UPPER NIOBRARA WHITE GROUNDWATER MODEL

PURPOSE

As a part of the development and implementation of an Integrated Management Plan (IMP) by the Upper Niobrara-White Natural Resources District (the District) and the Nebraska Department of Natural Resources (the Department), a groundwater model based on previous groundwater models and studies was built to create a tool for analyzing water supplies and uses in the upper portion of the Niobrara River Basin (Figure 1). It provides a suitable tool for the evaluation of hydrologically connected areas and management scenarios.

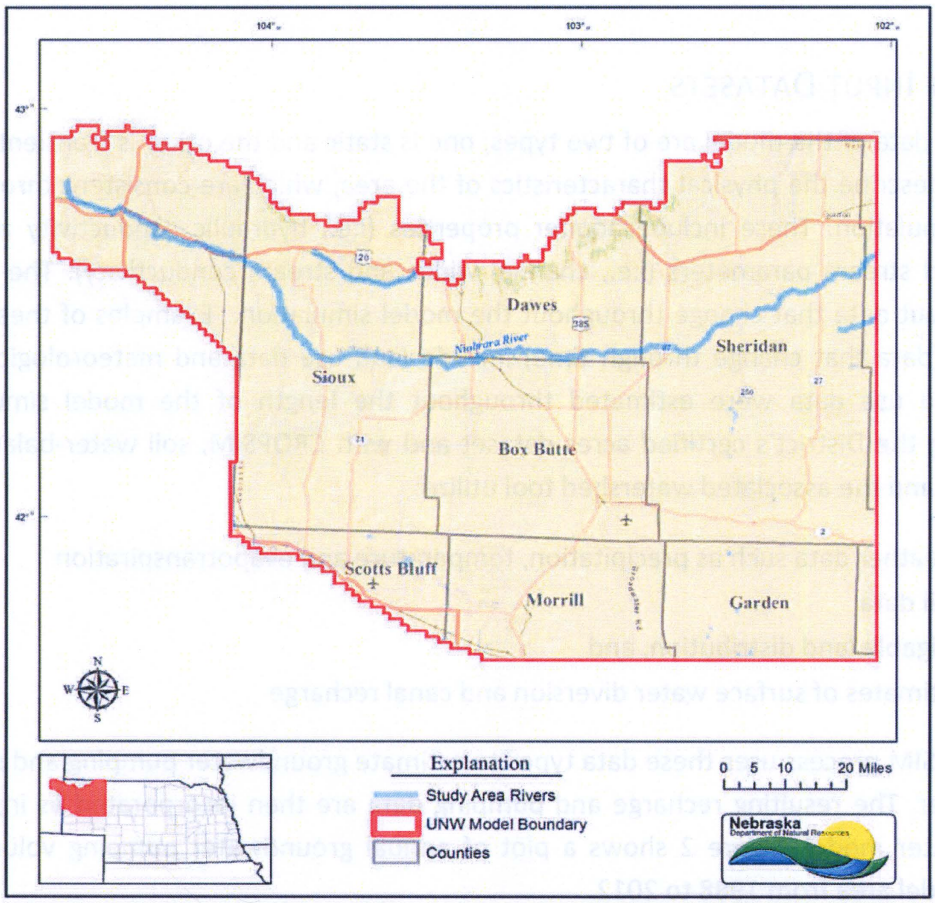


Figure 1. Map depicting the geographic area included within the Upper Niobrara White groundwater model (UNW Model).

The purpose of the model is to analyze conjunctive management scenarios along the river and explore the effects of changes in groundwater pumping within Box Butte County and in areas

along the Niobrara upstream of Box Butte Reservoir. Some important purposes of the groundwater model are:

- To quantify, at yearly and seasonal scales, the water supply in the basin above Gordon in a manner that is consistent with the Department's basin water supply concepts
- To quantify depletions to the baseflow component of gaged flow in the Niobrara River due to groundwater and surface water irrigation development
- To evaluate the impact of management scenarios, employing varying degrees of groundwater and surface water use, on Niobrara River baseflows
- To quantify and assess the effect of groundwater development in Box Butte County on the contribution of groundwater to surface water, including but not limited to the Niobrara River and Snake Creek

Types of Input Datasets

The input data of the model are of two types; one is static and the other is transient. The static datasets describe the physical characteristics of the area, which are consistent throughout the model simulation. These include aquifer properties (i.e., hydraulic conductivity and specific yield), and stream parameters (i.e., channel width and stream conductivity). The other data type is input data that change throughout the model simulation. Examples of these transient datasets (data that change through time) include land use data and meteorological weather data. Land use data were estimated throughout the length of the model simulations by combining the District's certified acres dataset and with CROPSIM, soil water-balance model. CROPSIM and the associated watershed tool utilize:

- Weather data such as precipitation, temperature and evapotranspiration
- Soil data
- Irrigable land distribution, and
- Estimates of surface water diversion and canal recharge

The CROPSIM process uses these data types to estimate groundwater pumping and recharge to the aquifer. The resulting recharge and pumping data are then incorporated as inputs to the groundwater model. Figure 2 shows a plot of annual groundwater pumping volume for the entire model area from 1988 to 2012.

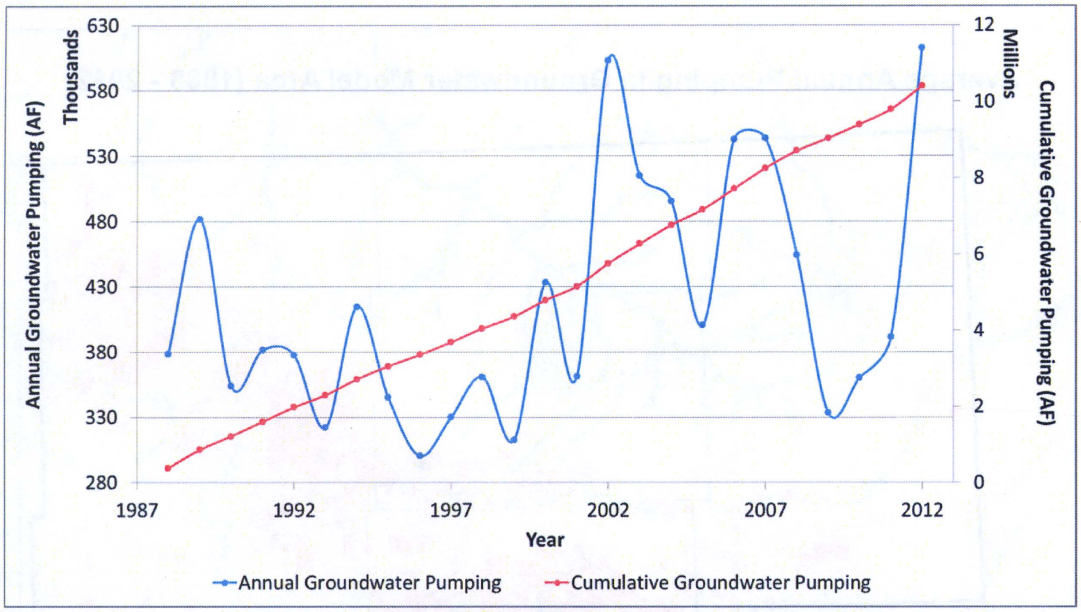


Figure 2. Annual groundwater pumping volume from the aquifer for the entire UNW Model area from 1987 to 2012.

Currently, this model uses only CROPSIM outputs to estimate groundwater pumping; however, if another method of estimating groundwater pumping is considered for future model runs (i.e., using pumping well metered data), it will be necessary to develop a method within the model to transition among different methods of estimating groundwater pumping. The updated method will need to account for the two different data approaches and smooth this abrupt change in the data. If such consideration is not given, transitioning from one data approach to another will result in an abrupt change in model results, which could impact future analyses.

Estimates of Groundwater Pumping

Groundwater pumping estimates are extremely important in groundwater models that calculate the effects of that pumping on groundwater levels and impacts to streamflows. Therefore, the CROPSIM process is extremely important to these modeling efforts. As mentioned above, transitioning to metered data would provide the most accurate estimates of groundwater pumping, but the CROPSIM model would still be necessary to estimate historical pumping or pumping in non-metered areas. The estimated average annual groundwater pumping volume (1988 to 2012) for the model area is shown in Figure 3.

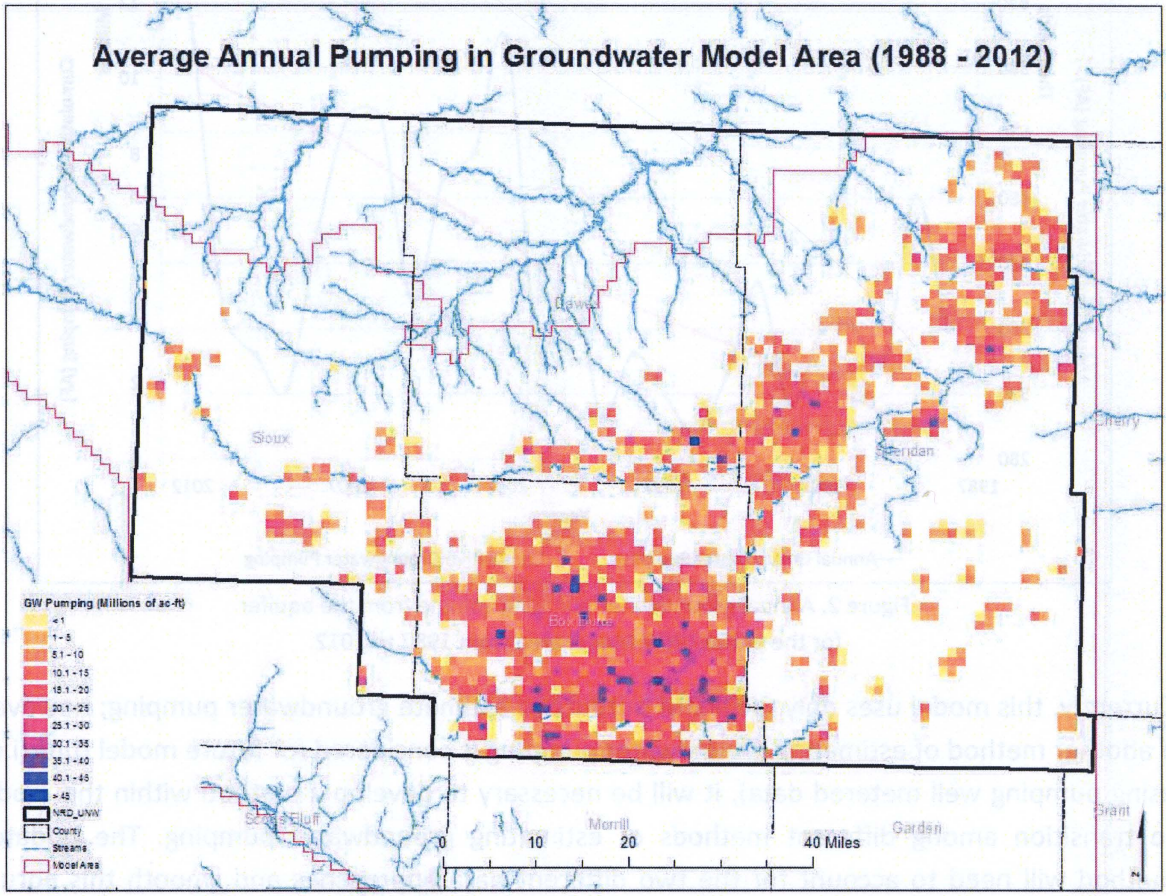


Figure 3. Spatial distribution of the estimated average annual groundwater pumping volume (average of 25 years, 1988 to 2012).

MODEL CALIBRATION

The outputs of the groundwater model are the groundwater elevation and drawdown within the model area, stream baseflow at assigned gages, and the transient water budget of different model components. The groundwater model was calibrated based on groundwater observation well readings available in the model area and observed baseflow at stream gages.

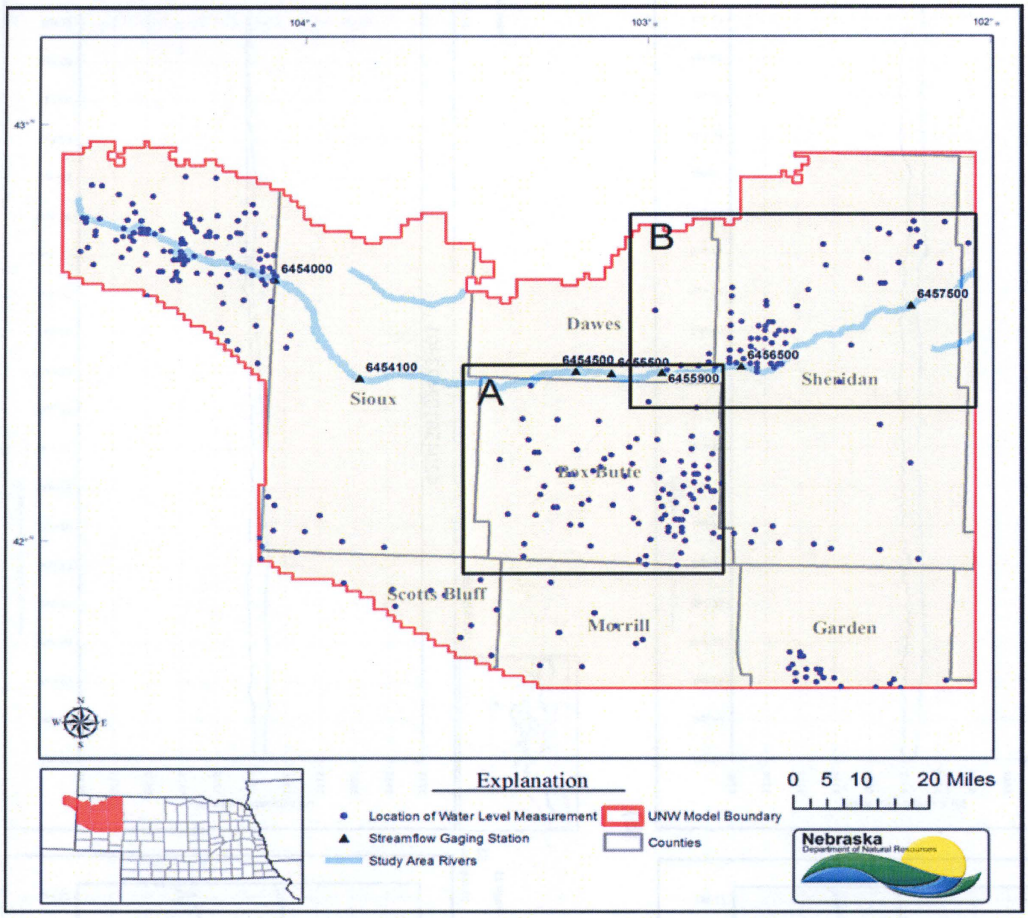
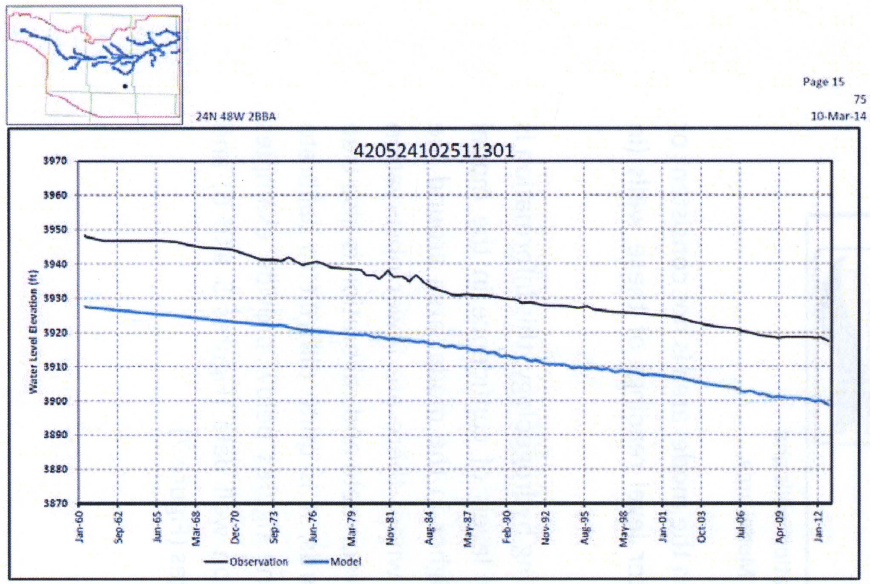


Figure 4. Location of groundwater observation wells and streamflow gaging stations in the UNW Model area.

As shown in Figure 4, the distribution of observation wells in the model area is not consistent or spaced evenly. Model calibration relies heavily upon water level readings of these wells (in addition to gaged streamflows).

In model areas where more information is available regarding hydrogeology, this information is incorporated in the model build, which generates higher levels of confidence in the model calibration. The level of confidence of model results is higher in the model area around the locations of observation wells and lower in model areas where there are fewer observation wells or observation wells are absent. This correlation between data and calibration is also true for geologic information in the model area. In other words, it is quite difficult to calibrate models in areas where little to no information exists. The figures below provide examples comparing simulated groundwater elevation to observation well data (Figures 5 and 6) and comparing simulated baseflow to observed baseflow at gages (Figure 7).



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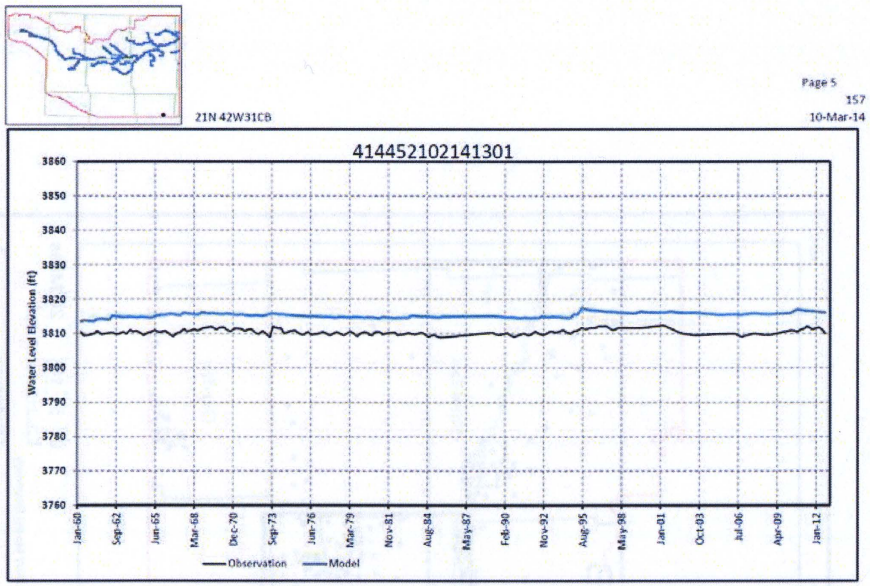

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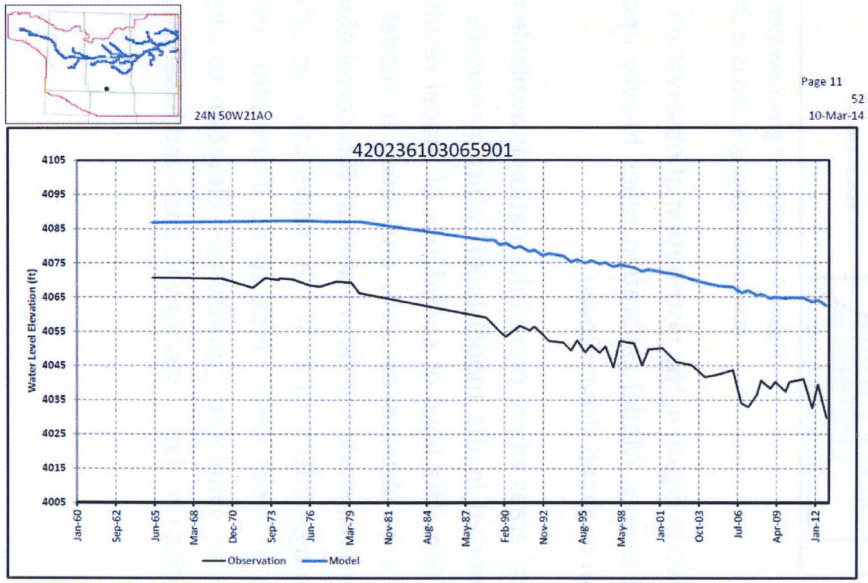
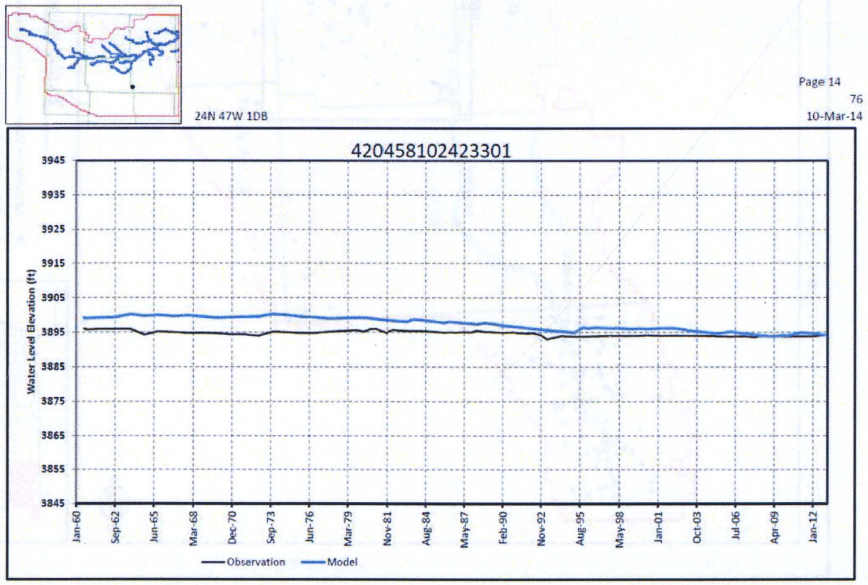
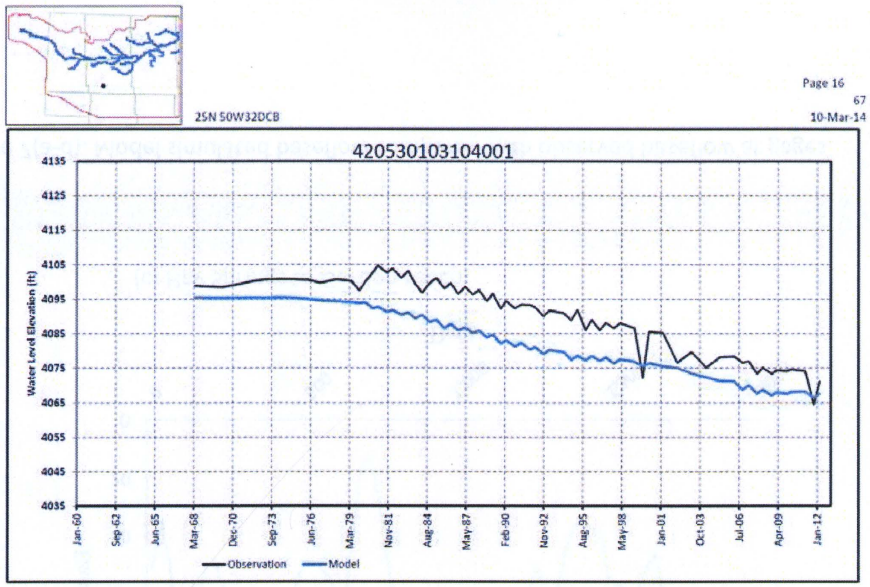


(c)



(d)

Figure 5(a-d). Well hydrographs from various locations throughout the UNW Model area, as shown in the inset map for each figure. Each figure compares model simulated groundwater elevation over time with observation well data from the same location. Additional hydrographs are displayed in Figure 6.



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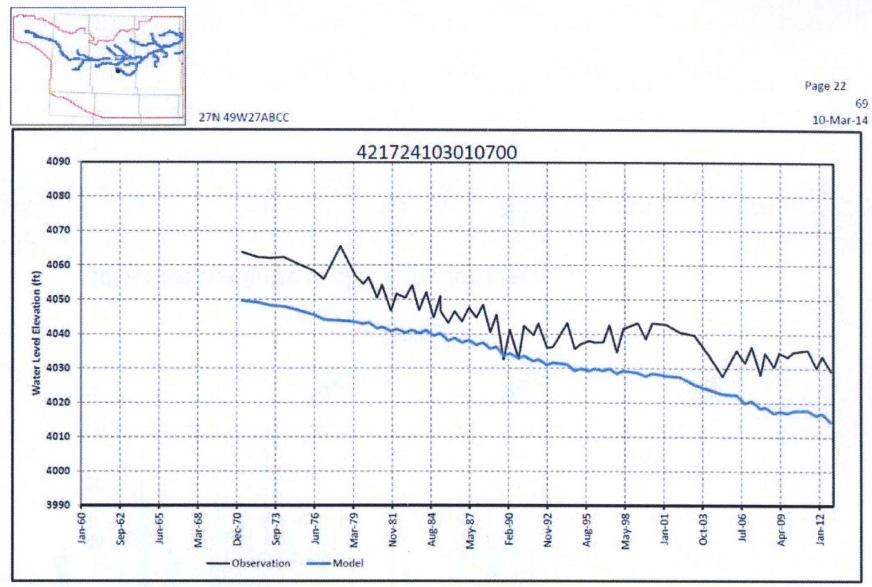

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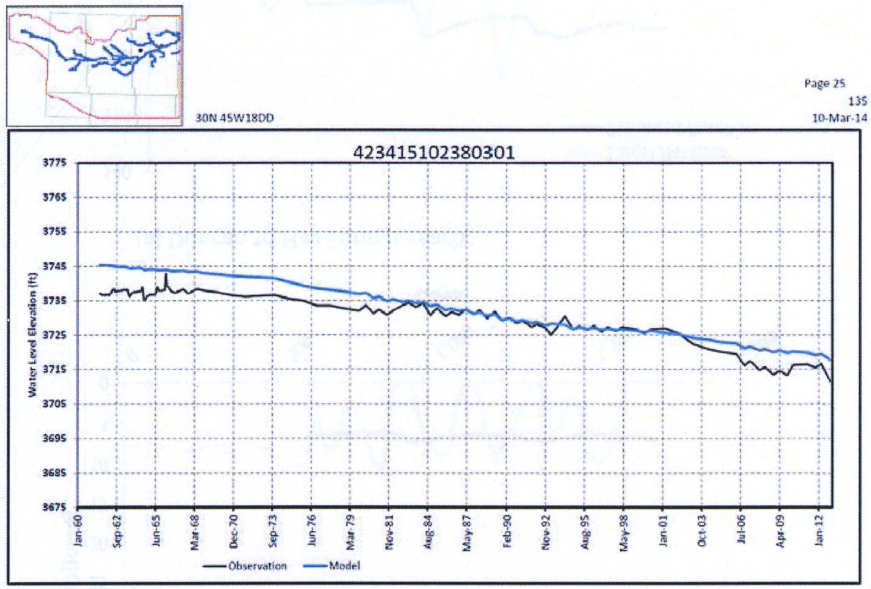

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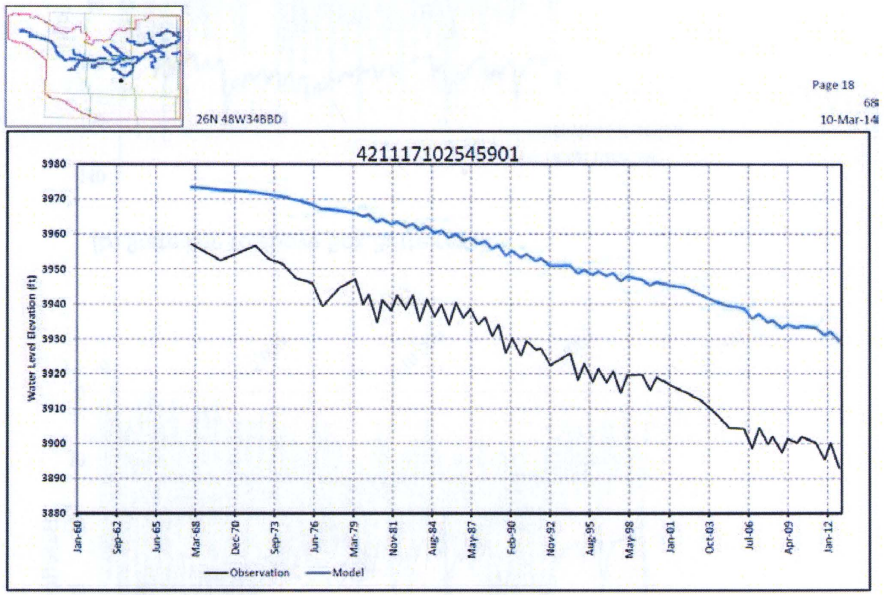
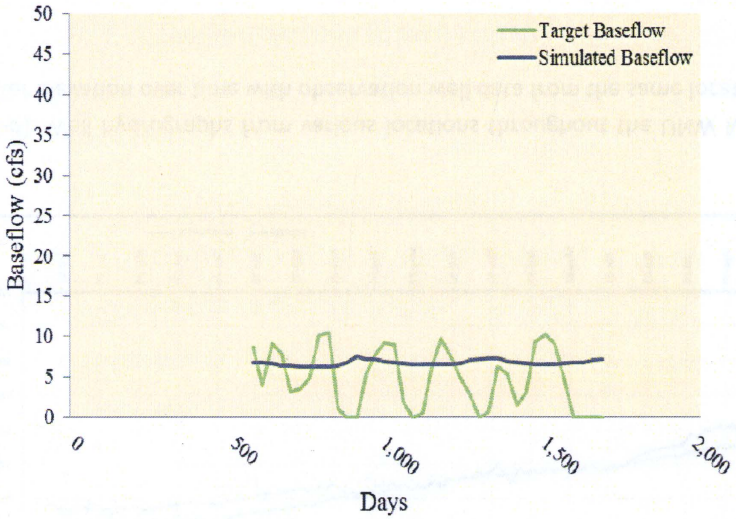
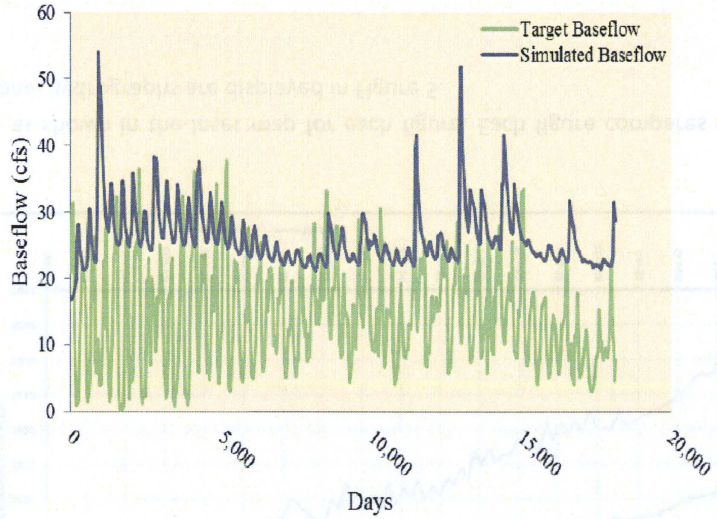


(d)

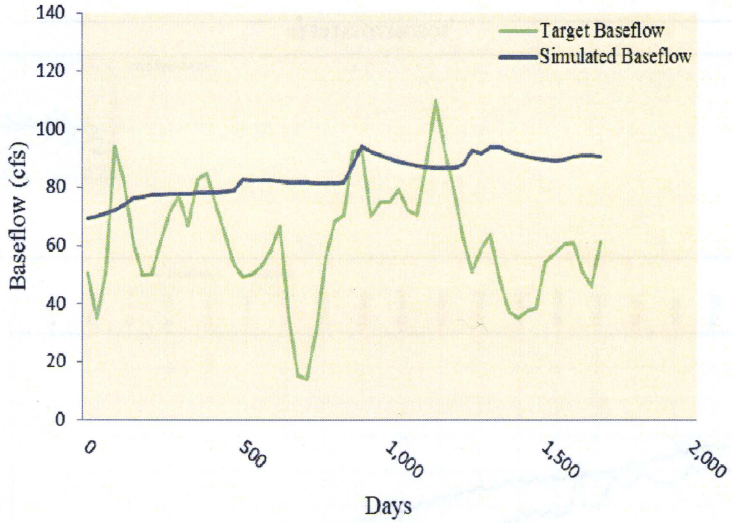
Figure 6(a-d). Well hydrographs from various locations throughout the UNW Model area, as shown in the inset map for each figure. Each figure compares model simulated groundwater elevation over time with observation well data from the same location. Additional hydrographs are displayed in Figure 5.



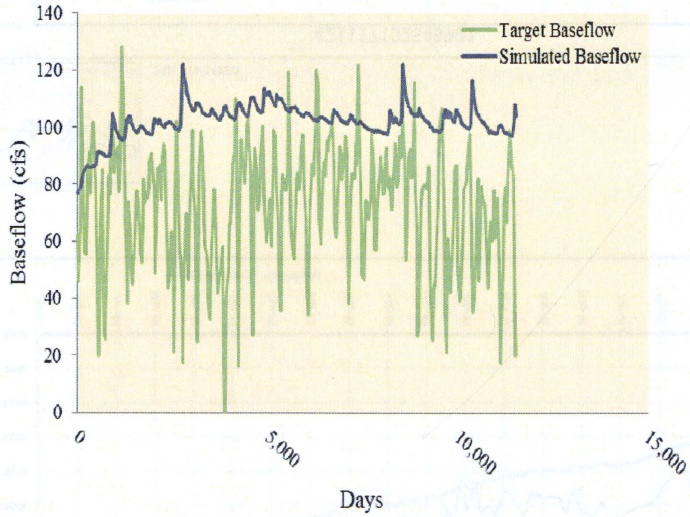
(a) Duncan to Hay Springs reach



(b) State line to above Box Butte reach



(c) Hay Springs to Gordon reach



(d) Above Box Butte to above Gordon reach

Figure 7(a-d). Model simulated baseflow compared with observed baseflow at gages.

A graph plot shown in Figure 8 is the model simulated result of annual baseflow volume discharged by aquifer into the Niobrara River. Increase in baseflow volume due to flooding events in the years 1995, 2000, and 2010 are captured by the model simulation.

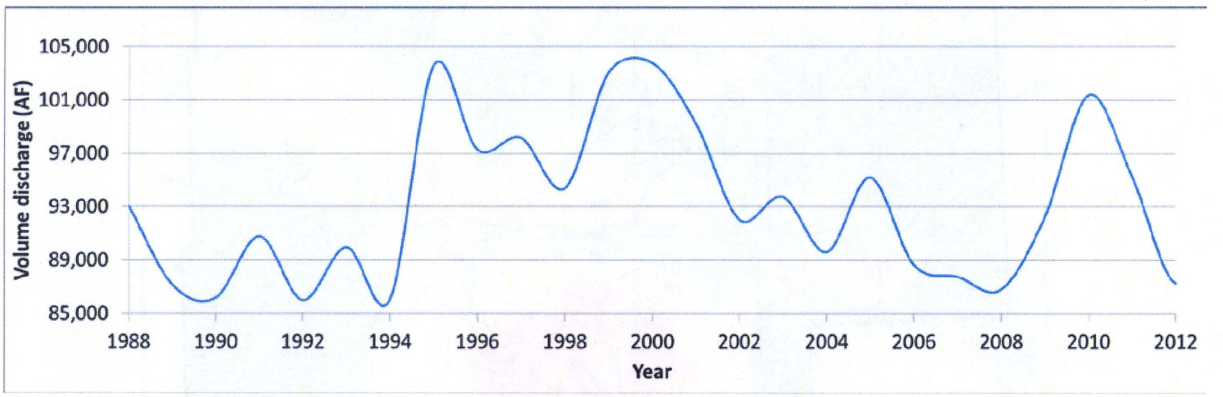


Figure 8. Annual baseflow volume discharge into the Niobrara River.

Given below, in Figure 9, is a map of the change in groundwater level, or drawdown, of the entire state of Nebraska from 1981 to 2013.

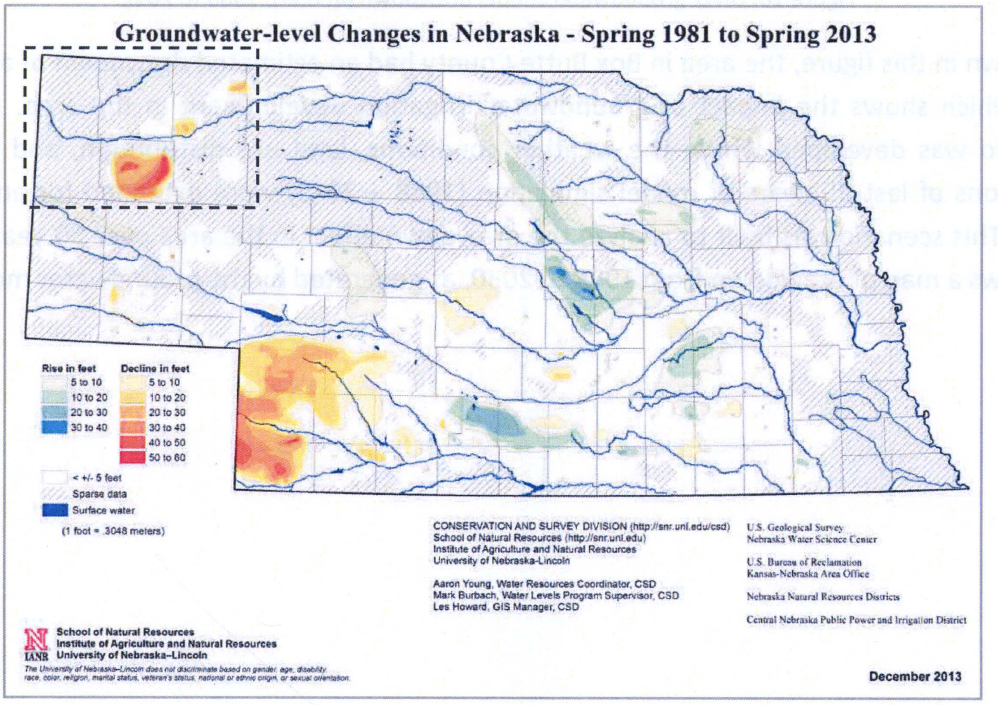


Figure 9. Groundwater-level changes in Nebraska (in feet), Spring 1981 to Spring 2013. The UNW Model area is located within the portion of the state indicated by the dashed black rectangle, which has been added to the original figure. The original figure was published by the School of Natural Resources at the University of Nebraska-Lincoln.

Figure 10 shows a map of drawdown generated by groundwater model from 1988 to 2012.

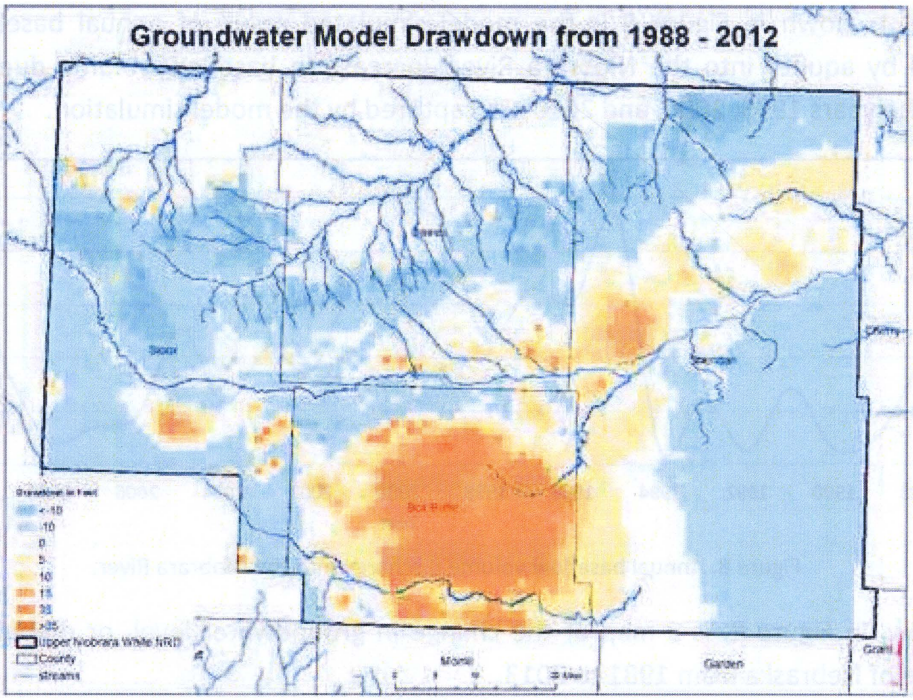


Figure 10. UNW groundwater model drawdown (in feet), 1988 to 2012.

As shown in this figure, the area in Box Butte County had an estimated drawdown of around 35 feet, which shows the impact of groundwater irrigation development in the area. A second scenario was developed where the weather conditions, land use distribution, and irrigation conditions of last 25 years of model simulation (1988 – 2012) were extended for another 25 years. This scenario was built to analyze the drawdown effect in the area over 50 years. Figure 11 shows a map of drawdown from 1988 to 2030, as generated by the groundwater model.

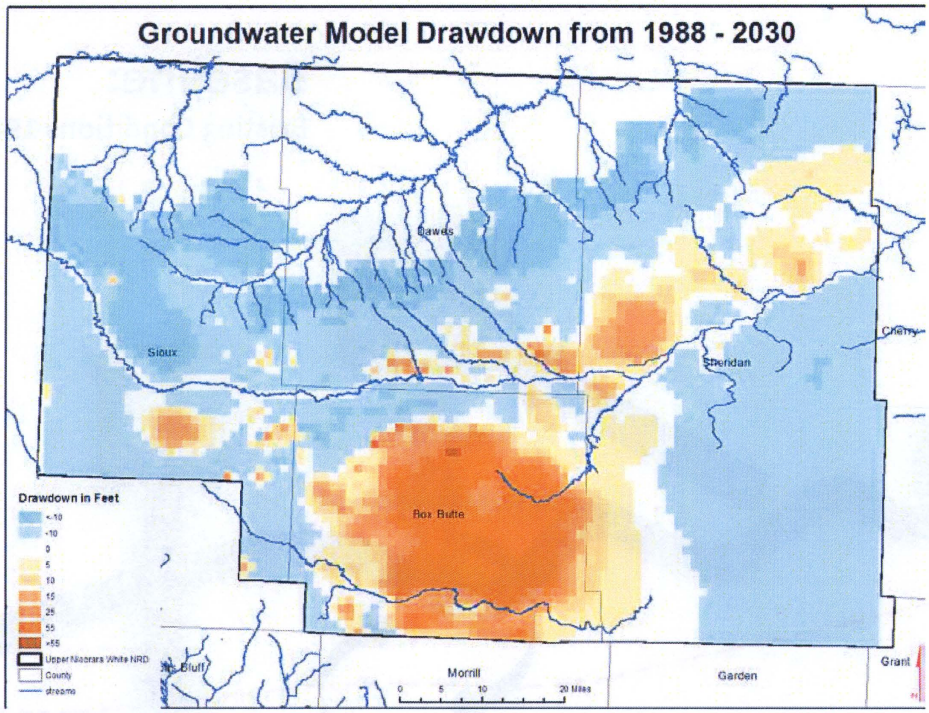


Figure 11. UNW groundwater model drawdown (in feet), 1988 to 2030.

Future Model Applications

Some of the applications of the groundwater model that have been competed so far are (i) quantification of the water supply in the basin and (ii) quantification of the depletions to the baseflow component of Niobrara River flow due to increased pumping over the past 50 years. Some current and potential model scenarios are illustrated in Figures 12-15.

Future potential applications of model include:

- Climate variability scenarios
  - Variability in precipitation and groundwater recharge
  - Wet and dry years
- Change in irrigated acreages
  - Expansion of or retired farmlands
  - Increase or decrease in groundwater pumping
- Various allocation scenarios
- Identification of areas for additional data collection, such as groundwater monitoring wells
- Identification of areas for further study, such as areas where geohydrologic data are sparse

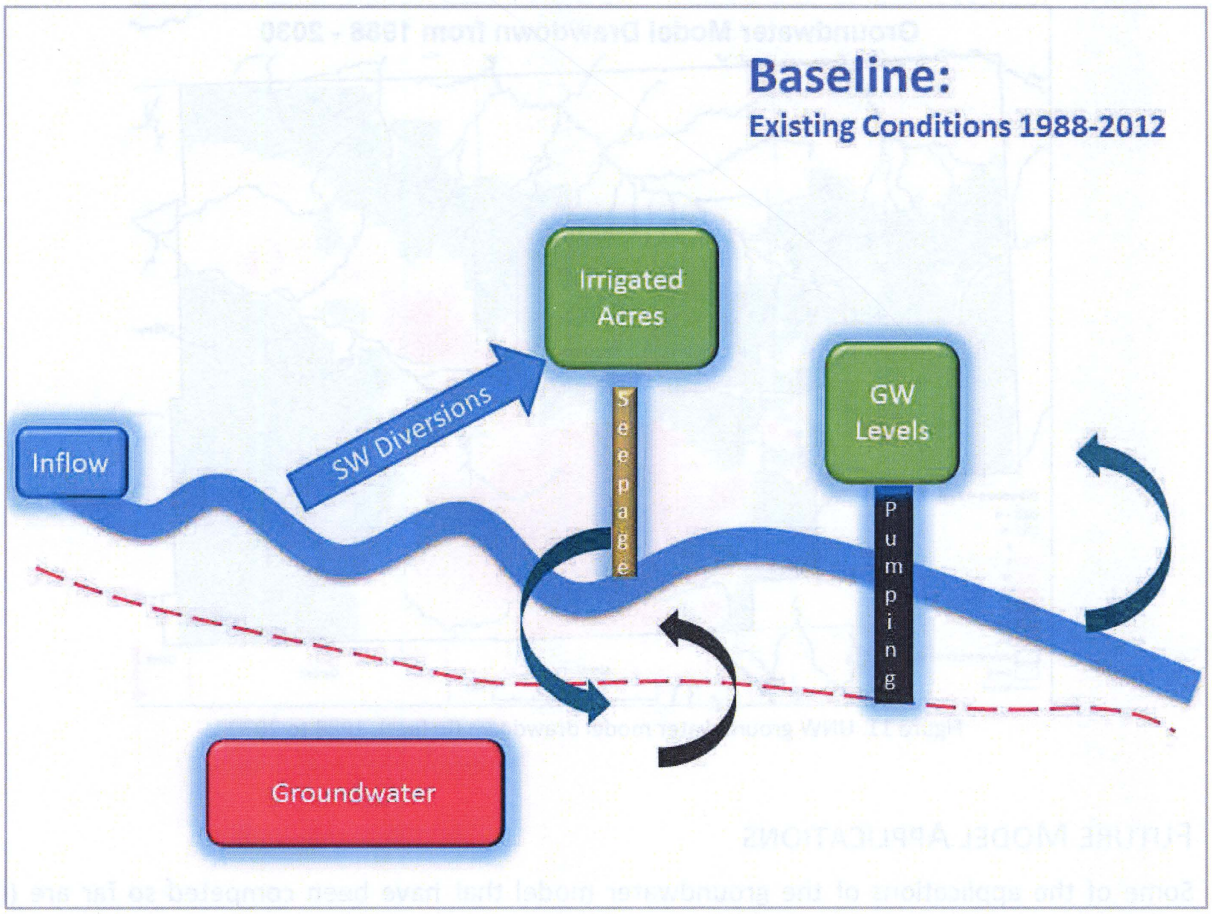
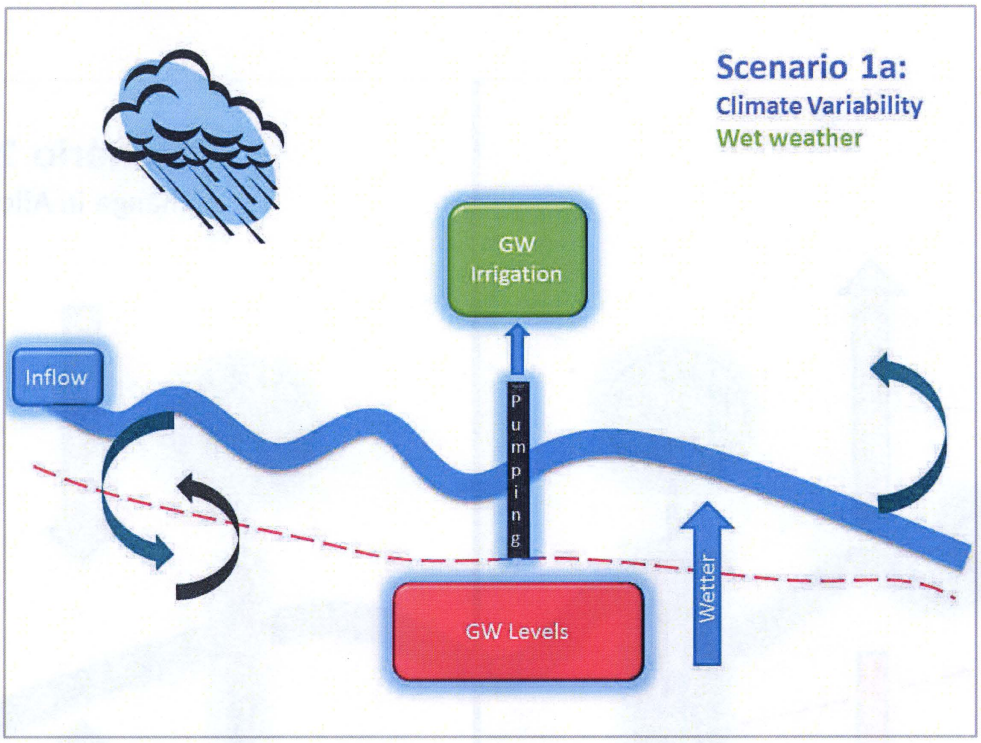


Figure 12. Baseline scenario. The baseline groundwater model results simulate existing conditions for 1988-2012. This modeling efford includes stream inflows, groundwater pumped, diversions, seepage, evapotranspiration, and irrigated acres. The model simulates groundwater levels for the basin.



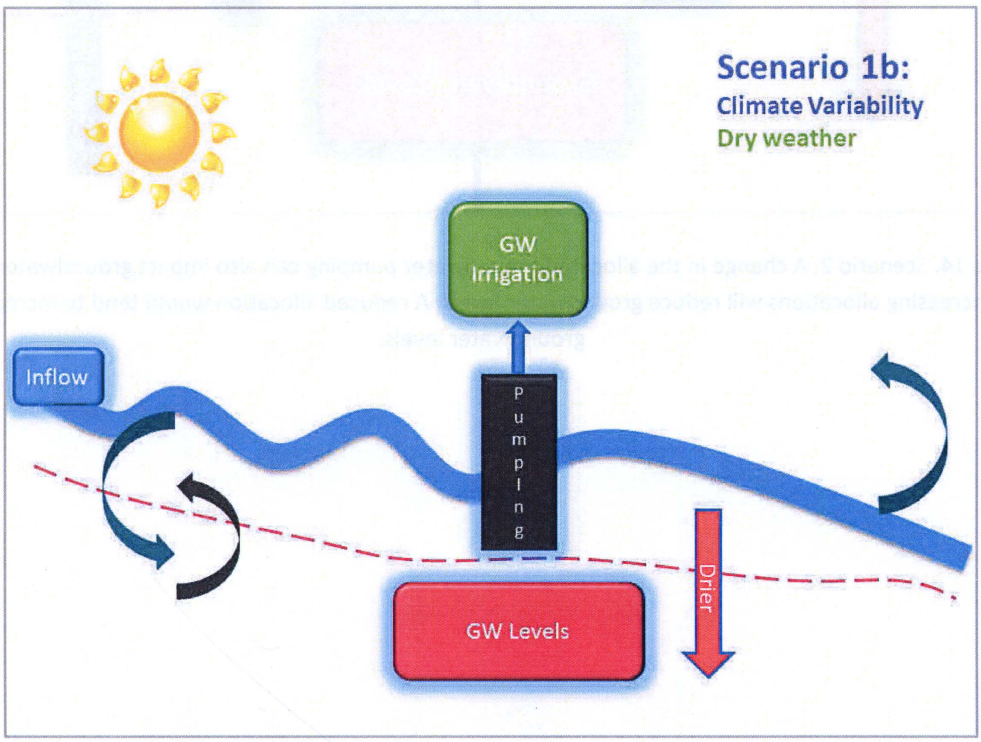


Figure 13. Scenario 1. Weather patterns can range from wetter to drier than normal. If the climate is wetter, groundwater levels are expected to rise. During drier weather, increased groundwater pumping is expected to decrease groundwater levels.

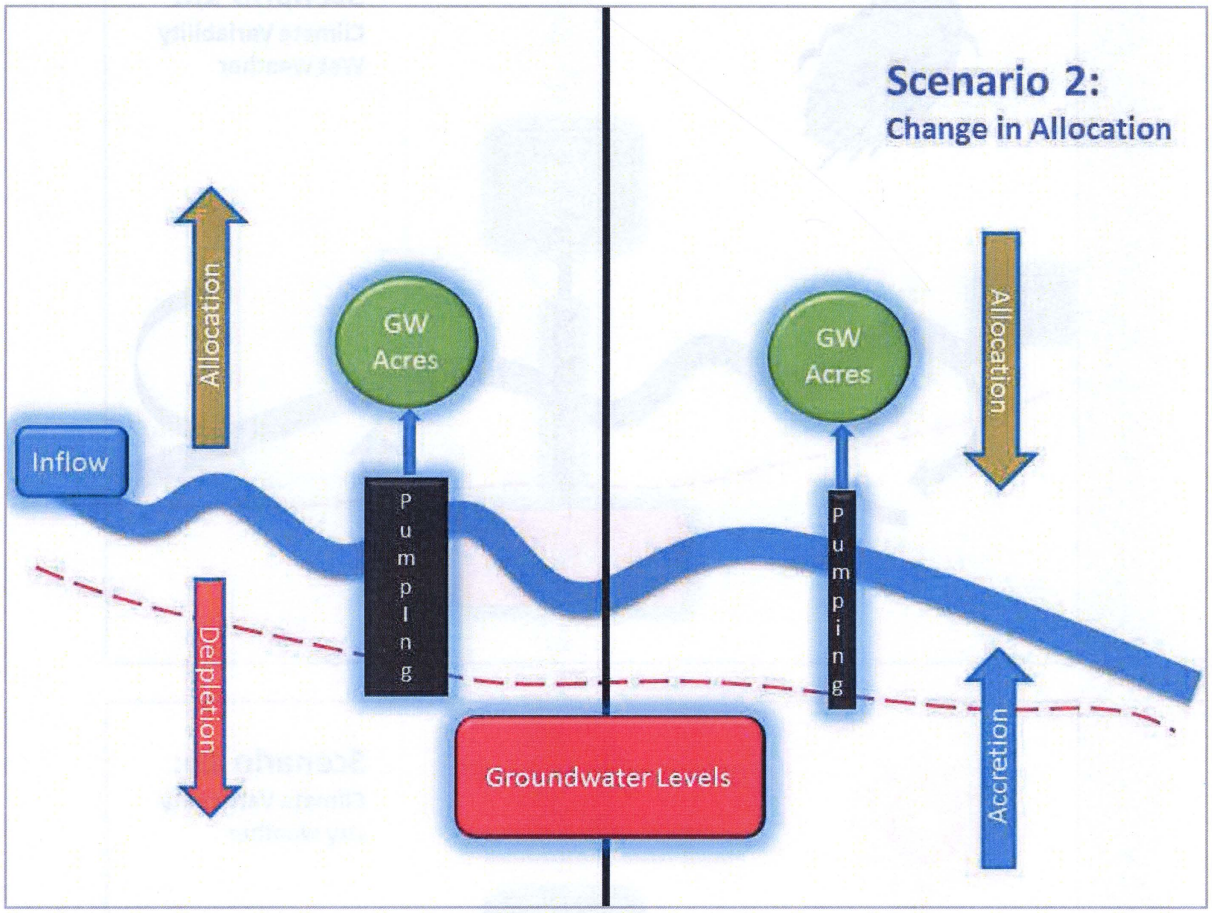


Figure 14. Scenario 2. A change in the allocated groundwater pumping can also impact groundwater levels. Increasing allocations will reduce groundwater levels. A reduced allocation would tend to increase groundwater levels.

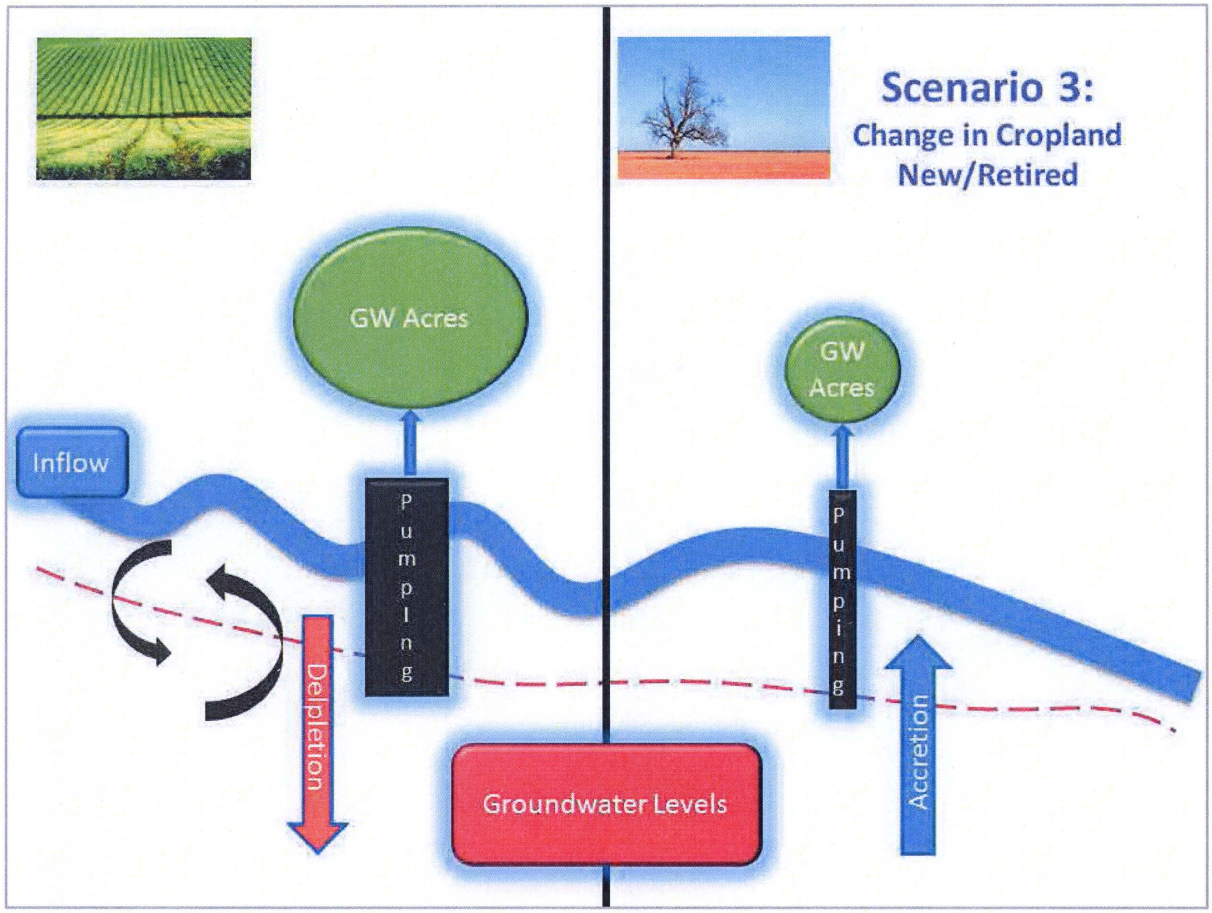


Figure 15. Scenario 3. Changes in cropland can directly and indirectly impact groundwater levels. New cropland can result in greater use of groundwater, and retired acres might decrease groundwater consumption. Changes in land use can also impact groundwater due to changes in recharge vs. runoff.