Interactive Management of a Conjunctive Use System Considering Quality Aspects.

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Abstract: A multi-step modelling approach is presented for a multi-objective decision problem of a conjunctive use system. The system includes a surface water reservoir with hydropower plant, a groundwater reservoir, an artificial recharge area and pumping fields as well as a channel distribution system for five irrigation areas. The water is conjunctively used for irrigation, hydro energy production, domestic and industrial water supply. Based on a long-term analysis of the hydrological system, an interactive procedure, using Incremental Dynamic Solving Technique and groundwater flow and solute transport simulation, is introduced for selecting preferred decisions. Applicability of the approach is illustrated by a case study of the Rio San Juan in Argentina.

INTRODUCTION

Efficient management of water resources is required to increase and sustain crop productivity in arid areas. An optimum utilization of the surface and groundwater resources is essential when demands are increasing and available resources are limited.

Systems approach has long been used in analysing conjunctive use problems. Several approaches, such as linear programming, dynamic programming, simulation, hierarchical or multilevel optimisation have been used (eg. Buras, 1963; Young & Bredehoeft, 1972; Haimes &Dreizen, 1977; Onta, Da Gupta & Harboe, 1991). A multi-step modelling approach is presented for a multi-objective decision problem of a conjunctive use system, which is affected by salinization and groundwater quality problems.

SYSTEM DESCRIPTION

The developed management model is applied to the conjunctive use system of Rio San Juan in Argentina (Fig. 1). The system includes a surface water reservoir with hydropower plant, a groundwater reservoir, artificial recharge areas and pumping fields, as well as a complex channel distribution system for five irrigation areas, which consists of secondary and tertiar canals.

The water resources are used conjunctively for irrigation, hydroenergy and water supply of the city. The main hydrological characteristic of the project is its situation in an arid climate, annual precipitation is very low, nearly all runoff is produced by melting of snow and glaciers in the Andes. Therefore during the year the runoff is mainly influenced by the season resp. sun radiation and less by precipitation. Additionally the long-term runoff over the year is mainly influenced by climatic variations. The other characteristics of the system are given in Tab. 1.

For the management of the system a set of different objective functions are given:
- max. energy production by hydropower plants,
- min. costs for groundwater pumping,
- max. irrigation areas,
- max./min. artificial groundwater recharge for dry resp. wet years,
- min./max. system outflow for dry resp. wet years.

An optimizing management strategy has been already developed for the system under quantity aspects using Incremental Dynamic Programming and simulation submodels (Correa & Billib, 1988). Actual quality problems made a new approach necessary: increasing of salinization in parts of the irrigation areas and increasing concentrations of nitrate in the groundwater (Fig. 2). Based on a multilevel management strategy involving simulation and optimization techniques (Correa & Billib, 1990), the following concept is developed.

MANAGEMENT CONCEPT

The concept is a stepwise procedure (Tab. 2), starting with long-term hydrological analysis to derive a draft for an overall target function. In this framework an interactive open-end algorithm is embedded to develop the short-term management for the surface reservoir, water distribution system and groundwater reservoir.

Once the preferred management rules are chosen for a year, the long-term impact on the groundwater quality is analysed by simulation. Loop-backs at different stages allow the decision maker to change objective functions or restrictions.

The conceptual diagram of the conjunctive use system is presented in Fig. 3. The system is characterised by a set of inputs and outputs, the system parameters, the decision variables, the state variables indicating the condition of the system at any time, and dynamic relationships regarding the interactions of the system components and externals.

The management procedure for the decision making process is made in three steps:

1. Long-term analysis of hydrological system

The objective of the long-term management is, to reach a dynamic equilibrium of the groundwater reservoir. The tools are time series analysis and development of a groundwater target function.

The long-term behaviour of the system depends strongly on the sequence of wet and dry periods. Long-term periodicities were identified by time series analysis of 74 years runoff data. As a result a target function for the long-term groundwater storage was defined (Correa & Billib, 1990)

Based on the periodic analysis, the future state of the groundwater is predicted. An actual adjustment of the prediction is made each year at the end of the winter season by remote sensed estimation of snow amount. Additionally the actual state of the groundwater level at the end of the last year is considered. The regulation of the aquifer can be done by artificial recharge, or pumping and use of a by-pass at the recharge area of the river. Depending on the over-all prediction (wet or dry period), the appropriate target function is chosen.

2. Short-term management (Hydrological year)

The objective of this step is to support the Decision Maker (DM) selecting efficient operation rules regarding all their preferences. This is done by an interactive open-end algorithm, enclosing simulation and optimisation of the three subsystems surface reservoir, distribution system and groundwater reservoir.

It starts with the actual state of the dominant water quality parameters, e.g. salt or nitrate concentration. Then threshold values of these parameters are chosen by the DM to restrict the decision space of the following optimisations. Surface and groundwater reservoir are optimised for the hydrological year by Incremental Dynamic Programming. The objective function (OF) is the selected target function of the long-term management or any other out of the OF-set selected by the DM (Fig. 4).

At each simulation step, the released and/or pumped water amounts are allocated to the different demand points. The Sequential Multiobjective Problem Solving Technique SEMOPS is chosen for the selection of the actual management strategy. The version of Bogardi & Duckstein (1992), involving evolution strategies, was modified by use of variable boundaries for the decision variables.

The management is optimised by SEMOPS regarding different irrigation areas, energy production at different plants, pumping costs and regulation of the groundwater reservoir using artificial recharge or pumping and by-pass (Tab.3).

Changes of the preferences, lead to a loop-back to the beginning of step 2 e.g. to reduce groundwater pumping for irrigation due to high energy costs or nitrate concentration and therefore to change reservoir releases for irrigation supply.

With the aid of the operation rules the groundwater reservoir is simulated. A 2 DIM-simulation model, based on the Finite-Difference-Method, is used and coupled with a solute transport model, based on the Random-Walk-Method.

If during the optimisation and simulation procedures any boundaries are touched, or the results are unsatisfying for the DM, the selected OF or decision space will be changed by a loop-back to the beginning of the short-term management.

3. Long-term analysis of groundwater quality

If the results are sufficient, a long-term simulation of the groundwater is started mainly to analyse the impact of the operation rules on the long-term behaviour of the quality parameters (Fig. 5). The result gives the DM additional information about the actual management and a loop-back to start step 2 is open.

The procedure stops, when the DM wants no change of the selected management rules.

RESULTS

The application of the multi-level system analysis to the conjunctive use system of San Juan/Argentina allowed the decision makers to learn the system behaviour under different preferences. Future development is still necessary for coupling the long term analysis of the groundwater subsystem with the periodycities, as well as for the regarding of quality objective functions.

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REFERENCES:

Bogardi, J.J. & Duckstein, L. (1992), Interactive multiobjective analysis embedding the decision maker's implicit preference function, Wat. Res. Bull., AWRA. 28, 1, 75-88.

Buras, N. (1963), Conjunctive operation of dams and aquifers, J. Hydr. Div., ASCE. 89 (6), 111-131.

Correa, N.R. & Billib, H.A. (1988), Long-Term Optimal Manaqement of a System with Conjunctive Use, Proc. VIth

IWRA World Congress on Water Resources. Ottawa,

Vol. I, 75-86.

Correa, N.R. & Billib, H.A. (1990), Strategies for the Management of an Irrigation System with Conjunctive Water Use - Consideration of Quality Aspects, Proc. XIVth ICID Congress. Rio de Janeiro, Vol. I, 91-102.

Haimes, Y.Y. & Dreizen, Y.C. (1977), Management of Groundwater and surface Water via Decomposition, Water Resour. Res., 13 (1), 59-77.

Onta, P.R., Das Gupta, A. & Herboe, R. (1991), Multistep Planning Model for Conjunctive Use of Surface and Ground-Water Resources, J. Water Res. P1. Mg.. ASCE, 117 (6), 662-678.

Young, R.A. & Bredehoeft, J.D. (1972), Digital Computer Si. mulation for Solving Management Problems of Conjunctive Groundwater and Surface Water Systems, Water Resour. Res., 8 (3), 533-556.

FIGURE CAPTIONS

Tab. 1 Characteristics of the systsm			
Area under irrigation			67.00 ha
Climate:	Potential Evaporation		1.230 mm/a
	Temerature		17,8 °C
Water requirement:	Irrigation		1.060 hm^3/a
	Population		60 hm^3/a
	Industry		12 hm^3/a
Water supply:	Reservoir inflow		2.020 hm^3/a
Capacities:	Surface reservoir		390 hm^3
	Groundwater extraction		600 hm^3/a
	Artificial groundwater recharge		170 hm^3/a

Tab. 2 Flow chart of the procedure				
Step 1: Long-term analysis of hydrological system				
	'- time series of analysis			
	'-groundwater prediction			
		↓		
Step 2: Short-term analysis (hydrological year)				
D	→	- quality restrictions		
E	→	- selection of objective functions		
C	→	- change of restrictions		
I				
S				
I	←	'- IDP for reservoir/groundwater system		
O	←	'- SEMOPS for allocations		
N		'- irrigation areas		
		'- municipal demand		
M		'- hydro energy		
A	→	'- simulation of groundwater flow and		
K		solute transport		
E				
R				
↑				
Step 3: Long-term analysis of groundwater quality				

Tab.3 Water allocation for alternative solutions by SEMOPS for February, dry year [hm³]

		Alternative Solutions									
Decision and Auxiliary Variables		1	2	3	4	5	6	7	8	9	10
Reservoir discharge	X1	106	106	106	106	106	106	106	106	106	106
Spring inflow	X2	2	2	2	2	2	2	2	2	2	2
Artificial groundwater recharge	X3	0	0	0	0	0	0	0	0	0	0
Canal inflow to irrigation area 5	X4	18	21	22	19	19	20	23	19	24	22
Supply of the well group 3	X5	26	26	23	24	26	23	25	25	24	22
Canal inflow to irrigation areas 1,2,3	X6	18	14	15	17	20	17	16	14	14	15
Supply of the well group 2	X7	4	8	7	5	2	5	6	8	8	7
Canal inflow to irrigation area 4	X8	52	52	51	54	53	53	52	55	55	55
Supply of the well group 1	X9	13	13	14	11	12	12	13	10	10	10
System outflow in Rio San Juan	X10	45	46	45	42	41	42	43	45	41	41
Canal discharge "Canal Cespedes"	XH1	87	85	90	92	91	96	97	93	91	94
Discharges in upper Rio San Juan	XH2	11	13	8	6	7	2	1	5	7	4
Canal discharge "Canal Quiroga"	XH3	19	21	26	23	20	28	31	26	24	26
By-pass to Rio San Juan	XH4	1	0	4	4	1	8	8	7	0	4
Discharges in lower Rio San Juan	XH5	11	13	8	6	7	2	1	5	7	4
Number of random-assignments		105	1646	969	263	1278	6629	122	3532	3878	1675