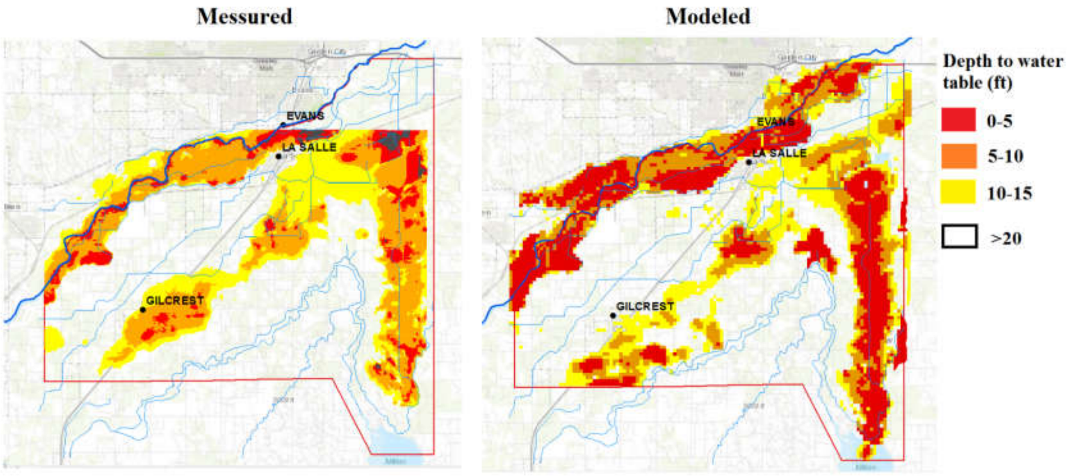


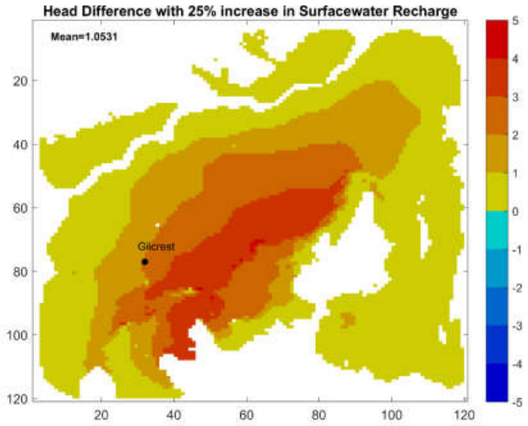
Figure 9. Map of (left) Measured and (right) simulated depth to water table (ft) in spring 2012.

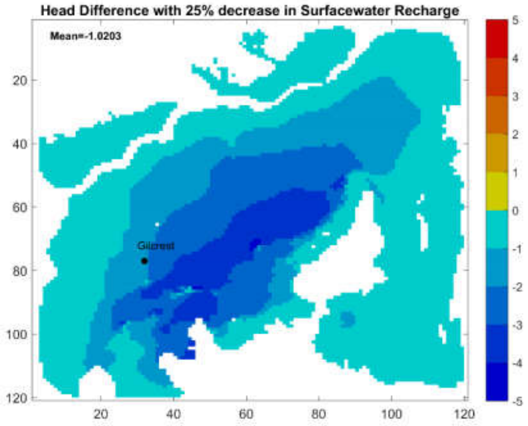
4. Model Application – Sensitivity Analysis

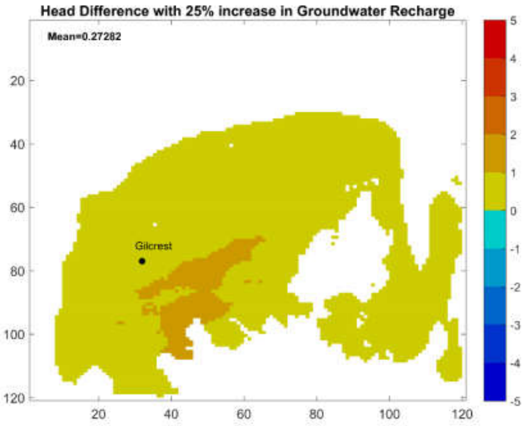
A preliminary sensitivity analysis was carried out to determine the relative influence of the groundwater sources and sinks. These sources and sinks are:

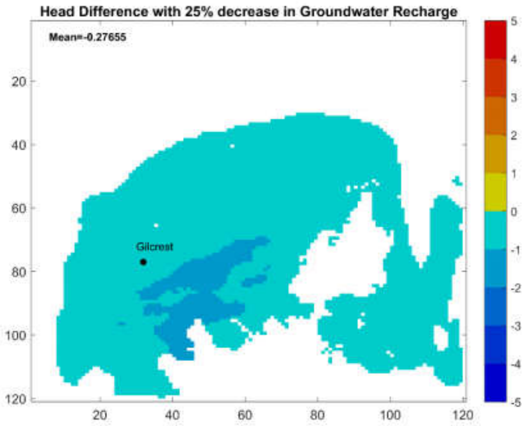
- Recharge from surface water (canal) irrigation
- Recharge from groundwater (pumping) irrigation
- Groundwater pumping
- Seepage from irrigation canals
- Seepage from recharge ponds

As a first analysis, each source/sink was tested for influence by increasing and then decreasing their magnitude by 25% throughout the entire model domain. For example, a 25% increase in groundwater pumping is simulated by increasing the pumping rate by 25% for each pumping well in the model. The following figures show the change in groundwater head (water table elevation) for each scenario. Red colors indicate an increase in head, whereas blue colors indicate a decrease in head. From these initial results, surface water recharge and canal seepage, followed by groundwater pumping, have the largest impact on groundwater head. However, these results do not relate the change to the actual quantity of groundwater added/removed from the system, which will be performed during the next phase of the project.






Head Difference with 25% increase in Groundwater Recharge
Mean=0.27282
Gilcrest
20 40 60 80 100 120
20 40 60 80 100 120
5 4 3 2 1 0 -1 -2 -3 -4 -5


Head Difference with 25% decrease in Groundwater Recharge
Mean=-0.27655
Gilcrest
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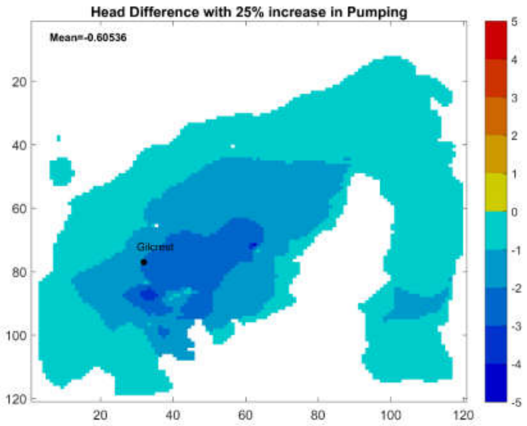
Head Difference with 25% increase in Pumping
Mean=-0.60536
Gilcrest
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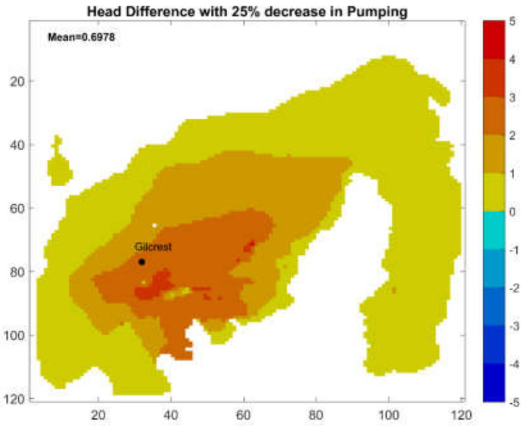
20 40 60 80 100 120
5 4 3 2 1 0 -1 -2 -3 -4 -5


Head Difference with 25% decrease in Pumping
Mean=0.6978
Gilcrest
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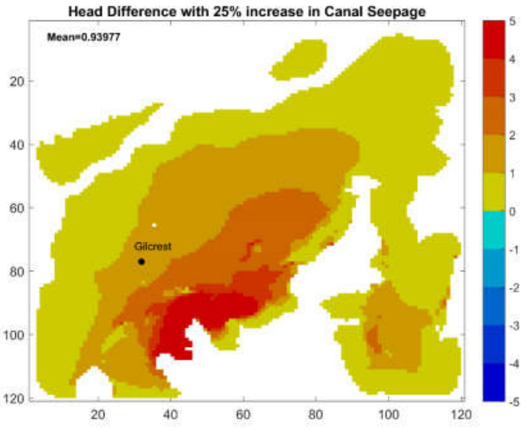
20 40 60 80 100 120
5 4 3 2 1 0 -1 -2 -3 -4 -5


Head Difference with 25% increase in Canal Seepage
Mean=0.93977
Gilcrest
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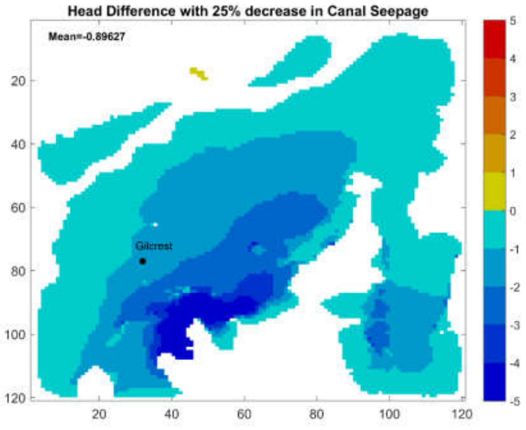
20 40 60 80 100 120
5 4 3 2 1 0 -1 -2 -3 -4 -5


Head Difference with 25% decrease in Canal Seepage
Mean=-0.89627
Gilcrest
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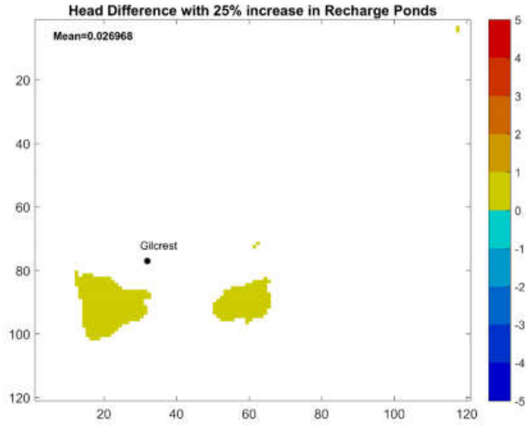
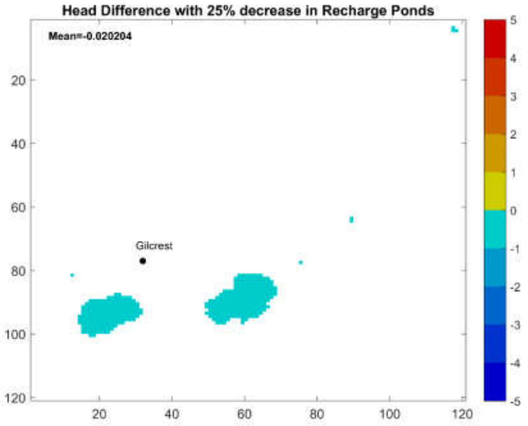
20 40 60 80 100 120
5 4 3 2 1 0 -1 -2 -3 -4 -5





5. Objectives for Next Phase

The next phase of the project includes:

- Extend the modeling period through 2017, using the following data:
    - Pumping data (obtained from CCWCD)
    - Recharge pond data (from CDWR database)
    - Recharge (surface water irrigation, groundwater irrigation)
    - Rainfall recharge)
    - Canal seepage
- Test model for the extended 2013-2017 time period, using observation data from the model domain. The water table data will be obtained from the DWR webpage for Gilcrest: (https://dnrweb.state.co.us/cdss/GroundWater/WaterLevels/Search?submitButton=Submit&SelectedPublicationAreaName=GILCREST%20HIGH%20GROUNDWATER%20AREA&SelectedAquiferName=All)
- Quantify influence of each source/sink on water table fluctuation. This will be done using a quantitative sensitivity analysis scheme (e.g. Sobol method, FAST method);