

INNOVATIVE SOLUTIONS FOR WATER WARS IN ISRAEL, JORDAN AND THE PALESTINIAN AUTHORITY

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ABSTRACT

In the late 1950s Jordan and Israel embarked on a race to collect, convey and disperse the free-flowing waters of the Jordan River below the Sea of Galilee. In 1955 the Johnston Unified Water Plan was adopted by both countries as a treaty of allocation rights. By 1961 the Jordanians completed their 110-km long East Ghor Canal, followed by Israel's 85-km long National Water Carrier, initially completed in 1964 and extended in 1969. The Johnston allocation plan was successfully implemented for 12 years, until the June 1967 war between Israel and her neighbor Arab states.

The Israelis have spearheaded the effort to exploit the region's limited water resources, using wells, pipelines, canals, recharge basins, drip irrigation, fertigation, wastewater recharge, saline irrigation and, most recently, turning to desalination. In 1977 they began looking at various options to bring sea water to the depleted Dead Sea Basin, followed by similar studies undertaken by the Jordanians a few years later.

A new water allocation plan was agreed upon as part of the 1994 Israel-Jordan peace treaty, but it failed to address Palestinian requests for additional allotments, which would necessarily have come from Jordan or Israel. The subject of water allocation has become a non-negotiable agenda for the Palestinian Authority in its ongoing political strife with Israel. In 1996 Harza Engineering Co of Chicago was retained by a joint steering committee created as part of a tri-lateral initiative between the United States, Jordan and Israel. Harza investigated the feasibility of constructing a Red Sea-Dead Sea canal/pipeline connection from Aqaba to the Dead Sea. Water will be pumped up 125m/410 ft from the Red Sea to a 45 km long tunnel portal, which will carry it beneath the 220m/722 ft crest of the Arava Valley, then plunge some 533m/1,750 ft to the South Basin of the Dead Sea. This water will be used to generate electricity and can be processed by reverse osmosis for desalination using the available pressure head generated by the extreme fall. The Dead Sea has been dropping an average 0.50m/1.64 ft per year since 1960, due to water removals from the upper Jordan River and increased potash extraction from Dead Sea brines by both countries.

At the United Nations world summit in September 2002, Israel and Jordan announced that they would join forces to build the Red Sea-Dead Sea canal. The 310 km/186 mi long pipeline will cost about \$1 billion, with construction due to begin in late 2003.

Joint ownership of such major engineering infrastructure between two sovereign nations often at odds with one another is unprecedented. The unconsolidated Lisan formation underlies much of the Jordan Valley. It was deposited during the Pleistocene enlargement of the Dead Sea, known as Lake Lisan. Engineering of structures such as dams, canals and dikes on the Lisan formation has proven treacherous.

Security concerns have also been raised on both sides; the pipeline may serve as a magnet for terrorists, similar to the Los Angeles-Owens River Aqueduct of the 1920s. The absence of any role involving the Palestinian Authority is also likely to complicate any long-lasting solution to that brewing problem, unless the Israelis or the Jordanians are willing to make water concessions or include the Palestinians in any development plans. That doesn't appear likely without the Israelis and Palestinians coming to some sort of binding agreement through economic development enticements similar to those offered by the United States to Egypt in the Camp David accords in 1979 and to the Jordanians in the Arava Treaty in 1994.

INTRODUCTION

Israel and the Palestinian Territories are separated from Jordan by the Syrian-African Rift, the longest valley in the world (Figure 1). The Jordan River is born in the slopes of Mt. Hermon (el 2814 m/9232 ft) which lies within the security zone occupied by Israel during the June 1967 war (it used to be within Syria). From the slopes of this Anti-Lebanon Mountain Range the Jordan River is born, coming together in the upper Hula Valley and flowing southward into the Sea of Galilee at 220m/722 ft below sea level. From here the river meanders almost 300 km/180 mi to travel the 105 km/63 mi straight line distance to the Dead Sea. The lower Jordan River is highly polluted by fertilizer and pesticides and is no longer potable or suitable for agricultural irrigation.

The Dead Sea is a pull-apart basin formed between the Jericho and Arava fault segments of the rift (Figure 2), which lie 14 km/8.4 mi apart. The North Basin of the Dead Sea is actively subsiding, with maximum bottom depth -730 m (Hall, 1979). The South Basin was much more shallow, and has been reclaimed for potash extraction by the Israelis (since 1966) and Jordanians (since 1977). The surface elevation of the Dead Sea began has been dropping with an accelerating rate, which has averaged about 0.50 m/1.64 ft per year since 1960 (Figure 3). It presently stands at -415 m below sea level, a drop of 25 m/82 ft since 1930. South of the Dead Sea lies the Arava Valley, which separates the Negev and Jordanian Deserts for a distance of roughly 200 km/120 mi. The Arava gradually rises to an elevation of 220 meters above sea level about 80 km from the head of the Gulf of Aqaba/Red Sea.

Since mid-1980s expanding populations of Israel, Jordan and Palestinian Authority creating a situation where dwindling shared water resources. These countries have been exhausting their groundwater reserves for crop production, even when many foodstuffs might be imported at a lower unit price. The Israelis have exhibited remarkable innovation in tackling their difficult water problems in the face of one of the world's

fastest growing populations. They have unintentionally supplied technical leadership in the water resources arena, their activities often triggering response and imitation by their Arab neighbors.

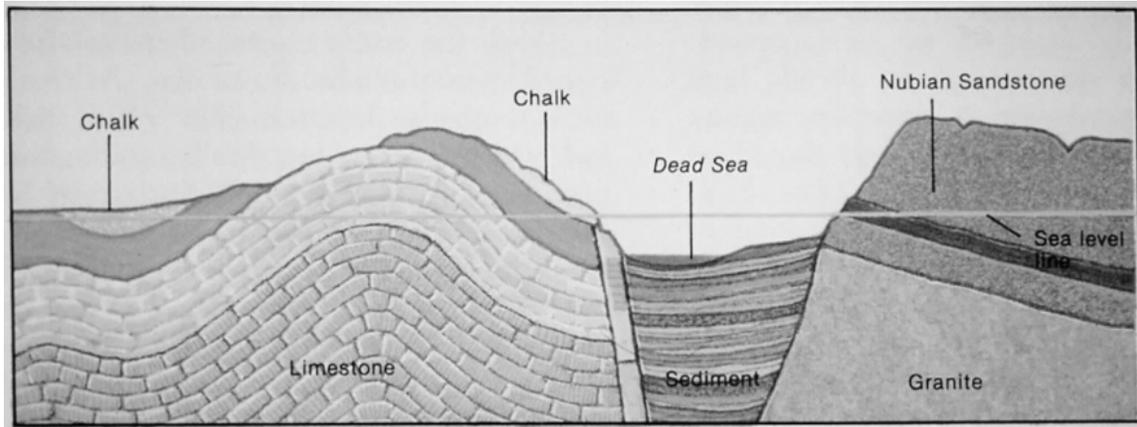


Figure 1 – Generalized geologic section through the Syrian-African Rift, between Israel and the West Bank territory on the left and Jordan on the right. The Dead Sea occupies the lowest point in a massive graben formed by a pull-apart basin between the Mediterranean and Arabian tectonic plates. Taken from Beitzel (1985).

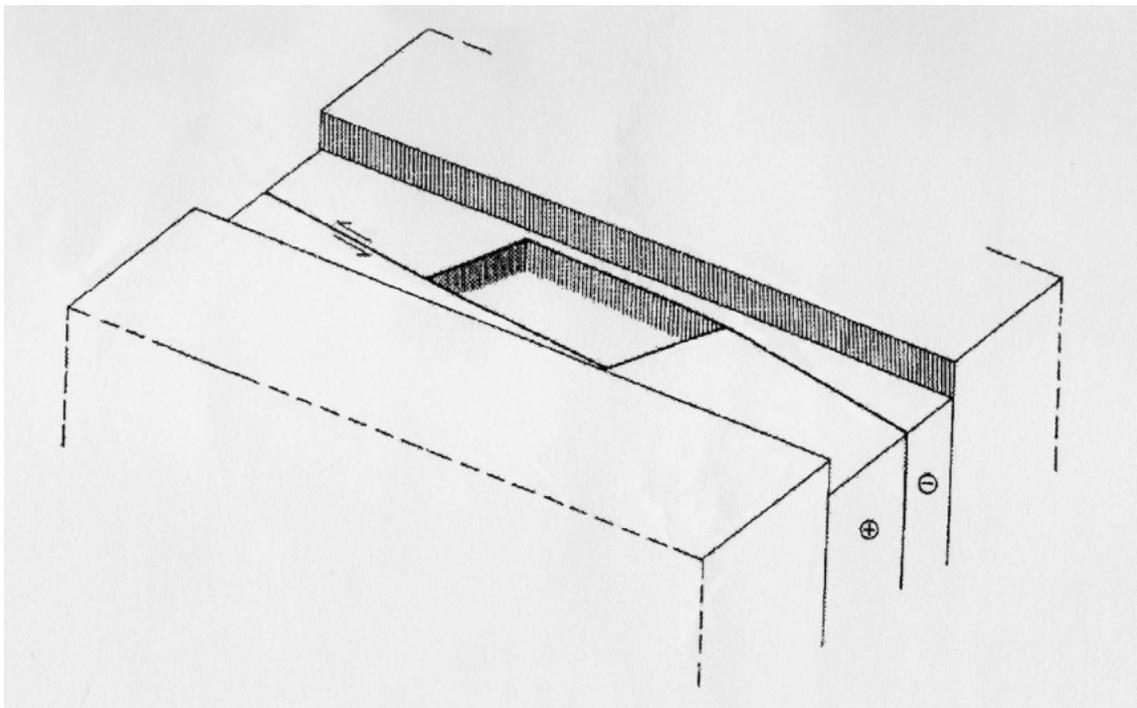


Figure 2 – Sketch showing the structural setting of the Dead Sea Basin. A pull-apart structure defines the basin, caught between two master strike-slip faults, the Arava (at right) and Jericho (at left), which are separated by about 14 km. Taken from Garfunkel (1997).

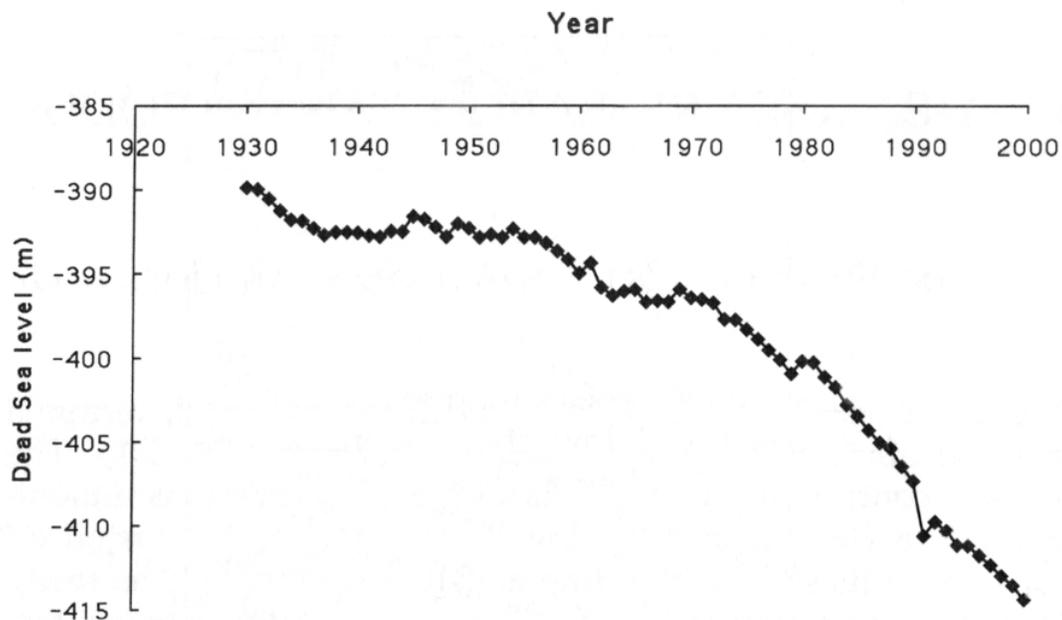


Figure 3 – Hydrograph of the Dead Sea water/brine level since 1929.

Middle East population growth averaging a staggering 3 percent annually. The current population of Israel and Palestinian Territories is approximately 8 million. The Arab population of Gaza and West Bank is 1.5 million. Israel's growth has come about in large part through three waves of immigration: the first following establishment of British mandate at end of First World War (1918); a second pulse after the Second World War, particularly 1948, when State of Israel was created; and a more recent influx of immigrants between 1987-2002, when 2 million Russian Jews settled in Israel. The population of Israel is expected to grow to 9 million by 2020. The population of the Palestinian Authority expected to jump to 3 million by 2020.

According to the World Bank, the Middle East has the highest median cost of water supply and sanitation in the world, reaching \$300 per capita in 1985, about double what it costs in the United States and about 5 times what it cost in Southeast Asia. In 1991 Starr (1991) asserted that Israel, the Palestinian lands (West Bank and Gaza) and Jordan are jointly facing a combined water deficit of at least 300 to 400 million cubic meters per year, and as much as 500 to 600 million cubic meters, depending on weather patterns and consumption (Casa, 1991). Jordan is growing at an alarming rate of 3.8 percent per year, one of the world's highest growth rates. Like Israel, Jordan has exhausted her natural water resources and must begin looking seriously at desalination and water import schemes to meet future demands.

BACKGROUND

Water Resources Development by Israel and Jordan

The first modern water conveyance system in the region was initiated in 1935 to bring well water from the Jezreel Valley southward through Palestine when it was a British mandate, all the way to the northern Negev Desert. Three experimental settlements were constructed in the Negev in 1943 followed by 11 more in 1946 and five in 1947. The first pipeline from the Jezreel Valley into the northwestern Negev was only 0.15 m in diameter, but stretched 190 km. This was completed in 1947. The first large scale supply system was a 1.68 m diameter pipeline extending 130 km from the Yarkon River to the Negev completed by the Israelis in 1948. It was capable of supplying 100×10^6 m³/yr.

In the late 1950s Jordan and Israel embarked on a race to collect, convey and disperse the free-flowing waters of the Jordan River below the Sea of Galilee. In 1955 the Johnston Unified Water Plan was adopted by both countries as a treaty of allocation rights, which was observed more or less successfully until the June 1967 war. By 1961 the Jordanians completed their 110-km long East Ghor Canal (now called the King Abdullah Canal). During the decade of the 1960s the Israelis were busy constructing their National Water Carrier, an 85 km long system of pipelines, open channels, tunnels, re-regulation pools and distribution reservoirs (Kantor, 2001). In 1964 the Arab League countries tried to sabotage the Israeli system by diverting water just downstream of the Sea of Galilee. The Israelis responded by moving their intake to the northwestern shore of Galilee, near Tabgha. When this didn't stop progress the Syrians began diverting the headwaters of the Jordan River (1964-65). The Israelis responded with a series of air strikes and commando raids on the Syrian diversion works (Gleick, 1993). This military actions contributed to the tensions that led to the 1967 war, when Israel secured the Golan Heights and Mt. Hermon, effectively doubling its domestic water supply. The National Water Carrier, which is often referred to as the Kinneret-Negev Conduit, was completed in 1969.

At the point of withdrawal water is lifted 372 m from the Sea of Galilee and flows by gravity to Israel's coastal plains and is pumped, in stages, to the kibbutzim in the northwestern Negev. Since completion of the system Israel has augmented its capacity by drilling hundreds of wells to tap groundwater resources along the route, so that the National Water Carrier is presently conveying around 400×10^6 m³/yr, which supplies about 25% of Israel. In January 1990 and the summer of 1991 it was shut down by draught conditions and deliveries to agricultural users were slashed 50%, bringing attention to how tenuous the water situation had already become in the face of two million Russian immigrants slated to enter the Country over the following decade.

For the Jordanians, quality water has become increasingly hard to find in the Jordan River Valley. The majority of Jordan's supply comes from the Yarmuk River and wells drilled in nahals and wadis during upper catchments east of the valley. Springs occur along the bounding faults. The Zarqa River supplies about 25% of the annual supply and

the remainder is collected from side wadis. After the 1994 Treaty of Peace was signed between Jordan and Israel, fresh water began moving through a pipeline from the Sea of Galilee to Jordan's King Abdullah Canal (formerly the East Ghor Canal).

Israel's Management of Water Resources

Aquifers

The Israelis generally tap two major aquifers. The Yarkon/Taninim or "Mountain" Aquifer that lies beneath north central Israel and the West Bank territory of the Palestinian Authority (Figure 4). 70 to 80% of the Mountain Aquifer theoretically lies beneath the West Bank, as well as 70 to 80% of the effective recharge area. But the recharged waters flow westward, toward the coastal plain. Since the mid-1960s the Israelis have tapped 25 to 45% of their agricultural water from this aquifer, causing a gradual but sustained depletion.

The Coastal Aquifer underlies the coastal plain, along the Mediterranean Sea in west central Israel. It is comprised of Plio-Pleistocene age sands and calcareous sandstone. Although the coastal aquifer contributes about $250 \times 10^6 \text{ m}^3/\text{yr.}$, sea water intrusion has become a nagging problem, obviating withdrawals within 40 to 80 m of the ground surface. The Coastal Aquifer does not extend beneath the West Bank but does lie beneath the entirety of the Gaza Strip.

Overdrafting of groundwater

During the first half century of Israeli development (1948-98) they succeeded in overdrafting the country's water resources between 15 and 20% beyond the recharge capacity (see lower water table in Figure 3). Although recharge efforts increased significantly each decade, so did harvest and consumption. An additional headache for all three countries has been increasing levels of groundwater pollution, mostly from pesticides, fertilizers and untreated sewage disposal. In the highly concentrated Gaza Strip (population just over one million), the Coastal Aquifer has become seriously contaminated, requiring additional water and sewage treatment infrastructure be constructed (Committee on Sustainable Water Supplies, 1999). But, loans for these improvements have not been forthcoming from foreign sources, fearful of instability popularized by the Palestinian Intifada which erupted in 1999.

The Israelis have developed an innovative multi-pronged attack to solve both their short and long-term problems with over-utilization of groundwater. The first practice they employed was drip irrigation, later adding fertilizers to create a dual irrigation process termed "fertigation". Another avenue of research was focused on developing salt tolerant species for agricultural crops. They have had some stunning initial successes raising crops irrigated with brackish water in the 1990s, to almost everyone's surprise. During this past decade they embraced wastewater reclamation for groundwater recharge of their

Coastal Aquifer. Their newest arena is reverse osmosis desalinization, which will come on-line sometime in 2004.

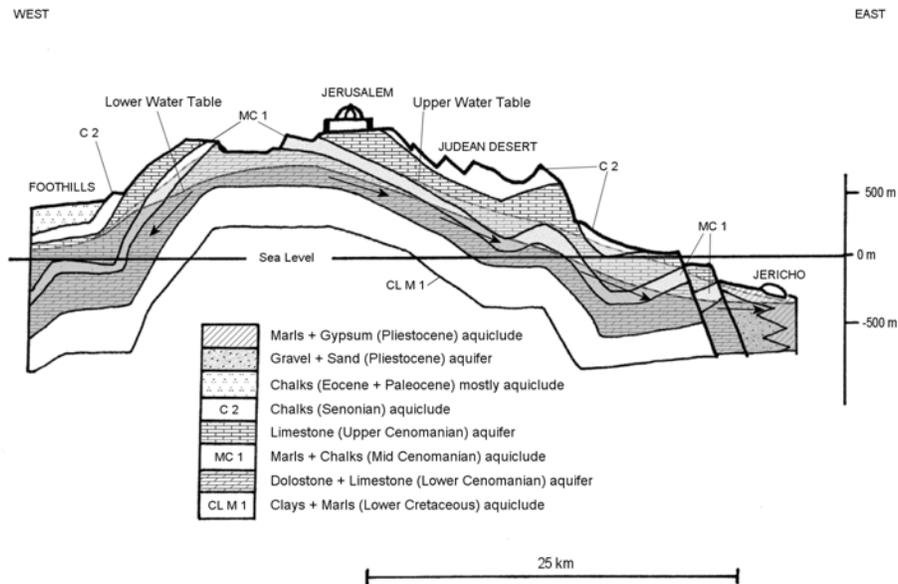


Figure 4 – Cross section through the Yarkon-Taninim, or Mountain Aquifer, in central Israel and the West Bank. This aquifer was steadily reduced between 1948 and 1991. The Israelis have not been able to recharge this aquifer as readily as the younger Coastal Aquifer underling the western coastal lowland. Based on information in Issar (2000).

Drip Irrigation

Agricultural irrigation in Israel is dominated by drip irrigation, initially introduced in some of the Negev kibbutzim in the late 1960s (White, 1978). In the past 15 years these system have been transitioned to subsurface micro-drip irrigation techniques, designed to reduce evaporation losses even further. This has been accompanied by the increasing employment of hot houses and green houses on kibbutzim all over Israel. Many of the Israeli drip systems now employ potassium chloride fertilizers, which they have dubbed “fertigation”.

Saline Water for Agriculture

For the past 20 years the Israelis have been experimenting with irrigating different crops using saline water (Sitton, 2003). Saline water has been used successfully on tomatoes, melons, cotton, olives, flowers and alfalfa, subject to controlled use in drip irrigation. This practice has allowed new groundwater withdrawals of lower quality groundwater in the Negev Desert region. The Israelis have experimented to determine the threshold tolerance of each crop and soil type. They have reported that expensive “sweet tomatoes” can be grown in hot houses using water with up to 3000 microseisms ($\mu\text{S}/\text{cm}$)

electroconductivity (EC) and up to 9000 EC saline water to irrigate alfalfa in more arid portions of the Negev. In this arena the Israelis are breaking new ground, which is likely to be emulated by other countries before long.

Wastewater Reclamation

Israel currently recycles approximately 250 to 300×10^6 m³/yr from sewage effluent. In 1995 the Israelis augmented their Shafdan Sewage Treatment Plant in Tel Aviv to recycle swage effluent on a large scale (120×10^6 m³/yr), solely for aquifer recharge and subsequent withdrawal for agricultural use (Sitton, 2003). The Shafdan plant processes wastewater from the 2.1 million population of Tel Aviv and 12 surrounding communities in the Dan Region. The effluent undergoes secondary treatment before being discharged into spreading basins for one day, then allowed to dry for 2 to 4 days. Filtration occurs naturally via percolation through Coastal Aquifer. The aquifer is then tapped from the Coastal Aquifer to provide agricultural water for the western Negev through the new Third Negev Pipeline, which presently conveys about 115×10^6 m³/yr.

In the research arena the Israelis are experimenting with membrane filtration to bring down the salinity of waste stream effluents so they can be applied directly to certain crops, in lieu of being treated via traditional groundwater percolation/filtration techniques.

Desalination of Sea Water at Coastal Sites

Israel's far flung Arab neighbors have actually spearheaded the movement towards dependence on desalination for domestic water supply. Until recently, 60% of the world's desalination capacity lay in Persian Gulf states, with Saudi Arabia accounting for almost a third of annual world production (Starr, 1991). Kuwait, Saudi Arabia and the United Arab Emirates are almost totally dependent on desalination for their fresh water supply. The Saudis have repeatedly expressed concern over the security of their immense power generation/desalination plants, which are strategically vulnerable to attack or sabotage.

The Israelis have recently decided to pursue desalination as an additional water source. By 2004 they hope to complete a reverse osmosis desalinization plant at Ashkelon which can produce 50×10^6 m³/yr of fresh water. Israel is in process of designing a second desalination plant with equal capacity. They estimate that the reverse osmosis process can produce cubic meter of water for just US\$0.57, making it an attractive alternative. If the two pilot plants are successful, the Israelis hope to expand their desalinization capacity to between 500 to 600×10^6 m³/yr by 2012. This could allow additional expansion of their agricultural holdings into irrigable parts of the Negev.

Recent plans to import water

In 1994 Turkey put forth a plan for a "Peace Canal" which would convey fresh water from the Ceyhan and Seyhan Rivers in Turkey to Syria, Jordan, Israel and the

Palestinians (Wachtel, 1994). The project was envisioned to be comprised of two subterranean pipelines which would run through western Syria, thence into a 60 km long 70 m wide tripartite canal. This canal would drop 150 m through two powerhouses on the Golan Heights and connect with Israel's National Water Carrier. The estimated cost was \$8 billion with 15 years needed for construction. In the end the Israelis rejected the scheme because of cost and security concerns.

Another scheme for importing Turkish water to Israel is through the use of "Medussa bags", enormous PVC-coated bladders measuring 650 x 150 meters with a 22 meter draft. These are capable of carrying 1.75 million cubic meters of water and can be towed by tugboats to a point several kilometers offshore, where the water would be pumped out. Then lifespan of the bladders is thought to be about seven years. The idea was to allow Israel another source of fresh water to recharge depleted aquifers. Israel feared that a regime change in Turkey could spell cessation of this source as well, so turned their attention to desalination plants solidly under their own control.

Water Resources of the Palestinian Authority

When the Declaration of Principles between Israel and the Palestinian Liberation Organization was signed in 1993, a provisional government was established over the West Bank and Gaza Strip known as The Palestinian Authority. West Bank Palestinians obtain their water from pre-1967 wells, but were not permitted to drill any additional wells until the 1994 treaty between Israel and the PLO. Palestinians can purchase additional water from Israel's National Water Carrier for a charge. While the Palestinians acknowledge that Israel provides requisite water to the West Bank settlements for domestic and industrial use, Israel refuses to increase the volume of water sufficient to sustain new agricultural crops, which the Palestinians maintain are desperately needed in light of their expanding population (which is growing at a rate of 3% per annum).

Both Jews and Arabs living in Israel use more water per capita than Palestinians in the West Bank or Gaza. But, domestic and industrial consumption only account for about 30% of Israel's water consumption. 70% of Israel's water is used to support their expansive agricultural enterprise, which includes water loving crops such as cotton and watermelons, targeting the European market. Although the agricultural sector supplies just 5% of Israel's Gross National Product, there is a bipartisan feeling among the country's leadership that food production should be given a high priority, to better insure self reliance in a world filled with potential enemies.

DISCUSSION

Forging Cooperation Between Jordan and Israel

Jordan's national policies have largely evolved as reactions to increasing Israeli development and utilization of the region's extractable water. Jordan has relied on a series of incremental measures, including dams, canals, deep withdrawal wells and drip irrigation technology. They have also investigated solar powered pumping and desalination of brackish groundwater in the northern Arava Valley, south of the Dead Sea and pumped storage schemes aimed at establishing massive desalination plants near Aqaba.

Israel, Jordan and the Palestinian Authority are linked by common aquifers subject to overdrafting and contamination. Formal protocols need to be developed for managing shared water resources. Assistance from international organizations and donor countries has historically been withheld because of perceived instability of the region.

One example was the al-Wahda Dam on the Yarmuk River, between Syria and Jordan (Figure 5). This project was originally conceived in 1955, but it wasn't until 1987 that engineering plans were completed and the search began for funding. The World Bank was approached, but Israel succeeded in lobbying against the project, based on its claim to approximately 3% of the tributary watershed feeding into the proposed reservoir, which lay on the border between Syria and Jordan. The Israelis were worried that the loss of this water could adversely affect downstream recharge, and hence, their groundwater withdrawals within and adjacent to the lower Jordan River Valley, between The Sea of Galilee and the Dead Sea. They suggested taking water from the Yarmuk and storing it in the Sea of Galilee, the outlet of which is within Israeli control. The Israelis were successful in preventing western funding of the project.

14% of the World Bank's lending is for hydro-development. In 1993 the Bank stated that water must be managed to meet national objectives, including social, security, and economic objectives, and that water is an international resource whose apportionment and distribution requires extensive research and international cooperation (Klump, 2002). In essence, the bank stated that all entities having ownership of the watershed in question, must agree on a protocol for development. This was impossible to achieve in the Jordan River watershed because of historic enmity between Israel, Jordan, Lebanon and Syria.

By 1999 relations between Jordan and Syria had improved to the point that the Wahda Dam was back on the negotiation table, but only if Arab funds could finance the \$300 million project. An agreement was signed between Jordan and Syria in July 1999 and funding was apportioned between the Jordanian national treasury, the Arab Fund for Economic and Social Development and the Islamic Development Bank, circumventing the World Bank. Despite all these maneuverings, ground remains unbroken at the site, awaiting decisions about foreign contractors and the requirement that 40% of the contract monies be given to Jordanian and Syrian subcontractors.

A new water allocation plan was agreed upon as part of the 1994 Israel-Jordan peace treaty, which has not been popular with the Jordanian people (Scham and Lucas, 2001). The treaty promised crucial allocations of water from Israel, cooperative efforts aimed at

finding additional resources, establishing increased storage within Jordan, water quality and protection measures and protection of shared groundwater resources.

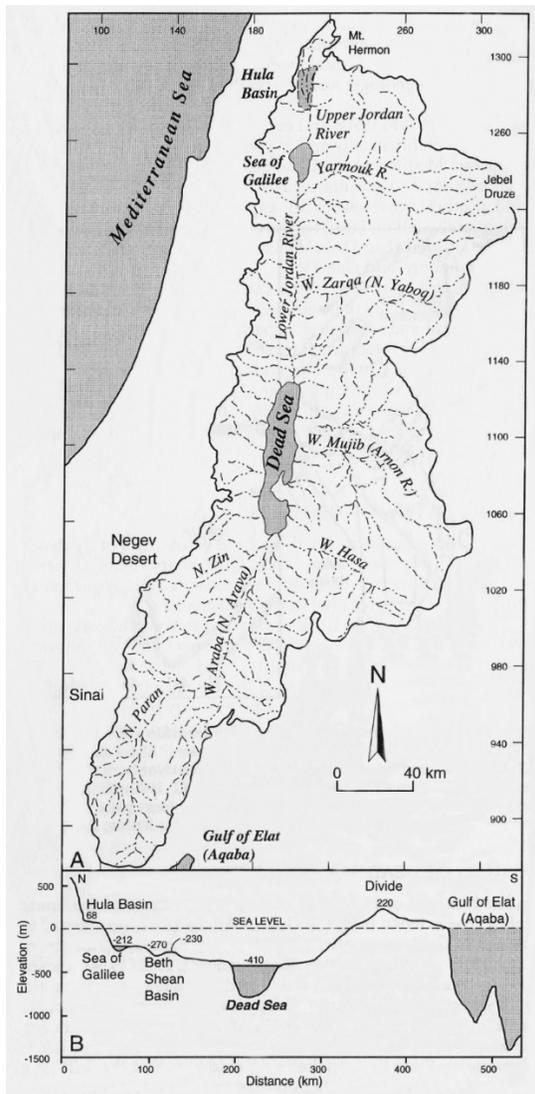


Figure 5 – The Dead Sea and its natural drainage basin, extending from Mt Hermon in the north to the Sinai Peninsula in the south, over 450 km. Most of the basin lies below sea level (see inset below). Taken from Niemi, Ben-Avraham and Gat (1997).

The treaty also mandates exchange of technical data for the first time between the two nations (Scham and Lucas, 2001). But the 1994 treaty failed to address Palestinian requests for additional allotments, which would necessarily have come from Jordan or Israel. The subject of water allocation has become a non-negotiable agenda for the Palestinian Authority in its ongoing political strife with Israel.

Mediterranean-Dead Sea Canal

In the 1950s, American soil scientist Walter C. Lowdermilk (1888-1974) proposed the construction of a sea water canal from the Mediterranean Ocean across the Negev Desert to the Dead Sea. He had previously authored a book which became a guide for water resources development by the Israelis (Lowdermilk, 1944). Lowdermilk showed that a 400 meter drop could generate 100 Mw of electrical power. The idea languished till 1977 when Israel began considering four

different routes for a canal to bring sea water into the depleted Dead Sea Basin. One of these was along the Arava Valley, withdrawing water from the Gulf of Aqaba at Elat. The other three possibilities were schemes that involved excavating long tunnels to bring water from the Mediterranean to the Dead Sea (Figure 6).

The Israelis ended up favoring the southernmost Med-Dead route, for reasons of military security, avoidance of possible contamination of the Mountain Aquifer in central Israel and proximity to the developing northern Negev Desert. They envisioned a flow rate of $1.6 \times 10^9 \text{ m}^3/\text{yr}$, or 1.3 million acre-feet/year. This would be sufficient to generate 800 million Kw-hrs of electricity and would refill the Dead Sea in 10 to 20 years time to the level it had prior to 1930 (about -390 m below sea level).

Figure 6 – Mediterranean-Dead Sea and Red Sea-Dead Sea canal routes examined by the Israelis in 1977. At that time the Israelis favored the southernmost Med-Dead route for better security and less potential for contamination of their Mountain Aquifer (taken from Arad and Beyth, 1990).

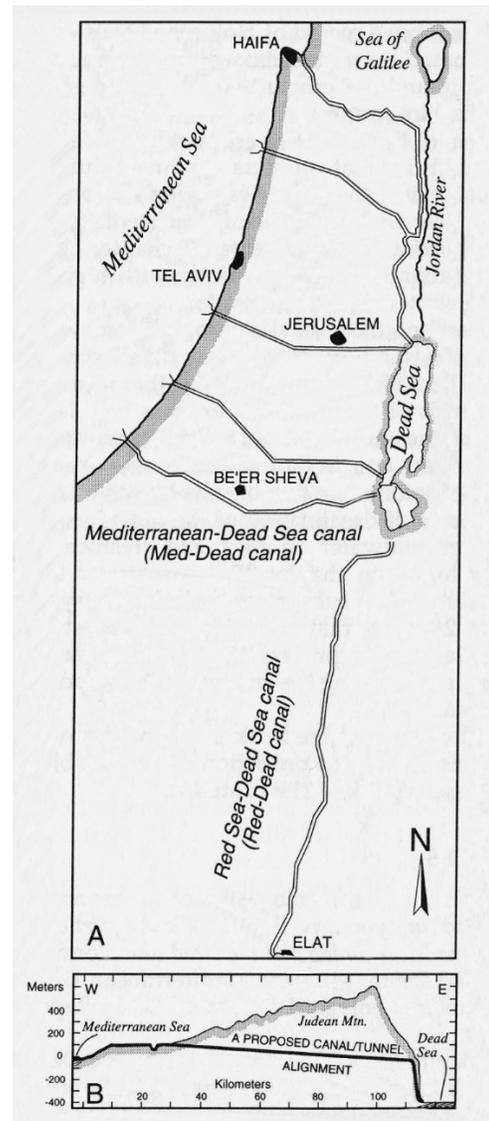
Red Sea- Dead Sea Canal

In the early 1980s Jordan began looking at the feasibility of a Red Sea-Dead Sea pipeline, extending from their Red Sea port at Aqaba. After the Jordanians signed the 1994 peace treaty the Jordan River Valley (JRV) was designated as a “special development area” as a result of a tri-lateral initiative between the United States, Jordan and Israel.

A JRV steering committee was formed to develop a master plan for integrated economic development of the Jordan watershed (Figure 4), Southern Ghors and the Arava Valley south to the Gulf of Aqaba. This development effort is being managed by a joint steering committee headed by American government officials with the U.S. Agency for International Development (USAID). The World Bank is serving as a facilitator for coordinating the necessary feasibility studies for projected improvements.

In 1996 the Italian government provided \$3.2 million for a comprehensive second phase engineering study of a possible Red Sea to Dead Sea Pipeline, hiring the Harza Engineering Company of Chicago. This study was completed in August 1997.

By the late 1990s engineering technology for desalination using reverse osmosis (RO) filtration had advanced sufficiently to allow the inclusion of this process in the water transfer scheme at a much lower cost than envisioned in the early 1980s. Hydropowered RO seawater desalination uses reverse osmosis, or “hyperfiltration”, to remove salt from sea water using water pressure. Hydrostatic pressure is applied to the seawater either by pumps (requiring electricity) or by elevation head. The saline feedwater is forced to overcome osmotic pressure equilibrium and driven through a semi-permeable polymetric membrane. The membrane catches salt particles, allowing only freshwater to



pass through. The flow of water under significant pressure head continually cleanses the membrane by a process termed “crossflow”. To maximize filtration efficiency desalination plants use spiral wound membranes mounted in high pressure chambers to

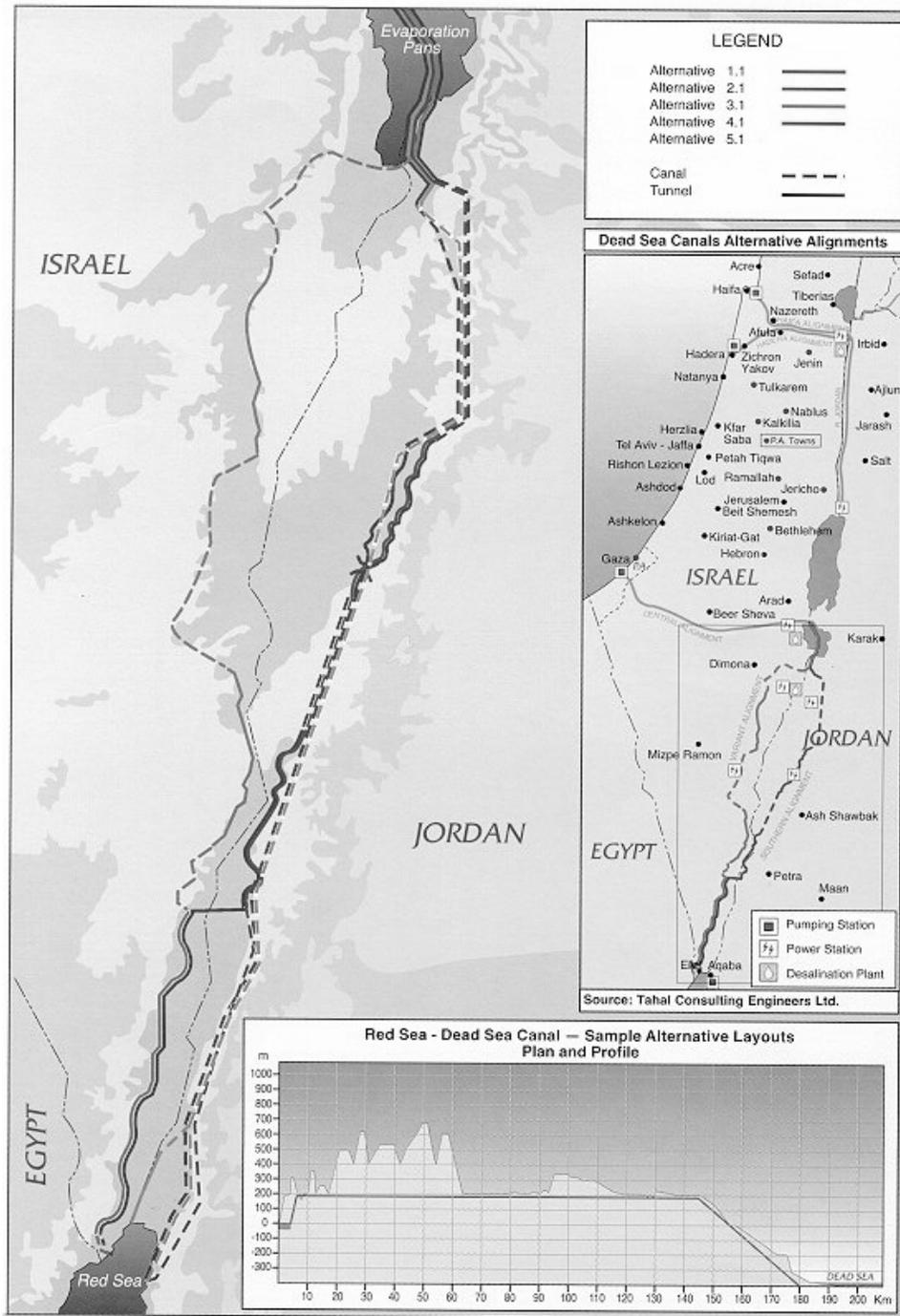


Figure 7 – Red Sea-Dead Sea pipeline-canal which will transport Red Sea water from the Gulf of Aqaba beneath the Arava Summit and down to the Dead Sea Basin, a distance of 186 km. The sea water will be lifted 125 m then cross beneath the Arava Summit in a 45 km long tunnel, then in a canal, through another 24 km tunnel, then drop 533 m on a average 1.52% slope to the Southern Basin of the Dead Sea. The conduit will be wholly contained within Jordan (taken from Harza Jordan River Valley Group, 1997).

maximize volume to surface area with relatively equal pressure. Between each curve in the spiral is a mesh separator which allows fresh water to pass through the membrane while the spiral shape of the membrane ridges create a significant crossflow along the membrane's upstream side, sweeping the retained salt crystals clear of the membrane (crossflow). Spiral wound membranes need to be replaced about once every seven years. This technology has revolutionized the desalination process, bringing down the cost significantly.

The Harza plan envisions lifting Red Sea water 125 m/410 feet, conveying it through two tunnels, 45 and 24 km long, well beneath the watershed divide at elevation 220 m/722 feet (Figure 7). At a point about 146 km north of the intake, the water would plunge some 533 m/1750 feet to the south basin of the Dead Sea, generating electricity or passed through RO hyperfiltration. The pressure head of is sufficient to drive the RO process, obviating the need for electrical power to generate the necessary membrane pressure.

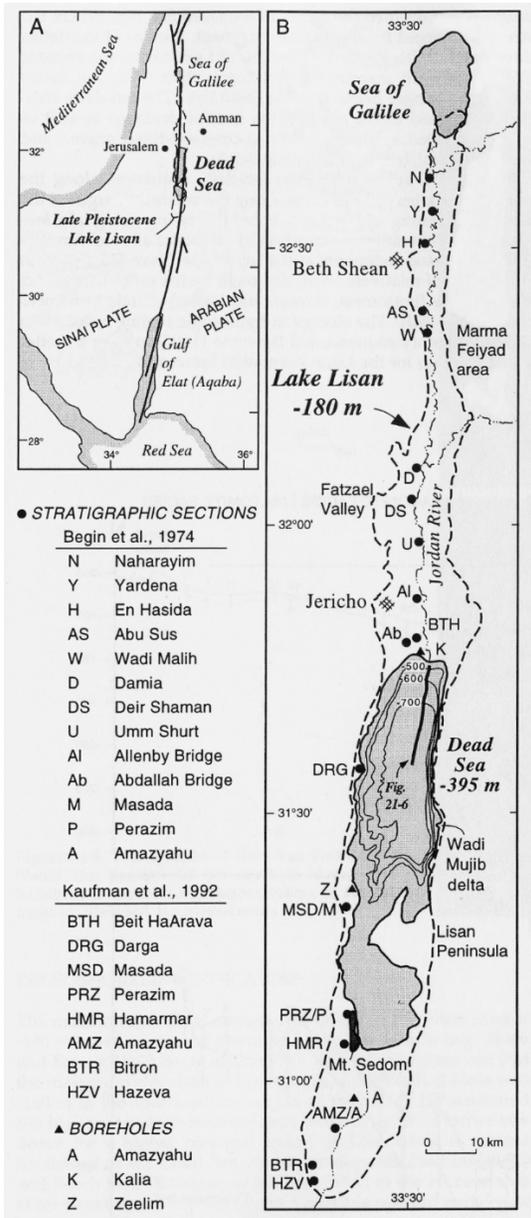
Both Jordan and Israel have expressed concern over lowering of the Dead Sea, which has been dropping about 0.50 m per year since 1960, due to water removals from the upper Jordan River for irrigation and increased potash extraction by both countries (Figure 3). The Dead Sea only receives about 10% of the flow that the Jordan River used to deliver prior to irrigation schemes that began siphoning off the water in the early 1960s. At the World Summit on Sustainable Development in Johannesburg in September 2002, Israel and Jordan announced that they would join forces to build the Red Sea-Dead Sea pipeline-canal, which was quickly dubbed the "Peace Conduit" by the media (Pinsker, 2002). The 310 km/186 mile long conduit will cost about \$800 million to construct, with construction due to begin in late 2003. Joint ownership of such major engineering infrastructure between two sovereign nations often at odds with one another is unprecedented.

Geotechnical Conditions of the Jordan Valley

The unconsolidated Lisan formation underlies all of the Jordan Valley. It was deposited during the Pleistocene enlargement of the Dead Sea, known as Lake Lisan. Lake Lisan filled 220 km of the Jordan River Valley, from the northern end of the Sea of Galilee to Hazeva, about 30 km south the extreme southern tip of the pre-1930 Red Sea South Basin (Figure 8). Lake Lisan was semi-stabilized at a surface elevation of -180 m, about 235 m above the present level of the Dead Sea (Niemi, 1997). This elevation is based on the upper levels of the Lisan marls. In the Wadi el-Hasa area near the southeastern margins of the Dead Sea these same units outcrop at -160 m. Clark (1988) has suggested these beds have been lifted by tectonic action since deposition.

Glacial Lake Lisan left a stratigraphic record that extends from 63 ka to 14 ka. During moist of that interim the lake fluctuated between elevations -180 and -360 m. One severe cycle was recorded between 14 and 11 ka, when the lake dropped from -180 m to almost -700 m, at the end of the Pleistocene. The final retreat of Pleistocene Lake Lisan is

marked by a series of lake terraces cascading down the western border escarpment on the Israeli side of the Dead Sea, between elevations of -182 and -384 m. Terraces below -270 m may represent fluctuations of the Dead Sea during the Holocene (last 11,000 years) according to Frumkin (1997).



Israeli side of the Dead Sea, between elevations of -182 and -384 m. Terraces below -270 m may represent fluctuations of the Dead Sea during the Holocene (last 11,000 years) according to Frumkin (1997).

During periods of low runoff-to-evaporation ratio Lake Lisan became brackish, and increasingly saline over the past 14 ka. The upper Lisan formation consists chiefly of an alternating series of finely laminated white aragonitic chalks and dark grey gypsiferous lacustrine marls. Varved sediments typify the formation in the middle of the old depositional basin (up to elevation -190 m), while clastic sediments predominate the formation about its margins, especially where local streams fed into Lake Lisan. The average rate of deposition appears to be about 1 mm/year in the Dead Sea's South Basin and as much as 10 mm/yr in the deeper North Basin (Neev and Hall, 1979).

Sediments deposited within Lake Lisan are distributed in well documented zones, with an aragonite facies dominating the JRV south of the Lisan Peninsula (between the North and South Basins of the Dead Sea) and northward along the valley, between Umm

Shurt and Wadi Malih. Between Wadi Malih and the Sea of Galilee a diatomite facies predominates (Figure 9). Within the lower Jordan Valley and around the North Basin of the Dead Sea a Gypsum facies dominates the landscape. The area is cut by numerous lystric faults associated with the down-warping of the Dead Sea's two basins.

Algal stromatolite structures are observed at various elevations in the Lisan Formation. These formed in the photic zone in shallow, highly saline water. The stromatolites occur

between elevations of -240 and -370 m, when Lake Lisan was shrinking and becoming increasingly saline.

The aragonitic facies is typified by extremely low relative densities, because sediment was deposited in the Dead Sea brine, which has a density of about 1.20. As a



Figure 9 – Soft diatomaceous facies of the Lisan foirmation deposited in Pleistocene Lake Lisan, as seen in the Jordan River Valley between the Sea of Galilee and the Dead Sea. The Jordan River is meandering in the foreground. These materials provide poor foundation for engineered structures. Photo by the author.



Figure 10 – 2.5 km of a 25 m high dike constructed for potash extraction failed during its initial filling in March 2000. The Lisan formation formed the dike foundation, on ground reclaimed in 1988 as the Dead Sea dropped. Several solution cavities were noted at 2 m depth, below an algal aragonite horizon. Photo by author.

consequence, the density of the Lisan marls is only 1.30 g/cm^3 (81 lbs/ft^3) with shear strengths of between 13 and 26 KPa (272 to 543 psf), making it very soft and deformable foundation for any sort of conventional structures, such as dams or levees. In March 2000 approximately 2.5 km of a new containment dike constructed around the Lisan Peninsula for potash extraction failed catastrophically, 55 million m^3 of brine eroded 15 million m^3 of dike and foundation material in just 30 minutes (Figure 10).

Occasional solution tunnels have been observed in the Lisan marl just below the uppermost aragonite horizon (Figure 10). Most of these cavities appear parallel to joint partings or small faults in the Lisan beds. Numerous sinkholes have been forming around the shoreline of the Dead Sea resulting from the dissolution of halite at shallow depth ($< 25 \text{ m}$) by fresh water runoff infiltrating the slopes which were formerly saturated with brine before the Dead Sea began dropping noticeably (after 1930). These have caused recurring disruption of transportation, tourism and mining activities along the western shore of the Dead Sea, with increasing frequency since 1985 (Arkin and Gilat, 2000).

CONCLUSIONS

Security concerns have also been raised on both sides; the pipeline may serve as a magnet for terrorists, similar to the Los Angeles-Owens River Aqueduct of the 1920s and the repeated attacks on a multinational oil pipeline in Columbia, which has accounted for almost half of the world's terrorist attacks the past few years (152 attacks in 2000 and 178 in 2001). The absence of any role involving the Palestinian Authority is also likely

to complicate any long-lasting solution to their increased need for water. The only possibility currently on the horizon may be USAID-funded improvement programs, similar to that granted to the Egyptians in 1979 and the Jordanians in 1994, when those countries signed peace treaties recognizing Israel (Starr, 1995). The Palestinians have sought Arab funding for desalination plants for some time, but without success. Unless the Israelis or the Jordanians are willing to make water concessions or include the Palestinians in their water development plans, the water situation will likely worsen. Nothing looks likely in the near term until the Palestinian Authority shows it's capable of governing itself and providing the requisite security to entice foreign investment.

In the near future survivability in the harsh climate of the Middle East will be driven economic sustainability. The most challenging aspect of expanding populations and infrastructure in Israel, Jordan and the Palestinian Authority will be water. Water infrastructure needs to be designed ahead of the domestic, industrial and political demands. Water is fundamental to life, for both bodily intake and maintenance of sanitation. Past experience with highly-developed nations such as the United States has shown that water supply systems must be redundant, so that supplies will not be consumed with the normal patterns of multi-year droughts. Instream reservoir storage has generally been limited to a 3-year model, meaning that below-average rainfall or man-induced loss of water storage lasting longer than 3 years could prove catastrophic. In the United States, interstate transfer of along natural watercourses have alleviated most drought related disasters because weather patterns usually affect isolated regions of the continent, allowing some areas to store excess runoff while other areas are being depleted.

By definition, redundant systems are those which employ different supply and delivery mechanisms so that complete breakdown of one or two supply lines can be obviated by tapping into parallel or alternative sources. Israel's multi-faceted approach to water resources development is second only to southern California and their attempts to devise schemes for reducing agricultural consumption and water quality are without peer at present. Israel's neighbors will likely follow her example and emulate as many of the alternative sources and methods of conservation as they can individually afford. However, much of that infrastructure will remain vulnerable to interdiction through terrorist attacks or overt acts of war.

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BIOGRAPHIC SKETCH OF THE AUTHOR

J. David Rogers received his B.S. degree in geology from the California State Polytechnic University in 1976, during which time he completed officer candidate training with the Marine Corps PLC program in Quantico, VA. After working a short time as a field geologist he entered graduate study in civil engineering at the University of California, Berkeley, receiving his M.S. degree in 1979 and Ph.D. in 1982.

In 1982 he joined Alan Kropp & Associates in Berkeley, becoming a professional engineer in 1983. In 1984 he formed Rogers/Pacific, Inc., a consulting firm specializing in forensic engineering, evaluation of natural hazards, and emergency mitigation of infrastructure failures, mostly for government entities. This same year he entered the Naval Reserve as an intelligence officer, working on special projects. He served in an active duty billet with the Tactical Training Team of Commander, Patrol Wings Pacific between October 1987 and August 1991. After this he was attached to reserve billets at the Naval Postgraduate School at Monterey, CA and the Naval and Maritime Intelligence Center in Washington, DC. He left the Navy Reserve as a Lieutenant Commander in 1995. By 1994 Rogers/Pacific had offices in the San Francisco and Los Angeles metropolitan areas and possessed a diverse range of specialists, which included geologists, geophysicists, civil, geological, geotechnical, and structural engineers, hydrologists, hydrogeologists, surveyors, and environmental planners.

In August 1994 he joined the civil engineering department at U.C. Berkeley as an Adjunct Professor, serving until 2001 when he accepted the Karl F. Hasselmann Chair in Geological Engineering at the University of Missouri-Rolla. He is the recipient of a great number of professional awards, including the E.B. Burwell Award of the Geological Society of America, the Rock Mechanics Award of the National Research Council, the Distinguished Project Award of the American Public Works Association, the R.H. Jahns Distinguished Lecturer in Engineering Geology Award and the Sigma Xi College of Distinguished Lecturers. He is a registered civil engineer, geologist, engineering geologist and hydrogeologist in California and a Certified Professional Geologist in several other states. Dr. Rogers served as a member of the Independent Panel to Investigate the Failure of Dead Sea Dike 19 for the Hashemite Kingdom of Jordan in 2000-2001.