Optimization modelling for groundwater and conjunctive use water policy development

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Abstract Planners must sometimes decide how to restrict or reduce groundwater use to prevent unacceptable future problems. Often there are several alternatives (policies). Comparing policies can involve formulating a sustained groundwater yield optimization problem and computing an optimal groundwater pumping strategy for each. This is easy via the SOMOS simulation/optimization (S/O) model. Subsequent analysis can include: flow simulation to predict transient water level response to pumping; and economic evaluation to estimate costs and returns. Two examples predict the best consequences of potential physical and legal management policies for alluvial and valley basin fill aquifers hydraulically linked to surface waters. Results show that: incorporating a physical sustainability requirement and legal water rights can help assure long term economic viability and ecosystems; and applying a pure socially egalitarian policy can be economically disastrous.

Key words management; groundwater; conjunctive; optimization; simulation/optimization; S/O; planning; water law; water right; SOMOS

INTRODUCTION

Predicting policy decision consequences before decisions are finalized helps avoid costly mistakes. For a particular situation, an accurate simulation/optimization (S/O) model can determine how to maximize achievement of policy goals, subject to imposed restrictions. A S/O model couples: a simulation module that can predict the consequences of management; and an optimization module that can compute the mathematically best management strategy for a posed management optimization problem.

A S/O model computes an optimal management strategy for a management problem posed by the user. A pumping (groundwater management) strategy is a set of spatially and possibly temporally distributed rates of extracting water from an aquifer. An optimal pumping strategy is mathematically the best that can be developed for its posed mathematical problem. A pumping strategy that is optimal for one problem is often sub-optimal for a different problem.

A particular posed optimization problem can be referred to as a scenario or formulation. Either includes all the assumptions necessary for specifying the optimization problem and for applying an adequate simulation model.

Modellers must input management strategies into simulation models (here termed S models), such as MODFLOW and MT3DMS. S models predict how the modelled physical system will respond to a strategy input by the user.

S/O models differ from S models because S/O models produce an optimal management strategy for the user-specified management problem. A S/O model user must input data to describe the management problem, plus data describing the physical system, but does not need to input the strategy to be simulated.

S/O models are better than S models for developing management strategies and plans. Because S/O models must have a way to predict system response to management, they incorporate S models or surrogates.

Optimal groundwater pumping strategies are readily applied in the field for situations in which relevant pumping is controllable. Peralta *et al.* (2003) list examples of groundwater contamination remediation, using the SOMOS code (SSOL, 2001; Peralta, 2003). There, a single entity might install dozens of extraction wells to remove contaminated water and then treat it to remove the contamination (pump and treat or PAT systems).

Optimal regional groundwater management strategies are applied less commonly in the field due to difficulty in controlling all pumping rates. On a regional or aquifer scale, S/O models are most suitable for determining the best that might be attainable, for a particular scenario.

This paper describes two S/O applications to regional or aquifer scales. The models simulate and optimize groundwater or conjunctive water management for coupled river-aquifer systems. In the first case, surface water is available for diversion to an area of severe groundwater over-mining. In the second case groundwater development is restricted because it would deplete river water flow.

CASE I. CONJUNCTIVE USE ADDRESSES PROBLEM OF UNSUSTAINABLE GROUNDWATER MINING

The Arkansas Grand Prairie overlies part of the Mississippi Alluvial Aquifer.

This is an important rice, soybean and aquaculture producing area. Historically, most of the region's water has come from a Quaternary aquifer that is part of the Mississippi Plain alluvial aquifer. Ground-water levels have been dropping in the Grand Prairie for many years, causing much potentiometric surface depression.

For four possible Grand Prairie policies, steady-state ground-water optimization, transient groundwater simulation, and economic evaluation are performed. These demonstrate that historic groundwater pumping is not sustainable, and reduction in water use and short-term economic loss will result from implementing any sustained yield strategy.

Strictly applying the correlative rights doctrine via reducing ground-water pumping of all users by the same percentage would cause severe hardship. Grave economic losses would result from the smallest across-the-board proportional (86 percent) reduction in ground-water pumping needed to achieve a sustained yield.

The least economic hardship (23 percent reduction in net return) would result if conservation measures are practiced and surface water is diverted from adjacent rivers. Omitting either of these actions will cause at least a one third total reduction in net return. Improved conservation alone would not solve the problem.

CASE II. STREAM DEPLETION RESTRICTS FUTURE GROUNDWATER PUMPING

Increasing population water need is causing water managers to look more closely at how much and where groundwater should be extracted from the Cache Valley aquifer of northeastern Utah and southeastern Idaho. Most of the 70 by 16 mile valley's surface water, the primary source for irrigation, originates in snowpacks outside the valley. Its groundwater results from precipitation, percolation of unconsumed irrigation water, and seepage from canals and streams. Wells supply domestic, industrial, public supply and irrigation water.

Because groundwater pumping reduces surface waters, downstream user water rights and environmental concerns can affect how much groundwater can be extracted from the valley aquifer. Here, the SOMO1 simulation/optimization module of SOMOS (SSOL, 2001), which incorporates the MODFLOW simulation model, estimates how groundwater should be extracted to achieve the best mix of sustainable population support, water rights, and ecosystem preservation for posed scenarios. Strategies are evaluated with respect to the heads and flows that would result from continuing 1990 pumping (termed the “background pumping rates”) to steady-state. According to the simulation model, the 52 cubic feet per second (cfs) of background pumping would ultimately cause 115 cfs of net water flow to rivers from the aquifer and 80 cfs discharge from aquifer to springs (drains). Continuing the 1990 pumping to steady-state is termed the “unmanaged scenario”.

SOMO1 computed maximum sustainable (steady) groundwater pumping strategies for scenarios, and groups of scenarios, that differ in utilized constraints. Group A scenarios evaluates the feasibility of supplying water to 18 towns using one candidate new well site for each, subject to: (1) head at new pumping cells cannot decline more than 30 feet in layers 1-4; (2) springs continue to flow where they flow in 1990 and the unmanaged scenario; (3) saturated aquifer-river seepage continues where it occurs in 1990 and the unmanaged scenario; and (4) total aquifer seepage to river cannot decrease by more than 10%.

Scenario Group A results show that sustainable pumping can increase 4-20 cfs above background rates. Other scenarios showed sustainable groundwater pumping could increase even with more restrictive river depletion constraints. Results encouraged the office of the state engineer to relax a moratorium that had been placed on further groundwater development. Plans include improving the simulation model to enhance predictive accuracy and optimization utility.

SUMMARY

Water policy decisions can significantly affect regional well-being. Evaluating potential policies via S/O models before finalization is important for systematically designing policies and regulations. Linear programming S/O models are valuable for sustainable groundwater policy situations.

To achieve sustainable agricultural production in the Grand Prairie without severe economic hardship, diversion of surface water is needed. A policy combining water conservation and importation would cause the least economic hardship. Severe economic dislocation would result from rigid adherence to a correlative rights doctrine without importation and conservation. In Cache Valley, increased groundwater pumping is sustainable without unacceptably harming ecosystems and water rights. For both study areas, S/O results can help guide the planning and policy development process. Computed strategies are not proposed for implementation. Improved knowledge of system parameters, such as conductances or maximum feasible boundary recharge rates can yield improved strategies (unlikely to change Grand Prairie strategy relative ranking).

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