Report as of FY2006 for 2005CO118G: "Development of Characterization Approaches and a Management Tool for the Groundwater-Surface Water System in the Vicinity of Sutherland Reservoir and Gerald Gentlemen Station, Lincoln County, Nebraska"

Publications

- unclassified:
  - None to date

Report Follows

Development of Characterization Approaches and a Management Tool for the Groundwater-Surface Water System in the Vicinity of Sutherland Reservoir and Gerald Gentlemen Station, Lincoln County, Nebraska

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Problem and Research Objectives

Conflict between competing uses for water (e.g. water for a power plant to generate electricity to run an irrigation pump and water for irrigation) indicates a need for improved management approaches. Effective use of data is essential to resolving this problem. Generally, we, as a society, have not fully tapped the information in available data because of difficulties associated with its integration. The global problem addressed by the research is improving hydrologic system characterization to reduce predictive uncertainty associated with ground water management problems through an iterative process that couples development of alternative conceptual models and data needs assessment. The specific problem to be used as a platform for developing this approach is water management in the vicinity of Sutherland Reservoir and the Gerald Gentlemen Station power plant, which overlies the High Plains (formerly Ogallala) Aquifer in Lincoln County, Nebraska.

This project develops an effective approach to characterization that focuses on reduction of the associated predictive uncertainty. In an iterative process, available data (of varying type) are integrated through modeling that yields predictions (and associated uncertainty) for evaluated scenarios. Analysis of the models indicates the most valuable additional data (type, location, and time) that could be collected and this is incorporated into the field investigations. The resulting data are used to modify the initial set of alternative models. The evolving models facilitate evaluation of the impact of alternative management scenarios on water levels in wells and discharges to the South Platte River.

<u>The Specific Problem that serves as a Platform for Improved Data Fusion</u>

Sutherland Reservoir provides cooling water for the Gerald Gentleman Station (GGS), a 1.4 Gw coal-fired power plant, one of the primary sources of power for Nebraska and surrounding states. Sutherland Reservoir stage has been maintained at or above a critical level since the late 1970s to allow the power plant intakes to receive cooling water for GGS. Over the years, measured and simulated ground-water levels in the underlying High Plains Aquifer indicate that leakage from the reservoir has raised ground water levels in a large, although poorly-defined, region surrounding the reservoir (Nebraska Conservation and Survey Division, 2004). Nearby farms and ranches have come to depend on this ground water for domestic and irrigation use. As of December 2004, nearly every major reservoir in the North Platte River Basin contained less than 30 percent of capacity storage water (Ed Kouma, USBR, personal comm.). The water supply forecast indicates that surface water supplies available to maintain Sutherland Reservoir elevations necessary for operations at GGS will be insufficient by the summer of 2006. To maintain water levels in times of drought, Nebraska Public Power District (NPPD) installed 38 high capacity wells in a 20-square mile area near the reservoir on the Gerald Gentleman Station property in the spring of 2004. These wells will extract water from the High Plains Aquifer and discharge to Sutherland Reservoir. Currently, NPPD project managers plan to utilize the well field starting in the summer of 2006, with a majority of the wells operating daily for up to four months. Pumping rates for these wells range from 1,600 to 2,700 gallons per minute. The same pumping schedule will likely occur during the summers of 2007 and 2008, and if dry climatic conditions persist, beyond 2008. If necessary, the well field may be used for more than the currently planned four months each year.

Data characterizing the system are sparse and estimates of hydraulic parameters differ in previous studies of the area, and interaction of groundwater within the High Plains Aquifer and water stored in Sutherland Reservoir is not understood. Consequently, the impact of the alternative management scenarios on water levels in wells and discharge to the South Platte River is unknown and a groundwater management model is needed for the study area. The Global Problem Sparse subsurface data cause us to be uncertain of the exact nature of ground water system structure and components. Consequently, it is best, although not always customary, practice to consider multiple representations of the structure of a ground water system before making predictions of system behavior. To the extent possible, items constituting differences in model structure should be automatically adjusted in the calibration process. However, this has been difficult to achieve, thus the need to consider a set of alternative models to some extent. The adjustable parameters of each alternative model must be calibrated (i.e. parameter values adjusted to obtain the best fit to the field data, e.g. using nonlinear regression) before models can be compared (Poeter and Hill 1997). Fortunately, the advent of high speed computing and robust inversion algorithms makes calibration of multiple models feasible. Often, prediction uncertainty is larger across the range of alternative model structures than arises from the misfit and insensitivity of any one optimized model, even to the extent that confidence intervals on predictions from some of the models may not include the values predicted by others. This issue is addressed by weighting the alternative models and calculating model-averaged predictions and intervals (Poeter and Anderson, 2005). If the model averaged predictions are so uncertain that a reasonable decision is untenable, then additional data should be collected to better constrain the range of reasonable models. Hence the iterative process of model development and data collection. The problem involving management of Sutherland Reservoir in Nebraska and predicting its impact on the High Plains aquifer is well suited to the development of a structured approach to iterative alternative model definition and data needs assessment.

Methodology

Task 1: Delineation of the Model Domain

Except for the South Platte River to the north, well defined natural hydraulic boundaries do not occur near the reservoir. Consequently, the model will extend from the Platte River on the north, southward on the order of fifteen miles, with an east-west extent of about 15 miles. The west, south and east boundary will be defined as constant head reflecting the approximate heads in the aquifer at those locations. Simulations of the regional COHYST model will facilitate delineation of boundary conditions and average material properties. The influence of stress on boundary 8 fluxes will be evaluated through out the project and the model domain will be adjusted appropriately.

Task 2: Compilation of available data
Historic data from NPPD, the USGS, and the University of Nebraska Conservation and Survey Division on hydrostratigraphy, hydraulic properties, water levels and flow rates will be coupled with the new lithologic and geophysical borehole data from the well field installation. These data will be supplemented with pertinent COHYST data for this locale in project databases of various formats (primarily in GIS formats). This database will also be the repository for all USGS hydrochemical data and age dates once it becomes available.

Task 3: Delineation of the hydrostratigraphic framework and associated hydraulic properties
Historical interpretation of the hydrostratigraphinc framework (Harza, 1993; Gutentag et al., 1984) will be used as a starting point for further refinement given the hydrostratigraphic data from the newly drilled well field. The surficial geology of the area is dominated by multiple layers of Quaternary loess and fine dune sand deposits that can locally be 50 to 100 feet thick. The base of the reservoir is directly within sand and gravel deposits up to 25 feet thick which facilitate rapid seepage rates. Discontinuous zones of paleosol, a few to several feet thick, presumably the Sangamon, exist below the coarse channel deposits. This sequence of deposits (coarse over fine) creates conditions that enhance horizontal flow of seepage below the reservoir. Fine to medium texture deposits (silts to fine sands up to 40 feet thick) underlie the paleosol. These units lie directly above the Ogallala Group, the primary unit comprising the High Plains Aquifer (up to 350 feet thick). The water table occurs within the upper units. The Ogallala in this area is a mixed sequence of sands and gravels, silts, clays, sandstones, and siltstones, varying substantially over short distances due to the depositional environment. Well yields can be large in this area of the Ogallala with some irrigation wells pumping on the order of 2,000 gallons per minute. The base of the High Plains Aquifer as defined by the USGS High Plains RASA and the Nebraska Platte River Cooperative Hydrology Study (2004) in this area is the Brule Formation, a massive clay- and siltstone (with some coarse deposits locally) within the White River Group (Gutentag and others, 1984).

Task 4: Development of alternative conceptual models Given the hydrostratigrphy and associated uncertainties developed in Task 3, alternative conceptual models will be developed and starting values for hydraulic parameters defined. The simplest geometry consists of continuous horizontal layers from the surface downward of 1) fine loess and sand dunes (50-100 feet), 2) sand and gravel (up to 25 feet thick), 3) paleosol, 4) silts and fine sands (up to 40 feet thick), and 5) the Ogallala, a heterogeneous mix of mixed sequence of sands and gravels, silts, clays, sandstones, and siltstones (up to 350 feet thick). Clearly some of these layers are discontinuous and vary in thickness. Evaluation of the presence, distribution and thickness of these materials will be explored through alternative conceptual models.

Task 5: Construction of numerical models representing the conceptual models Based on the results of tasks 1 through 4, numerical models will be developed using GMS to build the hydrostratigraphy, generate the grid and assign properties. The resulting files will be used for simulation external to GMS (EMRL, 2004) to facilitate manipulation of material zones 9 and inversion with UCODE_2005 and resulting heads and fluxes imported to GMS for visualization. Alternative schemes for finding an optimal zonation of the aquifer zones will be evaluated. Options include the alternatives discussed in a later section titled "Related Research". The more appropriate methods will be selected once the general character of the units are identified by analysis of the detailed hydrostratigraphic data recently acquired from drilling the new well field.

Task 6: Calibration of the models using nonlinear regression
The models will be calibrated using nonlinear regression techniques as implemented in UCODE_2005 (Poeter et al., 2005; Poeter and Hill, 1998, Poeter and Hill, 1997), which performs inverse modeling, posed as a parameter-estimation problem, using nonlinear regression. UCODE_2005 is a JUPITER (Joint Parameter IdenTification and Evaluation of Reliability) application (Banta et al., 2005). The JUPITER API is a computer programming environment that includes conventions and software components designed to support the development of computer programs that perform model sensitivity analysis, data needs evaluation, calibration, uncertainty evaluation, and (or) optimization currently under development by the USGS, in coordination with EPA. Statistics generated by UCODE and its post-processor (RESAN_2005) will be used to evaluate the most important parameters in each model as well as the type and location of additional data that would be most useful in reducing parameter and associated predictive uncertainty (Task 7). Evaluation of the important parameters will guide further conceptual model development. In addition, the statistics will be used to compare alternative models and guide development of an improved conceptual model of the region (Tasks 8 and 9).

Task 7: Recommendation of types and locations of data that will improve the model and reduce uncertainty Sensitivities of a model to given types, locations and time of data, as computed by UCODE, are independent of the data value. Increased sensitivity and decreased parameter correlation reduce predictive uncertainty. Consequently various options for data will be considered (at minimal cost) using the calibrated models before the substantial expenditure of field sampling and laboratory analysis. This feedback will be most valuable to the USGS in selecting locations where samples will be collected in 2006 to analyze for the characteristic natural tracers of the reservoir water identified by their work in 2005. The results of their findings in 2006 will be used to further improve the models and reduce prediction uncertainty.

Task 8: Estimation of seepage volume and flow paths
Seepage volume and flow paths will be calculated using the calibrated models and YCINT_2005, a UCODE_2005 post-processor. The values will be model-averaged to generate the best estimate of the volume and paths and the associated uncertainty. This will be accomplished using MMRI (Poeter et al., 2005), a multi-model inference algorithm, and a member of the Jupiter family of codes. MMRI operates on data exchange files from any JUPITER-based inversion algorithm (e.g. UCODE_2005), using them to rank and weight alternative models, then model-averages 10 parameters and predictions (Poeter and Anderson, 2005), using flexible, user-specified algorithms which include the maximum likelihood Bayesian model average (MLBMA) algorithm recommended by Neuman and Weirenga (2003).

Task 9: Prediction of the response of the flow system to various management scenarios
Alternative management scenarios will be defined as the project proceeds. At a minimum they will include steady pumping of all wells in the well field at the distributed rate found necessary to maintain the reservoir at a minimum level given the model calibrations, and some combinations of a subset of wells maintaining minimum levels. Additional scenarios will involve various strategies to recharge the aquifer by raising water levels in the reservoir via canal inflow during wet periods. Further scenarios will be developed as problems are identified (e.g. excessive drawdowns in surrounding wells or low flows in the Platte River) by modeling results. The predictions for each scenario will be averaged for all models using MMRI as discussed in task 8. Their uncertainty will be considered and if the range of uncertainty in predicted conditions is unacceptable recommendations will be made for further data collection to reduce that uncertainty.

Task 10: Preparation of papers delineating the approach, implementation and findings
Two papers will be prepared. One paper will delineate the approach for hydrologic system characterization that reduces predictive uncertainty associated with ground water management problems through an iterative process that couples development of alternative conceptual models, model averaging of predictions, and data needs assessment. The second paper will discuss the implementation of the approach for management of the Sutherland Reservoir and the findings of the project.

Task 11: Preparation and posting of a web page presenting project information
A web site, targeting a multi-level audience, will be developed with graphical displays highlighting project findings, the project report, public domain data, project model input and output files, and directions for their use (see section titled: Information Transfer Plan). Facilities Colorado School of Mines and the International Ground Water Modeling Center have complete computing facilities and software (e.g. Arc/Info, Access, MODFLOW2000, MODPATH, MT3D, GMS, GWV, UCODE among other hydrologic and geologic software) for conducting this work. Students and faculty will write software as necessary to accomplish the tasks. Basic field equipment including pumps, water level sounders, and water quality sampling equipment are available through Colorado School of Mines, but will be supplied by NPPD or their contractors. The USGS will provide geochemical sampling equipment and analysis laboratories.

Principal Findings and Significance

The model domain for the Sutherland Reservoir/ Gerald Gentlemen Station (GGS) investigation was defined as an area of approximately 1,000 square miles with the reservoir located slightly north of the center of the model domain and grid area. This area includes several surface water features and land use types and is sparsely populated.

Several types of pre-project data were compiled for the study. Sources for nearly all of these data include: the Nebraska Department of Natural Resources (NDNR); US Geological Survey (USGS); the University of Nebraska Conservation and Survey Division (CSD); the Nebraska Public Power District (NPPD); and the Platte River Cooperative Hydrology Study (COHYST). The data include historic river flows at several gages on the South Platte River (NDNR, USGS, COHYST), geologic borehole data (CSD, COHYST, NPPD), evapotranspiration data

(COHYST), area well records (NDNR), historic canal diversion and reservoir stage data (NDNR, NPPD), and land use imagery in the last 10 years (COHYST). A considerable effort was expended preparing the data for use in the groundwater model and other software interfaces.

To enhance model calibration, 7 multi-well monitoring nests were installed around the GGS wellfield and Sutherland Reservoir to monitor groundwater levels and identify distinct geochemical signatures of the groundwater at varying locations both vertically and horizontally. Surface water features, including canals, drains, the South Platte River, and Sutherland Reservoir were sampled for water quality. The samples were analyzed by the US Geological Survey. Sampling will continue to evaluate changes after pumping the well field for summer operation of GGS. Flow was, and continues to be measured at six previously unmonitored locations along drains in the model area. It appears that flow at these locations will be important to groundwater model calibration.

A database of geology from boreholes at the GGS site that were installed since 2004 was developed. Pre-project geologic borehole data were incorporated in the data base, such that it now includes over 70 boreholes within an area of less than 60 square miles in the vicinity of GGS. These borehole data have been analyzed in a stratigraphic modeling software interface which allows for three-dimensional modeling of the complex geologic data found at the Sutherland Reservoir/GGS site. These data have been used to generate one of the conceptual models being created for this project. Automated procedures for generating alternative conceptual models are under development.

Currently, four conceptual models with varying hydrostratigraphy at the Sutherland Reservoir/GGS site are being evaluated. These conceptual models include a two-dimensional representation, a three-dimensional two-layer representation, a four-layer representation using previously constructed COHYST data, and a five-layer representation using the new hydrostratigraphy that combines the new geologic borehole data with the COHYST borehole data. Additional conceptual models include alternate hydrostratigraphic representations of the geologic data, and varying representations of boundary conditions based on land-use practices that influence groundwater recharge and evapotranspiration.

Each model has been constructed as a numerical model and calibration has begun. Details of the calibration schemes are under development at this time. Based on preliminary assessments, recommendations have been for additional streamflow data and water quality data that will provide flow paths and mixing ratios for use in model calibration.