ISRAEL'S NATIONAL WATER CARRIER

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Key words : The National Water Carrier of Israel the main task is to transfer water from rainy north to arid south.

Resume. The National Water Carrier of Israel (Ha Movil Ha' Artzi). It is the main water project of Israel and its main task is to transfer water from the rainy north to the center and to the arid south. The National Water Carrier connects the Sea of Galilee with Israel's water system. The original goal was to provide irrigation water to Negev. Today 80% of the water is utilized for Israel's domestic consumption. Most of the water works in Israel are combined with the National Water Carrier for about 130 Km. The construction of the project started with the planning phase in 1956 and it was completed in 1964. The carrier consists of a system of aqueducts, tunnels, reservoirs and large pumping stations. Pipelines 108 "from Eschol reservoir (86 Km) to the Yarcon –Negev system at Rosh Ha'Ayin.

Introduction

The history of human civilization development is closely linked to the development of the techniques and methods by which men were able to obtain the food and the water necessary for their survival. Without water there cannot be life, nor for men and nor for fauna and flora. That is why, as the Bible mentions, water attracted groups of people and important historical events took place. This way, Abraham made peace with King Avimeleh besides his fountain in Beer Sheva (Seven Fountains). The first urban settlements date from the Bronze Age and when people hadn't had place anymore in the proximity of water sources, they began to make their own fountains in order to survive and to avoid wars between tribes. The Ottoman period is known as the most destructive stage of environmental degradation. The nomad tribes, forests destruction and uncontrolled fires contributed to this. The erosions and the alluvia brought from the mountains formed swamps and uncontrolled wild vegetation that brought mosquitoes and other disease carrying insects (e.g. malaria).

1. Geographic environment particularities

By the way it was formed, Israeli relief, especially the southern one, represents a quintessence of the Levantine paleo-geographic evolution of the Mediterranean Sea. The relief's disposition in higher and higher steps from the west to the east exposes to the western atmospheric circulation the slopes oriented towards the Mediterranean Sea; on these slopes, unlike on the eastern ones, the thermal advection favors rich precipitations.

To the south, the anticline and syncline structural lines have a east – west direction that favored the moving of the coast sands by the winds more along the syncline axes than on the anticlines direction. Thus, a sinuous line appears and limits the sands deposits over the old structures.

These superficial deposits, most of them mobile, that cover an old and varied structure (limestone, dolomite, old schist, sandstone etc.) are made of porous, permeable formations that favor the vertical circulation of water.

2. Hydrologic cycle

Israel is situated between Lebanon (to the north), a country rich in precipitations, and Egypt (to the south – west), a droughty country. That is why Israel has transition characteristics from the subtropical desert region to the wet tropical region. This is also the cause of the differences between the four longitudinal geographic bands: the seashore, the western hills, the Jordan valley and the western Cisjordan. There are also big latitudinal differences: the smallest amount of precipitations fall in the south, in the desert part, where the minimum is registered (the annual average ranks between 30 mm in the Arava and Iehuda deserts and 200 mm in Beer Sheva) and the highest to the north. The mountain (Jerusalem) and the cost region are richer in precipitations, while Galilee reaches up to 1100 mm/year.

The rainy season lasts for 3-4 months/year. Of the precipitation quantity that reaches the soil, 60% evaporates, 10% infiltrates the soil and gets to the aquifers and 5-10% drains into the valleys.

3. Hydrologic balance

The Israel's hydrographic net is mostly formed by semi-permanent watercourses, as the semi-arid environment (especially the geologic and climate factors) characteristic to the country, does not offer conditions favorable to the formation of surface water sources. The water resources potential in Israel is under 2000 million cubic meters a year, while the current demand exceeds 2150 million cubic meters/year.

These resources are divided as it follows: 52% underground waters and waters from the seasonal sources, 31% surface waters (Jordan River and its tributaries), 12% used and recycled for agriculture waters and 5% flood waters (from exceptional torrential precipitations).

The 150 million cubic meters is obtained of the desalinization, precipitations waters and treatment of used waters.

Israel has the following water resources:

1. The Jordan River system – with a 520 million cubic meters/year divides in two subsystems:

a. The Upper Jordan River that includes the northern springs and tributaries. It is known for the quality of its waters (20 mg chloride/liter);

b. The Lower Jordan River, in the south of Sea of Galilee, ends in the Dead Sea (250 km). The water of this part of the Jordan River is salty as it is alimented by the salty springs of the region.

2. The Sea of Galilee system (209 meters below sea level), with a 168 square km surface, contains 4 billion cubic meters of water. The lake is alimented by the precipitations and by the waters drained from the Hermon Mountain slopes, including the Jordan River with its tributaries, Dan that brings 250 million cubic meters/year, Hatbani 150 million cubic meters/year and Banias (Hermon) River with 120 million cubic meters/year. A total of 850 million cubic meters/year enter the Sea of Galilee (65% from the Jordan River and its tributaries and 35% from flood waters). We have to mention that here about 300 million cubic meters/year are lost by evaporation.

Beside these systems, we also have to mention a series of aquifers:

1. The seashore Pleistocene aquifer from Rosh Ha Nikra, situated at the Lebanon border, along the Mediterranean coast to the Gaza Strip – 700 million cubic meters/year;

2. The mountain aquifer (Turonian – Cenomanian sedimentary formations of Hebron and Hermon Mountains) – 450 million cubic meters/year.

3. Fossil water aquifers of the south (Negev Desert).

These aquifers are called fossil aquifers. Water is found at a big depth and it was collected in the periods when there were large quantities of water in Negev. In Arava there are salty water aquifers because of the way in which they formed. This region is a tectonic fold that filled in time with alluvia that formed thick salty layers of hundreds of meters. The water from the flood waters rises to the surface according to the capillary vessels principle.

Yehuda Desert gets its water of the springs that come from the water infiltration of the Jerusalem mountains slopes precipitations.

Of this hydrologic balance results that Israel has a deficit of water resources, so that the National Carrier was created in order to satisfy the water need. Besides the data offered by the hydric balance, for the design and the construction of the National Carrier additional arguments were taken into consideration, like: the rapid growth of the population and along this the increase of the domestic water demand, also due to the higher standard of life; the exaggerated pumping of water from the existent fountains that resulted into the sea water introduction and the water salting (especially in the center of the country); the development of the irrigated agriculture and the of the water consuming industry. It is thus clear that the existing water resources cannot ensure the Israel State an economic and politic security and nor the conditions for a durable development.

4. Plans for the water resources development

After the proclamation of the State of Israel and its UN recognition in 1948, the problem of the water resources became a national priority of strategic importance.

The new local resources. Researches were done in order to complete the Israel's water resources by exploiting also other resources. This way, by geo-technical drilling done in the proximity of already known aquifers, new ones were identified. At the beginning they were used locally by the regional communities (for domestic, agricultural and industrial consumption). Afterwards, these new resources were connected to the National Carrier.

"*The water treasure*" The first real step was the "Water treasure" plan made by the American engineer James Hayes that designed the installation system for water utilization of the Tennessee Valley (USA). He studied the conditions of the natural and socio-economic environment in Israel, based on which he established the water distribution criteria for the entire territory of Israel. His plan envisaged the beginning of the construction of the National Carrier at 10 km north of Sea of Galilee, deviating part of the Jordan's waters and from here would have begun the south flowing – to the Negev Desert. This way, the natural fall, from the capture point height to approximately 60 m above sea level, could be exploited. This project would have resulted into a considerable energy saving, necessary for the transportation of the water on the canal, but it was abandoned because it encountered Syria's opposition and later the UN resolutions against it.

Taking into account the geo-political reality, another project was made by the American specialist Johne Coton for the National Carrier' execution. He adapted the canal's route to the Israel's territorial reality, changing the position of the capture point of Jordan with a new one, this time of Sea of Galilee and renouncing at the Jordan River deviation.

This new track from the origin of the canal crosses a hilly region, highly fragmented, with a considerable relief energy that imposed expensive technical solutions in order to move up and down the water transported on the canal that crossed hilltops and valleys. For the same reason, investigations were made regarding the watercourses in the valleys and in Negev hydrometric observation points were set up for the evaluation of the water demand in this region. In order to apply this project, the National Carrier's construction by the state company

Mekorot was decided in the same period. (figure 1 presents a section of the National Carrier)

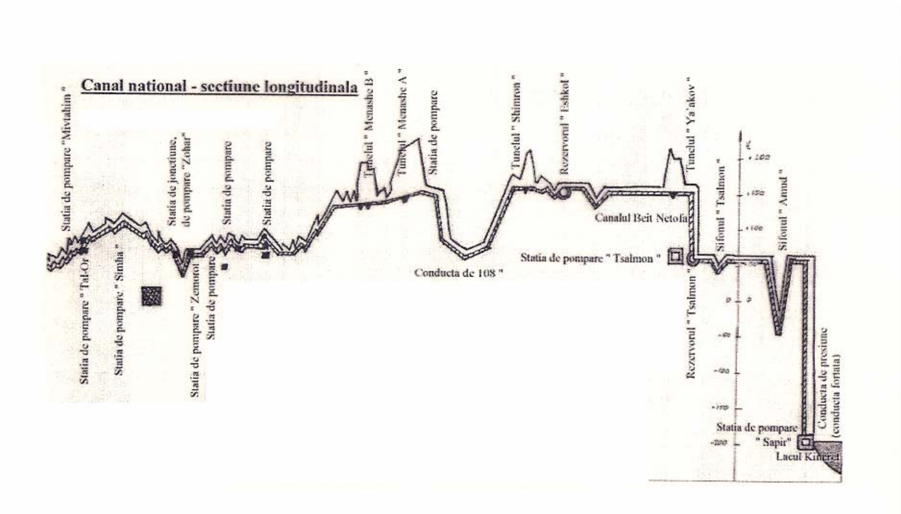

Fig. 1 - Longitudinal section of the National Carrier

General facts. The National Carrier is the largest development project executed in Israel. This project was initiated in the middle of the year 1950 and was completed in July 1964. The Carrier begins at the Sea of Galilee, in the north, and ends at Mitzpe Ramon in the south. The modification of the water supply route, from the Sea of Galilee and not directly from the Jordan River, made the works more difficult and they took longer because of the abrupt valleys (Amud and Talmon) and of the hard to pierce.

These problems were solved by tunnels carved in the mountains (Fig. 2) and the valleys were crossed by constructing U form pipes that used the communicating vessels principle. (Fig.3).

Sea of Galilee represents in this hydrotechnic complex the main drinking water reservoir. In order to satisfy the increasing water need, water from the neighboring aquifers was added to this reservoir.

Most of the water (2/3) comes from the north of the country and 1/3 from the waters of the Water Plants of Rosh Ha Ain.

The waters of the National Carrier get here and together with the Rosh Ha Ain springs (350 000 square m) that feed the Yarcon River flow into two large pipes – one towards Negev and the other to the towns in the centre of the country (Gush Dan).

These springs have large water quantities originated from the mountain aquifer (Iracon – Taninim) and they come to the surface naturally because of the geological structure faulting near to Rosh Ha' Ayin. This fault that cuts the monocline and stops the flowing to the west, forces the artesian exist of the water from the aquifer.

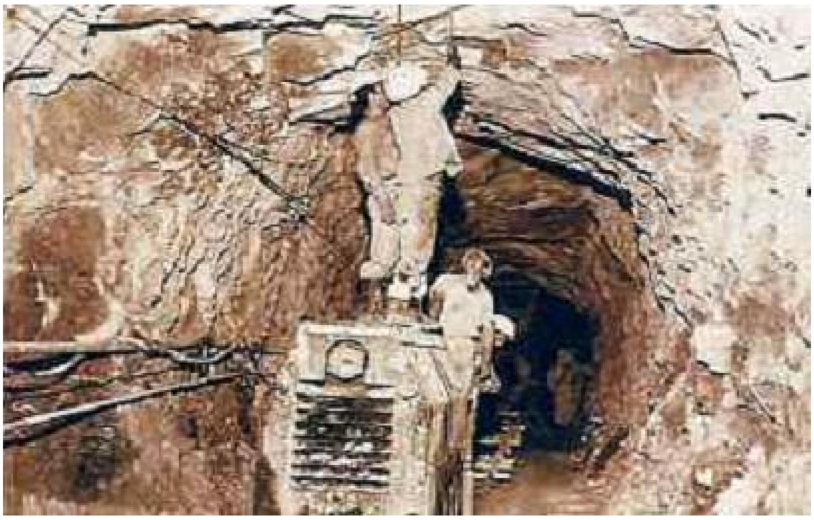

Fig. 2 - Excavations for the construction of the national carrier tunnels

In winter, when precipitations are abundant and he Kinneret has a water excess, this is introduced, through some sandy areas, into natural underground aquifers, where it is deposited for a long time. When the water demand increases, these deposited quantities are used, especially in the periods with a hydric deficit. The fresh water introduced in these aquifers also raises their level and stops the inflowing of the salty seawater. Moreover, this also ensures a low level of the aquifer's water salinity, consistent with the usage standards required by the domestic consumers of drinking water.

Pumping the Kinneret water from 209 meters below sea to + 44 meters was first necessary, in order to allow it to flow then through the canal carved into the rock by force of gravity. The water quantity pumped from Sea of Galilee is of approximately 500 million cubic meters/ year and it feeds the National Carrier.

At the exit from Sea of Galilee, two parallel canals were built (Fig 3 and 4). One for the high quality water of the upper Jordan (first line) and another canal (second line) that collects the waters and the salty springs of the lower Jordan and that are transported to the Dead Sea.

Fig. 3 - The National Carrier. Works to the adjacent pipes in 1950-1964. Making of the pipes set over the hilltops or crossing valleys

Fig. 4 - Open part of the National Carrier (line I) with a 17 km lenght at the exit of the Sea of Galilee

Fig. 5 - Open sector of the National Carrier (line II) that captures the salty springs on the western shore to the Dead Sea

This way the allowed quantity of chlorides is maintained.

The restructuring works of the local water plants, the improvement of the conservation and development of the aquifers and the implementation of modern techniques for the water management regarding the quality and the new researches were possible after the acquisition of the Mekorot shares by the State.

This project, among its numerous objectives, has as a target the intensive agriculture development in the Negev Desert by irrigation with water brought by the National Carrier and also the water distribution for the consumers in its way to the Negev Desert. In the beginning, the canal's objective was the irrigation, for 80%. Today the drinking water distribution reached 80% and the irrigation only 20%.

How does the canal work? The water captured from the bottom of the Sea of Galilee from 209 m is lifted by pipes set on the bottom of the lake to the Sapir Pumping Station (Fig. 5), found at the level of the water surface, where 3 absorbing pumps function, each with a 30 000 HP power and a pumping capacity of 6,75 cm/s. Water is then lifted from here through a concrete pipes system, which can resist to a 70 atmospheres pressure< water is pushed on a 2.2 km distance to the open canal of the upper Jordan with a 16 km length.

Fig. 6 - Sapir Pumping Station

Then, there are the two „siphons" through which water crosses the two valleys, circulating according to the communicating vessels principle. The two pipes have an internal diameter of 3.10 and 3.60 meters, the first one at a 150 m and the second at 80 m depth. From the canal, water is collected in the Eschol accumulation and purification reservoir and lifted through the Tzalmon pumping station at 115 m altitude. This was built in the mountains and, in order not to damage the environment, after the finalization of works it was covered, so that it fits into that particular scenery. From here, water is transported through the open canal to the mountain carved tunnel, Eilbun with a 850 m length, and to the open canal that begins at Beit Netufa and continues for a 17.5 km distance to the entrance to the closed pipe with a diameter of 108" (2.47 m) that goes to Rosh Ha'Ayn. These pipes go through three tunnels that cross the mountains: Shimron (1.5 km), Menashe A (6.5 km) and Menashe B (350 m). At Rosh Ha'Ayn the canal connects, through the pumping station, at the Yarcon – Negev plant pipes throughout which the canal's waters continue towards Negev.

Through tunnels, reservoirs and pipes that ensure the connection to other pumping stations like Tzalmon, Menashe, Rosh Ha'Ayin, Zohar, Simha, Tal-Or and Mivtahim and also decantation reservoirs where water is purified (Eschol reservoir, Fig. 7), both by mechanical (fine metallic screens) and by chemical and biological treatment.

Fig. 7 - Escol accumulation and purification reservoir

In these decantation reservoirs, a chlorine anti bacterial treatment takes place first and then a mechanical purification (water passes through sand layers where particles in suspension are retained and then through carbon filters that neutralizes chlorine). Tzalmon pumping station has the mission to lift water at 115 m altitude. It was built in the mountains and, in order not to damage the environment, after the finalization of works, it was covered, so that it fits into that particular scenery.

Due to the population growth and with it of the drinking water demand, the State decided to build the pipe with recycled used waters (the third line) for agriculture, that goes to Negev, Israel's granary.

In order to do this, a complex of pipes, parallel to the drinking water pipe system, was built; it is called the Yarcon – Negev Line and began working in 1989. The recycling plants of the center of the country transported through the Third Line 140 million cm/year of recycled water of the center of the country (Tel Aviv and the Gush Dan suburbs) in order to irrigate the Negev. This project released a considerable quantity of drinking water. Along the Third Line 6 reservoirs were built that collect water when demand is lower and distribute this water when the demand is higher.

5. The forth line to Jerusalem

This project that connects the National Carrier to Jerusalem was initiated by Mekorot in December 1990 and was finished on 5 of January 1994.

This project proved to be even more difficult to realize than the National Carrier, as it has a 42 km length.

This line brings water from the mountain aquifer, that is pumped by four stations and each of them lifts water at a 200-250 m height. This complex is connected to the National Carrier at Shar Ha'gai, Toba, Mota and at the entrance into the city at Ein Kerem through the Yarcon – Mizrah line.

The line distributes water mixed from several sources: from the forges of the region Shaar Ha'gai, Modein, from the Ben – Semen region and it supplies Jerusalem with 90 million cubic meters of water a year (60 million mixed).

Till the end of 1967, the Gahan River and the Nahal Ghidron, where Ein Rogel and Ein Tannin springs spring, were the Jerusalem's water reserve. Water was distributed twice a week, for money, so that a small part of the population had to drill their own wells into the rock. In 1990, the Jerusalem population counted 500 thousand inhabitants, but today it counts 950 thousand, which determined a considerable increase of the water demand. Today, Jerusalem gets its water of the following sources: 15% of the local drillings, 70% of the mountain aquifer and 15% of the National Carrier. Water is collected in reservoirs with a total height of 850 meters and it is distributed after a proper treatment.

Execution difficulties – logistic problems. Jerusalem is located in a mountainous region, difficult to cross, far from the water reserves; a few pumping stations are needed, each with a capacity of lifting water at 200 – 250 m. In order to choose the route for the pipes setting, the environmental issues, the existing infrastructure, the land ownership and the geopolitical and security issues were taken into consideration.

The water reserve is in the Aielon River basin and it goes from the Biniamin region to the west. Jerusalem is located on the watershed of the Sorek River basin. Thus, the concrete pipes towards Jerusalem have to connect both basins over the mountains crests. In order to ensure the pipes security, the line had to avoid crossing the occupied territories.

The fifth line, still towards Jerusalem, is being planned and designed and it will double the supply, from 57 million cubic meters a year to 115 million cubic meters, by doubling the pipes diameter, from 1 to 2 meters. The works will be finished by 2012.

Treatment of the National Carrier's waters. The Kinneret water has to be treated in order to reach the drinking water phase and the quality required by the international standards. The alluvia brought by the Jordan River, algae that grow, unicellular organisms, snails, earthworms etc. cause the water infection.

Several procedures are used for the water treatment:

1. **Physical-chemical** procedures, as soon as water arrives in the Escol reservoir. Chemical substances (Aluminium – sulphate Al2(SO4)3.18HsO, that due to their properties gather around them the floating particles that connect in large, heavier particles which sink, leaving the clean water continue its route;

2. **Biological treatment with fish**. Fish are introduced in the canal water to eat the algae, the earthworms and the snails; this is why they are called "Sanitarians". The better known sanitarians are the sea carp and the silver fish. Also, the herbivorous carp eats the vegetation in the water, while the Labrac fish eats the small fish in the tanks and the black carp eats snails and other organisms.

3. **Chemical treatment.** Chloride-dioxide and chloramine are introduced before the distribution of the water to the population. Water is enriched with fluorine, as this element is absent from the water and it helps fight the cavities.

4. **Filtration**. By the passage through sand filters, the last impurities that managed to arrive in the final phase are stopped. Water is then filtered through carbon filters that give it a good taste and neutralize the chlorine taste.

Ultraviolet radiation treatment. Besides the presented treatment procedures, water is also submitted to a purification process by means of ultraviolet radiation. This radiation develops thymine dimers, which block the reproduction processes of microorganisms (they destroy the DNA). In order to reach a 99,7% microorganisms destruction level, a 60mws/sqcm radiation is necessary, that is synonymous with a triple treatment of used waters.

National Carrier Maintenance. Periodically, the whole system is verified in order to ensure the continuity of its functioning. This way, pumps that wear down in time and lose their pumping capacity, are replaced. To follow the evolution of the wearing down degree, computerized surveillance system were implemented. Water pipes are constructed so that they can be closed sector by sector for cleaning. The concrete pipes have a 2.5 m diameter so that people in jeeps can enter them for checkups and repairs.

This system also ensures water distribution at a pressure that meets the demands of the consumers. With this system a significant energy saving takes place together with the prolongation of the guaranteed functioning period.

Laboratory water control. Three times a day, detailed analyses of the water chemistry are performed. The open section of the National Carrier benefits from a special attention, being permanently supervised, by cameras and by the security personnel, in order to completely eliminate any infestation or destruction risk by terrorist groups.

Water quality standard in Israel. Israel implemented the international standards for water quality, precisely the European and American ones.

The maximum allowed quantity of coliform bacteria is of 3 coliforms in 100 mg of water and for elements like the kyanite the maximum quota is of 0.05 mg/liter of water;

The accepted iron concentration: 1 mg/l of water. Iron concentration does not cause a health problem, but it's an aspect issue because it can give water a rusty color;

Alpha radiations; 0.1 Bekerel/liter of water;Chloridum: not more than 600 milligrams/liter of water; Nitrites: not more than 70 mg/liter of water;

Water is controlled at least once every three months in the labs that serve the carrier or in those of the Ministry of Health. There are monitored detectors where one can see if impurities or substances dangerous for the public health infiltrated into the water.

Conclusions

The National Carrier with its ramifications is one of the largest projects of Israel. Due to the success of this project, the development of the Israel desert region that includes 60% of its territory was rendered possible. Thanks to the water, it was possible to develop the intensive agriculture and the industry on the entire territory of Israel. Today there is no place without water from the taps, even if the rainy season lasts for only 3-4 months and this only in the north of the country. Thanks to the carrier, we can find settlements in the desert, where the inhabitants lead a healthy cultural and social life, contributing by their work in agriculture or industry to the development of the country's economy. Although the predictions say that in 2010, because of the population growth and of the increase of the water demand, the current net will not comply anymore, the forth line towards Jerusalem was built and the fifth line, still towards Jerusalem, having a double capacity compared to the existing one, is being designed. The investment in this project was huge, but it was worth it, because today we can profit of the results of this effort: the entire territory of Israel benefits of water supply.

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