Metadata of the chapter that will be visualized online

Series Title	Global Issues in Water Policy	
Chapter Title	Desalination in Israel	
Chapter SubTitle		
Copyright Year	2013	
Copyright Holder	Springer Science + Business Media Dordrecht	
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Abstract

Desalination was first developed in Israel in 1965, when Mekorot, Israel's national water utility, established the first seawater desalination facility using vaporization technology in an effort to address the chronic thirst of the city of Eilat, located at the extreme southern tip of Israel on the Red Sea. A highly energy-intensive process, Mekorot looked for an alternative, energy-saving process, which it found in the reverse osmosis (RO) technology developed in the United States. In the early 1970s after the energy crisis of the Yom Kippur War, Mekorot began installing small-scale brackish water RO-desalination plants and, within the decade, established 15 desalination plants that supplied water to the Arava valley residents. Increasing demand and decreasing supply of freshwater in the coming years encouraged Mekorot to develop seawater desalination as an additional source, and the first plant (which desalinated a mixture of seawater and the reject brine from desalinated brackish water) commenced operation in 1997 in Eilat (Mekorot, Desalination by Mekorot, Retrieved from http://www.mekorot.co.il/Eng/NewsEvents/catalogs/DesalinationMekorot.pdf, November 2006).

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Chapter 7
Desalination in Israel

Erica Spiritos and Clive Lipchin

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7.1 Desalination Technology in Israel: Introduction and History

Desalination was first developed in Israel in 1965, when Mekorot, Israel's national water utility, established the first seawater desalination facility using vaporization technology in an effort to address the chronic thirst of the city of Eilat, located at the extreme southern tip of Israel on the Red Sea. A highly energy-intensive process, Mekorot looked for an alternative, energy-saving process, which it found in the reverse osmosis (RO) technology developed in the United States. In the early 1970s after the energy crisis of the Yom Kippur War, Mekorot began installing small-scale brackish water RO-desalination plants and, within the decade, established 15 desalination plants that supplied water to the Arava valley residents. Increasing demand and decreasing supply of freshwater in the coming years encouraged Mekorot to develop seawater desalination as an additional source, and the first plant (which desalinated a mixture of seawater and the reject brine from desalinated brackish water) commenced operation in 1997 in Eilat (Mekorot 2006).

The motivation behind desalination of seawater in Israel stems from the fact that current demand and projected future demand cannot be met by natural freshwater sources alone – a disparity that results from population growth, overconsumption, misallocation, and pollution.

This chapter discusses the development of desalination in Israel and the evolution of desalination as a pivotal means to securing a sustainable water supply in Israel. The chapter covers desalination policy, technology, pricing, energy needs, and the health and environmental impacts of desalination.

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N. Becker (ed.), *Water Policy in Israel: Context, Issues and Options*,
Global Issues in Water Policy 4, DOI 10.1007/978-94-007-5911-4_7,
© Springer Science+Business Media Dordrecht 2013

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7.1.1 Desalination Master Plan for 2020

The Desalination Master Plan was first conceived in 1997 in an effort to bridge the gap between an increasing demand and limited supply of freshwater resources in Israel within the next 20 years, through the introduction of a potentially unconstrained source of water. As stated in the Plan, the overarching goal of the Israeli Water Authority is to "assure that water will be sustainable, available, and reliable in the required quantities, locations, and qualities." In regard to desalination, the Water Authority has undertaken a program designed to meet all of Israel's domestic water needs with desalinated seawater by expanding existing facilities, constructing new facilities, encouraging technology improvements in pretreatment and posttreatment, and promoting energy-saving technologies (Tenne 2011).

The Plan itself involves the estimation of desalinated water needs and the optimal sizes and distribution of plants required to satisfy this need. From an economic perspective, the Plan considered the costs of the desalination process and delivering it to the national water supply grid, as well as expenses relating to storage capacity, energy requirements, and operation. Benefits derived from increased water-consuming economic activity and from the improvement in water supply quality and quantity were examined and optimized (Dreizin et al. 2007). The Plan did not include an environmental or social impact assessment, leading to much criticism from those who would prefer a more precautionary or demand-management method of addressing Israel's water shortages.

7.2 Israel's Desalination Plants

7.2.1 Seawater Reverse Osmosis

In the past, desalination production was limited to the southern resort town of Eilat and the surrounding agricultural communities, where no alternative existed. Today, modern membrane technologies, increased energy efficiency, and decreased overall cost from US$2.50 per cubic meter in the 1970s to slightly more than US$0.50 by 2003 have allowed for widespread implementation of desalination facilities along the Mediterranean coast (Becker et al. 2010).

In Israel today, all large-scale desalination plants operate using the reverse osmosis technology – the most energy and cost efficient of current desalination methods – consisting of four major processes: (1) pretreatment, (2) pressurization, (3) membrane separation, and (4) posttreatment stabilization. In the initial pretreatment stage, suspended solids are removed from the feedwater, the pH is adjusted, and a threshold inhibitor is added for membrane protection. Next, the electric pumping system increases the pressure of the pretreated water to a level appropriate for the membrane capacity and seawater salinity. For seawater

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Table 7.1 Existing industrial-scale desalination facilities in Israel

Facility	Inauguration	Production (MCM/year)	Contractor
Ashkelon	Sept 2005	119	VID, a special purpose joint-venture company of IDE Technologies, Veolia and Dankner-Ellern Infrastructure
Palmachim	2007 (April 2010)	30 (45)	Via Maris Desalination Ltd. consortium
Hadera	2009	127	H2ID, a consortium of IDE Technologies (IDE) and Shikun & Binui Housing and Construction
Sorek	2013	150	SDL, owned by IDE Technologies and Hutchison Water International Holdings Pte.
Ashdod	2013	100	ADL, subsidiary of Mekorot

desalination, operating pressures range from 800 to 1,000 psi. In the third phase, the increased pressure is used to separate the concentrated seawater into two streams: the permeable membrane allows solvent (water) to pass through, leaving behind the solute (salts and other non-permeates) in a highly concentrated form known as brine. A small percentage of salts do, however, remain in the freshwater product stream, as no membrane system is 100% efficient in its rejection of dissolved salts. Finally, freshwater passes through a posttreatment phase that includes boron removal and remineralization, among other stabilization processes required to meet drinking water quality standards. Unlike in thermal desalination processes, no heating or phase change takes place. Rather, major use of energy is for pressurizing the feedwater, and so the energy requirements for RO depend directly on the concentration of salts in the feedwater.

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7.2.2 Existing Facilities and Plans for Future Expansion

At the start of 2012, Israel is home to three major seawater reverse osmosis (SWRO) desalination facilities located along the Mediterranean coastline at Ashkelon, Palmachim, and Hadera. In May 2011, the financing agreement was signed for the construction and operation of a desalination plant in Sorek, 2.2 km from the Mediterranean coast and 15 km south of Tel Aviv. Three months later, the Ministry of Finance signed an agreement for the construction of a fifth SWRO plant in the northern industrial zone of Ashdod. Production and construction details of the five major desalination plants (existing and planned) are presented in Table 7.1.

In total, the five desalination plants along Israel's Mediterranean coast will produce 540 MCM annually by 2013, accounting for 85% of domestic water consumption. By 2020, expansion of existing plants will increase the total production capacity to 750 MCM annually, accounting for 100% of Israel's domestic water consumption (GLOBES 2011).

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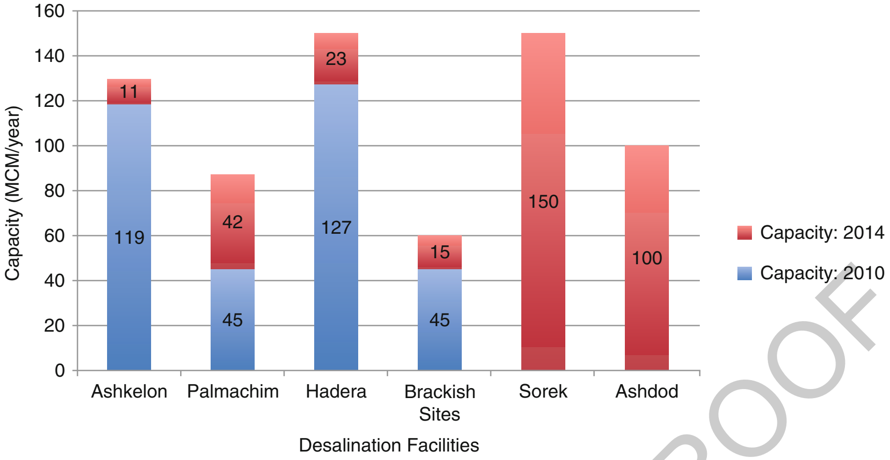

Fig. 7.1 Israel's desalination capacity (*Source*: Adapted from Tenne 2010)

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Several smaller desalination facilities desalinate brackish water from groundwater wells or a combination of brackish and seawater. The largest of these facilities is located in Eilat and produces roughly 13 MCM annually from combined brackish and seawater sources (Dreizin et al. 2007). In total, brackish water facilities in Eilat, the Arava, and the southern coastal plain of the Carmel produce 30 MCM/year. In the future, production is expected to reach 60 MCM/year in 2013 and 80–90 MCM/year by 2020 (Tenne 2010). The total production capacity is presented in Fig. 7.1.

Beyond the 2020 goal of 750 MCM, a second stage of the master plan, recently announced, provides for the establishment of five more desalination plants between 2040 and 2050. These facilities, which account for the needs of both Israel and the West Bank, will each have a production capacity of 150–200 MCM/year for a grand total of 1.75 billion cubic meters of desalinated water. The first of these plants is planned for the Western Galilee in northern Israel and will likely begin its production in 2017. Total cost of the plants and related infrastructure is estimated at US $15 billion, with 80% of the budget coming from water tariffs and 20% from the state. The National Planning Council has stated, however, that there is uncertainty regarding the construction of any of these five proposed plants, as it is difficult to predict future water demands.[1] In the meantime, any supplementary desalinated water that becomes available during the coming years will be used to aid in replenishing Israel's natural water systems.

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[1] http://www.globalwaterintel.com/archive/12/5/general/israel-build-five-new-desal-plants-2050.html

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7.3 Water–Energy Nexus

7.3.1 *Energy Consumption for Current Desalination Production*

In Israel, electricity is generated, transmitted, and distributed by the Israel Electric Corporation – the sole integrated electric utility and 99.85% owned by the State. In the decade from 1999 to 2009, the national cumulative electricity demand grew at an average rate of 3.6%. In 2009, 64.7% of the electricity produced by the IEC was generated by coal, 1.2% by fuel oil, 32.6% by natural gas, and 1.5% by diesel oil. All fuels used are imported from outside of Israel, with a proportion of natural gas, coming from Egypt (Israel Electric Corporation).

The volatility of obtaining natural gas from Egypt cannot be underestimated, especially as Egypt supplies 43% of Israel's natural gas and 40% of the country's total electricity. Eight times in 2011, Sinai Bedouin and terrorists halted the flow of natural gas from the Sinai Peninsula to Israel in protest of the export, resulting in losses amounting to US$1.5 million per day. Israel's lack of control over the availability of fuels, and the dependence of desalination plants on the national grid, means that any disruption in the supply (due to political or other reasons) would impact the State's ability to provide water for residents and industries.

Alternatively, recent natural gas discoveries in the offshore Tamar (9.1 trillion cubic feet) and Leviathan (twice as big) fields will mitigate the potential for harm by consolidating a greater fuel supply within Israel's borders, and the government is working quickly to develop this resource (Israel Electric Corporation). In January 2012, Delek Drilling signed a US$5 billion agreement to supply Dalia Power Energies Ltd. with Tamar natural gas for 17 years, and production is set to begin in 2013 (Solomon 2012). A summary of Israel's electricity generation and consumption are presented in Table 7.2.

Given Israel's energy insecurity, it is critical to consider how much energy is required to desalinate roughly 300 MCM/year or the 750 MCM/year expected by 2020. The cost, quantity, and source of energy consumed at each desalination facility are paramount in the design process, as the combined energy demand for all of Israel's desalination facilities places a non-negligible burden on the energy sector. To reduce the impact, Israel's Desalination Master Plan stipulates that all plants utilize "advanced energy-recovery devices to reduce specific energy consumptions to below 4 kWh/m^3" (Dreizin et al. 2007). According to Abraham Tenne, Head of Desalination Division and Water Technologies and Chairman of the Water Desalination Administration (WDA), the country has exceeded this goal by reducing the national average energetic cost of desalinated water to 3.5 kWh/m^3 (Tenne 2010).

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Table 7.2 Israel's electricity landscape

Generating system	Installed capacity	11,664 MW
	Peak demand	9,900 MW
	Electricity generated	53,177 million kWh
Electricity consumption	Total consumption	48,947 million kWh
	Average consumption growth (1997–2009)	3.6%
	Total revenues	18,704 million NIS (4,955 million USD)
	Average electricity price	38.21 agorot/kWh (10.12 cents)
	Total consumers	2.4 million
Fuel consumption (millions of tons)	Fuel oil	0.2
	Coal	12.3
	Gas oil	0.2
	Natural gas	2.7

AQ2 *Source*: Israel Electric Corporation (2009 data)

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In regard to the design and construction process for desalination plants, natural gas power generation is preferable to coal generation, and this is reflected in the bidding system for project developers. Natural gas power generation produces only 20% of the CO_2 emissions generated by coal power plants and is also approximately 7–8% cheaper than the energy provided by the national (coal-driven) power system. This savings reduces the cost of producing the desalinated water, thereby raising the bid score further (since cheaper water scores higher). Contractors for a desalination facility are also permitted to build a power plant that not sells additional energy to the national grid. This allows further reductions in the costs of the desalinated water product (thereby increasing the bid score further) (Tenne 2010).

Electricity is provided to the Ashkelon desalination plant from two redundant sources. A dedicated combined cycle cogeneration power station (built adjacent to the plant) runs on natural gas from the Yam Tethys reserve. Of the plant's 80-MW capacity, 56 MW are used for desalination and the surplus is sold to private customers and/or the Israel Electricity Company (Delek Group). Additionally, a 161-kW overhead line provides supply from the Israeli national grid (Water-Technology.net, Ashkelon).

According to the numbers in Table 7.3, the roughly 1,100 million kWh required in 2010 and 2,100 million kWh required in 2020 for desalination account for 2.06 and 3.91% of the 53,177 million kWh of the electricity generated by IEC in 2009. For comparison, Mekorot consumes 6% of Israel's total electricity production (Plaut 2000). Of that 6%, the National Water Carrier consumes two-thirds – approximately AQ3 100 MW/h (Meisen and Tatum 2011). The energy demand from desalination is therefore a central issue when designing a national master plan for water supply.

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Table 7.3 Annual energy consumption at existing desalination plants

	Capacity (MCM)		Energy consumption	Total energy (million kWh)	
Facility	2012	2020	(kWh/m^3)	2010 (2020)	Energy source
Ashkelon	119	130	3.85	454 (454)	Power plant and IEC grid connection
Palmachim	45	87	2.91 (2.38 post-retrofit)	131 (107)	IEC grid
Hadera	127	150	3.5	445 (525)	IEC grid
Sorek	0	150	3.5	0 (525)	Natural gas power plant and IEC grid
Ashdod	0	100	3.5	0 (350)	
Brackish	45	80	1.5	68 (120)	
Total	335	697		1,098 (2,081)	

7.3.2 *Cost of Energy for Desalination and Associated Impact on Energy Markets*

Currently, energy consumption constitutes approximately 30–44% of the total cost of water produced by an optimized RO-desalination plant (Semiat 2008). At the Ashkelon plant, energy amounts to US $0.21 of the $0.53 total cost (40%): it takes 3.5 kWh to purify 1 m^3 of water and power costs $0.06/kWh (Zetland 2011).

But the cost of energy is dynamic, and this volatility will surely affect the cost of desalination in the future. Desalination may compensate for reliability risk from drought, but corporate managers of desalination plants must account for risk in the form of energy price, regardless of whether the user pays a predetermined price for the water. On-site energy production from reliable sources is one way to address the energy price unpredictability.

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7.3.3 *Increasing Efficiency of the Desalination Process*

The laws of thermodynamics set an absolute minimum limit for the energy required for separating water from a salt solution – approximately 1 kWh/m^3 of water – and modern RO technology has come close to reaching this theoretical thermodynamic minimum. Efficiency has been achieved through large pumps that use modern turbines and other energy-recovery devices known as “turbochargers,” “pressure exchangers,” or “work exchangers,” which recover the energy content of the high-pressure brine leaving the membrane module. Additional savings are possible with the use of higher permeability membranes that do not compromise rejection capabilities – a technological advancement that would lead to a reduction in operating pressure. By improving the RO membranes, it will be possible to further

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reduce energy consumption by 10–30% or roughly 15% for the overall desalination process. Improved pretreatment and fouling control measures would also create more optimal conditions for desalination, but there is a threshold to efficiency (Semiat 2008).

The Hadera plant, for example, utilizes energy-recovery devices produced by Energy Recovery Inc., known as PX-220 pressure exchanger devices. These reduce CO_2 emissions by 2.3 million tons per year and are expected to save approximately 60% (700 MW) of power consumption at the plant annually, allowing for a lower price of the final product (Water-technology.net, Hadera).

In the future, desalination may reach a point where energy is no longer consumed, but produced. In November 2011, chief executive of IDE Technologies, Avshalom Felber, commented in a BBC broadcast: "Ten years from today, we can actually see seawater desalination . . . . turning the dice around and actually starting to produce energy – to produce renewable energy through forward osmosis process. That would mean, the same energy we invest now during the separation of water, we can create by merging streams of saline and non-saline water. This is the future of this industry, and it's going to be a real break-through on the kind of service water desalination can give to the world" (BBC 2011).

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7.3.4 Role of Renewable Energy in Desalination

Growing concern over the effect of greenhouse gas emissions on global climate change, and the volatility of externally sourced fossil fuels, has drawn attention to the possibility of using renewable energy sources (RES) for desalination in Israel. Two options exist for the use of renewable energy in desalination. Indirect use involves using RES to generate electricity used for desalination. Direct use involves the utilization of solar thermal energy for distillation by evaporation, for example, geothermal energy to power multistage flash desalination. Feasible sources of energy include wind, geothermal, solar thermal, and photovoltaic, although not all renewable sources can be used for each type of desalination process. Direct use of RES requires that the source be matched to its appropriate desalination process.

7.3.4.1 Solar Desalination

The combination of reverse osmosis desalination and solar energy is not only a promising field of development but also a highly appropriate one for a water-scarce, coastal country with high solar radiation. Interestingly, large-scale solar-driven RO desalination is still in its conceptual stage (as of 2009).

On a small and medium scale, however, solar desalination has been effectively carried out in three forms: (1) photovoltaic-powered reverse osmosis (PV-RO), (2) solar thermal-powered RO, and (3) hybrid solar desalination. In Kibbutz Maagan Michael (30 km south of Haifa), a brackish water RO-desalination system powered

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by 3.5 kWp PV and 0.6 kWp wind produces 3 m^3/day at a cost of US \$6.8/m^3. The system includes a diesel generator for backup, which was never used during the entire period of testing (Ghermandi and Messalem 2009).

Currently, several roadblocks still exist to commercial use of renewable energy in desalination. The first obstacle that must be overcome is the issue of energy storage for solar and wind, as desalination plants must operate continuously and at full capacity: 24 h a day, 365 days a year. Until a solution for the storage of this energy is developed, utilization of solar and wind power for large-scale desalination is limited. The second constraint is in regard to cost, an issue of primary importance to private developers of desalination plants. Because solar power is available only 25% of the time, the cost of desalination using solar energy is at least four times more expensive than conventional desalination powered by fossil fuels (Adu-Res 2006). Though solar-powered desalination has been researched for over 50 years, no commercial solar desalination plant is currently in operation – either small or large scale (Semiat 2008).

7.4 Environmental Impacts

First and foremost, seawater desalination is a manufacturing process and, by default, presents environmental concerns of varying nature and degree that must be understood and mitigated. Corporate responsibility, coupled with government regulation, may mitigate potential harm to natural aquatic and terrestrial ecosystems, but associated impact can never be entirely avoided. The question to be answered is whether desalination is still a worthwhile means of meeting Israel's freshwater needs, in spite of these impacts.

7.4.1 Damage to Marine Environment

7.4.1.1 Seawater Intake

Israel's direct (open) intake systems of delivering seawater to the desalination facility are known to increase the mortality rate of marine organisms residing in the vicinity of the desalination plant. Due to the great suction force and increased velocity surrounding intake openings – both necessary for the intake of large quantities of water – organisms may be trapped against intake screens (impingement) or be drawn into the plant with the seawater (entrainment). If starvation, exhaustion, and asphyxiation do not immediately kill impinged marine life, there is a significant possibility that some life-supporting biological function will be damaged, significantly reducing their chances for survival if they happen to be released back into the environment. Entrainment is considered to be lethal for all organisms as a result of extreme pressures within the intake system, collision

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with parts of the pump, high temperatures, and biocides such as chlorine used to prevent biofouling of membranes. Impingement is of high concern for fish, invertebrates, mammals, and birds, while entrainment affects smaller organisms such as phytoplankton, zooplankton, fish eggs and larvae, spores of kelp, and seaweed. From an economic perspective, trapped organisms increase biofouling of membranes, thereby reducing the life span of these pressure vessels (IAEA 2010).

The issue of marine life mortality is one that can be largely overcome by technological advancements in intake screening equipment. The oldest and most common traveling water screens feature mesh wire panels with 6–10-mm openings and are typically cleaned every few hours by a strong jet of water. An alternative version of this screen, called the Ristroph traveling screen, involves buckets that would trap and then return marine organisms to the sea. Passive wedgewire screens are another new development with a mesh size of 0.5–10 mm to prevent the entrance of smaller organisms into the intake system. Barriers that aim to deter organisms from the intake vicinity – such as strobe lights and air bubbles – have also had positive results when tested in conjunction with screen technologies. It is important to note, however, that technologies intended to address the issue of marine life mortality and biofouling do come at the price of reduced plant efficiency (IAEA 2010). Another alternative altogether involves indirect (subsurface) seawater intake, which avoids contact with marine life that is not nested beneath the ocean bottom. This alternative was considered for the Ashkelon plant, but was ultimately dismissed due to the potential danger of possible leaks into freshwater aquifers (IAEA 2010).

7.4.1.2 Brine Outflow

Perhaps the most worrisome environmental concern associated with desalination is of what to do with the concentrated brine that is a by-product of the treatment process. The brine solution has approximately twice the concentration of ambient seawater and contains a range of chemical additives including chlorine and other biocides to prevent membrane biofouling, antiscalants (polyphosphates, polymers) to prevent salt from forming on piping, coagulants (ferric sulfate, ferric chloride) to bind particles together, and sodium bisulfite to eliminate the chlorine, which can damage membranes (Safrai and Zask 2006). Brine also contains heavy metals introduced into the desalination process as a result of equipment corrosion (Cooley et al. 2006).

In Israel, this brine solution is diluted and pumped into the sea, with the expectation that the dilution of brine will mitigate the ecological harm done. Dilution is not, however, the solution to pollution in this case, as the high specific weight causes the brine to sink to the sea bottom, creating a “salty desert” surrounding the pipeline outlet. In general, brine accumulation in the affected area is generally permanent, continuously compounded by a constant flow from the facility, and not without consequence for the biotic community in the area (Einav and Lokiec 2006). Nevertheless, there are no scientifically documented cases of long-term ecological impact at the point of brine outflow.

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Other environmental concerns regarding this concentrated brine solution include (1) eutrophication due to phosphates enrichment if polyphosphates are used in the treatment process and if organic cleaning solutions are added to the brine, and (2) discoloration due to high concentration of iron, with high suspended solids and turbidity levels, and the impact of brine on the composition and distribution of marine life (Safrai and Zask 2006).

The extent of the brine's marine impact is dependent upon its concentration, discharge rate, the outlet pressure, and planning of the pipe system, in addition to natural hydrological phenomena such as bathymetry, currents, and waves. Currently, evaluation of the degree and range of impact is based on mathematical models and a limited amount of field data, so in this regard, we are learning in real time the consequences of our actions. Not to mention, different marine habitats such as coral reefs and rocky beaches will respond differently to the brine (Einav and Lokiec 2006). As such, the precautionary principle is recommended as an integral component in the establishment of new environmental regulations for desalination plants.

As of now, the Law for the Protection of the Coastal Environment (2004) stipulates that any planned facilities for seawater/brackish water desalination will be constructed with a clear plan for the removal of the concentrated desalination discharge. Discharge of brine into sea is permissible only with a valid, interministerial permit issued in accordance with the Prevention of Sea Pollution from Land-Based Sources Law (1988) and its regulations. The main issues considered are marine outfall, marine monitoring program, and discharge composition (Safrai and Zask 2006).

One potential solution to the problem of brine discharge is to utilize the concentrated solution for salt production. As if to solve the issue of energy consumption and brine disposal simultaneously, it turns out that an increase in energy recovery increases brine salinity, thereby reducing the size and cost of evaporation costs necessary for salt manufacturing. Thus, we arrive at the concept of dual-purpose plants for the production of desalinated water and salt. In this model, brine outfall facilities, and the pipe entering the sea used to discharge brine, are avoided.

In Eilat, such a plant (the 80:20 seawater–brackish water plant described above) has been in operation for 9 years, owned and operated by Mekorot. The salt production plant is owned by the Israel Salt Company 1976 Ltd., a private, public sector corporation. Improvements made to the facility have increased the annual production capacity from 118,000 to 150,000 tons in less than one decade. At this point in time, the major shortcoming of this closed-loop solution is that there exist few salt production facilities in the vicinity of desalination plants – there simply is not a large enough market for this product (Ravizky and Nadav 2007).

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7.4.2 Expropriation and Land Use Along Coastal Areas

While some may consider desalination plants to be technological masterpieces dotted along Israel's 273-km Mediterranean coastline, others will argue that this land should not be used for such industrialized activity. From an economic and

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Table 7.4 Air emissions per m^3 water for reverse osmosis desalination facilities

Emissions per m^3 water	Reverse osmosis
CO_2 [kg/m^3]	2–4
NO_x [g/m^3]	4–8
SO_x [g/m^3]	12–24
Non-methane volatile organic compounds [g/m^3]	1.5–3

Source: IAEA (2010)

engineering perspective, situating a facility closer to the shoreline is advantageous; proximity to the sea avoids the installation of pipes for transporting large amounts of seawater and brine that come with the associated risk of polluting underground aquifers in the event of a leak (Einav et al. 2002). In Israel, however, the real estate, environmental and social value of the shoreline has pressured the desalination industry to build in areas specifically designated for engineering installations in order to preserve land for tourism and recreation. For example, the Ashkelon facility was built 2 km south of the city, extends over an area of 70 dunam, and sits adjacent to the IEC Rothenberg Power Station.

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7.4.3 Air Pollution and Increased GHG Emissions due to Energy Consumption

The combustion of fossil fuels for electricity generation is responsible for approximately 50% of Israel's air pollution. In particular, power plants are responsible for 65% of the country's sulfur dioxide (SO_2) emissions, 45% of nitrogen oxide (NO_x) emissions, 38% of particulate emissions, and 60% of carbon dioxide emissions, all of which are known to have adverse health effects (MEP 2009). In this regard, the country's desalination plants – powered predominantly by the national grid that generates electricity from coal and natural gas – present an additional threat to the regional environment. Importantly, direct air emissions from desalination include only oxygen and nitrogen discharges associated with deaeration processes (IAEA 2010).

Assuming a specific energy capacity of 3.85 kWh/m^3, the desalination of 1 m^3 of water produces 3.432 kg CO_2/m^3 of carbon emissions. In 2020, when Israel's desalination capacity reaches its goal of 750 MCM/year, this will amount to 2.574 billion kg CO_2 annually. Illustrated in Table 7.4 and Fig. 7.2 are the GHG emissions per cubic meter of desalinated water with fossil fuels as the energy source.

7.4.4 Restoration of Freshwater Resources

The environmental impacts associated with desalination are surely not all negative. One of the most attractive aspects of this method of water resource management is the potential for restoration of freshwater resources as we begin to rely more

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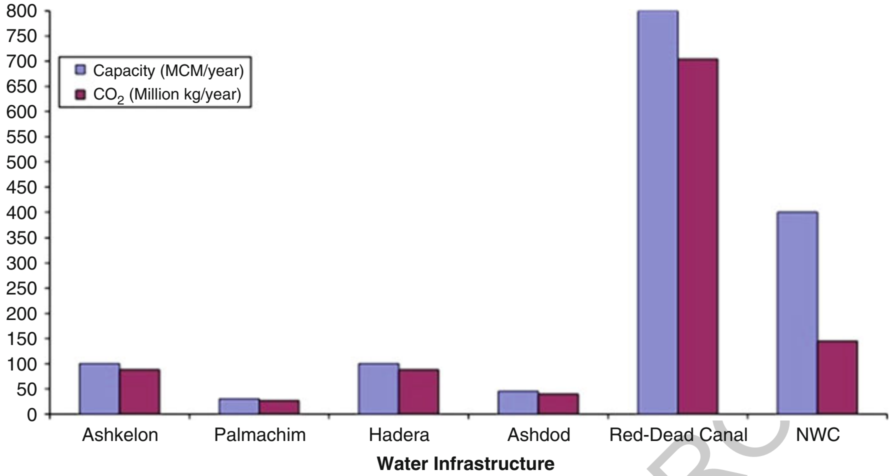

Fig. 7.2 Capacity and CO_2 emissions of water infrastructure in Israel

on seawater and less on fragile aquifers and declining surface water. It is true that overall demand for freshwater is increasing, but the expectation is that desalinated water will more than compensate for the additional consumption so that Israel can begin to manage its freshwater sources as a buffer instead of the primary supplier. This shift will pave the way for natural sources to be allocated for nature, recreation, and aesthetic use.

7.5 Economic Impacts

7.5.1 The Commercial Players

Mekorot: Israel's national water utility operates 31 desalination facilities including the new facility planned for Ashdod and the National Water Carrier that delivers 400 MCM/year of water distributed throughout the country. Mekorot supplies 80% of Israel's drinking water and 70% of national consumption.

IDE Technologies Ltd.: IDE is a publicly owned, joint venture between Israel Chemical Limited and the Delek Group. As a pioneer in desalination technologies, "the company specializes in the development, engineering, production and operation of advanced desalination as well as innovative industrial solutions." IDE has developed over 400 facilities globally and in Israel at Ashkelon, Hadera, and Sorek (IDE Company Profile).

Global Environmental Solutions Ltd.: GES invests its experience and human capital in the water sector. Most notably, GES played a role in constructing the

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Table 7.5 Price of desalinated water from Israel plants

Desalination plant	Price (NIS/m^3)
Ashkelon	2.60
Palmachim	2.90
Palmachim expanded[a]	2.07 (D&WR 2011)
Hadera	2.563 (http://www.globalwaterintel.com/archive/7/10/general/ide-takes-hadera-with-rock-bottom-price.html)
Sorek	2.01 (MFA 2011)
Ashdod	2.40 (Shemer 2011)

[a] Following expansion from 45 to 87 MCM

Palmachim desalination plant in 2005 and was commissioned to carry out the operation and maintenance of the facility. GES has designed, built, and currently operates brackish water and seawater desalination plants in Israel, the Gaza Strip, and Greece (GES Company Profile).

7.5.2 *The Price Tag on Desalination*

The price of desalinated water is site-specific, depending on total capacity, labor costs, energy sources, land availability, water salinity, and perhaps most significantly today – technological innovation. The price of desalinated water from each of Israel's industrial facilities is shown in Table 7.5.

7.5.2.1 Plant Financing

In Israel, almost all desalination facilities are based on a build–operate–transfer (BOT) contract, under which the concessionaire designs, builds, and operates the plant for a total period of 26.5 years, after which the plant is transferred to state ownership. Both domestic and international banks fund the large-scale plants, for which the total project cost runs between $200 million and $500 million. The financing details for the five major plants are outlined in Table 7.6.

7.5.2.2 Direct Costs

Desalination is undoubtedly the most expensive water treatment process, and the high capital costs of constructing each plant are only compounded by operation and maintenance costs. Energy and equipment are the most costly components of desalination, and all individual pieces of equipment seem to contribute equally to the expense (Semiat 2008). At Ashkelon, for example, about 42% of the price of

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Table 7.6 Financing Israel's desalination facilities

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Facility	Capital cost (USD)	Contract	Investors
Ashkelon	$212 M	BOT	23% equity, 77% dept
Palmachim	$100 M	BOO	Bank Hapoalim
Hadera	$425 M	BOO	International banks: European Investment Bank (EIB), Credit Agricole, Banco Espirito Santo
Sorek	$400 M	BOT	EIB, the European Development Bank, and Israel's Bank Hapoalim, and Bank Leumi
Ashdod	$423 M	BOT	Bank Hapoalim, EIB

water covers energy costs, variable operation and maintenance costs, membranes, and chemical costs, while 58% covers capital expenditures and operation and maintenance costs (Sauvet-Goichon 2007).

Nonetheless, the capital and operating costs of desalination are declining in large part due to technological improvements, economies of scale of larger plants, and increased level of experience among those in the industry. RO membrane technology has made the greatest leap of improvement: salt rejection has increased from 98.5 to 99.7% over the past decade, output from a membrane unit has increased from 60 to 84 m^3/day, and manufacturers are guaranteeing a longer life for their membranes (Cooley et al. 2006). Still, many argue that there is room for increased efficiency and that RO membranes are the low-hanging fruit for cost reduction (Semiat 2008).

According to Avshalom Felber, chief executive of IDE Technologies, the cost of desalinated water is expected to drop to as low as 35 cents in the next 10 years. Just a decade ago, the cost was above the $2 mark (Becker 2011). Recently, however, a counterforce has emerged to cost reduction of desalination in the form of increases in the cost of raw materials, energy, and rising interest rates (Cooley et al. 2006). As a result of these opposing forces, it is difficult to predict the actual cost of seawater desalination in the future.

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7.5.2.3 External Costs

In addition to the direct production costs of desalination, external costs must be considered to determine the comprehensive economic impact of this technology on Israeli society. External costs of desalination are associated with environmental impacts such as air pollution and greenhouse gas emissions, expropriation and land use along coastal areas, and damages to marine life caused by seawater intake and brine discharges.

In a 2010 analysis of the external costs of desalination performed by Dr. Nir Becker, the aforementioned environmental impacts were quantified and factored into the total cost of producing 1 m^3 of freshwater. The study was based on an

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average energy consumption of 4.25 kWh/m^3 (slightly higher than the national average in 2012) and assessed the costs associated with specific pollutants with estimates from the Israeli Ministry for Environmental Protection (Becker et al. 2010).

Considering that Israel produces roughly 280 MCM/year of desalinated water, the external cost of air pollution exceeds $36 million annually and will rise to nearly $100 million by 2020 when Israel is expected to produce 750 MCM. It should be noted, however, that estimated externalities from air pollution would decrease to 4.8 cents per cubic meter if desalinated water were produced solely with natural gas rather than the current fuel mix that is one third natural gas and two thirds coal (Becker et al. 2010).

Land use presents another significant external cost, as over half of the Israeli population lives along the coast, and this land is very highly valued. As such, the opportunity cost of the land upon which a desalination plant is constructed should be counted when determining the true cost of desalinated water. Using a weighted average of 190 NIS (US $0.50) per square meter of shoreline, and an assumed 100 m of shoreline and 7 ha of territory for every 100 MCM of desalinated water produced, land is worth US $0.034 per cubic meter. At the current desalination capacity, $10 million per year represents the alternative value of this land and nearly $26 million for a capacity of 750 MCM/year (Becker et al. 2010).

Additional externalities also arise from damage to marine resources caused by seawater intake and effluent discharge. Metals found in brine and the higher temperature characteristic of this solution can have adverse effects on the reproductive capabilities of some organisms, but in Israel, impacts on marine life from desalination have yet to be quantified (Becker et al. 2010).

Conversely, positive externalities also result from desalination. Reduced water salinity – from 250 mg Cl/L for freshwater to 100 mg Cl/L for desalinated water – can increase crop yield, improve aquifer water quality, and reduce costs for household and industrial electrical equipment and sanitary systems. Together, positive externalities are estimated at about US $0.10 per cubic meter.

In total, a lower bound on the externalities of desalination (positive and negative, and not including damages to marine life) is found to be US $0.065 per cubic meter. Adding this to the price of water would increase the direct cost by 8% (Becker et al. 2010).

7.5.3 *Government Subsidies of Desalinated Water*

Government subsidies of desalinated water are often required to increase affordability of the freshwater product. These subsidies are often visible, but may also be hidden as in the water produced by the Ashkelon facility. As the first large-scale desalination plant in Israel (and the world's largest at the time it commenced production in 2005), Ashkelon was able to offer freshwater at a cost of $0.53/m^3 because the land on which the plant was constructed was provided at no cost by the Israeli government (Cooley et al. 2006).

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7.5.4 *Privatization of Water Supply*

In Israel, the law declares, “The water resources of the State are public property, subject to the control of the state and destined for the needs of the inhabitants and development of the country” (Section 1, Water Law 5719-1959) (MFA 2002a, b). As such, those who advocate for water as a basic human right have raised concern over the commoditization of this resource similar to any other consumption good. At the end of the day, the question is whether private sector control over the production, supply, and management of this resource is in the public’s best interest. Those privatizations can be quite beneficial; it is also associated with decreased transparency and accountability, price hikes caused by the introduction of additional profit margins, service deterioration, and noncompliance with health and environmental regulations resulting from a lack of regulation of corporations involved.

With the exception of the Ashdod plant, all of Israel’s water desalination facilities involve some sort of public–private partnership, in which governments call upon the expertise of the private sector, and risk is allocated to the sector best equipped to manage it. The result is that Israel is increasingly dependent on the terms of 25-year contracts that are typical for build–operate–transfer (BOT) and build–operate–own (BOO) desalination plants.

Since the construction of the Ashkelon, Palmachim, and Hadera plants, a 7-year drought forced the government to ask manufacturers to increase their production in exchange for higher rates (to cover the costs of expansion and increase their profit margin). No longer in a competitive process with a range of options, Israel is at the mercy of the contracted corporations. As a result, each time there is a water shortage and the government must negotiate to increase production, the agreed upon price is higher (sometimes by 6–7%) than initially offered. Ultimately, Israelis will cover this price increase in their water bills. There seems to be no end in sight for this corporate control: when the Sorek plant commences production in 2013, IDE will produce 75% of the country’s desalinated water and 25% of Israel’s drinking water (Bar-Eli 2011).

To reconcile the positive aspects of privatization with the potentially adverse aspects, Friends of the Earth – Middle East has outlined the following recommendations (Becker et al. 2004):

1. A municipal corporation may transfer to the private sector in a variety of ways parts of the construction, management, and maintenance of water and sewage systems, as long as ownership and long term control over assets remain in public hands. The complete privatization of water corporations should be avoided.
2. Public participation in the regulation of water and sewage corporations should be implemented, widened and institutionalized so as to strengthen the regulatory agency. Principles of democratic regulation, as are practiced in the regulation of a variety of public utilities in the US, may provide an adequate structure for the regulation of private as well as public monopolies.

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3. The disconnection from water services of homes, hospitals, schools and other institutions should be prohibited by law or at least by regulations.
4. In determining the price of water, water saving should be encouraged while safeguarding the access of all residents to a reasonable amount of water. To that end, it is recommended to establish a per capita consumption threshold of water, which should be available at low cost. Any water consumed above that threshold should be priced high enough so as to provide a real incentive to save water.

7.6 Water Quality Impacts

By design, the quality of desalinated seawater is quite high, as RO membranes remove most impurities. There are, however, several concerns associated with this treatment process due to low mineral content. Importantly, desalinated water does get mixed in with other freshwater in the National Water Carrier distribution system, supplementing the remineralization process that takes place during posttreatment.

7.6.1 Health Concerns

High boron concentrations in seawater are perhaps the most talked-about health issue associated with desalination, as boron is known to cause developmental and reproductive toxicity in animals and irritation of the digestive tract. RO membranes remove 50–70% of this element from the seawater where boron concentrations are as high as 4–7 mg/L, and additional boron is removed during the posttreatment process (Cooley et al. 2006). To meet the World Health Organization (WHO) standard of 0.5 mg/L, the Hadera plant uses a Cascade Boron Treatment system that produces water with a boron concentration of 0.3 mg/L. At the Ashkelon plant, the Boron Polishing System constitutes 10% of the overall energy costs (Garb 2008).

Posttreatment presents a second concern, however, as essential nutrients such as calcium, magnesium, and sulfate are found in natural freshwater but missing from desalinated water. Israel's National Water Carrier contains water with dissolved magnesium levels of 20–25 mg/L, whereas water from the Ashkelon plant contains no magnesium. Similarly, calcium concentrations in desalinated water are 40–46 mg/L, compared to 45–60 mg/L found in natural freshwater. Posttreatment processes expected in future desalination facilities – such as dissolving calcium carbonate with carbon dioxide – will further reduce calcium concentrations to 32 mg/L (Yerimiyahu 2007).

There is also concern that lower calcium and carbonate concentrations will serve to degrade the piping system of the distribution network, with public health

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and financial ramifications. As a result of acidic product water, toxic metals such as nickel, copper, lead, cadmium, and zinc can be leached from the distribution system. Such corrosion may be harmful to human health and reduce useful life of the system. Fortunately, this problem is corrected in the posttreatment stage with the reintroduction of calcium carbonate in the form of lime or limestone, which neutralizes the pH of the water and forms a nonporous film along the pipeline (Yerimiyahu 2007).

7.6.2 Implications for Agriculture

Originally, water produced by the Ashkelon desalination facility was designed for human consumption, and not for agricultural use. However, low population density in southern Israel has allowed for a substantial percentage of the supply to be used by farmers. This shift in irrigation water from natural freshwater sources to purified seawater has had both positive and negative effects on the healthy growth of crops.

The lower salinity of desalinated water is what makes this water so appealing for agricultural use, as high Na^+ and Cl^- concentrations damage soils, stunt plant growth, and alter the environment. The salinity of water produced at the Ashkelon plant – measured by electrical conductivity (EC) – is 0.2–0.3 dS/m, compared to water from the national distribution system that has an EC roughly three to five times higher (Yerimiyahu 2007).

On the other hand, high boron concentrations in seawater have had adverse reproductive and developmental effects on irrigated crops, including tomatoes, basil, and certain varieties of flowers (Yerimiyahu 2007). Citrus species are found to be particularly sensitive, with a boron tolerance threshold of 0.4–0.75 mg/L (Bick and Oron 2005). When water produced at the Eilat plant (without posttreatment for boron removal) caused damage to sensitive crops, Israel became the first country to set a boron limit of 0.04 mg/L. This concentration is similar to that of drinking water from freshwater sources and is achieved only with the additional posttreatment (Garb 2008).

Calcium and magnesium deficiencies described above also cause physiological defects in crops (Yerimiyahu 2007). To meet agricultural needs, farmers may need to incorporate missing nutrients into their fertilizers. Due to mixing of natural freshwater and desalinated water in the National Water Carrier, the quality of irrigation water is unpredictable, and farmers do not have the capacity to prepare for fluctuations. On the other hand, desalinated water is meant for several uses and must simultaneously be optimized for agricultural benefit and for drinking water consumption. At the very least, however, increasing the concentrations of calcium and magnesium in desalinated water will have a positive impact on both agricultural production and on public health (Yerimiyahu 2007).

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7.7 Trans-boundary Management with the Palestinian Authority and Jordan

Regional cooperation and trans-boundary management of water resources are viewed as vital to sustainable use of precious resources and for the peace-building process among Israelis, Palestinians, and Jordanians. Currently, industrial-scale desalination facilities do not exist in either the West Bank or Jordan (both landlocked) or in the Gaza Strip due to the lack of resources to invest in this technology. Such a possibility, however, is far from closed for the future.

7.7.1 Red Sea–Dead Sea Conveyance

The Red Sea–Dead Sea Conveyance has been proposed as a means of restoring the declining water level of the Dead Sea. Historically, the surface of the Dead Sea was 392 m below sea level – the lowest point on Earth. In the past 30 years, however, diversion of water from the Jordan River (which feeds the salty lake) to the north has caused the water level of the Dead Sea to drop to 417 m below sea level. The average annual inflow has decreased from 1,200 to 250 MCM/year, and as a result, the surface area has been reduced from 940 to 637 km^2 (Abu Qdais 2007).

Due to the economic, cultural, and touristic importance of this trans-boundary body of water, Israel, Jordan, and Palestine have come together to identify solutions for its restoration while simultaneously increasing water security in the region. To this end, the World Bank and Coyne & Bellier of France, in coordination with the governments of Israel, Palestine, and Jordan, have conducted a feasibility study for the construction of a 250-km conveyance to transport 1,900 MCM/year from the Red Sea to the Dead Sea. Called the Red–Dead Sea Conveyer (RDSC) or "Peace Canal," this project would pump seawater from the Gulf of Aqaba to an elevation of 170 m below sea level in the Arava Desert and then flow by gravity to the Dead Sea. The 570-m head differential would generate 550 MW of electricity, to be used for three purposes: (1) to power the initial pumping, (2) to power 850 MCM/year of seawater desalination based on 45% recovery, and (3) to yield a power surplus of over 100 MW (Hersh 2005).

The opportunity for seawater desalination is particularly attractive to Jordan – one of the top ten water poorest countries in the world – as it would increase national water supply by 50% (Hersh 2005). The desalination plant, located at the southern Dead Sea, will discharge brine into the Dead Sea at a rate of 1,050 MCM/year, with a dissolved solid concentration of 72,220 mg/L – far below the salinity of the Dead Sea (Abu Qdais 2007). This difference in salt concentration (and density) is expected to result in stratification similar to the phenomenon that takes place when brine is discharged into the Mediterranean, except that in this instance, the brine is less salty than the receiving body of water. Additionally, the range of chemicals used in the desalination process is expected to affect the chemistry of the Dead Sea (Abu Qdais 2007).

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On May 9, 2005, the 2-year feasibility study was launched by Israel, Jordan, the Palestinian Authority, and the World Bank – costing $US 15million – to analyze the economic, environmental, and social impacts of the project. Environmental concerns are paramount: seawater intake may affect the fragile marine ecosystem and coral reefs of the Gulf, leaks or spills along the pipeline may contaminate freshwater aquifers, and the mixing of seawater from the Red Sea (with a salt concentration of 60–100 ppt) with Dead Sea saltwater (300 ppt) may have adverse effects on the Dead Sea and dependent industries of tourism and potash (Hersh 2005). Conversely, restoration of the Dead Sea will preserve the agricultural land of the Jordan Valley, sustain the tourist and industrial activities of the Dead Sea, and reverse sinkhole formation, a natural phenomenon due to the declining Dead Sea water that has caused serious damage to local infrastructure. In total, capital investment of the project is about US$ 3.8 billion, which includes the costs of the conduit, RO plant, and distribution system (Abu Qdais 2007).

7.7.2 *Regional Water and Energy Grids*

The future of water security in the region lies in the integrated management of the Jordan River Basin, an 18,000-km^2 watershed that encompasses much of Israel, the Palestinian territory of the West Bank, and parts of Jordan, Lebanon, and Syria. Undeniably a challenge, yet perhaps a blessing in this conflict-ridden part of the world, cooperation on energy and water issues is vital for the sustainable use of resources and could prove to be a grounds for peace-building and reconciliation.

As explored in a previous section, on the water–energy nexus, it is becoming increasingly clear in this water-stressed, energy-poor region in which population is growing that scarce resources must be co-developed. Great amounts of energy are needed to pump, treat, desalinate, and distribute freshwater for agricultural, industrial, and residential use. On the other hand, large amounts of water are needed in the production of energy. Fortunately, both Israel and Jordan have resources that, when combined, would be hugely beneficial for both parties. In Israel, access to the Mediterranean Sea and technological know-how to produce large amounts of desalinated water could be used to improve regional water security. In Jordan, large tracts of unused desert with a high degree of direct solar irradiance may be used to produce solar energy and meet regional energy demands and in particular, to desalinate seawater in Israel. In the Jordan River Basin, solar energy could produce an estimated 17,000 terawatt-hours of electricity annually, 170 times the current regional consumption of less than 100 terawatt-hours (Meisen and Tatum 2011).

Motivation for regional cooperation lies in the climate change models that predict average temperature increases in the Jordan River Basin by up to 3.1°C in winter and 3.7°C in summer. This increase is expected to result in a 20–30% decrease in average rainfall over the next 30 years, causing reduced flow of the Jordan River, desertification of arable land, and increased unpredictability of natural disasters (Meisen and Tatum 2011).

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