# THE FORECASTED NEGATIVE IMPACT OF GLOBAL WARMING ON THE WATER RESOURCES OF THE MIDDLE EAST AND HOW TO MITIGATE IT

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## ABSTRACT

The author’s investigation supported by research from Mediterranean countries shows that the present water shortage may worsen, once the globe warms. Thus, a water shortage catastrophe in the Middle East seems imminent. By understanding and evaluating future climatic trends and changes, in which long periods of drought may alternate with periods of abundance and floods, emphasis should be put on enlarging long-term storage capacity, especially that of groundwater resources, this, in some cases, on account of water quality in these reservoirs. The planned, long-term utilization of fossil aquifers, underlying most countries, should also be investigated. Parallel to the climate change with its impact on the hydrologic cycle there will be increasing urbanization and a consequent rising demand for urban water supply, which may be partly answered by desalination of seawater or brackish groundwater, creating more urban sewage water. This after treatment can be reused and also be recharged into aquifers for the purpose of long-term storage. These two changes as well as pressure from population increase and rising standard of living mandate new plans for water resources management , including the creation of a regional, cooperative, long-term plan for the Middle East aiming at increasing and sharing its scarce water resources by agreements on trans-boundary influence and transport.

## I. INTRODUCTION

The impact of past climate changes on the hydrology has been investigated by the author. This in order to foresee what may be the impact of the Global Change on the hydro-geological regime of the Middle East in general, and Israel and Palestine in particular. As measurements are restricted to a little more than a century, the only solution is the reconstruction of past climates and their impact on the environment, by the use of proxy-data. These include ancient sea, river and lake levels, chemical and environmental isotope data

($^{18}$O,$^{2}$H, $^{13}$C and Sr ) in cave, lake and sea sediments and in fluid inclusions, tree-rings, pollen assemblages. From these quasi-parameters the components of past hydrological cycles were deduced and were used for forecasting the future (Issar, 2003, 2004)

## II. IMPACT OF CLIMATE CHANGES DURING THE PAST

Figure 1 represents part of the proxy data which were used in order to decipher the nature of climate changes during the last 7000 years. The first curve is of the changes in the quantities of precipitation gathered from the changes in the composition of the environmental isotopes (oxygen 18 & carbon 13) in the stalagmites in the Soreq Cave near Jerusalem (Bar-Matthews, Ayalon, et al. 1998) The last research enabled the estimation of the quantity of rains during historical periods. This was done by sampling contemporary rain and investigating the $^{18}$O and $^{13}$C isotopes' ratios, and then correlating it with the annual quantity of rain. Periods of high precipitation corresponded with periods of low temperatures.

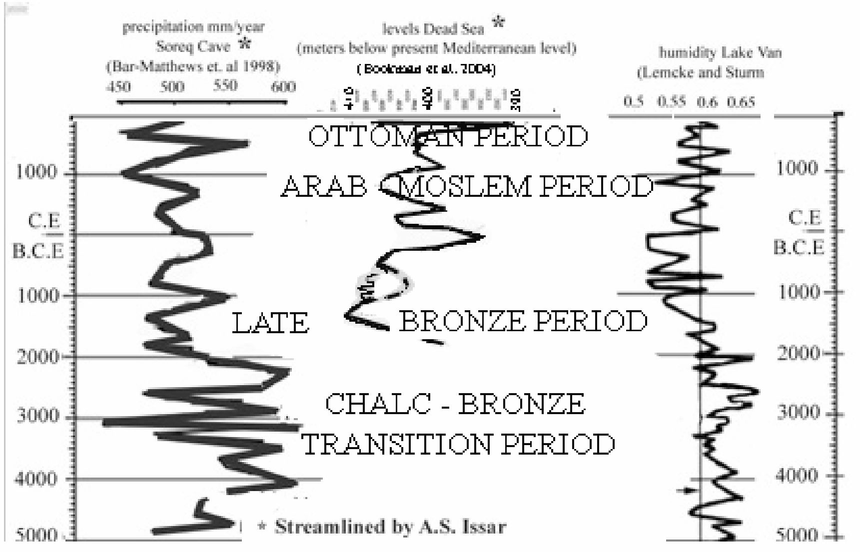

Fig. 1. Main warm dry periods in the ME during the last 7000 years

The second curve represents ancient levels of the Dead Sea as deciphered from its exposed sediments (Bookman et al. 2004) As can be seen, allowing for minor differences on the time scale, due to difference in type of sediments and their dating, periods of high values of precipitation correspond with high levels of the Dead Sea and vice versa.

The third curve portrays the ancient levels of humidity at Lake Van in Anatolia as deciphered from the chemistry of its sediments. Taking into account the constraints, mentioned earlier, with regard to the exact correspondence in time, it could be seen that the general sequence of periods of warm dry climate, according to the stalagmites correspond with low levels of the Dead Sea, which correspond with low levels of humidity at Lake Van and vice versa.

The main conclusion is that during cold periods the Middle East became humid, while warm periods were drier. Correlating the major climate changes with historical and archaeological data showed that during cold humid periods the Fertile Crescent flourished, while warm dry periods spelled socio-economic crises, desertion of urban centres especially along the desert margins, as well as processes of desertification. The warmer the climate (as can be seen by the oxygen 18 ratios) the drier it was (as can be seen from the lakes’ data) with severe socio-economic crisis (archaeological data). In contrast, Egypt fared better, economically speaking, during most warm periods, and worse during cold climates. This was due, most probably, because the Nile gets its water from the tropical and sub tropical rain systems.

A study of archaeological data from the various sites in the Fertile Crescent, situated along the margins of the desert, which experienced crisis during periods of dryness, shows that not all places shared the same fate. Urban and rural centres, which got their water supply from non-perennial streams or perched local aquifers, like Arad, Avdat and most of the Decapolis cities in Transjordan did not survive. On the other hand, sites like Jericho and Beit Sha’an that were lucky to get their supply from rivers or springs fed by regional aquifers, survived and when totally deserted it was only temporarily. The perennial springs, which mitigated the impact of periods of dryness and also enabled the rapid restoration of these emerged in most cases from the limestone and dolomite aquifers of Jurassic and Cretaceous i.e. Mesozoic age and in some cases of Eocene age. The aquiferous rocks of the Mesozoic age happen to build the backbone of the anticlinorial structures of the Taurides, Zagroids and Syrian arch, thus forming the high mountainous regions, which get high amounts of precipitation, which recharge the regional aquifers. These emerge as perennial springs feeding the main rivers of the Fertile Crescent. It can be concluded that these geological pre-conditions i.e. deposition of limestone and dolomite rocks during the Mesozoic and the post-Mesozoic folding, generated the hydrogeological conditions, which helped the civilizations of the Fertile Crescent to survive during periods of warm and dry climate.

In addition to natural pre-conditions, cultural adaptations should not be neglected. An important lesson, which can be drawn from investigating the archaeological sites is that in many cases a crisis resulting from the decline of the flow of a spring was postponed or entirely averted by human resourcefulness and innovation such as augmenting and lengthening the period of flow by tunneling, or by inventing methods of pumping from wells.

## III. THE PAST AS A KEY TO FORECAST THE FUTURE

The main forecast based on the above-mentioned observations is that the expected intensification of the Greenhouse Effect will spell a dryer period in the Middle East, i.e. longer droughts and declining yearly average precipitation. This will cause the drying up of small springs especially in the areas of relatively low rainfall average, and the decline of the flow of the big springs feeding the main rivers in this region. Also the average amount of surface runoff will decline. This being said, it should be taken into consideration that while the multi-annual average of precipitation will decline, there may be years of higher percentages of precipitation, resulting in floods and also partially refilling of the depleted aquifers. This may happen after big volcanic explosions, like after that of the Pinatubo in the early nineties.

As during the past, the decline of flow of the big springs and consequently the rivers fed by them will depend on the geography of the area of recharge of the aquifers and on their long term storage capacity. In general terms it can be said that the big springs emerging from the limestone aquifers of Mesozoic age feeding the rivers of Mesopotamia, Anatolia, Syria and Lebanon (including the Jordan) will decline but still persist. To what degree will this happen is a matter of further research. On the other hand it is expected that the tropical and subtropical systems feeding the Nile will become stronger, resulting in higher levels of this river.

## IV. THE PRESENT

As was pointed out in the previous chapter the impact of the decline in the average precipitation, on the flow of springs will be mitigated to a certain extent by the enormous storage capacity of the regional aquifers. In many regions the utilization of these aquifers can be enhanced by drilling and lowering of the water table in years of want, taking all the precaution not undertake irreversible steps. The general recommendation should thus be:

1. Develop the tools in which the storage capacity of regional aquifers should be optimally managed.
2. The artificial enlargement of storage, when possible.
3. Transfer water from regions of abundance but little use to regions where the opposite conditions exist.
4. Development of new untapped water resources.

To evaluate the possibility of undertaking these steps the present situation has to taken into consideration.

### IVa. Hydrogeological status of major aquifers of Israel and Palestine.

The practical application of these steps will be demonstrated while investigating the case of the water resources of Israel and Palestine. For this purpose a brief general survey of the hydrogelogy of this part of the Middle East will be given. The regional aquifers in this part of the Middle East are the following:

1. The Jurassic and Cretaceous limestone aquifers feeding the Sea of Galilee.

These aquifers supply the base flow of the Jordan River, which feeds the Sea of Galilee. The great part of the recharge area of these aquifers is in Syria and Lebanon. To this lake also flow springs and winter floods from the Galilee and the Golan Heights. Due to topographical reasons the groundwater storage of these aquifers can not be tapped and the overflow of these aquifers is stored in the Sea of Galilee. Presently the operational storage capacity of these aquifers is about 560 MCM (about 25% of Israel's annual consumptive use) due to evaporation and contribution from saline springs the salinity of the water of this lake is about 220 mg Cl/l

## 2. The Cenomanian Turonian limestone (Judea Group) aquifer.

This aquifer is built of permeable limestone and dolomite. Its permeability is a function of dissolution processes. The recharge areas are mainly in the mountainous area from where as ground water it flows to all directions, north, south, west and east. The western flank of the anticlinorium forms the Yarkon-Taninim aquifer. The annual recharge of the Yarkon Taninim system is about 350 MCM. The increase in water pumping from the aquifer reduced the western natural discharge in the Taninim springs to about 33 MCM of brackish water. The total quantity pumped annually from this aquifer is about 570 MCM i.e. twice the recharge, which results in the exploitation of the one time reserve and depletion of the water table. Due to the high permeability of this aquifer the water table rises sharply during wet years and declines quickly.

The part of the Judean Group aquifer east to the ground water divide is flowing towards The Rift Valley. Part of it to the fresh to mostly brackish springs flowing into the Dead Sea. A part flows to the North East to the Beit Shean Valley. The quantity that flows to the northeast and east is about 250 MCM. The springs along the eastern coast of the Dead Sea get their salts, most probably, from the contact with the interface of the Dead Sea water. Thus fresh water may be tapped more to the east, nearer to the ground water divide. This means deep wells and pumping from great depth, which implies non-conventional methods of drilling and pumping.

## 3. The Coastal Plain aquifer of Quaternary age.

The third aquifer of importance is the Coastal Plain aquifer. It is built of permeable sandstone rocks. With inter-bedding layers of semi-permeable loam to impermeable clay in-between the sandstone layers, dividing them into sub-aquifers. This subdivision is especially developed in the western part of the coastal plain, where one borehole may go through a few separate sub-aquifers, each having a different head and sometimes also different quality. Due to this separation the infiltration from the rain falling on the sandstone layers in the western part, as well as polluting solutes, affects only the upper most sub-aquifer. In this part of the Coastal Plain, all along the coast, there are areas in which; due to over pumping and decline of the groundwater table, there is a penetration of the sea interface. This, however, is differentiated according to the position of the hydraulic head in each sub aquifer. The separating layers disappear a few kilometers away from the shoreline towards the east, and the sub aquifers merge together to form one phreatic system. This causes the water table of the aquifer to be directly fed by the water infiltrating into the subsurface. In general terms one can say that in the central and eastern part of the Coastal Plain the aquifer is one unit, being subdivided only by semi-permeable loams, which retard but do not confine vertical flow. Moreover, these layers, due to their clay content, may act, as filters by absorbing pollutants, like heavy metals.

Generally, the ground water flow in the Coastal Plain aquifer is from east to west (from the recharge area on land toward the outlet which is the sea), except in areas of over-pumping, where the massive lowering of the water table has produced cones of depression. In these areas the flow is directed towards the "sinks".

On the whole the thickest part of the aquifer (about 150m) is along the seashore. Towards the east the aquifer thins out to a few tens of meters. As mentioned already, the Coastal Plain aquifer is recharged by rain falling on its surface and to some extent by floods coming from the mountains. It is also fed by return flow from irrigation and leakage from the sewage systems. The annual average natural recharge (including the flow from the east, calculated by the Hydrological Service of Israel for the year 1998/9 reached 155 MCM, about 60 MCM is recharged annually due to infiltration from irrigation and about 110MCM was recharged artificially. In total about 505 MCM, were pumped out annually. About 27 MCM flowed to the sea.

The average salinity of the water in this aquifer in Israel has risen from 100 mg/l Cl during the thirties to 200 at present and is rising 2.4 mg/l annually. This is mainly due to backflow from irrigation and recharge by reclaimed sewage. Nitrates increased from an average of 10 mg/l in the 1930's to about 60 mg/l at present. It is rising at the annual rate of 0.5 mg/l. In the part of the Coastal Plain underlying Gaza, the situation is even worse, and approximately 44 percent of the wells show nitrate concentrations higher than 90 mg/l (Melloul and Collin, 1994).

### 4. The aquifers under the Negev

Three main aquifers containing fresh to brackish water underlie the Negev Desert.

a. The Nubian Sandstone (N.S) aquifer, belonging to the Kurnub Group, of Lower Cretaceous Age. The average thickness is about 250 meters. The salinity varies between 800 to 2000 mg/l Cl. The water is fossil; age range is around 20.000 years
b. The limestone-dolomite aquifer belonging to the Judean Group of Cenomanian-Turonian age. Its average thickness about 500 m. Salinities range from 500 to 2000 mg/l Cl. The water is mainly fossil; its age range is around 10.000 years.
c. The alluvial aquifer of the Rift Valley. Its thickness varies from a few tens to a few hundred m. Recharge is contemporary. Salinities are mostly low. This aquifer is not within the scope of the current research.

In general it can be said that the first two aquifers are part of a regional aquifer extending below the Sinai Desert. The general direction of flow is from the outcrops bordering the igneous block of southern Sinai towards the Suez Gulf in the west and the Rift Valley and Dead Sea in the east. Recharge takes place on the outcrops extending along the crests of the anticlines and the erosion sinks exposing these rocks. In the areas surrounding these anticlines local groundwater mounds are formed in which water is younger and less saline. However, the quantities of contemporary recharge are negligible in comparison with the general quantity of fossil water stored in the aquifers.

Research carried out by the author and his colleagues have shown that the fossil water aquifers under the Negev can be regarded as a regional resource, containing a volume of water to last for centuries, even when quantities in the order of magnitude of 300 million $m^3$ are planned to be pumped annually.

## V. THE FUTURE PLANS FOR WATER DEVELOPMENT.

It is obvious to all the authorities concerned with the future development and management of the water resources of Israel that the potential for the development of new natural water resources is negligible and the answer for future demand for household consumption will come from desalination of brackish and seawater, while the supply to answer part of the demand for agriculture will come from reclaimed sewage. In the Negev the development of the fossil water aquifers, as well as reclaimed sewage will gurantee future supply. In 1994 about 365 MCM of sewage water was produced in Israel, of which about 309 MCM was treated. From this about 254 MCM have been used. About 136 MCM have been treated to the level allowed for irrigation and was used directly (Klein 1999). The rest was partly recharged into the Coastal Plain aquifer and part flowed to the sea. According to the Hydrological Survey (1998) the quantity of reclaimed sewage recharged into the Coastal Plain aquifer in 1997/8, was 110 MCM. Needless to say that this has affected the quality of water in this aquifer. The plan for future development of reclaimed sewage prepared by TAHAL in 1997 for the Water Commissioner, forecasts that in the year 2020 about 593 MCM will be available, from which 494 MCM will be directly used to answer part of the agricultural demand. The rest will be recharged or used for recreation sites, such as keeping the flow of rivers etc. The rest of the demand by agriculture reaching 647 MCM will come from natural resources.

In the forthcoming sub-chapters will be presented additional directions of solutions for the water problems of Israel and Palestine. Needless to say, that the execution of these ideas will have to be done stage by stage, parallel to the progress of the peace process. Yet, it is important to proceed with the preparation of a master plan based on new ideas and concepts in the first place in order to eliminate unnecessary obstacles to the peace talks, and in the second place to give negotiators new ways of thought.

This optimistic attitude is supported, in some way, by a survey of the history of the development of the water resources of Israel. This survey shows that from time to time experts expressed the opinion that the limited water resources of this area will not be sufficient to supply a new modern agricultural and industrial society. The innovations in all that concerns methods of water development and use, introduced by water engineers, hydro-geologists and agronomists have falsified this prophecy.

### V. a. The development of a new long-term storage reservoir for Israel and the Palestinian Authority in the Coastal Plain aquifer.

According to various estimates annual agricultural water demand by the year 2020, in Israel and Palestine is expected to reach 1,540 MCM. Taking into account that part of it will have to come from reclaimed sewage water, which when fully exploited in both countries may reach 650, with about 900 MCM from natural resources, there will still remain an unsatisfied annual demand of about 400 million MCM for agriculture. All this is said when no major deterioration of the climate is forecasted. Once a pessimistic forecast is adopted, the fall in the natural supply may amount to 25% of the present average amount. This will bring the deficit for agricultural demand to 500 MCM/y

Taking this figure into consideration, one can not escape from the conclusion that water supply from natural resources for irrigation will have to be reduced drastically by the year 2020 (and even totally cut during spells of dry years) and a major part of the urban demand of the Israeli population will have to be met by the desalination of brackish and of seawater. At the same time the increased demand for agriculture will be mainly by the Palestinian population, and for this purpose the use of reclaimed sewage will increase.

Considering these general assumptions, the two main problems to be dealt with are:

1. The storage of surplus of water during years when precipitation will be above the average.
2. The storage of reclaimed sewage in general and in particular during the winter months, when supply exceeds the seasonal demand for irrigation.

Examining the various aquifers from the point of view of storage, it seems clear that the greatest potential for further augmentation of storage is in the Coastal Plain. This is due to the fact that the sandstone layers from which this aquifer is built have a high storativity coefficient (average 10%), due to their high porosity. At the same time the velocity of flow in the sandstones is relatively low due to low permeability coefficient (K=1m/d). On the other hand the high permeability of the limestone aquifer (K=100m/d) causes water recharged to flow to the outlets in a rather short time. Another fact, which has to be taken into consideration is that in the eastern part of the Coastal Plain a large volume of the aquiferous layers is unsaturated, and can be recharged artificially providing additional storage.

The shifting of the recharge and storage areas to the east is a prerequisite in order to meet the future requirements for storage, which should reach about five times more than that of the present. Today this is carried out in a region densely populated and as the demand and cost of land is increasing. Moreover the location of the present subsurface storage field of the treated sewage of the central Coastal Plain (the Shafdan) is at a rather small distance from the sea. This is an area underlain by confining layers, which limits the inflow of the recharged water to the deeper aquifer and thus causes water to flow to the sea. If the proximity to the sea remains, these losses will become even more pronounced once the quantity stored is increased.
Taking the above mentioned basic assumptions, concerning desalination and agricultural use, into consideration, as well as the hydrogeological characteristics of the Coastal Plain which enables the storing of reclaimed sewage and floodwater. Then when the Israeli and the Palestinian Authorities collaborate, they will be able together to close the gap between availability and demand.

In the first place the Coastal Plain aquifer will have to become the conjoint storage for Israel and the Palestinian Authority. Once the recharge of reclaimed sewage and storage areas will shift from western part of the region to its eastern part it will be possible to recharge and store also the floodwater coming from the Palestinian territory. At the same time Israel will have to plan anew its recharge areas for its reclaimed sewage as well as floodwater. Due to paleo-environmental conditions, which existed during the Quaternary period, all the riverbeds, which cross the Coastal Plain are underlain by thick layers of clay. Moreover, adequate natural sites for storage dams are very rare in the central and western parts of the Coastal Plain. These conditions dictate that the best places for storage and later gradual recharge of the floods are in the eastern parts of this region, close to the foothills.

As part of the new cooperative planning, storage in the part of the Coastal Plain underlying the Gaza Strip should follow a similar policy. This will enable the recovery of the over-pumped aquifer of the Gaza. This can only be done once the gap between supply and demand in this region will be supplied from Israel and local desalination projects. On the whole the total quantity of water recharged annually to the Coastal Plain aquifer would be of the order of magnitude of 600 MCM. The quality of this water supply would be as follows:

1. One-third recharged from precipitation, infiltration from urban runoff and returning irrigation water would contain about 300 mg/l Cl.
2. Another third, coming from the winter flow of the Jordan River, diverted above the Sea of Galilee to the Israeli National Carrier would contain about 100 mg/l Cl.
3. One-third will come from reclaimed wastewater, would contain an average of 400 mg/l Cl.

All this would eventually combine to give an average water quality of about 270 mg/l Cl.

This conceptual model of the coastal aquifer as the main long-term storage aquifer is an example for a new way of thought, a regional plan for Israel and the Palestinian Authority.

### V. b. Diversion projects of the Jordan and Yarmouk rivers

As mentioned this plan takes into consideration the diverting of part of the flow of the Jordan River above the Sea of Galilee, at about 100 meters above sea level (the original plan for the National Water Carrier). This will enable the use the Sea of Galilee as storage for Yarmouk River floodwater instead. This would also help Jordan store water for its Jordan Valley agriculture without the need of a big dam on the Yarmouk River. Currently, the Jordan flow is stored in the Sea of Galilee, 200 meters below sea level, from which it is later lifted and distributed through the National Water Carrier to areas extending mainly over regions averaging 150 meters above sea level in altitude. Pumping thus requires about 12 percent of total Israeli electricity production and raises the average cost of water in Israel to 0.30 US $ per cubic meter (Lonergan and Brooks, 1994).

### V. c. Changing the regime of flow of the mountain aquifer.

Once the role of the Coastal Plain aquifer is recognized as a storage reservoir for a regional water supply of low-grade water the limestone aquifer of central Israel will remain the main supply of water of drinking quality. This will require close cooperation between Israel and the Palestine. Cooperative efforts will enable the two parties to capture the water from the eastern subsurface drainage basin of the mountain aquifer about 100 million cubic meters per year, which flows to the Rift Valley to emerge as brackish or saline springs.

### V. d. Development of new recharge techniques.

A series of problems related to the more technical aspects of recharge calls for interdisciplinary brain-storming, in which geologists, environmentalists, water engineers, and economists attempt to devise solutions to problems of inventing new recharge methods, and locating new recharge areas in a region with a very high population density. A special emphasize has to be put on the reclamation and storage of water from built up and paved urban areas. This either by the development of porous concrete and asphalt or by devices of collection of urban runoff and its recharge.

### V. e. Utilization of one time reserve from fossil aquifers.

A series of studies by the present author (Issar et al. 1973, Issar and Nativ 1988, Tzur et al 1989, Issar 1994) have shown that a few hundred million cubic meters per year may be pumped out from the Nubian Sandstone aquifers underlying the Negev and Sinai. This pumping is guaranteed for at least the coming century. The actual quantity and duration would be a function of the management policies and various economic factors. In principal, however, such a project is technically feasible, and the water is of adequate quality. Although this water source is not replenishable, it may be regarded as any other non-replenishable resource (e.g. oil, coal, and iron ore). In other words, the evaluation of whether or not to use it should be based on economic considerations.

### V. f. Importing water from Turkey

Turkey has proposed a mega-project of transporting water from the eastern Mediterranean coastal area of Turkey to Syria, Jordan, Saudi Arabia, and the Gulf Emirates in the past. The Turkish plan includes two pipelines. The western line would extend 2,800 kilometers and pump 1,300 million cubic meters per year to Syria, Jordan, and Western Saudi Arabia. The eastern line would cover 4,000 kilometers en route to the Persian Gulf, through Kuwait, Eastern Saudi Arabia, Bahrain, and Qatar. An alternative pipeline has also been proposed (unofficially) to supply water to Syria, Jordan and the West Bank, its capacity being 730 million cubic meters per year (Lonergan and Brooks, 1994).

While the problem of water scarcity of Syria is more that of transport from one part to the other, the problems of Jordan, Palestine, Israel and especially Egypt is much more crucial than that of the Arabian Peninsula. The most crucial problem is that of the fast growing population of Egypt where the demand for food supply may pose a severe economical crisis in this country if no special measures are taken to boost its available water supply. Thus an alternative plan to that mentioned above should aim to avoid this catastrophe and at the same time solve the long-term problems of water shortage in Israel, Palestine and Jordan. This plan, in view of the forecasts of global climate change, is a "win or win" project. This because the warming of the oceans may bring a strengthening of the monsoons, which would in turn cause during some years a surplus of water in the Nile River exceeding the capacity of the Aswan dam. Yet, this is still only a hypothesis. Thus, when the likely water shortage develops in Egypt, a Turkish project may bring water from north (Turkey) to south (Egypt), but if there is an abundance of water in the south, a Nile-based project may work in the opposite direction.

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