ground water

The Water Crisis in the Gaza Strip: Prospects for Resolution

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Abstract

Israel and the Palestinian Authority share the southern Mediterranean coastal aquifer. Long-term overexploitation in the Gaza Strip has resulted in a decreasing water table, accompanied by the degradation of its water quality. Due to high levels of salinity and nitrate and boron pollution, most of the ground water is inadequate for both domestic and agricultural consumption. The rapid rate of population growth in the Gaza Strip and dependence upon ground water as a single water source present a serious challenge for future political stability and economic development. Here, we integrate the results of geochemical studies and numerical modeling to postulate different management scenarios for joint management between Israel and the Palestinian Authority. The chemical and isotopic data show that most of the salinity phenomena in the Gaza Strip are derived from the natural flow of saline ground water from Israel toward the Gaza Strip. As a result, the southern coastal aquifer does not resemble a classic "upstream-downstream" dispute because Israel's pumping of the saline ground water reduces the salinization rates of ground water in the Gaza Strip. Simulation of different pumping scenarios using a monolayer, hydrodynamic, two-dimensional model (MARTHE) confirms the hypothesis that increasing pumping along the Gaza Strip border combined with a moderate reduction of pumping within the Gaza Strip would improve ground water quality within the Gaza Strip. We find that pumping the saline ground water for a source of reverse-osmosis desalination and then supplying the desalinated water to the Gaza Strip should be an essential component of a future joint management strategy between Israel and the Palestinian Authority.

Introduction

The unique advantage of an upstream water user over a downstream water user limits the ability of states to cooperate over a shared water resource because the benefits of cooperation are asymmetrical and unevenly distributed. In the Middle East, there are numerous shared river and ground water basins (e.g., Tigris-Euphrates, Nile, and Jordan rivers and the Western Mountain and Disi aquifers) that can be demarcated according to an upstream-downstream division (see, e.g., Elhance 1999; Lowi 1993; Waterbury 1994; Amery and Wolf 2000). Israel and the Palestinian Authority share two ground water basins in which one party is upstream and the other is downstream: the coastal aquifer and the Western Mountain aquifer. In the Western Mountain aquifer, the Palestinian Authority is physically the upstream user and Israel is the downstream user; here, the natural replenishment takes place within the West Bank, but the natural flow of the ground water is toward Israel. In contrast, the Palestinian Authority is the downstream user in the coastal aquifer as the ground water flow is from the eastern part of the aquifer within Israeli territory toward the Gaza Strip (Figure 1). The downstream position of the Palestinians in the coastal aquifer places them at a physical disadvantage vis-a-vis their upstream neighbor—Israel—since the party that holds the upstream advantage can de facto determine the quantity and quality of the water flow for the downstream user.

After Kuwait, the Gaza Strip is the next most "water-poor" region in the world, with 52 m^3 available per person each year (International Atomic Energy Agency Fact Sheet 2003). The Gaza Strip is also one of the most densely populated areas in the world, where

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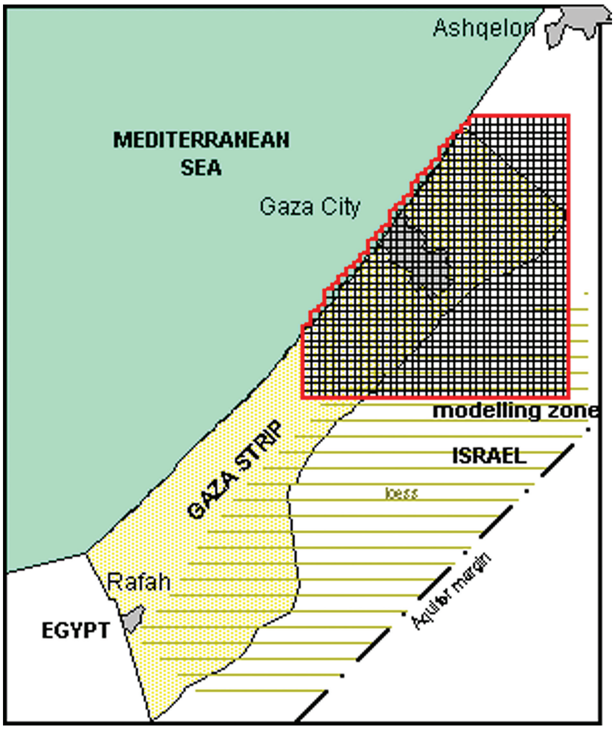

Figure 1. Location map of the southern Mediterranean coastal aquifer and the Gaza Strip. Note the distribution area of the loess soil in the eastern part of the aquifer and the grid with 500-m² meshes that was used in the numerical modeling.

more than 1.2 million Palestinians are crowded into an area of ~400 km^2 (40 km long and 6 to 12 km wide). More than half of the population is younger than 15 years of age, and because of the high population growth rate (~4%), the population is expected to reach 2.5 million in the next decade (Sontag 2000; Shqueir 1995; Ministry of Health, Palestinian Authority 2003).

The high population growth rate in the Gaza Strip is placing a considerable strain on its water resources whereby supply cannot meet demand. Moreover, the shortage of water resources in the region acts as a severe constraint on human and economic development. Not surprisingly, the combination of water scarcity, high fertility rates, a shattered economy, weak political institutions, and the ongoing *intifada* has destabilized the political and social situation within the Palestinian Authority and exacerbated the high level of violence between Israel and the Palestinian Authority (see, e.g., Kelly and Homer-Dixon 1998).

In spite of the seeming intractability of the political conflict between Israel and the Palestinian Authority, we find that opportunities exist for water to serve as a source of cooperation rather than conflict. Specifically, we propose that the southern coastal aquifer could serve as a source of environmental peacemaking (see, e.g., Conca and Dabelko 2002) if recent hydrogeological and hydrochemical data are incorporated into water management solutions. While it is commonly assumed that Israel's upstream use of the coastal aquifer (i.e., pumping and treatment) could aggravate relations with the Palestinian Authority, we suggest instead that it has the potential to provide a cooperative water management solution rather than precipitate a new water conflict.

Water Quality in the Southern Coastal Aquifer and Isotopic Evidence for the Sources of Salinity

The coastal aquifer extends ~120 km along the Mediterranean coastline of Israel and the Gaza Strip. It is composed of Pliocene-Pleistocene calcareous sandstone, sands, sandy loam, and clays. The width of the aquifer in the Gaza Strip is 20 km, and its thickness varies from 200 m in the west along the coastline to a few meters in the eastern margins (Vengosh et al. 1999). In the eastern part, the depth of the saturated zone varies between 30 and 80 m, whereas in the western part within the Gaza Strip, the depth is 120 to 150 m (Mercado 1968; Fink 1992; Livshitz 1999; Guttman 2002).

The natural flow regime in the aquifer is from southeast to northwest toward the Mediterranean Sea. Thus, the ground water flows from Israel downstream toward the Gaza Strip. Recharge occurs along the flow paths through the unsaturated zone in areas of sand dunes (i.e., central aquifer) but is restricted by the thick layers of loess soils, particularly in the eastern areas of the aquifer. The amount of precipitation decreases by 50% from the north (~400 mm) to the south (200 mm). Since the 1960s, deep hydrological depressions, which have resulted from the overexploitation of the aquifer, have diverted the natural flow direction within the Gaza Strip. This has created preferential ground water flows from the east and from the west toward the center of these depressions (Mercado 1968; Fink 1992; Melloul and Bibas 1992; Livshitz 1999; Guttman 2002).

Israel and the Palestinian Authority (i.e., the Gaza Strip) share the southern part of the Mediterranean coastal aquifer. From the Israeli part of the aquifer, Israel withdraws 6 to 10 million cubic meters (MCM)/year of saline ground water (>1000 mg Cl/L) for agricultural purposes (Guttman 2002). Israel also pumps from its wells within the Gaza Strip ~5 MCM/year for use within its settlements. In the Gaza Strip, the Palestinians pump ~150 MCM/year from ~4000 agricultural wells and 95 municipal wells, of which 60 MCM/year is used for domestic consumption and 90 MCM/year for agricultural consumption (Moe et al. 2001; Assaf 2001).

The water crisis in the Gaza Strip stems from the growing water deficit as the amount of water exploitation in the Gaza Strip (155 MCM/year) is not balanced by natural or anthropogenic replenishments. The natural replenishment of the aquifer is estimated to be 35 MCM/year, while the anthropogenic replenishment (agricultural return flow and waste water) is estimated at 52 MCM/year; the lateral inflow from the eastern part of the aquifer is 37 MCM/year (Moe et al. 2001; Fink 1992). Overall, the Gaza Strip is facing an annual deficit of ~30 MCM/year (Moe et al. 2001). Because of the water deficit, regional water levels have lowered, and deep hydrological depressions have formed in the urban areas of the Gaza Strip including Gaza City in the north and Rafah in the south (Moe et al. 2001; Mercado 1968; Fink 1992; Melloul and Bibas 1992).

Parallel to the long-term water shortage, the quality of the ground water has deteriorated, whereby saline water is rapidly replacing fresh water in many parts of the Gaza Strip. Moe et al. (2001) have documented salinization rates approaching ~10 mg Cl/L/year. In general, three zones of salinity can be identified in the Gaza Strip (Figure 2): (1) high-saline ground water with exponential rates of salinization along the western margin of the aquifer, mainly due to sea water intrusion; (2) a moderate-saline zone in most areas of the Gaza Strip (Cl = 200 to 1000 mg/L); and (3) a high-salinity zone (>1000 mg/L) along the border with Israel. A general trend of a salinity reduction along the flow path from east to west is observed.

Hydrogeological data suggest that the aquifer system is continuous, and as a consequence, the ground water flows from Israel into the Gaza Strip (Mercado 1968; Fink 1992; Guttman 2002). Recent geochemical and isotopic (boron, strontium, oxygen, hydrogen) results (Vengosh et al. 2002, 2005) confirm that the chemical and isotopic compositions of ground water in the eastern area of the Gaza Strip are indeed identical to those of ground water located in Israeli territory (Figure 2). Moreover, the isotopic data indicate that the original salinity of the water is derived from saline ground water emerging from the adjacent and underlying Eocene aquitard (Vengosh et al. 2002, 2005). Thus, the major source of salinity in the aquifer in the Gaza Strip is derived from the flow of natural saline ground water from the eastern part of the aquifer toward the Gaza Strip. The long-term reduction of the water tables because of overexploitation has increased the water gradients and rate of water flow toward the Gaza Strip. Sea water intrusion has also resulted in salinization of ground water in the western part of the aquifer, but the geochemical and isotopic data indicate that the extent of sea water intrusion is limited. As a result of the long-term salinization process, the chloride content of ground water in several parts of the aquifer exceeds 1000 mg/L (Figure 2), which is much higher than the upper acceptable limit for drinking water in Israel—600 mg/L. In Europe and the United States, the upper level is 250 mg/L. In fact, only ~10% of the total water exploited in the Gaza Strip may be considered fresh water—that is, which meets the World Health Organization (WHO) drinking water standard for chloride of 250 mg/L. If pumping continues at these unsustainable rates, it will destroy the aquifer's capacity to resist sea water intrusion from the west and saline ground water from the east, thereby making it totally unsuitable for human consumption or for irrigated agriculture within the next few decades.

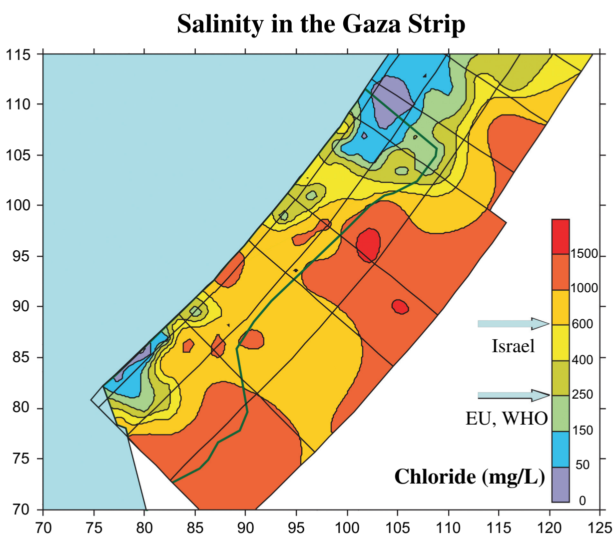

Figure 2. Chloride (mg/L) distribution in the southern Mediterranean coastal aquifer and Gaza Strip as compared to Israel and international (e.g., WHO recommendation) drinking water regulations.

An additional source of pollution in the Gaza Strip is nitrates. Nitrate levels in some areas reach concentrations of 500 mg/L. More than 50% of domestic municipal wells in the Gaza Strip have nitrate concentrations that exceed WHO guidelines of 45 mg/L (UNEP 2003; Vengosh et al. 2005). The level of nitrate contamination has been rising so rapidly that most of Gaza's drinking water wells are no longer adequate for human consumption. Nevertheless, domestic wells continue to supply ground water of poor quality to local communities for drinking water. Additional water quality problems that are associated with the salinity are the high levels of boron (Vengosh et al. 2002, 2005) and fluoride in ground water in the Gaza Strip. In the eastern part of the aquifer, boron concentration in ground water exceeds 1 mg/L, which is the new standard for drinking water in the European Union (European Drinking Water Directive, 98/83/EC). While high concentrations of boron in water could potentially have a toxic effect on human health, they are known to have a deleterious impact on sensitive agricultural crops such as citrus fruits, resulting in significant loss in their yields. Given that citrus is one of the main agricultural products in the Gaza Strip (UNSCO 1996), an increase in boron concentrations could further damage the already weakened agricultural economy in the Gaza Strip. Likewise, ground water in the southern part of the aquifer has high fluoride content (>2 mg/L), which is linked to skeletal and tooth fluorosis (Assaf 2001).

In short, accelerating water quality degradation underlies the water crisis in the Gaza Strip. At present, plumes of relatively fresh water exist only in the northern and southern parts of the Gaza Strip (Figure 2). Yet, these fresh plumes are rapidly disappearing at the same time that the remaining drinking water does not meet any international standards. Intensification of the salinization process means that the domestic sector will experience a transition from brackish (600 to 1000 mg Cl/L) to saline (>1000 mg Cl/L) water. In addition, the long-term effects of irrigation with saline water will exacerbate the problem of soil salinization and drastically reduce agriculture yields, hampering any prospects for future agriculture development.

Ground Water Salinization and International Law

A well-developed body of international law exists for the protection of surface water shared by two or more states. The 1997 United Nations Convention on the

Non-Navigational Uses of International Watercourses (though not yet in force) reflects prevailing international customary law on the nonnavigational uses of surface water and related ground water. In contrast, a parallel body of international law for ground water that is not related to surface water is still in its formative stage. Indeed, international law is extremely weak when applied to international ground water basins, and few international treaties exist that cover shared ground water bodies (see, e.g., McCaffrey 1999; Gleick 1994; Wohlwend 2002; Benvenisti 1996). Nevertheless, the integration of scientific results with the commonly accepted principles of international law provides the foundation for the water management scenarios we propose for the coastal aquifer in the subsequent section.

Besides the efforts of the International Law Association's Seoul Rules on international ground water and the Bellagio Draft Treaty (Hayton and Utton 1989) to devise legal mechanisms for protecting international ground water resources, some (Barberis 1991; Macoun 1995; McCaffrey 1999) suggest that the basic principles and rules that are relevant for other shared resources—the obligation not to cause significant harm, the duty of equitable and reasonable use, the obligation of prior notification, and the duty to negotiate—can be applied directly to transboundary ground water resources. In particular, the obligation not to cause significant harm between upstream and downstream users is especially pertinent for addressing the deteriorating quality in the coastal aquifer. Because pumping takes place on both sides of the border separating Israel from the Gaza Strip, international law then would advise that upstream pumping by Israel should not cause significant harm downstream in the Gaza Strip. Moreover, international law would recommend that Israel only withdraw a reasonable amount of the water so as not to exacerbate the water crisis (i.e., both quantity and quality) in the Gaza Strip.

When the source of the contamination is natural, international law, however, maintains that each country is not obligated to modify the natural state of the resource for the benefit of the other (Barberis 1991). Since the hydrological, geochemical, and isotopic data indicate that the major source of salinity in the Gaza Strip is natural (Vengosh et al. 2005), this implies that Israel is not obligated to prevent the worsening of the water quality downstream from the Israeli side of the aquifer. Ironically, while it could be assumed that Israel's pumping of the ground water might have an adverse effect on water quality in the Gaza Strip, we argue instead that Israel's pumping of the ground water before it reaches Gaza is actually preventing further deterioration in the quality of the aquifer within the Gaza Strip. Moreover, since the hydrological and hydrochemical data indicate that the salinity is primarily derived from the flow of saline ground water from Israel to the Gaza Strip, we posit that Israel should continue to pump the ground water before it reaches the Gaza Strip since it is preventing further deterioration in the quality of the downstream aquifer within the Gaza Strip, despite reducing the natural flow from Israel to the Palestinian Authority.

However, in such situations where the source of "harm" is natural and international law suggests that states need not alter their actions, we find that cooperation is still essential to prevent causing harm to the aquifer. Rather than turning to international legal mechanisms, policymakers and water managers must turn to political solutions to build cooperative management schemes.

Alternative Options for Managing the Water Crisis in the Gaza Strip

The rapidly growing population and expanding urbanization in the Gaza Strip during the past few decades have increased pressure on the aquifer, contributing to its overexploitation and the formation of deep hydrological depressions. The estimated water demand for the domestic sector in the Gaza Strip is expected to double during the next decade and triple within two decades (Assaf 2001). Thus, further increases in the size of population and consequent exploitation will diminish the aquifer's quality, as long as it serves as the primary source of water. Moe et al. (2001), for example, estimate that depletion of the aquifer could occur in 20 to 25 years (using an average rate of aquifer depletion of ~25 MCM/year).

Given the findings that the predominant source of the salinity problem in the Gaza Strip is due to the natural inflow of saline water from the east (Vengosh et al. 2002, 2005) and that political solutions are necessary for sustainable water management because of the limited applicability of international law, in this section, we expand upon two possible alternatives for future management that specifically take into account the ground water component.

The first alternative simply entails maintaining the status quo in which the Palestinian Authority develops water management policies independent of Israel. Following the 1993 Declaration of Principles on Interim Self-Government Arrangements and the 1994 Agreement on Gaza Strip and Jericho Area, water management over the coastal aquifer in the Gaza Strip was transferred to the Palestinian Water Authority. Since then, the Palestinian Water Authority has developed a National Water Plan (UNEP 2003; El-Sharif 2000), which aims to ensure equitable use, sustainable management, and development of the water resources in the Palestinian Authority. Yet, if the Palestinian Authority continues to pump from the coastal aquifer, saline ground water from the eastern side will continue to spread, further reducing the amount of available water for drinking and agricultural purposes.

In this alternative, the only plausible solution to the water crisis in Gaza is to increase the supply of external water. For example, one way is to transfer Nile River water from Egypt through El Arish to the Gaza Strip (see, e.g., Gleick 1994). Yet, such water transfers that include peace pipelines are complicated by the politics of the region; while Egypt might agree to transfer water to the Gaza Strip, it is physically dependent upon the upstream users in the Nile Basin. Although a water-sharing agreement exists between Egypt and Sudan over the sharing of the Nile (80-20 split), the agreement leaves out the other eight riparians in the Nile Basin, including Ethiopia, which is an upstream riparian. If Ethiopia chooses to augment its current use in order to expand agriculture, attempts to transfer water to the Gaza Strip would be even more unlikely, especially since 85% of the Nile's flow originates in Ethiopia.

Another way in which the Palestinian Authority could increase the supply of external water is to introduce desalination either of brackish ground water or sea water. Indeed, the Palestinian Water Authority and foreign donors have channeled substantial resources into planning and building desalination plants in the Gaza Strip. Currently, five small reverse-osmosis desalination plants operate in the Gaza Strip and use brackish ground water to supply ~2.8 MCM/year desalinated water. The overall maximum capacity of these plants is 3.9 MCM/year (data calculated from Assaf 2001). In addition, the donor community is committed to building larger desalination plants that will use sea water as a source for desalination. One of these initiatives is a large-scale desalination plant with a capacity of ~55 MCM/year that is being planned with support from the U.S. Agency for International Development (UNEP 2003; Assaf 2001). The large-scale building of desalination plants is a major infrastructure challenge and requires substantial international investment and a long-term commitment on the part of the donor community. Recent developments in reverse-osmosis technology have, moreover, reduced the cost of sea water desalination. For example, in Israel the cost of desalinated sea water that will be produced in the planned desalination plant in Ashkelon is \$0.55/m^3. As much as large-scale desalination will reduce the pumping from the aquifer and improve significantly the quality of supplied water and the quality of the inorganic constituents of the generated sewage, it will not resolve the water crisis entirely. By 2010, a large-scale desalination plant will produce only half of the estimated domestic demand (110 MCM/year). Pumping from the aquifer will continue in order to meet increasing demands of the domestic and agricultural sectors. Thus, in this scenario where the Palestinian Authority carries out water management policies irrespective of Israel, the quality of the ground water will continue to deteriorate and eventually become unsuitable for domestic consumption. Over time, the water supply in the Gaza Strip will become totally dependent upon external sources of water.

The second alternative is based upon Israel and the Palestinian Authority adopting the principle of joint management (Macoun 1995; Haddad et al. 1999). A negotiated joint pumping plan would involve Israel increasing its pumping in order to reduce the flow of saline water from the Israeli area to the Gaza Strip at the same time that the Palestinians would limit and even reduce pumping within the Gaza Strip. In this scenario, the saline ground water pumped by Israel will be desalinized along the border and then transported to the Gaza Strip.

The deterioration of water quality within the Gaza Strip presents a unique challenge for sustainable water management over the southern coastal aquifer precisely because the salinization problem is a naturally occurring phenomenon that is exacerbated by overexploitation in the Gaza Strip. While Israel's upstream consumption does not contribute to the deterioration of water quality in the Gaza Strip, as in a traditional upstream/downstream situation, Israel can, nevertheless, play an important role in mitigating the salinity problem. An increase in water exploitation on the Israeli side of the border can mitigate the salinity problem by reducing the natural saline flow toward the Gaza Strip. In a similar manner, during the 1970s, Israel was able to reduce the salinity in the Sea of Galilee from ~400 to 220 mg Cl/L by diverting the saline springs that naturally flow into the lake. A diversion by increasing pumping in the coastal aquifer might produce a similar reduction in salinity in the Gaza Strip.

Although the increase in pumping by Israel would reduce the water yield for the Gaza Strip, turning the water-sharing situation into a classic upstream-downstream problem in which the parties are at odds over water quantity does not have to be the outcome. Rather, the pumped saline ground water can be used as a source for small-scale desalination plants along the Israeli-Palestinian border in which the desalinated water will be supplied for domestic application in the Gaza Strip. Moreover, this will facilitate a reduction in pumping within the Gaza Strip. In short, a joint management plan consists of the following two components: the reduction of the saline flow from Israel to the Gaza Strip and the reduction of pumping within the Gaza Strip. In the following section, we test by numerical modeling possible management scenarios that are derived from implementation of the joint management plan.

Modeling the Joint Management Scenarios

A simple, monolayer, hydrodynamic, two-dimensional model was constructed for the northern part of the Gaza Strip (Figure 1) and its immediate surroundings in order to test the effect of possible joint management scenarios on the ground water salinity. This model uses the MARTHE software (Thiéry 1993) and takes into account topography, aquifer depth, and water level measured in 1998. This information is derived from an existing regional three-dimensional model, developed by Camp Dresser and McKee together with the Palestinian Water Authority, in the framework of the Coastal Aquifer Management Program project (Moe et al. 2001).

The grid that has been used in the MARTHE model is a regular grid with square meshes of 500-m width. The water levels and the chloride concentrations at the boundaries are fixed. The major water components that were used in the model are (1) water entering from the north, with Cl = 0 to 50 mg/L; (2) southeastern saline inflow (from the border of Israel), with Cl = 1500 mg/L; (3) atmospheric recharge via the unsaturated zone, without nitrate pollution and Cl = 20 mg/L; and (4) recharge from anthropogenic sources, with high nitrate level and Cl = 300 mg/L. The assumed annual recharge including natural and induced recharge is 55 MCM over the model domain. However, the recharge is not homogeneously distributed. Its distribution follows the nitrate concentration distribution. In addition, no infiltration is considered in the southeastern part of the model, where a loess layer is supposed to act as an impervious barrier to recharge. The total annual ground water abstraction by pumping is 90 MCM/year, of which 4.1 MCM/year derives from the Israeli wells located along the eastern border. After calibration based on 1998 water level and pumping rates, we obtained simulated salinity distribution that is consistent with the measured salinity situation of the aquifer (Figure 3).

Table 1 summarizes the simulation results. We tested the impact on the steady-state water quality of several scenarios including increasing pumping in the existing Israeli wells east of Gaza, "construction" of new wells along the eastern border of the Gaza Strip, and decreased pumping within the Gaza Strip. The results show that different combinations of increased pumping in the eastern side and decreased pumping within the Gaza Strip lead to an overall reduction in the salinity within the northern Gaza Strip (Table 1). A drawback of increased pumping in the east would be a local enhancement of sea water intrusion (scenarios 1a, 1b, and 2). However, we observed that this effect is considerably diminished, if the increased pumping at the eastern border of Gaza is combined with a decrease in pumping within the Gaza Strip (scenarios 4a, 4b; Table 1; Figure 4). We found that an efficient improvement of the water quality in the Gaza Strip is tripling of the pumping (12 MCM) in the eastern wells, combined with a reduction of pumping (by 9.1 MCM) in the Gaza Strip, which corresponds to an overall 10% reduction in pumping rates in the northern Gaza Strip (Figure 4).

It should be emphasized that the absolute values obtained in the model (Table 1) are only qualitative as they are dependent on model calibration and simplification assumptions that were considered in order to build the model. Hence, the model results indicate trends and should not be taken as absolute values. Nevertheless, the numerical simulation results clearly indicate that joint management plans between Israel and the Palestinian Authority can improve the quality of the aquifer. Although the simulation results predict that the expected average magnitude of chloride modification over the whole modeled area in Gaza is relatively low (up to 18 mg/L), the results infer that the joint management alternative will prevent further deterioration of the water quality in the aquifer (i.e., to halt the salinization process). The reduction in the pumping rates inside the Gaza Strip can be achieved if the supplementary pumped saline ground water along the border will be desalinated and transferred to the domestic sector in the Gaza Strip.

It is also important to stress that the amount of brackish water that can be used for desalination is not sufficient to meet all of the estimated domestic demand in the Gaza Strip (110 MCM/year) for the next decade. Thus, a large-scale sea water desalination plant should also be part of a joint water management plan. Nonetheless, we argue that sea water desalination must be combined with a joint management program with Israel for reducing the flow of saline ground water and hence remediation of the quality of the ground water.

Conclusions

In many cases in the Middle East, transboundary aquifers and river basins are shared by political entities that have hostile relations, which makes sustainable water management extremely difficult. In the southern coastal aquifer in the Gaza Strip, long-term overexploitation has resulted in an environmental disaster in which the water quality has deteriorated to the point where most of it is

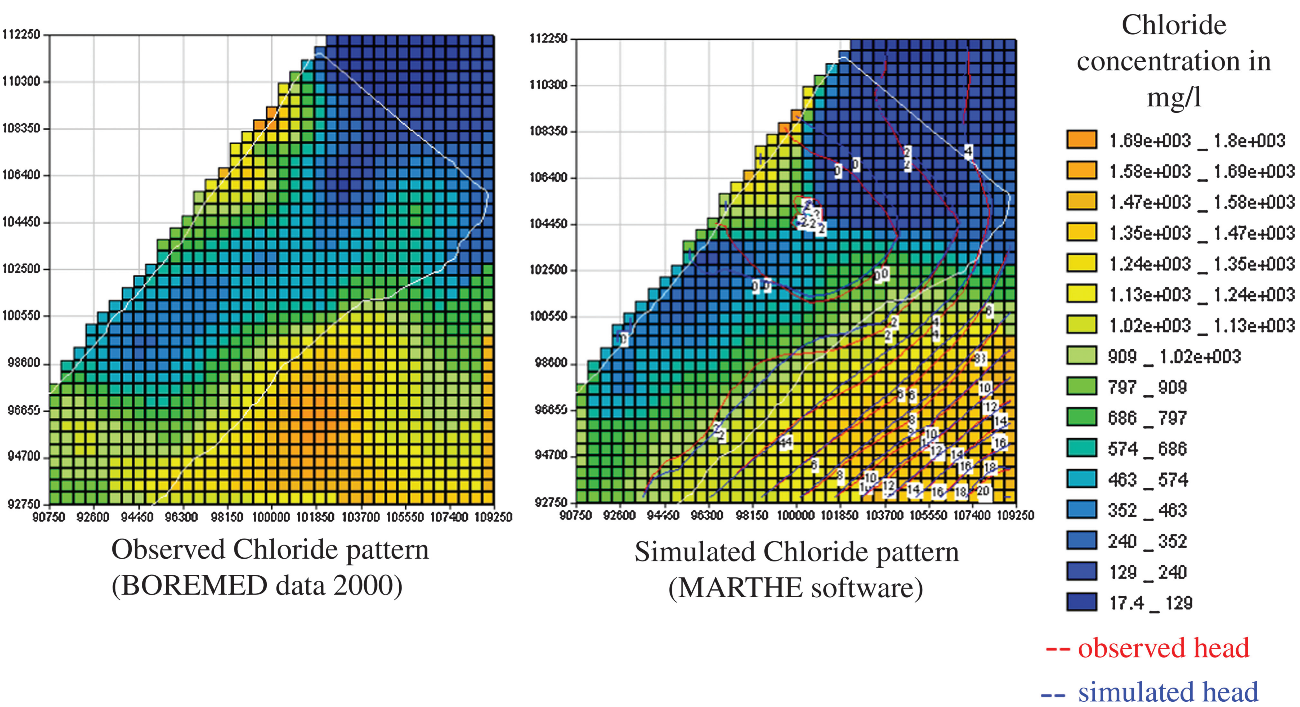

Figure 3. A comparison between measured (BOREMED project data base for 2000) and simulated chloride patterns computed from a steady-state flow and transport simulation using the MARTHE model.

Table 1
Simulation Results of Different Exploitation Scenarios and Water Quality Consequences

Scenario	Pumping in the Eastern Side (MCM)	Pumping in the North of Gaza Strip (MCM)	Average Water Quality Changes (mg/L)[1]	Magnitude of Water Quality Changes (mg/L)[1]	Sea Water Intrusion (maximum, in meter)[2]
Current	4.1	90	—	Figure 1	~1500
1a	8.2	90	−5	−80 to +130	~2500
1b	12.3	90	−9	−170 to +200	~2500
2[3]	4.1	90	−5	−50 to +130	~2500
3a	4.1	85.9[4]	−5	−400 to +40	0
3b	4.1	81[5]	−7	−700 to +150	0
4a	8.2[6]	85.9[6]	−10	−270 to +30	0
4b	12.3[7]	81[7]	−18 (Figure 4)	−400 to +50	0

[1]Minus sign refers to water quality improvement, plus sign to an increase of salinity.
[2]The extent of sea water intrusion into the aquifer (SE-NW dimension).
[3]"Construction" of 11 new wells along the border in order to create a hydrological barrier between the eastern side of the aquifer and the Gaza Strip.
[4]Wells in the vicinity of Gaza City reduce pumping by 10%, whereas other wells continue to pump as in current situation.
[5]An overall 10% reduction in pumping in the north of Gaza Strip.
[6]Combination of increased (×2) pumping in the east and reduction in the vicinity of Gaza City.
[7]Combination of increased (×3) pumping in the east and reduction in the north of Gaza Strip.

no longer suitable for human consumption and agricultural purposes. Ironically, while cooperation would seem highly unlikely given the upstream-downstream scenario and the political tension in the region, the severe water situation in the Gaza Strip could serve as a source of environmental peacemaking between Israel and the Palestinian Authority. Evaluation of the hydrological system with the use of geochemistry and isotope hydrology (Vengosh et al. 2002, 2005), combined with the results of a numerical simulation model, reveals that most of the salinization phenomena in the Gaza Strip are derived from the flow of saline ground water from Israeli territory to the Gaza Strip. Consequently, increasing use of the saline water by the upstream user (Israel) might improve the quality of the downstream aquifer (Gaza Strip). We tested this hypothesis by a numerical model that was established to predict the water quality modifications upon different water management alternatives. Specifically, the model results show that pumping the saline ground water along the border combined with an equivalent decrease in pumping within the Gaza Strip might improve the quality of the ground water and halt the salinization process. Using the saline ground water as a source for reverse-osmosis desalination can provide an additional vital source for domestic consumption in Gaza that would compensate the reduction in exploitation. This management alternative has mutual benefits for both parties. For the Palestinian Authority, it obtains another source of

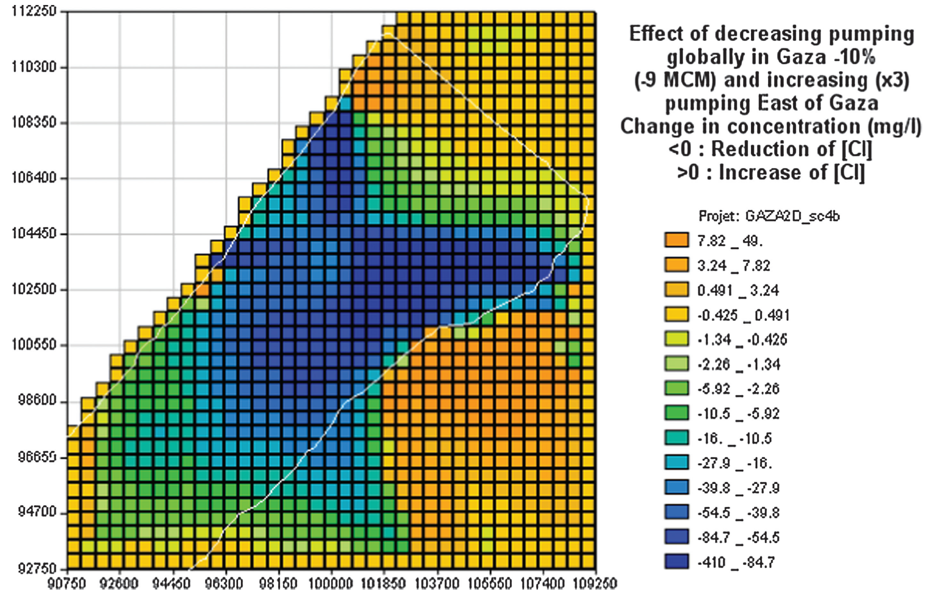

Figure 4. Simulation model of tripled pumping in the existing wells near the eastern limit of Gaza Strip (+8.2 MCM) and a reduction by 10% of the pumping in the Gaza wellfield (−9 MCM; scenario 4b, Table 1). The simulation predicts an overall reduction of the salinity and limited intrusion of sea water.

drinking water for its growing population and remediation of the salinity problem in the Gaza Strip. For Israel, the transfer of desalinated ground water could serve as a goodwill gesture and lessen the political tension between the parties.

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