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Utilizing Wastewater Reuse and Desalination Processes to Reduce the Environmental Impacts of Agriculture

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1. Introduction

Designing production processes with reduced environmental impacts is becoming more important. In many industries, including but not limited to agricultural production, water use and wastewater generation have a major share in the total environmental impact of the production processes.

Integrating water and wastewater processes into industrial processes requires a multi-dimensional analysis that takes into account the various potential water sources, as well as the different options of wastewater treatment available. We developed a model for planning water supply from diverse sources, including groundwater, the water from national supply sources, wastewater reuse and seawater desalination. The model integrates hydrological, technological and economic considerations, and estimates the economic and environmental impacts of alternative water management policies.

The model was implemented on the case study of agricultural production processes, based on the unique geographical characteristics of Emek Heffer and northern Sharon regions in Israel. The hydrological model was developed on the basis of the specific hydrological database for these regions, and enabled to plan the local water resources use and forecast the chlorides concentration in the aquifer. Based on the results of the model and economic data, the costs of desalination processes and of the water supply to the region under various scenarios were estimated. The results include recommendations for the water treatment level and for desalination of different water sources, and forecasts of the implementation costs. We conclude that the economic cost of improving the quality of the supplied water and of the aquifer water should be considered in the planning of agricultural production to reduce its environmental impacts at minimal economic cost.

2. Background

Designing production processes with reduced environmental impacts is becoming more important. In many industries, including but not limited to agricultural production, water

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use and wastewater generation have a major share in the total environmental impact of the production processes. At the same time, increasing water shortage has caused an increase in issues related to water pollution as a result of wastewater use, as well as the option of wastewater reuse, mainly for agriculture.

Water use and wastewater production are part of nearly every type of production process, including urban, industrial, and, of course, agricultural. Choosing a different mix of water supply sources, or defining a different quality threshold for wastewater treatment, changes the groundwater quality levels over time; changes the financial costs to both the urban consumers and the farmers (also leading indirectly to changes in the consumer budget); changes the level of health risks faced by the consumers from drinking water and consuming food irrigated with wastewater; and changes the long-term ecological balance.

To address all of these concerns the choice of wastewater reuse and desalination processes should be done from a multidisciplinary view, taking into consideration not only the technological aspects of process design, but also the hydrological impacts, the economic implications for urban consumers and farmers, and the environmental – health and ecosystem – impacts of these processes.

We developed a model for planning water supply from diverse water supply sources, including groundwater, the water from national supply sources, wastewater reuse and seawater desalination, as well as the different options of wastewater treatment available. The model integrates hydrological, technological and economic considerations, and estimates the economic and environmental impacts of alternative water management policies. Through the model, we examine a case study of water supply to a chosen region that consists of both urban and agricultural areas. National and regional policy decisions regarding permits for well drilling, and thresholds for the level of water salinity allowed in drinking water and in water for irrigation can vary between regions, and in the same region over time. We considered the range of policy variations by using a range of potential policy scenarios in the model, and estimating the economic and environmental impacts across these policy scenarios.

3. Model structure

The model was constructed as a decision making tool that is meant to enable managers to plan the water supply process to their region, based on combining water from different potential sources, supplied to a combination of different end-users in urban and rural areas of that region. The assumed goals of the decision makers include minimal costs as well as minimal environmental impacts (specifically, minimal groundwater salinity levels). The potential water sources in the model include groundwater, national carrier water, treated wastewater for irrigation, and desalinated sea water.

The model is composed of four sub-components that describe the different types of processes that are part of the decision making complex: policy planning processes, physical hydrological water flow processes, technological water supply and treatment processes, and the economic implications of these processes. The planning sub-component describes the geographical area allocations between different water users. The hydrological sub-component describes the physical structure of the water source supply and is used to predict the aquifer water levels and the salinity concentration over time. The technological sub-component describes the available relevant water treatment and desalination processes and the ensuing costs. The economic sub-component is used to calculate the optimal treatment quantities and levels and the total cost of these decisions.

Description of the model's sub-components

A. *Policy planning component:* Includes a unique database for the hydrological cells in the case study region, structured in order to compute the demand for water by the various end users.

B. *Hydrological component:* Used to plan the water sources and to predict the groundwater levels and the chloride concentration in the aquifer. The model is based on the hydrological cells described by the national hydrological service in Israel. Each hydrological cell is constructed of an upper and a lower layer. The upper layer represents the unsaturated zone, stretching downward from the ground level to the top surface of the groundwater. The bottom layer represents the saturated zone, i.e., the groundwater, stretching from the top surface of the groundwater down to the bottom base of the aquifer.

The hydrological model is based on ten assumptions:

- The hydraulic characteristics of each layer are uniform and do not change over time, although they can vary from one cell to another.
- Surface water with varying chloride levels seep vertically downward through the unsaturated zone to the saturated zone.
- The surface water sources reaching the unsaturated zone may include water from the following sources: rain water, fresh water, wastewater used for irrigation, and water leakage from various sources.
- Only part of the water entering the unsaturated zone actually reaches the groundwater (for example, some water uptake by plants may occur in the process); but the chloride mass that is mixed with the water reaches the saturated zone in its entirety.
- The chloride moves downward with the water it is dissolved in, at the average rate of water movement, with no dispersion on the way.
- There are no additional sources of water or dissolved chlorides in the unsaturated zone.
- The flow of the chloride mass from the unsaturated zone to the the saturated zone of each cell is characterized by two consecutive time periods. The first period, Period A, begins with the entry of the water and dissolved chlorides into the unsaturated zone; the second period, Period B, begins when that water first reaches the saturated zone.
- In addition to the flow that enters from the unsaturated zone, water and dissolved chlorides may also enter a given hydrological cell from its neighboring cells and from drilling.
- The chloride mass in the cell's unsaturated zone is concentrated in an area termed “the mixing area”. Which lies from the groundwater surface to the depth of the drilling for pumping water out.
- The systems' land borders – the eastern, northern and southern borders – are impervious to entry of water and salt. The western border is an open border (reaching the sea).

The water supply is designated for two sectors: town and agriculture, which receive two types of water – fresh water and wastewater. The hydrological model is based on hydrological and planning input data, and enables to produce outputs for each one of the cells that include water balances and chloride masses as well as forecasts of water levels and chloride concentrations in the saturated zone, over a pre-defined period of time.

The hydrological model was used to quantify the potential water quantity available for pumping water in each hydrological cell, under the assumption that in each cell the water supply is equal to the water demand. The water sources for each hydrological cell were computed under the assumption of giving first priority to water supply from local sources, i.e., pumping from drillings in that cell's area, which is done within the limitation of the available water quantity, and under the limitations of the total annual pumping allowed from that aquifer. The volume of the additional water needed as supplement to fill the total water demand is supplied by National Carrier water, and the water consumers in the hydrological cells along the beach can only get their water from that national source. Agricultural use is given priority in water pumping, and irrigation with wastewater will continue at its present volume.

The predefined salinity threshold was based on policy considerations relating to the water supplied to the city, or to the city and agricultural uses, or for groundwater under a steady state condition. Our aim was to examine the implications of policy choices regarding different water quality thresholds on the level of groundwater salinity over time and on the costs of water supply to the region.

To do that, we examined a variety of scenarios that defined the threshold levels between the range of 50 to 250 mg Chlorides per liter (mg/Cl.). The forecasted level of groundwater salinity over one hundred years was computed for each scenario, based on the hydrological model's mathematical equations.

We compared the different scenarios for a steady-state solution, defined as a situation where the groundwater level and the chloride concentration in each cell do not change over time. The steady-state solution for the groundwater level is calculated by solving the set of equations for the annual water balance volume in the cells, when the total volume of water entering the cell from the unsaturated zone and from the neighboring cells is equal to the total volume of water that is pumped out of the cell. The steady-state of chloride concentration in the groundwater of each cell is calculated by solving the set of equations for the annual balance of chloride mass in the cells; that is, multiplying the components of the steady-state water balance with the target concentrations, when the total chloride mass entering the cell is equal to the total mass of chlorides that is pumped out of that cell.

C. *Technological component:* We calculated the costs of water desalination for each one of the potentially available water supply sources, based on engineering and technological data. We examined the alternative desalination processes available in order to evaluate the alternatives that were found as relevant, and calculate their average costs. The desalination alternative based on the Reverse Osmosis technology include desalination of brackish water, local well water, and wastewater, with the addition of pre-treatments that include tertiary treatment and pre-membrane treatments, while incorporating them with the water supplied from national sources, that were meant to serve as the main water supply source.

The desalination costs are influenced by different parameters such as the size of the plant, the quality of the feeding water and placement of the wastewater plant. The costs are also influenced by a number of planning variables, including rate of return on investment, various expenditure processes, the availability of plant operations, energy costs, membranes, chemicals, manpower, maintenance and overhead costs. The input data include: water quantity, the quality of the raw data that we fed into the system, the quality of the final product, rates of absorption, depth of drilling, pipe lengths, altitude of the desalination plant and volume of water storage.

D. *Economic component:* We computed the quantity of water that should be desalinated, and estimated the total costs of the water supply to the region for each of the alternative water sources. When the salinity of the supplied water exceeds the predefined threshold, water desalination processes are initiated. The desalinated water is then mixed with the additional sources of water supply in order to maintain the threshold, and the required quantity of desalinated water is computed accordingly. The multiplication by the cost of desalination gives the total cost of desalination, and accordingly, the total costs of water supply for the region for each alternative option of desalination.

4. The case study region

The model was implemented on a specific case study region, composed of eight hydrological cells located along the coast in the central/north-central part of Israel. The area includes the city of Netanya, whose urban wastewater flow is the main source of the total wastewater supply to the region. The case study region was further divided into two sub-regions - Emek Heffer and Northern Sharon - each composed of four hydrological cells. The Emek Heffer hydrological cells lie on the northern border of the Northern Sharon hydrological cells, and parallel to them.

The Israel National Hydrological Service divides the shore aquifer area into 16 areas, and each area includes four hydrological cells, lying from west to east. The Western Shore cells are the cells closest to the beach, followed by Western Aquifer cells and Eastern Aquifer cells, where most of the pumping in concentrated, and finally by the Eastern cells. The cells are divided by straight lines that divide the entire coastal area into square cells, with no consideration for the division of the areas according to geographical characteristics or urban administrative borders. Establishing a data base by hydrological cells was very complex, because the information needed for the allocation of the area among users and water uses does not exist for each individual hydrological cell.

We established the database by hydrological cells using a set of maps that included the administrative urban areas, horticultural areas by crop and built area. The combined maps resulted in the calculated area allocation presented in Table 1. The Emek Heffer area is mostly agricultural, while in the Northern Sharon area, which includes the city of Netanaya, close to half the area is defined as an urban area.

Area	Emek Heffer	Northern Sharon
Total agricultural	8.24	8.28
Build area	1.02	1.14
Citrus crops	1.21	2.89
Other horticultural crops	0.69	1.05
Field crops (estimation)	5.30	3.19
Total urban area	0.11	7.87
Total area	8.35	16.16

Table 1. Hydrological database results: Area use allocation (hectares)

For each hydrological cell we estimated the demand for water by type of users, based on established norms of water use by crop and water use by number of residents. The amount of wastewater used for irrigation was given. As Table 2 shows, the total water use in Emek Heffer was 24.6 million cubic meters (mcm) per year, of which 90% was used for irrigation, while in Northern Sharon the total use was 59.4 mcm/year, of which 58 percent was used for irrigation (in both areas the irrigation water use includes the wastewater data).

Type of water use	Emek Heffer	Northern Sharon	Total
Urban water use	2.6	24.7	27.3
Freshwater for agriculture	9.6	31.3	40.9
Total demand for freshwater	12.2	56.0	68.2
Wastewater	12.4	3.4	15.8
Total irrigation water	22.0	34.7	56.7
Total demand for water	24.6	59.4	84.0

Table 2. Hydrological database results: Water use allocation (mcm)

The results of the planning component, including area allocation and water use for each hydrological cell, as described above, was used as input data for the hydrological component, which was applied to predict the groundwater level and salinity over time, and for the technological component, which was applied to examine the relevant desalination technologies and the ensuing costs. The results of the hydrological and technological components were used in turn as inputs for the economic component, which was applied to evaluate and compare the the scope of desalination and the costs under different scenarios.

5. The results of the model

5.1 The hydrological component

The hydrological component was based on the results of the planning component, as described above. The levels of salinity are predicted over time for a variety of scenarios, who differ from each other in the predefined salinity thresholds permitted for urban and agricultural use. The baseline scenario – scenario 1 – describes a policy of defining a establishing a threshold of 250 mg/Cl., only for urban use. Scenarios 2, 3 and 4 include established thresholds for agricultural water use, at the levels of 250 (scenario 2), 150 (scenario 3), and 50 mg/Cl (scenario 4). The fifth scenario – scenario 5 – describes an agricultural area on the one extreme, which based on freshwater irrigation alone, and the final scenario – scenario 6 – is description of the opposite extreme scenario, which allows irrigation with highly saline wastewater. The scenarios are summarized in Table 3.

For each scenario, we predicted the groundwater salinity levels over time and after one hundred years. The salinity level was found to increase over time in every hydrological cell except for the two Western Shore cells, where pumping is not allowed. The results for each scenario are presented in Table 4. For the baseline scenario (scenario 1), the salinity in year 100 in the Emek Heffer region reaches 846, 497, and 1192 mg/Cl for the Western Aquifer cell, Eastern Aquifer cell and Eastern cells, respectively. The salinity levels in year 100 in the Northern Sharon area under this scenario reach 132, 100, and 739 mg/Cl for the Western Aquifer cell, Eastern Aquifer cell and Eastern cells, respectively.

Scenario	Salinity threshold for urban water use (mg/Cl.)	Salinity threshold for agricultural water use (mg/Cl.)	Irrigation with wastewater included?
1 (baseline)	250	-	Yes
2	250	250	Yes
3	150	150	Yes
4	50	50	Yes
5	250	-	No
6	250	-	Yes, with high salinity

Table 3. Scenarios for the model

Cell	Scenario 1 Urban threshold 250 mg/Cl.	Scenario 2 Add agricultural threshold 250 mg/Cl.	Scenario 3 Add agricultural threshold 150 mg/Cl.	Scenario 4 Add agricultural threshold 50 mg/Cl.	Scenario 5 No irrigation with wastewater	Scenario 6 Irrigation with highly saline wastewater
Emek Heffer						
Western Shore	310	189	210	137	232	370
Western Aquifer	846	459	364	182	741	1016
Eastern Aquifer	497	358	243	110	418	644
Eastern	1192	841	690	364	1639	1485
Entire Emek Heffer	*716*	*453*	*357*	*182*	*716*	*907*
Northern Sharon						
Western Shore	180	115	159	122	161	192
Western Aquifer	132	150	116	75	133	143
Eastern Aquifer	100	102	94	66	91	112
Eastern	739	654	438	222	693	760
Entire Northern Sharon	*158*	*159*	*130*	*84*	*157*	*174*

Table 4. Predicted chloride concentration in groundwater in year 100 by scenario (mg/Cl.)

Scenarios 1 – 4 describe a gradual increase in the strictness of the water quality regulations. Scenario one, as mentioned above, includes predefined salinity thresholds for urban use alone, while scenarios 2 – 4 include salinity thresholds for agricultural water use as well, with the level of salinity permitted becoming gradually lower from scenario 2 to scenario 4. Comparing the different scenarios for a given cell, by examining each row individually across the first four columns of Table 4, shows that as the policy becomes more strict, the resulting salinity level over time is lower. For example, looking at the results for Emek Heffer's Eastern Aquifer cell, the chloride concentration in year 100 is 497 mg/Cl under the baseline scenario, which defines only urban water use thresholds, and becomes gradually lower through scenario 2 with an added restriction of 250 mg/Cl for agricultural water use as well, resulting in a salinity level of 358 in year 100; scenario 3, with an increased restriction of agricultural water use salinity level to 150 mg/Cl resulting in a groundwater chlorine concentration level of 243 mg/Cl in year 100; and finally scenario 4, which has the greatest salinity level restriction, permitting only 50 mg/Cl, and resulting in the lowest salinity level of 110 mg/Cl in year 100. Comparing scenario 5, which does not include any irrigation with wastewater, with scenario 6, which includes irrigation with highly saline wastewater, shows that irrigation with freshwater alone decreases the level of groundwater salinity in year 100 by 191 mg/Cl for the entire area of Emek Heffer.

We calculated the predicted chloride concentration under a steady-state situation, where the groundwater level and the chloride concentration in each cell do not change over time (Table 5). Under the baseline scenario, with a salinity threshold for urban water use alone of 250 mg/Cl, the resulting salinity level in the aquifer water under steady-state conditions is 1,358 mg/Cl in Emek Heffer and 318 mg/Cl in Northern Sharon. Under scenario 2, which includes a threshold of 250 mg/Cl for both urban and agricultural water use, the aquifer steady-state salinity level is 553 mg/Cl in Emek Heffer and 265 mg/Cl in Northern Sharon.

	Scenario 1: urban threshold of 250 mg/Cl		Scenario 2: both urban & agricultural thresholds of 250 mg/Cl	
Cell	Year 100	Steady-State	Year 100	Steady-State
		Emek Heffer		
Western Shore	310	704	189	329
Western Aquifer	846	1358	459	514
Eastern Aquifer	497	548	358	380
Eastern	1192	2884	841	977
Entire Emek Heffer	*716*	*1358*	*453*	*553*
		Northern Sharon		
Western Shore	180	176	115	174
Western Aquifer	132	200	150	197
Eastern Aquifer	100	244	102	204
Eastern	739	1184	654	670
Entire Northern Sharon	*158*	*318*	*159*	*265*

Table 5. Chloride concentration in year 100 and under steady-state conditions (mg/Cl)

The calculated chloride concentration in irrigation water needed to maintain an aquifer salinity threshold of 250 is shown in Table 6. For the entire Emek Heffer area, for example, the permitted chloride concentration in irrigation water would be 92 mg/Cl.

Scenario / Cell	Scenario 1 Urban threshold 250 mg/Cl.	Scenario 2 Add agricultural threshold 250 mg/Cl.	Scenario 3 Add agricultural threshold 150 mg/Cl.	Scenario 4 Add agricultural threshold 50 mg/Cl.
Emek Heffer				
Western Shore	379	381	273	52
Western Aquifer	75	76	84	50
Eastern Aquifer	139	145	151	50
Eastern	28	28	28	34
Entire Emek Heffer	*88*	*92*	*91*	*45*
Northern Sharon				
Western Shore	1492	1522	918	314
Western Aquifer	283	327	195	63
Eastern Aquifer	411	333	189	53
Eastern	72	72	72	54
Entire Northern Sharon	*243*	*233*	*142*	*57*

Table 6. Chloride concentration in irrigation water (mg/Cl) for a steady-state aquifer salinity threshold of 250 mg/Cl

So far, we have seen the implications of lowering or increasing the permitted threshold on the state of the aquifer. From these results we might conclude that a policy of strict thresholds level is preferable. However, this kind of policy comes at a cost; in the following sections we demonstrate the financial implications of the different salinity thresholds.

5.2 The technological component

The average cost of desalination under representative initial conditions is shown in Table 7. Based on the relevant alternatives for the Emek Heffer area, the cost of brackish water desalination is 36 cents per cubic meter (cm); the cost of national carrier water desalination is 29.4 cents/cm (depending, in practice, on the size of the plant); the cost of wastewater desalination is 41.6 cents/cm and the cost of seawater desalination is 54.2 cents/cm (again, the cost depends on the size of the plant; these calculations were done for a plant size of 50 mcm/year).

	Brackish	National carrier	Wastewater	Seawater
Infrastructure	13.0	14.6	3.3	32.5
Desalination	23.0	14.8	38.3	21.7
Total	36.0	29.4	41.6	54.2

Table 7. Average cost of desalination (cents per cm)

5.3 The economic component

The economic component of the model is used to estimate the total costs of water supply for each area for the different scenarios. The inputs for this component are the outputs of the previously described components: From the planning component results we took the water sources as inputs for the economic component; from the hydrological component we took the predictions of chloride concentration over time; and from the technological component we took the average costs of desalination for each potential source of water supply (groundwater, which is brackish water, national carrier water, wastewater and seawater).

The results of the economic component for the entire area of Emek Heffer are presented in the following tables. The total net present value (that is, the total economic value translated into today's economic value) is presented in Table 8, and the annual costs under steady-state conditions are shown in Table 9, for each one of the scenarios (except for the scenario of irrigation with highly saline water, which is not likely to be used as an actual policy option).

The results in Table 8 show that under scenario 1 (urban water salinity threshold of 250 mg/Cl), the net present cost of the water supply ranges from 95.19 million dollars for brackish water (groundwater) desalination to 96.44 million dollars for seawater desalination. In scenario 2 (urban and agricultural water salinity thresholds of 250 mg/Cl), the net present cost ranges from 101.08 million dollars for groundwater desalination, 177.69 million dollars for wastewater desalination and up to 207.09 million dollars for seawater desalination. In scenario 3 (salinity thresholds of 150 mg/Cl) the net present cost ranges from 120.58 million dollars for groundwater desalination, 216.71 million dollars for wastewater desalination and up to 353.49 million dollars for seawater desalination. In scenario 4 (salinity thresholds of 50 mg/Cl) the net present cost ranges from 219.19 million dollars for groundwater desalination, 246.70 million dollars for wastewater desalination and up to 392.47 million dollars for seawater desalination. In all of the scenarios, the lowest desalination costs were for National Carrier water, followed by groundwater, wastewater and seawater. We should note that seawater desalination is mostly meant to increase the total water supply available, so the cost of their desalination for improving the water quality includes only the additional costs.

Scenario	1	2	3	4	5
Desalinated water source	Urban threshold	Urban & agricultural thresholds	Medium-level salinity threshold	Low-level salinity threshold	No irrigation with wastewater
Brackish (groundwater)	95.19	101.06	120.58	219.19	129.57
Cost increase	-	5.87	19.52	95.61	-
Wastewater	-	177.69	216.71	246.70	-
Seawater	96.44	207.09	353.49	392.47	132.36

Table 8. Net present value of the cost for 100 years (million dollars)

In comparing between the scenarios, we can see that improving the salinity threshold from 250 mg/Cl for urban use alone to 250 mg/Cl for agricultural water use as well involves an increase in the total net present cost of water supply to the Emek Heffer area by 5.87 million dollars. Introducing the stricter condition of 150 mg/Cl involves an increase in cost of 19.52 million dollars, and the strictest threshold scenario of 50 mg/Cl involves the relatively high increase in cost of 98.61 million dollars.

The results in Table 9 show that under scenario 1 the annual cost ranges from 4.98 million dollars for groundwater desalination up to 5.26 million dollars a year for seawater desalination. Under the conditions of scenario 2, the annual cost ranges from 5.54 million dollars for groundwater desalination to 8.96 million dollars for wastewater desalination and up to 15.52 million dollars for seawater desalination. Under scenario 3, the annual cost ranges from 7.55 million dollars for groundwater desalination, 10.40 million dollars for wastewater desalination and up to 17.03 million dollars for seawater desalination. Under scenario 5, the annual cost ranges from 10.63 million dollars for groundwater desalination, 11.83 million dollars for wastewater desalination and up to 18.83 million dollars for seawater desalination. Again, in all of the scenarios examined, the lowest desalination costs were for National Carrier water, followed by groundwater, wastewater and seawater.
The comparison between the scenarios shows that improving the salinity threshold from 250 mg/Cl for urban use alone to 250 mg/Cl for agricultural water use as well involves an increase in the annual cost of the water supply to the Emek Heffer area by 0.56 million dollars. Introducing the stricter condition of 150 mg/Cl involves an increase in cost of 2.57 million dollars, and the strictest threshold scenario of 50 mg/Cl involves the relatively high cost increase of 5.65 million dollars. Maintaining a salinity threshold level of 250 mg/Cl for the aquifer water involves an annual cost ranging from 9.9 to 13.29 million dollars.

Scenario	1	2	3	4	5
Desalinated water source	Urban threshold	Urban & agricultural thresholds	Medium-level salinity threshold	Low-level salinity threshold	No irrigation with wastewater
Brackish (groundwater)	4.98	5.54	7.55	10.63	7.09
Cost increase	-	0.56	2.57	5.65	-
Wastewater	-	8.96	10.40	11.83	-
Seawater	5.26	15.52	17.03	18.83	11.62
Maintaining aquifer threshold level	9.90	9.82	11.06	13.29	10.65
Cost increase	4.92	4.28	3.51	2.66	3.56

Table 9. Annual cost under steady-state conditions (million dollars)

Compared with the threshold of 250 mg/Cl for urban water use alone, the net present value of the cost increase involved in a policy of a 150 mg/Cl threshold for urban and agricultural water use is 27.64 million dollars, and for a threshold of 50 mg/Cl the cost increase is 126.25 million dollars (Table 8). The increase in the annual cost under a steady-state condition for a threshold of 150 mg/Cl for urban and agricultural water is 3.13 million dollars, and for a threshold of 50 mg/Cl – 8.78 million dollars. The total water quantity in question is 24.6 mcm, meaning that the annual increase in cost per cm for improving the threshold for urban and agricultural water to 150 mg/Cl and 50 mg/Cl is 12.5 and 35.5 cents per cm, respectively. It should be noted that determining a threshold of 50 mg/Cl involves a relatively large increase in costs.
Maintaining a threshold of 250 mg/Cl for the aquifer water involves an annual cost increase of 2.66 to 4.92 million dollars, compared with the lowest cost for the same scenario without

the condition of maintaining the aquifer water salinity threshold. That means that the increase in annual cost per cm for maintaining a sustainable aquifer, with a salinity level of 250 mg/Cl under a steady-state conditions, ranges from 10.8 to 20 cents/cm.

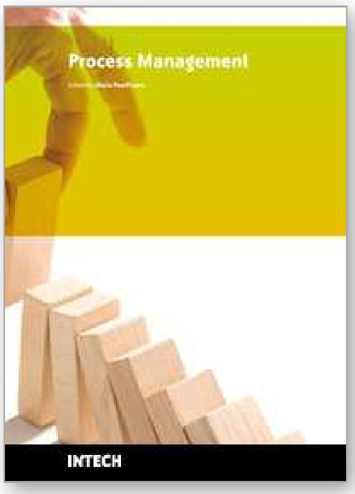
The Israeli water sector is currently under conditions of water shortage, and at the stage of planning and establishing seawater desalination plants. At the same time, farmers have been moving to extensive use of wastewater for irrigation, which enables a significant reduction of the demand for freshwater for irrigation, as well as providing a practical solution for wastewater disposal. However, the problem of wastewater salinity should be addressed. The use of wastewater and desalinated seawater provide a partial solution for the problem of water shortage, but the impact on the deterioration of groundwater quality, as expressed in the increase in salinity levels, cannot be ignored. We have presented alternatives for water desalination in order to improve their quality and found that desalinating groundwater and wastewater can be done at a relatively low cost, although some technological and administrative issues remain to be addressed. Both issues of the quality of the water supply and the sustainability of the aquifer are important in the short term as well as in the long term. This research presents the additional costs of stricter salinity threshold levels that will help maintain a sustainable aquifer. Policy makers would need to weigh these additional costs against the added benefits.

6. Summary and conclusions

We developed an hydrological model for planning the water supply from different sources and predicting the chloride concentrations in the aquifer water, and implemented it on a unique database constructed for the case study of the hydrological cells of the Emek Heffer and Northern Sharon areas in Israel. We also estimated the costs of various desalination processes under these regional conditions, and calculated the total cost of the water supply for different policy-making scenarios.

Several findings arise from calculating the costs involved in improving the salinity threshold for water supply to the city and/or agriculture, or for maintaining a sustainable steady-state aquifer. The main conclusions are that the lowest-cost alternative is brackish water desalination; desalination of national carrier water is feasible under large-scale use conditions; wastewater desalination is important to maintain the agricultural water salinity threshold; and finally, seawater desalination is worthwhile when their contribution is essential for the national water balance. If we wish to maintain a salinity threshold of 250 mg/Cl in the aquifer water, we need to limit the salinity level of the irrigation water in Emek Heffer to approximately 90 mg/Cl. The additional annual expenditure needed to maintain the aquifer salinity level is between 2.5 to 5 million dollars, or between 10.75 to 20 cents per cm. It is important to keep in mind that improving the quality of the water supply and the quality of the groundwater comes at an economic price that has to be taken into consideration in the decision making process.

The model we developed and applied is used to examine the planning, hydrological, technological and economic aspects of the supply and desalination of different water sources, and to examine the implications on the economy, on groundwater quality and on the environment. The model's advantages lie in its multidisciplinary nature and in its practical applicability, as well as in its ability to evaluate and direct scenarios of supply and treatment of different water sources. At this stage, the model includes only the salinity level component of water quality, but the model can be expanded to examine the treatment of other components, such as nitrogen concentrations, and can be developed as a computerized model that will improve the policy-makers ability to make informed decisions.



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The content of the book has been structured into four technical research sections with total of 18 chapters written by well recognized researchers worldwide. These sections are: 1. process and performance management and their measurement methods, 2. management of manufacturing processes with the aim to be quickly adaptable after real situation demands and their control, 3. quality management information and communication systems, their integration and risk management, 4. management processes of healthcare and water, construction and demolition waste problems and integration of environmental processes into management decisions.