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GROUND-WATER STORAGE AND ARTIFICIAL RECHARGE

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COASTAL PLAIN AQUIFER, ISRAEL*

The background information for the coastal plain aquifer is as follows:

(a) Region: eastern shore of the Mediterranean Sea;

(b) Geography: the coastal plain is a gently inclined, undulating area which rises from the shores of the Mediterranean to maximum elevations of about 80 m above sea level at a distance of 15-20 km from the coast, and is bounded on the east by the foot-hills of the mountains of Judea and Samaria. The northern boundary of the coastal plain is formed by a promontory of the Carmel Mountain in the south. The Shiqma River may be taken as the southern boundary because from here southward climatic and hydrological conditions become semi-desertic. A number of rivers with very erratic, short periods of flow cross the plain from east to west. The only perennial river, the Yarkon near Tel Aviv, divides the coastal plain into northern and southern parts;

(c) Climate: semi-arid, Mediterranean type. Rainfall occurs only during the winter (October-April) and averages about 550 mm/year in the northern part and from 400 to 500 mm/year in the southern part;

(d) Reservoir type: sedimentary; calcareous sand and sandstone and intercalated marly strata deposited in a littoral environment;

(e) Methods of investigation: the geology is known in great detail from hundreds of exploitation and observation bore-holes. Water levels and the salt-fresh-water contact are monitored by means of an extensive network of observation bore-holes. Quantitative investigations were carried out with the aid of mathematical techniques and analogue models.

Ground-water reservoirs

The aquifer is composed of littoral-marine calcareous sands, calcareous sandstones and intercalated layers and lenses of marly loams, all of Pleistocene age. It has a maximum thickness of 130 m at the sea shore and wedges out at the foot-hills in the east.

The aquifer is underlain by a layer of blue-black shales several hundred metres thick, probably of Neogene age. Near the eastern part of the aquifer boundary, the shales are replaced by chalky-marly formations of Senonian-Eocene age. The aquifer and the underlying shales present no recognizable tectonic features.

The thickness of the aquifer near the coast is about 130 m. At a distance of about 10 km from the shore it is 80-100 m thick and further east it rapidly wedges out. The effective thickness of the aquifers is about 25 per cent less than the above geometric thickness, owing to the intercalated semi-pervious to impervious marly strata.

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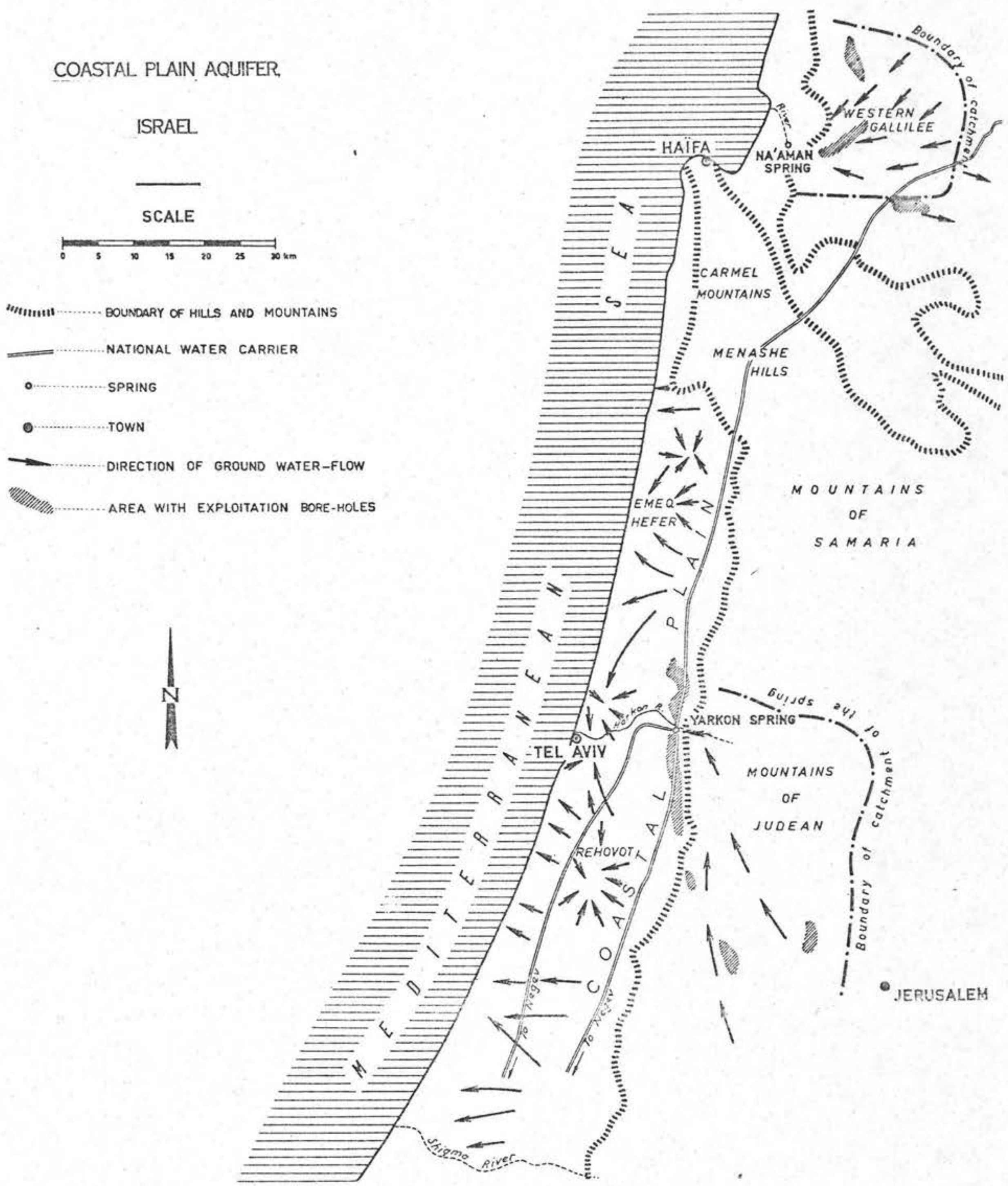
* Case study No. 6 prepared by S. Mandel (Israel).

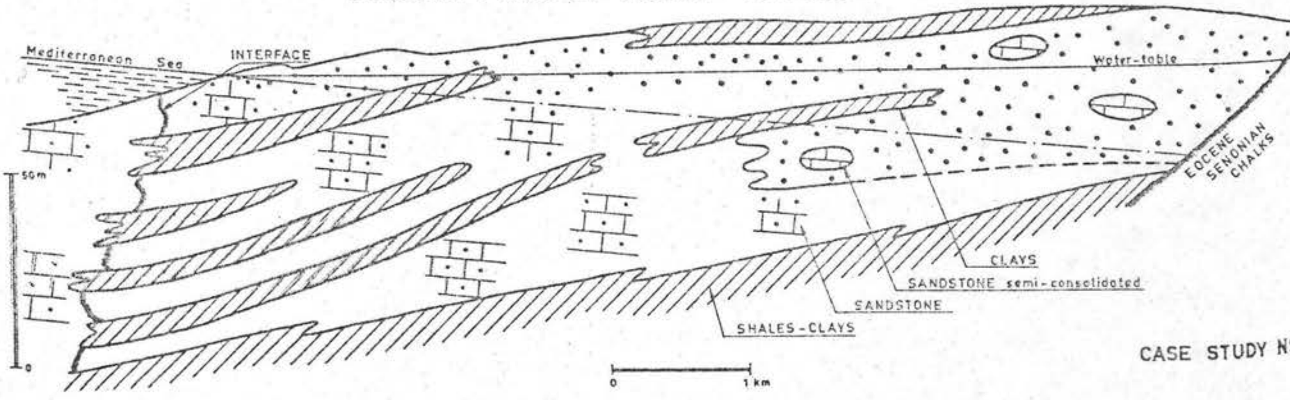
FIGURE 14

COASTAL PLAIN AQUIFER

ISRAEL



COASTAL PLAIN OF ISRAEL - SCHEMATIC CROSS-SECTION



Transmissivity of the aquifer is 1,000-4,000 m^2/day near the coast and only 100-500 m^2/day at the eastern edge. Its specific yield is 15-20 per cent. The aquifer stores 20 x 10^6 m^3/sq km near the coast; 10 x 10^6 m^3/sq km at 10 km inland. Water quality is mainly in the range between 120 and 300 ppm. Total dissolved solids (TDS) is 50-130 ppm Chlor-Ion.

The aquifer is replenished by rainfall over the coastal plain and, to a small extent, by seepage from the seasonal rivers traversing the plain.

The aquifer discharges into the Mediterranean Sea in the west; only a few very minor springs and swamps near the coast indicate ground-water drainage to the surface. In the natural state, ground-water level contour lines ran parallel to the coast; i.e., natural flow-lines were perpendicular to the sea coast. Natural replenishment has been determined to be about 230 x 10^6 m^3/year, on the average. In the natural state, about 2 x 10^6 m^3/year of water discharge into the sea through each kilometre of coastline.

The aquifer underlies one of the most fertile and most densely settled regions of Israel. Its exploitation amounted to only about 60 x 10^6 m^3/year in 1948, but increased by leaps and bounds in the succeeding years, and reached 480 x 10^6 m^3/year in 1962. This represents about 45 per cent of the total amount of water used throughout the country in that year, and exceeds the estimated safe yield, about 190 x 10^6 m^3/year, by a factor of 2.5. Over-exploitation caused a very marked lowering of the water levels, which were depressed below sea level in some areas. From 1963 onwards, water from the Jordan River was imported into the region and the hydrological situation has now stabilized at a safe level.

Utilization of ground water

The aquifer is exploited by several hundred bore-holes with average yields of 250-350 m^3/h. The bore-holes operate from 2,500 to 3,500 h/year, mainly during the summer months (June-September).

The impervious bottom of the aquifer, which ascends towards the east, is relied upon to control sea-water intrusion. It is intended to keep the ground-water levels sufficiently high at a distance of 2-3 km from the coast, so that sea water cannot intrude above the impervious bottom further inland. Between this line and the coast, withdrawals by means of shallow bore-holes are rigidly controlled. A scheme to this effect, the "coastal collector", is in the pilot-plant stage.

Apart from its function as a source of water, the aquifer is also used as a storage reservoir for flood water from rivers, and as a storage reservoir for water from the Jordan River conduit. Management of the aquifer is greatly aided by the network of observation bore-holes. Furthermore, pumpage is gauged and strictly supervised by law.

Most of the bore-holes are owned and operated by Mekoroth Water Co. Ltd., which supplies water for farm irrigation at about \$0.04 per m^3 (calculated at the 1971 rate of exchange). The price of urban water supply is determined by the municipalities and varies considerably from place to place.

In towns, water rates follow a sliding scale. The quantity which is considered basic is supplied to each household at a low rate, while consumption in excess of this quantity obliges the user to pay much more.

The high cost of water, the sliding rate scale in towns and a vigorous campaign of educating the public has led to a remarkable reduction of water-demand per unit of irrigated area and per capita, without adverse effects of productivity or the standard of living.

Artificial recharge schemes

The purposes of the replenishment of the aquifer by water from the Jordan River are as follows:

(a) Restoration of safe ground-water levels in the coastal aquifer;

(b) Long years of storage of water from the Jordan River, the yield of which changes very erratically from year to year. The storage capacity of Lake Tiberias is insufficient to regulate these fluctuations and, therefore, underground storage must be utilized;

(c) Seasonal storage. During winter, in addition to the natural replenishment, the aquifer is artificially replenished with water from Lake Tiberias so that it can be more heavily exploited during summer.

The operation of the system is described below.

Water from Lake Tiberias is conveyed to the central and southern parts of the country by the National Water Carrier. This pipeline is connected with most of the bore-holes by means of a network of subsidiary lines. All the water in the National Carrier is pre-treated and is of potable quality.

The extraction wells are also used during winter for recharging. The wells are 80-120 m deep; their specific discharge is about 50 $m^3/h/m$ of drawdown. For extraction purposes, they are operated with yields of 200-300 m^3/h. The lower parts of the wells consist only of slotted pipes, which are put opposite the more consolidated parts of the aquifer. No gravel packs or other special filter elements are installed. A small part of artificial replenishment is carried out through improvised spreading-grounds. During winter and spring, 1968/69, 31 bore-holes and three spreading-grounds were used for artificial replenishment of water from the Jordan; 62×10^6 m^3 were recharged through bore-holes, and 5×10^6 m^3 through spreading-grounds.

A bacterial slime forms on the well face and greatly impairs the efficiency of operations after about one month of uninterrupted injection. It was found that a few hours of pumping cleans the well-face and restores the capacity of the bore-hole. The water which is pumped during these short cleaning periods is dark and smelly, and must be discarded.

The estimated cost of injecting Jordan River water into bore-holes is $\$0.015/m^3$ (at the 1971 rate of exchange). This estimate mainly reflects the cost of energy and manpower for supervision, since only small items of installation were constructed specifically for injection purposes.

Operations are carried out by Mekoroth Water Co. Ltd., within the framework of the water laws of Israel.

Because this is one of the major tools for the management of the water resources of Israel, operations will be continued and expanded. Additional chlorination may be required to combat clogging.

Artificial replenishment in the area of Emeq Hefer

Emeq Hefer (Hefer Valley) is situated about 40 km north of Tel Aviv and covers an area of about 110 sq km. The permissible annual yield of ground water from the aquifer of the coastal plain in this region is about 15×10^6 m^3/year. The area is intensively cultivated and its water requirements greatly exceed this quantity. During the late 1950s about 40×10^6 m^3 of ground water were pumped annually from the aquifer. As a consequence, the water levels declined sharply and sea-water intrusion became critical. A pipeline was constructed conveying additional water supplies from an aquifer of Cretaceous limestone situated 15 km to the east of Emeq Hefer. This water is used partly for irrigation and, during the winter, partly for artificial replenishment.

The purpose of artificial replenishment was:

(a) To restore acceptable hydrological conditions in the aquifer; (b) to utilize the coastal aquifer as a seasonal storage reservoir, so that larger quantities can be pumped from it during summer; (c) to optimize operation of the regional water-supply system.

At first, existing exploitation bore-holes were used for injection. Later on, owing to legal difficulties with the private well-owners, several special injection bore-holes were added. Currently, recharge is carried out in nine bore-holes operating at an approximate recharge rate of 220 m^3/h/bore-hole. In 1965/66, recharge operations reached a peak of almost 10×10^6 m^3, and they have been continued on a reduced scale since then.

The scheme works satisfactorily, as long as clean ground water from the Cretaceous aquifer is used for injection. Trial runs with water from the Jordan River produced clogging effects by bacterial growths on the face of the well. The cost of injecting water amounts to about $US 0.02/$m^3$. Operations are carried out by Mekoroth Water Co. Ltd. Private well-owners, who benefit from the operations, are billed for injected water. The scheme will be continued.

Elimination of sea-water intrusion in the Tel Aviv area

Greater Tel Aviv is a densely populated area extending over about 100 sq km. Until 1958, its water supply depended solely on local wells exploiting the Pleistocene aquifer. The permissible yield, about 17×10^6 m^3/year, was exceeded in the early 1950s and withdrawals reached more than 80×10^6 m^3 in 1957/58. A deep cone of depression formed and sea water intruded to a distance of 2.4 km from the sea coast, putting many wells out of action. From 1959 to 1964, exploitation was reduced and water was imported to satisfy the requirements of the area. While the cone of depression created by the excessive pumpage slowly filled up, sea water continued to move inland.

The purpose of the project was to build a temporary fresh-water barrier to check the advance of sea water until the water levels further inland recover sufficiently. Water from the line of the Jordan River was injected into 22 city wells parallel to the shore line and at distances of 1.5-3 km east of it. Later on, additional wells were drilled, especially for recharge to the bottom of the aquifer. About 140 x 10^6 m^3 were recharged in this way during the years 1964-1966. Observations showed that the advance of the zone of diffusion was checked during the winter, while during the summer a slow eastward movement was still recognizable. The scale of operations was then reduced and they will be discontinued in the near future, because, in the former cones of depression, water levels have now approached the calculated safe conditions.

Work in a densely built-up area presented the usual engineering problems. It was difficult to maintain the required rates of injection in each bore-hole and, simultaneously, to maintain the regular urban water supply from the same network. The water of the Jordan River used for injection caused clogging by bacterial growths and the capacity of the wells had to be reconstituted by short pumping periods.

Artificial replenishment by surface water from the Shiqma River

The Shiqma River forms the southern boundary of the coastal plain. It drains an area of 734 sq km with an average annual rainfall of about 350 mm/year. The river is in flood only during a few days each winter and dry the rest of the time. Several completely dry years are on record. An average flow of 7 x 10^6 m^3/year may be taken as an indicative value of the river flow.

Good sites for surface storage cannot be found on the river and evaporation losses from an open water-surface would, in any case, greatly impair their efficiency. Ground-water storage is the only way to utilize the flash floods. A storage reservoir with a capacity of 2.8 x 10^6 m^3 holds the flood and also serves as settling pond.

A pumping station with a capacity of 10,000 m^3/h conveys the water through a 48-inch pipeline and conveyance channel over a distance of 3,000 m to spreading-grounds covering an area of about 40 ha, situated on sand dunes at an elevation of about 10 m above the reservoir. The spreading-grounds have a capacity of about 800,000 m^3 of water. Infiltration rates are about 1,000 mm/day at the start of each season, decline to about 250 mm/day after 20 days of operation and remain at that level until the end of the short season. The water is recovered by bore-holes, which had been in operation prior to the construction of the dam. However, artificial replenishment makes it possible to maintain a high rate of ground-water abstraction.

The turbidity of raw water is around 10,000 ppm suspended solids, but it varies widely from flood to flood; in one exceptional flood-wave of 12.5 x 10^6 m^3 volume, turbidities of 50,000 ppm were reached. As a rule, water with a turbidity of only 500 ppm or less is spread on the grounds. For this purpose, detention periods of 5-7 days in the reservoir are necessary.

The following figures, which are expressed in millions of cubic metres, summarize operational records. In view of the very large variability of climatic conditions in this area, it is misleading to calculate averages from the short record.

Totals for period	Total flow in river	Diverted into spreading-grounds	Lost over spillway	Losses from reservoir	Accumulated silt in reservoir
1960/61-1967/68	67.3	28.6	35.2	3.5	1.1

Settling of silt in the hold-over reservoir is too slow. If, in a wet year, floods occur at intervals of less than 10 days, they meet a full reservoir and are lost over the spillway. The addition of coagulants and/or heightening of the dam are under study. Infiltration rates in the sand dunes declined from their initial peak, but remained at a satisfactory level during the last few years.

Amortization for investment amounts to about $US 0.57/$m^3$/year, calculated with an interest rate of 8 per cent for a 25-year period of total amortization at the 1971 rate of exchange. Operating expenses are about $US 0.05/$m^3$. The entire plant is operated by Mekoroth Water Co. Ltd., under the water laws of Israel. It is desirable to solve the above-mentioned problems, but operations will, in any case, continue.

Artificial replenishment by surface water from the Menashe Streams

The four seasonal streams, Snunit, Ada, Barkan and Mishmaroth, drain an area of 110 sq km in the region of the Menashe Hills toward the Mediterranean Sea. The watersheds of the rivers are underlain by chalky limestone which forms a shallow aquifer. The seasonal river-flow lasts from December to April and averages 15 x 10^6 m^3/year, within a significant range of 3-40 x 10^6 m^3/year. The river-flow is composed of a base flow fed from numerous springs, and superimposed short periods of floods. The base flow accounts for about 70 per cent of the total. The project diverts the four streams by gravity, recharges the water into the aquifer of the coastal plain and recovers it by pumpage in bore-holes. The project was undertaken for the purpose of seasonal storage and exploitation of surface water.

A diversion canal, mainly earth, about 10 km long with a carrying capacity of about 10 m^3/sec, crosses the four streams with a diversion structure on each, and enters into the detention and desilting reservoir of 2.4 x 10^6 m^3 capacity. From here, another earth canal about 2 km long carries the water into the spreading-basins, permitting intermittent operation aimed at the prevention of clogging by suspended matter and the restoration of infiltration capacity by drying after partial clogging.

The maximum piezometric level in the aquifer is about 25 m below the bottom of the spreading-basins. Due to low-lying areas in the vicinity, the aquifer storage is somewhat limited. The aquifer is 30-50 m thick and its transmissivity is from 800 to 1,000 m^2/day; the coefficient of storage is about 0.20. The underground reservoir is exploited by 10 pumping wells surrounding the spreading-basins and discharging into a local network that is connected to the National Water Carrier.

The major part of the project was constructed in the summer of 1966, was put into operation in the winter of 1966/67 and was finally completed prior to the winter of 1967/68.

The following operational records are available. All figures are in millions of cubic metres.

Hydrological year	Diverted flow	Spills	Infiltration In spreading grounds	Infiltration In reservoir	Infiltration In canals
1966/67	12.0	0.15	7.5	2.8	1.7
1967/68	3.8	-	0.2	2.9	0.7
1968/69	20.5	not measured	10.2	4.5	5.8

The silt load is small, from 160 to 300 ppm for river-discharges of 1-3 m^3/sec and from 50 to 100 ppm for smaller river discharges.

The underground storage capacity is small and the distance from the sea is only about 3 km; therefore, the site is not suitable for many years of storage. Eventually, additional bore-holes may have to be drilled to enable quicker extraction of ground water before it escapes into the sea. The watershed area of the rivers is now heavily settled and partly industrialized. Pollution of the raw water may become a problem.

References:

Aberbach, S. and A. Sellinger. Review of artificial groundwater recharge in the coastal plain of Israel. Bulletin of IASH year XII, 1:65-67, March 1969.

Schmorak, S. Salt water encroachment in the coastal plain of Israel. International Association of Scientific Hydrology, publication No. 72, pp. 305-318, March 1967.