PRICING OF WATER AND EFFLUENT IN A SUSTAINABLE SALT REGIME IN ISRAEL

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Abstract:

Water withdrawal and irrigation in arid zones increase salt concentration in aquifers. The utilization of effluent further augments the concentration by adding salt from households and industry. A sustainable salt regime can be maintained if salt is removed from at least some of the water sources. The paper analyzes theoretically the pricing of water and effluent in a sustainable regime for the coastal aquifer in Israel.

Keywords: Irrigation, salt concentration, effluent, pricing, sustainability.

1. INTRODUCTION

A substantial proportion of water used in the urban sector finds its way to the sewerage and is treated and recycled as effluent. Urban users add salt to the water and are carried in the effluent. Consequently irrigation with recycled water adds salt to the soil and the water beneath its surface; the accumulated salt is detrimental to soil structure and plants. A sustainable salt regime is a set of policies maintaining salt concentration at a constant level and preventing its accumulation. The analysis of a sustainable salt regime cannot be limited to effect effluent and a comprehensive approach is will cover both quantities and prices. Prices are part and parcel of any water policy: they affect supply and use of the resources. An economic analysis of a sustainable salt regime in the coastal region, hydrology of water and salt in the region are presented, alternative policies are compared, and associated prices are derived [1].

1.1. Background

Israel has three major water reservoirs: Lake Kinneret (the Sea of Galilee, the coastal aquifer along the shore of the Mediterranean Sea, and the Mountain aquifer, partly under the hills of the West Bank [2]. The coastal region, receives water from all three reservoirs. The water is supplied from here to the region's urban centers and agriculture [3].

M.K. Zaidi (ed.), *Wastewater Reuse–Risk Assessment, Decision-Making and Environmental Security*, 219–225.

2. METHODS

2.1. An Illustration

In the illustration (Figure 1) precipitation is added to the groundwater (replenishment), part of the water is withdrawn for irrigation and the rest is outflow to the sea. Irrigated water evaporates from the surface of the land and plants and part of it reaches the groundwater as irrigation return flow. In parallel to the water flow, salts are recorded in the diagram: concentration in ppm chlorides in parentheses and a quantity in tons. These magnitudes will be explained below.

2.2. The Algebraic Model, Water and Salt [4]

Quantities in the illustrative model are flows per year. The variables are

	Water in MCM	Salts, chlorides in tons/y
Replenishment	R	
Autonomous salts		Δ
Irrigation (freshwater)	H	M_H
Irrigation return flow	Z	M_Z
Outflow to sea	Y	M_Y
Evapotranspiration	E	

As indicated above, salts are added to aquifers from ocean spray, underground brines, and seawater intrusion. These sources are termed here autonomous since the amount of salt added to the aquifer in this way is not a function of the quantity of water used (in the coastal aquifer, in reality, there is also entry of salt from noncoastal sources in quantities proportional to the water used). Hence, we treat the replenishment as if it did not carry any salt and write the autonomous amounts separately. The balancing equations for a reservoir in the steady state are

Condition	Balancing equation	Equation number
Water balance	$R+Z=H+Y$	Equation 1
Salt balance	$\Delta+M_Z=M_H+M_Y$	Equation 2
Irrigation return flow	$Z=0.17H$	Equation 3
Irrigation return flow	$H=E+Z$	Equation 4

Equations 1 and 2 describe the entry of water and salts into the reservoir and exit away from it. The water supply is augmented with the irrigation return flow. Salt comes from autonomous sources. Equation 3 defines that the return flow is 17% of the quantity of water in irrigation (an assessment received from hydrologists). Equation 4, completes the picture, it separates irrigation water to the part evaporated and the part returning to the reservoir.

For the sake of the illustration, let us assume (water in MCM/Y; salt, chlorides, in tons per year): replenishment $R = 90$, autonomous salt $\Delta = 4{,}500$. Groundwater outflow to the Mediterranean Sea $Y = 30$. As indicated, in the steady state, entering quantities are identical to quantities leaving the aquifer. By Equation 1, the balance for water is $90 + 0.17H = H + 30$

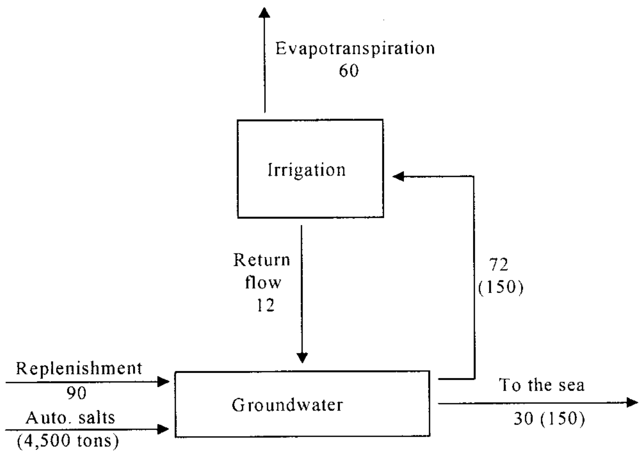

Figure 1. Conceptual illustration, water flows

Hence irrigation $H = 72$, return flow $Z = 12$, evapotranspiration $E = 60$ (Figure 1).

To calculate the concentration of salt in the flow of water in the model, in the steady state, salt added to the aquifer leaves it. Also, salt deposited by irrigation move to the aquifer with the return flow; hence $M_Z = M_Y$ and these variables may be dropped from Equation 2. Accordingly, define the concentration of salt in the outflow to the sea as P and write the equality $\Delta = M_Y$

$$4500 = 30P \qquad (1)$$

The concentration of salts in the outflow to the sea is 150 ppm chlorides. Also, since groundwater is the source of the outflow, the concentration of chlorides in the groundwater will be 150 ppm as well.

To sharpen the intuitive grasp the concept of the steady state notice that the endogenous variable in the model is the concentration of salt in the groundwater and consider a slight modification of the basic data: assume that exit of water to the sea is not 30 MCM/Y but 25 MCM/Y. The solution of Equation 5 will now be 180 ppm chlorides (not 150). With a smaller quantity flowing to the sea, the concentration of salt in the aquifer is larger; the larger concentration ensures that, even with a smaller outflow, all the salt added from whatever sources are flushed to the sea (180 × 25 = 4,500).

2.3. The Coastal Aquifer

Only salt from autonomous sources entered the aquifer in the above illustration, and they all left the reservoir with water drained to the sea. Table 1 lists water and salt as forecasted for the coastal region for the year 2020. These are the data incorporated into our empirical analysis to be described below. The natural sources supplying to the coastal region, 640 MCM, are the coastal aquifer, Lake Kinneret, and the mountain aquifer, but only the salt carried by the water of the two last sources are listed in the table—the salts contained in water withdrawn from the coastal aquifer and used for irrigation above it are just recycled, they do not add to the quantity of salt in the reservoir.

As explained above, autonomous sources add salts that are not carried in water. The forecast is that 393 MCM of effluent will be used above the coastal aquifer in 2020; the salts in the effluent line are the salts added by urban users of water. Salts in the water supplied to households and other consumers in town are listed in other lines in the Table 1. Water is expected to leave the aquifer in 2020 through two channels, 30 MCM each, one is water withdrawn from the aquifer and exported to other regions, and the other is drainage to the sea. Repeating the calculation of the above illustration for the data of Table 1, one finds that a steady state could be maintained in the aquifer's water with salt concentration of 500 ppm. This concentration is however too high for households and agriculture; the sustainability of the aquifer cannot rely solely on natural processes and salt must also be removed actively.

Table 1. Quantities of water and salt in the coastal aquifer, 2020 forecast

	Water (MCM)	Salts (tons chlorides)
Natural sources	640	70,200
Autonomous		12,600
Des. seawater	225	4,500
Effluent	393	39,300
Export, freshwater	–30	
Drainage to the sea	–30	
Return flow	50	
Total	1,268	126,600

2.4. Prices and Extraction Levies

We set price equal to marginal cost. The economic rational behind marginal cost price is that they deliver the relevant information; they present the individual users of water, in any of the sectors, with the cost of the resource to society at large. With this policy, individuals can act freely, following their own private interests but, when doing so, directed to take into account the correct effects of their actions on others. Among the marginal cost items we include the scarcity value of water; its corresponding price is the extraction levy. Scarcity values arise when sources of water are utilized up to capacity—up to the safe yield. The scarcity value is a marginal cost since, when all available water is utilized; an additional unit supplied to one individual is taken away from another. The loss where the supply was reduced is the cost. Unlike conventional prices paid to the providers of water, the extraction levy is collected by the government; the government functions here as the representative of society, of the public at large, since the public is the owner of the resource.

The marginal cost is determined theoretically in a mathematical programming model presented in the Appendix. The model is both broader, in some aspects, and narrower (in others) than the framework of the discussion in the article. It incorporates agricultural production, a feature that is not included explicitly in the paper, but, for simplicity, import of mountain water and exit of water and effluent from the region, either to the sea or to other regions is disregarded in the formulation of the Appendix. The objective function of the programming model is the value of agricultural output *minus* the cost of the water economy. The sources of freshwater are the coastal aquifer, Lake Kinneret, and seawater desalination; effluent is used in agriculture. There are two consuming sectors in the model: urban and agriculture. The urban sector receives a predetermined quantity of water. A given ratio of the water used in this sector is collected as sewage and, after treatment, provided as effluent. Irrigation deposits salt on the surface of the land and identical quantities are added to the water in the aquifer. Additional salt come from autonomous sources (ocean spray and underground brines). Freshwater desalination is used to remove the salt. By assumption, prices are set equal to marginal cost.

In the low demand case, the coastal region is supplied with freshwater from the local aquifer and from Lake Kinneret; seawater is not desalinated. Salt is removed by desalination of natural water. The price of freshwater is determined by the marginal product of water in agriculture and it is set, in equilibrium (at maximum net income), to equal the cost of moving water from Lake Kinneret *plus* the cost per CM of removing from the water of the coastal aquifer the salts imported with the lake's water. The price farmers pay for the effluent is a fraction of the price of freshwater, the fraction representing the comparative productivity of the recycled wastewater.

In this low demand case, only the coastal water is scarce and has, in the model, a scarcity value. This value, and hence the extraction levy of coastal water, is equal to the price of freshwater *minus* the cost of its withdrawal from the aquifer. No scarcity value is attributed to the water of Lake Kinneret. The urban sector is seen in the program as if selling the effluent to agriculture; hence the net price urban dwellers pay for water equals the opportunity cost, the marginal productivity of water in agriculture, *plus* the cost of treating the sewage *minus* the price farmers pay for the effluent (recall that only part of the water used in town ends as effluent).

In the high demand case, seawater desalination is activated and the marginal productivity of water in agriculture is equal to the cost of desalination *plus* the cost of the removal of the (small amount) of salts left in the desalinated water. Desalinated water is supplied when the other water sources cannot satisfy the demand. Hence, in this case, the withdrawal constraint in Lake Kinneret is binding and the scarcity value of its water is positive; it is equal to the marginal productivity of water at the cost *minus* the cost of moving the water from the lake. and *minus* the cost of removing the salt carried in the Kinneret water. It is interesting to examine the difference in the cost of the lake's water in the two demand cases. In the low demand case, the users of water pay for the removal of the imported salts; the higher salt concentration in the water from Lake Kinneret, the higher the price of water. In the high demand case, on the other hand, water users pay the same price whatever the salt concentration in the lake's water is.

3. CONCLUSIONS

The utilization of effluent further augments the concentration by adding salts from households and industry. A sustainable salt regime can be maintained if slats are removed from the water resources. A theoretical analysis of pricing of water and effluent in a sustainable regime for the coastal aquifer in Israel was presented.

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