AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

האוניברסיטה העברית בירושלים
The Hebrew University of Jerusalem

המחלקה לכלכלה חקלאית ומנהל
The Department of Agricultural Economics and Management

המרכז למחקר בכלכלה חקלאית
The Center for Agricultural Economic Research

Discussion Paper No. 12.01

Water Management in Israel: Rules vs. Discretion

by

Or Goldfarb and Yoav Kislev

Papers by members of the Department can be found in their home sites:

מאמרים של חברי המחלקה נמצאים גם באתרי הבית שלהם:

http://departments.agri.huji.ac.il/economics/indexh.html

P.O. Box 12, Rehovot 76100

ת.ד. 12, רחובות 76100

Water Management in Israel: Rules vs. Discretion*

Or Goldfarb and Yoav Kislev**

In this paper we are trying to address two issues. The first is management of the water economy under uncertainty and the second issue is the mode of management: we suggest management by rule.

Water reservoirs are common pools; they must be managed collectively. In Israel, by law, all water sources are publicly owned and their utilization is under the control of the State, managed by the Water Commissioner.[1] The Commissioner is given a set of powerful instruments to enforce the law and the chosen management policies. The law, however, does not specify the desired policy or the duties of the Commissioner. The implication of this omission is that the lawmakers trusted the Commissioner to manage by discretion, to use professional judgment in formulating policies and directing the sector. Experience has taught, however, that management by discretion has failed. Throughout the years, the Commissioner allowed overdrafting, the water sector was brought at least twice in recent years to a severe crisis, and the reservoirs have been depleted and polluted. Moreover, facing strong resistance of the farm lobby, the Commissioner has been only partly successful in implementing austerity measures in emergency drought periods. We present here a model of management under uncertainty and in the last section of the paper discuss the possibility of this model to be the basis for management by rule.

---

* Prepared for the conference Irrigation Water Policies: Micro and Macro Considerations, Agadir, Morocco, June 2002.
** Respectively, of the Water Commission and the Hebrew University. We are grateful to Devoira Auerbach for editorial assitance.
[1] For a survey of the major issues in the water economy in Israel, see Kislev (2001).

Three Nested Circles

The analysis in the paper is based on programming performed in three nested stages. The inner circle in Figure 1 stands for the dynamic programming in a Markovian model serving as a formal representation of management under uncertainty. It will be explained below. The second circle represents the analysis of the optimal size of agriculture and flexible desalination—to be activated only in periods of shortage. The external circle in the diagram represents the excess demand of water over and above natural sources. This demand is determined by the size of agriculture and the projected growth of the urban sector.

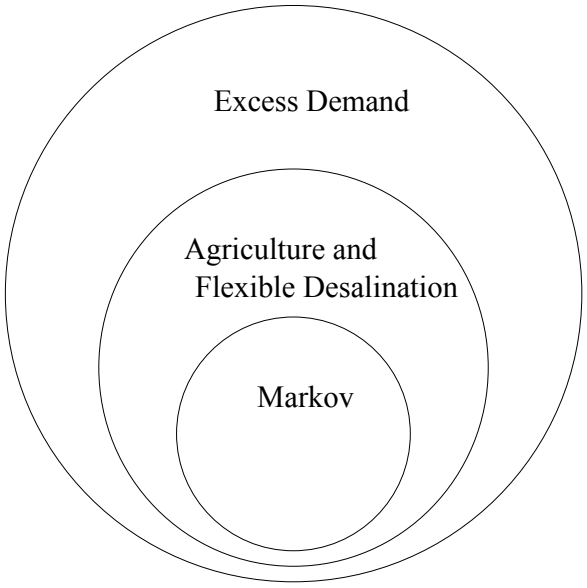

Figure 1: The Three Programming Circles

Agriculture plays two different roles in the water economy. Agriculture is a consumer of water and the larger the farming sector, the more water it uses. With limited natural resources, the size of agriculture will determine the time and the scale of desalination, excess demand in Figure 1. The second role that agriculture may perform is as a reserve for emergencies. Water allocation to agriculture can be cut in dry years to

avoid difficulties in urban supply. In other words, agriculture may serve as a buffer. The two roles are connected: agriculture can serve as a buffer only if its water use in regular years is large enough to be a basis for cuts.

The source of uncertainty in the water economy lies in the underlying nature of the sector. Precipitation, in varying amounts, comes in the winter, while most of the utilization is in the summer. The appropriate time to inform the farmers about cuts in supply—if needed—is in the fall, when spring planting can still be adjusted. But the decision in the fall is done under uncertainty, before the winter rains. The solution in the Markovian model is simple: decide on allocation for the summer according to the condition of the reservoirs in the fall. Allocation is large, when the reservoirs are relatively full; supply to agriculture is cut when the reservoirs are empty. The contribution of programming is in formulating an explicit policy—management rules that are expressed as quantitative relations between water in the reservoirs and allocation to agriculture.

Flexible desalination may modify the policy. Desalination plants, in times of emergency and shortage, will reduce or even eliminate the need to cut agricultural allocation. In this way, the planning of supply under uncertainty, here in the Markovian model, is connected to average supply and to the decision on desalination plants and their destiny—for continuous or flexible operation.

Framework and Assumptions

The programming horizon in the analysis is 20 years.[2] For simplicity and clarity of exposition, programming was constrained at this stage to a relatively narrow framework and to a small number of alternatives. The dynamic programming of management under uncertainty covers the water economy of the National Project, which supplies approximately two thirds of the water in the country. We view all reservoirs as if they were a single cell and disregard differences in enrichment or extraction in the separate reservoirs. The state of the reservoir is defined for the month of September every year, and the reservoir may be, by assumption, in one of the following states: *High* +200; that is, the amount of water in the reservoir exceeds by 200 MCM (million cubic meters) the amount associated with the "red line"—the guideline for marking the lowest water elevation in the reservoir. *Intermediate* 0; the red line. *Low* –200; water in the reservoir is 200 MCM less than the red line and over-utilization has occurred.

Replenishment is the amount of water added yearly to the reservoirs. We adopted the following values and their probabilities: dry year 1,050 MCM (with probability 0.10); average year 1,550 MCM (0.80); rainy year 2,000 MCM (0.10).

The size of agriculture is defined here (disregarding livestock production) by the amount of water allocated from the National Project. *Basic agriculture* is the amount of water allocated to agriculture in regular years. In emergency and shortage, allocation may be curtailed temporarily. The reference for the analysis is the situation in 1998 when basic agriculture, as defined here, was allotted 700 MCM/Y (MCM per year).

The size of basic agriculture, plus the allocation to agriculture outside the

[2] Extending the horizon of the program to more than 20 years did not change the plan for the first several years. It can be safely assumed that with changing future conditions, programming will be repeated. Hence a 20-year horizon is sufficient for our problem.

National Project and the growing urban supply, will determine the total quantity demanded of fresh water and hence excess demand—and desalination. For example, basic agriculture of 700 MCM/Y requires immediate construction of desalination plants of 300 MCM/Y; however, if basic agriculture is of 300 MCM/Y, the first desalination plant will be constructed in 2006 and with a smaller capacity of only 50 MCM/Y.

By the model, the Water Commissioner has at his disposal a set of possible actions. The decision on a policy is a choice of actions to be associated with the states of the reservoirs. These associations are then the chosen policy rules. In connection with management under uncertainty of supply from natural sources—in the two internal circles of Figure 1—the alternative actions are:

a. Construction of desalination plants to reduce variability of supply. We shall analyze two alternatives, continuous and flexible operation.

b. Temporary curtailment of supply to agriculture in dry spells.

c. Over-utilization of the reservoirs, below the red lines, up to 400 MCM.

d. Shortage in urban supply. This alternative is taken as a choice of the last resort. Shortage occurs only if the reservoirs were over-utilized by 400 MCM and there was not enough water to provide for urban demand.

The Objective Function and the Cost of Policy

The objective of the program is to minimize cost. The chosen policy is the set of management rules that achieves this goal. The cost is measured as expected capitalized value for 20 years.

The concept of cost in the analysis is differential. We measure *changes* in cost

caused by changes in the program of the water economy. The reference for comparison is the water sector of 1998 when allocation to agriculture from the National Project was 700 MCM and there was no desalination of seawater. The differential cost may have several origins: reduction of the size of basic agriculture (from 700 MCM/Y) reduces the product of the sector, this is taken as cost; cuts in supply to agriculture in emergency is costly; we give a monetary value to over-utilization of the reservoirs and to shortage in urban supply. An additional component is the cost of seawater desalination. Details follow.

Basic Agriculture: Since farmers have not used all their water quotas in recent years, we accepted the price they paid as the value of marginal product of water at the basic quantity (700 MCM/Y). Deducting the variable cost of water transfer and adding a sum for social contribution of green agriculture, we arrive at NIS 1 per CM.[3] When calculating VMP of lower quantities, we assumed unitary elasticity of demand.

Emergency cuts in Allocation: In emergency, unexpected cuts will damage expensive crops and idle irrigation equipments and other production assets. We took the value of NIS 2.20 per CM for unexpected cuts in allocation of water to agriculture.

Over-utilization: It was assumed that over-utilization of the reservoirs will require desalination of part of the water supplied for 15 years. Accordingly, we constructed a rising cost function approximated by $y = 2.21x + 0.00003x^2$ where y is cost in NIS per CM and x is over-utilization in CM.

The Urban Sector: To represent the high cost of shortage in the urban sector we took the value of NIS 40 per CM.

Seawater Desalination: Fixed cost, capital and labor, of desalination is expected

[3] NIS is New Israeli Sheqel, approximately $0.25 at the time of the analysis.

to be NIS 1.60 per CM. Variable cost, of energy, is taken as NIS 1.20 per CM.

Markov Chains and Policy Choice

The stochastic model of the water economy is a finite Markov chain.[4] The states are defined by the amount of water in the reservoirs in the autumn of every year. The transformation from one state to another, from one year to the next, is determined by precipitation and water utilization. The states are defined, high=1, intermediate=2, low=3. We write now, as an example, two Markov matrices *P* for two alternative policies for basic agriculture of 600 MCM/Y and the corresponding cost vectors *C*.[5]

Policy *a*: Do not cut allocation to agriculture even if in the fall the reservoir is low.

(1) $$P_a = \begin{bmatrix} 0.9 & 0 & 0.1 \\ 0.1 & 0.8 & 0.1 \\ 0.1 & 0 & 0.9 \end{bmatrix} \qquad C_a = \begin{bmatrix} 95 \\ 590 \\ 1,746 \end{bmatrix}$$

Policy *b*: Do not cut supply to agriculture if the reservoirs are high in the fall, cut 200 MCM if the reservoirs are in intermediate position or they are or low.

(2) $$P_b = \begin{bmatrix} 0.9 & 0 & 0.1 \\ 0.9 & 0 & 0.1 \\ 0.1 & 0.8 & 0.1 \end{bmatrix} \qquad C_b = \begin{bmatrix} 95 \\ 540 \\ 1,036 \end{bmatrix}$$

Moving from equation (1) to (2), one notes the reduction in the probability of reaching states 2 and 3, intermediate or low reservoirs. Policy *b* protects the reservoirs relative to *a*. By policy *b*, allocation to agriculture will be curtailed, at a cost, when the reservoirs are low. However, policy *a* entails a greater probability of over-utilization of

[4] The first to suggest and formulate a Markov chain model of a single cell aquifer in Israel was Levin (Bear and Levin, 1966). To our knowledge, his model has never been applied in the water economy.
[5] Given a policy matrix, a cost (expected) is associated with each state.

the reservoirs. Consequently, policy *a* is, in general, more costly than policy *b*.

Policy choice is the choice of a Markov matrix *P* that minimizes cost. The algorithm was dynamic programming (Hadley, 1964).

The Programs

Programming was done in two stages and 48 combinations. In the first stage we found for each combination the cost minimizing policy. In the second stage we looked for the combination with the lowest overall cost (Table 1 below). Every combination incorporated three alternatives from the following.

Desalination plants: no plant, 100 MCM/Y, 200 MCM/Y (3 alternatives).

Desalination: continuous, flexible (2 alternatives).

Basic agriculture; 0, 100, ..., 700 MCM/Y (8 alternatives).

Table 1: **Total Cost (million NIS, expected present value for 20 years)**

Basic Agriculture	0	100	200	300	400	500	600	700
Excess Demand	635	1,905	3,789	6,064	8,729	12,698	16,630	20,022
Reduction of Ag.	22,938	15,087	10,769	7,236	4,880	2,970	1,400	0
Markov	2,305	3,497	3,953	4,980	6,015	4,835	2,931	2,634
Total	25,878	20,489	18,511	18,280	19,624	20,503	20,961	22,656

Table 1 summarizes the analysis. The table reports cost for 8 alternatives of basic agriculture; form 0 to 700 MCM/Y. The second row, Excess Demand, is the cost of desalination to satisfy the quantities demanded as basic agriculture grows from one alternative to the next. The third row, Reduction of Ag., is the opportunity cost of not producing in agriculture, relative to the reference size of 700 MCM/Y.

The fourth row in the table, Markov, is the cost associated with water supply under uncertainty. Here the components are the cost of emergency cuts in supply to agriculture, over-utilization of the reservoirs, and desalination to reduce variability of

supply. The entries in the fourth row were constructed in a two-stage minimization process. For each size of basic agriculture, water management policy was chosen in dynamic programming for five alternatives of desalination: no desalination, continuous desalination, and flexible desalination; in both cases of 100 or 200 MCM/Y. The entry in the fourth row is the minimum cost over these five alternatives for each size of basic agriculture. The program suggested no desalination for basic agriculture of 0, 600, and 700 MCM/Y. When basic agriculture is zero, desalination to reduce supply variability is not needed, and in a relatively large agriculture, desalination is more expensive than cuts in supply during emergency periods. For the other sizes of agriculture, flexible desalination was found less costly than continuous desalination.

The overall minimum in Table 1 is for agriculture of 300 MCM/Y. With 250 MCM/Y outside of the national project, our program recommends fresh water allocation to agriculture of 550 MCM/Y as against 950 MCM/Y that the sector used in 1998.

Remarks

Space restrictions prevent us from demonstrating the rich set of conclusions and insights of the analysis; but two findings, perhaps unexpected, can be pointed out. First, a comparison of the relatively small values of the row marked Markov in Table 1 to the entries in the other two rows reveals that incorporating uncertainty into the analysis of the water economy does not modify significantly the optimal plan. Agriculture is not called to act as a buffer for dry spells. Second, by conventional wisdom, desalination plants, being capital intensive, should be operated continuously. We found that flexible operation is preferred.

It is however important to emphasize that the conclusions of the study are determined by the nature of the analysis and by the assumptions adopted. For example, we included in the value of the marginal product of water in agriculture NIS 0.50 per CM as a contribution of farming to the environment; many would regard this assessment as an exaggeration.

Flexible desalination raises a political issue and an economic question. The first is that once a desalination plant has been constructed, political lobbies will demand that it be operated continuously ("it is a waste to let a plant stay idle"). If this (economically unsound) demand is accepted, agriculture will expand and allocation will have to be cut in emergency periods with all the difficulties experienced in recent times. The economic question is about water pricing. The way the programming was done, desalination was activated when the *variable* cost of desalinated water was lower than cuts in supply or over-utilization. (Total costs were considered in the decision of whether to construct a desalination plant.) If the suggested policy is implemented, farmers will take the desalinated water if its price is equal to variable cost, but then payments for water will not cover total cost. This is a typical case of pricing in the presence of economies of scale, here up to capacity of the plant (Bös, 1994). Extraction levies, reflecting scarcity values, have recently been instituted in Israel. The levies may cover the fixed cost of desalination, but we shall not elaborate here on this issue.

The analysis was conducted as if all decisions are made by the planner and water users act mechanically. However, once the chosen policy is to cut allocation to agriculture in emergencies, and that policy is made public, farmers will plan their operations with this possibility in mind. For example, they may plant, on part of their

land, inexpensive crops that are not damaged severely when water is in short supply. Another alternative is to institute water markets where farmers in need purchase allotments from others. These adjustments may lower the cost of emergency cuts in supply and may also alter some of the conclusions of our analysis.

Rules vs. Discretion

When management was by discretion, the Water Commissioner was constantly subject to political pressure to expand supply to agriculture; and indeed, quotas were increased despite professional advice. The ensuing over-utilization resulted in an ever-growing deficit in the reservoirs and a succession of dry years threw the water sector into an acute crisis. When the severity of the situation was realized, the Commissioner tried to curtail supply to agriculture but his efforts were frustrated when the farmers and their political lobby succeeded in dragging the authorities into extended discussions of procedure and compensation.

We envisage management by rules to be implemented along the following general lines: The government will be presented with a program for the water sector. The program will be made of three parts. The core of the program will be a set of management rules and associated costs. The rules and the costs will be programmed in a model similar to the one presented here. Needless to say, if implemented, the model will be more detailed and its assumptions rechecked. The second part of the program will consist of special rules; such as, development plans, prices, or quotas for emergency situation in dry years. The third part of the program will detail the programming methods and the assumptions.

The program will be transparent and subject to public debate. In due course the government will select a *policy*, a set of rules to adopt. The government, guided by general welfare considerations, need not choose the cost minimizing set. The Water Commissioner and the public, particularly the farmers, will know the rules in advance and what to expect in rainy or dry years. There will be no need for political bickering when an emergency situation materializes. A water authority will monitor the sector and the implementation of the rules adopted. The Commissioner will be judged by his adherence to the selected policy and the specified goals.

We should be realistic; the best plan can be watered down in the political arena. It should in fact be expected to be watered down: farmers and others, including in some cases the Commissioner himself, will rather have a more flexible policy regime, believing that they may squeeze preferential treatment if the rules are not cut and clear. A realistic outcome will always be a compromise. The question is whether a compromise is worth the effort invested in its implementation. We believe it is.

References

Bear, J. and O. Levin, *An Optimal Utilization of an Aquifer as an Element in a System of Water Resources*, The Technion, Israel Institute of Technology and the Technion Institution for Research and Development, 1966 (Hebrew).

Bös, Dieter, *Pricing and Price Regulation, An Economic Theory for Public Enterprises and Public Utilities*, Elsevier Science, 1994.

Hadley, G., *Non-Linear and Dynamic Programming*, Addison-Wesley, 1964.

Kislev, Yoav, *The Water Economy of Israel*, Discussion Paper No. 11.01, The Department of Agricultural Economics and Management, The Hebrew University, 2001.