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Sustainable Integrated Water Resources Management (IWRM) in a Semi-Arid Area

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Abstract: This study concerns developing methods for sustainable IWRM in a semi-arid area. The paper refers to the Coastal Plain (CP), which is the most populated part of the area between the Mediterranean and the River Jordan (AB-MARJ). We consider in semi-arid areas all quantities of available water should compose part of the regional water resources. However, sustainability of such an approach means covering all available quantities of water, providing water of proper quality to all consumers, and controlling the quality decline of water resources. We comply with these missions by applying economic guidelines to optimize the supply of water needs of all regional consumers. Further, sustainable management of the regional water resources in semi-arid areas needs proper policies and legislation aiming at enriching the regional water quantities, and preserving and improving the quality of available regional water resources. This study provides outlines for achieving such goals in the CP of Israel, where the Coastal Plain Aquifer (CPA) comprises the major storage of freshwater.

Keywords: Groundwater Pollution, Integrated Water Resources, Semi-arid Areas, Water Recycling, Regional Water Resources, Preserving Water Resources

Introduction

QUALITY OF THE environment needs proper care of soil, water and air. However, in semi-arid areas water comprises an important commodity connected with developing the human society. This commodity is subject to various influences originating from economic, political, social and environmental considerations. The present paper concerns proper solutions to complying with water needs in the Coastal Plain of Israel, which composes part of the area between the Mediterranean and the River Jordan (AB-MARJ).

Many documents concern sustainability of supplying enough water to all consumers that exist in the AB-MARJ. The average annual natural replenished water of this area is about 1,800 mcm (million cubic meters). Figure 1 shows the major aquifers and surface water, which currently supply water to all consumers in the AB-MARJ. The maximum annual amount of rain in the north is about 900 mm, whereas the region south of Beersheba, called Southern Negev is desert, with minute available quantities of freshwater. Figure 1 also shows the National Water Carrier, which transfers an annual amount of about 400 mcm of freshwater from Lake Kinneret (Sea of Galilee) to most areas of Israel. About groundwater, the major aquifers are: a) The Coastal Plain Aquifer (CPA), and b) The Mountain Aquifer (MA). Figure 2 incorporates a schematic description of water fluxes between soil surface and the aquifers that exist in the AB-MARJ. This figure implies about various issues of water resources management, like sharing of water between Israel and the Palestinian Authority, general concern about transboundary water resources, socio-economic and political issues affecting water needs. All these topics are associated with sustainable management of water resources in the AB-MARJ. However, because of limited space of this article, we intend to focus our discussion only on sustainability of integrated management of water resources at the Coastal Plain (CP), where most quantities of water come from the Coastal Plain Aquifer (CPA). In our opinion sustainability of such management requires reference to balancing budgets of water resources quantities and quality. Further proper consideration of socio-economic parameters and legistation is crucial for achieving the preservation of sufficient quantities of water resources with proper quality for all regional consumers.

The average annual natural replenishment of the CPA is about 250 mmc (Allison and Hughes 1978). However, the quality of groundwater of the CPA is subject to continuous decline. Figure 3 shows the current distribution of chloride concentrations in the CPA. It shows that now in many areas the chloride concentration is higher than values acceptable by common water quality directives of the EU and EPA.

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Figure 4 shows the current distribution of nitrate concentrations in the CPA. It shows that now in many areas also the nitrate concentration is higher than values acceptable by common water quality directives of the EU and EPA. Further, Figure 5 shows the measured distribution of tetrachloroethylene (PCE) in the CPA at Tel Aviv area (Graber et al. 2000a, b, 2001, 2002, Naval Ordnance 1997, 2000). It shows that in Tel Aviv area concentrations of PCE are higher than acceptable for drinking water. PCE is only one contaminating compound of the various chlorinated hydrocarbons that contaminate the CPA in Tel Aviv area. Further, various heavy metals contaminate parts of the CPA (e.g., Naval Ordnance 1997, 2000). The presence of such pollutants avoids using groundwater of the CPA at Tel Aviv area for supplying drinking water. Various studies (e.g., Kanfi 1986, Rubin and Braester 2000) have shown that fossil fuels contaminate many parts of the CPA. The cumulative information about groundwater quality decline in the CPA calls for studying possible measures aiming at controlling this phenomenon (Rubin and Rubin 2003a, b, Rubin 2004).

Following the information of the preceding paragraph, we have determined the objectives of this study, which are crucial for achieving sustainable integrated water resoueces management in semi-arid areas:

- Quantifying water resources quality by simplified means,
- Supplying outlines for providing drinking water of good quality to the population,
- Supplying outlines for improving the quality of groundwater,
- Supplying outlines for minimizing contaminant penetrating into groundwater.

Balancing the Regional Water Resources Budget

In 1948 about 2 million people lived-in the AB-MARJ, which now incorporates Israel and the Palestinian Authority. Presently, more than 10 million people live in the AB-MARJ, and more than 5 million of them leave at the Coastal Plain (CP). Water consumers at the CP incorporate agricultural, domestic, and industrial consumers, and natural habitats.

After the foundation of the State of Israel, Water Authorities of Israel built huge pipelines to transfer water from the CPA to the Negev. However, since the 50's the CPA could not provide enough quantities of water to all its water consumers. In 1964 the National Water Carrier started to work and balanced the water budget in Israel, including the CP. Since then water needs continuously increase. Therefore, the water authorities have continuously invested effort in balancing water budget in the CP. However, as discussed in the next section, currently the major concern of the water authorities is the continuous decline of groundwater quality in the CPA.

Figure 6 represents a schematic description of water fluxes entering the CPA and leaving this aquifer. This figure may provide some ideas about balancing the water budget of the CPA. According to Figure 6, major water storages are the Mediterranean, atmosphere and the CPA. For water budget balance calculations, we should only refer to the latter storage and consider that other storages are infinite. For simplifying the calculation and reference to most sensitive parts of the CPA, we apply the schematics of Fig. 6 to slices of the CP, where each slice extends between the eastern and western (Mediterranean) boundaries of the CPA. The different storages of water and water fluxes shown in Fig. 6 are:

$W\ aq$ = volume of water stored in the slice of the CPA
$W\ at$ = volume of water stored in the atmosphere
$W\ s$ = volume of water stored in the Mediterranean
$Q\ a$ = flux of rain arriving at the land surface (about 30% of this flux percolates into the aquifer)
$Q\ av$ = flux of evapotranspiration (about 70% of all types of water released on the land is subject to evapotranspiration, and 30% percolates into the aquifers)
$Q\ db$ = flux of brine out of desalination plants
$Q\ ds$ = flux of water from the sea into desalination plants
$Q\ dsn$ = flux of freshwater from desalination plants to the population (it can also represent freshwater import from overseas)
$Q\ gsd$ = flux of groundwater into the Mediterranean
$Q\ ir$ = flux of freshwater used for irrigation (about 30% of this flux percolates into the aquifer)
$Q\ iw$ = flux of treated wastewater used for irrigation (about 30% of this flux percolates into the aquifer)
$Q\ nc$ = flux of water supplied to population and irrigation from the National Water Carrier
$Q\ ncr$ = flux of aquifer recharge (during winter) supplied from the National Water Carrier
$Q\ p$ = flux of water pumped from the aquifer for all supplies and freshwater irrigation
$Q\ pc = Q\ du$ flux of freshwater supplied to the domestic and industrial consumers
$Q\ sav$ = flux of water evaporating from the Mediterranean into the atmosphere

Q sr = flux of surface runoff flowing into the Mediterranean (composes about 5% of *Q a*)

Q w = flux of wastewater from all consumers into the wastewater treatment plants

There are some connections between various water fluxes shown in Fig. 6: The total amount of water used by the agriculture, *Q ag*:

$$(1)\quad Q_{ag} = Q_{ir} + Q_{iw}$$

The total water amount used by domestic and industrial consumers, *Q du*:

$$(2)\quad Q_{du} = Q_{p} + Q_{nc} + Q_{dsn} - Q_{ir}$$

The total water of natural replenishment available to all types of consumers, *Q nr*:

$$(3)\quad Q_{nr} = Q_{a} - Q_{sr} - Q_{sav}$$

Where

Q sav = soil evaporation that follows rainstorms

We should note that *Q nr* incorporates needs of the human society and natural habitats.

Various water fluxes of Fig. 6 represent components controlling water budget balance in the CPA. The following expression provides rough information about the balance between changes in water storage within the slice of the CPA and those water fluxes:

$$(4)\quad \frac{dW_{aq}}{dt} = Q_{a} - Q_{av} - Q_{sr} - Q_{p} + Q_{ir} + Q_{iw} + Q_{ncr} - Q_{gsd}$$

Where:

t = time

The right hand side (RHS) of Eq. (4) represents the net annual aquifer recharge. Sustainability of balancing the regional water budget means each side of Eq. (4) vanishes. To avoid depletion of the CPA we may only temporarily allow negative values of the RHS of Eq. (4). Generally, a time period of positive value of the RHS should follow a time period of negative value of this side of Eq. (4). However, growth of the population and rising life quality of the population increase domestic water needs, but the value of *Q p* should not increase. As discussed in the next section, recently the value of *Q p* has decreased in various parts of the CPA because of serious decline of groundwater quality. There are several approaches leading to balance the regional water budget. We may increase the efficiency of water consumption by all consumers (e.g. Zur, visited 2006). This approach is probably the least expensive, but it may add limited quantities of water. However, it may allow transfer of water rights from agriculture to urban consumers. All types of water recycling (e.g., SRCSD, visited 2006) by treating effluents may also help in bridging the difference between restored natural water and water needs of the consumers.

Surface runoff composes about 5% of the rain. The Water Commission and other agencies provide support to developing methods of harvesting floodwater. Such methods were successful in various dry areas, like semi-arid regions of Australia (e.g, Salisbury Environment, visited 2006).

All approaches described in the preceding paragraphs can help to bridge the difference between the consumer water needs and the natural water resources replenishment. However, when these methods are fully effective and consumers still need more water quantities we should use desalination plants and possibly import water from overseas. Therefore, the declared policy of the Water Commission incorporates the following missions (Israel's Water Economy, 2002)

- To preserve and protect the existing reserves, in quality and quantity.

- To increase considerably the supply of potable water, mainly through seawater desalination and purification of water sources.
- To advance treating sewage, its collection and purification, turning it into the main source of water for agriculture (replacing potable water).
- To intensify water saving in all sectors by economic measures - raising the price, as well as by legal means, enforcement, improved management and organization.
- To invest in Agrotechnology, to convert agriculture to using mainly low quality water - recycled waste water, brackish and flood-water.

Another important feature of the CPA is risk of seawater intrusion, namely negative value of *Q gsd*. Because the Mediterranean comprises the western boundary of the CPA, even under temporary negative values of each side of Eq. (4) we should avoid seawater intrusion, and keeping positive values of *Q gsd* . Pumping of groundwater and injection of water into the aquifer to create barriers against seawater intrusion may be needed in draughts. In most places water authorities of Israel keep the value of *Q gsd* at a minimum level, capable to avoid seawater intrusion into the CPA. One exception is Tel-Aviv area, where groundwater contains high concentrations of volatile organic compounds (VOCs); and therefore the value of *Q gsd* is large in that area. Another exception is in some areas of Gaza Strip (southern part of the CPA), where farmers have pumped large quantities of water and caused negative values of *Q gsd*. Equation (4) and Fig. 6 show that by producing large quantities of water by desalination plants, *Q dsn* (net desalination flux) or by importing large quantities of freshwater we may reduce the need for pumping from the aquifer, namely reducing the value of *Q p*.

Aspects of Water Resources Quality

The continuous decline of the CPA groundwater quality originates from three types of compounds: a) Minerals, like chlorides and nitrates, b) Organic micropollutants, like volatile organic compounds (VOCs), mainly chlorinated hydrocarbons, and c) Heavy metals, namely inorganic micropollutants.

Wherever, concentrations of micropollutants and risks to the environment are very high, possibly remediation of the aquifer is the proper approach. Such needs call for improved natural attenuation (see McCarty and Ellis, 2002). Otherwise, possibly artificial remediation is the proper approach. However, groundwater contamination by VOCs in the CPA probably does not justify the high expenses of aquifer remediation. Renewal of pumping from the local wells and treating the groundwater by various methods like UV will probably provide good quality drinking water to the area of Tel-Aviv. In several parts of the CPA near Tel-Aviv concentrations of heavy metals like lead and cadmium are higher than accepted by drinking water quality codes. Again in such places treating the pumped groundwater by efficient technologies is probably the proper solution. Until recently the water authorities have not imposed treating pumped groundwater before supplying it to domestic users. However, little by little local and central governmental authorities realize that treating groundwater is a must at the CP. Treating groundwater contaminated by micropollutants in Tel-Aviv area costs a fraction of desalting seawater.

About balancing budgets of the different minerals in groundwater of the CPA (mainly, chloride and nitrate), as shown in the next section:

- We should control the supply of minerals into the vadose zone,
- We should avoid supplying water with high mineral concentration to domestic consumers, and
- We should preserve the mineral concentrations in groundwater at acceptable levels.

Balancing the Budget of Minerals

All fluxes of water shown in Fig. 6, except for *Q a* include some quantities of minerals. Further, recycling of water within the water cycle of Fig. 6 incorporates risks of increasing the content of minerals in groundwater. We may apply a simplifying postulate claiming each quantity of minerals released into the environment, e.g. by all types of irrigation, may arrive at the aquifer, unless it is subject to uptake by vegetation. Further, mineral concentration in all water quantities percolating through the vadose zone increases by ΔCvz.

Nitrate concentration in groundwater increases by crop fertilizing and irrigation. Therefore, according to the postulate of the preceding paragraph, we may preserve nitrate concentration in groundwater by controlling the supply of fertilizers to crops. Chloride concentration in groundwater increases because of all types of irrigation. Chloride concentration in water released into the environment and percolating through the vadose zone increases about 50 ppm. Therefore, even by irrigating with freshwater we increase chloride concentration in groundwater. Water percolating through the vadose zone transfers remains of fertilizers into groundwater. Decaying organic materials may also release nitrate that later arrives at groundwater with water percolating through the vadose zone. Figures 4 and 5 show that we should balance mineral concentration in groundwater of the CPA. It means balancing between fluxes of minerals entering the aquifer and those leaving the aquifer. We extend Eq. (4) to consider each mineral and get:

$$\frac{d}{dt}\left(W_{aq}C\right) = Q_a C_a + \left(Q_a - Q_{sr} + Q_{ir} + Q_{iw} - Q_{av}\right)\Delta C_{vz} + Q_{ir}C_{ir} + Q_{iw}C_{iw} + Q_{ncr}C_{nc} - (Q_p + Q_{gsd})C + FC_{ha} - FC_{pu} \quad (5)$$

Where:

C = mineral concentration of the CPA groundwater
C a = mineral concentration of the rainwater (usually small)
C ir = mineral concentration of freshwater used for irrigation
C iw = mineral concentration of treated wastewater used for irrigation
C nc = chloride concentration of National Carrier water (about 220 - 240 ppm)
Δ*C vz* = increase of mineral concentration of water percolating via the vadose zone
FC ha = flux of mineral caused by human action (like fertilizing)
FC pu = flux of mineral caused by plant uptake

Values of *FC ha* and *FC pu* are significant to balancing the nitrate content, but are almost irrelevant to chloride content. Further, missions of controlling nitrate concentration in groundwater need particular reference to decreasing *FC ha* and adjusting its value to cover the value of *FC pu*. Such missions mainly consider proper guidance and control of agricultural actions. On the other hand, calculations of balancing chloride content should mainly refer to management of water resources. Anyhow, high concentrations of both minerals should reduce. And the question is "How should we reduce concentrations of nitrates and chlorides in groundwater?" This question leads to developing methods of sustainable use of the regional water resources. For simplicity of the scope of this study in following paragraphs, we limit our discussion to chloride concentrations, namely ignore the effect of the two last terms of Eq. (5).

For developing Eq. (5), we assume the storage of the aquifer, *Waq* is almost constant. We may consider that domestic uses increase chloride concentration by Δ*C du* = 100ppm. Therefore, chloride concentration of wastewater is greater than concentration of water supplied to domestic consumers by this amount. Common secondary treatment of wastewater decreases nitrogen content, but has no effect on chloride content.

Figure 5 implies chloride concentration of water used for freshwater irrigation, *C ir* is:

$$C_{ir} = \frac{Q_p C + Q_{nc} C_{nc}}{Q_p + Q_{nc}} = \alpha_{ir} C + \beta_{ir} \quad (6)$$

Where:

$$\alpha_{ir} = \frac{Q_p}{Q_p + Q_{nc}}; \quad \beta_{ir} = \frac{Q_{nc} C_{nc}}{Q_p + Q_{nc}} \quad (7)$$

By irrigating crops we supply chloride into the environment, according to our postulate of the first paragraph of this section, this quantity of chloride arrives at the aquifer. Further, about 70 percent of the water supplied into the environment by irrigation is subject to evaporation. Therefore, about 30 percent of this water percolates through the vadose zone where it gains and later transfers into the aquifer an extra chloride concentration of about 50 ppm.

As chloride concentration of the National Water Carrier is about 220 ppm, Eq. (6) implies that irrigating with this water enhances the increase of chloride concentration in groundwater to about 270 ppm. In places of chloride concentration in groundwater of above 270 ppm, irrigating with water of the National Water Carrier decreases the chloride concentration.

Figure 5 also implies the chloride concentration of water supplied to domestic consumers, C_{du} is:

$$(8)\quad C_{du} = \frac{Q_p C + Q_{nc} C_{nc} - Q_{ir} C_{ir} + Q_{dsn} C_{dsn}}{Q_p + Q_{nc} - Q_{ir} + Q_{dsn}} = \alpha_{du} C + \beta_{du}$$

Where

$$(9)\quad \alpha_{du} = \frac{Q_p - \alpha_{ir} Q_{ir}}{Q_p + Q_{nc} - Q_{ir} + Q_{dsn}}; \quad \beta_{du} = \frac{Q_{nc} C_{nc} - \beta_{ir} Q_{ir} + Q_{dsn} C_{dsn}}{Q_p + Q_{nc} - Q_{ir} + Q_{dsn}}$$

C_{dsn} = chloride concentration of water supplied by desalination plants

Therefore, chloride concentration of treated wastewater, C_{iw} is:

$$(10)\quad C_{iw} = \alpha_{du} C + \beta_{du} + \Delta C_{du}$$

Where

ΔC_{du} = increase of chloride concentration by domestic uses (about 100 ppm)

We consider the storage of the aquifer, W_{aq} is subject only to small changes and introduce Eqs. (6) – (10) into Eq. (5) to get the following equation of balancing the chloride concentration in groundwater:

$$(11)\quad W_{aq} \frac{dC}{dt} = B - AC$$

Where

$$(12)\quad A = Q_p + Q_{gsd} - \alpha_{ir} Q_{ir} - \alpha_{du} Q_{iw}$$

$$(13)\quad B = Q_a C_a + Q_{ncr} C_{nc} + \left(Q_a - Q_{sr} + Q_{ir} + Q_{iw} - Q_{av}\right) \Delta C_{vz} + \beta_{ir} Q_{ir} + \beta_{du} Q_{iw} + Q_{iw} \Delta C_{du}$$

Direct integration of Eq. (11) yields

$$(14)\ C = C_{eq} - \left(C_{eq} - C_0\right)\exp\left(-\frac{At}{W_{aq}}\right)$$

Where $C\ eq$ = equilibrium concentration of chloride in groundwater

$$(15)\ C_{eq} = \frac{B}{A}$$

Equations (8) – (15) comply with the first objective of this study. They provide a simplified tool for quantifying quality control of groundwater. These expressions help us to identify proper outlines for complying with the two following objectives of this study.

Equations (8) – (15) show that we may achieve the objective of reducing the value of *C eq* by increasing the value of *A* and/or decreasing the value of *B*. Therefore, we should check each term affecting values of these quantities and consider methods leading to acceptable values of *C eq*. Large values of *A* also lead to faster arriving at *C eq* in the aquifer. Equations (12) and (13) show the significant effect of all types of irrigation on *C eq*. Irrigation reduces the value of *A* and increases the value of *B*. Therefore, reduced values of *C ir* and *C iw* may help to balance the budget of chloride (and other minerals) in groundwater. Some scientists (Zaslavsky, 2000) have stressed the negative effect of irrigating crops with treated wastewater and suggested treating all wastewater of Israel to a level acceptable by drinking water standards. Asano (visited 2006) provides details about methods and places taking measures enriching their local water resources by advanced wastewater treatment. Deshmukh (2004) provided us details about producing water of drinking quality of one third of the domestic wastewater of Orange County, CA. Orange County injects this water of high quality into the aquifer to control seawater intrusion and avoid depletion of the local groundwater resources. Advanced treated wastewater is a major source of drinking water to people of the city Windhoek, Namibia (Gadgil 1998). However, treating domestic wastewater to very high levels is a single method of reducing the ratio of *B* to *A*. To identify the best method of reducing this ratio we should consider all terms comprising this expression. In the next paragraph we represent another method with potential feasibility.

Water supplied by desalination plants includes about 20 ppm total dissolved solids (TDS). Therefore, according to Eq. (12) we may apply some desalination methods to reduce the value of *C du* and therefore also *A* decreases. Further, if we apply desalination methods to treat all water quantities supplied to domestic uses, and farmers irrigate all crops with treated wastewater then according to Eq. (8) the value of *C du* approaches 20 ppm, and Eq. (10) implies $C\ iw \approx 120$ ppm. Equations (8) - (15) imply possible control of the increasing mineral concentration in groundwater by irrigating with treated wastewater, provided mineral concentration in water of domestic use is low. We may consider a hypothetical scenario of pumping all quantities of the aquifer natural recharge to domestic uses via desalination plant. Then about 70 percent of the natural recharge may be available as treated wastewater for irrigation. According to Eqs. (1) – (3), such a procedure means

$$Q_p = Q_{du} = Q_{nr},\ Q_{ag} = 0.7Q_{nr}$$

A discharge 0.3*Q ag* arrives at the aquifer with added chloride concentration of 50 ppm; and a discharge 0.3*Q ag* with the aquifer chloride concentration flows into the sea. According to Eqs. (8) – (15), such a water resouces management leads to equilibrium chloride concentration in groundwater of about 120 ppm. By looking at Fig. 3, we may consider that limiting chloride concentration at the CPA to such level is definitely positive. However, during wintertime there is no need for crop irrigation. Therefore, we should devote some parts of the CPA to storage of treated wastewater, by e.g. applying the practice gained with storing the treated wastewater of Tel-Aviv area in Shafdan (Dan Region) Treating Plant (e.g, Icekson-Tal et al. 2003). However, to identify the best method of supplying drinking water of good quality simultaneously with controlling the mineral concentration in groundwater we should also consider economic and legislative factors. We may achieve these missions by applying the methodology that is given in the following sections.

Economic and Financial Aspects

Economic and financial aspects incorporate a very important part in the development of sustainable water resources management. However, due to limited space, this paper includes a brief presentation and discussion of these issues with relevance to the CP. According to the Israeli Water Law all water resources in Israel belong to the nation, and the Water Commissioner settles its uses by providing "water rights". Consumers using water amounts exceeding their water rights pay high prices for these extra water quantities.

Shaham (2006) has provided us some estimated costs of water in various places of Israel. The current cost of one cubic meter of water supplied by Mekorot (The National Water Company) varies between 10 cents (all prices are in American money) and about 85 cents per cubic meter. The price of water supplied by the National Water Carrier is about 30 cents per cubic meter. At the CP the price of all types of water supplied by Mekorot is about 30 cents. However, the central government subsidizes water supplied to agriculture. Therefore, farmers pay about 25 cents per cubic meter in all parts of Israel, for water included with their "water rights". Costs of supplying water from private wells in the CP are smaller, but well owners should pay a "water production tax" for pumping groundwater of the nation.

Cost of water for domestic use in urban areas is about 1.2 dollar per cubic meter. Usually municipalities apply the water needs of the consumers for collecting extra taxes. Probably in the future municipalities will be required to use these taxes for improving their water supply networks, and the quality of water supplied to their citizens.

Treating wastewater to the quality imposed by Barcelona treaty before its transfer into the Mediterranean costs about 55 cents per cubic meter. This price represents the basis for providing wastewater as a raw material for recycling. Treating wastewater to irrigating cotton costs about 25 cents per cubic meter. However, the central government limits irrigating cotton with treated wastewater to places with no environmental and groundwater quality risks. We should consider extra 30 cents per cubic meter of this water for reservoirs, pipelines, maintenance, etc. Therefore, treated wastewater can be considered as a commodity provided free for cotton irrigation. In Shafdan (Dan Region), wastewater infiltrating ponds, reservoirs, pipelines, energy and maintenance cost about 45 cents per cubic meter. Farmers can use this water for unlimited crop irrigation. We may consider treating wastewater already treated to the quality of Barcelona Treaty to drinking water by extra costs of about 60 cents. However, usually communities reject the idea of supplying treated wastewater of drinking water quality to the population. Therefore, communities at the coastal zone often prefer to deliver treated wastewater into seas and oceans (California Coastal Commission, visited 2006) and supply drinking water from desalination plants. Also the ministry of health of Israel does not accept the idea of "drinking water from wastewater". On the other hand farmers in Israel cannot pay more than 25 cents per cubic meter for irrigation. Therefore, farmers already get subsidies for their water supplied for irrigation. Nobody can imagine the government producing water of drinking quality for irrigating crops and thereby increasing subsidies to agriculture. Therefore, producing drinking water from wastewater represents supplying commodity with no consumers.

Treating water of the National Water Carrier to quality of drinking water (without reducing mineral concentrations) costs about 10 cents per cubic meter. Treating pumped groundwater to reduce nitrate and chloride content costs about 45 cents per cubic meter (Reiz 2005). Desalting seawater costs about 70 cents per cubic meter. These figures show that by the costs of desalting seawater we may treat significantly larger quantities of pumped groundwater. Further, water consumers in urban communities already pay for their water prices higher than costs of water produced by seawater desalination. By providing good guidance public opinion will probably accept the idea of supplying water of very high quality to the people (for such water they precently pay about 2,000 dollar per cubic meter in the grocery) for added several cents.

We may finish this section by proposing treating pumped groundwater for supplying drinking water of high quality to domestic consumers. Such an approach will produce wastewater with chloride content of about 120 ppm. Probably irrigating crops with such wastewater treated to unlimited irrigation will establish chloride content in the CPA to a level of up to 120 ppm. The extreme case of 120 ppm chloride takes place if all natural recharge is supplied to domestic users and later treated for wastewater irrigation. Treating groundwater before its transfer to domestic users may be an efficient method for providing proper answers to the two most important objectives of this study:

- It improves the quality of drinking water supplied to the population,
- It reduces mineral concentration build-up in groundwater

Organization and Political issues

We have already mentioned that according to the unique water law of Israel water resources in the country belong to the nation. Because of these unique circumstances sustainable management of water resources in Israel depends on parameters of high levels of politics. Again, due to limited space, we only provide a brief discussion of such issues. There are some advantages of "water belonging to the nation". In the 60's of the previous century the government could complete the National Water Carrier and transfer water from the northern part of the country to its south. Nowadays, to comply with needs for drinking water for the growing population the central government can gradually transfer water rights from the agriculture to domestic consumers. On the other hand the government converts freshwater rights of farmers to rights of irrigating crops with treated wastewater. Now, the Water Commission (central government) supports large-scale projects of desalination, to supply drinking water to the population (Israel's Water Economy, 2002). Another initiative of the central government is to import drinking water from overseas. However, cumulative experience with waterworks provides no clear-cut proof the water law of Israel gives better results about managing water resources than in other countries. In many places initiatives identical with those of the Water Commission in Israel have succeeded without involving the central government. In California rich communities in Los Angeles area buy water from less successful communities existing in the northern part of the state. Urban communities in Florida and California have built desalination plants without involving the central government. Usually private and local initiatives and management are more efficient than those of the central government. However, optimal supply of water, energy and public transportation is usually obtained by the local government rather than private companies.

The preceding paragraph provides information about the success of the central government to supply proper quantities of water to all consumers in Israel. However, the central government has been less successful in controlling companies and individuals that contaminate groundwater resources. Such a control is most important at the CP, where largest population density takes place. However, it is difficult for the central government to preserve the quality of its groundwater in such places. Probably local community government could be more efficient about this issue, provided the groundwater belongs to this community. Cumulative experience shows that local people have better chances to preserve the quality of the local water resources. The National Water Carrier gets its water from Lake Kinneret (Sea of Galilee) and its watershed. In the 70's, the Water Commissioner understood that preserving the quality of this water is a national mission. He also understood that an authority managed by people living in that area has most chances to comply with such a mission. Since then the Kinneret Management represents the Water Commission and preserves the water quality in Lake Kinneret. Therefore, for more than three decades the quality of water in Lake Kinneret is stable.

The preceding paragraph provides brief pieces of information showing the Water Commission should give to local governments more responsibility about preserving the quality of groundwater in the CPA. However, there is no responsibility without benefits to all parties. As an example, we may imagine the Water Commissioner allowing the municipality of Tel-Aviv and nearby municipalities full control on the CPA at their area. Probably, these municipalities may easily collect information about groundwater contaminating bodies. They may also apply engineering and economic feasibility studies to decide whether it is better to pump and treat the contaminated groundwater or buying water produced by desalting seawater. However, the power of the Water Commissioner comes from the water law, and transfer of power to local governments cannot depend on positive willingness of the Water Commissioner. Probably some amendments to the water law should instrument this trend. We may summarize that best control of human actions leading to continuous decline of groundwater quality in the CPA needs comprehensive review of the Israeli water law and transfer of power from the central government to governments of local communities. Many publications (e.g., McCarty and Ellis 2002) stress the crucial role of the local community in controlling groundwater pollution. The water law in Israel should allow such involvement.

Concluding Remark

Sastainable management of regional water resources means providing sufficient quantities of water with proper quality to all regional consumers. This study concerns the major issues and parameters that allow such development where water resources are scarce. The study concerns the particular example of the CP in Israel and introduces four different objectives, whose achievent may lead to sustainable development of regional integrated water resources management:

- Quantifying water resources quality by simplified means,
- Supplying outlines for providing drinking water of good quality to the population,
- Supplying outlines for improving the quality of groundwater,
- Supplying outlines for minimizing contaminant penetrating into groundwater.

A simplifying model based on calculations of overall mass conservation may help to achieve the first objective and identify proper avenues for achieving the second and third objectives. By considering economic and financial factors we found that taking away minerals from water supplied to domestic uses is a promising method for preserving the water resources quality.

All actions leading to proper sastainable IWRM depend on socio-economic, financial and legislative parameters. This study suggests legislative measures of transferring more power and responsibility (with some benefits) to the local governments from the central government.

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Figure 1: Major Aquifers and Surface Water in the Area

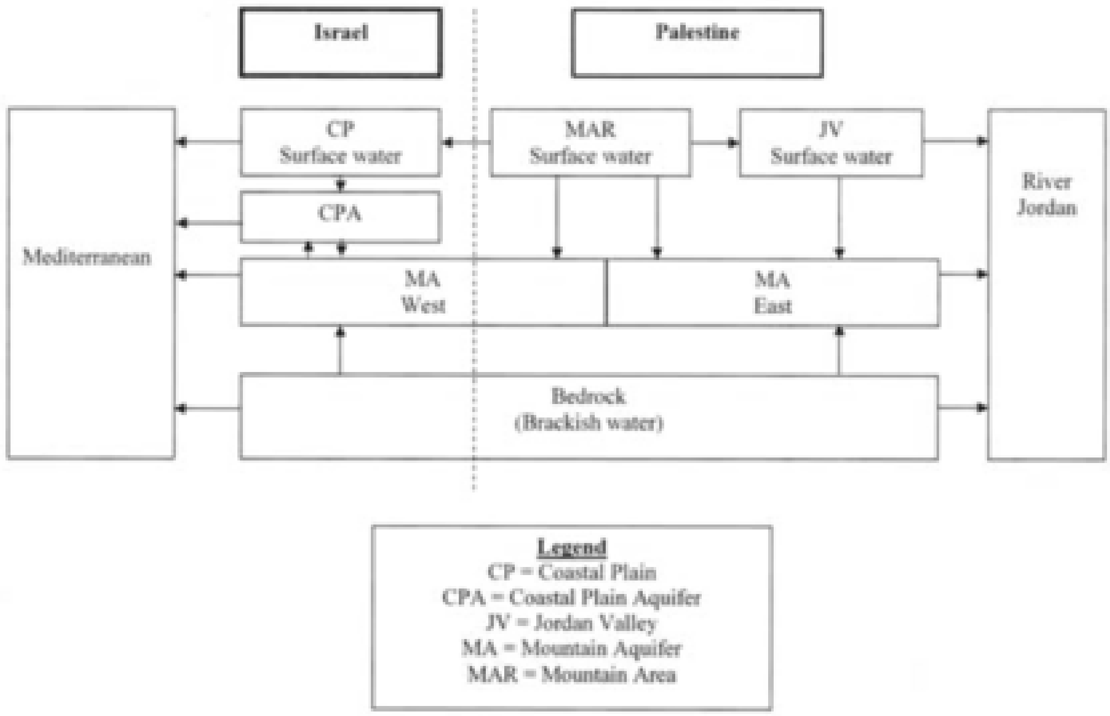

Figure 2: Fluxes of Water in the Area between the Mediterranean and River Jordan (AB-MARJ)

Figure 3: Chloride concentrations in the CPA

Figure 4: Nitrate concentrations in the CPA

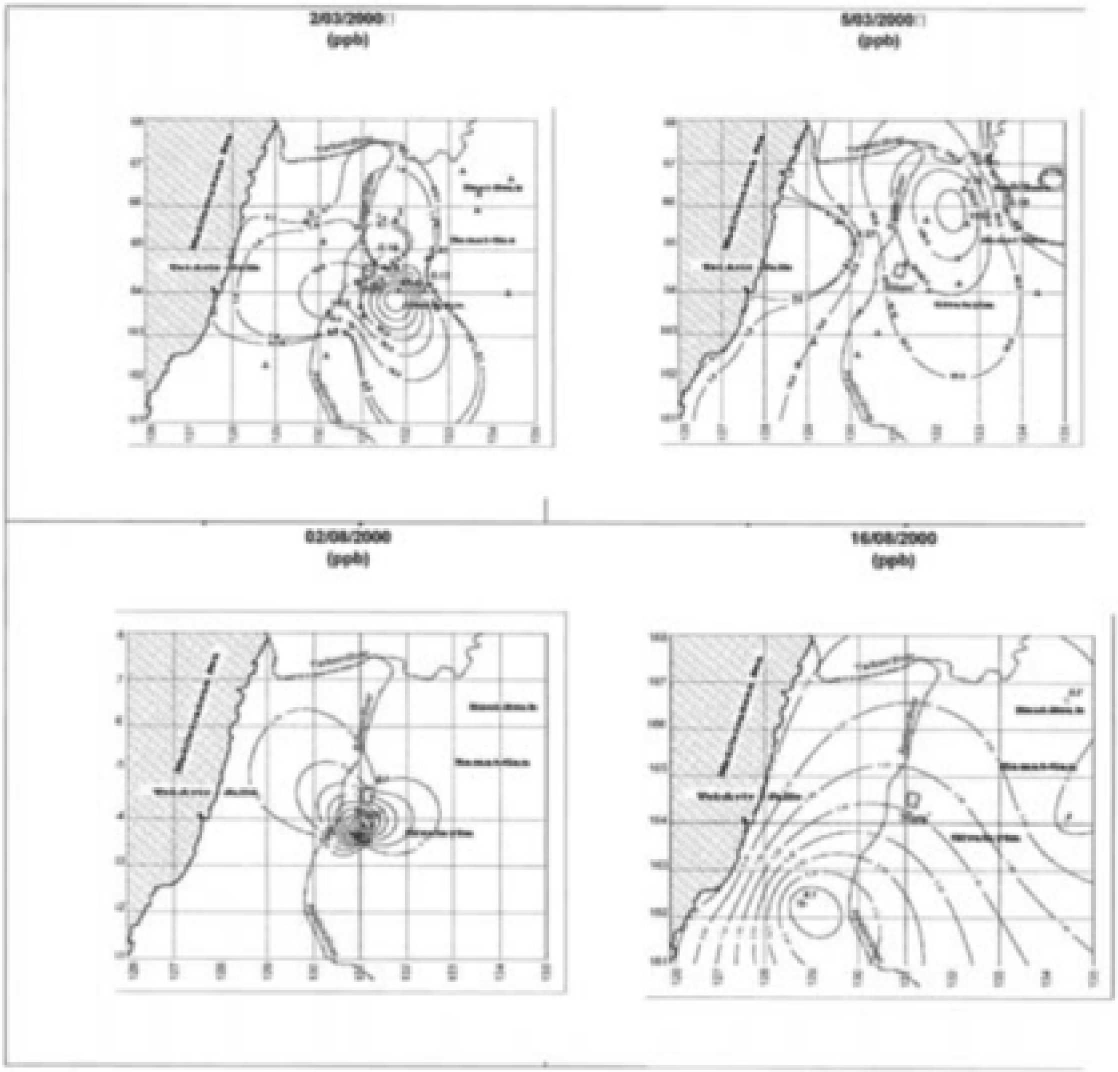

Figure 5: Measured PCE concentrations at Tel-Aviv area

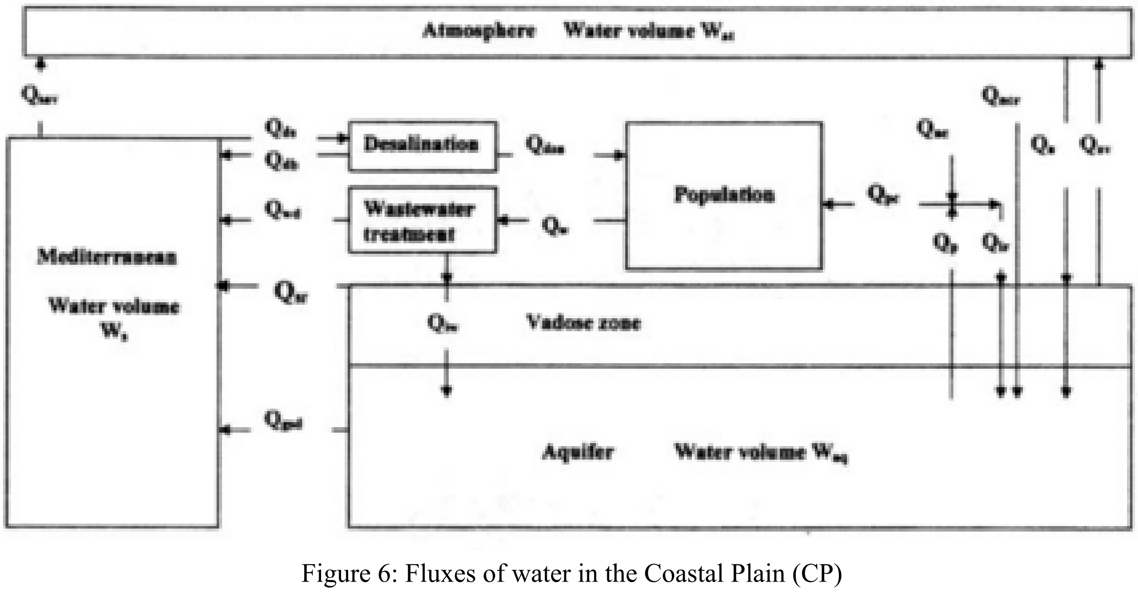

Figure 6: Fluxes of water in the Coastal Plain (CP)

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