Physics Today

Israel: A water innovator

David Kramer

Citation: Physics Today 69(6), 24 (2016); doi: 10.1063/PT.3.3193
View online: http://dx.doi.org/10.1063/PT.3.3193
View Table of Contents: http://scitation.aip.org/content/aip/magazine/physicstoday/69/6?ver=pdfcov
Published by the AIP Publishing

Israel: A water innovator

A combination of desalination, wastewater reuse, and efficient irrigation have produced water independence.

There is perhaps no better symbol of the water deficiency in the Middle East than the Dead Sea. Its waters, 10 times as saline as the ocean, can support only highly adapted bacteria and fungi. But its level in recent years has plunged at the rate of 1 meter annually as its lifeblood, the Jordan River, was diverted to supply water to Israel, Syria, and Jordan. As the inland sea retreats, it has left behind mudflats and thousands of sinkholes, some of them 25 meters deep.

In the midst of scarcity, however, Israel has become a model of sustainable water infrastructure—so much so that its government in 2013 declared the nation's water supply immune to the weather's vagaries and independent of the climate's aridity. Once a source of national nail-biting, the level of the Sea of Galilee is no longer an issue, and the nation even exports 100 million cubic meters of water to Jordan each year.

A world leader in desalination, Israel now obtains around 30% of its potable water supply from five reverse-osmosis (RO) plants. (See the Quick Study by Greg Thiel, PHYSICS TODAY, June 2015, page 66.) Israel recycles 85% of its wastewater for use in irrigation; Spain, which is second in water reuse, recycles 20%, and the US, a few percent at most. Israel's water distribution system is centralized under government control, and the nation pioneered the use of drip irrigation for agriculture in the 1960s.

"The Israeli water program has got to be the most advanced in the world," US energy secretary Ernest Moniz says. Moniz visited Israel in April and signed an agreement with his Israeli counterpart, Yuval Steinitz, minister of national infrastructures, energy, and water resources, to expand cooperative R&D on desalination, water treatment, and energy. Moniz says teams from the two countries will hold a competition to design a more advanced energy-efficient desalination plant. The two ministers also announced an exchange program for postdocs who work on energy and water.

Challenges abound

Although Israel is now self-sufficient, water scarcity and quality issues plague its neighbors. Jordan is water-starved; most homes don't have running water. Egypt is concerned that its supply from the Nile River will be curtailed with completion of the Grand Ethiopian Renaissance Dam on the Blue Nile in 2017. Up to a half-million Syrians living in the Euphrates River valley had to give up farming due to reduced flow from damming and pollution from agricultural runoff and industrial operations upstream in Turkey. That created a migration to shantytowns in cities where the ongoing civil war was born, notes Osnat Gillor of the environmental hydrology and microbiology department at the Zuckerberg Institute for Water Research, which is located at Ben-Gurion University of the Negev. BGU hosts Israel's only dedicated water research program.

Sub-Saharan Africa has no shortage of water: One day's flow over Victoria Falls is equivalent to the annual consumption of Israel. In Ghana, Kenya, and other countries, the problem is providing access to clean drinking water, says Zuckerberg director Noam Weisbrod.

DAVID KRAMER

PUMPS AT THE SOREK DESALINATION PLANT force seawater under high pressure through reverse-osmosis membranes to remove salt and other impurities. The world's largest reverse-osmosis plant, Sorek supplies potable water to 1.5 million people.

DAVID KRAMER

THE SHAFDAN TREATMENT PLANT near Tel Aviv treats wastewater generated by 2.5 million people. Israel recycles 85% of its wastewater for irrigation.

Worldwide, he says, 1.8 million children die each year from diarrhea, mostly from drinking contaminated water. Around 600 water-related nongovernmental organizations spend billions of dollars a year in Africa with limited success.

Through a rural water development program, BGU has sent faculty and students to Ethiopia, Uganda, and other African nations to provide low-tech, inexpensive fixes such as drilling wells and installing pumps. Although many nongovernmental organizations are doing the same, Weisbrod says, few are willing to maintain the infrastructure once it's installed. "There are a lot of white elephants," he says. This year's BGU trip to Uganda will be focused solely on well rehabilitation.

Leading reverse osmosis

Israel's five RO plants produce a combined 600 million cubic meters of water a year. They draw water from the Mediterranean Sea through sand filters that remove large solids. The seawater is then pumped under high pressure through cylindrical multistage polymer filters. Successively smaller pores trap particles, microorganisms, and large molecules. In the final stage, nearly pure water permeates through the RO membrane, and up to 99.8% of the salt and other minerals are left behind. Despite the permeate's near purity, a post-RO treatment is required to remove boron, which is toxic to plants at very low concentrations.

The newest RO facility, Sorek, is also the world's largest (see photo on page 24). It opened in 2013 and has an annual capacity of 150 million cubic meters. Located 15 kilometers south of Tel Aviv, it supplies potable water to 1.5 million people. With diameters of 41 cm, Sorek's cylindrical elements are twice the width of those at the other Israeli plants, and their vertical arrangement not only saves floor space but also makes it easy to clean the equipment and restart the RO process. Some 50 000 filter elements, each costing $2000, are used at Sorek. With proper upkeep, they can last up to 10 years, says Boris Liberman, vice president of IDE Technologies, which built and operates the Sorek plant and 400 other RO plants in 40 countries. The IDE-built plant in Carlsbad, California, completed last year, is the largest in the Western Hemisphere, with a capacity of 204 000 cubic meters per day.

Worldwide, 15 000 RO plants are located in 125 countries. They typically require 1.25–2.5 kilowatt-hours to desalinate a cubic meter of water, says Moshe Herzberg, a professor in the Zuckerberg Institute's desalination and water treatment department. RO costs have declined from nearly $1.60 per cubic meter in the 1990s to around 58 cents per cubic meter at Sorek.

A major problem with RO is biofouling. Over time, the growth and accumulation of microorganisms, algae, and plants will slow the flux of water through the filters. Because oxidizing disinfectants such as hydrogen peroxide will destroy the polymer membranes, the filter assemblies must be cleaned with a combination of detergents and alkali solutions. The cleaning is done in place, which requires taking the membranes out of service. And cleaning-solution wastes must be treated before being discharged. One area of research is discovering polymers that can withstand oxidizing agents, says Herzberg. Another focus is on hydrogels to coat the filter membranes. The hydrogels mimic jellyfish flesh, which is impervious to biofouling.

A related problem, scaling, arises from the buildup of salts and other inorganic materials on filters. To prevent scaling, polyelectrolyte antiscalents are added to the water. But those polymers can promote biofouling, either by providing a nutritional source for microorganisms or by altering membrane surface properties, BGU researchers have found.

A BGU spinoff called ROTEC, for Reverse Osmosis Technologies, has developed a novel descaling system that works by periodically switching the direction of flow, so that the first membrane assembly in the series becomes the last. Extensive precipitation is prevented by using relatively unsalty intake water to sweep away the scale-forming particles at the opposite, supersaturated end of the membrane array. Noam Perlmutter, the company's CEO, says ROTEC systems have been installed in the Netherlands and at Coca-Cola bottling plants in China and Chile.

Christopher Arnusch, a lecturer at Zuckerberg, is experimenting with using two- and three-dimensional printing to deposit polymer coatings on filter membranes. In contrast to the conventional dipping method of polymerization, 3D printing permits the fabrication of patterned polymer surfaces. "We showed that patterned membranes gave slightly better permeates and salt rejections than membranes made conventionally. We're trying to find out why that is," he says.

Some polymer deposition patterns appear to inhibit biofouling better than others. "Parallel stripes showed the least amount of fouling compared to a control membrane and worked much better than perpendicular stripes," Arnusch says. Membrane manufacturers could easily and inexpensively incorporate 3D polymerization into their fabrication processes, he adds.

Wastewater

Israeli innovation is also evident in wastewater treatment. The Shafdan plant south of Tel Aviv treats about 400 000 cubic meters of wastewater per day from a population of more than 2.5 million people. Touted as the largest and most advanced facility in the Middle

East, the plant is set apart by its use of the surrounding sand dunes to perform the final, tertiary phase of treatment. In earlier steps, the sludge has been settled out and the wastewater has undergone microbial treatment. By the time the water percolates to an aquifer 100 meters deep, a process that takes months, it is all but free from contaminants and approved for agriculture. Shafdan, the largest single-point source of water in Israel, supplies 60% of the water for agricultural needs in the Negev desert.

Treated wastewater in Israel can be used only for irrigation. It's supplied through a dedicated distribution system run by the state. Israel's standards for treated water in agriculture are more stringent than those of the World Health Organization, says Gillor.

Attitudes toward wastewater reuse vary widely. Singapore, dependent on neighboring Malaysia and Indonesia for most of its water supply, uses treated wastewater in its potable supply. Public outcry quashed a proposal in Orange County, California, to replenish an aquifer with treated wastewater.

Irrigation

Worldwide, about 60% of water used in agriculture is lost through evaporation, runoff, drainage, or leakage, says Naftali Lazarovitch of BGU's French Associates Institute for Agriculture and Biotechnology of Drylands. Forty percent of the global land mass is dry land and is home to one-third of the world's population. Seventy-five percent of Israel, including the Negev, is considered dry land. The desert provides a handy field laboratory for BGU's irrigation R&D, since it receives an average of about 90 millimeters of precipitation annually, little of which is absorbed by the crusty, rocky soil.

Israel invented modern drip irrigation, which delivers water, including treated wastewater, directly to the root zone of plants and crops. The plastic drip tubing is ubiquitous, even around landscaping, in the desert city of Beersheba, where BGU's main campus is located. In addition to reducing water use and evaporation compared with sprinkling, drip irrigation works on steep slopes and precisely deposits liquid fertilizers and pesticides where they are needed.

To further improve drip irrigation efficiency, BGU researchers developed a simple capillary barrier that blocks water flow from roots. It consists of a layer of gravel placed in the bottoms of shallow trenches that are just below the root zone of bell peppers. The trenches are then backfilled with soil. Bell pepper yields improved by 25%, and water usage was reduced. Farmers began using the technology even before the experiments were completed, says Lazarovitch. Installing the barriers is expensive, however, and farmers may need 10 years to recover their investment.

At a 300 hectare site in the nearby desert, Jhonathan Ephrath of the French Associates focuses on growing olive trees using only runoff from the very infrequent rains. Called catchment irrigation, the 2000-year-old practice works because barren soils don't readily absorb water, so some of it can be directed to the trees. The catchment area is as much as 30 times the area covered by the trees. Because olive tree growth varies naturally for reasons largely unknown, several years will be required to draw conclusions from the experiments, Ephrath says. Catchment irrigation could be used in arid regions of the developing world to cultivate fast-growing acacia trees for cooking fuel, he adds.

DAVID KRAMER

A DEVICE DEVELOPED AT BEN-GURION UNIVERSITY distills nitrogen from manure to produce liquid fertilizer that can be applied by drip irrigation. The university is seeking funding to scale up and commercialize the process.

COURTESY OF HEZI YIZHAQ

BUSHES IN THE LADAKH REGION of Jammu and Kashmir, an Indian-administered state, display characteristic line and circle patterns that form in response to prolonged drought.

Restoring the desert

Ehud Meron, a BGU physicist, studies the spatial reorganization of vegetation under prolonged drought conditions. "There is a whole field of nonlinear physics about patterns in nature. These also appear in ecosystems," he says.

In response to prolonged stress from lack of water, vegetation dies off in distinct patterns to make optimum use of available water, says Meron. Below a critical rainfall level, circular gaps start to form. As the drought progresses, plants retreat into a broken-line pattern, as in the image below, and then into circles. The bare ground provides an additional collection area from which the remaining plants draw water to survive.

Modeling has indicated that planting in stripes to restore vegetation, as is often done along embankments, is not optimal because that configuration isn't resilient to drought. Instead, says Meron, fragmented planting, as in a rhombic grid, is likely to produce a more sustainable ecosystem.

As for the Dead Sea, there have long been proposals to connect it to the Red Sea. The main purpose would not be to save the dwindling basin but to desalinate water for Jordan. The Jordanian government asked for proposals from industry by the end of last month to build and operate a desalination pilot plant to be located near the Red Sea. Ultimately, pipelines would be built to bring more water to a second desalination plant near the Dead Sea. The effluent from that plant would help replenish those waters, with unknown impacts on the ecology. The 430 meter elevation drop from the Red Sea to the Dead Sea could be used to produce hydroelectric power.

But the pilot project will require $1 billion or more in funding, and it's not clear where that money would come from, let alone the $10 billion estimated for the full version.

David Kramer