of the GEWEX Global Land-Atmosphere System Study (GLASS). However, few of these model evaluations have used long-term data sets (greater than one or two years) or have been carried out in semi-arid regions. Understanding the interaction of land surface processes with climate and its impact on the water cycle is crucial for predicting the availability of water resources in semi-arid regions. A recently proposed PILPS SanPedro-Sevilleta experiment is being undertaken in the southwestern U.S. using five semi-arid vegetation sites (including two from this study). A systematic analysis is undertaken based on the framework proposed for the PILPS experiment, testing some of the hypotheses for the calibration and cross-validation of land-surface schemes. This specific study analyzes the National Center for Environmental Prediction (NCEP) Noah land-surface model, one of several "community" or "multi-group" models that are evolving in land-surface studies. The MOCOM algorithm (a general purpose multi-criteria optimization algorithm that provides an estimate of the Pareto solution space) is linked with the Noah model to estimate parameters for two semi-arid biomes, a desert shrub and grassland, which have continuous meteorological and flux measurements over a four-year period. The model shows improved performance with calibrations (over default) and the model also does fairly well for sensible heat and ground temperature over the longer term. However, the increase in latent heat during short-term climatic events (the year-to-year monsoon and winter-time El Niño events) is not captured well in model simulations. The application of site-specific parameters at the two field sites does improve performance, but in the absence of calibration data, a proxy-basin set of parameters can be applied with only a slight decline in performance. Results from this analysis also show that several of the vegetation and soil parameters vary dependent on the length and period of calibration. Inadequate representation of these processes may result in large uncertainty in parameter estimates for semi-arid regions. The performance of models for long-term climate change scenarios is difficult to assess; however, the goal is that calibration and evaluation studies such as this and the PILPS SanPedro-Sevilleta experiment will lead to improved parameter estimates for use in regional and global long-term climate studies.

H11A-07 0930h

Evaluating the Influence of Spatial Processes and Information on Local Moisture-Outflow Relations: Characterizing the Scale of Interaction Using Soil Moisture and Precipitation Observations

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The issue of scale in land surface hydrology is often important. Components of root zone outflow (evapotranspiration, drainage, and runoff processes) are dependent on soil moisture. In some cases, this dependence can be reasonably described at the point scale (e.g. the Darcy and Richards equations). However, at larger scales, these interrelationships become increasingly complex and uncertain. Small-scale processes are one of many factors that may influence large-scale behavior. In modeling or monitoring frameworks, the presence of subgrid heterogeneity in landcover, soil parameters or forcings, non-linear flux behavior, and lateral flows or processes all can have substantial impacts on large scale behavior. A successful hydrologic model must balance the importance of these different factors with the need for computational efficiency and tractability. For example, one can conceive of two possible models for soil moisture - outflow relationships at a given location. A simpler model is an "independent columns" approach; i.e. outflow can be completely represented as a function of the soil moisture at that location only. However, in many cases this is a not valid model; lateral interactions and flow among sites may exist and influence the components of outflow at measured point, and/or large-scale phenomena may affect outflow in a way that is not captured by a locally independent model. In such cases, some sort of spatial aspect must be incorporated and addressed if moisture relations are to be successfully described, predicted or aggregated. Here we use a non-linear water balance parameterization, fit to observational precipitation and soil moisture data. The parameters are optimized by exploiting the equilibrium tendency of soil moisture time series. Spatial information is introduced through two parameters that modify the drainage and evaporation functions, and the importance of these parameters to the performance of the model is assessed by statistically evaluating their effect on the stationarity of the modeled soil moisture trace through entropy estimates; thereby determining whether lateral flows or processes are contributing to the observed behavior. An example with data from the Illinois Climate Network is presented.

H11A-08 0945h

Spatial Variability and Multiscale Errors in Assimilated Soil Moisture Fields

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Coupled land-atmosphere models are increasingly focused on using assimilated near-surface soil-moisture to improve the prediction of moisture and heat fluxes. Given that these models have a non-linear dependence on the soil-moisture state, it should be expected that errors in the observed soil-moisture will propagate through the system and influence the predictions of the model. Of particular concern is the situation when model predictions are made at scales that are different from that of the observation scales of the soil-moisture. In this case the transformation process of the soil-moisture from one scale to another introduces additional errors that will influence the prediction. The purpose of this study is to develop an understanding of the influence of multiscale observational errors in the soil-moisture on the prediction of surface fluxes. The following approach is adopted. We use the SGP'97 near-surface soil-moisture observation from ESTAR images at 0.8 km (resampled to 1 km). These observations are available for 16 days during the period June 18, 1997 to July 16, 1997. Using these we obtain estimates of the near-surface soil-moisture at several scales (1, 2, 4, 8, 16 and 32 km). This is accomplished through a multiscale estimation technique using a mean differenced fractal model [Kumar, 1999]. These multiscale near-surface observations are assimilated using extended Kalman filtering algorithm embedded in the NCAR-LSM (Land Surface Model). The assimilation is performed, once daily on the days when observations are available, at all scales for the entire study period to predict the soil-moisture profile and the surface energy fluxes. This allows us to address two key issues: (1) assessment of how the estimation error evolves with different moisture conditions as a function of scale, and (2) assessment of the spatial variability of assimilated fields at different scales. From the multiscaling results, we can observe that the estimation errors grow as the moisture increases in general at all the scales. Also there is a decrease in the estimation error as the scale increases. The assimilated fields show consistent spatial variation at all scales but also show their dependence on assimilation frequency and rainfall events. This analysis will help us understand the model response as a function of scale. It also helps in developing a better framework for specifying the error statistics in the assimilation algorithm. [Kumar, 1999] Kumar, P., A Multiple Scale State-Space Model for Characterizing Subgrid Scale Variability of Near-Surface Soil Moisture, IEEE Transactions on Geoscience and Remote Sensing, 37(1), January 1999.

H11B MCC: 3024 Monday 0800h

Optimization for Model Calibration and Management in Water Resources I *(joint with NG)*

Presiding: **C A Shoemaker,** Cornell University**; S Sorooshian,** University of California, Irvine

H11B-01 0800h

Assessing Model Structural Uncertainty Using a Split Sample Approach for a Distributed Water Quality Model

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A method for assessing model structural uncertainty as opposed to the more commonly investigated parameter uncertainty is presented that should aid in the development of improved water quality models. Elsewhere (see van Griensven and Meixner abstract, this session) we have developed a methodology (ParaSol) to estimate model parameter uncertainty. Uncertainty is typically estimated with a specific time period of data. However from experience with model calibration problems we know that we need to employ split sample and other evaluation tests to estimate the confidence we should have in our models and our methods. Evaluation tests generally give us qualitative data about confidence in our models. Here we propose a method that uses the split sample approach to generate a quantitative estimate of model structural uncertainty. The Sources of Uncertainty Global Assessment using Split SamplES (SUNGLASSES) method is designed to assess predictive uncertainty that is not captured by parameter or physical input uncertainty. We assume that this additional uncertainty represents model structural error in how the model represents the physical, chemical, and biological processes incorporated into water quality models. This method operates by selecting a threshold for a sample statistic (bias in our case), when the sample statistic for a model simulation is below the threshold the simulation is acceptable. Where this methodology differs from others is that the threshold is determined by evaluating whether the chosen threshold will capture simulations during an evaluation time period (hence split sample) that was not used to initially calibrate the model and generate parameter estimates. Most existing methods rely solely on sample statistics during a calibration period. The new method thus captures an element of predictive error that originates in the structural conception of the processes controlling water quality. The described method is applied on a Soil Water Assessment Tool (SWAT) model of Honey Creek, a tributary of the Sandusky catchment in Ohio. Water flow and sediment loads are analyzed. The results show the minor importance of model parameter uncertainty assessed by ParaSol in view of the total model uncertainty that was assessed by SUNGLASSES.

H11B-02 0815h

Parameter uncertainty assessment for distributed water quality models

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A new method is developed by the authors that assess the parameter uncertainty in distributed water quality models for multiple outputs in an efficient and effective way. Distributed water quality models have a high number of parameters, high parameter correlations, several output variables and a complex structure leading to multiple minima in the objective function. General uncertainty/optimization methods based on random sampling as GLUE or local methods such as PEST are often not applicable for theoretical or practical reasons. Therefore, the method "ParaSol" (Parameter Solutions) is developed to perform optimization and model parameter uncertainty analysis for complex models such as distributed (water quality) models. Optimization is achieved by adapting the SCE-UA to enable it to account for multi-objective problems while not being trapped in a localized minimum. The simulations performed by the SCE-UA are further used for uncertainty analysis. Two methods have been developed that select "good" parameter solutions out of the SCE-UA simulations based on an objective threshold. The first method is based on chi-squared statistics to delineate the confidence regions around the optimum/optima. The second method uses Bayesian statistics to define high probability regions whereby it accounts for the fact that the high probability regions are likely to be sampled more densely. The application of ParaSol on the flow and sediments simulations for Honey creek (Ohio) showed that, when 2 years of daily data are used, the confidence regions are very small when the chi -squared statistics are used and even smaller when using the Bayesian statistics. The results were also used to validate the suitability of SCE-UA sampling for uncertainty analysis by comparing to 500000 Monte Carlo samples. It was shown that the SCE-UA sampling was more effective and efficient as none of the Monte Carlo samples were close to the minimum or within the confidence region defined by ParaSol.

H11B-03 0830h

Combined Parameter and State Estimation of Hydrological Models Using Ensemble Kalman Filter

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The response of hydrologic models is mainly defined by parameters, as the physical and generally time-invariant representation of watershed characteristics and states, as storages of water that are propagated by model physics. Some of the parameters may be measured directly but others are not easily estimated, therefore adjustment of initial values or calibration is needed. The model calibration process attempts to minimize the systematic bias arising due to inaccurate parameterization. Calibration is commonly accomplished in a batch-processing scheme where the available data is used at once to minimize the long-term bias in the simulation. On the other hand, to estimate the state variables of a system, data assimilation techniques, which are sequential data processing algorithms, are commonly used. Unlike the batch-processing scheme, data assimilation does not require long data record to be kept in storage. It has the capability to estimate the variables at each time step. Ensemble Kalman filter (EnKF) is an efficient data assimilation procedure for state estimation in hydrological modeling. The main goal of this study is to use the state augmentation technique in the context of EnKF to estimate both state variables and parameters simultaneously in a conceptual rainfall-runoff model. In this procedure one can detect the time variation of parameters while minimizing the short-term bias in the system. Different sources of uncertainties including forcing data (precipitation) error and output (streamflow) error are considered. The impact of the magnitude of perturbation against the number of ensemble members on the efficiency and accuracy of the estimation is investigated and a procedure for tuning these hyper-parameters is proposed.

H11B-04 0845h

A New Function Approximation Optimization Algorithm for Automatic Calibration of Complex Nonlinear Water Resource Models

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Site-specific pollution transport models are based on field data and the calibration of those parameter values that cannot be directly measured. This combination of field data and calibrated model is a powerful tool in environmental analysis. However, one of the difficulties with complex nonlinear models is that the calibration process can be time consuming for the modeler and computationally very demanding if it is done thoroughly. Automatic calibration methods employing optimization methods can reduce both the human and computer time required to do a thorough calibration. This paper will discuss the use of function approximation optimization for automatic calibration of complex models arising in environmental and water resource management. We will describe a new algorithm developed by the authors for optimization of nonlinear, non-convex problems, including those arising in water resources. The procedure is designed for use with "costly" functions, i.e. those that take a substantial amount of CPU for each evaluation of the water resources simulation model. The method uses function approximation of the objective function to guide the search procedure and to reduce the number of times the objective function must be evaluated. A comparison will be presented of the performance of different algorithms (including the new function approximation algorithm) on test functions that have multiple local optima. The new function approximation method performs better than earlier function approximation optimization methods on most of the test problems. This analysis will also be related to two other papers in this session that apply the new function approximation algorithm to optimal calibration to field-data based models including a) a transport model of enhanced bioremediation of chlorinated ethenes (Mugunthan et al.) at a DOD site and b) a watershed model in NY state (Tolson et al.).

H11B-05 0900h

Comparison of Optimization Algorithms for the Automatic Calibration of a Watershed Model to Measured Flow, Sediment and Phosphorus Data

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This study compares multiple heuristic optimization algorithms for automatic calibration of a watershed model to flow and water quality data. The automatic calibration of the watershed model in this study involves simultaneously calibrating the model to flow, suspended sediment, particulate and total dissolved phosphorus data by modifying up to 20 model parameters. A single-objective function is defined by a weighted sum of the measures of model and data agreement for each of the measured constituents. The heuristic optimization algorithms compared in this study are the Shuffled Complex Evolution (SCE-UA) algorithm developed by Duan et al., a Genetic Algorithm (GA) and a newly developed function approximation algorithm by Regis and Shoemaker described in another paper appearing in this session. Although the SCE and GA algorithms have been previously used to calibrate hydrologic models, their application to calibration of watershed models to measured sediment or nutrient data is much less common. This is the first application of a function approximation algorithm to the calibration of a watershed model to flow, sediment and phosphorus data. The watershed model applied in this study is a modified version of the Soil and Water Assessment Tool (SWAT2000). The case study area is a small (37 km^2), mainly rural watershed in Upstate New York called Town Brook that drains to New York City's (NYC) drinking water supply system. Town Brook is a sub-watershed in NYC's Cannonsville drinking water reservoir watershed (1178 km^2). Mitigating phosphorus loading to this and other NYC drinking water reservoirs is critical to avoid construction of an estimated 8 billion dollar water filtration plant. A SWAT2000 model was previously developed by the authors to model phosphorus loading from the entire watershed to the Cannonsville Reservoir. Initial SWAT2000 model parameters for the Town Brook scale model were derived from the larger scale Cannonsville Basin model. This study is focused on automatically calibrating the Town Brook model to approximately two years of Town Brook water quality data (suspended sediment loading and phosphorus) with the various heuristic optimization algorithms. The best automatic calibration results are compared with the initial trial-and-error calibration results to gauge the improvement in model predictive performance achieved by automatic calibration.

H11B-06 0915h

Calibration of Biokinetic and Biological Parameters for a Groundwater Bioremediation Model using Heuristics and Function Approximation Optimization

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Heuristics and function approximation optimization methods were applied in calibrating biological and biokinetic parameters for a computationally expensive groundwater bioremediation model for engineered reductive dechlorination of chlorinated ethenes. Multi-species groundwater bioremediation models that use monod type kinetics are often not amenable to traditional derivative based optimization due to stiff biokinetic equations. The performance of three heuristic methods, Stochastic Greedy Search (GS), Real Genetic Algorithm (RGA), Derandomized Evolution Strategy (DES), and, Function Approximation Optimization based on Radial Basis Function (FA-RBF) were compared on three-dimensional hypothetical and field problems. GS was implemented so as to perform a more global search. Optimization results on hypothetical problem indicated that FA-RBF performed statistically significantly better than heuristic based evolutionary algorithms at a 10% significance level. Further, this particular implementation of GS performed well and proved superior to RGA. These heuristic methods and FA-RBF, with the exception of RGA, were applied to calibrate biological and biokinetic parameters using treatability test data for enhanced bioremediation at a Naval Air Station in Alameda Point, CA. All three methods performed well and identified similar solutions. The approximate simulation times for the hypothetical and real problems were 7 min and 2.5 hours respectively. Calibration of such computationally expensive models by heuristic and function approximation methods appears promising.

H11B-07 0930h

Optimization of Engineering Design of Subsurface Environmental Remediation Systems: Development and Testing of Community Benchmark Problems

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It is well established that the design of economically efficient subsurface remediation systems can benefit from the joint use of formal optimization and simulation models. It is also well known that obtaining the optimal solution for such designs is usually difficult and computationally expensive, due to the characteristic nonlinear, nonconvex nature of the solution spaces. We believe that more rapid progress on optimal design methods might result from both improved methods of evaluation and comparison of existing methods on realistic problems and from the investigation of novel methods not yet studied in subsurface remediation field. This work responds to these needs. We have designed a set of systematic test problems to be attacked by the engineering and mathematics community, as a means for benchmarking and comparing optimization approaches. The test problems pose many of the difficulties anticipated in solving real-world problems such as (a) mixed continuous and integer, nonlinear objective functions, (b) the combination of boundary conditions and system parameters gives rise to complex relationships between the objective function, the decision variables, the constraints, and the state variables, (c) evaluation of the objective function is based on solving model equations that are difficult to solve accurately and quickly; and (d) the number and range of decision variables is potentially enormous. The physical problems include water supply design problems in freshwater and freshwater-saltwater systems, a contaminant plume capture zone design problem, and a contaminant plume pump-and-treat design problem. Problem domains are specified in terms of hydraulic conductivity distributions- from homogeneous domains to spatially-correlated random fields- and in terms of confined vs. unconfined conditions. Each problem is specified completely in mathematical and numerical terms, but sufficient flexibility is allowed to provide for a wide range of problem solution approaches. For example, the user is free to select a flow and transport simulator and to specify spatial and temporal discretizations. This paper will describe the test problems and initial results.

H11B-08 0945h

Consideration of Time as a Decision Variable in Subsurface Remediation Optimization

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Remediation time frames are normally fixed by a number of management and regulatory issues without consideration of the interaction between remediation cost and the time constraint. This work looks at the implications of the time constraint by considering time as a decision variable in the optimization process. We utilize a multi-objective optimization of a hypothetical contaminated aquifer that results in a trade off curve of total remediation time vs. remediation costs. This curve allows decision makers to view the full range of options for time and cost. The cost function includes treatment, pumping and management costs. The multi-objective problem is formulated to minimize the design cost while also minimizing the remediation time. The Niched Pareto Genetic Algorithm (NPGA) has been modified to allow enforcement of water quality constraints. The addition of this constraint enforcement is developed by two methods. The first method initiates a penalty in the fitness values as the enforcement mechanism. The second uses the niching domination to apply the constraint. Each of these methods is innovative in remediation optimization work. Comparisons of the two methods are presented. Three sets of numerical computational experiments are performed to produce tradeoff curves of cost and total time. The experiments increase in computational effort as the complexity of the time variables increases. In each experiment the cost objective will be a function of pumping rate. The first experiment will use a single management period, where total time is the decision variable. The second will use multiple management periods of fixed length, where the number of management periods is the decision variable. The third will have the number of management periods and the length of the periods as decision variables. This method of investigation in to the impact of time as an optimization variable incorporates the full range of management possibilities. Comparisons of the three experiments are presented as tradeoff curves of total remediation time vs. cost.

H11C MCC: Level 2 Monday 0830h

Recent Advances in GIS and Data Visualization in Regional-Scale Groundwater Modeling I Posters

Presiding: **C Zheng,** University of Alabama**; P Hsieh,** U.S. Geological Survey

H11C-0877 0830h POSTER

Use of GIS and Data Visualization Tools for Modeling Aquifer Architecture and Generating Aquifer Vulnerability Maps at a Regional Scale

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The Grand Forks aquifer aquifer is one of the first aquifers in the province of British Columbia to undergo a full hydrogeologic characterization because of its importance as a water supply. It is also being used as a case study area for modelling the impact of climate change on groundwater. The aquifer consists of a layered sequence of glacial and alluvial sediments overlying bedrock, which from the top down are comprised of gravel, sand, silt and clay. Aquifer hydrostratigraphy was defined based on some over 300 water well records contained from in the BC Ministry of Water, Land and Air Protection Water WellWELL Database. Lithology data were first standardized to correct errors in syntax, grammar and spelling, recognize equivalent terms, and classify the materials into dominant types so that calculations involving the database could be more easily undertaken. Standardized data have beenwere then used to construct an aquifer architecture model that can be used as input to a numerical groundwater flow model and to construct a vulnerability map. The three-dimensional aquifer architecture model was developed in the data visualization software (GMS) by first constructing cross-sections, and later, generating a solid model that represents the layering and spatial heterogeneity of the aquifer. The bedrock surface was modeled using geostatistical techniques to produce a bedrock digital elevation model (DEM) that better constrains the lower bound of the model. Layers were imported into the numerical groundwater flow code, Visual MODFLOW, and are being used to model current climate conditions and climate change scenarios for the Grand Forks region. A GIS was also used to capture the spatial variability in the input parameters that are used to construct vulnerability maps. Using the DRASTIC approach, indices were assigned to each of seven hydrogeologic parameters. A rastor map was generated for each. A digitized soils map was used to assign soil material and soil topography indices to soil polygons. Indices for depth to water, aquifer media at the water table, aquifer conductivity and impact of vadoze zone were derived from well lithology data, and were interpolated within the GIS to provide a continuous surfaces. Spatial variability in recharge reflects both natural recharge and estimates of return flow from water pumped to irrigate cropsirrigation. The rastor maps for each parameter index were weighted and added togethersummed to produce the DRASTIC vulnerability index map. The use of GIS and data visualization software is invaluable for effectively managing the volume of data and representing spatial variability in regional aquifers.

H11C-0878 0830h POSTER

Automated Geographic Simplification Tools for Development of Regional Scale Groundwater Flow Models

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The analytic element method is well suited for modeling regional scale saturated groundwater flow. Recent advances enable the solution of models with tens of thousands of hydrogeologic features over scales of hundreds of kilometers. In order to implement such models, automated techniques are desired to translate regional scale conceptual models and/or readily available hydrologic base maps into model features. A suite of tools derived from standard cartographic generalization operators have been developed to perform these simplification tasks. Highly detailed digitized surface features (e.g. river and lake boundaries) are simplified into representative elements and strings of elements using algorithms designed to capture important geometric and physical properties. These simplified models are more computationally efficient and achieve similar (often nearly identical) results. In addition, a general framework for application of simplification operators to vector-based numerical models has been developed.

URL: http://www.groundwater.buffalo.edu

H11C-0879 0830h POSTER

Enhancement of Aquifer Vulnerability Indexing Using the Analytic Element Method

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Indexing methods are used for the evaluation of aquifer vulnerability and establishing guidelines for the protection of ground-water resources. The principle of the indexing method is to use map layers of various influences on ground water to determine the overall vulnerability of an aquifer to anthropogenic stresses. The analytic element method (AEM) of ground-water flow modeling can be used to enhance indexing methods by rapidly calculating a potentiometric surface based primarily on surface water features. This potentiometric map can be combined with a digital elevation model to produce a map of depth to the water table. This is an improvement over simple water table interpolation methods because it is physically based and properly represents surface water features, hydraulic boundaries, and changes in hydraulic conductivity. The AEM software, SPLIT, is used in a geographic information system based graphical user interface to improve an aquifer vulnerability assessment for a valley-fill aquifer in western New York State. A GIS-based graphical user interface allows automated conversion of hydrography vector data into analytic elements.

H11C-0880 0830h POSTER

Application of GIS and Visualization Technology in the Regional-Scale Ground-Water Modeling of the Twentynine Palms and San Jose Areas, California

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Application of GIS and visualization technology significantly contributes to the efficiency and success of developing ground-water models in the Twentynine Palms and San Jose areas, California. Visualizations from GIS and other tools can help to formulate the conceptual model by quickly revealing the basinwide geohydrologic characteristics and changes of a ground-water flow system, and by identifying the most influential components of system dynamics. In addition, 3-D visualizations and animations can help validate the conceptual formulation and the numerical calibration of the model by checking for model-input data errors, revealing cause and effect relationships, and identifying hidden design flaws in model layering and other critical flow components. Two case studies will be presented: The first is a desert basin (near the town of Twentynine Palms) characterized by a fault-controlled ground-water flow system. The second is a coastal basin (Santa Clara Valley including the city of San Jose) characterized by complex, temporally variable flow components - including artificial recharge through a large system of ponds and stream channels, dynamically changing inter-layer flow from hundreds of multi-aquifer wells, pumping-driven subsidence and recovery, and climatically variable natural recharge. For the Twentynine Palms area, more than 10,000 historical ground-water level and water-quality measurements were retrieved from the USGS databases. The combined use of GIS and visualization tools allowed these data to be swiftly organized and interpreted, and depicted by water-level and water-quality maps with a variety of themes for different uses. Overlaying and cross-correlating these maps with other hydrological, geological, geophysical, and geochemical data not only helped to quickly identify the major geohydrologic characteristics controlling the natural variation of hydraulic head in space, such as faults, basin-bottom altitude, and aquifer stratigraphies, but also helped to identify the temporal changes induced by human activities, such as pumping. For the San Jose area, a regional-scale ground-water/surface-water flow model was developed with 6 model layers, 360 monthly stress periods, and complex flow components. The model was visualized by creating animations for both hydraulic head and land subsidence. Cell-by-cell flow of individual flow components was also animated. These included simulated infiltration from climatically variable natural recharge, interlayer flow through multi-aquifer well bores, flow gains and losses along stream channels, and storage change in response to system recharge and discharge. These animations were used to examine consistency with other independent observations, such as measured water-level distribution, mapped gaining and losing stream reaches, and INSAR-interpreted subsidence and uplift. In addition, they revealed enormous detail on the spatial and temporal variation of both individual flow components as well as the entire flow system, and thus significantly increased understanding of system dynamics and improved the accuracy of model simulations.

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GIS integration in applied ground water resource modeling

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Groundwater modeling employs spatially distributed data in the construction of models as well as in the presentation of the models to vested interests and decision makers. Numerous commercial groundwater modeling interfaces have attempted a GIS like integration within the modeling system, with some what limited success. We will show a complete modeling development-execution-result analysis procedure which is fully rooted in a GIS environment. All model setup/input as well as results are in a GIS, thus easing access and applicability. A key aspect of the process is that the resulting model is independent of the modeling code. The procedure utilizes spatially distributed information on soil type, climate and land use to develop maps and time series for recharge. At the same time a geological editor integrated in a GIS interface is used