Optimal annual operation of a water supply and distribution system

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A model for determining the optimal operation of Israel's National Water System over 1 year, with monthly time increments, is described. The water system contains the Main National Carrier – some 250 km long from the Kinneret (Sea of Galillee) in the north to the Negev region in the south – and some 25 regional water systems connected to it. Water is taken from the Kinneret and from two aquifers. Water transfers may take place between the National Carrier and regional systems, and between interconnected regional systems.

The mathematical model of the system represents its monthly production and transfer capacities. Given the monthly demands which have to be met and the hydraulic constraints the model determines the month-by-month operating plan which minimizes energy costs over the year.

The optimization model is formulated as a linear program. This necessitates several types of approximations and linearizations, which are discussed in detail. The optimal operating plan for 1977–78 is compared with the actual operation of that year and conclusions are drawn from the comparison concerning the practicality and adequacy of the model's output and the potential for effective operation and for energy savings.

INTRODUCTION

Israel has an integrated water system in which some 25 regional projects are linked to the main supply sources by means of the National Water Carrier (Fig. 1). The main supply sources are the Kinneret (Sea of Galillee) in the north, a coastal aquifer situated along the Mediterranean coast, and the Yarkon-Taninim aquifer, lying parallel and to the east of the coastal aquifer. The general operational problem is to transfer water from the north to the south. However, since rainfall occurs exclusively in the winter months while the peak demand is in the summer and there is considerable between-year variability in the inflow to the Kinneret, the aquifers are also used as storage elements for recharge of surplus Kinneret water, as well as naturally replenished supply sources. This results in a complex operation problem in which satisfaction of consumer demand is constrained by hydrologic considerations.

While the individual regional projects have a certain degree of independence in operation, their interaction with other regional projects and with the National Carrier (in the form of amounts of water to be transferred) must be coordinated by a central authority which acts according to global and long term considerations when making operational decisions. Mekorot Water Co. Ltd is in charge of operating all these systems. The work reported here, deals with a model for operating the National Carrier, including the aggregate operation of the regional systems.

Operation decisions cover a wide spectrum of time periods. Daily operation responds to the changes in demand and to possible (although quite rare) failure of equipment. This is done routinely by the engineering staff. This day by day operation must, however, be determined primarily by considerations of a longer range, since the system is used to operate the reservoirs while meeting the demands. This paper deals with operation of the system over one year, using monthly time periods.

MODELLING APPROACH

We are dealing with a hydrologic-hydraulic system, whose principal component is the water distribution system: pipelines, pumps, reservoirs and valves. One must, however, include the sources as well: Lake Kinneret (Sea of Galillee) in the north and 'cells' (i.e. regions) of the aquifers. A schematic representation of the physical system, as shown in Fig. 2, is used as the basis of the management model. In constructing the model one must decide on the level of aggregation to be used. For the monthly operation considered herein, and because we are primarily concerned with operating decisions for the National System as a whole, the schematization indicated in Fig. 2 was selected. In it each regional project appears as a block, which has some or all of the components shown in Fig. 3.

The schematic, Fig. 2, is the basis for a transportation-type model, with monthly time periods. For each element in the system 12 monthly operational variables are defined: withdrawals from each source and transfers in each line, and recharge to aquifer cells.

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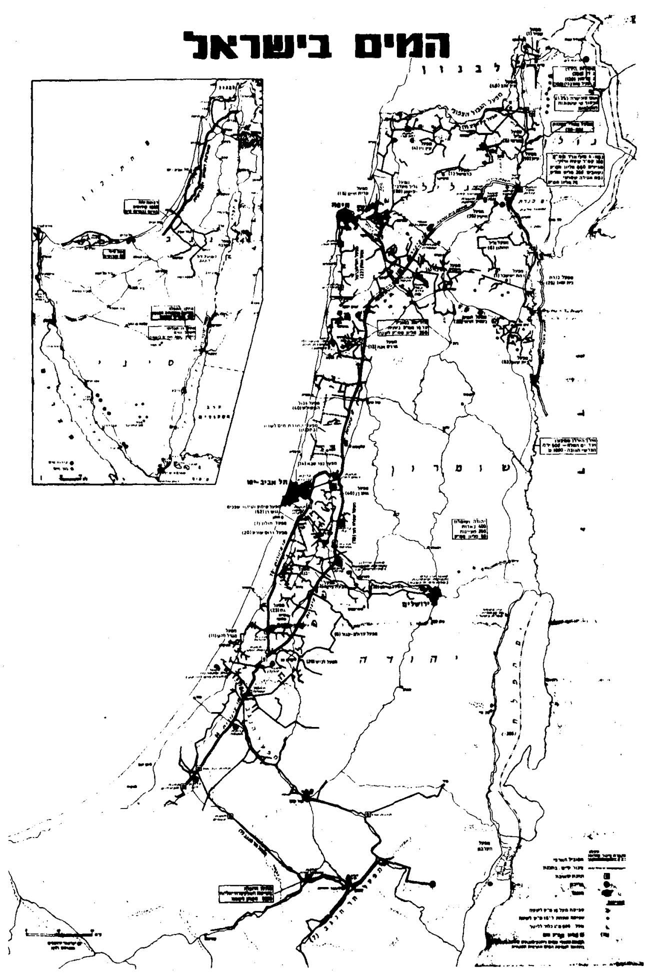

Figure 1. The Israeli water system

The objective function for operating the system over 1 year may be of two types: (a) minimize operating costs (energy), and (b) maximize some measure of 'hydrologic benefit' or minimize 'hydrologic damage' for the sources. At present the first of these is being used, while the second was tried in earlier stages of the project.

The model for optimal operation is cast as a linear program. Some linearizations are needed, primarily in describing the hydraulics. The model is constructed on the basis of detailed plans of the water systems. It is then fed by data from various data bases employed regularly by the supply company, Mekorot, for recording water flows and energy consumption and for setting up allocated future demands.

The LP is constructed for a 12 month period, starting at any selected month and ending a year later. The optimal solution is an operating plan for 1 year, which may be examined and updated (by rerunning the program) as the year progresses and new data become available.

THE MATHEMATICAL MODEL

The linear programming model of the system contains about 4400 variables (12 groups of 360 monthly variables and 80 global variables) and 1500 constraints (12 groups of 120 monthly constraints and 60 global constraints). Within the monthly groups the variables and constraints can be further divided into subgroups, with each subgroup modelling a particular aspect of the system.

Decision variables

The following decision variables are defined:

(a) Monthly quantities of water transferred between various 'nodes' of the system: sources, regional projects, nodes on the main lines. These quantities relate to aggregates of hydraulic components, e.g. a

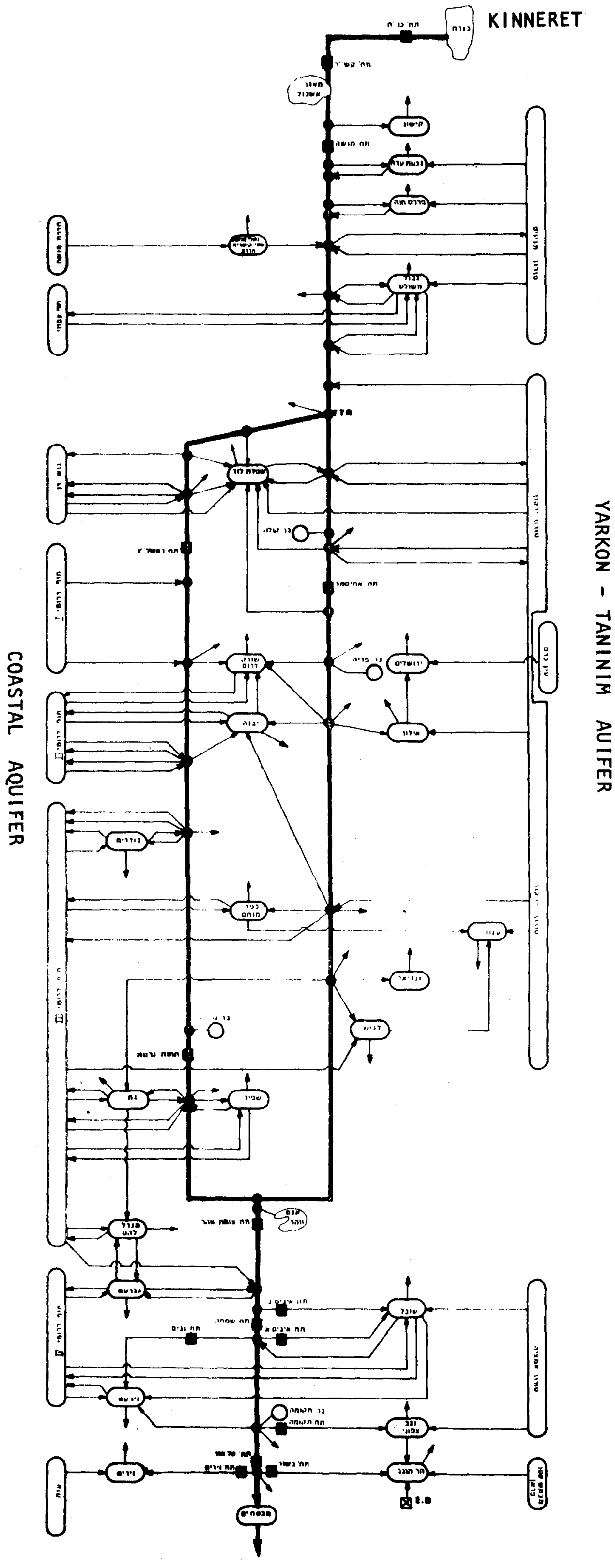

Figure 2. The National Water System

group of wells for pumpage from an aquifer cell to a regional project or a node on a main line, or for recharge to the aquifer; a set of pipes for transferring water between regional projects and the main lines or between adjacent regional projects. The model does not consider the question of distributing the aggregate monthly transfer amounts among the individual components represented by the variable.

(b) Average monthly heads at various points of the hydraulic system. The conceptual and practical difficulties of incorporating the hydraulics of the system in the model are discussed later.

(c) Monthly consumption in regional projects and by consumers connected directly to the main lines. For operational studies these variables are fixed *a priori* to forecasted monthly values, but in the context of a demand management policy they could be regarded as decision variables.

(d) Special control variables for the main pump stations. The role and use of these variables is described later.

Constraints

The following constraints types are defined.

(a) Kinneret: amount to be wirhdrawn
(b) Continuity equations for nodes on the main lines
(c) Water balances for the regional projects
(d) Water balances for aquifer cells
(e) Hydraulics of segments in the main lines
(f) Hydraulics of pumping stations on the main lines
(g) Zohar reservoir continuity equation
(h) Water quality and other special restrictions

These constraints are discussed in greater detail in a later section.

The objective function

For operational studies of the system the appropriate objective is minimization of energy costs. For each water transfer variable an energy coefficient (representing watt-hr/m^3) is determined from operation records of the pumps represented by the variable. These coefficients are approximate, since the actual unit energy requirement of a group of interconnected pumps would depend both on the total amount pumped and the distribution of this amount in time and among the individual pumps. However, since the model does not consider the internal operation of aggregated groups of pumps, an average energy coefficient has to suffice. For production variables – pumpage from wells – the coefficient is calculated by division of the total annual energy requirement of the group of wells under consideration, by the total annual production of the group. If booster pumps are included in the well group, only their energy is considered in the calculation. For variables representing water transfers through boosters, total boosting energy is divided by the total amount of water transferred to obtain the average unit energy requirement. Variables representing gravity transfers do not appear in the objective function. Neither do recharge variables appear in the objective function except where the water has to be pumped to the recharge site. Large boosting stations on the main lines are handled in a more realistic manner, in which the energy requirement is related to the average dynamic head as well as the amount pumped.

A special computer program has been developed for the calculation of the energy coefficients. This program accesses a file containing historical operation data, and the calculated coefficients are written on a file in a format which enables it to be read directly into the linear programming model (by means of the REVISE procedure of the IBM linear programming package, MPSX).

The Kinneret

Lake Kinneret, which has a mean annual yield of about 500 million cubic metres (from the Jordan River and adjacent catchment areas), is the main supply of surface water for the system. From an energy requirement viewpoint it is also the most expensive source with a pumping head of about 350 m, compared to average pumping heads from the aquifers of about 70 m. The aquifers are also nearer to the demand points. Thus with an energy objective function Kinneret water would receive a very low priority and the model would attempt to pump as much water as possible from the aquifers. Such a strategy does not, however, conform to long term operation objectives of the system, in which hydrologic considerations play a dominant role. If water is not pumped from the Kinneret there is a high probability that it will eventually be spilled in flood years and be lost to the system; and since the marginal product value of water to the economy is higher than the cost of pumpage from the Kinneret, storage in the aquifers, and repumpage at a later stage, it is necessary to 'force' the model to use Kinneret water. For this reason the Kinneret does not appear explicitly in the model. Instead, it is represented as a source at the northern end of the system, with the annual and monthly amount being fixed externally. These amounts are determined through the use of other models, which consider the operation of the Kinneret in detail.

Water balances for regional projects and nodes on the main lines

The water balance constraints for regional projects and main line nodes reflect the principle of mass conservation at such points and simply state that the algebraic sum of all flows into and out of the point (including consumption demands) must be zero. For each main line node and each regional project there are 12 balance equations, one for each month. Figure 3 is an example of a regional project (Soreq Darom, denoted SD) for which the continuity equation in month i is:

$$PSD41(i) - RSD41(i) + PSD(i) + Q36SD(i) - RSD(i) + Q25SD(i) + QYSD(i) + Q35SD(i) - DSD(i) = 0 \quad i = 1, \ldots, 12 \qquad (1)$$

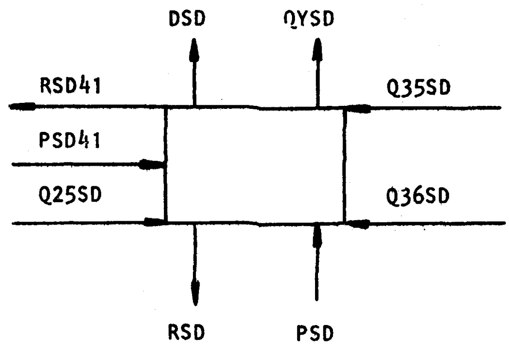

Figure 3. Schematic of a regional project

where:

PSDxx = Pumpage from aquifer cell *xx* to the project
RSDxx = Recharge from the project to aquifer cell *xx*
QxxSD = Transfer from node *xx* on the main line to the project
QYSD = Transfer from a neighboring system *Y* (Yavneh) to the project
DSD = Demand in the project

Similar equations are written for nodes on main lines.

Aquifers

The ground water aquifers are divided into some 30 cells (Fig. 2) with the policy for allocating pumpage and recharge among them being based on long term hydrologic considerations. In an annual model these long term considerations can be incorporated in three ways: priorities, preference functions, and annual pumpage/recharge constraints. In the first method the aquifers are ranked in order of pumpage priority and recharge priority, and the production (i.e. pumpage from wells) and recharge variables appear in the objective function with penalty cost coefficients arbitrarily chosen to reflect the relative priority of pumping and recharge among the cells. This approach was used in earlier versions of the model but was later abandoned mainly because of the difficulty of determining rational penalty values in relation to the energy costs. In the second method 'target' water levels for each cell are given and the model attempts to minimize the deviations from these levels. The deviations appear in the objective function with a penalty cost. As in the first method, it is not as yet possible to determine a penalty function which is rational in economic or hydrologic terms. In addition, there is considerable difficulty in deciding upon rational target levels. In the third method, which is being used at present, upper and lower limits on the annual net pumpage from each aquifer cell are determined by higher level models[1] and are used as constraints for the annual operation. The model is thus free to determine monthly pumpage and recharge in each cell, based on energy consideration subject to physical and hydrologic constraints on the total annual net pumpage.

This approach has the advantage of being simple to implement in the annual model and of not requiring any irrational or fictitious quantities such as penalty costs or functions. The model thus includes a single equation for each aquifer cell which calculates the annual net pumpage (pumpage minus recharge) for the cell and this amount is constrained to be within prescribed limits. Constraint equations can also be placed on the total net pumpage of groups of cells; at present two such groups are defined, corresponding to the coastal and Yarkon-Taninim aquifers.

Main line hydraulics

Since the internal operation of the regional systems is not considered by the model, explicit constraints pertaining to the hydraulics of the system are defined only for the main pipelines and the booster stations on these lines. The difficulty in modeling the hydraulics of the main lines is due to the fact that the model only deals with monthly flow amounts. Since flow conditions are not uniform throughout the month, but are subject to daily and weekly cycles, the problem is how to formulate constraints which correctly reflect the system's hydraulic capabilities.

The procedure adopted in the model at present is to calculate a representative instantaneous flow for each month and then check the feasibility of this derived instantaneous flow pattern by means of linearized versions of the Hazen-Williams pipe flow equation.

The representative instantaneous flow is the monthly quantity divided by 700 h, the recorded average availability of the hydraulic system, due to planned outages and unscheduled failures. Ten equations per month are required, for each of the ten sections of the main hydraulic system (Fig. 4). The equations are included in the model so that the choice of monthly flow amounts, their translation into representative instantaneous flow, and the check for feasibility by means of the ten hydraulic equations are performed concurrently, thus ensuring that the monthly flows will be feasible. In effect each set of ten hydraulic equations (one set for each month) forms a network solver for the main system.

We are not altogether satisfied with this procedure. First, the 700 h per month is a somewhat arbitrary value, although it does stem from actual field data on system availability. But more importantly, it has not been proven that the average flow used in formulating the hydraulic constraints neither under nor over estimates the true monthly carrying capacity of the system.

It would have been possible to improve the hydraulic representation by considering more than one representative instantaneous flow pattern, e.g., average flow, peak flow, low flows. This has been done by Alperovits and Shamir[2] in a method for optimal design of water distribution systems. This approach does not present any conceptual difficulty; however, for each additional instantaneous flow condition to be considered, 120 additional equations would be required, ten equations for each of the 12 months. In this case the monthly energy requirement of the booster stations on the main lines would be calculated using

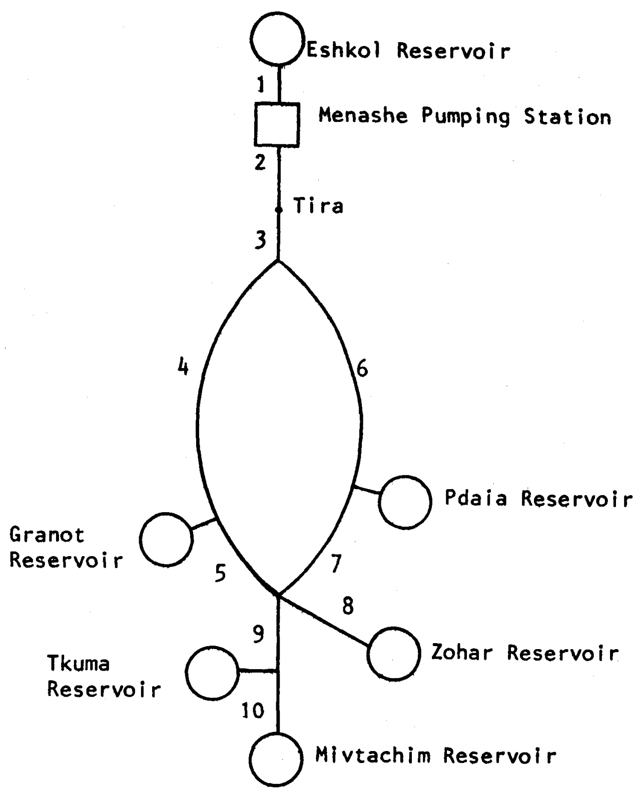

Figure 4. Schematic of the main system showing sections for which hydraulic equations are defined

estimates of the proportion of the month the system 'spends' in each of the instantaneous flow states.

Despite the reservations regarding the modeling of the main line hydraulics with only one flow condition, it should be pointed out that the practice of checking hydraulic feasibility by means of representative flow values is used by engineers for manual calculations pertaining to system operation (usually they are peak values).

It should also be realised that in practice the demands, and especially peak demands, are not rigid. If a peak demand cannot be met due to hydraulic or other limitations the actual consumption would automatically decrease and in all probability would be compensated for by increased demands during non-peak periods.

Mainline pump stations

Energy requirements for well and booster pumps in the regional systems is accounted for through the use of coefficients which represent the average watt-hour per cubic meter requirement of groups of pumps, while the only hydraulic constraints appear in the form of bounds defining the maximum allowable monthly amount which can be pumped. These bounds are calculated from the average hourly capacity of the group of pumps multiplied by the number of hours per month. However, for the main line booster pumps, where much larger amounts of water are involved, it was felt that a more realistic model is required which would take into account the head-discharge characteristics of the pump units comprising the station as well as the varying unit energy requirement as expressed by the efficiency curves. This was done as follows:

The operation of a main line booster is represented by a monthly flow amount and an average monthly dynamic head value which can be conceived of as an average of the operating states of the station within the month, weighted by the length of time the station spends in each state. As an example the head-discharge relationships for a booster station with three units in parallel are shown in Fig. 5. The curve on the left represents a single unit, that in the middle two units in parallel, and that on the right three units in parallel. In principle, a curve is required for all feasible configurations of the pump units in the station. The curves are given in terms of the monthly amounts which would be pumped if the station were operated continuously for the whole month at the corresponding dynamic head value. On each curve three points are defined (the number of points is arbitrary). For each point three constants are defined, where (i,j) is the jth point on the ith curve:

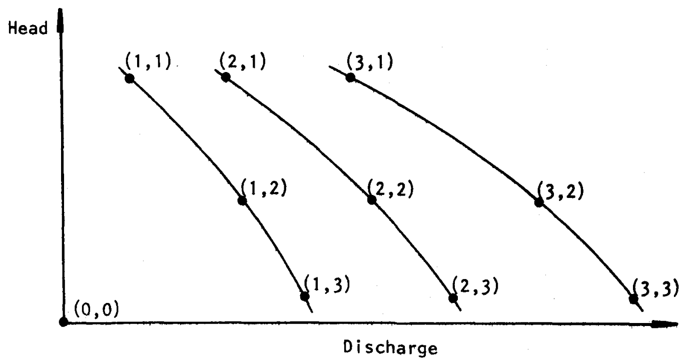

Figure 5. Characteristic curves for mainline pumping stations

$H(i,j)$ the dynamic head

$Q(i,j)$ the monthly amount which would be pumped if the station was operated continuously at a constant dynamic head $H(i,j)$

$E(i,j)$ the total energy requirement for operation under the above conditions (in Kw hr).

In addition, the point $(0,0)$ representing station shutdown for the whole month, is also defined. ($H(0,0) = Q(0,0) = E(0,0) = 0$). Furthermore, for each point a weight $w(i,j)$ is defined which can be interpreted as the proportion of the month that the station spends at point (i,j). The sum of these weights is unity. The weighted average dynamic head, the monthly discharge, and the energy requirement are then given as follows:

$$h = \sum_{i,j} w(i,j)\, H(i,j) \qquad (2)$$

$$q = \sum_{i,j} w(i,j)\, Q(i,j) \qquad (3)$$

$$e = \sum_{i,j} w(i,j)\, E(i,j) \qquad (4)$$

h and q are included in the hydraulic equations for the relevant line, and e appears in the objective function. The point (h,q) will always fall within the convex region defined by the points (i,j). For each booster station there are 12 sets (one set for each month) of variables $w(i,j)$ and equations for q, h and e.

Pumpage/recharge constraints

The system contains many dual purpose wells which are used for recharge to the aquifer as well as for pumpage from it. Thus there are many cases in the model where a recharge variable and a production (pumpage) variable both refer to the same group of wells. In the normal course of events the structure of the model ensures that one of the variables in such production/recharge pairs will always be zero. Non-zero values for both variables would imply that water is being pumped and some of it is being recharged back in the same time period at the same place; since pumpage entails an energy expenditure which the model is attempting to minimize, such a situation could not be optimal. However, situations could arise in which the model would actually assign non-zero values to both variables. For example, local groundwater hydrological conditions might dictate that in a particular aquifer cell a net annual production is to be allowed but that in a section of it there is to be recharge to fill a local groundwater deficit. In such a case a positive lower limit could be placed on the recharge to the cell. If the cost of pumping from the cell is low, as compared, say, to other cells, the model would also indicate pumpage.

Now, if the recharge and the pumpage are through the same wells, a constraint would be required to ensure that the model does not attempt to recharge and pump in these wells at the same time. For example, let RM be the maximum amount that can be recharged if the wells are used only for recharge throughout the month, and let PM be the amount pumped if the wells are used only for pumpage. It is clear that if the actual pumpage, P, is PM, then the actual recharge, R, must be zero. Conversely, if R, the actual recharge, equals the maximum RM, then $P=0$. On the other hand, if recharge takes place during a portion of the month, pumpage can take place during the remainder. There is thus a trade-off between the recharge and the pumpage. We assume that this trade-off is linear, although in practice it is not, due to the non-linearity of the hydraulic system connecting the wells. The problem is further complicated when some of the wells represented by a recharge variable are not dual-purpose and thus if all the dual-purpose wells are used for pumpage, recharge can still take place. Similarly, the production variable could include dual- and single-purpose wells. The pumpage/recharge constraint thus takes the following form, using the linear trade-off assumption:

If the dual-purpose wells are used exclusively for recharge, the maximum possible monthly recharge is RA including single-purpose recharge facilities and the maximum possible pumpage (from the single-purpose wells) is PA. Similarly, if the dual-purpose wells are used exclusively for pumpage, then the maximum possible monthly pumpage (including single-purpose pumpage wells) is PC and the maximum possible recharge (from single-purpose recharge facilities) is RC. These four values define two points in the pumpage/recharge plane (see Fig. 6). A straight line through these points defines the constraint which states, for example, that if the monthly recharge is RB, then the monthly pumpage cannot be greater than PB. The constraint is written as an inequality so that in fact all points below the line are feasible.

$$(PC-PA)R+(RA-RC)P \geqslant PA\cdot RC-RA\cdot PC \quad (5)$$

$$R \leqslant RA$$

$$P \leqslant PC$$

Zohar reservoir

This reservoir is located at the southern confluence node of the main loop in the hydraulic system (see Fig. 4). It has a capacity of about 10 million cubic meters, and is the only over-month surface reservoir in the system apart from Lake Kinneret. There are several smaller reservoirs, but they serve only for daily or weekly regulation. Thus only the Zohar reservoir has to be taken into account explicitly in the monthly operation model. The following constraints are defined (repeated for each month):

(a) A mass balance equation which relates storage at the beginning and end of the month, inflow, outflow, seepage and evaporation losses. Rainfall is not included due to the small surface area and low annual rainfall, and neither is runoff due to the small size of the catchment area.
(b) A hydraulic equation for the pipe connecting the reservoir to the system.
(c) A volume vs. water level equation. Volume is required in the mass balance equation, water level in the hydraulic equation. The actual relation is non-linear but a linear approximation is used which gives elevation as a function of mean volume for the month. Different approximations are used for each month. After each solution of the *LP* the linear approximations are checked and if necessary they are changed and the problem rerun. Usually no more than two or three such iterations are required.
(d) A volume–surface area equation. The surface area is required to calculate the seepage and evaporation losses which are needed in the mass balance equation. This non-linear relation is also linearized for each month.

The above equations are repeated for each month. One additional equation is defined which ensures that the level at the end of the last month is greater or equal to the level at the beginning of the first month. In the absence of this equation the model would empty the reservoir since in effect it is an energy-free source.

Special constraints

Special constraints may be needed for a variety of reasons. Following are some examples.

(a) Quality constraints. Water from the Kinneret may have a different quality to that of the aquifers. In some years its salinity rises (due to the existence of saline springs on the banks and in the lake itself) to unacceptable limits. Also, smell and taste problems arise due to biological activity in the lake. In such cases it might be decided to restrict the use of water from the lake by defining constraints which for example, limit the proportion of Kinneret water in the supply to a regional system.
(b) Hydraulic problems in regional systems. Although internal hydraulics of regional systems are not represented explicitly in the model, hydraulic considerations can in some cases be included. For example, it might be known that a certain proportion of the demand in a regional system cannot be supplied by water from the main line due to topography and/or limitations in the distribution system. In such a case a positive (and not zero) lower bound would be placed on the production variable within that region itself, and only the remainder can be supplied from the main line.

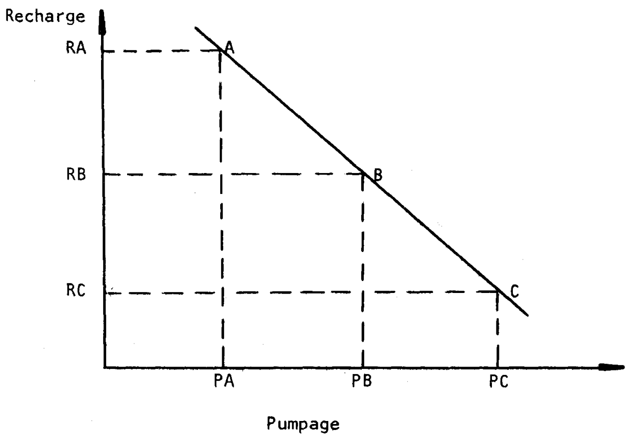

Figure 6. Pumpage/recharge constraint for dual purpose wells

RESULTS

Operation

A comparison has been made between the actual operation for the year 1977-78 and the optimal plan obtained from the model for the same period. The main results are as follows:

(a) The model indicated an energy saving relative to the actual consumption of about 50 million kilowatt-hours, approximately 6% of the total for the year.

At October 1979 prices this represents about 65 million Israeli pounds ($2 million) per year.

(b) The saving in energy could have been brought about by reduced aquifer pumping and recharge activity. Pertinent figures are presented in the following table (amounts in million cubic meters)

	Actual operation	Model
Pumpage	309.6	256.5
Recharge	65.8	26.6
Net production	243.9	229.6

The discrepancy in the above table of 14 million cubic meters (MCM) between the actual net production (243.9 MCM) and that of the model (229.9 MCM) is due to unaccounted-for losses in the system (leaks and measurement inaccuracies). To account for these losses consumption in the model should have been increased accordingly. This was inadevertantly neglected when the data were prepared. In any event, the trend of the results from the model is clear and indicates that the same net production could have been achieved with a considerable reduction in aquifer pumpage (and an equal reduction, in absolute terms, in recharge). It appears that in the actual operation some 40 MCM were needlessly pumped from the aquifers and then recharged!

Planning and design

Although the model was originally conceived to provide operation plans, it can also serve as a valuable tool for general planning and design studies. Following is a brief discussion of some of these aspects.

(a) The marginal value of water. The dual variables of the *LP* solution and results obtained by the RANGE subroutine (on the IBM package) allow for the determination of marginal costs of water supply (in terms of watt-hour per cubic meter) and the analysis of the way in which consumption changes would influence the operation of the system. In conjunction with the 1977–78 operation study, such an analysis was made of the effects of increasing the March 1978 consumption in a southern regional system (Har Ha'Negev). The actual consumption for this month was 2.08 MCM and the marginal cost at this level was 2.18 Kw-hr per cubic meter. As the demand is increased the marginal cost also increases and the flow patterns within the system change. These changes are propagated northward from the demand point and also affect the system in different months due to the annual constraints on net pumpage. The maximum amount which the system is able to supply to this regional project in March is 4.4 MCM at which point the marginal cost is 9.3 Kw-hr per cubic meter!

(b) Detection of 'bottlenecks' in the system. Flow transfer variables from the main lines to regional systems and between neighbouring regional systems, which take on their upper bound values in the solution, represent bottlenecks in the system. The reduced costs of these variables represent the marginal operating cost of increasing the capacity of the installations represented by the variable. This cost can be compared with the capital costs which would be incurred. The RANGE subroutines provides information concerning the extent to which such capacity increases would be effective.

(c) Seasonal storage as an energy saving device. If seasonal storage facilities were available at a particular demand point, then instead of specifying the monthly consumption requirements at this point, it would be possible to specify only the total annual amount and allow the model to determine a monthly supply schecule. This would result in an energy saving compared to the case where each monthly amount is fixed *a priori*. Comparison of the supply schedule with the monthly consumption values provides the storage requirement, and the cost of this storage can be compared with the energy saving.

(d) Design changes to the hydraulic system. Proposed hydraulic changes to the system, such as the addition of pipes, pumps and operational reservoirs (which control the head in the main lines) can be studied with respect to their effect on the operation of the system and the energy requirement. These effects can then be compared with the capital cost involved.

APPLICATION

The model has not, as yet, been used in an operational sense. It is hoped that this will be done in the forthcoming 1980–81 supply year. In this respect several points are worth mentioning.

(a) The model is intended to serve as an aid to planning the annual operation of the system. As such, it will not provide solutions to all problems which may arise, in particular those which pertain to shorter term operation considerations.

(b) It is essential that a follow-up and monitoring program be adopted. This entails regular meetings between analysts and operation personnel, at which sufficient information about the current and future operation must be available. The purpose of these meetings would be to plan the future operation, using the results of the model as a basis for discussion. In this way operation goals will be achieved and the effectiveness of the model enhanced. Such an operation planning program does not exist at present, but we regard it as essential for effective and successful use of the model.

(c) It is expected that the model will have to undergo further calibration within the above mentioned planning program. In fact, the parameter values for the model will have to be monitored continuously with appropriate changes being made to account for new installations, significant breakdowns or planned shutdowns of pumping stations for maintenance, etc.

CONCLUSION

The analysis of the 1977–78 operation year indicates a potential saving of 6% of the total energy requirement for the system. We believe that this is sufficiently high to warrant further effort in implementing the required planning program, in which the model would play a central role.

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