# Has technology trumped adaptive management? A review of Israel's idiosyncratic hydrological history

Alon Tal

As water resources become in increasingly short supply, their management emerges as one the planet's most pressing challenges. In ancient days, entire civilisations collapsed as a result of myopic water policies and an inability to adapt to changing environmental conditions.[1] The situation is likely to grow worse. All told, humanity's global groundwater footprint today is 3.5

Global Environment 9 (2016): 484–515
© 2016 The White Horse Press.
doi: 10.3197/ge.2016.090208

times the actual areas of available aquifer, with 1.7 billion people living above groundwater resources that are threatened.[2]As scarcity came to characterise the realities of regions around the world, thoughtful, efficient and nimble management that adapts to ever-changing circumstances became imperative. In retrospect, the national histories of water management differ dramatically, with some successful efforts worthy of evaluation and even emulation. At the same time, there has often been a gap between well-meaning declarations and water-wise practices. During the twentieth and 21st centuries, a long litany of water-related follies are associated with environmental, social and economic disruption.

Mismanagement has sealed the fate of hundreds of water resources and millions of people during the past fifty years. In Africa, Lake Chad, the second largest water body on the continent essentially disappeared due to diversions and ill-considered water projects.[3] The shrinking of the Aral Sea has emerged as a symbol of centralised, myopic and inflexible water planning.[4] Prospects for restoration are slim.[5] One can ascribe such disasters to the poor governance associated with Communist or developing countries. But there is plenty of hydrological 'malpractice' in the developed world as well. Take, for example, the largest ground water resource in the US, the Ogalala aquifer. Lying under eight states spanning northern Texas and the Great Plains, this seemingly inexhaustible resource is being progres-

[1] Daniel Hillel, *Out of the Earth, Civilization and the Life of the Soil,* (New York: Free Press, 1991) pp. 95–119; Jared Diamond, *Collapse, How Societies Choose to Fail or Succeed* (New York: Penguin, 2006).

[2] Tom Gleeson, Yoshide Wada, Marc F.P Bierkens and Ludovicus P. H van Beek, 'Water balance of global aquifers revealed by groundwater footprint', *Nature* **488** (2012): 197–200.

[3] UNEP, 'Lake Chad: Almost Gone', *Vital Water Graphics, An Overview of the State of the World's Fresh and Marine Waters – 2nd Edition*, (Nairobi: UNEP, 2008) http://www.unep.org/dewa/vitalwater/article116.html

[4] Phillip Micklin, 'The Aral Sea Disaster', *Annual Review of Earth and Planetary Sciences* **35** (2007): 47–72.

[5] Phillip Micklin, N.V.Aladin, Igor Pltnikov, 'Efforts to Revive the Aral Sea', in *The Aral Sea, The Devastation and Partial Rehabilitation of a Great Lake*, (New York: Springer, 2014).

sively mined. In some areas the shallow groundwater has dropped by several metres[6] with water quality steadily deteriorating.[7] Once depleted, it may take some six thousand years for rainfall to replenish it.

There are many reasons why effective water management strategies have often been so elusive. Water supply traditionally relied on rainfall, making conditions inherently unpredictable in large areas of the world. In order to successfully respond to the vicissitudes of weather, the environment and other factors, for over forty years, 'Adaptive Management' has been championed as an intelligent basis for designing natural resource programs in general[8] and implementing water policy in particular.[9] Formal articulation of the 'adaptive management' concept emerged in the late 1970s when first promoted by Canadian academic, Crawford Stanley Holling, a 'father' of ecological economics.[10]

In the water context, the fundamental assumption is that, given the pervasive uncertainties associated with climate and other drivers of hydrological systems, it is impossible to predict what will affect water resources and how systems will respond. An effective water management strategy, therefore, must be adaptive and build in the 'ability to change management practices based on new experiences and insights'.[11] By doing so, a country bases its operational decisions

[6] Sandra Postel, 'Drought Hastens Groundwater Depletion in the Texas Panhandle', *National Geographic* 24 July 2014 http://voices.nationalgeographic.com/2014/07/24/drought-hastens-groundwater-depletion-in-the-texas-panhandle/.

[7] Sriroop, Chaudhuri and Srinivasulu Ale, 'Long term (1960–2010) trends in groundwater contamination and salinization in the Ogallala aquifer in Texas', *Journal of Hydrology* **513** (2014): 376–390.

[8] C. Walters, *Adaptive Management of Renewable Resources*, (New York: MacMillan, 1986); T.P. Hughes, L.H. Gunderson, C. Folke, A.H. Baird, D. Bellwood and F. Berkes, 'Adaptive management of the Great Barrier Reef and the Grand Canyon World Heritage areas', *Ambio* **36** (2007): 586–592.

[9] National Research Council, *Adaptive Management for Water Resources Project Planning*. (Washington D.C.: National Academies Press, 2004); Nathan Engle, 'Adaptive Capacity and Its Assessment', *Global Environmental Change* **21**/2 (2011): 647–656.

[10] Crawford Stanley Holling, *Adaptive Environmental Assessment and Management* (New York: John Wiley and Sons, 1978).

[11] Claudia Pahl-Wostl, 'Transitions towards adaptive management of water

on an ongoing learning process[12] that monitors the outcomes of the system and selects policies by evaluating the plausibility of alternative hypotheses using real-time data and associated insights.

Long before academics characterised this approach in the academic literature, there were states and societies that utilised resources in a manner consistent with adaptive principals.[13] Many more jurisdictions adopted adaptive strategies as experts advocating the approach became more prescriptive and operational rules more widely disseminated.

Not all places that purported to adopt 'adaptive approaches' have successfully averted hydrological fiascos. The case of the Ogalala suggests that more than lip service is needed.[14] Nonetheless, one country that appears to have effectively embraced an adaptive water management strategy is Israel. By several criteria its idiosyncratic history of water management essentially constitutes a 'success story'.[15] Despite the exponential growth in population, extremely contentious geopolitical hydro-politics, a booming economy and expanded agricultural production, water supply is increasingly reliable, clean and inexpensive. Resourceful water managers needed to adapt quickly to an ever-changing reality – and they did. Knowingly or unknowingly they employed 'adaptive management' in their decision making.

During the past decade, the fundamental dynamics driving Is-

facing climate and global change', *Water Resource Management* **21/**49–62 (2007): 51.

[12] B.T. Bormann, P.G. Cunningham, M.H. Brookes, V.W. Manning and M.W. Collopy, *Adaptive Ecosystem Management in the Pacific Northwest.* (Washington, D.C., USDA Forest Service, 1994).

[13] J. Halbe, C. Pahl-Wostl, J. Sendzimir and J. Adamowski, 'Towards adaptive and integrated management paradigms to meet the challenges of water governance', *Water Science and Technology* **67**/11 (2013): 2651–2660.

[14] Richard Hornbeck and Pinar Keskin, 'The Historically Evolving Impact of the Ogallala Aquifer: Agricultural Adaptation to Groundwater and Drought', *American Economic Journal: Applied Economics* **6**/1 (2014): 190–219.

[15] Na'ama Teschner and Maya Negev, 'The development of water infrastructures in Israel: past, present and future', in S.B. Megdal, R.G. Varady and S. Eden (eds), *Shared Borders, Shared Waters* (Leiden: CRC Press, 2013); Alon Tal, 'Seeking Sustainability: Israel's Evolving Water Management Strategy', *Science* **313** (2006): 1081–1084.

raeli water policy appear to be changing. The most recent phase in Israel's water management strategy involves a significant investment in desalination plants. A decade after this transition it is possible to form some interim conclusions. For the first time, water supply is not dependent on the weather. Notwithstanding burgeoning demand, supply became more predictable than ever before. In its commitment to water supply technologies that rely on the sea, the country finds it has access to a seemingly inexhaustible source of fresh water. With the historic hydrological uncertainty no longer a dominant factor in water management decisions, it is well to ask whether the traditional 'adaptive management' approach still constitutes a relevant strategy for Israel's water managers.

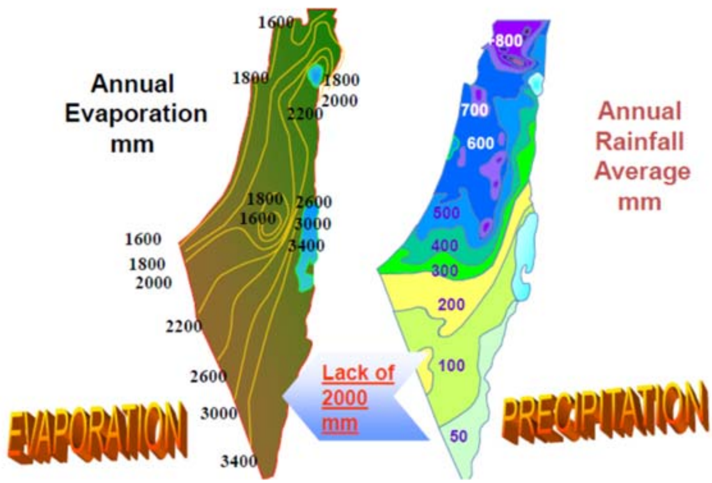
An informed answer to this question requires a review of Israel's historic efforts to provide water to its growing population. This article briefly reviews five different stages in Israel's water management history, all of which arose due to a prevailing orientation, best characterised as *adaptive management*. The dynamics of the most recent initiative to ensure water supply, however, appear to be entirely different. The additional 550 million cubic metres produced annually in Israel's desalination plants unquestionably created a new reality. It can also be argued that, while climatic uncertainties are reduced, new uncertainties emerged to take their place. Adaptive management may take on different forms as monitoring will target other critical conditions affecting water supply. Yet, conceptually the same nimble, scientifically sound and adaptive approach which informed Israel's historic water policy remains essential to future water management security.

## Phase 1: Hydro-Socialism

Given the country's Zionist (and during its early years) 'Socialist' identity, Israeli development strategy was directly linked to restoring a culture of flourishing Jewish agriculture.[16] From its inception, wa-

[16] Clive Lipchin, 'Water Culture in Israel', in A. Tal and A. Abed-Rabbo (eds), *Water Wisdom, a New Menu for Palestinian and Israeli Cooperation in Water Management* (New Brunswick: NJ, Rutgers University Press, 2010), pp. 71–75.

**Figure 1. Geographic Asymmetry: Evaporation and precipitation levels in Israel and the Palestinian Authority. Source: Israel Water Authority**




ter resources became the central focus of infrastructure investment. The challenges were not inconsequential.

The most salient characteristics of Israel's hydrological reality involve both temporal and geographic asymmetry. As seen in Figure 1, Israel and the Palestinian Authority are located along a very steep rain gradient, where southern, hyper-arid regions frequently receive only 10–20 mm of rain annually, while small sections of the north enjoy 'tropical' levels of precipitation. Jordan faces comparable climatic dynamics.

After the State of Israel was created in 1948, Simha Blass, the head of the newly created water department in the Ministry of Agriculture, set out to remedy these natural 'inequalities' by planning two major infrastructure projects. These were designed to carry water to the thirsty drylands of the south and allow for the development of agricultural settlement there.[17] In 1955, his team completed construction of a water carrier which transferred one hundred million cubic metres (mcm) from the headwaters of the Yarkon River to new settlements in the Negev desert.[18] Upon completion, it became the centrepiece of a national policy that can best be described as 'hydrological Socialism', which sought to provide equal access and identical prices of potable water to the entire population.

Over the eight years that it took to construct Israel's National water carrier, the project price tag reached $US175 million, at the time an astronomical sum.[19] This project constituted some eighty per cent of all investment in the country's water infrastructure.[20] The original plans envisioned a pipeline that would bring water from northern Galilee and take advantage of the altitude difference to let gravity bring water southward. When this plan became the subject of international controversy and contentious debates in the UN Security Council[21] Israel adapted, making a tactical retreat and changed the routing of the carrier.

By moving its starting point thirty kilometres to the south and using the Kinneret Lake (Sea of Galilee) as a national reservoir, Israel could plausibly argue that it was simply transferring internal water resources within its sovereign borders in an optimal manner. Because the Kinneret is the lowest fresh water lake in the world, lying at some 210 metres below sea level, this modest geographic shift was anything but modest topographically. Water needed to be pumped hundreds of metres up the hillsides of the Galilee to the newly built Eshkol reservoir where it could be treated. From the reservoir, water

[17] David Ben Gurion, 'Southbound', in *Studies in the Bible* (Tel Aviv: Am Oved, 1969) pp. 132–144.

[18] Alon Tal, *Pollution in a Promised Land – An Environmental History of Israel* (Berkeley: California, University of California Press, 2002).

[19] Yael Shoham and Ofra Sarig, *The National Water Carrier* (Sapir: Mekorot, 1995).

[20] Itzhak Galnorr, 'Water Policy Making in Israel', in Hillel Shuva (ed.), *Water Quality Management Under Conditions of Scarcity, Israel as a Case Study* (New York: Academic Press, 1980) pp. 287–314.

[21] Simcha Blass, *Water in Strife and Action* (Givataim: Masada, 1973).

was released into a national grid, via 108-inch steel and concrete pipes, that wound some 86 kilometres to the center of the country and eventually beyond.[22]

For decades, the National Water Carrier delivered most of the water to Israeli agricultural and domestic consumers. Once a national grid of pipelines was established, Israel's Socialist water managers could offer the same price to consumers everywhere across the country even though the actual costs associated with delivering the water varied dramatically. When it was operating round-the-clock, the Water Carrier consumed 2,400 megawatts of electricity a day to power the pumps. During the country's early years, this constituted a substantial proportion of the country's entire base-load.

Water quality in the Kinneret Lake was not ideal, but the water management strategy adapted and began to address the high levels of salinity and turbidity. Coagulation and flocculation processes using aluminum sulfate in the reservoirs now adsorbs to the sediments and turns them into larger 'flocs' which then settle into the settlement basin, reducing turbidity dramatically. In addition, a 'Saline Carrier' diverts water from saline springs and releases them in the Jordan River, south of the lake. Consequently, chlorine levels in the Kinneret dropped by fifty per cent to a far more acceptable 200 mg/l level.[23]

By all counts the National Water Carrier was a game changer. Israel's agricultural lands expanded into semi-arid regions that had previously been inaccessible to farmers. Due to the hydrological boost that the Carrier gave peripheral regions, today Israel cultivates some 350,000 hectares of land, with agriculture zoning established on fifteen per cent of all land.[24] Water managers adapted to severe scarcity with a bold solution that remains in place to this day.

The first stage in Israel's water management programme showed

[22] Alon Tal, *Pollution in a Promised Land.*

[23] Richard E. Laster, 'Lake Kinneret and the Law', *Israel Law Review* **12**/3 (1977): 296.

[24] Iris Hann 'Open Space in an Urban Society', in Daniel Orenstein, Alon Tal, Char Miller (eds), *Between Ruin and Restoration, An Environmental History of Israel* (Pittsburgh: University of Pittsburgh Press, 2014) pp. 146–167.

the kind of audacity and flexibility that would characterise subsequent stages of Israel's water management history. The infrastructure development reflected the results of a learning process that was at once dynamic, scientifically driven and, most of all, pragmatic. Menachem Kantor, an engineer who later became Israel's Water Commissioner was on the team that planned and built the two great water carriers. His description of the chaotic, but ultimately efficacious, modus operandi is telling:

> We made mistakes but you have to remember what little information we had at the time. We were already working on the Yarkon-Negev line when Martin Goldsmith, of the Hydrology Service comes to me and tells me, 'I hear you are planning wells in this area. You know there won't be any water soon if you do.' I said: 'How do you know?' and he said 'It's my business to know.' So I ran and told Blass and he told me – that old Yekke doesn't know what he's talking about. So I went back to Goldsmith and said 'I need proof. Blass doesn't believe it.' And Goldsmith said, 'If you need proof, we have to measure all the wells from Benyamina to Beer Sheva.' That would have taken months. So round the clock we measured what we could for two days and I sat by the phone collecting the results all night. But Goldsmith was right. I passed on the information and as a result we converted the pump station to an emergency station for the National Water Carrier.[25]

Even the copious additional supply of water provided by the water carriers would soon be inadequate for the country's needs as the population burgeoned from one million people in 1950 to two million in 1960 and three million by 1970. At the same time, with more people using water from the National Water Carrier, more sewage was produced, creating a hygiene crisis. In response to these factors, Israel adapted and moved into its second phase of water management.

[25] Menahem Kantor, personal interview with author, Kibbutz Maagan Michael, 20 Nov. 1997.

## Phase 2: Wastewater Reuse

As of 2015, Israel recycles 400 billion litres or 86 per cent of its sewage each year.[26] Internationally this is unprecedented: Spain recycles seventeen per cent of its waste water; Australia – ten per cent; Italy – eight per cent; and the US and Central Europe, a mere one per cent. How did this unique development take place? A central component of adaptive management has always been monitoring and data. Hillel Shuval was one of two professionals working at the new country's Sanitation Department in the Ministry of Health. He explained:

> In 1950, there was very little information about sewage treatment. We carried out the first survey in the Galilee around the Jordan River. The fact of the matter is that in that period none of the kibbutzim had central sewage systems. All were based on outhouses and Kiryat Shmoneh [Israel's northernmost town – A.T.] hadn't even been built yet.[27]

When faced with the combined problems of increasingly acute water shortages and widespread contamination, Shuval and his colleagues decided that treating and recycling the growing amounts of sewage collected was a logical way to adapt.[28]

Israel's Ministry of Health facilitating the initial foray into utilisation of wastewater during the 1950s is hardly intuitive. Typically, health ministries, responsible for mitigating possible exposures to pathogens in sewage systems, are extremely cautious when hygiene and excrement are involved. A more conventional path at the time would have been minimal sewage treatment and dilution by discharging effluents into a river or the sea. But the Ministry's Sanitation Department in the 1950s reckoned that with extremely limited

[26] Isabel Kireshner, 'Aided by the Sea, Israel Overcomes an Old Foe: Drought', *New York Times,* 29 May 2015, http://www.nytimes.com/2015/05/30/world/middleeast/water-revolution-in-israel-overcomes-any-threat-of-drought.html?_r=0.

[27] Hillel Shuval, Personal interview with author, Jerusalem, 30 Dec. 1997.

[28] Hillel Shuval, 'Quality Management Aspects of Wastewater Reuse in Israel', in Hillel Shuval (ed.), *Water Quality Management Under Conditions of Scarcity, Israel as a Case Study* (New York: Academic Press, 1980).

national economic resources, the most promising strategy for addressing the mounting sewage mess was to enlist allies who might invest in a wastewater reuse infrastructure. Then, as regulators, they could influence the quality of sewage treatment.

The prevailing assumption was that, if cities could charge money and increase their income by selling treated effluents to the agricultural sector, they would be willing to devote capital resources to environmental infrastructure. The other ally that was mobilised to promote wastewater reuse was Israel's agricultural community. Farmers faced intermittent water scarcity during dry years, shortages that were especially acute before the National Water Carrier went online. Desperate for a reliable source of water, many farmers had already begun to recycle sewage after basic treatment or even no sanitation at all. Rather than fight the trend, the Ministry of Health experts realised that to avoid a public health fiasco, it was as well to become engaged.[29]

Once again, water managers moved quickly. A National Masterplan was proposed in 1956 that envisioned 150 million cubic metres of waste water recycled that would be directed to local irrigation.[30] Guidelines were adopted by the Ministry of Health, which required modest treatment levels. The plan was soon put into action, jump-starting Israel's new wastewater reuse venture. Over fifty related projects were implemented by 1962, linking Israel's municipal waste plants to farms around the country. The wastewater reuse standards were hastily promulgated using little data. They were not especially demanding. Yet in retrospect, they proved to be largely effective in preventing the anticipated health hazards from pathogens in irrigation effluents: some twenty years into the wastewater reuse transition, an epidemiological study among farmers suggested that *human health* was hardly affected by the utilisation of effluents.[31] Monitor-

[29] Alon Tal, *Pollution in a Promised Land*.

[30] Alberto Wachs, 'The Outlook for Wastewater Utilization in Israel', in Hillel Shuval (ed.), *Developments in Water Quality Research* (Ann Arbor, Michigan: Ann Arbor Science Publishers, 1971), pp. 109–111.

[31] Badri Fattal and Hillel Shuval, 'Historical Prospective Epidemiological Study of Wastewater Utilization in Kibbutzim in Israel, 1974–77', in Hillel Shu-

ing a technically literate agricultural community was a critical component of policy implementation.

The cumulative *environmental* impact of utilising effluents with a range of other residual chemicals and high general salinity, however, may be less salutary.[32] For instance, crops suffered a variety of toxic effects from the high concentrations of Boron that were initially present in the recycled irrigation water. Eventually, regulations were enacted that banned Boron in locally sold detergents and the problem quickly disappeared.

The larger problem was that sewage treatment remained fairly rudimentary for Israel's initial forty years, even as effluent utilisation pushed on full speed ahead. Systematically, Israeli sprinklers were spraying water with micro-contaminants onto crops, and some percolated into underlying groundwater. Chemicals ranging from industrial solvents[33] to pharmaceuticals[34] were found in aquifers underlying agriculture fields.

By the 1950s, primary treatment for sewage was fairly well established in Israel. Secondary treatment took a while longer to become a normative feature of municipal infrastructures. Indeed, *activated sludge* processes were only introduced on a serious scale after the opening of the Shifdan plant for the greater Tel Aviv region in December 1969. It would take decades until this 'technology-of-choice' became widely adopted.

Progress was slow because environmental infrastructure was not a national budget priority. Nonetheless, during the 1990s, as general affluence and environmental awareness improved, this changed. Investment since 1993 has been reasonable, with $US2.3 billion

val (ed.), *Developments in Arid Zone Ecology and Environmental Quality* (Philadelphia: Balaban ISS, 1981), pp. 333–343.

[32] Dan Zaslavsky, Rami Guhteh and Ayal Sahar, *Policies for Utilizing Sewage in Israel – Sewage Treatment for Effluent Irrigation or Desalinating Effluents to Drinking Water Quality,* (Haifa: Technion, 2004); Alon Tal, 'Management of Transboundary Wastewater Discharges', in Megdal, Varady and Eden (eds), *Shared Borders, Shared Waters*, pp. 221–232.

[33] Leah Muszkot, et al., 'Large Scale Contamination of Deep Groundwaters by Organic Pollutants', *Advances in Mass Spectrometry* **11B** (1990): 1628.

invested in 4,000 infrastructure projects. By 2009, secondary treatment was already in place in 92 per cent of Israel's wastewater treatment plants. Over a billion dollars was spent on wastewater infrastructure during the past decade, adding close to 150 million cubic metres of recycled effluent to the total amount available water.

By the end of the 1990s it was clear that Israel's 1981 standards for wastewater treatment were no longer adequate. A simple, so-called: '20/30' standard was required of discharges from wastewater treatment plants (WWTPs). This was a reference to the maximally allowed 20 mg/l Biological Oxygen Demand (BOD) and 30 mg/l for Total Suspended Solids (TSS). Israeli sewage treatment criteria at the time were essentially based on European water quality parameters. The problem was that conditions in Israel are fundamentally different from in Europe where treated wastewater can be released and diluted in rushing rivers.[35] This turned out to matter a great deal when stream rehabilitation became a national objective.

Most of Israel's streams are naturally ephemeral, with riverbeds lying dry for much of the year. By the 1970s, many of these streams flowed year round, with currents comprised primarily of wastewater and effluents. With sewage only treated to European levels, and little dilution provided by natural fresh water flow, rehabilitation of stream ecosystems was practically impossible. Led by experts from the relatively new bureaucracy at the Ministry of Environment, Israeli water managers adapted with an ambitious proposal. After prolonged negotiations between competing ministries and interest groups, new, stringent standards for wastewater reuse were promulgated.[36]

The new effluent criteria are more detailed and complex. The standards are bifurcated: criteria are set for one of two different effluent

[34] Dror Avisar, Yael Lester and Daniel Ronen, 'Sulfamethoxazole Contamination of a Deep Phreatic Aquifer', *Science of the Total Environment* **407** (2009): 4278–4282.

[35] Alon Tal, 'Management of Transboundary Wastewater Discharges', in Megdal, Varady and Eden (eds), *Shared Borders, Shared Waters*, pp. 221–232.

[36] Phoenix Lawhon and Moshe Schwartz, 'Linking environmental and economic sustainability in establishing standards for wastewater re-use in Israel', *Water Science and Technology* **53**/9 (2006): 203–12.

uses: utilisation by agriculture or release into streams.[37] This reflects a recognition that agriculture can accommodate higher concentrations for some parameters, like nutrients, than aquatic ecological systems. All of the standards are more stringent than the earlier ones. For instance, Israel's relatively lenient '20–30' standard was replaced by a far more demanding 10/10 BOD/TSS requirement, which enhanced the potential for stream rehabilitation using treating wastewater.[38] Many new parameters were added as part of these so-called 'Inbar Standards', named after Ministry of Environment Deputy Director, Yossi Inbar, who chaired the inter-ministerial committee. These include heavy metals such as chromium, nickel, lead, cadmium, zinc and iron.

A snapshot from 2016 shows that the sewage strategy was largely successful and meaningful progress was made. Over a thirty-year period, Israeli WWTPs came to accommodate more than three times the original quantities, today receiving 505 mcm of sewage, 470 million mcm (93 per cent) of which is treated. After evaporation, 400 mcm (86 per cent) is available for reuse by farmers. Roughly half of Israel's sewage at present undergoes advanced tertiary treatment while the other half still relies on secondary treatment, but the historical trend is evident. As the more stringent treatment standards are phased in, new infrastructure projects gradually upgrade the level of treatment at WWTPs. In the foreseeable future, all Israeli effluents reaching agriculture will undergo tertiary treatment.

While there have been inevitable malfunctions and specific management problems, historic investment in infrastructure has paid off. Wastewater quality for the most part is high. For example, a recent three-year study measured numerous micro-contaminants that affect the endocrine system (EDCs) in Israeli wastewater showed that concentrations in *treated* wastewater were significantly lower than in other developed countries and did not pose a significant public health threat.[39]

[37] Yossi Inbar, 'Wastewater Treatment and Reuse in Israel', in in *Water Wisdom, A New Menu for Palestinian and Israeli Cooperation in Water Management*, pp. 183–188.

[38] Yossi Inbar, 'New Standards for Treated Wastewater Reuse in Israel', in M.K. Zaidi (ed.) *Wastewater Reuse, Risk Assessment, Decision Making and Environmental Security* (Dordrecht, Springer, 2007), pp. 291–296.

[39] Pniela Dotan, Tal Godinger, Wad Odeh, Ludmila Groisman, Nader Al-

In short, over a fifty-year period, wastewater became the dominant source of irrigation water for Israel's farmers. Already, less than half the country's irrigation water comes from freshwater resources. The majority of water allocated to agriculture involves recycled effluents and brackish water. Over the next 35 years, these trends will continue, at which point only about a quarter of irrigation water will use conventional fresh water resources. Israeli farmers were never thrilled with the smells and nastiness of even well-treated sewage. After half a century, however, effluent reuse is here to stay and is now an integral element/part of the culture of Israeli agriculture. This is partly the result of engaging these key stakeholders in the adaptive response to water scarcity.

## Phase 3: Storage

The asymmetrical climatic conditions in Israel created a problem: There was plenty of wastewater for irrigation available during the rainy season (October–April). But during these months, many farmers had all the water they needed from natural precipitation. Storing effluents until they were actually needed during the dryer summer months presented a new infrastructure challenge. Initially water reservoirs were designed to harvest floodwaters, which would otherwise evaporate after running into wadis and low-laying grounds. The collected rainwater would percolate into nearby aquifers limiting evaporative loss.[40] The goal from a water management perspective was to improve the quality and increase the quantity of ground water by replenishing aquifers. Farmers, however, soon came to realise that the new collection system constituted a bonanza for them. They began to demand that the local Water Associations which oversaw the reservoirs deliver the impounded floodwaters directly for irrigation in nearby fields. As these associations were typically run by representatives of agricultural communities, they acceded to these expectations.

Khateeb, Alfred Abed Rabbo, Alon Tal and Shai Arnon, 'Occurrence and fate of endocrine disrupting compounds in wastewater treatment plants in Israel and the Palestinian West Bank', *Chemosphere* **155** (2016): 86–93.

[40] Alon Tal, 'Seeking Sustainability', 1081–1084.

As the issue of seasonality of demand and storage of effluents became more salient, an initial infrastructure and funding framework was already in place. The highest yield wadis and watersheds had already been connected to floodwater reservoirs. Here again, water managers adapted. The profile of Israel's reservoir project changed completely and the new basins were quickly designed to accommodate treated effluents. Beginning in the 1990s, as part of their development assistance for Israel's periphery, the Jewish National Fund (JNF), a public corporation, began constructing effluent reservoirs, replete with plastic liners and piping infrastructure. A national storage network emerged, with over 240 reservoirs that collectively deliver 260 mcm of water to Israel's water system. Over eighty per cent of water supplied by the reservoir system today is recycled wastewater. By 2010, more than fifty per cent of the wastewater delivered to the agricultural sector for irrigation was previously stored in a JNF reservoir.[41]

The water quality of effluents utilised by Israeli agriculture was originally poor, but has steadily improved. Only 65 per cent of effluents in a recent study met the old 20 / 30 BOD and TSS requirements. Most of the samples measured failed to meet the new 'Inbar' standards.[42] The study revealed a problem with WWTPs that are unable to adequately treat discharges from dairies and beef operations, due to the high organic and nutrient loadings. Ultimately, storage reservoirs were never expected to do the 'heavy lifting' in improving sewage treatment. Rather, their function has been to provide storage capacity for effluents until they are needed for irrigation.

## Phase 4: Conservation and Demand Reduction

The first three phases of Israel's water management focused on expanding water supply. But policies that seek an even hydrological

[41] KKL (Keren Kayemeth L'Yisrael) (2015) 'KKL Assistance to the Water System', http://www.kkl.org.il/water-activity/water-for-israel/water-resources/

[42] Ofir Kfir, Alon Tal, Amit Gross and Eilon Adar, 'Assessing the effectiveness of waste water reuse reservoirs in Israel: Results of a National Survey', *Resources, Conservation and Recycling* **68** (2012): 76–87.

balance sheet also need to think about reducing demand. During Israel's first five decades, the vast majority of the country's water went to agricultural consumers. It made sense from a policy perspective to focus water conservation interventions on this sector. The highly subsidised water prices available to the country's farmers, however, did little to create economic incentives for improving efficiency. Nonetheless, Israel's growers are considered some of the most water-efficient farmers in the world. How did this come about?

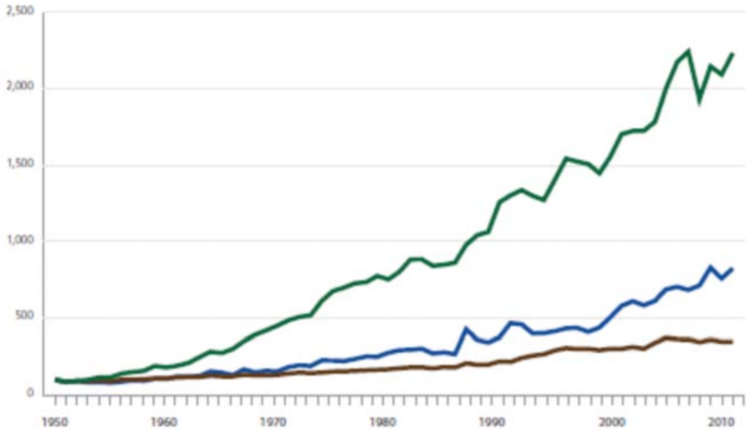
It can be argued that Israel got lucky when a technological innovation made good agronomic sense as well as good hydrological sense. By the 1960s Simcha Blass had left Israel's water bureaucracy after a series of acrimonious disagreements with his former patron (and future Prime Minister) Levi Eshkol. This left him the time to direct his considerable talents to engineering. In his memoirs, Blass writes that the idea for drip irrigation actually came to him in the 1930s. He realised that limiting irrigation water to plants to tiny pulses, so that the root zones receive their water (and fertiliser) through a steady flow of individual drops, provides a double bonus: not only are copious amounts of water saved, but the plants are far happier. It would take the availability of inexpensive plastics to transform the insight into a marketable product. By 1965 he had a workable prototype and a struggling young kibbutz near Beer Sheva, Hatzerim, was delighted to become his business partner.[43] Thus the Netafim corporation, which produces a significant percentage of the world's drip irrigation equipment, was established.

In addition to the commercial success, from a hydrological perspective, the introduction of drip irrigation technology during the 1960s and 1970s constituted a genuine revolution. It contributed enormously to the phenomenal yields attained by Israeli farmers.[44] Drip irrigation not only became ubiquitous in the fields of Israel's communal farms (the kibbutzim and moshavim), but municipal landscapers and home gardeners also became converts. Even though the amount of

[43] Simcha Blass, *Water in Strife and Action*.

[44] Daniel Hillel, '40 years of drip irrigation: Reviewing the past, prospects for the future', *CSA News* **53** (2008): 3–7.

**Figure 2. Growth in Israeli produce based on a matrix of fertility, labour and water: 1950–2013. Source: Statistical Atlas of Israeli Agriculture, 2013**




(Green = all crops Blue = field crops and Brown= livestock)

water provided to local farmers has not increased for more than sixty years now, as Figure 2 shows there has been a sixteen-fold increase in the overall value of Israeli agricultural production.

Farmers today produce 2,000 per cent more fruit per person and 300 per cent more vegetables per capita than they did during the 1950s.[45]

It was not only farmers who adopted water saving technologies. Israel's increasingly urban population took innumerable measures to reduce water consumption: low and dual-flush toilets became commonplace in houses and public restrooms; kitchens did not install

[45] Yoav Kislev and Shaul Tsaban, *Statistical Atlas of Israeli Agriculture, 2013* (Beit Dagan, Israel Ministry of Agriculture, 2013) http://www.moag.gov.il/agri/Files/atlas_haklaut.pdf; Alon Tal, 'To Make a Desert Bloom – The Israeli Agriculture Adventure and the Quest for Sustainability', *Agricultural History* **81**/2 (2007): 228–258.

water wasteful garbage disposals; water-saving showerheads were introduced, replacing free flowing ones. A policy was adopted which monitored municipal pipe leaks closely, prioritising infrastructure maintenance through economic incentives to city governments, making Israeli cities the least 'leaky' in the world. On average, only ten per cent of the water reaching Israeli towns is lost to leakage during delivery.[46] This is less than a third of that escaping municipal pipelines in countries bordering Israel.[47]

Water saving measures were not merely technological fixes. Engaging the public's hearts and minds became a significant part of Israel's water conservation strategy. Financial incentives offered one alternative policy instrument to 'command and control' prescriptions. To encourage conservation, the Israeli pricing system introduced a 'two-block tariff system', where municipal consumers who use less than 3.5 cm/month pay 2.3 dollars/cm while those using more pay 3.7 dollars/cm.[48] Still environmental economists assumed that water would remain a highly 'inelastic' commodity and that people were unlikely to reduce their personal consumption in response to increased pricing. Appealing to a public sense of duty was deemed more promising.

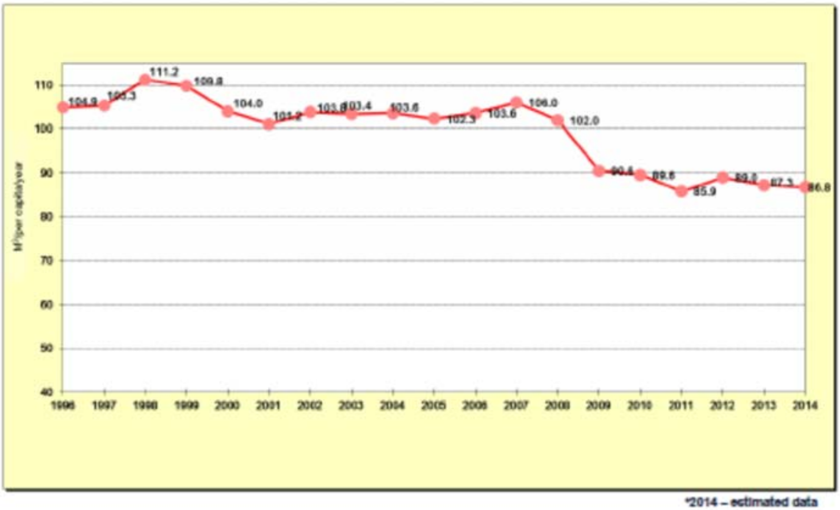
For instance, after four years of droughts, in 2009 Israel's government prepared rules to ban the watering of park lawns. Municipalities sued and the court disqualified the rules as arbitrary and capricious. The Water Authority decided to make a direct plea to municipal consumers. In the spring and summer of 2009, the Israeli public defied conventional economic wisdom by reducing its water consumption voluntarily by over fifteen per cent. This was largely in response to a high profile advertising campaign, featuring local celebrities such as dancer Renana Raz, 'Israeli idol' diva 'Nanette' and

[46] Ynet correspondents, 'Research: Roughly 10 percent of water leaks from pipes', *Ynet,* (24 Feb. 2009) http://www.ynet.co.il/articles/0,7340,L-3676733,00.html.

[47] Haim Gvirtzman, *The Israeli-Palestinian Water Conflict: An Israeli Perspective* (Ramat Gan: Begin-Sadat Center for Strategic Studies, Bar Ilan University, 2012).

[48] Israel Water Authority, *Water Sector in Israel, IWRM Model,* presentation at the World Water Forum, (2015), http://www.water.gov.il/Hebrew/ProfessionalInfoAndData/2012/02Israel%20Water%20Sector%20-%20IWRM%20Model.pdf.

**Figure 3. Domestic Israeli Per Capita Water Consumption, 1996–2014**



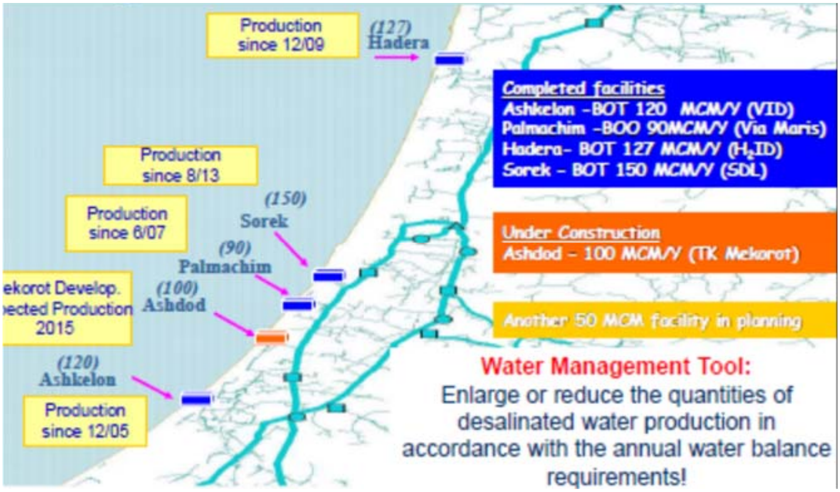

Source: Israel Water Authority.

super model 'Bar Rafaeli' who implored the public to save the Kinneret Lake by reducing water consumption. As can be seen in Figure 3, despite a substantial increase in the per capita income and quality of life, per capita, municipal water use by Israelis has dropped by roughly twenty per cent since it peaked in 1998.

## Phase 5: Desalination

Faced with alarming projections about imminent water shortages, on 4 April 2002 the Israeli government decided to respond decisively by approving the construction of four sea desalination plants on the Mediterranean coast. These plants were to be the first of a new generation of desalination plants, based on reverse osmosis membranes developed in Israel during the 1960s by Professor Sidney

**Figure 4. Cost of Israeli desalinated water (per cubic metre) relative to other countries**




Source: Israel Water Authority, 2015.

Loeb at Ben Gurion University.[49] The assumption was that the plants would produce some 250 million cubic metres of desalinised water annually. In order to reduce the associated public expenditures, the financing model adopted was 'BOT' – 'Build, Operate Transport'.[50] A tender was issued, for the first time bringing the private sector into Israel's municipal water delivery business.[51] Thirteen years later,

[49] Bob Weintraub, 'Sidney Loeb', *Bulletin of the Israel Chemical Society* **8** (2001): 8–9, https://drive.google.com/file/d/1hpgY6dd0Qtb4M6xnNXhutP4pMxidq_jqG962VzWt_W7-hssGnSxSzjTY8RvW/edit.

[50] Abraham Tenne, *Sea Water Desalination in Israel: Planning, Coping with Difficulties, and Economic Aspects of Long-term Risks* (Tel Aviv: Israel Water Authority, 2010) http://www.water.gov.il/Hebrew/ProfessionalInfoAndData/2012/12-Desalination-in-Israel.pdf.

[51] Alon Tal, 'The Desalination Debate – Lessons Learned Thus Far', *Environment* **53**/5 (2011): 35–49.

the results exceeded even the most optimistic expectations. Figure 4 shows Israeli desalination facilities established by 2015 and their production levels.

All told, Israel produces over 500 million cubic metres of water with another 100 mcm of sea water desal capacity added in a new facility opening in Ashdod.[52] This constitutes a fifty per cent increase in fresh water supply. Expectations are that these amounts will definitely double and possibly triple in the future.

The quality of the water produced by Israel's desalination plant turned out to be exceptional. In all cases, the actual chemical parameters for desalinated drinking water produced turned out to be significantly higher than the level stipulated in the contract with the operating consortia. Indeed, the water initially was so clean that farmers found that their plants did poorly when irrigated with desalinated water, which lacked key ions such as calcium (Ca2+), magnesium (Mg2+) and sulfate (SO4 2–). Since that time these elements have been added to desalinated water before it is released into the national water supply grid.[53]

There is little doubt that technological improvements, the associated economic savings and private-sector involvement in desalination drove Israel's recent transformation in water management strategy. Figure 5 contrasts Israeli desalination prices with those in other countries. Locally, high quality drinking water can be produced for rates that just exceed US50 cents, making Israeli desalinated water the least expensive in the world.[54] (Municipal consumers pay far more for their water than the actual production costs, presumably to cover the expense of delivery systems.) Overall, desalinated water in Israel today costs little more than the traditional sources of water from the Jordan River Basin via the National Water Carrier and is of better quality.

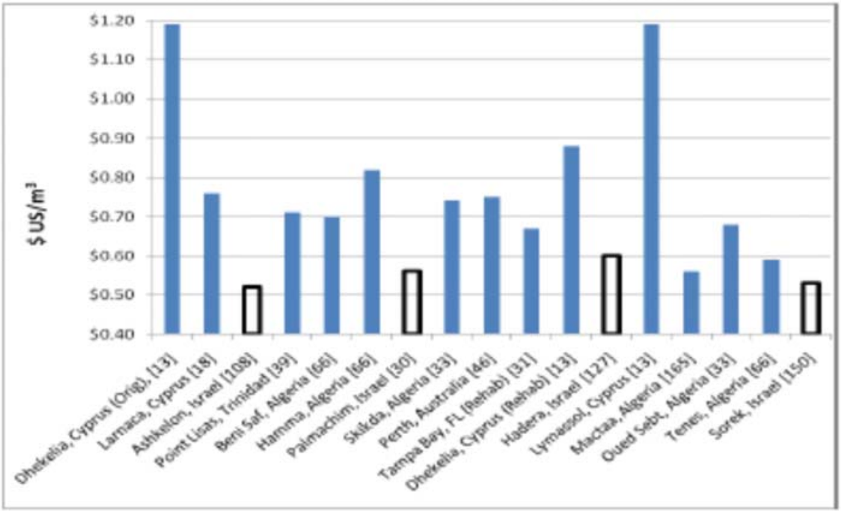
At the time when the transition to desalination was discussed,

[52] Israel Water Authority, *Water Sector in Israel, Zoom on Desalination,* presentation at the World Water Forum (2015)

[53] U. Yermiyahu, A. Tal, A. Ben-Gal, A. Bar-Tal, J. Tarchisky and O. Lahav, 'Rethinking Desalinated Water Quality and Agriculture', *Science* **318** (2007): 920–21.

[54] Israel Water Authority, *Water Sector in Israel, Zoom on Desalination.*

**Figure 5. Cost of Israeli desalinated water (per cubic metre) relative to other countries**




Source: Israel Water Authority, 2015.

relatively few objections surfaced among Israel's generally combative environmental movement.[55] There are several possible explanations for the apparent complacency. These include the significance of expanded water sources to stream restoration and reconciling water conflicts with the Palestinians, as well as an underlying technological optimism among Israeli NGOs.

It is not as if environmental concerns do not exist. Potentially detrimental environmental impacts of seawater desalination identified at the time of the programme's inception included:

- Compromised beachfront and loss of access by the public;
- Marine contamination caused by returning brine into the sea containing a variety of chemicals used during the treatment process; and

– Discharges of greenhouse gases and other air pollutants associated with the prodigious energy requirements required by desalination process;

In retrospect, thus far the first concern has not been a salient factor in Israel. Local desal plants have been integrated into existing infrastructures already located on the coast (e.g., electrical power plants). This has led to no net-loss of publicly accessible beach areas. Figure 5 offers an aerial photograph of a typical desalination plant based on the Hadera coast. Because the plant is so neatly embedded inside the existing electricity power station, it is difficult to discern the precise building (in this case the blue-sided structure) which houses the membranes.

Despite impressive progress in plant efficiency, the energy required to desalinate water remains significant. For instance, a new, modestly sized, 250 Ml desalination plant will consume energy commensurate with 500,000 tons of $CO_2$ emissions – the equivalent of 120,000 new cars on the road. To reduce greenhouse gas loadings, natural gas cogeneration is used in some facilities, but most plants rely on the electricity grid which is still roughly fifty per cent coal fired. (Following recent discoveries in Israel's Mediterranean territorial waters, in general Israel's electricity supply should become increasingly based on natural gas.) Israel's Water Authority has published its intent that the next generation of desal facilities be run on solar energy.[56]

The potential for contamination due to the impact of brine discharge on marine ecosystems has been raised.[57] In particular, there is concern in the Gulf of Arabia where desalination plants have been operating for decades.[58] Most concerns focused on the impact of the

[55] Alon Tal, 'The Desalination Debate': 35–49.

[56] Israel Water Authority (2015) *The Wastewater and Treated Effluents Infrastructure Development in Israel,* presentation at the World Water Forum, 2015.

[57] D.A. Roberts, E.L. Johnston, and N.A. Knott, 'Impacts of desalination plant discharges on the marine environment: A critical review of published studies', *Water Research* **44** (2010): 5117–5128; Pilar Palomar and Iñigo. J. Losada,, 'Impacts of Brine Discharge on the Marine Environment. Modelling as a Predictive Tool' in M. Schorr (ed.), *Desalination, Trends and Technologies* (InTech, 2011), pp. 279–310.

[58] S. Lattemann and T. Hopner. 'Environmental impact and impact assess-

**Figure 6. Aerial photo of desalination plant in Hadera, Israel**

saline brine on benthic communities.[59] After over a decade of monitoring, however, there do not yet appear to be signs of significant effects on Israel's marine environment from brine discharges emanating from desalination plants.

Findings from the first study published about the environmental consequences of Israel's brine discharges suggest that in the immediate vicinity of the outfall there are higher salinity concentrations and temperatures. Elevated levels of nutrient concentrations and turbidity were also measured in this limited area. These were linked to lower local densities of phytoplankton found. On the other hand, the microbial community outside a radius of 1.3 kilometers from the outfall of the brine did not appear to be affected.[60] Subsequent monitoring reached the same conclusion.

ment of seawater desalination'. Desalination **220** (2008): 1–15.

[59] J.L. Sánchez-Lizaso, J. Romero, J. Ruiz, E. Gacia, J. L. Buceta, O. Invers, Y. Fernández Torquemada, J. Mas, A. Ruiz-Mateo and M. Manzaner. 'Salinity tolerance of the Mediterranean seagrass *Posidonia oceanica*: recommendations to minimize the impact of brine discharges from desalination plants', *Desalination* **221** (2008): 602–607.

[60] Dror Drami, Yosef Yacobi, Noga Stambler and Nurit Kress, 'Seawater quality and microbial communities at a desalination plant marine outfall. A field study at the Israeli Mediterranean coast', *Water Research* **45**/17 (2011): 5440–5462.

Dr. Yuval Cohen, one of Israel's most senior marine biologists summarises the myriad monitoring reports conducted by Israel's government and by desalination plants about conditions in Israel's territorial, Mediterranean waters:

> Overall, taking chl-a as a proxy for phytoplankton biomass, the monitoring data shows that the concentrates of the three SWRO plants do not have significant impact on the phytoplankton biomass in the receiving areas … The concentrations of phosphate reflect the natural phosphate in the source (feed) seawater … In general, the concentrations of heavy metals measured in the sediments at the three areas were within the range of the natural concentrations in shallow sediments along the Israeli coastline and lower than the 'effects range low' (ERL) values developed by the US National Oceanic and Atmospheric Administration.[61]

Results were similar in monitoring reports from California.[62]

This in no way means that no impact from discharges exists. Concerns about possible pollution to the marine environment and long-term effects due to a range of chemicals utilised in the production process remain real, especially given the proliferation of new desal plants along the Mediterranean shoreline. However, not all the chemicals contained in the discharged brine are considered deleterious. They include iron or aluminum salts that serve as coagulants in the pre-treatment stage; biocides like chlorine or sodium sulfite; polyphosphate or polyphosphonate anti-scalants that prevent the fouling of the membranes; and the acidic and alkaline solutions and detergents used as cleaning solutions for the Reverse Osmosis membranes.

Zalul – Israel's most active and combative NGO focusing on marine environmental quality at present has not targeted desalination facilities. While their website describes the theoretical risks associated with desalination discharges, they are open in acknowledging:

[61] Yuval Cohen, 'Seawater desalination and the environment – the Israeli experience'.

[62] Weston Solutions, 'High-Salinity Sensitivity Study: Short-and Long-Term Exposure Assessment, Carson, California, West Basin Municipal District' (April 2013).

> The little research that has been conducted near the desalination facilities, however, has not yet shown a broad impact of desalination on the marine environment, even as the researchers admit that the number of studies conducted has been too modest and that they should be expanded and deepened before reaching a final conclusions.[63]

A committee of twenty scientists from the Technion, Israel's leading scientific/engineering university evaluated the impact of the brine discharges from Israel's desalination plants on the Mediterranean environment. While the committee could not identify any biological damage to the marine environment, its report adopts the spirit of the precautionary principal and recommends measures to avoid any associated ecological risks. These include:

> a) A prohibition on the presence of chlorine in water residuals leaving the (desalination) system into the marine environment.
> b) A requirement to neutralise the acids, bases and oxidizing compounds before discharging them into the marine environment.
> c) Assessing the chemical make-up of the materials used in the desalination process (primarily iron salts) inter alia, to identify heavy metals. These inspections should be implemented on an annual basis.[64]

In summary, ten years into Israel's desalination experiment, no significant, far less catastrophic, environmental impacts are evident.

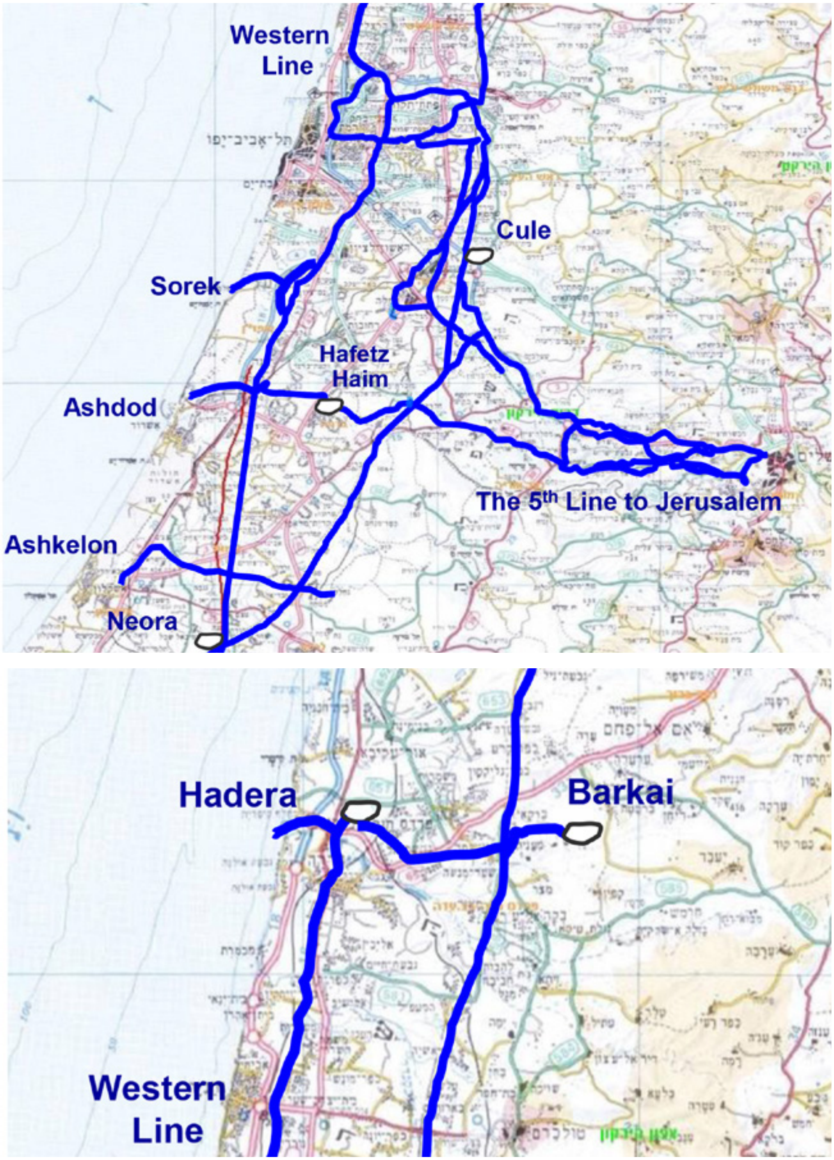
Profound changes brought about by this final fifth phase of Israel's water management history involved the transformation of basic assumptions in water management that had been axiomatic during the first five decades of Israel's history.[65] The basic 'hydrological Socialism' of Israel's early years remains largely in place: water development is still planned by the state, and prices remained uniform for consumers across the country. Yet, private consortia began

[63] Zalul, 'Desalination' website last visited 28 Dec. 2015, http://www.zalul.org.il/?page_id=112.

[64] Yoram Avnimelech, 'The Effect of Desalination Plants on the Sea and the Marine Environment', *Ecology and Environment* **3**/3 (2012): 211–213.

[65] Eran Feitelson and Gad Rosenthal, 'Desalination, space and power: The ramifications of Israel's changing water geography', *Geoforum* **43**/2 (2012): 272–284.

### Figure 7. New water grid in Israel emanating from central water sources




Source: Israel Water Authority.

to produce a growing percentage of Israeli water. The Galilee and Israel's Northern provinces ceased to play the role of hydrological 'benefactor' for the desiccated southlands. Figure 7 shows the new water lines produced by the desalination production. In fact, during recent drought years, the national water carrier essentially ceased to operate. Israel's southlands received most of their water from recycled effluents and desalinated sources based in the country's central and southern coastal region.

## Conclusion: Adapting adaptive management

The very different stages of Israel's water management history share a fundamental, common element. Water managers were attentive to changing circumstances and the periodic challenges and crises they presented. They did not hesitate to utilise emerging technologies and to craft policies that offered swift and usually effective responses. Unfortunately, the adaptive management approach was not always swift enough to prevent irreversible damage. Water resources have surely suffered during Israel's 67 years of rapid development: Streams became putrid and often moribund sewage conduits; aquifers became depleted and polluted.[66] Aquatic habitats were drained or fell into disrepair. And the steady decline in the Dead Sea waterline has significant environmental, economic and ethical implications with no clear strategy for rehabilitation in site.[67]

As the country considers its present state of affairs, there are those who believe that the age of scarcity is over.[68] Desalination is seen as a

[66] Alon Tal, *The Environment in Israel: Natural Resources, Crises, Campaigns and Policy from the Advent of Zionism until Twenty-first Century*, (B'nei Brak HaKibbutz HaMeuhad Press, 2006).

[67] Sagi Filin, Yoav Avni, Amit Baruch, Smadar Morik Reuama Arav and Shmuel Marco, 'Characterization of land degradation along the receding Dead Sea coastal zone using airborne laser scanning', *Geomorphology* **206** / 1 (2014): 403–420.

[68] Yuval Elizur. 'Over and Drought: Why the End of Israel's Water Shortage Is a Secret', *Haaretz* (24 Jan. 2014) http://www.haaretz.com/news/national/1.570374.

game changer. Surely Israel's water system will never be the same. One recent analysis argues that the technological breakthrough undermined age-old 'hydro-ideological support for agriculture', introduced 'new ideas of abundance' and 'displaced environmental externalities'.[69]

One could also argue that a happy result of the country's historic policies is that, for the first time, Israel's farmers have reliable irrigation sources. In the past, Israel's adaptive management meant that when rainfall levels dropped, water allocations to farmers were cut by as much as fifty per cent, with little or no warning.[70] This made environmental sense but drove farmers crazy. Weather inconsistencies only modestly affect sewage production and have no meaningful effect on desalination facilities. Today, agricultural operators can plan for the future with far greater confidence.

By eliminating hydrological uncertainties one might reach the conclusion that the underlying rationale behind Israel's traditional adaptive management approach to water resources (responding to climatic vicissitudes) is no longer valid. It is certainly true that, during recent summers, Israelis hardly felt the overall drop in precipitation levels, as they continued to enjoy uninterrupted desalinated water. In 2014, to save money, the government only used seventy per cent of its desal capacity, leading neighbouring countries to protest that they surely could use the additional supply.[71]

The era of water surfeit has only begun. All signs point to a new generation of desalination facilities that will be built in Israel. New tenders promise to be more environmentally friendly, including integration of local recycled materials and full reliance on natural gas or renewable energy sources·[72]

[69] N. Teschner, Y. Garb and J. Paavola, 'The Role of Technology in Policy Dynamics: The Case of Desalination in Israel', *Environmental Policy and Governance* **23**: 91–103.

[70] Amira Cohen, 'Increase in water allocations to farmers being considered', *Haaretz* (26 Feb. 2003) http://www.haaretz.com/print-edition/business/increase-in-water-allocations-to-farmers-being-considered-1.17951

[71] Sharon Udasin, 'Desalination facilities to run at 70% capacity for 2014', *Jerusalem Post* (1 Feb. 2014).

[72] Israel Water Authority, *Water Sector in Israel, Zoom on Desalination.*

Some environmentalists express misgivings about Israel's desalination experience because of the complacency that might be created by surpluses. A local ethic venerating modest consumption took decades to nurture and constitutes an important collective moral virtue. According to this view, water conservation constituted an important perspective for a society that will always face natural resource shortages. Notwithstanding technological progress and the 'larger pie' now available, there is surely little room for apathy regarding Israel's future water resources. Dependence on desalination means that uncertainty has changed but has hardly disappeared. Susceptibility due to variations in rainfall has given way to other vulnerabilities:

> The price of electricity will drive the price of desalinated water for consumers for the foreseeable future, making the system vulnerable to any turbulence in world energy markets.[73]
>
> Concentrating Israeli drinking water production in five or six centralised facilities makes the entire system vulnerable to the long and mid-range rockets of hostile forces in Gaza and Lebanon during the country's intermittent military skirmishes.
>
> Contamination of marine waters by Israel's neighbours threatens to compromise desal facilities that are situated just up the coast. For example, the discharge of raw sewage into the sea in Gaza has already affected the desalination process in Ashkelon, where the plant was closed for four days in February 2016 due to Palestinian sewage discharges.[74]

Although uncertainty and threats to reliable supply remain, an historic environmental evaluation of Israel's water history does not indicate that decisions made along the way, including the most recent shift to desalination, were mistakes. Indeed, without the new infrastructure, it is difficult to imagine how Israel would be able to maintain its present level of water delivery in the face of relentless population growth. At present, this grand hydrological experiment

[73] Yaakov Garb, 'Desalination in Israel, Status, Prospects and Context', in A. Tal and A. Abed-Rabbo (eds) *Water Wisdom*, pp. 238–45.

[74] Michelle-Malka-Grossman, 'Gaza sewage crisis is a ticking timebomb for Israel' *Jerusalem Post,* 17 March 2016, http://www.jpost.com/Arab-Israeli-Conflict/Gaza-sewage-crisis-is-a-ticking-timebomb-for-Israel-448335.

appears to be largely positive. This is especially true when one considers expanded water resources as a key to resolving a central area of conflict between Israel and the Palestinians.

Nonetheless, just as in days gone by, a desalinated Israel will still have to continue to monitor conditions affecting its water supply system as closely as ever and develop contingencies that allow it to adapt in the event of future changes. A programme of adaptive management may have less reason to monitor the rain and more reasons to monitor the geopolitical and environmental dynamics. But the fundamental lesson emerging from Israel's hydrological history is still valid: an ability to make decisions nimbly about water resources based on analytically sound processing of scientific information constitutes the best strategy for a sustainable future.