A Review on Optimal Dewatering of Aquifers Using Groundwater Modelling

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ABSTRACT

With the aid of modern scientific research and developments in construction technology, new construction projects have expanded in response to increasing world population and industrialization. Due to the acceleration in constructional works, suitable areas for construction have diminished, resulting in selection of less appropriate sites with foundation problems. High ground water tables are one of the most frequently encountered foundation problems, requiring deep excavations in pervious soils below the water table. To obtain the best working conditions and slope stability, appropriate dewatering systems are safer and more economical when compared with other methods for sites requiring deep excavations below the water table. The magnitude and cost of a dewatering project depend on the size and depth of the required excavation and the length of time the dewatered condition must be maintained. In this paper review has been done on various groundwater techniques used for groundwater modelling. Embedding technique and response matrix techniques are studied and compared.

Keywords: dewatering, optimization, ground water modelling

I. INTRODUCTION

Water that occurs below the surface of earth is generally termed as groundwater. The main source of groundwater is infiltration of rainwater. The infiltrated water percolates deeply after meeting soil requirements and gets stored as groundwater. The geological formations which store water and are sufficiently permeable to transmit and yield water in usable quantities are called aquifers. The aquifers may get recharged directly from above through processes of precipitation and infiltration or they may have recharge area somewhere else on earth's surface. The objectives of modelling studies in India have been mainly groundwater recharge study, studies related to dynamic behavior of the water table, stream aquifer interaction studies, sea-water intrusion etc. The most widely used numerical groundwater flow model is MODFLOW. It is a three dimensional finite difference groundwater model which is developed by United States Geological Survey (McDonald and Harbaugh, 1988). Processing Modflow for Windows (PMWIN) offer a totally integrated simulation system for modeling groundwater flow and transport processes with MODFLOW88, MODFLOW-96, PMPATH, MT3D, MT3DMS, MOC3D, PEST and UCODE.

For modelling of groundwater management, two approaches are in use, The Embedding Technique which directly incorporates the ground-water flow equations as constraints in an optimization framework (Alley et al., 1976; Aguado and Remson, 1974, 1980) and The Response Matrix Method which utilizes superposition and linear systems theory to simulate ground-water flow. In this approach unit responses are developed with the help of external groundwater simulation model. Each unit response represents the effect of unit impulse (such as unit pumping for a brief time period) on hydraulic heads of the entire system. These unit responses are termed response functions (Venetis, 1968), Dirac delta functions (Maddock, 1974), discrete kernels (Morel-Seytoux and Daly, 1975) or response functions (Atwood and Gorelick, 1985). Complete assembly of unit responses known as response matrix is used in management model.

II. GROUNDWATER MODELS

Groundwater models are important tools in the analysis of groundwater problems. The groundwater models have been divided by Peck et al. (1988) into three groups i.e. prediction models, management models and evaluation models. To predict the response of system, prediction models use behavior of groundwater system. Such models utilize governing flow equation having numerical or analytical solution.

The groundwater management models are divided by Tung (1987) into two categories: simulation and optimization. Numerical groundwater models are employed in the simulation approach in which management policy are successively adjusted until the responses of the aquifer system become both acceptable and feasible. Bredehoeft and Young (1970) used the simulation approach in groundwater management. Direct optimization has also been used to obtain solution of groundwater management models. Generally lumped-system models are concerned with temporal allocation of water. Due to computationally simpler lumped-system models are used in early stages of planning and development. Domenico et al. (1968) used lumped system for optimal groundwater management. Buras (1963) also used lumped-system models in conjunctive use managements.

III. EMBEDDING TECHNIQUE

Aguado and Remson (1974) initially presented the embedding method for hydraulic management of aquifers using linear formulations that incorporates numerical approximations of groundwater equations as constraints. Finite difference approximations were used in both transient and steady state problems. In all examples maximization of hydraulic heads at specified locations was the primary objective. Constraints were placed upon heads, pumping rates and gradients. The examples treated both confined and unconfined hydraulics. The governing equation used for the confined case was linear and the resulting finite difference approximations were treated as linear constraints. For the unconfined aquifer case, the steady state equation was treated as linear with respect to the square of the hydraulic heads (Remson et al. 1971). Aguado et al. (1977) demonstrated the effect of variations in parameters and input data on optimal solution of a linear programing management model. The objective was to minimize steady state total pumping rate. Optimization model determined the optimal locations and discharge rates of wells. Rectangular area was dewatered upto a specified level. Aguado and Remson (1980) minimized the sum of pumping cost and installation cost for unconfined aquifer dewatering problem using mixed-integer programming algorithm and described problem as fixed-charge problem. In such a problem, certain variables (those corresponding to the setup charge for well installation) were integers. Each integer took a value of one when setup charges were to be considered and a value of zero when no well was to be constructed.

IV. RESPONSE MATRIX APPROACH

Lee and Aronofsky (1958) initially proposed the incorporation of response matrix into a linear program. They developed a linear programing management model which sought to maximize profits from oil production. In a petroleum reservoir pumping stresses were linearly converted into pressure changes by using a response matrix. Deninger (1970) used linear programming formulation to increase total discharge from a well. The author used non equilibrium formula (Theis, 1935) for obtaining drawdown response matrix. He also formulated management model to minimize the cost of water production. Constraints were written which limited drawdowns and accounted for pump and well facility limitations. The objective function was nonlinear because water production costs were assumed to be directly proportional to the products of the rates of discharge and the lifts. The unknown in the problem were discharge rates and lift. To solve this problem the use of quadratic programing was suggested. Maddock (1972a) solved the nonlinear problem whose objective was to minimize pumping cost. The response matrix was developed, called as algebraic technological function which related seasonal pumping at wells in the system to drawdown at those wells. It represented the change in drawdown induced due to unit pumping at each well. Seasons constraints guaranteed meeting semiannual water targets and set upper limits on the pumping capacity of each well. Rosenwald and Green (1974) used mixed integer programming in conjunction with a response matrix to determine the optimum location of wells. The proper sequencing of flow rates from those wells were determined by the model so that the difference between the production-demand curve and the flow curve actually attained is minimized. Remson and Gorelick (1980) utilized the embedding technique to minimize the groundwater. The management goals were dewatering of two excavation areas and obtaining water for export from the system. Model determined the optimal pumping rates and steady state hydraulic head distribution.

Gorelick (1983) classified groundwater management models to be of two categories: water allocation model and hydraulics or policy evaluation. Groundwater hydraulic management models determine pumping rates and optimal locations of various wells under a variety of restrictions placed upon local drawdown, hydraulic gradients and amount of water production targets. Groundwater policy evaluation and allocation models is used to study the effect upon groundwater use of institutional policies i.e. taxes and quotas. Groundwater hydraulic management model incorporate a simulation model of a particular groundwater system as constraints in the management model. Management decisions as well as simulation of groundwater behavior are accomplished simultaneously. He explained two techniques: The embedding method and response matrix method.

V. COMPARISON BETWEEN EMBEDDING METHOD AND RESPONSE MATRIX METHOD

In the 'embedding method,' finite difference or finite element approximations of the governing groundwater flow equations are incorporated as constraint set of a linear programing model. Decision variables are hydraulic heads at each node as well as local stresses such as pumping rates and boundary conditions. In the 'response matrix approach', unit responses are developed using an external groundwater simulation model. Each unit response describes the influence of a unit stress upon hydraulic heads at points of interest throughout a system. An assemblage of the unit responses, a response matrix, is included in the management model.

VII. CONCLUSION

In many groundwater planning and management models nonlinear objective function and nonlinear constraints are used. By using nonlinear programming (NLP) these models can be solved. In dewatering problem objective function is to minimize the cost of pumping. Total cost can be of two type. Variable cost which includes cost due to pumping and fixed cost which is cost of installation. Total sum of these two costs should be minimum for economic dewatering.

VIII. REFERENCES

Aguado, E.; Remson, I.; Pikul, M. F.; Thomas, W. A. 1974. Optimal Pumping for Aquifer Dewatering. *J. Hydraul. Div., Am. Soc. Civ. Eng.* **HY7-100:** 860–877.

Aguado, E.; Remson, I. 1980. Groundwater Management with Fixed Charges. *J. Water Resour. Planning Manage. Div., Am. Soc. Civ. Eng.* **WR2-106:** 375–382.

Aguado, E.; Sitar, N.; Remson, I. 1977. Sensitivity Analysis in Aquifer Studies. *Water Resour. Res.* **13**: 733–737.

Alley, W. M.; Aguado, E.; Remson, I. 1976. Aquifer Management Under Transient and Steady-State Conditions. *Water Resour. Bull.* **12:** 963–972.

Bredehoeft, J. D.; Young, R. A. 1970. The temporal allocation of ground water—A simulation approach. *Water Resour. Res.* **6:** 3–21

Buras, N. Conjunctive Operation of Dams and Aquifers. *J. Hydrau. Div.* **89**: 111131

Deninger, R. A. 1970. Systems Analysis of Water Supply Systems. *Water Resour. Bull.* **6:** 573–579.

Domenico, P. A.; Anderson, D. V.; Case, C. M. 1968. Optimal ground-water mining. *Water Resour. Res.* **4:** 247–255.

Fisher Atwood, D.; Gorelick, S. M. 1985. Hydraulic gradient control for groundwater contaminant removal. *J. Hydrol.*, **76:** 85--106.

Larson, S. P.; Maddock T. III; Papadopulos S., Optimization techniques applied to groundwater development**,** *Mere. Int. Assoc. Hydrogeol***. 13:** 57-67.

Lee, A. S.; Aronofsky, J. S. 1958. A Linear Programming Model for Scheduling Crude Oil Production. *J. Petrol Technol.* **213:** 51–54.

Maddock, T. III 1972a. Algebraic Technological Function from a Simulation Model. *Water Resour. Res.* **8:** 129–134.

Maddock, T. III 1972b. A Groundwater Planning Model: A Basis for a Data Collection Network. Presented at the *Int. Symp. on Uncertainties in Hydrologic and Water Resource Systems* (Tuscon, AZ: Int. Assoc. Sci. Hydrol.).

Maddock, T. III, 1974a. The operation of a stream-aquifer system under stochastic demands. *Water Resources Research*, *10*(1): 1-10.

Maddock, T. III (1974b). Nonlinear technological functions for aquifers whose transmissivities vary with drawdown. *Water Resour. Res.*, *10*(4).

Maddock, T. III; Haimes, Y. Y. 1975. A tax system for groundwater management. *Water Resources Research*. **11(1):** 7-14.

McDonald, M. G. and Harbaugh, A. W. 1988. A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model. *U.S. Geological Survey, Techniques of Water Resources Investigations, Book 6, Chapter A1.*

Morel-Seytoux, H. J.; Daly, C. J. 1975. A discrete kernel generator for stream-aquifer studies. *Water Resour. Res.* **11:** 253–260.

Peck, A. S.; Gorelick, S. M.; de Marshily, G.; Foster, S.; Kovalevsky, V. 1988. Consequences of Spatial Variability in Aquifer Properties and Data Limitations for Groundwater Modeling Practice. *IAHS Publication no. 175.*

Remson, I.; Gorelick, S. M. 1980. Management models incorporating groundwater variables, in Operations Research in Agriculture and Water Resources. Edited by Yaron D.; Tapiero, C. S.

Rosenwald, G. W.; Green, D. W. 1974. A Method for Determining the Optimum Location of Wells in a Reservoir Using Mixed-Integer Programming. *Soc. Res. Eng. J.* **14:** 44–54.

Tung, YK. 1987. Multi-objective stochastic groundwater management of non-uniform, homogeneous aquifers. *Water Resour. Manage.* Res **1:** 241-254

Venetis C. 1968. On the impulse response of an aquifer. *International Association of Scientific Hydrology.* 13:3, 136-139