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Seeking Sustainability: Israel's Evolving Water Management Strategy

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Despite the accompanying dangers of water development, the current situation in Africa is such that most people living close to major rivers and lakes in Africa need not be subjected to the waterborne diseases that previously plagued them. The vertical control programs with the tools to prevent death, blindness, and disfigurement have proved that they can work, and by 2006 they are reaching ever more people with donated or inexpensive drugs. The health of children in areas that have been reached is improving, and they are gaining a better start in life. The tools are available, and political will has been activated. WHO has grasped the challenge of integrating the control of neglected waterborne diseases and is now in a position to lead the world's global health partnerships into the next final control of morbidity due to waterborne diseases (*36*), which may indeed mean that they can be consigned to history.

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PERSPECTIVE

Seeking Sustainability: Israel's Evolving Water Management Strategy

Alon Tal

The water management policies adopted to address Israel's chronic scarcity have not been without environmental consequences. Yet, through a trial-and-error process, a combined strategy of water transport, rainwater harvesting, and wastewater reuse and desalination, along with a variety of water conservation measures, have put the country on a more sustainable path for the future.

At a time when many dry-land nations face water resource crises (*1*, *2*), Israel's water management experience offers a substantial basis for optimism. Some 60 years of developing water sources and delivery systems, along with technological innovation and regulatory programs, have strengthened national efforts to provide water to a growing population and agricultural sector. At the same time, this growth has led to a number of adverse environmental consequences that future policies will need to address. These include seawater intrusion into overpumped aquifers, groundwater nitrification from fertilizers and sewage, and contamination from industrial pollutants, garbage dumps, gas stations, and myriad nonpoint sources (*3*, *4*). Here, I focus on the relative successes and ramifications of what, in retrospect, has been a trial-and-error process.

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The major focus in Israeli water policy is and has always been expanding supply. Israel's sole natural freshwater lake, Kinneret (also called the Sea of Galilee or Lake Tiberias), holds roughly one-third of the country's replenishable water supply. Along with the mountain aquifer system, which provides an additional 20%, it lies in a transboundary watershed that is still the subject of international dispute. Nonetheless, even before a final allocation deal is brokered, annual water availability is less than 250 m^3 per person (250,000 liters). The internationally recognized Falkenmark indicator sets 1000 m^3 per person as a minimum annual level below which countries experience water stress; hence, present supplies place Israel at 50% of the annual per capita "absolute scarcity" level of 500 m^3 (*5*).

The principal national investments in increasing water supply have involved four initiatives: (i) integrated management of Lake Kinneret and groundwater aquifers, which feed into an integrated national water grid; (ii) water harvesting via a network of rain-fed reservoirs; (iii) wastewater treatment and reuse for irrigation; and (iv) desalination of seawater and brackish groundwater.

Water Transport

Massive water transport projects have greatly expanded irrigation and domestic supply in arid regions from California to Libya (*6*–*8*). However, the associated water quality problems and mining of nonrenewable aquifers can lead to a steady decline in available water resources. Israel's adaptive experience in this context is instructive.

Beginning in 1964, water has been conveyed from Israel's relatively wet northern Galilee (precipitation up to 700 mm/year) to depleted central aquifers and to the arid southlands (precipitation 20 to 200 mm/year) via a "National Water Carrier" (Fig. 1). Although this undertaking led to a large increase in cultivated land and harvests in the country's semiarid regions, it also exacerbated salinity problems and, to a lesser extent, raised turbidity levels in water.

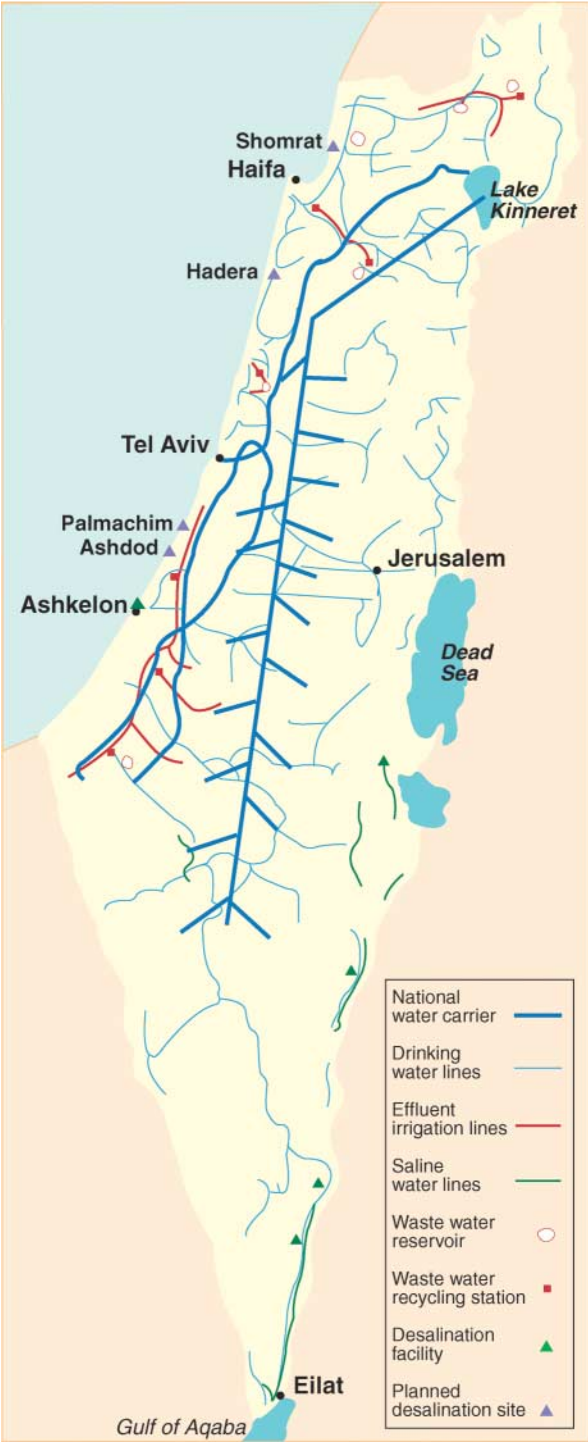

Fig. 1. The National Water Carrier and other major water resources.

The water originating in Lake Kinneret was relatively salty, with average chloride concentrations reaching 390 mg/liter (*9*). Diversion of saline streams that fed Lake Kinneret to the lower Jordan River during the 1970s reduced concentrations to between 220 and 270 mg/liter. Nonetheless, water transport still contributes an estimated 170,000 metric tons of chlorides to the soils and groundwater in the center of the country (*10*). Present efforts focus on conscientious management of the surrounding watershed, further reduction of Kinneret salinity levels, and dilution of National Water Carrier flow with low-salt, desalinized waters. Some experts and environmentalists argue that the long-term salinization damage—along with the steady desiccation of the Dead Sea, deprived of the Jordan River water—justifies the decommissioning of the National Water Carrier (*11*).

At the same time, the suspended solid levels in the water supply, arising from natural turbidity in Lake Kinneret, have raised aesthetic and health concerns. A new system of sand filtration and treatment for the reservoirs of the National Water Carrier will begin operating in autumn 2006 to control turbidity and also to increase pH levels, thereby reducing the corrosivity of the water and minimizing chemical reactions with other water sources. Although this upgrade was delayed for some time because of its expense, an internal cost-benefit analysis showed that the investment was easily justified.

Water Harvesting and Reservoirs

Water supplies in Israel have been augmented by an aggressive program of collecting rainwater, spearheaded by the Jewish National Fund (JNF), a public-interest corporation. Starting in the 1980s, a network of 178 reservoirs was established across the country's rain gradient, with most located in semiarid and hyperarid regions. The system currently collects 125 million m^3/year, which constitutes 7% of the total water in Israel's system, collectively capable of irrigating 300 million m^2 of farmland (*12*).

The first wave of reservoirs relied on damming and impounding floodwaters, with the primary objective of replenishing groundwater. Beyond the reduced evaporation, the filtration associated with percolation through underlying soils enhances water quality. (However, pressure from farmers to control this stored water has often resulted in direct connection of the reservoirs to irrigation systems, so that these water quality improvements frequently are not realized.) Reservoirs can also bring the added benefits of fish farming, recreation, and swimming. Most of the recently constructed reservoirs hold treated wastewater, stored before agricultural use during the summer and autumn dry seasons. With the anticipated increase in overall water supply due to desalination technologies (see below), the need for reservoirs to store the resulting effluents will grow, especially during the rainy winter season when irrigation demand is low.

Although reservoirs can expand water supplies in arid regions, the creation of this harvesting infrastructure requires capital that is often unavailable at the local level. Depending on size and underlying soil composition, reservoirs with a capacity of 0.5 to 2 million m^3 take between 1 and 2 years to build and cost $1 million to $5 million. Once built, however, reservoirs serve to empower the local agricultural communities that operate them and would otherwise remain highly reliant on the country's centralized water bureaucracy. Communities can determine irrigation rates and storage regimes during the dry seasons. Water quality monitoring is a critical operational component in efforts to mitigate the risk of high concentrations of phosphates, phenols, nitrates, boron, and pesticides found in agricultural discharges and to control salinity in wastewater reservoirs.

Wastewater Reuse

In 1953 Israel drafted the world's first set of standards for wastewater reuse, and effluent recycling emerged as a central element of Israeli domestic water policy (*13*). At present, 91% of all municipal sewage in Israel is treated, 73% of which is recycled [versus 2.5% in the United States (*14*)], contributing roughly one-fifth of Israel's total supply. Typically, the effluents reaching farm operations come from nearby cities, with the exception of Tel Aviv's metropolitan plant, which transports roughly one-quarter of the country's sewage (130 million m^3/year) 100 km southward to the Negev desert. Treatment is based on an activated sludge process that incorporates additional nitrogen removal. After treatment, the water is piped to spreading bases where it is injected into the ground for recharge of a regional aquifer. Here the water undergoes additional filtering and seasonal storage before it is pumped for irrigation (*15*).

Concerns about the effect of sewage recycling initially focused on public health and led to the authorization of the Ministry of Health as the oversight agency for matters concerning effluent treatment and reuse. During the 1970s, a major epidemiological study in 81 agricultural communities compared health effects among farmers who used sewage effluents with those who did not, but found no significant difference in morbidity and mortality trends (*16*). Starting in 1992, a new standard for secondary treatment facilities required a maximum concentration of 20 mg/liter BOD (biological oxygen demand, a measure of organic pollution in wastewater) and 30 mg/liter for TSS (total suspended solids). However, this "20/30" secondary sewage treatment level proved inadequate for a variety of reasons.

The range of crops that can be grown at this treatment level is relatively narrow because of the presence of pathogens in the effluents. Directly consumed vegetables, for example, are excluded from allowable crops at this treatment level, as are many fruit trees. The salinity in the wastewater posed risks to soils and fresh water sources. Boron compounds, common in detergents, were not efficiently removed and accumulated in recycled wastewater, contributing to soil structure problems. Moreover, during the 1980s, industrial solvents such as toluene and benzene began to appear in Israeli rural well samples (*17*). Their presence was attributed to inadequate sewage treatment and widespread irrigation with effluents.

It became clear that effluent standards at 20/30 levels—which make sense in regions such as Europe, where the river dilution factor is considerable—are insufficient in arid environments, where wastewater is recycled or supplies most of the baseline flow in naturally ephemeral streams. Ultimately, ecosystem recovery in Israeli rivers will have to be based on higher quality effluents (*18*). In April 2005, the Israeli government approved the recommendations of an expert committee that increased the stringency of sewage treatment requirements. Maximum BOD and TSS were reduced to 10 mg/liter. The standard contains a long list of new criteria for salinity as well as concentrations of boron, heavy metals, and nutrients. The criteria are dichotomous, with limits set for agricultural irrigation often differing from those set for wastewater discharged into streams. For example, an ammonia standard of 20 mg/liter is set for agricultural reuse, whereas concerns about eutrophication led to a stringent 1.5 mg/liter requirement for discharge into streams. The banning of boron in detergents has already resulted in reduced wastewater concentrations.

The estimated cost of the 10-year phase-in of advanced tertiary sewage treatment is $220 million (*19*). The economic burden for meeting the new standards will be much easier in the large municipal facilities than in the nonmechanized smaller plants that produce a quarter of the country's effluents.

Desalination

Desalination constitutes the most recently adopted component of Israel's water management strategy. In the past, prohibitively high costs limited the scope of desalination to reverse-osmosis facilities in remote southern agricultural communities and at the Red Sea resort town of Eilat, where no viable alternative water source existed. Today the combination of modern membrane technologies, reduced energy consumption, and the economies of scale associated with mass production yields very-high-quality drinking water on Israel's Mediterranean coast at a cost of less than $0.60 per 1000 liters (1 m^3).

Inland desalination facilities, designed to treat large local supplies of brackish groundwater with lower salt concentrations, are expected to produce water at roughly $0.30/$m^3$. Figure 2 shows the general cost reduction trends associated with desalination worldwide. These rates belie the logic of the much-discussed Israeli acquisition of Turkish water (*20*) to be shipped by tankers, which at present prices would cost more than twice as much as the desalinized alternative.

The new economic dynamics led to a 2002 government decision to build five new reverse-osmosis desalination plants over the coming years. The facilities are expected to produce more than 300 million m^3/year, adding some 15% to present drinking water supplies (*21*). Table 1 shows the Israel Water Commission's anticipated growth in water production.

In 2005 the VID Desalination Company consortium opened the first of these desalination plants in the Mediterranean city of Ashkelon, having received rights to build and operate the $250 million facility for 25 years (*22*). With production of 100 million m^3/year, it is currently the largest reverse-osmosis seawater desalination plant in the world. The average energy demand is 3.85 kWh per m^3 of water. Mounting oil costs have not raised water prices much beyond the original target of $0.52/$m^3$. Seawater is pumped via three submerged high-density plastic pipelines that stretch 1 km into the sea. Water is collected at a depth of 7 m, the approximate midpoint between the surface and the seafloor. The seawater undergoes a pretreatment process in two parallel production lines to ensure reliability in the event of blockages. A two-stage gravel, sand, and anthracite filtration process precedes the water's entry into the facility's 32 reverse-osmosis treatment trains, filling four stories and containing 40,000 membrane elements. Fouling of the membrane stacks is avoided by adding phosphonate antiscalant chemicals before the water reaches the stacks.

Although there was little active opposition to Israel's new desalination initiative, several environmental concerns have been articulated. These concerns include the loss of public coastal open spaces, the cumulative impact of brine discharges into a concentrated area of the sea, and the additional greenhouse gases associated with the attendant electricity generation (*23*). The quality of the water itself, however, is excellent.

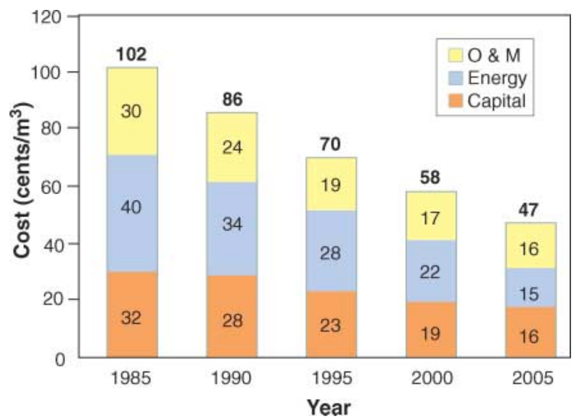

Fig. 2. Trends in cost breakdown: Reverse-osmosis seawater desalination. Source: Israel Water Commission, 2005.

Table 1. Planned expansion of the Israeli water supply. Source: Israel Water Commission, 2005.

	Established or projected water supply (million m^3)								
	2002	2003	2004	2005	2006	2007	2008	2009	2010
Seawater desalination	—	—	—	40	110	130	140	270	315
Recycling system	—	—	—	—	—	15	35	35	35
Brackish water desalination	1	8	15	20	30	55	55	55	55
Water imports	—	—	—	—	—	—	—	—	50
Total additional potable water	1	8	15	60	140	200	230	360	455
Treated effluents (for agriculture)	295	332	359	390	441	461	471	491	509

The new Ashkelon plant, for example, incorporates a treatment process to address the natural boron concentration in seawater; with a removal efficiency of 92%, the process reduces boron concentrations down to a mere 0.4 mg/liter. Chloride levels after treatment are so low (20 mg/liter) that the desalinated water is actually mixed into the national water grid to dilute the high salinity in the "fresh" water. When the city of Be'er Sheva began using the desalinated water in early 2006, chlorides in the sewage effluents it sent to agriculture plummeted to 100 to 150 mg/liter, concentrations that even critics of widespread sewage reuse find sustainable.

Conservation and Demand Management

Despite the primary policy focus on increasing supply, Israel's Water Commission has also strengthened conservation and demand management programs as part of an overall national strategy. In the urban sector, most economic analyses suggest that demand for water is highly inelastic and thus not responsive to price regulation (*24*). Rather, a combination of technology diffusion (upgrading of inefficient plumbing infrastructure, along with car wash and toilet regulations) and seasonal usage restrictions for spray irrigation has kept industrial and domestic per capita water consumption steady despite the rise in living standards during the past 40 years (*25*).

The most striking increase in water use efficiency has occurred in the agricultural sector. During Israel's first half-century, the country's population grew by a factor of 7 while agricultural production expanded by a factor of 16 (*26*). At the same time, the proportion of high-quality fresh water allocated to farmers steadily declined. The invention and introduction of drip irrigation in Israel during the 1960s was the most important innovation behind this increase in "crop per drop."

Drip irrigation solves several vexing problems for farmers. The paramount challenge in irrigation has always been to control the salinity that accumulates in soils as plants absorb water but leave the salts behind. By decreasing overall water delivery, drip irrigation reduces residual salts. Nonetheless, drainage systems that collect and dispose of saline leachate remain important components of a sustainable system in soil with low permeability (*27*). In addition, drip technology facilitates cultivation on steep terrains and in shallow soils, with computerized systems delivering nutrients and oxygen to the root zones at optimal intervals for their use by growing plants.

A new generation of subsurface drip irrigation systems provides additional improvements by maintaining a dry soil surface. Drippers are typically buried at 7 to 30 cm under the soil surface (*28*). The subsurface positioning of drip emitters conserves water, controls weeds, minimizes runoff and evaporation, increases longevity of the system, eases the use of heavy equipment in the field, and prevents human contact with low-quality water (*29*). Moreover, subsurface irrigation reduces labor, obviating seasonal installation and collection of surface drip system laterals. Installing a system constitutes a relatively expensive capital investment and is hardly trouble-free. Clogging and root infiltration have been mitigated by a variety of filtration and chemical approaches.

Outlook

Israel still faces considerable water management challenges. The Dead Sea, the lowest and saltiest lake on the planet, is literally disappearing, with an average annual drop in water level of 1.2 m/year. This is a predictable result of the 1 billion m^3/year diversion of the natural flow from Lake Kinneret and the Jordan and Yarmoukh rivers (*30*). Compliance with industrial discharge standards remains spotty. Urbanization and proliferation of paved surfaces threaten to undermine aquifer recharge (*31*). Streams, whose natural base flow has largely been replaced by effluents, cannot support ecological systems. A renewed peace process would undoubtedly lead to greater water allocation demands from Palestinians and perhaps Jordanians and Syrians (*32*). Finally, the existing pollution in aquifers is severe enough (or the taste from chlorination unpleasant enough) to motivate more than 70% of the public to buy bottled water (*33*).

Given the anticipated water concessions to Israel's neighbors associated with future peace agreements, expansion of the water supply will be necessary to maintain present levels of agricultural, domestic, and industrial activities. In addition, a new statutory commitment to stream restoration will further increase demand as water managers begin returning a "fair share" to the ecosystem. Present indicators suggest that continued technological development, coupled with ongoing water conservation and pollution prevention policies, should enable the country to meet these future hydrological challenges. At the same time, experience teaches us that new technologies have environmental ramifications that must be anticipated and addressed if water management is to be sustainable.

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ERRATUM

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Special Section on Freshwater Resources: Perspectives: "Seeking sustainability: Israel's evolving water management strategy" by A. Tal (25 Aug. 2006, p. 1081). Figure 1, the schematic drawing of the National Water Carrier course, was inaccurate. A more precise map is shown here.