Development of Limited Water Resources: Historical and Technological Aspects

October 2000

by Dr. Dov Sitton

Applied Research Institutes, Ben-Gurion University of the Negev

Historical background

". . . and the scorched land will become a pool, and the thirsty ground springs of water" (Isaiah 35:7)

Scarcity of water has always been the dominant factor in agriculture throughout most of the arid Middle East, with its population relying on scanty and erratic seasonal rains or on rivers for their water supply. In Egypt, for example, the Nile was the only stable source of water in an otherwise desert landscape. In ancient times, sustained agriculture was limited to narrow strips of land on either side of the river. Even today, farming in Egypt is localized mainly along the banks of the Nile.

The climate of present-day Israel is strongly affected by the proximity of the desert to the south and east. Most of Israel's territory is classed as arid (60%) or semi-arid. Rain falls only in the winter, mainly between November and March. Average annual rainfall ranges from 400 to 800 mm. in the northern and western parts of the country and declines sharply toward the south and east. A dry season with practically no rain prevails from about the beginning of April to the end of October.

Until the beginning of the 20th century, agriculture in the Land was almost entirely rainfed, and therefore was limited to the northern part of the country and the coastal area. In some northern localities, where spring-water was available, fields were irrigated. The water was conveyed by gravitation from the source to the fields in open dirt canals. Each farmer was supposed to get his share of water for several hours once every few days or weeks. However, due to heavy loss of water along the transportation route - resulting from fast percolation into the ground - the water was distributed unevenly, and farmers furthest from the source were left with little water. Along the coast, underground water was raised from shallow wells with the help of 'norias' (bucket-type water-wheels) driven by donkey or ox. The water was collected in a pool and from there conveyed by gravitation to adjacent plantations (mainly orange groves). Such wells were dug manually and the output was low.

The notion that agriculture requires a reliable water supply began to take hold only at the end of the 19th century and the beginning of the 20th century. This revolutionary change in attitude was introduced to the area mainly by the Jewish settlers, who were ready to adopt advanced technologies and know-how. Such technologies were introduced by immigrants with specialized skills and professional training. Among them were people experienced in advanced methods of drilling through hard layers of rock and pumping large quantities of water from deep wells.

The role of irrigation in advanced agriculture

The use of irrigation in traditional farming is hampered by several constraints:

- Sources of water, especially under arid and semi-arid conditions, are usually very limited in quantity and are not readily available.
- Water is conveyed to the fields in canals by gravitation, which means that the ground needs to be leveled. Hilly terrain and slopes, therefore, cannot be irrigated by this method.
- The traditional practice of constructing dirt canals results in considerable loss of water due to percolation of water into the soil. The longer the canals, the larger the loss.
- The supply of water declines along the line of distribution, leading to unequal sharing of the limited resources.

Another disadvantage of traditional irrigation is that the water supply is inevitably irregular, resulting in an inability to meet the needs of the crops and thus in poor yields.

In view of the circumstances prevailing at the turn of the 20th century in the area, notably the predominance of dry farming with its almost exclusive reliance on seasonal rains, the introduction of new concepts into agriculture involved not merely technical changes but also profound modification of the strategy and scale of agricultural progress.

Two main elements are responsible for the passage from traditional to modern water utilization in agriculture: the human factor, and the introduction and use of newly imported technologies.

Following the establishment of the British Mandate at the end of the First World War, many Jewish immigrants came to Palestine, mainly from Europe. Many of their number were highly motivated and keen to establish new agricultural settlements. They were inclined to examine and apply new agrotechnologies, they understood the significance of modern know-how based on scientific studies, and they were eager to take advice from scientists and professionals. But perhaps the pivotal factor in their success was their ability to join together and establish organizations for the purpose of raising funds, formulating policies, and drawing up plans for physical development. All these efforts culminated in the 1920s and 1930s in the establishment of a large number of new agricultural settlements.

As part of the settlement movement, geologists led by Prof. L. Picard (who immigrated from Germany in 1924) were recruited to search for underground water. Modern drilling equipment capable of drilling to great depths through hard rock layers, efficient pumping machines and newly introduced materials such as cement and metal pipes were all enlisted to help develop dependable systems of water supply. However, beyond these technical efforts, the challenge was met by radically modifying the concept of what an adequate water supply should be.

As mentioned earlier, rainfall in Israel is limited to winter and declines from north to south and from west to east. Furthermore, total annual rainfall fluctuates considerably, drought years being frequent. Planning and building a reliable water supply system must take these constraints into account; that is, it must assure bridging between seasons (winter and summer), regions (north and south), and years (with adequate and inadequate precipitation).

Thus, in the early stages, settlements joined together on a local basis, invested money to search for underground water, and succeeded in providing a more or less uninterrupted water supply.

Later on, a broader view of the problem of water supply was adopted. The first concerted effort to build a large-scale project was in 1935. The leaders of this project were Levi Eshkol, later Prime Minister of Israel, and Simcha Blass, an engineer who became prominent in the design and development of all the main water projects in the country. The project was designed and carried out between 1935 and 1938 by Mekorot, the newly established public water company. The water came from three wells drilled into the western flanks of the valley of Jezreel. The main features of the project were:

- Conveyance of water in metal pipes under high pressure, allowing uninterrupted supply over long distances. The high pressure made it possible to irrigate the fields with sprinklers, superseding traditional flood irrigation.
- Incorporation of two concrete tanks and two open reservoirs, instrumental in providing a constant water supply. The water was pumped into the reservoirs at night, when the cost of electricity was relatively low; thereafter the water was channeled into the irrigation system without interruption.

The issue of water resources availability and the potential for further development of advanced systems to provide adequate supply was not merely an academic or technological question. It also had political implications. Indeed, national rights to the land lay at the heart of the conflict between the Jewish and the Arab communities. British government policy was to place restrictions on the purchase of land by Jews, establishment of new settlements and also on immigration to Palestine, based on the argument that physical conditions prohibited further growth of the existing population. One of the measures taken by the leadership of the Jewish community to counter British policy was to demonstrate that, with proper development, the land could sustain a much larger population. Hence, considerable effort was invested in conceiving and designing water projects.

Water supply projects

In the late 1930s it was accepted by the leading figures in the field that the following principles should guide future water projects:

Planning

- Any system developed to provide water should bridge between areas where water is available and those where it is in short supply, as well as between the rainy and the dry seasons. Therefore, water from rivers, floods and springs should be stored in reservoirs, underground aquifers and tanks for eventual conveyance in supply lines according to needs. Also, water surplus from rainy years should be stored for use in dry years.

- Water should be conveyed under pressure in pipes. While requiring substantial financial input, this approach circumvents topographic limitations and minimizes water losses, thus promoting long-term water saving. It also guarantees balanced and fair distribution among end users.
- Planning should be comprehensive. That is, the water projects must convey water all over the country to meet the needs of the growing population and of extensive agricultural development, especially in the Negev, the southern region of the country (the scarcity of rainfall characterizes the Negev region as arid land).

From 1939 onwards, several plans for conveying water to the Negev were drawn up, mainly by Simcha Blass. A comprehensive study entitled, "Water resources in the Land of Israel: prospects for irrigation and hydro-electric development" was prepared by Mekorot in 1944, and at about the same time, experts on water and land conservation from the US became involved in studying and presenting schemes for water projects. W.K. Lowdermilk, a highly reputed American expert on soil conservation and hydrology, published a book ("Palestine - Land of the Promise") on the possibilities of developing water projects in Palestine, also in 1944. In the same year, J.B. Hays, an American expert on dams and water conservation, visited the country to examine the prospects for planning a water project. His book, "Tennessee Valley Authority of the Jordan," was published a few years later. Hays continued his studies after the establishment of the State of Israel (1948) and presented several versions of a master plan for the development of irrigation and hydroelectric power. He was later joined by his colleague, J.S. Cotton, who submitted a master plan in 1955 that was eventually adopted by the government and served as the blueprint for the planning and construction of the National Water Carrier.

Construction

As part of a drive to settle the Negev, the arid southern region of the country, three experimental settlements were established in 1943. The aim was to explore soil conditions in the region, the availability of water (including data on annual precipitation), and what crops could be cultivated under prevailing conditions. Another eleven settlements were established in the Negev in 1946 and a further five in 1947, equipped and financed as before by the Jewish national institutions.

From the very start, it was clear that in the Negev the main limiting factor from the standpoint of agriculture was the scarcity of water. The awareness that successful modern agriculture hinged upon irrigation, which required a reliable supply of water, led to the launching of a series of exploratory studies. These included meteorological, geological and hydrological surveys. Attempts were made to drill wells and draw underground water near the settlements; however, the quantities obtained were small, and the salinity of the water was often too high for agricultural use. Attempts to build dams and reservoirs to collect seasonal floodwaters failed because of the large fluctuations from year to year in the quantity and intensity of the floods, as well as technical difficulties. Eventually, it was concluded that the only way to secure a dependable and sufficiently large supply of water was to transport fresh water from northern sources via pipes.

The first 'Negev pipeline', became operative in 1947 and assured a reliable if limited supply of water to most of the settlements in the Negev (although several settlements still had to rely on local wells). This modest pipeline transported water from wells in the northwestern Negev, an area relatively rich in underground water. The first stage consisted of 190 km. of 6"-diameter pipes supplying one million cubic meters (MCM) annually. Later on this line was converted to a 20"-diameter pipeline supplying 30 MCM annually. The significance of this pipeline was that the concept of transporting water from farther north to sustain the southern arid section of the country was now firmly established.

This pioneering endeavor was followed by two large-scale projects to supply water to the Negev. The first was the 'Yarkon-Negev pipeline', constructed soon after the establishment of the State. This 66"-diameter pipeline transported 100 MCM of water annually from the Yarkon River to the Negev over a distance of 130 km.

Although this was an ambitious project in terms of the means available at the time, it soon became clear that a larger and more comprehensive system was necessary. This perception culminated in a second large-scale project, the ambitious National Water Carrier. The main function of the Carrier was to convey water to the southern region of the country from the Sea of Galilee (Hebrew, Yam Kinneret, Lake Kinneret) in the north. The original plan was to draw water from the Jordan River before it entered the lake. The first stages of the groundwork began in 1953. However, because of strong opposition by Syria and a United Nations resolution, Israel was forced to suspend work and modify the initial design. The final plans were approved in 1956, and the National Water Carrier was completed and functioning by 1964. The Carrier is a combination of underground pipelines, open canals, interim reservoirs and tunnels, supplying about 400 MCM annually. Water from the lake, located some 220 m. below sea level, is pumped to an elevation of about 152 m. above sea level. From this height, the water flows by gravitation to the coastal region, whence it is pumped to the Negev.

In addition to the Sea of Galilee, two large aquifers, the Mountain Aquifer and the Coastal Aquifer, contribute some 350 MCM and 250 MCM respectively, to the Carrier each year.

The National Water Carrier functions not only as the main supplier of water, but also as an outlet for surplus water from the north in winter and early spring, as well as a source of recharge to the underground aquifers in the coastal region. Most of the regional water systems are incorporated into the National Water Carrier to form a well-balanced network in which water can be shifted from one line to another according to conditions and needs.

Supply and demand - management of limited water resources

The fresh water resources of Israel, which average about 2,000 MCM annually, are already being exploited to the limit. However, the country's population is growing constantly, and so is the demand for water. Urgent measures must be taken to provide additional quantities of water. An important potential source is marginal water, a category that comprises effluents, saline water and seawater. Adequate treatment - purification in the case of sewage water and desalination for saline water and seawater - can provide the much-needed extra water.

Sewage water

Increasing quantities of sewage water have been finding their way into the environment, endangering groundwater and other sources of fresh water. The pressing need to find alternate sources of water, together with the critical condition of the environment, led the Water Commission to set up the Shafdan plant, a large-scale project for processing sewage to produce highly purified water. This procedure results in two major benefits: the aquifer serves as an underground reservoir for the recharged water - preventing losses by evaporation - and water is pumped off when needed, mainly in summer; percolation of the water through soil layers provides an additional cleaning phase.

About 110 MCM of this purified water is transported annually via a separate pipeline called the 'Third Negev Pipeline' to the western Negev for use in irrigation. Thanks to the high degree of purification of the treated water, it can be used for all crops without risk to health.

Additional sewage water purification plants are already under construction or on the planning boards. It is expected that most of the water allocated for agriculture will eventually consist of purified effluents, so that quality fresh water can eventually be shifted from agricultural to domestic uses.

Smaller-scale plants all over the country provide treated sewage water for irrigation of fields located a short distance from the source of the effluent. In many cases treatment is minimal, and use of the treated water is restricted to crops such as cotton in the summer. However, small projects of this type are reported to be highly cost-effective.

Saline water and seawater

There are two categories of water available for desalination, saline (brackish) water and seawater. Desalting of seawater is costly, owing to the high concentration of salts. Therefore, efforts to develop a cheaper process are currently focusing on saline water. In the long run, however, seawater will also have to be used as a source of potable water.

Several methods for desalting saline water have been investigated in Israel since the early 1960s. Among these, reverse osmosis has been shown to be efficient and relatively inexpensive; however, today it costs about 25% more to produce potable water by reverse osmosis than to purify sewage water.

The leading desalination project is located near Eilat, a city on the Red Sea at the southern tip of Israel - the driest region of the country, with negligible amounts of precipitation. The population of Eilat is about 40,000 plus an annual influx of some 500,000 tourists. Until 1997, all the drinkable water supplied to Eilat was obtained from desalination of underground brackish water. The desalinated water is produced by reverse osmosis in two plants with a combined output of about 36,000 cubic meters per day (about 13 MCM annually). As a result of the ever-increasing demand for a reliable supply of drinkable water, a third unit for seawater desalination was added to the already existing units (the water is pumped from the Red Sea). At present, the annual output of this unit is about 3.5 MCM.

Desalination of saline water is preferred to desalination of seawater, since the energy required to produce drinkable water from saline water is 0.8 to 1.0 kWh per cubic meter, and 73% of the water input is recovered, while the energy required for desalination of seawater is about 3.85 kWh per cubic meter, and only 50% of the water input is recovered. However, underground saline water is spread over relatively large areas and the availability of this water in the vicinity of Eilat is limited. The supply of seawater, on the other hand, is infinite. Therefore, future production of desalinated water will have to rely mainly on seawater.

In addition to assuring an important additional source of potable water, the development of an efficient method of desalination will help reverse the current and dangerous trend towards salinization of the fresh-water aquifers, including the crucial coastal aquifer.

To a limited extent, untreated saline water is already being put to use for crop irrigation. Many studies have been carried out to investigate whether saline water can be used to irrigate crops. It was found that certain crops such as cotton, tomato and melon readily tolerate saline water (up to 7-8 dS/m electric conductivity, equivalent to salinity of 0.41-0.47 % NaCl). However, to minimize accumulation of salts around plant roots and facilitate leaching away of those salts that do accumulate, it is essential a) to use drip irrigation systems to deliver the saline water and b) to cultivate the plants in a soil-less medium or in light soils (sandy or loamy-sandy soil). In the case of these tolerant crops, the use of saline water can result in the saving of fresh water.

Advanced methods of irrigation

In Israel, the agriculture sector is the major consumer of water. Thus, in order to curtail the total water consumption, the amount of water allocated to agriculture has been subjected to a number of restrictions, especially since the early 1990s. From a total consumption of 2,008 MCM in 1997, 1,264 MCM (63%) was used for agriculture, as compared to the situation in 1985 when water consumption for agriculture was 1,389 MCM out of a total of 1,920 MCM (72%). There is no doubt that efficient use of water for irrigation is a paramount priority.

One of the most important agrotechnological innovations is probably the invention in Israel of drip irrigation by Simcha Blass and his son (the father conceived the idea, the son developed the dripper).

Drip irrigation has many advantages over other irrigation methods:

- Water is discharged uniformly from every dripper fitted onto the lateral pipe. This is true even on moderately sloping terrain. Furthermore, the development of compensated drippers enables uniform irrigation on steeper slopes and the ability to extend laterals with drippers over greater distances.
- Via the drippers, fertilizers can be supplied to the plant together with the water ('fertigation').
- Water and fertilizers are delivered directly to the root system rather than to the total area of the field, thereby economizing on both water and fertilizers.

- The quantity of water delivered can be optimized to fit different soil types, avoiding percolation of water beyond the root zone. Furthermore, sandy soils, which cannot be watered by furrows or by flooding, can be efficiently irrigated with drippers.
- The emergence of weeds is minimized.
- Between the planted rows the dry ground facilitates comfortable access in the field for workers and machines throughout the season.
- Exploitation of poor quality water (saline water or effluents) is made possible because:

1. Drip irrigation, unlike sprinkler irrigation, makes it possible to utilize saline water. This is because direct contact between water and leaves is avoided, thus obviating burns.
2. Drip irrigation causes salts to be continuously washed away from the root system, avoiding salt accumulation in the immediate vicinity of the roots. This is important when irrigating salinized soils or irrigating with saline water.
3. Drip irrigation allows the use of minimally treated sewage water because the water is delivered directly to the ground, minimizing health risks.

- Drippers with a given discharge of water (of the order of several liters per hour) can be installed at any spacing to accommodate the needs of any crop.
- Drip irrigation is the most efficient method of irrigation when it comes to water saving. Since the drippers emit the water directly to the soil adjacent to the root system, which absorbs the water immediately, evaporation is minimal. This characteristic is especially important under the conditions prevailing in arid zones. In irrigation by sprinklers or by surface methods, evaporation is enhanced by winds, while in drip irrigation the impact of winds is minimal.
- High-quality drip irrigation equipment can last for fifteen to twenty years if maintained properly.

Water use efficiency (WUE) is defined as the ratio between the amount of water taken up by the plant and the total amount of water applied. Studies show that drip irrigation has a WUE of about 95%, versus 45% for surface irrigation and 75% for sprinkler irrigation. To sum up, then, it may be concluded that drip irrigation has many advantages over other methods of irrigation, and that it is also superior to surface and sprinkler irrigation in regard to water saving, especially under conditions of limited water supply.

The Current situation

In recent years, the water supply in Israel has reached a stage of critically fragile balance between supply and demand as a result of several factors:

- A sequence of drought years, resulting in inadequate replenishment of water reservoirs (both surface and underground aquifers) in combination with over-pumping of the already dwindling water reserves.
- Rapid increase in population due to immigration (from 4.8 million in 1990 to 6.3 million in 2000 - 31% increase in 10 years), leading to increased water consumption for domestic use.

- Hesitation and lagging of policy-makers to allocate proper financial resources for much needed large-scale projects of reclamation and purification of urban sewage water and construction of plants for desalination of seawater.

Conclusions

This review describes how the constraints of limited water resources and an arid and semi-arid environment were overcome by a leadership capable of defining future needs and identifying and implementing appropriate solutions. Advanced technologies proved indispensable in this process. Yet, in recent years, the continuously increasing demand for water, mainly for domestic use, has created a chronic situation in which all available water from natural sources is being used up. The only solution to ensuring a dependable supply of water for both domestic and agricultural use requires that several steps be taken concurrently to implement regulations and measures for saving water and to construct immediately large-scale plants for desalination of seawater and reclamation of urban effluents.

Applied Research Institutes
Ben Gurion University of the Negev
Be'er Sheva
Tel: (972)-7-646-1967
Fax: (972)-7-647-2984
e-mail: dsitton@bgumail.bgu.ac.il