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PROBLEMS OF AN OVER-DEVELOPED WATER SYSTEM - THE ISRAELI CASE

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INTRODUCTION

Israel is located on the northern edge of the Inter-Tropical Convergence Zone (ITCA) where air masses which ascend in the more humid regions converge to the south and north, and descend. This downward movement of air masses warms and dries them up, resulting in the formation of the largest desert in the world, which extends from the Sahara in northern Africa to Ruba Al Khali in Saudi Arabia (Figure 1).

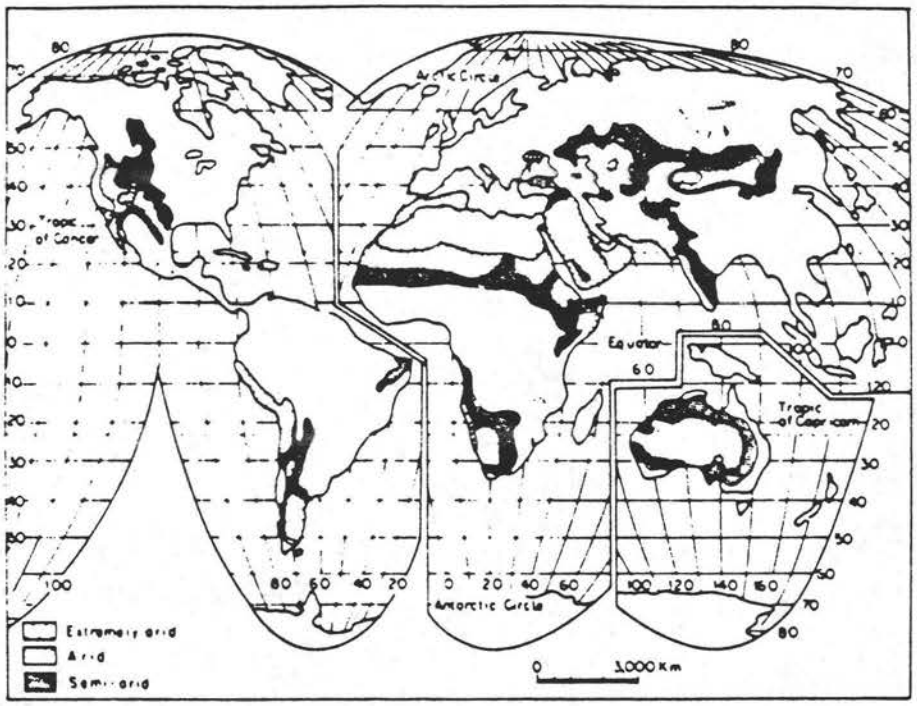

Figure 1. Desert zones of the world (modified from Driscoll, 1986).

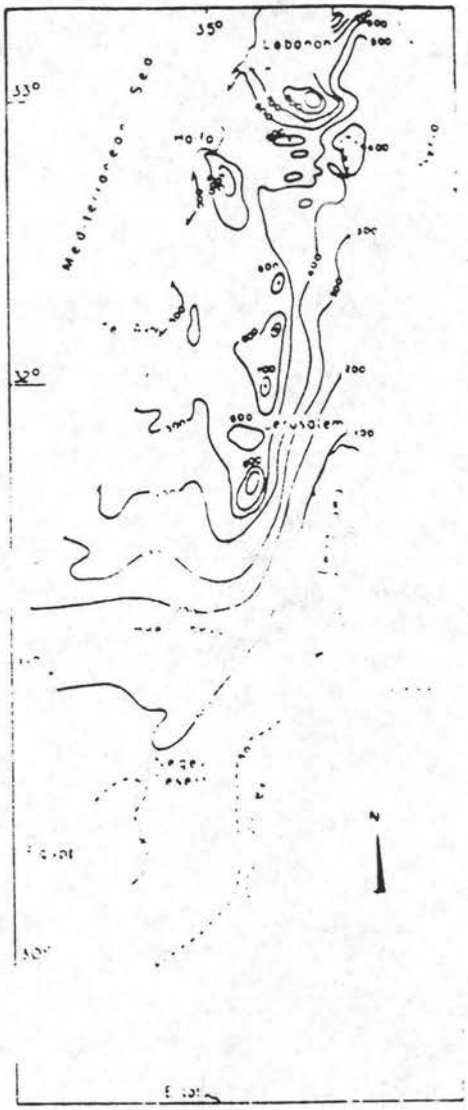

Figure 2. Distribution map of annual precipitation in Israel Grinwald, 1983)

The southern part of Israel, wedged in between north Africa and Arabia is the Negev desert. Annual precipitation diminishes from 200 mm in its northern part to 50 mm in the south, while annual potential evaporation is about ten times higher (Figure 2). The climate in the northern part of the country is of the Mediterranean type, namely, short, humid and cold winters (December to February), and hot, dry summers. Annual precipitation in the northern part of the country ranges from200 to over 1000 mm.

Being on the edge of a desert zone means not only low precipitation but also large variations in the annual precipitation from year to year. Droughts which may extend over a period of years, affect the country from time to time. Archeological, hydrological and palynological findings such as water level of the Dead Sea (Klein, 1982) as well as in the settlement and desertion of the Negev (Issar and Issar, 1987), show that during historical times climatic changes extended over decades and centuries.

At the end of the 19th century, the country was sparsely populated because of difficult climatic conditions and the degeneracy of the Ottoman government system. The hostile environment challenged the young Jewish settlers who came from eastern Europe. They soon learned that in order to ensure a decent and stable income they can not rely on rain water to irrigate their lands; the only way to become independent of the capricious climate was to drill wells and use groundwater for irrigation. Groundwater was, however, costly and in order to make full use of it, intensive techniques of agriculture and advanced systems of irrigation were introduced. During the 40 years since Israel gained its indepenence in 1948, the population of Israel has increased from 0.5 to 4.5 million. Most of this population lives in urban centers spread mainly along the Mediterranean coastal plain; the arid part of the country is still sparsely populated.

WATER DEFICIENCY

Efforts to bridge the gap between water demand and short supply has characterized the country throughout history. Ruins of aquaducts and irrigation projects as well as abandoned water wells are spread all over the country. Modern technology, as already indicated, is based on the pumpage of groundwater, which increases the available water resources and provides storage capacity for drought periods. Current annual water consumption in Israel (mean values for the period 1980-1985) is 1926 million cubic metres (MCM) (1.56 million acre-ft); only 1808 of that amount can be gained back by annual precipitation (Hydrological Service of Israel, 1986). The remaining water supplied is derived primarily by groundwater mining in aquifers which causes their water-table to decline. Several dry years in a row, resulting in low recharge rate, can threaten water quality in the mined aquifers, owing to sea-water encroachment or increasing leakage of underlying brines. Distribution of water consumption indicates that about two-thirds of water is allocated to agricultural activities. The increasing demand for water has brought the water-planning authorities to develop marginal water resources such as brackish groundwater, recycled waste water, and storage of runoff water that would otherwise be lost to the sea. Consequently, the use of lower-quality water has increased, resulting in some places in soil salinization, and groundwater pollution.

WATER SOURCES OF ISRAEL

Three major sources supply most of the water in Israel. The Sea of Galilee, fed by the Jordan River that emerges from the mountains of Lebanon, and by runoff water from the Galilee and the Golan Heights, provides 25% of the total consumption. The Coastal-Plain aquifer, built of sandstone, supplies 26% and the Mountain aquifer, built of limestone and dolomite, another 22% of the total consumption. In addition to the above-mentioned regional aquifers, much smaller quantities of water are supplied from local aquifers built mainly of basalts, chalks, and young alluvial deposits. Small storage dams for flood water and reclaimed waste water were also constructed to help local demand. Table 1 presents the current production from each major water source and compares it to its water potential. Data in Table 1 indicate that the two major aquifers were heavily overpumped during the last years. Following is a more detailed description of the Israeli water-supply system.

The Sea of Galilee occupying 170 sq. km (42 000 acres) is the only fresh-water lake in Israel. During the years 1980-1985, the mean annual contribution of the Jordan River to the lake was 494 MCM. Surface runoff and waste water contributed an additional 216 MCM. The rest came from the direct precipitation, saline springs at the lake bottom, and the Yarmouk River (65, 19 and 18 MCM, respectively). Of the 812 MCM that annually flowed into the lake during this period, 294 was lost to evaporation, about 500 was pumped for water supply and 42 was allowed to flow out into the southern part of the Jordan River on its way to the Dead Sea. The lake is also a major recreation asset as well as a commercial fishing center.

The distribution of major aquifers in Israel is shown in Figure 3. The Coastal aquifer which lies parallel to the Mediterranean coast is built of Pilo-Pleistocene sand and sandstone interfingering with shales (Figure 4). The aquifer is separated from the underlying formations by Neogene shales and marls. Generally, groundwater is unconfined in the sandstone, but, wherever the interfingering shales form a local separation, groundwater may be confined. Natural mean annual recharge into the aquifer amounts to about 219 MCM. Major flow direction is generally toward the Mediterranean Sea.

The Mountain aquifer is built of Upper Cretaceous limestone and dolomite of Cenomanian and Touronian age. Large karstic cavities and channels control the aquifer's high transmissivities. Groundwater in the aquifer is confined in the foothill region (Figure 5), where the aquifer is covered by marls

TABLE 1. PRODUCTION, INJECTION AND OVERPUMPAGE FROM WATER RESOURCES IN ISRAEL

(Mean values for 1980-1985 water quantities are in million cubic metres)

Source	Potential	Pumpage	Injection	Net Pumpage	Discharge	Over Pumpage
Sea of Galilee	455	497	18	497		24
Coastal aquifer	283	433	83	350		67
Mountain aquifer	330	363	23	340	47	57
Lower Cret. to Pal aquifer		30		30		

*Data regarding the Sea of Galilee, Coastal and Mountain aquifers are taken from the Hydrological Service of Israel Report (1986). Data about the Lower Cretaceous to Paleozoic aquifer are from unpublished report of Issar and Levin (1986).

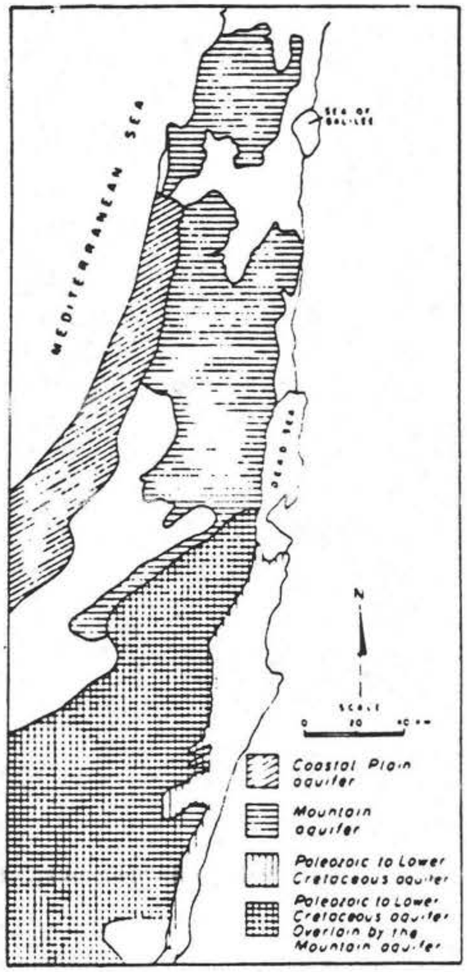

Figure 3. Distribution of major aquifers in Israel (modified from Hydrological Service of Israel, 1986).

and chalks of Senonian age and by younger formations; groundwater is unconfined along the major topographic high of the Judea and Samaria mountains, where the limestone and dolomite outcrop. The aquifer is recharged by direct precipitation (about 350 MCM/yr). In the past, the aquifer discharged to the west, north, and east through freshwater, brackish, and saline springs. The increase in water pumpage from the aquifer reduced the western natural discharge to less than 50 MCM of saline water, about 160 MCM still flow east via springs to the Dead Sea, the valleys of Ysra el and Jordan, southwest below the Valley of Beer Sheva, and north toward Lebanon.

A fourth aquifer underlies the Negev Desert and extends to Sinai. The aquifer is composed mainly of Paleozoic and Lower Cretaceous sandstone and of Jurassic limestone, dolomite and sandstone. The aquifer contains brackish to saline groundwater. Its upper part (in the Lower Cretaceous rocks) is pumped along the Arava Rift Valley for irrigation and near the Dead-Sea area for the mining and chemical industries. The present annual pumpage is about 30 MCM, which is only a small fraction of the aquifer water potential. Water in the aquifer is confined, except for small areas, and is not currently recharged. Consequently, pumpage of water from the aquifer is actually mining of water.

MANAGEMENT OF MAJOR WATER RESOURCES

Since the 1950s the Sea of Galilee together with the Coastal and Mountain aquifers have been operated as one system in order to (1) transfer water from areas of surplus to the drier parts of the country, and (2) to reduce the water losses to the Dead Sea and Mediterranean. Water from the Sea of Galilee is being pumped into the National Water Carrier (NWC) (Figure 6) and is being transferred to central and southern Israel. Water from the Mountain aquifer is pumped and added into the NWC system. During and prior to the winter season, as much water as possible is pumped from the Sea of Galilee into the NWC system, in order to increase the storage capacity of the lake and to reduce the amount of lake water that overflows to the southern part of the Jordan River and to the Dead Sea. Because at winter time less water from the north is needed in the south, water from the NWC is recharged into the Coastal and Mountain aquifers to compensate for the summer overwithdrawals. Alternation between pumpage and overflow operations in

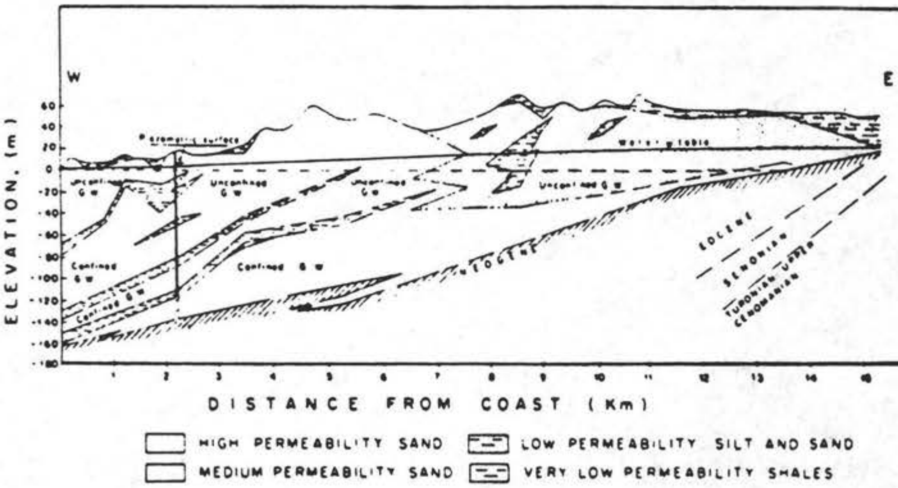

Figure 4. Geological cross section of the Coastal-Plain aquifer, Israel (Bachmat, 1963)

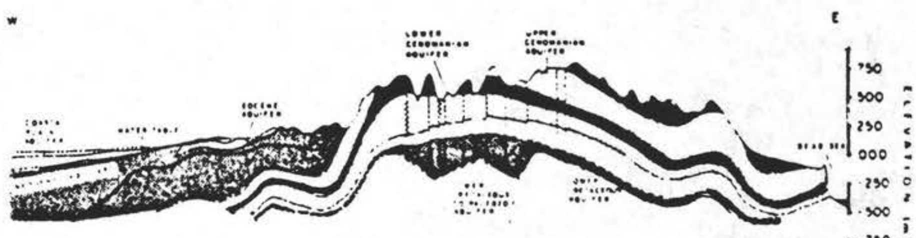

Figure 5. A west-east hydrogeological section throughout the major aquifers of Israel (modified from Grinwald, 1980).

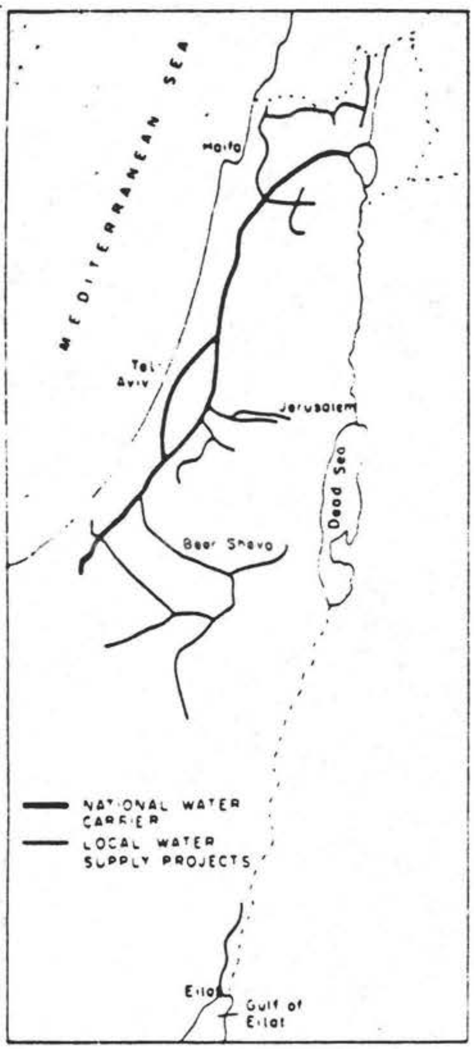

Figure 6. Water supply system of Israel (modified from Yaakobovich and Prushensky, 1975).

the lake is controlled by the minimum lake level of -212 m, required by recreational activities as well as by the location of the pumping stations along the lake shoreline, and the maximum lake level of -209 m, required to prevent flooding of various facilities and cultivated lands adjacent to the shoreline. Thus the resulting operational water storage in this surface natural reservoir is about three metres, which amounts to about 500 MCM (405 500 acre-ft). Because of the uncertainty involved in the forecast of future precipitation and resulting runoff events, more lake water than necessary is often released into the Jordan and the Dead Sea, and by the end of the winter only a fraction of the operational capacity is full. Consequently, only part of the water that could have been recharged into the aquifers is available, resulting in overpumpage from the aquifers, followed by water-table declines.

Supplying water from the NWC and recharging the Coastal and Mountain aquifer by the Sea of Galilee water involves problems of water quality. Chlorinity in the Sea of Galilee water had reached in the past 340 mg/L. The major source of salt to the lake are upwelling brines of up to18 000 mg/L chloride. Saline springs are issuing from the lake bottom and from along the lake coast. Some of the springs along the coast were captured and channeled into a conduit which takes their water south of the lake to the Jordan River. However, springs that emerge at the lake bottom could not be captured and continue to contribute salts to the lake water. The construction of the saline-water conduit resulted in significant decline of lake salinity to current chloride concentration of about 21[illegible] mg/L. Yet, recharging the Mount[illegible] and Coastal aquifers with lake w[illegible] means, in places, adding salts t[illegible] fresher groundwater. Irrigati[illegible] lake water on the coastal pl[illegible] soils, also results in sim[illegible] quence.

Management of pu[illegible] Coastal and Mountai[illegible] trolled by a water balan[illegible] each zone in these aquifers. [illegible] is restricted, as much as possi[illegible] the annual natural and artificial re[illegible] charge. Nevertheless, during the period of 1980-1985, mean annual pumpage and natural discharge in the Mountain aquifer exceeded annual natural and artificial recharge by 57 MCM (Table 1). The excessive pumpage resulted in water-table decline of 0.2 to 0.25 cm/yr. These drawdowns were followed by a significant decrease of discharge in places, mainly south of the Carmel Mountain, and by salinity increase in the central foothills area. Salinity changes may be attributed to leakage of brine from adjacent formations, and sea-water intrusion into the aquifer's karstic channels.

Overpumpage of the coastal aquifer may result in sea-water intrusion, as the aquifer is open to the sea along its entire western boundary. Based on the long-term water balance prepared by this aquifer, mean natural recharge amounts to about 220 MCM, and backflow from irrigation and leakage from supply system is about 120 MCM. On the other hand, the required water flow to the sea to prevent sea-water encroachment is about 60 MCM, thus, leaving only about 280 MCM for potential pumpage. Considering salinity constraints, the available water for pumpage is only about 240 MCM (Bachmat, 1980). However, during the period of 1980-1985 over 430 MCM of water was pumped annually, only 83 MCM was artificially recharged, resulting in excessive mean annual pumpage of 67 MCM of water. During cert[illegible] years annual overpumpage ex[illegible]0 MCM, resulting in water-l[illegible]1 to 0 15 m/yr and [illegible]t of sea water by [illegible] water-table [illegible]d along [illegible]and [illegible]is [illegible]ates [illegible]quifer [illegible]area of [illegible]ural and inc[illegible]ed above it. Becau[illegible] only a few metres dee[illegible]ter contamination evidence[illegible]creasing nitrate concentrations is common. Artificial recharge of recycled wastewater also adds to the contaminants load. Water salinity and contamination will probably increase in these isolated depressions, caused by overpumpage, because flushing of salts and contaminants by groundwater flow into the sea does not occur.

The management of the three major water resources of Israel as one hydrological system, as indicated above, guaranteed a steady water supply and

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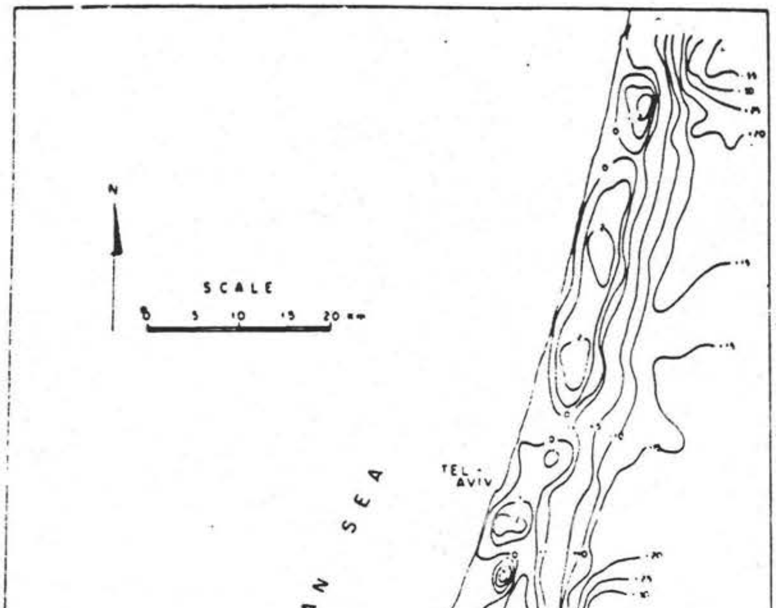

Figure 7 Water level map of the Coastal aquifer, Israel, 1985 (modified from Hydrological Service of Israel, 1986).

the development of the more arid parts of Israel. Yet, a few years of drought, as well as the increasing urban demand for water, indicated that this system is not capable to expand much further to supply expected water needs toward the end of the century, not to speak beyond the year 2000. The main reason is that the system lacks ample long-term storage capacity to bridge the gap between years of abundance and periods of want. In other words, while the long-term storage need to guarantee the basic supply is in the order of magnitude of 4000 MCM, the available storage in all surface and subsurface reservoirs is about 2500 MCM. The presence of this gap means that in dry years, groundwater will have to be mined, whereas during affluent years water will flow to the Mediterranean and Dead Sea rather than be stored.

DEVELOPMENT OF MARGINAL WATER

Because no more readily-used water resources were available for development, efforts to increase water potential has led to study and exploitation of marginal water resources. These include treating wastewater, storing runoff water and the use of brackish water.

Recycling of wastewater can add up to 250 MCM of water for irrigation, thus releasing fresh water for domestic use. Major drawbacks of this water source are the high expenses involved in treating wastewater and the dual piping system required to distribute it separately from potable water. The treatment of sewage of Tel-Aviv areas is a major effort to develop this water resource. Currently about 60 MCM are treated annually. It is planned that by the end of the century about 120 MCM of wastewater will be treated. The treated water is recharged into the Coastal aquifer; it is then pumped and transferred by a special pipe line to the northern Negev. Chlorinity of the water ranges from 200 to 250 mg/L and is similar to the Sea of Galilee water provided by the NWC. Based on its chemical quality, this water can be graded as potable water, however, it will be solely used for irrigation. In addition to this regional project, there exist other local plants such as in Ysra'el Valley, where treated wastewater is mixed with runoff and brackish groundwater and is used for irrigation.

More than 260 surface reservoirs were constructed alongside of or on ephemeral streams to harvest flash-flood water that could otherwise get lost (Figure 8). Usually, these reservoirs contain also treated wastewater. Their typical volume ranges from 100 000 to 500 000 cubic metres, and their total capacity amounts to about 100 MCM. Water losses out of these reservoirs through leakage and evaporation are a major hindrance to the effective use of the water. One of the attractive features, however, is their dilution capacity which allows for the addition of low-quality water, thus increasing the available water quantity for use.

Saline and brackish water (dissolved solids content of 1000 mg/L separates fresh from brackish water, whereas

Figure 8. Reservoirs for storage of runoff-water and treated wastewater (modified from Grinwald, 1980).

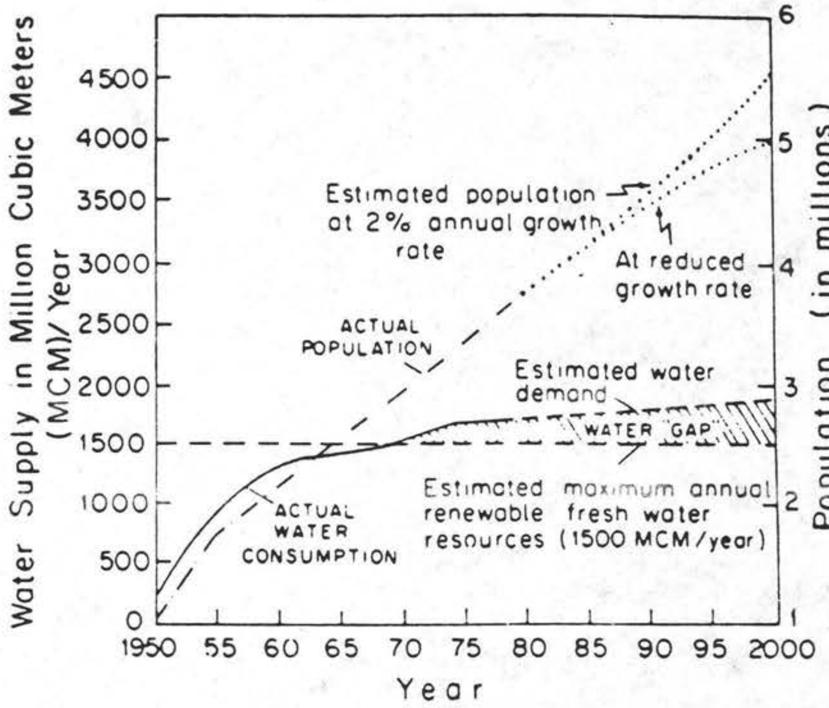

Figure 9. Estimated population growth and water demand in Israel in the year 2000 (Shuval, 1981).

4000 mg/L of dissolved solids separates brackish from saline water) occurs throughout Israel in various locations and aquifers. In northern Israel, saline and brackish water occurs primarily in deep aquifers and as springs. The salinization mechanism of some of these springs such as the Sea of Galilee saline springs, or the Tanninnim Springs (which form the western natural outlet of the Mountain aquifer), is not yet clear. In both instances, a better understanding of the salinization mechanism is essential for its management. The most effective salinity management can be achieved by groundwater pumpage upstream the springs, as well as by manipulations of the Sea of Galilee lake levels. In southern Israel, most groundwater is brackish to saline, including water in shallow aquifers. Brackish groundwater is used directly by the Dead Sea industries (18 MCM) and for irrigation in the Arava Valley (12 MCM), and is partly desalinated (by reverse osmosis) for domestic use for the City of Eilat. Water potential of brackish groundwater in northern Israel amounts to about 230 MCM, however, in southern Israel, its potential is much greater and amounts to billions of cubic metres located in the Lower Cretaceous toPaleozoic rocks sequence. This major water resource is used only to a small extent relative to its potential as indicated above.

POTENTIAL SOLUTIONS FOR WATER DEMAND

As shown in Figure 9, the gap between demand and availability of resources will increase in the future. Thus current trends of overpumpage of fresh water in aquifers will become more crucial, especially during long spells of dry years. This problem can be solved in several directions:

(a) By cutting water allocation for irrigation. Because over two-thirds of the national water consumption is used in agriculture, a reduction in water allocation to this sector will reduce the water shortage.

(b) By increasing the efficiency of irrigation systems. Though farmers in Israel use water efficiently, and during the last twenty years production has increased by a factor of 4 with the same amount of water, there is yet still room for innovations.

(c) By developing all potential brackish water in northern Israel (230 MCM). This will involve the problem of combining brackish water into the fresh-water system. This can be accomplished by either changing water quality standards throughout the entire system, or by the allocation of low-quality water to a specific sector such as agriculture. It seems that the second alternative is more feasible.

(d) By developing brackish water in the Nubian Sandstone aquifer in Lower Cretaceous to Paleozic rocks in the northern Negev. This will reduce the amount of NWC water used in the Negev, and alternatively will enable the use of this water for aquifers recharge in the central part of the country. Brackish water in the Negev can be used directly, or after dilution with recycled wastewater from central Israel, that will be carried into the area via the wastewater carrier which is presently under construction, thus increasing its quantity and quality. As stated previously the Nubian Sandstone aquifer is not currently recharged, but the vast amounts of water stored in it will suffice for many years, if properly managed.

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Preference of one alternative over the others is not a technical hydrologic issue, but an economic and political decision, as long as water prices are controlled by the water authorities of Israel. Both alternatives (c) and (d) offer not only a substantial increase of water amounts for use, but also include the long-term storage reservoir which is currently absent in the water-supply system.

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