

SIMULATION/OPTIMIZATION APPLICATIONS AND SOFTWARE FOR OPTIMAL GROUND-WATER AND CONJUNCTIVE WATER MANAGEMENT

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ABSTRACT

Diverse water management simulation/optimization (S/O) experiences promoted the development of many S/O modeling approaches and models. Several of these are being incorporated within the Simulation/Optimization Modeling System (SOMOS). Non-modeler water scientists or engineers can apply one SOMOS module to optimize field-scale groundwater and conjunctive water management. Experienced groundwater modelers can apply other modules to optimally manage complex heterogeneous aquifer and stream-aquifer systems. SOMOS employs a variety of simulation models and approaches and optimization algorithms to optimize flow and contaminant management. SOMOS or its precursor modules have been well proven in real-world projects. Designed for use by consultants, students, academics, and agencies, SOMOS' powerful optimization and artificial intelligence modules will improve user satisfaction with developed strategies. SOMOS can help increase water use, protection, and cleanup and reduce cost.

INTRODUCTION

Optimization is needed to improve water management for a wide range of situations, differing in media, temporal and spatial dimensionality, and types of fluxes and contaminants. No single simulation/optimization (S/O) modeling approach is best for all situations. Optimally managing water is aided by using S/O models that include both simulation and optimization abilities. At Utah State University, Dept of Biological and Irrigation Engineering (DBIE), and formerly at the University of Arkansas, Dept. of Biological and Agricultural Engineering (DBAE) students and faculty developed and applied many S/O approaches and models. This paper shows diverse water management situations addressable by S/O modeling. These experiences have affected the evolution of the described SOMOS (Simulation/Optimization Modeling System) software.

A normal simulation model (sometimes termed an S model) uses analytical equations or sets of numerical equations to predict physical system response to management. Likewise, a S/O model needs to be able to simulate system response to management. Approaches for simulating within S/O models include: (1) embedding analytical or numerical equations or models directly; and (2) using substitute simulators. One substitute simulator is the response matrix (RM) approach. An RM model represents hydraulic response to stimulus using influence coefficients and superposition equations. Other surrogate simulators, sometimes used for nonlinear variables, are response surfaces or neural networks. In our S/O models, we have used embedding, response matrix, response surface, and neural network surrogate simulators.

In addition to simulation ability, S/O models need procedures for developing optimal water management strategies. Optimization algorithms differ in their suitability for different types of optimization problems. We have developed S/O models that perform: linear (LP), quadratic (QP), nonlinear (NLP), mixed integer (MIP) and mixed integer nonlinear (MINLP) optimization; employing simplex, gradient search, outer approximation and heuristic or evolutionary optimization techniques.

SAMPLE S/O MODELING APPLICATIONS

DBAE and DBIE have optimized management for study areas ranging from one-dimensional vertical sections of the vadose zone (Peralta et al, 1994; Musharrafieh et al, 1995); to three-dimensional

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saturated groundwater systems (Gharbi and Peralta, 1994; Takahashi and Peralta, 1995); to dynamic stream-aquifer systems (Peralta et al, 1988; Peralta et al, 1990).

For government planning agencies, we have developed models and strategies for optimizing sustained groundwater yield planning and conjunctive water use for areas up to 35,000 km² in size (Ranjha et al, 1990; Peralta et al, 1995a,b; Gharbi and Peralta, 1994). Although often intended to emphasize providing sustainable water supply for large irrigated areas (Peralta et al, 1995a,b), the models have been valuable to determine tradeoffs in management in areas having conflict between agricultural, municipal and industrial users (Takahashi and Peralta, 1995), and between human and natural ecosystem uses (Belaineh and Peralta, 1995; Chowdhury and Peralta, 1995).

If pumping should be optimized from most model cells (as in some regional-scale sustained-yield groundwater planning studies), our embedding approach S/O models have been more practical than those using the RM approach (Peralta and Datta, 1990; Peralta et al, 1991; Peralta et al, 1995a). Possibly, our examples of embedding optimization are the largest or most complex reported (Gharbi and Peralta, 1994; Takahashi and Peralta, 1995).

Our S/O models have helped optimize management of flow and transport within the unsaturated and saturated subsurface and surface waters. They have addressed contamination resulting from nonpoint (Peralta et al, 1995b; Gharbi and Peralta, 1994; Peralta, 1999) or point sources (Aly and Peralta, 1999ab). Addressed contaminants have ranged from those normally interesting in agriculture, such as salt, nutrients, and pesticides (Musharrafieh, 1995; Peralta et al, 1994); to industrial contaminants such as fuels and solvents (Peralta et al, 1997). Shieh and Peralta (1997a,b) demonstrated optimizing bioremediation for steady or transient flow and transport. In a companion paper, Peralta (2001) summarizes six applications of optimization to pump and treat systems remediating industrially contaminated groundwater. Sites addressed both porous and fractured aquifers (Hegazy and Peralta, 1997). One of the sites was a large and complex mathematical problem (HGS, 1999). That involved optimizing extraction from fourteen wells, injection at six wells and two trenches; and twenty-one layer flow and transport models to achieve contaminant containment and cleanup.

SOMOS

SOMOS (Simulation/Optimization Modeling System) is the evolving product of over five generations of different approaches to groundwater management optimization. SOMOS consists of a set of S/O modules designed to cover a diverse range of study areas and data availability. These modules: (a) utilize well-known simulation model(s) to predict hydrogeologic system response to stimuli; and (b) employ optimization algorithms to develop the best water management strategies for a posed management problem. Discussed modules include AOA, SO1 and SO3.

SOA is an S/O module that employs analytical equations and the RM method for simulation. SOA is designed for optimizing groundwater or conjunctive water management for relatively small-scale applications. SOA is being incorporated during 2001 as it evolves from the CONJUS model that was developed to fulfill a need of the Food and Agriculture Organization of the United Nations (Peralta, 1999). It helps field-level personnel optimize conjunctive (coordinated) use of ground water and surface water. This user-friendly model performs linear and nonlinear optimization for managing water quantity and quality in relatively simple stream-aquifer systems.

SOA assumes relatively homogeneous systems and employs analytical expressions for computing aquifer and stream response to system management. It allows constraining: aquifer head response to pumping, stream stage change, and several source and sink terms; stream depletion response to groundwater pumping; and delivered water quality. Demonstrated decision variables have included groundwater pumping rate, diversion rate, and surface storage reservoir size.

SO1 and SO3 are suitable for complex heterogeneous systems. Respectively, they have evolved from REMAX (Peralta and Aly, 1995) and REMAXIM (HGS and SSQL, 2000), and other predecessors. In their evolutionary steps and specialty versions they have been used for pump and treat optimization and for

managing complicated systems--consisting of surface reservoir, stream, aquifer, canal distribution system, return flow system, irrigation unit command area, and municipal and industrial use (Belaine et al, 1999).

To describe flow, SO1 uses the porous media MODFLOW ground-water flow model, including the STR stream flow package (Prudic, 1989). SO1 develops discretized convolution integrals that substitute for MODFLOW in the optimization process. SO1 is ideal for predicting and managing stream depletion for heterogeneous systems. SO1 precursors have been applied to groundwater quantity or quality management in several states and continents. SO1 is excellent for hydraulic optimization (accurately addressing even nonlinear unconfined aquifers), and can optimize cleanup.

To predict contaminant transport, SO1 can use polynomial equations developed statistically from outputs of any other simulation model. Ejaz and Peralta (1995a,b) developed polynomials to predict surface-water pollutant concentrations while optimally coordinating ground water and river water use or pollutant loading. Cooper et al (1998) made polynomials describing non-aqueous phase liquids to optimize floating petroleum management. SO1 uses powerful optimization algorithms to solve linear, nonlinear, mixed integer, and mixed integer nonlinear optimization problems.

To simulate flow and transport, SO3 uses MODFLOW, MT3DMS, and artificial neural networks. For optimization, SO3 uses heuristic optimization with or without artificial intelligence.

SUMMARY

SOMOS is the most powerful groundwater S/O modeling software we are aware of. SOMOS modules incorporate the capabilities of many preceding S/O models. SOMOS modules utilize a variety of simulation models and approaches and powerful mathematical programming or heuristic optimization solvers. SOMOS can solve linear, nonlinear, mixed integer and combination-type optimization problems for linear and nonlinear aquifer and stream-aquifer systems. SOMOS modules address a range of hydrogeologic and management situations. The easy-to-use SOA module is suitable for use by both non-modelers and modelers. SO1 and SO3 are best used by groundwater modelers. SO1 is most useful for water supply management. SO3 is most useful for groundwater contaminant plume management. SOMOS features are those we have found most useful through years of application. SOMOS use can significantly improve water planning and management.

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