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THE CONTEXT OF LOCALLY MANAGED IRRIGATION IN ISRAEL: POLICIES, PLANNING AND PERFORMANCE

L. Shanan and S. Berkowicz

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IIMI International Irrigation Management Institute

P.O. Box 2075, Colombo, Sri Lanka.
Telephone: 94-1-867404 Telex: 22318 IIMIHQ CE
Facsimile: 94-1-866854 E-Mail: IIMI (CGNET), IIMI@CGNET.COM (INTERNET)

Purpose of the Series

The *Short Report Series on Locally Managed Irrigation* is designed to disseminate concise information on the role of local management in irrigation and irrigation management transfer or turnover experiences and policies. The *Series* is distributed worldwide to a broad range of people—policymakers, planners, researchers, donors and officials in both public and nongovernmental organizations—who are concerned with the irrigated agriculture sector. IIMI's goal is not to promote policies such as irrigation management transfer, but to enhance the knowledge base available to decision makers and advisors as they face questions of policy adoption and strategies for implementation.

Locally managed irrigation can be of many types, such as traditional farmer-constructed diversion or tank schemes, indigenous and often new lift irrigation, government-constructed but farmer-managed irrigation systems and systems where management is or has been transferred from an outside agency to a local user organization.

By "irrigation management transfer" we mean some degree of transfer of responsibility and authority for irrigation management from the government to farmer groups or other nongovernmental entities. This generally involves contraction of the role of the state and expansion of the role of the private sector and water users in irrigation management. In other words, there is a shifting upstream of the point where management responsibility and control of the water supply are transferred from the irrigation authority to local management. This may involve changes in policies, procedures, practices and the performance of irrigated agriculture. It may or may not involve "privatization" of ownership of the assets of the irrigation system. The *Short Report Series* addresses questions such as the following:

What are the necessary conditions which support viable locally managed irrigation?

What socio-technical conditions, institutional arrangements and change processes lead to sustainable locally managed irrigation?

What is the range of different models that are being applied worldwide for turnover or transfer of responsibility for local management for recently developed irrigation?

What are the effects of management transfer on the productivity, profitability, financial viability, equity, efficiency and sustainability of irrigated agriculture?

What are the perspectives of farmers, managers, policymakers, urban consumers and other stakeholders in irrigated agriculture about irrigation management transfer?

What adjustments in government may be needed as a result of turnover to provide support to locally managed irrigation systems and to improve productivity in the public sector?

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Dr. Douglas Vermillion or Dr. Sam H. Johnson III,
Program on Local Management, IIMI,
P.O. Box 2075, Colombo, Sri Lanka.
Fax: 94-1-866854; Telex: 22318 IIMIHQ CE;
E-Mail: IIMI (CGNET), IIMI@CGNET.COM (INTERNET)
Telephone: 94-1-867404

Editors' Note

One of the most important problems facing the water resource sectors of many countries today is how to deal with the rising competition for water and the need to produce more food with less water. Another important issue is, "what are the supporting conditions, provided by governments, that are needed to enable effective local management of irrigation?"

It is widely recognized that Israel has made considerable progress in responding to both issues although rising competition for water continues to be a serious problem. Israel's sophisticated water-conserving irrigation technologies are well known. Somewhat less well known are its national water law, water allocation arrangements and clearly defined and mutually supporting roles between the state and local organizations for irrigation management. Israel has also made a transition from an irrigated agriculture sector which was labor-intensive and had low levels of investment to a highly commercialized and heavily invested sector. Many countries are attempting to make a similar transition. Shanan and Berkowicz attribute much of Israel's ability to make this transition to the reliability of irrigation management achieved by the above combination of institutional and technical factors.

This Short Report describes the distinctive combination of technology, water law, institutions and management methods which have resulted in relatively high levels of irrigation performance in Israel. We recommend it not as a universally applicable model, but as an indication of how one country has developed a relatively compatible system of water law and institutions, irrigation infrastructure and division of responsibility for management.

The Context of Locally Managed Irrigation in Israel: Policies, Planning and Performance[1]

L. Shanan[2] and S. Berkowicz[3]

Abstract

The policies, water laws and planning criteria for water resources and irrigation development in Israel are reviewed in this report, and the operation of the main water supply systems and the farm-level delivery networks are assessed. The national water system is, for the most part, operated by a government-sponsored public company while municipal and village systems are managed through locally elected councils accountable to the public. Private and national water supplies are regulated by government allocations and pricing policies. In the irrigation sector, performance has been high. Water distribution has been assured and equitable, deliveries are timely and irrigation networks generally operate efficiently. System reliability has been one of the main factors enabling the government to adopt policies which moved irrigated agriculture from a labor-intensive, low-investment sector to a commercialized, export-oriented one. Drip and sprinkler systems have replaced surface irrigation methods and high production has been achieved with advanced agricultural practices and skillful farm management.

Physical Setting

Israel is a small Middle Eastern country about 21,000 km^2 in size situated on the eastern shore of the Mediterranean Sea between the continents of Asia and Africa. It is a land rich in contrasts in terms of population and religions (Jewish, Christian, Druze and Moslem), as well as in urban and rural settlement structure where cooperative agriculture and industry compete with private enterprise.

Israel has a large variety of landscapes as a result of folding and faulting and a great variability in climate. Arid and desert areas are, at the most, 200 km distant from humid regions; deep valleys, some almost 400 meters below sea level, can be seen with the naked eye from nearby mountain peaks. The topography of Israel is characterized by a central mountain range reaching 1,000 meters above mean sea level. To the west of this range the slopes lead to the Mediterranean Coastal Plain, while to the east they drop steeply to the Jordan Rift Valley (Figure 1).

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1 This paper refers to the area within Israel's pre-June, 1967 boundaries.

2 Consulting Engineer and Professor of Hydrology, Department of Physical Geography, Hebrew University of Jerusalem, Jerusalem, Israel 91904.

3 Professor, Department of Physical Geography and Arid Ecosystems Research Centre, Hebrew University of Jerusalem, Jerusalem, Israel 91904.

The country can be divided into four main climatic zones: humid, subhumid, semiarid and arid, as shown in Figure 2. The semiarid and arid Negev comprises almost 60 percent of Israel's land area. Two main seasons characterize the climate in Israel: a mild rainy winter and a hot dry summer. Rains start in October–November and end in March–April. Average winter rainfall in the north is about 900 mm, decreasing to about 200 mm in Beersheva, and to less than 25 mm in Eilat at the southernmost tip of Israel. The mean monthly temperature in the coldest month is between 6 and 10 °C in mountain areas, between 12 and 14 °C in the Coastal Plain, and between 14 and 16 °C in the Jordan Valley. In the hottest summer months, the mean monthly temperature is between 24 and 26 °C in most parts of Israel except the Jordon Valley when it may reach 30–32 °C. During spring and autumn, hot, dry, dusty winds originating in the deserts of the region blow from the east or south; temperatures often rise to above 36 °C and humidity drops to less than 10 percent. In the mountainous areas above 600 m elevation, snow falls occasionally in winter. The mean annual potential evaporation ranges from about 1,300 mm in the north to about 2,500 mm in the south. Most of Israel has a 365 day annual growing season.

The important water resources of Israel consist of Lake Kinneret (also known as the Sea of Galilee), which has a surface area of about 175 km^2, the Jordan River, two main aquifers (the Coastal Plain Aquifer and Central Mountain Aquifer), and a number of smaller subregional aquifers in the Western Galilee and in the Beit Shean areas (Figure 3). The Coastal Plain Aquifer drains to the Mediterranean Sea and consists mainly of sandy and sandstone formations underlain by a thick bed of clay. The Central Mountain Aquifer comprises limestone formations that slope down under the eastern edge of the clay layers beneath the Coastal Plain. The Jordan River, about 250 km in length, is the only river with any significant flow in Israel. It starts in the north, falling 260 meters to Lake Kinneret situated about 210 meters below mean sea level. It then flows out and meanders toward the Dead Sea and enters it at 392 meters below sea level—the lowest place on the earth's surface.

Historical Background

Throughout this land, numerous remains of water development projects, some dating back at least 4,000 years, are evidence of the prosperous economies of those times. All these civilizations played key roles in maintaining trade routes, linking the economies of Europe to those of Asia and Africa. An excellent example of one of the water supply projects is a 2,500 year-old system which could supply about 350,000 m^3 of water annually to Jerusalem through 64 km of aqueducts, on-line storage reservoirs, tunnels, siphons and stone pipes (Amit 1989). The system integrated the use of springs, groundwater and surface water and was still in partial use in 1948. Another fine example is a system of aqueducts, tunnels and flood storage dams that brought five million cubic meters of water a year to the affluent coastal city of Caesarea with its fountains, public baths and amphitheater (Amit 1989). No less impressive are the clearly visible remnants of productive civilizations in the Negev Desert south of Beersheva dating back more than 2,000 years. These ancient settlers were organized into a centrally planned society that developed ingenious techniques for harvesting runoff water from stony desert hillsides to irrigate private farms in terraced *wadi* (a dry watercourse) bottoms and establish stable sedentary communities (Evenari et al. 1982).

Although the Jewish people have maintained a continuous residence in the region since historical times, modern Jewish settlement began in the early part of the twentieth century in Ottoman Palestine. Until the 1930s, irrigation and agriculture of the Jewish settlers followed the pattern of Middle Eastern *felaheen* (peasant) farming. This was based on minimal financial investment and almost unlimited manual labour; there were few alternatives for employment other than in agriculture. Hillside cultivation (orchards, vineyards, vegetables and olive groves), combined with subsistence farming of cereals and fodder crops in the plains, formed the basis of agriculture. Starting in the 1930s, Jewish farming entered a modernization phase when tractors replaced animals and manual labour, and deep tubewells were drilled instead of shallow hand-dug wells. Reclamation and drainage projects brought about a significant change in land use and the plains and lowlands became the economic core of Jewish irrigated and nonirrigated agricultural development.

In 1948, the British Mandate was terminated and the State of Israel established. The initial population of Israel comprised 717,000 Jews and 156,000 non-Jews. The following years, however, were characterized by rapid population growth as a result of large-scale Jewish immigration from Europe and the surrounding Arab countries. By 1992, the Jewish population had reached about 4.2 million of a total population of 5.2 million; the population density of Israel is about 250 people per square kilometer.

For a country starting with a weak industrial base and few local raw materials, agriculture had to play a central role in the absorption of immigrants even though they were not in any way experienced in farming and its related sectors. The government planners thus decided to harness the enterprising spirit and potential of the immigrants to push agriculture from traditional labour-intensive farming to a more productive and efficient form of agriculture. In the early 1950s, the construction of the National Water Carrier (see section below) was initiated with the aim of increasing the irrigated area of Israel. After 1960, when reliable water supplies became available from deep tubewells and from the National Water Carrier, Jewish agriculture began to focus on high-yielding crop varieties, and the use of new irrigation technologies, fertilizers and pest control measures. Citrus and other fruit orchards, vineyards, cotton, commercial fish ponds, export flowers and vegetables, greenhouse agriculture, sprinkler and drip irrigation are today common features of modern Israeli agriculture and Jewish farmers have become innovators and leaders in many sectors of irrigation science. This paper focuses on the policies and planning methodologies that brought about development in the irrigation sector and assesses the performance of the water delivery systems.

Policies

To understand the dynamic national planning policies of Israel, one must consider the principles which formed the basis of Israel's socio-political ideology. The principles, particularly relating to irrigation development, include: (a) encouraging large-scale immigration and the social and cultural integration of the newcomers, (b) establishing new rural and agricultural settlements, (c) promoting pioneering and egalitarian ventures which stress self-employment and cooperative or collective farming, and (d) fostering both private and cooperative enterprises in all economic sectors.

Israel was established as a secular democracy with a parliament elected on a proportional representation basis. The courts are independent of the executive branch and the fair and just enforcement of law is characteristic of Israeli life. The interplay between political party ideologies and various economic interests has continually brought about changes in the strategies of many planning policies. It is worth noticing that until 1977, the Labour Party dominated the politics of Israel. The pioneering and social welfare policies they introduced during the first three decades of Israel's existence have remained unique aspects of Israel's development.

National, regional and local planning of agriculture and irrigation have always been the responsibility of the central government. The Arab-Israel conflict which dominated the unstable geopolitical situation in the region often directed the policymakers to consider that security (rather than economics) determine the strategic goals of settlement and irrigation. Agriculture carries great weight in Israeli social concepts although contemporary Israel is a highly urbanized society. In 1960, 15 percent of the Jewish population was employed in agriculture, but by 1992 this had dropped to about 3.4 percent (Table 1). In absolute terms, the number of Jews employed in agriculture is not expected to change significantly in the foreseeable future. This movement of Jews from agriculture to other sectors, as indicated in Table 1, is also paralleled in the changing patterns of the non-Jewish inhabitants of Israel whose farming population decreased from 47.5 percent to 4.3 percent during the period 1961–92 (Table 1).

Water Rights and Allocation

From the inception of the State of Israel, water was recognized as a scarce national resource. At that time, considering that more than half of Israel was arid and desert, Israeli Prime Minister David Ben-Gourion set planning targets when he declared: "We must conquer the desert, lest the desert conquer us." It was realized that water would have to become a nationalized resource, owned and regulated by the government. The problems of security and the differences between the social and private costs justified the introduction of a comprehensive water supply system. In order to grant the government the powers to control water development on a national scale, the Israel "Water Law" was legislated in 1959 (Water Commissioner 1975). This law, which formed the framework for all irrigation development in Israel, stated: "Israel's water sources are public property, controlled by the State and devoted to the needs of its residents and the country's development ... A person's right in land does not grant him rights in a water source located on that land or passing through it within its boundaries."

The Water Law thus enabled the government to control both surface water and groundwater and Israel became a forerunner in regulating these two sources in an integrated national plan. Control over existing private wells was considered necessary so as to avoid the over utilization that would otherwise inevitably occur since private costs do not reflect the social costs of replenishment, aquifer pollution and the value of opportunities foregone elsewhere. People who have been users of water (both surface water and groundwater) prior to the promulgation of the Water Law were given rights to continue using these waters contingent on their beneficial use.

The major objective of the Water Law was to exploit the water resources by allocating transferable and non-transferable water rights to consumers for beneficial use. Another objective of the Water Law was to establish water prices and maximize the economic contribution of irrigated agriculture to the national wealth. In line with the egalitarian approach of the government to the development of all regions of Israel, especially border areas and the arid zones far from water sources, the Water Law provided for the establishment of an equalization fund "to reduce the difference between water charges in different parts of the country." The fund was financed by levies on water allocations to users. The main instrument for ensuring equitable allocations was non-transferable quotas granted to users. Under the law, a relatively low rate was charged for the quota and, by using a step function principle, higher rates (up to triple the basic rate) were charged for the remainder of the water used by a consumer. The higher rates charged after the quota is exceeded served as a deterrent to noncompliance.

The Water Law established a Water Commissioner's Office responsible for implementing the policies. Since Israel's National Water Carrier (see below) was designed as a pressure pipe system, all deliveries could be recorded with reliable standard water meters. They monitored bimonthly qqotas taking into account differential evapotranspiration rates. In this way, water use in agricqlture was made a function of crop requirement and the penalties for exceeding the quotas were imposed bimonthly. These policies acted as a strong incentive for efficient use of water particularly in the season of peak demand. Water meters are maintained in good working condition.

The National Water Carrier

The overall water plan for Israel integrated all the resources into a comprehensive scheme so that (a) water could be conveyed from regions of excess in the north to regions of scarcity in the south and (b) the system would have operational flexibility so that surface water and groundwater could be stored in aquifers and water transferred interregionally. This storage, transfer and distribution of water has been carried out by the National Water Carrier (Figure 3). Part of this carrier consists of an open canal but the main network comprises pre-stressed concrete pipes 70 to 108 inches in diameter. About 400 million cubic meters (MCM) of water are pumped out annually from Lake Kinneret (210 m below mean sea level) to an elevation of 152 meters from which point it flows by gravity to the Coastal Plain. The central mountain areas and regions further south receive water by additional pump lifts. The carrier delivers water to local systems rather than supplying individual consumers directly from the main system. Its peak delivery capacity is 20 m^3 per second. The project comprises pumping stations, pipelines, canals, tunnels and operational reservoirs. Construction commenced in 1953 and was completed in 1964. The length of the system's main conduit is 130 km, and the capital investment in the project was valued at the time as US$147 million.

Water Supply and Demand

The short-term water potential from the present network is estimated to be about 2,020 MCM per year (Table 2). Groundwater represents about 60 percent of this amount and the aquifers, together with Lake Kinneret, have an operating storage capacity equivalent to about a one-year supply. This allows for considerable interannual and interseasonal flexibility. The short-term demand which can be met with the present engineering structures is predicted to reach about 2,090 MCM in the year 2000 (Table 3). This will be met with the combined use of three sources—fresh water, saline water and the reuse of treated sewage (Table 3). Agricultural demand is expected to be about 56 percent of the total demand, and will receive about 63 percent of its requirements from fresh water sources, 27 percent from saline sources and the remaining 10 percent from treated sewage projects. Between 1950 and 1990, while the amount of land under cultivation increased by 175 percent to reach about 437,100 ha, there was a concomitant 550 percent increase in the irrigated area which expanded to 205,700 ha (Table 4). The overall average water allocation for the irrigated areas is about 575 mm per year measured at the head of the system.

Institutional Framework

In 1950, the government established a national water planning company, *Tahal*, which was given the primary responsibility to design all major national and regional water projects. A second company, *Mekorot,* was set up to function as a construction agency and water supplier from all national projects to municipalities, local councils, agricultural settlements, and private enterprises (industrial and agricultural). Prices charged by *Mekorot* are user-related (agricultural, domestic or industrial) and have varied over time depending on government-controlled pricing policies. Private and public companies have also been granted permits to develop local water resources (generally, groundwater) and they have been allocated quotas based on prevailing hydrologic conditions and the national development policies. Municipalities and local councils have been authorized to increase the price to the consumer at approved rates to cover the cost of operation and maintenance of the water and sewage systems and the disposal of effluent.

The management of the supply of water to the agricultural sector is unique to Israel. The overwhelming majority of agricultural settlements that have been established in Israel over the last 70 years are either *moshavim* of *kibbutzim*. A moshav is a cooperative village comprising about 300-350 ha. While farm equipment, machinery and storage facilities are family owned, purchasing and marketing functions are cooperatively organized. Farming is "mixed," comprising mainly citrus and other fruit orchards, dairy, chicken, vegetables, vineyards and greenhouses. *Mekorot* supplies water to a moshav as one unit. The moshav council, elected annually for managing the community, is also responsible both for water deliveries to the individual farmer and for monitoring water use. The kibbutz, on the other hand, is a collective community generally comprising 150–400 families settled on 300–500 ha of land with a communally organized system of production and consumption. Farming is also "mixed" but many units are large enough to be operated on an industrialized scale with regional transport, storage and packing cooperatives forming important related activities. *Mekorot* supplies water to a kibbutz as a single unit and the kibbutz management committee, elected annually, is responsible for water use by the various units.

The national water supply network is managed and operated by the government through *Mekorot* which delivers water to consumers on the basis of seasonal and monthly allocations. Since its inception, *Mekorot* continually expanded its activities and at present controls about 67 percent of all water resources of Israel (Ministry of Agriculture 1986). The remainder is controlled by municipalities, settlements and private consumers. The settlements, municipalities and rural villages receiving their water from *Mekorot*, plan and construct the distribution network beyond the government water outlet, and are responsible for deliveries to the individual farmer or consumer. They are committed to supplying the approved bimonthly quotas to consumers and monitoring deliveries. Private wells are also monitored bimonthly by the authorities to ensure that they conform to the allocations.

Water allocation at the farm level is also based on bimonthly quotas to individual farmers. Transfer of water at the village level occurs occasionally between private farms and between farmers in the moshav. Transfer between villages of kibbutzim is uncommon and require the approval of the authorities. Distribution networks are generally concrete-lined steel pipes with an external asphalt covering and are laid about one meter underground. Pipes are designed to withstand at least 6 atmospheres of working pressure. Gate valves and air release valves are installed above ground in order to simplify the maintenance and operation of the networks. Maintenance of networks beyond the government outlet is the responsibility of the kibbutz, moshav or municipality. Regular maintenance is carried out by local staff, but works costing more than US$20,000 are usually constructed by private contractors on the basis of competitive bids and public tenders.

Operation and Management of the Water System

Optimum management strategies for the short-term and long-term use of water resources were determined by combining a systems analysis approach with modelling techniques. Political and economic policies and alternative water allocations are incorporated into the models in the form of targets and constraints. The benefits foregone by using a specific strategy by a particular sector instead of its next best alternative can be evaluated by a model. In this way, the economic costs of constraints are calculated and submitted to the political and economic decision makers.

The integrated planning system is shown in Figure 4 (Frankiel and Goodall 1978). The model has undergone continual improvement so as to include new problems and aspects which were not considered during the earlier stages of the national water plan (such as water quality, salinity and groundwater pollution). The analysis also evaluates the costs of developing alternative resources, using aquifers for storage and controlling the growth of water demand. The objective function maximizes (at various probability levels) the present value of the net benefits resulting from a specific water supply condition. The model also simulates the effects of variable seasonal allocations to economic sectors and regions taking into account different water resources development levels. The economic costs of institutional constraints are determined so that proper weights can be given to them to simulate anticipated levels of production, employment and income in the rural regions. Sample forecasts of allocations, development, storage and deficits for the planning horizon up to the year 2000, as predicted by the model in 1974, are given in Figure 5 (Frankiel and Goodall 1978).

Water Charges

Economic theory in regard to resource use requires that water be priced at its marginal cost, i.e., the extra cost needed to produce another unit of water. In Israel, the price of water has not been dictated solely by economic considerations because of immigration and development policies and the overall pattern of agricultural settlement. Government policies have always determined the amount of agricultural land and water the farmers could have, the region in which farms could be established and, in many cases, the credit terms and prices they receive for part or all of their produce. Consequently, water charges have been considered as one of the factors affecting the whole system.

Water costs in Israel have been ranked into three categories (Kallay 1979) (prices and costs given in this section are for 1992):

a) "Low cost" water: Shallow well water and surface water requiring low conveyance and distribution investments, costing from US$0.10 to US$0.15 per cubic meter.

b) "Moderate cost" water: Deep well water and/or surface water with high distribution and pumping investments, costing from US$0.30 to US#0.80 per cubic meter.

c) "High cost" water: Water pumped to high elevations and desalinized water, costing more than US$0.80 per cubic meter.

Water supply policies are based on three main principles:

1. Conveying water from the areas with plentiful supplies located in the north to the arid and semiarid regions in the south.

2. Developing supplies from a variety of sources in an integrated national plan to meet the anticipated water requirement based on the expected 40–50 year population growth of the country. The developments include the mining of finite aquifer reserves (particularly in the coastal zone), the use of saline water suitable for agricultural production and reuse of treated municipal effluents in agriculture.

3. Ensuring efficient use of water through a combination of allocations, pricing policies and the introduction of innovative technologies for minimizing waste in irrigation and in industry.

In Israel, the cost of water is related to the cost of electricity. The National Carrier starts from Lake Kinneret and requires the pumping of about 300–400 MCM/year with about 360 meters of initial static lift at a cost of about 1.2 kWh of power for every cubic meter delivered. Furthermore, since all irrigation in Israel uses either sprinkler or drip technologies, water supplied to a consumer outlet must be at a pressure of at least 2.5 atmospheres. Consequently, by the time water reaches the furthest and highest delivery points, the electric power expended on each marginal cubic meter of water amounts to about 4 kWh. In 1992, the water system used 1,955 million kWh out of a total production of 24,019 million, i.e., 8 percent of the electricity generated in Israel (Statistical Abstracts of Israel 1993).

The pricing of water to the different sectors is indirectly related to the three levels of development costs described above. The price of domestic water (after the municipalities have added the approved levies for operation, maintenance and waste disposal) is about US$0.7–1.0 per cubic meter. Since domestic consumption of water in Israel is based on an allocation of 100–180 m^3 of water per family per year, the average family spends up to US$150 annually on water (excluding the watering of lawns and gardens). This represents about 1 percent of the annual expenditure of an average family. A family that uses more than its allocation pays about US$1.6 per cubic meter of extra water.

In the industrial sector, while the food processing and paper industries with high water use requirements are sensitive to the cost of water, the "dry" industries such as diamond, furniture manufacturing, tourism, and pharmaceutical and chemical production can easily bear the cost of "medium cost" water. Industrial water has been priced at about US$0.2 per cubic meter for the allocated volume of water, at US$0.4 per cubic meter for the use of extra water up to 10 percent more of the allocation, and at US$0.6 per cubic meter for further water supplies.

Where agriculture is concerned, the water production value of profitable agriculture is generally more than US$0.12 per cubic meter. Hence agricultural water has been priced at about US$0.10 per cubic meter for the first 50 percent of the allocation and at US$0.14 per cubic meter for the remainder. For the first 10 percent addition above the allocation, water is priced at about US$0.26 per cubic meter and at about US$0.5 per cubic meter for further excessive use. Considering that average allocated water use of crops varies from 3,000 to 7,000 m^3 /ha, annual water costs are about US$360–480 per hectare. Only high production can justify these water costs. Cotton farmers, for example, must produce at least 4.5 tons/ha, and citrus farmers 5.0 tons/ha in order to maintain their long-term economic stability. On the other hand, a farm family, without using hired labour, can cultivate 0.3 to 0.4 ha under intensive greenhouse agriculture producing mainly export vegetables or flowers. A greenhouse of this size would use about 5,000 m^3 of water per year and gross annual returns would be about US$45,000. Since the cost of water would not exceed US$600 per year, water costs are not a production constraint.

Below the government outlets, consumer management organizations (municipality, moshav, kibbutz, etc.) are legally obligated to deliver to outlets their monthly quotas as established by the Water Commission. These quotas are promulgated by the Commissioner every year, about two months prior to the initiation of the irrigation season, together with details of the step-function price of water for each use category (agriculture, industry, municipality). This gives sufficient time for farmers below the government outlet to plan their seasonal cropping patterns taking into account both the price of water and the amount of water available to them. Deliveries to the government outlet are monitored by *Mekorot* and deliveries to individual consumers are monitored by the management organization concerned (municipality, moshav, kibbutz). In the step-function pricing system, excessive water use may cost up to three times the price of allocated water.

This built-in financial penalty for overuse of water has proved to be an effective restraint on consumers to remain within their quotas. It has also encouraged users to regard water as a scarce national resource. Farmers, particularly those who use 60 percent of the water resources of Israel, have found that they cannot afford to exceed their allocations if they wish to remain economically viable. The rare occurrences of "water theft" have been brought to court expeditiously. The fines imposed on the culprits have discouraged the practice.

Research and Extension

Agricultural research in Israel has been closely associated with the efficient use of water. The Agricultural Research Organization (ARO) of the Israel Ministry of Agriculture established field research stations in all the climatic regions of Israel so as to deal with local problems. A well-organized and active extension service closely linked to these stations and to the farmers succeeded in: (a) training new immigrants with no previous agricultural experience to become excellent farmers within a decade, (b) developing new irrigation techniques suitable for intensive and extensive irrigation in the private sector and cooperative farming sector, (c) introducing new high-yielding crop varieties which are efficient water users, and (d) encouraging the introduction of greenhouse agriculture, primarily for export flowers and vegetables.

The extension service developed a special methodology for training farmers, which later became known as the "Training and Visit System" and which, over the last two decades, has been adopted either implicitly or explicitly by many developing countries on the recommendation of the World Bank (Benor et al. 1984). Dynamic changes have taken place in the extension service. In the 1950s, extension service officers, usually high school graduates with some general farming experience, could easily keep ahead of the less-educated immigrant farmers. By the 1980s, farmers had acquired considerable experience and many of the new generation held academic degrees. Consequently, the extension service is today staffed by highly qualified personnel with academic specialization as well as practical experience. In 1985, the ARO established a commercial arm (PERI Ltd.) to obtain patent rights, market Israeli knowhow and engage in joint ventures. The income of this company exceeded US$20 million in 1993.

Research and extension have played an important role in the advancement of irrigated agriculture in Israel. Government credit programs encouraged farmers to introduce innovative technologies proposed by the extension services. Most kibbutzim today plan their cropping system using simulation modelling techniques and the irrigation schedules are based on computer programs which take into account soil conditions, plant characteristics and prevailing climatic conditions. In some cases, sophisticated solenoid gate valves are operated by remote control devices that function according to the output instructions of these programs.

The quantity of water allocated to any particular farm unit has never been sufficient to enable all of it to be irrigated. Water has always been a limiting constraint on farmers' income and they therefore endeavour to use this resource as efficiently as possible. The changes that have taken place in the use of water for cotton is a good example of significantly increased water use efficiency. In the 1960s, raw cotton yields were around 2.8-3.3. tons/ha and water use was between 5,500 and 6,500 m^3/ha, with a production efficiency of about 0.5 kg per cubic meter of water. By the 1980s, raw cotton yields had risen to 4.0–4.5 tons/ha and water use had been reduced to 4,000–4,500 m^3/ha giving a production efficiency of 1.0 kg per cubic meter of water. This twofold increase in water efficiency was achieved by combining new irrigation technologies with more water-efficient varieties and improved farm management.

The changes that have been brought about in the commercial fish pond sector is another example of improvements achieved in yield and in efficient water use. In the 1960s, fish grown in shallow ponds (about 1.2 meters deep) produced about 2.5 tons/ha of fish, using about 15,000 m^3 of water per hectare. Water use efficiency stood at 0.17 kg fish per cubic meter of water and fish production was regarded as an inefficient water user.

By 1980, commercial fish farming technology had been transformed. Fish ponds were constructed 2.5–4.0 meters deep and their design took into account fish breeding requirements, polyculture of two or more fish species living and maturing in different depth layers of the ponds, and mechanized feeding and harvesting operations. In order to maintain high levels of dissolved oxygen in the water, drainage water from the ponds is circulated at a rate of about 10–20 l/s/ha and in some ponds the process is accelerated with the use of surface aerators. With these integrated systems, fish yields doubled to more than 5 tons/ha while water use was reduced to about 8,000 m^3/ha. Water use efficiency in the 1980s reached about 0.63 kg of fish per cubic meter of water representing a 370 percent improvement since the 1960s. Furthermore, commercial fish production has become a multipurpose enterprise and the ponds are also useful in other ways: (a) temporary detention of irrigation water for night storage or inter-seasonal storage, (b) storage of winter flood flows that are pumped into the ponds and would otherwise be lost to the sea, (c) after producing a second fish crop in spring, water remaining in the ponds is used for irrigating summer season cotton, (d) saline water which is otherwise unsuitable for agriculture is diverted to the ponds and (e) the ponds often serve as tertiary treatment for domestic sewage.

Since the 1980s, changes have taken place in farmers' incomes in many village communities. With the diversification of economic activities in most villages, only 30–40 percent of the employed residents are now actually engaged in agriculture. The advantage of scale enjoyed by the kibbutzim has allowed them to move into industrial enterprises which offset the economic constraints imposed by their water allocation. On the other hand, the moshavim, because they lack the economy of scale, have been more restricted in their capacity to adjust and many smallholder farmers work outside in various occupations to supplement their incomes.

Greenhouse agriculture is an important aspect of Israel today and many farmers attain record yields. For example, tomato plants are produced in individual pots and can develop as creepers reaching 15 meters in length and producing up to 320 tons/ha. Arab farmers in Israel have also moved from traditional basin and furrow irrigation to sprinkler and drip systems, and many are also greenhouse farmers. It is worth noting that in the last decade, these advances have "crossed the border" into the administered territories and sprinkler, drip and greenhouse schemes are today common features in these areas.

Performance of the National Water Plan

The performance of Israel's Water Plan, assessed in relation to the original target, is briefly reviewed below.

1. Irrigated Areas

The irrigated area has increased from 17,000 ha in 1948 to about 205,700 ha in 1990—a 12 fold increase equivalent to an average 6 percent annual growth rate. At the same time, the agricultural sector advanced from growing labour-intensive, minimum-investment, low-yielding crops to an industrialized high-investment sector based on high-yielding specialized varieties.

2. The "Water Law"

This law and its concomitant regulations ensured continuous dynamic planning and beneficial use of the water resources. It also enabled the government to establish a suitable institutional framework for granting and monitoring seasonal water allocations to all users as well as enforcing compliance with the regulations.

3. Efficient Use of Water

In the agricultural, domestic and industrial sectors, government-sponsored measures minimized waste, encouraged use of effluents, sewage and saline waters and fostered the development of modern technologies for irrigation, such as sprinklers, drip irrigation and greenhouse agriculture.

4. Water Charges

The government water pricing policy gave priority (i.e., cheaper water) to agriculture so as to meet national policy targets. The total revenue resulting from differential water charges covered operation and maintenance costs, part of the investment costs and the cost of disposal of sewage effluents. Pricing was uniform all over the country irrespective of location, in the same way that electric power pricing in most countries is not related to the distance of the user from the power plant. The operation and maintenance of the system has been carried out at a high level of performance. Overall efficiency of the system from water source to plant is high, averaging about 75 percent compared to 10–20 percent for most developing countries (Shanan 1992). Water allocations to farmers (measured at the government outlet) vary from 250 to 800 mm depending on crop variety. Average water use by agriculture (measured at the plant) is about 430 mm per year.

5. Irrigation Network Management

The management of the main irrigation networks is the responsibility of the government. Operation of the main system has been of a high standard and deliveries to consumers were assured and timely according to approved quotas. Consequently, the networks operated by local councils and farmers below the government outlet were also able to assure timely delivery of the approved quotas to the individual farmer. Bimonthly field readings of water meters are punched into hand-held recording computers and the periodical water use record and water bill of each consumer are prepared by authorized service companies. The total cost of meter reading, maintenance and accounting is equivalent to about 0.2 workdays per year per hectare. Regular maintenance work generally consists of replacing damaged or leaky pipes and maintaining gate valves, air valves, pumps, motors, wells and electronic control equipment. In the kibbutz and moshav, work requiring semiskilled labor is usually carried out by a member of the cooperative as part of his regular duties. Maintenance tasks that need specialized skills (electrical, mechanical, electronic or hydraulic) are done under contract work by authorized service companies.

6. Separation of Management of National and Consumer Networks

The management and operation of the national irrigation network are completely independent of the consumer management organizations below the government outlets. *Mekorot*, which operates the national networks, has, for more than forty years, successfully delivered to all its consumers timely and assured supplies according to the seasonal allocations promulgated by the Water Commissioner. *Mekorot* has been able to fulfil its contractual obligations and deliver the quotas at the agreed flow rates and pressures due to both the managerial skills of the operating staff and the numerous backup and on-line storage facilities that have been included in the system. Assured deliveries by *Mekorot* have been the most significant operational success that enabled the independent downstream consumer organizations also to provide timely supplies to individual consumers. These independent consumer-operated networks include flexible compound pipe networks, elevated storage tanks, and on-line reservoirs that facilitate the downstream operation of the system and enable the local management to meet emergency conditions that might arise.

7. Research and Extension Services

Research and extension services have worked in close association with the farmers, continually introducing new crops and high-yielding as well as salt-tolerant and drought-resistant varieties. Because water has been a limiting factor in agricultural growth, crops were, in most cases, evaluated on their yield per unit of water rather than yield per unit of land and farmers were encouraged to plant varieties with high water use efficiency factors. Extension service officers have continually advanced their levels of professional proficiency according to the changing demands of the irrigation sector.

Based on performance indicators recently proposed by the International Irrigation Management Institute (Murray-Rust and Snellen 1993), the National Water Plan of Israel can be assessed as having high levels of performance. Anticipated objectives were fulfilled, targets achieved and the available water resource used efficiently. The overall system management was always accountable for its performance and responded to the continually changing needs of the farmers within the limitations imposed by national policies. The planning and operation of the system were of a high standard and adapted to the potential technological capabilities of the community for which it was designed. The institutional framework established by a Water Law ensured that the management of the system would maintain high levels of performance in relation to equitable water allocation, reliability of supplies and timeliness of deliveries. Network mismanagement and corruption which are common to many irrigation systems in developing countries (Shanan 1992) are absent from the Israeli scene.

Future Problems and Prospects

Israel, like other advancing industrialized countries, faces environmental problems related to agricultural development and urbanization (Wolman and Fournier 1987). Water quality records show that Israel must manage its groundwaters skillfully so as to prevent hazardous consequences developing, particularly in the Coastal Plain. The combination of a shallow phreatic water table, sandy soils, dense populations, and excessive pumping have caused a rise in the salinity and pollution levels of this aquifer. Using the results of simulation models, groundwater abstraction has been controlled and groundwater has been recharged with surface water. The aquifer is being managed carefully so that water quality will conform to acceptable standards.

Economists hold that government policies must be motivated by two objectives—increasing national wealth and improving income distribution. Israel's development programs in the water resource and irrigation sectors have conformed to these aims by using a comprehensive planning process which took into account the limited resources, continually chancing demands, pollution parameters, and social and political variables. Israel has demonstrated that with a democratic structure, planning combined with a political will allows vested interests to compete in a mixed economy and, despite limited resources, enables satisfactory rates of economic growth to be maintained. The Israel Export Institute has reported that all agricultural exports showed an increase from US$55 million in 1962 to US$1,109 million in 1992, with estimates for 1993 at US$1,200 million. The Gross National Product of Israel rose tenfold in 40 years to reach about US$10,700 per capita per year in 1992, equivalent to a mean annual rate of about 6 percent, and it was achieved despite the hostile political situation prevailing in the region.

As the twenty-first century approaches, it is clear that Israel will have to make adjustments to its priorities in water use. With the anticipated increase in population and the expansion of industry, some of the fresh water supplies at present being used by agriculture will have to be allocated to industrial and domestic use. Agriculture will have to adjust its production targets by reducing the extent of the areas at present targeted for relatively high water users (fish ponds, cotton, bananas, etc.) and by replacing them with more efficient water users (sunflower, greenhouse agriculture, etc.) as well as by expanding the program for the re-use of sewage effluents. It is also expected that early in the twenty-first century, the price of desalinized saline water will allow it to become a new economic source of water for municipal and domestic supplies.

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Figure 1. *Schematic topographic cross section of Israel from the Mediterranean Sea to the Rift Valley (Klein 1988).*

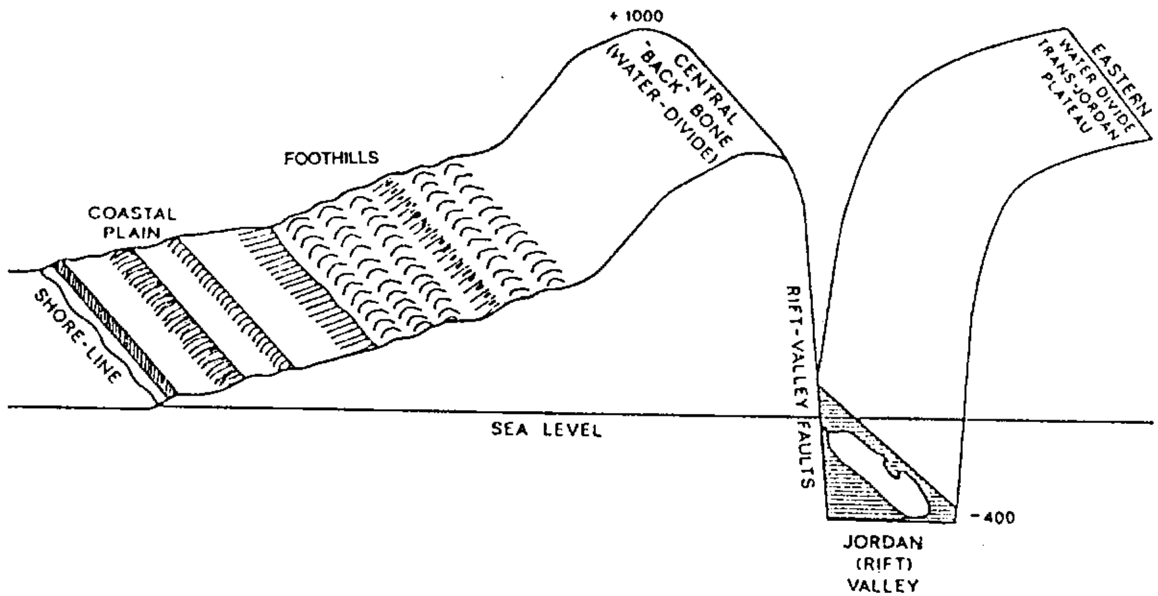

Figure 2. ***Left:*** *Rainfall map of Israel and the Administered Territories. Shading in increments of 200 mm (Israel Meteotological Service 1990). Standard rainfall averages are for 1961–90.*

Right: *Climatic regions of Israel according to the Thonthwaite Moisture Index (after Sadan and Pohoryles 1979).*

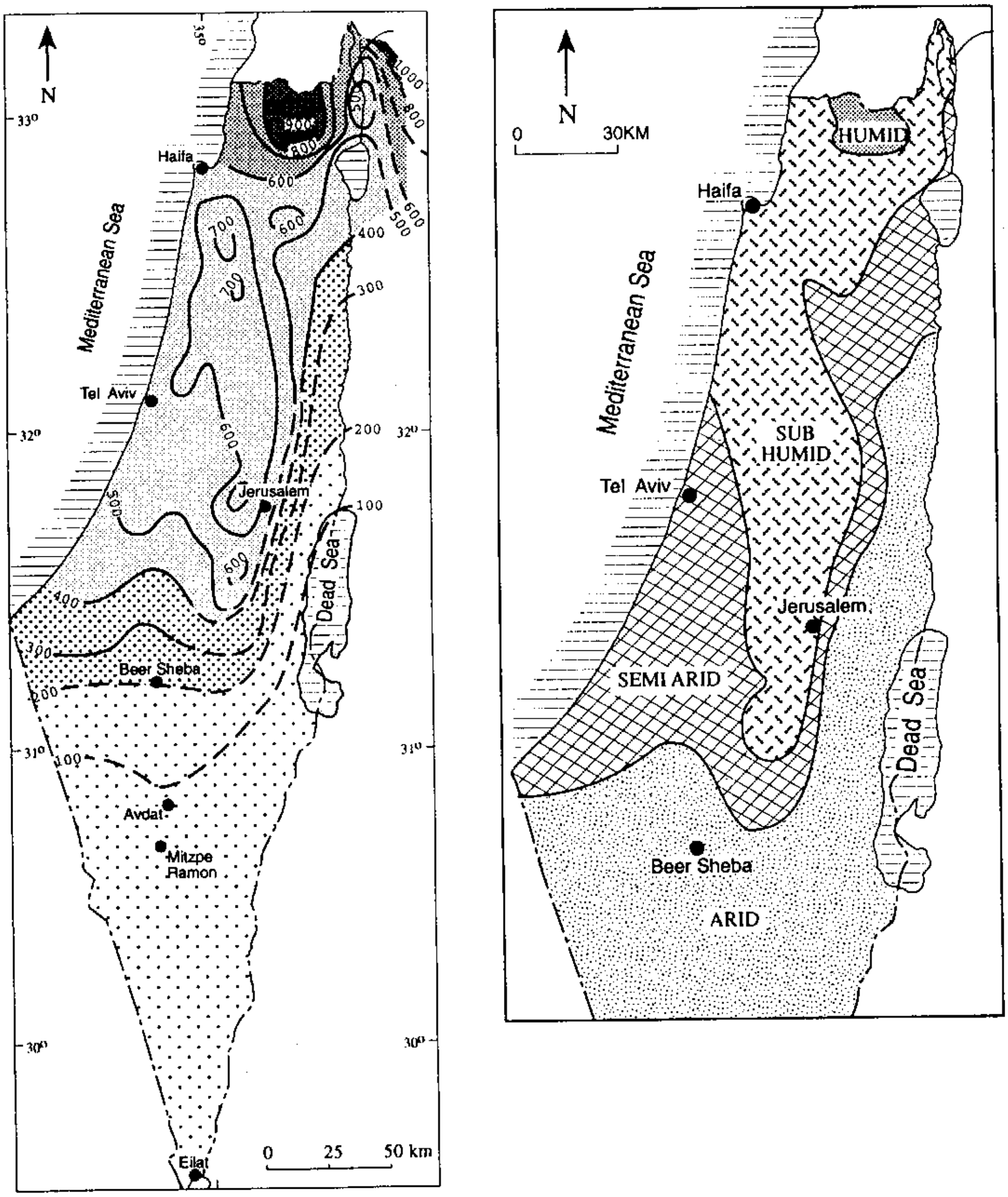

Figure 3. The National Water Carrier and distribution system (after Doron 1993).

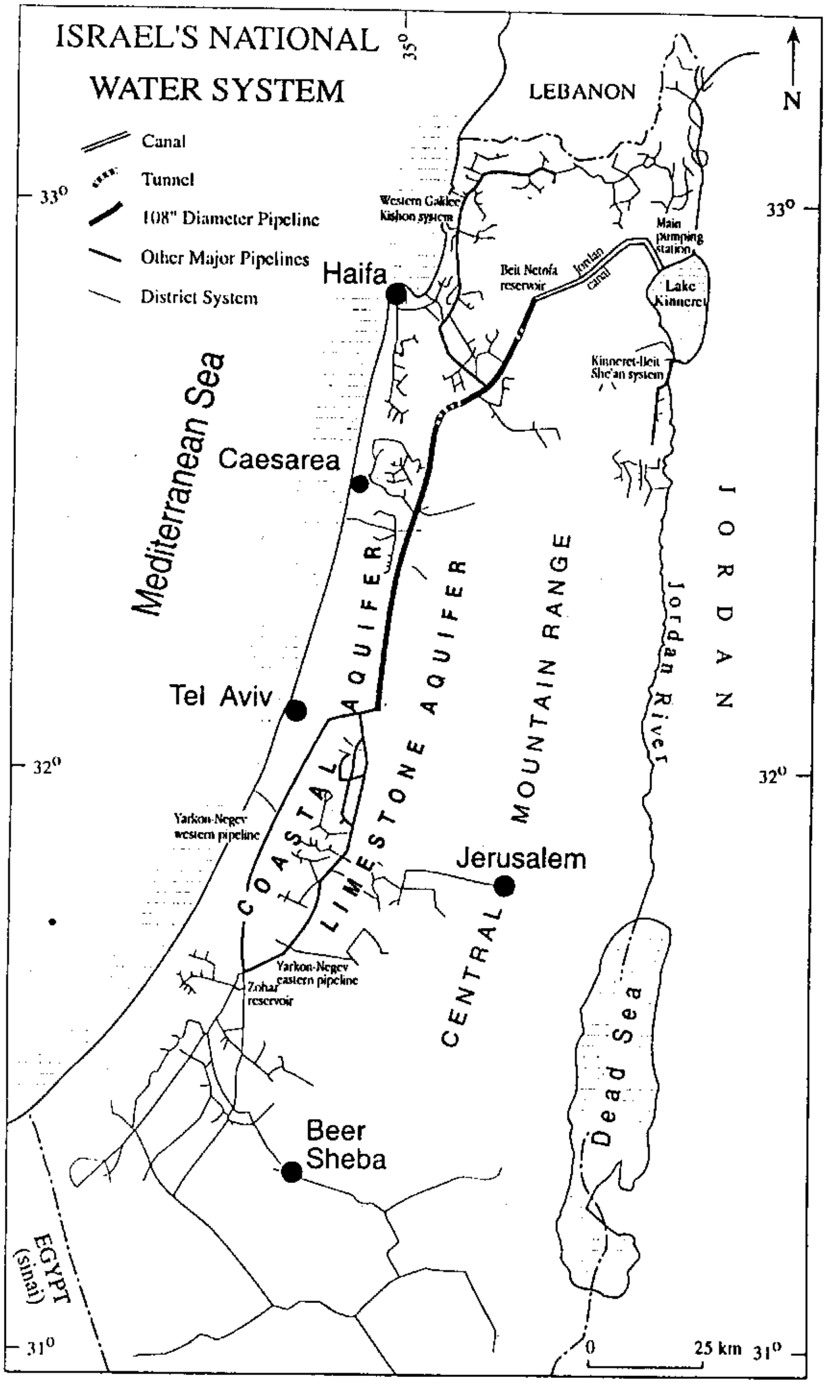

Figure 4. The integrated planning process for Israeli water resources (Frankiel and Goodall 1978).

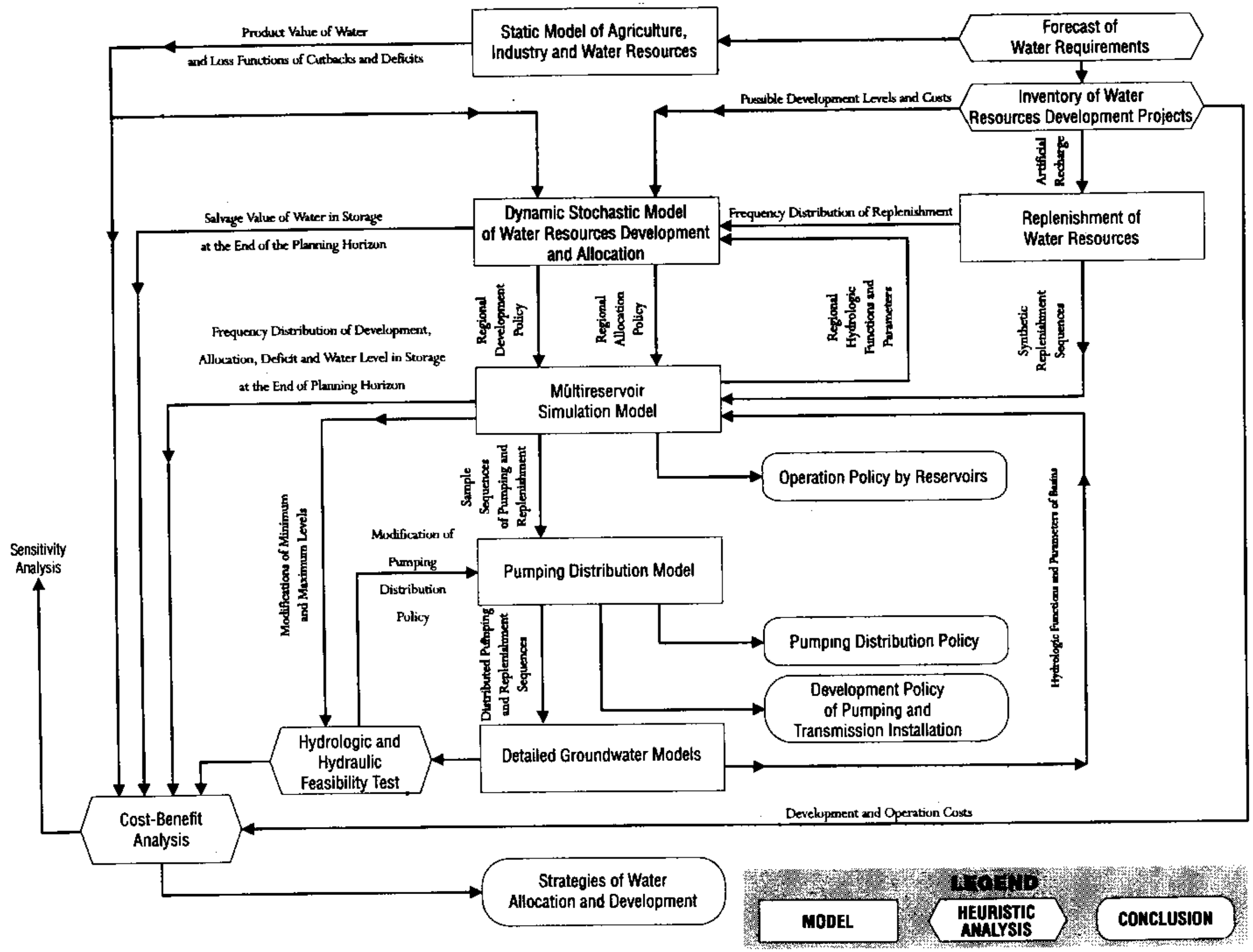

Figure 5. Long-term forecasts from the dynamic stochastic model of water resources development and allocation in Israel (Frankiel and Goodall 1978).

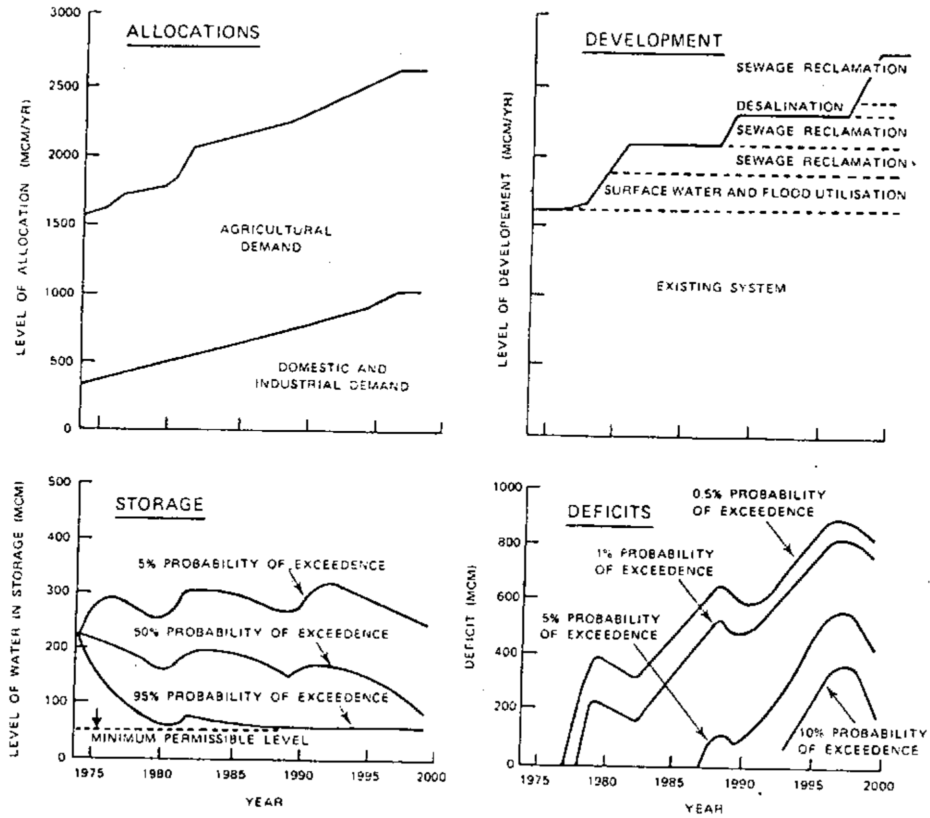

Table 1. Changes in employment in Israel by economic sector (values within brackets are percentages) (from or derived from Statistical Abstracts of Israel, 1993).

	1959–69			1992		
	JEWS	**NON-JEWS**	**TOTAL**	**JEWS**	**NON-JEWS**	**TOTAL**
Agriculture*	97,800 (15)	23,300 (47.5)	121,100 (17.3)	49,300 (3.4)	8,500 (4.3)	57,800 (3.5)
Industry	n/a	n/a	162,900 (23.2)	306,200 (21.1)	42,600 (21.4)	348,800 (21.3)
Construction	n/a	n/a	65,400 (9.3)	68,200 (4.7)	39,400 (19.8)	107,600 (6.6)
Commerce, etc.	n/a	n/a	352,400 (50.2)	1,027,300 (70.8)	108,500 (54.5)	1,135,800 (68.6)
Total	653,400	48,400	701,800 (100)	1,451,000 (100)	199,000 (100)	1,650,000 (100)

* Including forestry and fishing, which together comprise less than 5 percent of the total number employed.

Note: n/a = not available.

Table 2. Present, annual, available water supplies in Israel (Tahal 1988).

Source	Available supply (million m^3)
Groundwater	1,290
Lake Kinneret and Upper Jordan River	500
Lower Jordan River	80
Other surface supplies	40
Reuse of usage	110
Total	2,020

Table 3. Annual demand (in million m^3) anticipated by the year 2000 (Tahal 1988).

Sector	Water resource			
	Fresh	Saline	Treated sewage	Total
Agriculture	740	120	320	1,180
Municipal, domestic and industry	865	40	5	910
Total	1,605	160	325	2,090

Table 4. Changes in the amount of land (in '000 ha) under irrigation in Israel (Statistical Abstracts of Israel 1990, 1993).

	1950		1960		1990	
Cultivated area	248		407.5		437.1	
Cultivated area that is irrigated*	37.5	(15%)	130.5	(32%)	205.7	(47%)

* Includes area of irrigated crops receiving supplemental irrigation.