Groundwater Management

Aguado, E., and Remson, I. (1980). "Groundwater management with fixed charges." *J. Water Resour. Plng. and Mgmt.*, ASCE, 106(2), 375–382.

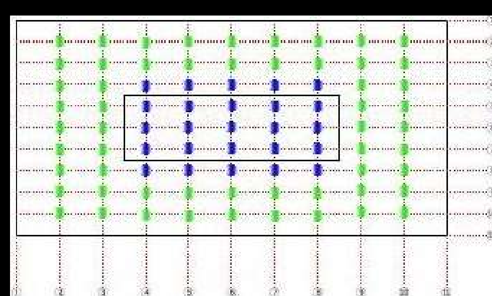
PROBLEM 1

Determination of the optimal well locations and discharge schedules for maintaining water levels below a specified level at an excavation site.

No pumping

Available for pumping

No pumping was allowed at nodes within or adjacent to the excavation !!!



The objective function requires the <u>minimization of total pumping costs</u>. The total cost would the be the sum of steady-state pumping cost and the well installation cost.

$$\text{Minimize } Z = c_1\, q_1 + c_2 q_2 + \ldots\ldots\ldots + c_n\, q_n$$

CONSTRAINTS

- The system of linear algebraic equations obtained by either finite differences or finite elements from the numerical approximation of the governing ground-water differential equations

$$h_f = h_0 - (a_1\ q_1 + a_2 q_2 + \dots\dots\dots + a_n\ q_n)$$

where

h_f = final head at location control point

h_0 = original head

q_j = discharge at well j

- Dewatering constraints

$$h_f \leq h_{min}$$

EXAMPLE

Four well locations has been choosen for a foundation area so as to lower the groundwater level. The steady-state water level at the most critical point in the foundation area can be estimated as

$$h = 1.0 + (1.5*Q_1 + 2.2*Q_2 + 1.8*Q_3 + 1.3*Q_4)$$

and the following equation is valid for the pumping costs

$$MAL_j = 42 * Q_j$$

where h : water level at most critical point (m)

Q_j : discharge at wellji (m^3/sec)

MAL_j : pumping cost for well j (TL)

Write a linear programming model that will estimate the most economical pumping schedule to lower the groundwater level to 6 meters if the maximum discharge is limited to 2 m^3/sec for every pump and solve via LINDO program.

EXAM QUESTION

Four well locations has been choosen for a foundation area so as to lower the groundwater level. The steady-state water level at the most critical point in the foundation area can be estimated as

$$h = 1.0 + (1.5*Q_1 + 2.2*Q_2 + 1.8*Q_3 + 1.3*Q_4)$$

and the following equation is valid for the pumping costs

$$MAL_j = 20 + 42 * Q_j$$

where h : water level at most critical point (m)
Q_j : discharge at wellji (m^3/sec)
MAL_j : pumping cost for well j (TL)

Write a linear programming model that will estimate the most economical pumping schedule to lower the groundwater level to 6 meters if the maximum discharge is limited to 2 m^3/sec for every pump.

Note : Make sure that the constant in the cost equation (20) should not exist when discharge is zero.

PROBLEM 2

High rates of urbanization and increased agriculture have raised the demand for ground water in some coastal regions.

The objective is the development and operation of the groundwater system while minimizing the potential impacts of saltwater intrusion.

- Several groundwater management models were developed to determine the optimal planning and operating policies of a coastal aquifer in southern Turkey threatened by saltwater intrusion.
- Steady-state and transient finite-element simulation models, representing the response of the system, are linked to optimization models using response functions.
- All models were subject to constraints related to the systems response equations, demand requirements, drawdown limitations at saltwater-intrusion control locations and pumping wells, and discharge bounds.

Coastal Aquifer Management

Hallaji, K., Yazicigil, H., 1996. Optimal management of a coastal aquifer in southern Turkey. J. Water Resour. Plan. Mgmt 122(4), 233–244.

Hydrogeological setting of the study area

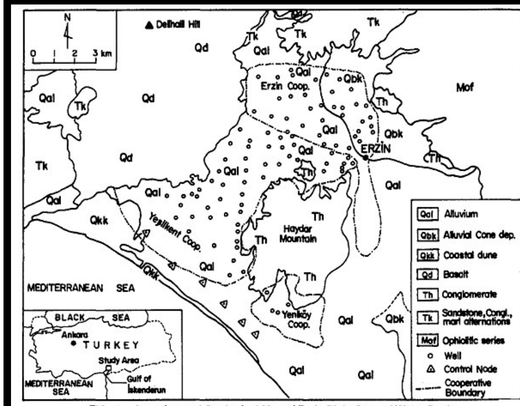


FIG. 1. Location and Geological Map of Erzin Plain Ground Water Basin

TABLE 1. Monthly Water Demands of Agricultural Cooperatives in Erzin Plain

Cooperative (1)	Monthly Water Demand (m^3/s) May (2)	June (3)	July (4)	Aug. (5)	Sept. (6)	Oct. (7)
Yeniköy	0.09724	0.08295	0.14095	0.14995	0.06754	0.10536
Yeşilkent	0.65917	0.48285	1.19789	1.33078	0.29372	0.59783
Erzin	0.45633	0.40233	0.62127	0.66550	0.35457	0.43755

The steady-state drawdown

$$s(k) = \sum_{j=1}^{NPW} \beta(k,j)Q(j)$$

where

- s(k): drawdown at well k(L)
- Q(j): average volumetric discharge at pumping well j
- β(k,j): average drawdown at well k due to unit pumpage at well j
- NPW: total number of pumping

The factors considered important in the development of management models were

- controlled aquifer drawdown
- meeting water demands
- preservation of groundwater quality
- well-capacity limitations

All models are subject to :

- water-demand limitations
- drawdown limitations
- maximum pumping rate constraints
- minimum pumping rate constraints

Maximization of Total Pumpage

This model maximizes the total quantity of water that can be pumped from existing wells of the Erzin plain for steady-state conditions while satisfying system constraints that prevent undesirable consequences of pumping

$$\text{Max } Z = \sum_{k=1}^{NPW} Q(k)$$

Q(k): pumping rate of the kth well.

The total number of pumping wells was 94

- **CD1, CD2, and CD3 are the amount of water that was used by Yeniköy, Yeşilköy and Erzin cooperatives in 1990**

$$\sum_{k=1}^{4} Q(k) \geq CD_1$$

$$\sum_{k=5}^{58} Q(k) \geq CD_2$$

$$\sum_{k=59}^{94} Q(k) \geq CD_3$$

- **Drawdown at the pumping-well and saltwater-control nodes must not exceed specified values(s(k): maximum allowable drawdown of the kth well or salt water control node)**

$$\sum_{j=1}^{NPW} \beta(k, j)Q(j) \leq s_{\max}(k); \quad k = 1, \ldots, 100$$

- **The maximum pumping rate constraints limit the pumping rate from any well to its design capacity (Qmax(k): maximum allowable pumping rate)**

$$Q(k) \leq Q_{\max}(k); \quad k = 1, \ldots, 94$$

- **The minimum pumping rate constraints ensure that the amount of pumping for each well must not be less than the minimum amount required from that well**

$$Q(k) \geq Q_{\min}(k); \quad k = 1, \ldots, 94$$

Minimization of Total Drawdown

- The objective function of this models is to minimize the total drawdowns at the pumping wells and salt-water control nodes while satisfying demand requirements of the cooperatives and well capacity and drawdown limitations

$$\text{Min } Z = \sum_{k=1}^{NW} s(k)$$

Minimization of the drawdowns at saltwater control nodes

The objective funtion is to minimize to the sum of drawdowns at the salt-water control nodes along coast.

Drawdown at the pumping wells, however, were constrained by their maximum allowable limits

$$\text{Min } Z = \sum_{k=1}^{NCN} s(k)$$

NCN: the number of control nodes

Minimization of Pumping Cost

The objective is to minimize the total pumping cost of wells in Erzin plain.

$$\text{Min } Z = \sum_{k=1}^{NPW} C(k)L(k)Q(k) + \sum_{k=1}^{NPW} \sum_{j=1}^{NPW} C(k)Q(k)\beta(k,j)Q(j)$$

Transient Management Models

Two models are considered for transient conditions

- Maximization of total pumpage
- Minimization of total drawdown

Transient response function

$$s(k,n) = \sum_{j=1}^{NPW} \sum_{i=1}^{n} \beta(k,j,n-i+1)Q(j,i)$$

- S(k,n) : drawdown at well k at the end of the pumping period n(L)
- Q(j,i) : average volumetric rate of discharge at well j during pumping period i
- B (k,j, n-i+1) : average drawdown at well k at the end of pumping period n pulse of pumpage at well j applied throughout the pumping period i

Maximization of total pumpage

- The objective function is to maximize the sum of the monthly pumpage rates of the wells while satisfying the temporal variations in monthly demands of the cooperatives and drawdown and pumping limitations

$$\text{Max } Z = \sum_{k=1}^{NPW} \sum_{n=1}^{NTS} Q(k, n)$$

- Q(k,n): pumpage at kth well in the nth period
- NTS: total number of time steps

The constraints of this model are

- Water demand limitations
- Drawdown limitations
- Maximum pumping rate constraints
- Minimum pumping rate limitations
- CD1, CD2 and CD3 are the monthly demand that were used by Yeniköy, Yeşilkent and Erzin cooperatives in 1990

$$\sum_{k=1}^{4} Q(k, n) \geq CD_1(n); \quad n = 1, 2, \ldots, 6$$

$$\sum_{k=5}^{58} Q(k, n) \geq CD_2(n); \quad n = 1, 2, \ldots, 6$$

$$\sum_{k=59}^{94} Q(k, n) \geq CD_3(n); \quad n = 1, 2, \ldots, 6$$

- At the pumping wells or saltwater-control nodes the drawdowns must not exceed some specified values for all steps

$$\sum_{j=1}^{NPW} \sum_{i=1}^{n} \beta(k, j, n-i+1) Q(j, i) \leq s_{max}(k); \quad k = 1, \ldots, 100 \quad n = 1, \ldots, 6 \qquad (17)$$

$$Q(k, n) \leq Q_{max}(k); \quad k = 1, \ldots, 94 \quad n = 1, \ldots, 6$$

$$Q(k, n) \geq Q_{min}(k); \quad k = 1, \ldots, 94 \quad n = 1, \ldots, 6$$

Minimization of Total Drawdown

The objective function is to minimize the sum of drawdown of the pumping wells and saltwater-control nodes for all pumping periods while satisfying the temporal variations in water demands of each cooperative, maximum allowable drawdowns at the saltwater-control nodes

$$\text{Min } Z = \sum_{k=1}^{NW} \sum_{n=1}^{NTS} s(k, n)$$