Annals of Arid Zone 42(3&4): 483-492, 2003

Advanced Agrotechnologies Under Limited Water Resources: A Tool in the Battle Against Desertification in Israel

Dov Sitton
Ben Gurion University of Negev, P.O.B. 653, Beer Sheva 84105, Israel

Abstract: Arid regions are characterized by scarce unreliable precipitation together with strong solar radiation and high levels of water evaporation. Such conditions can obviously never allow the establishment of rainfed agriculture. The introduction of advanced agrotechnologies and inexpensive, yet simple to operate, drip irrigation aid in the creation of sustainable agriculture under arid conditions. The advantages of drip irrigation are presented and discussed against a background of the experience and know-how developed in Israel.

Key words: Arid regions, rain-fed agriculture, drip irrigation, fertigation, marginal water.

Desertification affects arid regions throughout the world, rendering the populations of vast areas destitute and threatening them with famine. Reversing the process by which the desert invades arable land and turns it into a desolate waste is one of the greatest challenges facing the communities and nations of arid regions.

From the very inception of modern Israel, settling the desert and turning it into farming land have been viewed as a national priority of the first importance. This has necessitated revision of traditional farming regarding supply of water to arid regions, combined with suitable adaptation and implementation of advanced agricultural methods and accumulated experience.

Background

The climate of Israel is profoundly affected by the proximity of vast tracts of desert to the south and east. Precipitation is limited to the winter season, which extends essentially from November to March. Annual rainfall averages between 400 and 800 mm in the north and west of the country and declines sharply toward the south and east, dropping almost to zero. Thus, most of the area of Israel is characterized by semi-arid and arid conditions. About 60% of the land is classed as arid and needs to be irrigated all year round to sustain agriculture, and even where precipitation is relatively high – in the northern and western parts – summer crops require irrigation between May and October.

All over the country, but much more so in the southern and eastern regions, the annual precipitation varies considerably from one year to the next. Under such climatic conditions the water supply picture is one of a fragile balance between supply and demand.

Agriculture under Arid Conditions – A Historical Perspective

Until the beginning of the 20th century, agriculture in Palestine, being almost entirely rain-fed, 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 of water into the ground, the water was distributed unevenly. Farmers furthest from the source were frequently 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 southern part of the country, called the Negev, was inhabited mainly by nomadic Bedouin tribes. The Bedouin – who around 1948 numbered some 11,000 and were spread out over an area of about 10,000 sq. km – subsisted principally on sheep, goat and camel herding. The Bedouin tribes moved around periodically in search of pasture and water. Being wholly dependent on erratic seasonal rains and floods, they were often short of food for themselves and for their flocks.

In certain areas – mainly the northern and western Negev – semi-nomadic Bedouin practiced a subsistence agriculture that relied wholly on the erratic rainfall. The crops grown were mainly barley and wheat, and farming was restricted to winter and early spring crops. Drought and crop failure were frequent events. An additional type of farming practiced on a very small scale by the Bedouin was based on stone dams erected by the ancient Nabateans and Byzantines. Such dams, supplemented by simple barriers made of dirt, were used to collect floodwaters and promote deep wetting of the ground. Under such conditions the Bedouin were able to plant a small number of fruit trees, such as grape, almond and pomegranate, and to cultivate vegetables through the summer.

The notion that agriculture requires a reliable water supply began to take hold at the end of the 19th and beginning of the 20th century. This revolutionary change in attitude was introduced to the area mainly by the Jewish settlers, who were characterized by readiness and motivation 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 and in 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 not readily available.
- Water is conveyed to the fields in canals by gravitation, which means that ground needs to be levelled. Hilly terrain and slopes, therefore, cannot be irrigated by this method.

- The traditional practice of constructing dirt canals results in large losses of water due to percolation of water into the soil. Evaporation, enhanced by high intensity sun radiation, dry air, and high temperatures, is another cause of water loss. The longer the canals, the larger the losses.

- The supply of water declines along the line of distribution, leading to unequal sharing of the already limited resources.

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

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

Early Construction of Water Projects

The first modern agricultural settlements to be established in Palestine were planted in the north and date back to the 1920s and 1930s. They were based on the most advanced agrotechnologies of the time. Later this settlement activity expanded towards the southern, more arid regions.

The first concerted effort to build a large-scale water project occurred in 1935. The leading spirits of this project were Levi Eshkol, eventually Prime Minister of Israel, and Simcha Blass (1973), an engineer who later played a prominent role in designing and developing all of the country's principal water projects. The project was designed and carried out between 1935 and 1938 by Mekorot, the newly established public water company. The source of the water was three wells drilled into the western flanks of the valley of Jezreel. The main features of the project were:

- Conveyance of the water in metal pipes under high pressure, allowing uninterrupted supply over long distances and overcoming topographic barriers. The use of pipes rather than open canals prevented water loss by evaporation and leakage. 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 unceasing water supply. The water was pumped into the reservoirs at night, when the cost of electricity was relatively low; thereafter the water was supplied into the irrigaiton system without interruption.

Creating a Water Supply for the Southern Region

From the very start of the pioneering endeavor to settle the more arid southern region, it was apparent that the main limiting factor from the point of view of agriculture would be the scarcity of water. The recognition that the establishment of a modern and economically viable agriculture hinged on irrigation, which in turn called for 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; however, the quantities obtained were quite 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 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 of securing a dependable and sufficiently large supply of water for agriculture was to transport fresh water from northern sources via pipes.

A small number of studies and surveys were carried out in the 1920s. These pointed to a pessimistic conclusion – namely that scanty rains, lack of local sources of water and infertile soils precluded successful farming in the Negev. Furthermore, the agrotechnologies available at the time did not offer ways of overcoming local environmental limitations. There is no doubt that the early surveyors were influenced by the meager, rain-fed agriculture practiced by the Bedouin.

A little later it was realized that the establishment of small communities dedicated to exploring local conditions was essential to planning future settlement in the Negev. In 1943 three experimental settlements were established in the Negev, each roughly 30 km away from the others. The main aim was to explore soil conditions, availability of water (including data on annual precipitation), and the kind of crops that could be cultivated under prevailing conditions. Another eleven settlements equipped and financed by Jewish national institutions were founded in the region in 1946, and a further five settlements in 1947.

Water Supply Projects – Planning and Construction

It was agreed among leading figures in the field that the following principles should guide future planning of water projects:

- Any system developed to provide water must act as a bridge between areas where water is available and those where water is in short supply, as well as between the rainy and the dry season. 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 to be used in dry years.

- Water should be conveyed under pressure in pipes. While requiring substantial financial inputs, this approach circumvents topographic limitations and minimizes water losses, promoting long-term water saving. It also guarantees balanced and equitable distribution among end users.

- Planning must be comprehensive. That is, the water projects must convey water all over the country to meet the combined needs of the growing population and of extensive agricultural development, especially in the southern part of the country.

The first pipeline, installed in 1947, assured a reliable but limited supply of water to most of the settlements of the Negev - although several of them still needed to rely on local wells. This pipeline transported water from wells in the northern Negev. The first stage, installed and functioning in 1947, consisted of 190 km of 6"-diameter pipelines system supplying 1 million cubic meters (MCM) annually. Later on this line was converted to a 20" pipeline supplying 30 MCM annually. This pioneering endeavor was followed by two large-scale projects, which will be described below. The significance of this early pipeline was that the concept of transporting water from the north to sustain the southern arid section of the country had become firmly established.

The first large-scale project constructed to provide the new settlers with an adequate water supply system was a 66"-diameter pipeline conveying water from the springs feeding the Yarqon River over a distance of 130 km to the Negev. The annual output of this line was about 100 MCM.

The second large-scale project, the National Water Carrier (NWC), the most ambitious water supply project to date, was designed mainly to convey water to the southern region from the Sea of Galilee in the north. The plans were approved in 1956, and the 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 Sea of Galilee, located about 220 meters 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 water from the Sea of Galilee, the NWC is supplied by two large aquifers, the Mountain Aquifer and the Coastal Aquifer. 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 and as a source for recharging underground aquifers in the coastal region.

Advanced Methods of Irrigation

In Israel the agricultural sector is the main consumer of water Fig. 1. To curtail total water consumption, the amount of water allocated to agriculture has been subjected to a number of cuts, especially since the early 1990s (Grinwald and Bibas, 1989). In 1985 water consumption for agriculture was 1,389 MCM out of a total consumption of 1,920 MCM (72%); by 1997 only 1,264 MCM (63%) was used for agriculture out of a total of 2,008 MCM. Water-efficient irrigation is therefore a major priority (Anonymous, 1999).

One of the most important recent 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 drippers fitted onto a lateral pipe. This is true even on moderately sloping terrain. Furthermore, the development of compensated drippers enables uniform irrigation on steeper slopes and the capability 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.

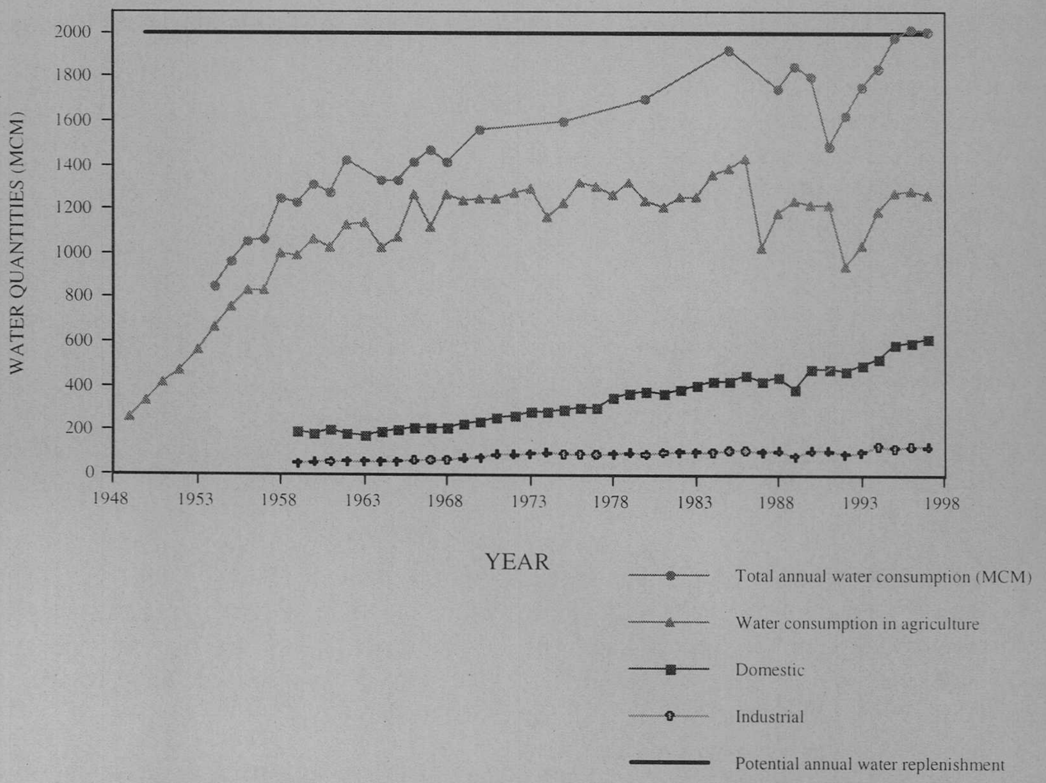

Fig. 1. Water consumption by different sectors.

- 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 furrow irrigation 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:
- 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.

— Drip irrigation causes salts to be continuously washed away from the root system, avoiding their accumulation in the immediate vicinity of the roots. This is important when irrigating salinized soils or irrigating with saline water.

— 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 deliver water directly to the soil adjoining the root system, which absorbs the water immediately, evaporation to the air 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 wind is minimal.
- High-quality drip irrigation equipment can last for fifteen to twenty years if maintained properly.

A new, modified drip irrigation system was developed several years ago for small-scale farmers (Fig. 2). Known as the 'family drip system' or 'gravitation drip system', it is designed for use where both water supply and financial means are very limited. A simple container – such as a barrel, or a hand-built container coated with plastic to prevent leakage - is filled with water and positioned about one meter above field level. Opening a valve causes water to flow by gravitation into the drip system. The container can be filled using a manual pump, obviating the need for a source of energy. Fertilizers may be added to the water, as in a conventional drip system.

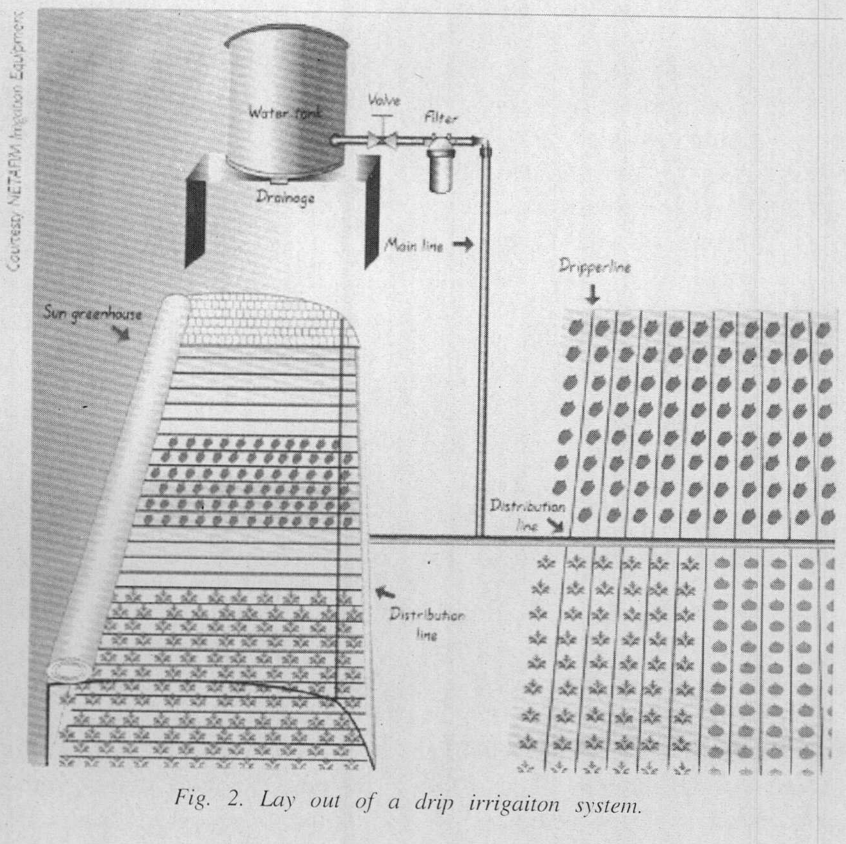

Fig. 2. Lay out of a drip irrigaiton system.

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, drip irrigation has many advantages over other methods of irrigation, and it is also superior to surface and sprinkler irrigation in regard to water saving, especially under conditions of limited water supply.

Recycling 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 supply, 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. The treated water is recharged to a nearby aquifer. This procedure results in two major benefits: (a) The aquifer serves as an underground reservoir for the recharged water, preventing losses by evaporation; water is stored mainly in winter and pumped off when needed, i.e., mainly in summer. (b) 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 under construction or are 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 (Brackish) and Seawater

There are two categories of water available for desalination, saline and seawater. Several methods for desalting saline water have been investigated in Israel since the early sixties (Anonymous, 1994). Among these, reverse osmosis has been shown to be the most efficient and relatively inexpensive.

At present the leading functioning desalination project is located near Eilat, a resort 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 54,000 plus an annual influx of about 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 m^3 day^{-1} (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.

Eventually, desalination of saline water is preferred to desalination of sea water, 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 is limited. The supply of seawater, on the other hand, is infinite. Therefore, future production of desalinated water will 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 to 8 dS m^{-1} electric conductivity, equivalent to salinity of 0.41 to 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 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 saving of fresh water.

The Role of Research in Arid Zones

From the very early exploratory agricultural communities in the arid regions of Israel to the large settlement projects and all the way to the present, there has been a continuous and fruitful interaction between farmers and scientists. Many problems deriving from the conditions specific to arid regions have been investigated by researchers, leading to successful solutions and innovative discoveries. Among many others are the development of methods for ameliorating salinized soils, the use of saline water for irrigation, the development and breeding of new varieties of vegetables and other crops, and the working out of a methodology for incorporating fertilizers in irrigation water by means of drip systems.

The extension services provided by the Ministry of Agriculture have been instrumental in the introduction to the farmers of advanced agrotechnologies, new varieties and proper agricultural management. The close cooperation between farmers, extension officers and researchers is the main factor that drives the success of farming all over the country and more so in the arid Negev.

Current Situation

In recent years water resources in Israel have become severely depleted, and the equilibrium between supply and demand is now fragile in the extreme. Several factors are responsible for this situation, the main ones being:

- A sequence of drought years that has led to inadequate replenishment of water reservoirs (both surface and underground aquifers), combined with over-pumping of dwindling water reservoirs.
- Rapid population growth – from 4.8 million in 1990 to 6.3 million in 2000, or a 31% increase in 10 years – due to immigration, leading to increased water consumption.
- Hesitation and foot-dragging among policy-makers with regard to allocating money for much needed large-scale projects – reclamation and purification of urban sewage water (which replace fresh, high quality water for agricultural uses), and most important - construction of plants for desalination of brackish and seawater.

Faced with a critical situation in regard to the water supply, the Government has at last resolved to take the necessary steps:

- It has decided on the immediate launching of desalination projects. A tender was issued, and among several private companies competing for the tender, three have apparently been selected. Desalination of seawater is scheduled to commence around 2004 or 2005. At this stage it is planned to produce quantities of 200 MCM annually.
- Quantities of fresh high-quality water allocated to agriculture will be reduced significantly.
- In future, larger quantities of treated recycled sewage water will replace fresh water for irrigation.
- Cost of water for agricultural use will gradually be pegged to the same levels as water for domestic use, which will mean near-doubling of the present price.

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 way of ensuring a dependable supply of water for both domestic and agricultural use is to take urgent steps to implement regulations and measures for saving water and concurrently to construct immediately large-scale plants for desalination of seawater and reclamation of urban effluents.

Reference

Anonymous, 1994. *Desalination and Special Projects Unit – Five-year Plan for Development of Desalinated Water Sources (1995-2000)* (in Hebrew), Mekorot Water Co. Ltd. 1994.

Anonymous 1997. *Development, Use and Condition of Water Sources in Israel* (in Hebrew). Hydrologic Service, Water Commission, Ministry of National Infrastructure, State of Israel.

Anonymous, 1999. *Statistical Abstract of Israel (Cumulative data) 1999*. Central Bureau of Statistics. State of Israel.

Blass, S. 1973. *Water in Strife and Action* (in Hebrew). Massada Ltd. Israel

Grinwald, Z. and Bibas, M. 1989. *Water in Israel – Administrative and Operational Aspects, Consumption and Extraction (1962-1989)* (in Hebrew). Water Commission, Ministry of Agriculture, State of Israel.