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Banking for alleviating the conflicting interests for water between the competing agricultural and urban sectors

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Abstract

A possible remedy to water shortage is to implement a water banking policy (water supply insurance). This work presents an effective administrative managerial tool that does not require significant technical means. The novelty of the manuscript is in the design of the water banking concept used here to resolve the conflicting interests between the agricultural and municipal sectors in regions that regularly suffer from water scarcity. A theoretical deterministic model was developed that considers two periods, the current year vs. future years. A Monte Carlo simulation was conducted in which stochastic rainfall conditions were introduced over many periods (up to 25 years). The Monte-Carlo software enables to tackle stochastic data and to exclude deterministic information that is less realistic. Water banking policy is demonstrated, in which certain parameters (e.g., environmental and hydrological conditions) are varied. Other options for addressing water shortages include the increased production of new waters by enhanced desalination and/or by reusing wastewater or by harvesting runoff. As they are beyond the scope of this article, these other alternatives will not be discussed. Banking can be effectively exploited to solve immediate supply problems and to promote the long-term restoration of local water sources.

Keywords: Water banking; Water rights; Municipal sector; Agricultural sector; Conflicting interests; Simulation.

Introduction

The two main water consumers around the world, the municipal and agricultural sectors typically have specific water rights (WR) that, in their most basic form, are expressed in the annual water quota of each sector [1, 2, 3]. Under conditions of abundance, water amounts, water rights and the related water allocation (subject to given quotas) are satisfied without undue difficulty. Problems naturally arise when the total available amounts of water cannot meet the demands, a scenario that forces authorities to make tough water allocation decisions based not only on the relevant WR, but also on transportation costs and on certain market characteristics [4, 5, 6]. Top priority for water allocation frequently goes to the municipal sector, while the agricultural sector has the rights to the residual quotas. In Israel, the first priority for water allocation is granted to the municipal and industrial sectors the third priority to agriculture, and the lowest priority is reserved for "other uses" ("green purposes") [7, 8, 9]. This policy of awarding higher priority to the municipal sector (including industry) while granting lower, actually residual, priority to the agricultural sector is typical for water scarce regions [10, 11, 12]. Under water stress conditions, decision-makers are subject to lobbying pressure by officials from the water organizations in a process that yields recurrent, non-rational and conflicting decisions [13]. Consequently, satisfactory water allocation between the municipal and the agricultural sectors, subject to their rights, has become a critical problem [11]. Part of that problem is expressed by the risks associated with supplying restricted amounts of water for agricultural irrigation and that have been assessed in several reports [14]. Among the main conclusions is that water supply insurance may help farmers to manage confronting risks. Moreover, municipal water allocations are often supply-constrained and fall seriously short of urban requirements and demands [15]. One approach to alleviating temporary, regional shortages is to import water from countries where it is abundant [16, 17]. Water can be transported over large distances by pipes and canals or overseas by dragging large-volume "medusa bags". Emphasized economic, social and environmental benefits of transferring water between basins in Canada and the "USA [18]." Myriad ambitious ideas have been proposed (but were unrealized) to transport water from Alaska to Southern California, from Newfoundland and Labrador to various destinations, and from India to Vietnam as a sub-system of Asian International Waters [19]. Transferring water from Turkey to Northern Cyprus via a submerged pipe was assessed, at 0.46 USD/m^3 [20]. A slightly lower transportation cost, in the range of 0.17–0.35 USD/m^3, was assessed by when using large "medusa bags" [21]. Anticipated that the "medusa bag" transportation technology could also be applied in many Mediterranean countries such as France (Rhone River), Greece (Achelos River), Iran (Karoun River) and others [21, 22]. Importing water from external sources also enhance the gradual restoration of underground water resources and reservoirs enabling their utilization rather than their complete depletion. However, irrelevant considerations driven by politics and conflicting interests (CI) often prevent importation altogether, regardless of whether it is for consumption or for restoration [23, 24, 25]. The shareholders can withdraw water from their share overtime in accordance with their preference for stability of water deliveries. The reservoir (storage) authority does not manage reservoir release but keeps record of individual shareholder's withdrawals and net inflows to monitor the quantity of water in each shareholder's capacity share.

Conflicting Interests and Water Banking

A theoretical solution is proposed to mitigate the conflicting interests between municipal and agricultural water use, the two major water consuming sectors, by adopting a Water Banking Policy (WBP). The overriding goals of such a policy include to guarantee minimal damage to the existing water sources and to facilitate their restoration [26-28]. WBP a novel approach in which water is stored temporarily in water rich regions (including those outside the target country). As such, it is a managerial tool that can be applied on a limited scale to alleviate global water shortages by exploiting open surface reservoirs and underground storage to prepare for future water stress periods [27, 29, 30]. Effectively applied, water banking could enable water scarce countries to fill their temporary storage sites. The success of any WBP, however, depends on the establishment of an administrative agreement between the partners, who also have the necessary technical capacities (pumping) in place before they can execute water banking. The conjunctive use and management of groundwater and surface water constitutes an acceptable means to restore the water resources in countries that suffer from water stress [31, 32]. Plans like the Tadlee Scheme (Morocco) and the water use policies implemented in the Rechna Doab area (Punjab, Pakistan) demonstrate how groundwater shortages due to aquifer depletion can be managed [31]. Since in both cases, water restoration is executed through the controlled release of water from storages, they qualify as conjunctive water use approaches [33]. The defined parameter to improve the policy of water release from storages is a kind of "insurance cost" as stated previously. This policy confers on the principal competing sectors the benefits of implementing an integrated counterbalanced approach to water resource management that does not endanger the livelihoods of the area's farmers. Indeed, the exploitation of both water and soil banking approaches where water is scarce appears to ensure uninterrupted food supplies from area farms [34]. One has to add that seawater desalination is an alternative solution to water shortage issues.

The Goal of Water Banking Policies

According to the WBP, an insurer purchases amounts of water that are deposited in a "water bank" [Kern bank (California) is an international facility]. Banking (or insurance) claims are settled during severe droughts by supplying water according to the terms of the insurance policy [35, 36]. Water banking allows the stockpiling of water supplies to offset the inevitable shortages suffered in water scarce regions. It is implemented by investing in groundwater, surface water and/or other sources. It allows water to be imported from any external, water-rich resource to the target region [37, 38]. The agreement signed between the Metropolitan Water District of Southern California and the Municipal Water District of Orange County (California) facilitated importing water from the bank in Kern County to the agricultural areas of Orange County [39]. This setup can be considered as an example of partial water shortage insurance [40]. It demonstrates under which conditions the stakeholders decide the terms that water will be transferred to specific destinations.

The Goal of the Work

The goal of this work is to demonstrate through analytical analysis that, particularly under conditions of water scarcity, a well-crafted WBP can actually benefit both of the two main competing sectors. As such, the anticipated benefits the banking agreement confers on both sectors render it an effective way to eliminate conflict between them by reducing the resistance of the agricultural sector, as the residual claimant, to the importation of water from external sources at its own expense. Note that this paper only addresses the consensus between the sectors, and as such, the actual water transfer agreement between the buyer and an external seller, which is beyond the scope of the work, is not discussed.

The Essence of the Proposed Water Banking Model

The theoretical water banking model is deterministic and considers two periods, the current year *vs*. the future one. The WBP is derived from financial studies of the conflicting interests between bondholders and shareholders [41, 42]. The legitimacy of a WBP-based approach and its comparable financial components are listed in Table 1, which shows the analogous parallels between a national water economy system and a firm with debt. Similar to the financial situation for bondholders and shareholders in terms of money, first rights of water allocation go to the municipal sector while rights of residual claims are granted to agricultural.

Table 1: Comparative characteristics of a national water economy system vs. a firm with debt

Parameter	Firm with debt	National water economy system
Top priorities	Bondholders	Municipal sector
Residual claim	Shareholders	Agricultural sector
Conflicting interests under agreement	Advisable economic investment	Water importation to allow water resource restoration
Banking/Insurance	Financial covenant in the bond contract that requires banking coverage	Water insurance

The analogy of a national water economy system with a financial equivalent allows WBPs to be adapted to economic and financial theories (specifically, insurance theory) and then analyzed accordingly. Such a theory-driven approach can enhance the control of water sources in geographic regions that are prone to water scarcity. In this work, the integration of several concepts from the theory of finance provides an original outlook on the national water economy. Moreover, the model provides the theoretical foundations for the effective management and control of water allocation between the urban and agricultural sectors.

The Theoretical Banking Model

Basics of Water Banking Policy (WBP)

The level of discount is calculated by, for example, using the water's Present Value (PV), which can be done by assessing two successive water supply periods based on a discount rate of, e.g., 25%/period. Accordingly, a volume amount of 100 units that is obtained in the second period is equivalent to 80 units that are obtained in the first period (100/1.25 = 80)]. The model addresses two successive water supply periods, and all the subsequent periods (from the third period onward) are assessed in terms of the PV of water in the second period. The model addresses two periods: the present (first period) and a subsequent period (second period). Actions that are taken (or, alternatively, the failure to take action) in the second period will determine the state of the national water economy in all subsequent periods. If the water sources are adequately restored during the second period, all future periods (third period and onward) will have adequate water supplies. If such measures are not taken in the second period, then under future conditions of stress, the water sources may be irreversibly depleted. The present values of water in the third and subsequent periods are estimated relative to the second period. Any consecutive periods refer to the situation of present and future combined water sources and the related environmental state (mainly precipitation for groundwater recharge and other storage replenishment strategies). From the perspective of the first period, the second period is characterized by the uncertainty of future environmental conditions. Two anticipated scenarios are possible for the second period: (i) a non-drought period where the PV of the water quantity in the national water economy will be V* [in units of million cubic meters (MCM)] in terms of the second period (V* is for a non-drought period), and (ii) a drought period, where the PV in terms of the second period will be reduced by L(E) [reduction in water availability (MCM); E is the x-axis in Figs. 1 and 2] due to the current environmental and hydrological conditions (EnHyC). Under drought conditions, the PV of the water in the second period will thus be:

$$V_d(E)=V^*-L(E) \tag{1}$$

where $V_d(E)$ is the PV of the amount of available water (MCM) in the second period under drought conditions, V* is the volume of water in the national water economy, and L(E) is the reduction in water availability during the second period in the national water economy system (Figure 1).

When drought conditions are experienced in the second period, endangering the national water economy, "stakeholders" may decide to import water and inject it into local aquifers as a way both to cope with the water stress and to ensure that the water sources will be fully restored. The amount of water to be imported during the second period [$V_{im}(E)$, MCM] depends on the current EnHyC (E), and in financial terms, it can be viewed as an investment. Importing the amount $V_{im}(E)$ will increase the PV of the water in terms of the second period (i.e., from the third period onward) as a result of restoring the water resources (the PV of water amounts will be reset to V*). The quantitative expression for the PV of the water amounts in the second period under drought conditions and with water importation is given by $V_r(E)$ (MCM). The term $V_r(E)$ is the PV of the amount of water imported during the second period under drought conditions, and $V_{im}(t)$ is the amount of water imported in the second period from the bank (MCM):

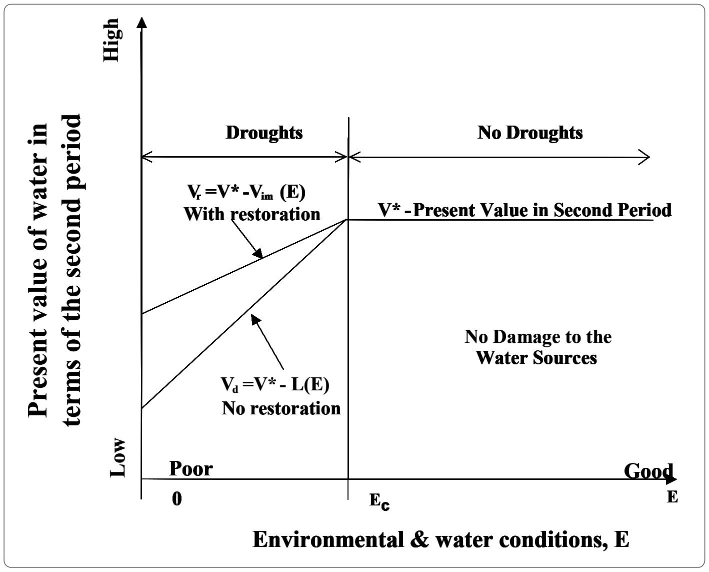

Figure 1: Considerations for water importation in the case of only one sector

$$V_r(E)=V^*-Vim(E) \tag{2}$$

Water importation, similar to its' subsequent injection into the aquifers and its storage to replenish reservoirs, is analogous to an earlier investment that subsequently generates revenues at a later date. The benefit from an investment is measured based on its Net Present Value (NPV). A positive NPV means that the PV of the revenues is larger than that of the investment, thus endorsing the investment. A positive NPV in the national water economy means that by preventing aquifer destruction (by injection), the PV of water amounts in future periods is larger than that of the amount of water that was injected (without injection, many aquifers and other storage facilities will probably be deteriorated). The NPV of the restoration is measured in terms of the second period. It is assumed that the NPV of restoration is greater than zero, and thus, in this case, water importation is deemed to be an economically sound strategy, namely, $L(E) > V_{im}(E)$. For the case in which the national water economy consists of only one sector, there will be no objection to water importation. The single sector will enhance water importation, for each situation (E) reflecting drought (Figure 1). A drought situation is defined as one in which all points are located to the left of E_c (E_c is the upper limit of EnHyC describing drought) and for which the drought is less severe, i.e., advancing along the x-axis (E) (Figure 1). Note that under drought, $E < E_c$ The condition $V_r(E) > V_d(E)$ always exists, meaning that the importation of water and its injection into aquifers, groundwater and/or surface water during drought is always preferable.

Analytical Description of the System

Using a financial approach can be further exploited by implementing sophisticated analytical tools. It can be assumed that the markets are complete (thus, no transportation expenses are considered), and the density function of the environmental and water conditions is given by g(E). The PV of the water in terms of the first period, assuming a system with only one water sector, is given by V (MCM) as the sum of the terms of the density functions for the two different environmental and hydrological conditions (Figure 1 and Equation 3):

$$\begin{aligned} V &= \int_0^{\infty} V^* g(E)de - \int_0^{E_c} L(E)g(E)de + \int_0^{E_c} [L(E) - V_m(E)]g(E)de \\ &= \int_0^{E_c} [V^* - V_m(E)]g(E)de + \int_{E_c}^{\infty} V^* g(E)de \\ &= \int_0^{E_c} [V_r(E)]g(E)de + \int_{E_c}^{\infty} V^* g(E)de \end{aligned} \tag{3}$$

The situation of two competing sectors in the national water economy, however, is different. Under drought conditions, the municipal sector will have the first priority for water allocation while the agricultural sector will receive the residual priority [13]. Moreover, the conflict between the two sectors will escalate as will the expectations of the municipal sector that the agricultural sector assume responsibility and import water at its own expense as long as the region is affected by drought. Therefore, under these conditions, neither the importation of water nor the recovery of water sources is guaranteed.

Analysis and Related Assumptions

In this model, it is assumed that under drought conditions, the agricultural sector will import water at its own expense for the following reasons: (i) it has residual rights for water and (ii) water use by the agricultural sector jeopardizes the reliability of the municipal water supply [5, 43, 44]. Another assumption is that the PV (in terms of the second period) of the municipal water quota is V_m (MCM). The municipal sector will insist on receiving the PV amount of V_m, assuming that the agricultural sector imports water to replenish the local resources that are suffering from severe drought conditions. If the municipal sector cannot rely on the agricultural sector to import water in a timely fashion, it will insist on being awarded an even larger quota than V_m in the second period. Its insistence that it receive a larger quota can be interpreted as protective measure taken by the municipal sector to finance or offset the risk that the water sources will not be adequately restored for future use by the national water economy. This larger quota, however, may even exceed the potential risk (typical for a situation in which the water wealth is diverted from the agricultural to the municipal sector). The conflicting interests between the two sectors are illustrated in Figure 2. Under unfavorable environmental and hydrological conditions, expressed as $0 < E < E_a$, and subtracting the amount of water imported in the second period and the municipal quota from the water volume in the non-drought period (given in MCM):

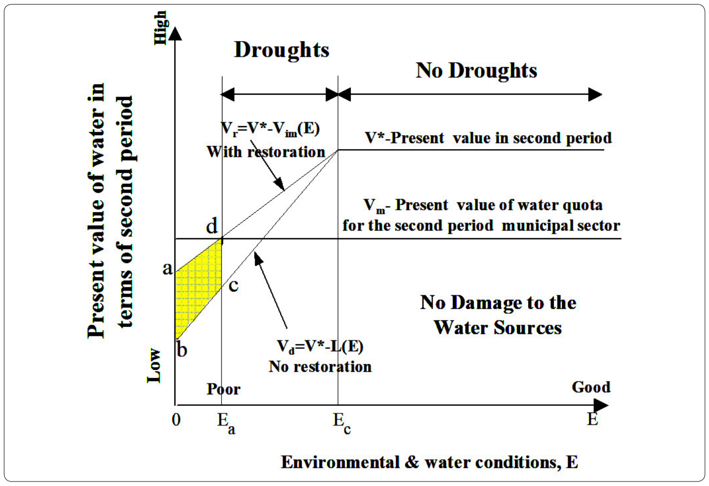

Figure 2: Considerations for water importation for a case involving two sectors

$$V^* - V_{im}(E) - V_m < 0 \qquad 0 < E < E_a \tag{4}$$

Under this scenario, the agricultural sector's agreement to import water actually worsens its situation. Moreover, if the environmental and hydrological conditions decline further then ($E < E_a$, i.e., severe drought conditions), indicating that water importation for the agricultural sector is economically inadvisable, since the municipal sector will be the main beneficiary (Figure 2). The assumptions taken in this case are based on actual water use data from Israel, where about 60% of the total area of the country receives annually less than 200 mm of precipitation.

In the event that the agricultural sector objects to importing water and its objection is accepted at the national decision-making level (i.e., water is not imported), then the PV of the available water of the national water economy in terms of the first period will be given by equation 5 (note the limits of the EnHyC of the three given terms of the integral; Figure 2):

$$\begin{aligned} V &= \int_0^{E_a} [V^* - L(E)]g(E)de + \int_{E_a}^{E_c} [V^* - V_{im}(E)]g(E)de + \int_{E_c}^{\infty} V^* g(E)de \\ &= \int_0^{E_a} [V_d(E)]g(E)de + \int_{E_a}^{E_c} [V_r(E)]g(E)de + \int_{E_c}^{\infty} V^* g(E)de \end{aligned} \tag{5}$$

The scenario described above, wherein the agricultural sector successfully rejects the demands to import water at its expense, is typical in cases in which this sector has an influential lobby. However, when the agricultural sector has limited influence, then the required amount of water will be imported, partly or entirely, and the water shortage will be resolved.

A comparison of equations 3 and 5 shows that the PV of the water is lower by a volume ΔV (Equation 6 and the shaded area *abcd* in Figure 2), which is representative of the case in which two sectors are involved but the interests of only one of the sectors is taken into account (and the water for the municipal sector is not guaranteed). The ΔV referred to above represents the loss in PV amounts of water (in terms of the first period) caused by an absence of restoration (under an investment problem).

$$\Delta V = \int_0^{E_a} [L(E) - V_{im}(E)]g(E)de \tag{6}$$

According to Figure 2, as long as the water quota is allocated to the municipal sector (Equation 7), then there are no conflicting interests between the two sectors regarding water importation, namely, the municipal quota is smaller than the amount under drought conditions:

$$V_m < V_r(E) \qquad \text{for all } E \tag{7}$$

Implementation of the Water Banking Model

Water banking contracts with legitimate external bodies (e.g., other countries) or the use of international water banks could potentially resolve the conflict between the two sectors and guarantee that adequate amounts of water are imported. Water banking will be efficient under conditions of severe drought when EnHyC is given by $0 \leq E < E_a$ (Figure 2), since in this case, not only does a genuine conflict exist, there is also uncertainty regarding whether restoration actions will be implemented [44]. The agricultural sector will be indifferent to water importation of the amount $V_{im}(E_a)$ {the vertical distance between the line V* and the line $[V^* - V_{im}(E_a)]$ in Figure 2}. Although drought also exists when $E_a \leq E < E_c$, as this case is devoid of conflict, the water resource will be replenished. Assuming actuarially fair insurance, the banking premium at this time is given by Π:

$$\Pi = \int_{0}^{Ea} [V_{im}(E) - V_{im}(E_a)]g(E)de \tag{8}$$

In the framework of a water banking agreement, during the first period, the agricultural sector will purchase an amount Π of water on the world market and then transfer it to another country or to an international water bank that will insure the national water economy. The PV of the available water amount V (in terms of the first period) in the national water economy system (for the scenario wherein the water amount to be allocated to the municipal sector is not guaranteed) and the implementation of a banking policy are given by Equation 9, which is dependent on the municipal quota, the density function, the non-drought period and the amount of water imported:

$$V = \int_{0}^{E_a} V_m g(E)de + \int_{E_a}^{E_c} [V^* - V_{im}(E)]g(E)de + \int_{E_c}^{\infty} V^* g(E)de - \int_{0}^{E_a} [V_{im}(E_a)]g(E)de$$

$$= \int_{0}^{E_a} V_m g(E)de + \int_{E_a}^{E_c} [V_r(E)]g(E)de + \int_{E_c}^{\infty} V^* g(E)de - \int_{0}^{E_a} [V_{im}(E_a)]g(E)de \tag{9}$$

Under these conditions, the PV of the available water in the national water economy system will be the PV of the quotas of the two sectors minus the banking premium. From the geometry of Figure 2, the following expression can be derived for the range 0 to E_a in EnHyC values (Equation 10):

$$\int_{0}^{E_a} V_m g(E)de = \int_{0}^{E_a} [V^* - V_{im}(E)]g(E)de + \int_{0}^{E_a} [V_{im}(E) - V_{im}(E_a)]g(E)de$$

$$= \int_{0}^{E_a} [V_r(E)]g(E)de + \int_{0}^{E_a} [V_{im}(E) - V_{im}(E_a)]g(E)de \tag{10}$$

The ultimate Equation 10 refers to the PV of the available water amount in a national water economy in which water allocation to the municipal sector is not guaranteed. The "implemented" purchased for the water supply is given by:

$$V = \int_{0}^{E_c} [V^* - V_{im}(E)]g(E)de + \int_{E_c}^{\infty} V^* g(E)de$$

$$= \int_{0}^{E_c} [V_r(E)]g(E)de + \int_{E_c}^{\infty} V^* g(E)de \tag{11}$$

Note that Equation 11 refers to the scenario involving one sector only (Equation 3).

Dynamic Stochastic Simulation - Model Validation

General Conditions

The theoretical deterministic model considers two periods, the current year vs. the future. For validation, a complementary Monte Carlo simulation was conducted in which stochastic rainfall conditions were introduced over a series of periods (up to 25 years and 180,000 simulation runs). The simulation model was run primarily to validate the results and was essentially a marginal part of the study. Different levels of the WBP were demonstrated across multiple simulations that were run for each period.

1) EnHyC values, designated by E, are sampled randomly for the [0, 1] interval. There are two possibilities:
   (a) If $E < 0.3 = E_c$, i.e., there is a drought, and the actual water amount is V, which is calculated (as shown in Figure 2) by V=50+3166.67(E).
   (b) If $E > 0.3 = E_c$, then V=V*=1,000. This is the case of no drought.
2) There are two possible policies for the agricultural sector (Table 2):
   (a) To always keep its obligation to restore the water reservoirs (when $0 \leq E \leq E_c$) by importing water in a timely fashion and by using the expression: $V_{im}=V^*-V$ where $V^*=1,000$ (as an example).
   (b) To restore the water reservoirs (underground and open surface) only when $E_a \leq E < E_c = 0.3$, but not to restore them when $0 \leq E_a \leq E_c$. In this case, from this stage until the end of the time horizon and current level, V will be maintained.
3) The actual quota that the municipal sector will receive is given by following:
   (a) $V_{ma} = V_m$ if V = 1,000. In this case, V_{ga}, the actual residual allocation for agricultural, is $V_{ga} = V^* - V_m = 1{,}000 - V_m$.
   (b) Under restoration, the condition $V_{ma} = V_m$ exists. However, $V_{ga} = V - V_m - V_{im}$, where V_{im} is the amount of imported water.
   (c) If the restoration requirement is not kept for $E < E_a$, then $V_{ma} = V$, where V is the current value given by V = 50 + 3166.67(E) for the last problematic situation $E < E_a$, namely, severe drought conditions. Obviously, in this case, $V_{ma} < V_m$. Moreover, under these catastrophic conditions (severe drought), $V_{ga} = 0$ until the end of the time horizons.

The above assumptions are based on intense contact with the State of Turkey to import water into Israel due to the problems caused by the recurring droughts suffered in the region.

Effects of Changing the Simulation Parameters

During the simulation experiments, four parameters, which were considered to be the main parameters, were varied:

1) The number of periods (time horizons): five scenarios.
2) V_m: the municipal water quota for every period (in this simulation, it is not expressed in PV terms); however, three levels were considered.
3) E_a: EnHyC values below this critical cutoff signify severe drought for which the agricultural sector will decide not to honor its obligation of water restoration; six possible scenarios were examined.
4) The decision of whether to import water for restoration can go either way. Other parameters include, for example, variation in the interest rates, transportation costs and environmental conditions. Table 2 provides the values for each parameter. The total number of simulation combinations is 180 (5 × 3 × 6 × 2). Each combination was run approximately 1,000 times.

Table 2: Layout of the simulation experimental

Parameter	**Values**	**Number of options**
Number of periods	5, 10, 15, 20, 25	5
V_m: municipal water quota for every period	600, 800	2
Policy	To restore or not	2
Critical environmental and hydrological conditions describing severe drought for which the agricultural sector will decide not to meet its water restoration obligation	0.01, 0.02, 0.03, 0.04, 0.05, 0.06	6

Results

Samples of Simulation Results

Representative results for some simulation runs are presented. In addition to giving the results in terms of the above parameters, the main results are also expressed by the NPV for the agricultural sector (Table 3). One of the main variables (E_a), expressing the lowest level at which the agricultural sector is ready to keep its pledge to restore the water resources, was changed systematically (e.g., when $E_a = 0.06$, the agricultural sector was less willing to maintain its pledge than when $E_a = 0.01$). The NPV values in Table 3 indicate the aquifer volume of water to be allocated to the agricultural sector under the given scenario. It implies that the NPV is equal to the water allocated to the agricultural sector minus the amount imported for restoration at the expense of the agricultural sector.

Table 3: The net present value* of the agricultural sector's residual allocation (NPV_{ga}) when the municipal water quota is $V_m = 600$, for various time horizons T, and policies; E_a is the lowest level at which the agricultural sector is prepared to keep its pledge to restore the aquifer; "A" = restoration obligation is kept in the case of $E < E_a$; "B" = restoration obligation is not kept in the case of $E < E_a$ and is kept in the case of $E_a \leq E < E$

Number. of Periods per Simulation, T	**$E_a = 0.01$**		**$E_a = 0.02$**		**$E_a = 0.03$**		**$E_a = 0.04$**		**$E_a = 0.05$**		**$E_a = 0.06$**	
	A	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
5	170	176	167	177	154	167	166	182	173	189	156	178
10	156	155	166	168	157	157	165	166	167	165	168	165
15	159	156	161	154	166	153	160	145	167	148	162	138
20	162	155	165	149	165	144	168	140	165	133	164	123
25	163	150	166	145	162	133	164	124	167	118	164	112

* NPV_{ga} - net average water amount per period for the agricultural sector.

E_a - lowest EnHyC value at which the agricultural sector is prepared to keep its pledge to restore the aquifer.

A - restoration obligation is kept in case $E < E_a$.

B - restoration obligation is not kept in case $E < E_a$ and is kept when $E_a \leq E < E_c$.

Table 4: The net present value* of the agricultural sector's residual allocation (NPV_{ga}), when the municipal water quota is $V_m = 800$, for various time horizons, T and policies

Number of Periods per Simulation, T	**$E_a = 0.01$**		**$E_a = 0.02$**		**$E_a = 0.03$**		**$E_a = 0.04$**		**$E_a = 0.05$**		**$E_a = 0.06$**	
	A	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
5	3	12	5	23	3	26	2	32	**	-	-	-
10	5	14	4	22	2	25	2	31	-	-	-	-
15	5	12	0	15	2	23	1	27	-	-	-	-
20	4	12	3	16	2	22	5	27	-	-	-	-
25	5	11	7	19	6	22	6	25	-	-	-	-

* NPV_{ga} - net average water amount per period for the agricultural sector.

E_a - lowest EnHyC value at which the agricultural sector is prepared to keep its obligation to restore the aquifer.

A - restoration obligation is kept in case $E < E_a$.

B - restoration obligation is not kept in case $E < E_a$ and is kept when $E_a \leq E < E_c$.

** - unfeasible scenario

From the point of view of the national water economy (V), it is always reasonable to invest in water restoration namely, under severe drought conditions when $E < E_a$ [44]. However, from the point of view of the agricultural sector only, it is economically inadvisable to keep the restoration obligation:

1) As shown in Tables 3 and 4, when the time horizon, T, increases, in almost all cases, it is worthwhile to maintain restoration activity, even when $E < E_a$, for every E_a (exceptions are the extreme cases of $E_a \leq 0.02$ where a severe drought is rare).
2) As V_m, the municipal water quota for every period, increases, it is not worthwhile for the agricultural sector to carry out restoration in cases of severe drought ($E < E_a$). This phenomenon is comparable to a leveraged firm under financial stress. Note that in Table 4, when $V_m = 800$ Million Cubic Meters (MCM), the maximal feasible value of E_a is 0.47; and there is no feasible solution when $E_a > 0.04$ (Figure 2) [45].

A Numerical Example Based on the Water Banking Approach

Over the course of two consecutive water consumption periods, two potential precipitation regimes (drought vs. rainy conditions) with equal probabilities of occurrence are possible. In the numerical example below, a discounted water supply is assumed for the second period (a period either of drought or of abundant precipitation is assumed between the first and second periods). The PV of the available water in a national water economy in the second period is 1,000 million cubic meters (MCM). For illustrative purposes only, some simplified examples follow. A water-prosperous period is considered, or alternatively, an amount of 200 MCM for a severe drought is assumed. If a drought occurs in the second period, the injection of 600 MCM of imported water is deemed to be satisfactory for restoration (simulation experiments proved that restoration led to the creation of a positive NPV) to maintain the national water economy system in a reversible, restorable condition. (This restoration effort will provide a PV of 800 MCM in terms of the second period; see above example). Due to the restoration, the PV of the national water economy system will return to its original state of 1,000 MCM (= 200 + 800). From the general point of view it is indeed a preferable economy. The PV of water amounts for one sector only for a volume of imported water V_{im} of 600 MCM (needed for restoration to maintain reversible conditions; Table 3) calculated in terms of the equal probabilities for prosperous and drought periods is given by (equation 12):

$$\begin{aligned} V(\text{One sector}) &= Pr_pV^* + (1-Pr_p)V_r \\ &= 0.5*1{,}000+0.5*(1{,}000-600) = 700 \quad \text{MCM} \quad (12) \end{aligned}$$

where Pr_p is the probability of favorable environmental and water conditions (for example, a rainy period) and $(1-Pr_p)$ is the probability of adverse environmental and water conditions (for example, a drought period). The municipal sector in the national water economy normally has the top priority in water allocation, while the agricultural sector typically has the right to residual claims. In this numerical example, the PV (in terms of the second period) of the municipal water quota will be $V_m = 500$ MCM, a scenario in which the municipal sector assumes that, should there be a severe drought, the agricultural sector will import water to replenish the regional water sources. Under severe drought conditions, the PV amount of water (in terms of the first period) will actually be allocated to the municipal sector, V_{ma} however, assuming that V_d is equal to 200 MCM (the PV amount of water during the drought period), only 350 MCM will be available (Equation 13):

$$\begin{aligned} V_{ma} &= Pr_pV_m + (1-Pr_p)V_d \\ &= 0.5*500+0.5*200=350 \quad \text{MCM} \quad (13) \end{aligned}$$

The PV (in terms of the first period) of the actual water amount to be allocated to the agricultural sector V_{ga} will now be 250 MCM (Equation 14):

$$\begin{aligned} V_{ga} &= Pr_p\,(V^*-V_{ma}) + (1-Pr_p)(V_d - V_m) \\ &= 0.5*500+0.5*0 = 250 \text{ MCM and } V_d - V_m \geq 0 \quad (14) \end{aligned}$$

The term $(V_d - V_m) \geq 0$ is positive, since it is impossible to accumulate negative amounts of water. By implementing the WBP, the PV (in terms of the first period) of the total available amount of water (i.e., two sectors) in the national water economy, V, will now be only 600 MCM (Equation 15):

$$\begin{aligned} V(\text{Two sectors}) &= V_{ma}+V_{ga} \\ &= 350+250 = 600 \quad \text{MCM} \quad (15) \end{aligned}$$

where the PV of the water in the national water economy is thus cut by 100 MCM (compare Equations 12 and 15), emphasizing the difference between the systems with one and two sectors. Under these conditions, if the agricultural sector objects to importing water at its own expense (since the imported water will not satisfy its water use needs) and no waters are imported, then the national water economy will suffer irreversible damage. If water is indeed imported in the second period, then the water quota allocated to the municipal sector will be associated with no risk. Importing water during the second period will increase the water PV to be allocated to the municipal sector by 150 MCM (from 350 MCM to 500 MCM). In comparison, the PV of the agricultural sector will be reduced by 50 MCM (from 250 MCM to 200 MCM). In this case, the PV of the national water economy will increase by 100 MCM (150 MCM less 50 MCM). If the PV (in terms of the second period) of the municipal water quota is only $V_m = 200$ MCM, there will be no risk and no conflicting interests [24]. Under these circumstances, water will be imported, and the demands of both sectors will be satisfied. An equilibrium can be reached in this case if, for example, the PV of the quota for the municipal sector is 400 MCM. At this municipal water quota, the agricultural sector will not object to the importation of water at its expense. When the PV of the quota for the municipal sector exceeds 400 MCM, it will be necessary to enforce the WBP to eliminate conflicting interests. Assuming actuarially fair insurance, the insurance premiums in the first period will be Π. To insure the national water economy, the agricultural sector will purchase an amount of water Π on the world markets in the first period and then transfer it to another country or an international water bank for storage. The premium of 300 MCM is based on the assumption that 600 MCM will be imported in the drought period {assuming a probability of 50% for drought [$(1-Pr_p) = 0.5$], which yields 0.5 × 600 = 300 MCM}. The PV for the municipal sector (in terms of the first period) and enforcing the WBP will now be 500 MCM, and the PV of the agricultural sector will be 200 MCM (500 minus a premium of 300 according to Equations 13 and 14). Accordingly, the PV (in terms of the first period) of the total available amount of water V, in the national water economy system will now be 700 MCM (Equation 16):

$$\begin{aligned} V(\text{Two sectors}) &= V_{ma}+V_{ga} \\ &= 500+200 = 700 \quad \text{MCM} \quad (16) \end{aligned}$$

The numerical value of V is equal to that of a national water economy with only one sector, and there are no contradictory attitudes toward water resource restoration. The numerical examples illustrate the role of water insurance for cases of complete insurance coverage, but this is not always required. Banking policies that cover an amount of, e.g., 100 MCM for the national water economy in the case of drought in the second period can also be implemented. The agricultural sector will import 500 MCM (600 MCM will be required for restoration minus the 100 MCM insurance coverage to yield 500 MCM), but it will regain 500 MCM in terms of the second period. The logical conclusion of this example is that the insurance coverage must be equal to (or larger than) a critical value that will effectively minimize the conflicting interests between the sectors. Using the above example, the critical volume V_c can be assessed by (Equation 17)

$$\begin{aligned} V_c &= V_m - V_E(t) \\ &= 500 - 400 = 100 \quad \text{MCM} \end{aligned} \tag{17}$$

where V_c is the critical water volume, V_m is the PV value in terms of the second period of the municipal water quota, and $V_r(E)$ is the PV of the amount of water in the second period under drought conditions and water importation.

Summary and Conclusions

Water banking is an administrative tool that can be applied to facilitate legal transfer actions and the market exchange of different commodities, such as stored water and surface and ground water. Accordingly, the bank leases water from sellers and subsequently, subject to the stipulations of the signed agreement, transfers it to the buyers. This mechanism also allows water rights to be transferred between users. A conceptual economic-engineering model based on the water banking concept was developed and demonstrated with the goal of minimizing the conflicting interests of the two main water sectors, urban and agricultural, in most countries. Under severe drought, the agricultural sector, which typically has a strong lobby, may oppose water importation at its own expense to restore local water sources. Non-renewal of water sources may result in irreversible damage to the existing water sources. Therefore, the failure to import water during drought and the corresponding failure to recharge the aquifer despite its advisability is comparable to the failure in a financial market to exercise options of resources saving prior to its expiration date. The implementation of a WBP can help resolve water-related conflicts and maintain water sources in conditions that remain amenable to recovery. According to the anticipated conditions, water banking (insurance) can be exploited to ease the stress and benefit all the stakeholders in the national water system. The WBP is based on financial theory proposed in financial studies that address the conflicting interests between bondholders and shareholders [41]. In the national water economy, the municipal sector is analogous to the bondholders (both have first rights) while the agricultural sector is analogous to the shareholders (both have residual claims). It implied that water importation costs are born exclusively by the agricultural sector, despite the fact that importation of water during severe drought benefits only the municipal sector. Primarily in arid regions, the relationship of the agricultural and urban sectors in terms of water rights is often characterized by a complex set of conflicting interests. Disputes related to water supply can be solved by investing in water restoration, which occurs mainly under severe drought conditions, i.e., when $E < E_a$. From the perspective of the agricultural sector, the maintenance of its restoration obligations under severe drought conditions is not economically advisable. A WBP provides an optimal solution to resolve this conflict. The suggested theoretical model presented here is deterministic type and considers only two periods. To validate the results for a general case, we used a stochastic simulation over many periods (up to 25 years). The simulation was run for 180 configurations, each with 1,000 runs. Although other control variables could be included in the model, for illustrative purposes and for the present study, the parameters cited above are the most important ones that can be analyzed in the framework of this study. The concepts of water banks and water exchanges that are designed to preserve water resources in arid regions are among the most frequently discussed approaches in the world of water rights. But what exactly are the benefits of water banks? Actually, the water bank is an operational tool used to facilitate the legal transfer and market exchange of various types of waters. It enables water to be leased from willing sellers and holders and then transferred in exchanges of water rights on behalf of willing buyers. The design and operation of water banks vary depending on the watershed involved and on the local water supply needs. In addition to its being a vital natural resource, water is also a societal symbol – a "total social fact" – and one's ability to easily access water is related to status, reflecting the connection between water and society and life quality. In terms of quality of life, water and the environment are economic goods. Endeavors to privatize water invoke a wide range of reactions and social movements, wherein the right of all humans to easy access to water is the driving force against privatization. These are the main concepts underlying and advancing the notion of the ancient rights of humans to water.

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Statement

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