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MUNICIPAL WASTEWATER TREATMENT AND REUSE:

I. TREATMENT OPTIMIZATION AND REUSE FOR REGIONAL IRRIGATION

by

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Rehovoth, Israel, P.O.B. 12

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ABSTRACT

Municipal wastewater warrants increased attention as a potential environmental pollution and a possible irrigation water source. A long-run mathematical programming model aimed at regional optimization with regard to plant capacity, treatment level, allocation of the effluent to the participating farms and cropping patterns at each farm is presented. The model is applied to an agricultural region in Israel which includes a town and several farms. The results indicate the necessity of a subsidy for regional cooperation and provide a regional setup of reusing municipal wastewater for irrigation. The optimal solution enables each farm to reallocate the fresh water quota among the different land sections, to cultivate new land areas and to expand the irrigated crops by using effluent. The acceptability of the regional optimal solution by the town and the farms is discussed in another paper.

TREATMENT OPTIMIZATION OF MUNICIPAL WASTEWATER AND REUSE FOR REGIONAL IRRIGATION

Municipal wastewater warrants increased attention as a potential environmental pollution and a possible irrigation water source. Under certain conditions, use of municipal effluent (treated wastewater) for irrigation, is an effective means for wastewater removal. Using wastewater for irrigation of certain crops (Table 1) allows a less stringent treatment level in comparison to disposing of the wastewater to lakes and rivers to be utilized later and may thus alleviate environmental problems. It also has the advantages of providing extra water for farmers who use the wastewater.

Municipal wastewater is generally treated in Western Europe and parts of the United States (Messer, 1982; Asano and Mandancy, 1982) for discharge to streams and lakes, which might ultimately be used as sources of drinking water. Accordingly, the professional literature concentrates primarily on this issue and addresses: (a) the choice of a treatment facility that fulfills given health and environmental requirements at minimal cost and (b) the related treatment cost-sharing scheme among the polluting agents such as domestic and industrial users (Dorfman, 1972; Giglio and Wrightington, 1972; Papke, et al., 1977; Loehman, et al., 1979; Nakamura and Brill, 1979; and Rinaldi, et al. 1979).

Irrigation with effluent is a rather recent practice and therefore the literature in this field is not as extensive as the literature dealing with the disposal of municipal wastewater to lakes and rivers.

In arid and semi-arid parts of the world like southern California, Texas and Israel, much effort is being devoted toward coordinating effluent quality with agricultural crop requirements, and toward adapting environmental-quality regulations for using effluent for irrigation as a cost effective outlet for wastewater (Feigin et al., 1977; Tahal, 1978; Moore et al., 1984; Victurine et al., 1984; Goodwin et al., 1984; California State Water Resources Control Board, 1984).

This paper deals with a regional approach for municipal wastewater management through treatment and irrigation, subject to strict public health regulation aimed at preserving environmental quality. A regional wastewater treatment system and its distribution to farms within a region offers economic advantages to the potential participants; but it requires the establishment of a special regional organization. A region involved in such endeavor faces the following interrelated problems:

a) Determination of the appropriate regional boundaries with due consideration to treatment plant capacity as well as the capacity and layout of the wastewater and effluent conveyance systems;
b) Determination of the wastewater treatment level;
c) Allocation of the effluent (treated wastewater) to the farms within the region;
d) The selection of optimal cropping patterns;
e) Cost allocation to the participants;
f) Level of government subsidy, if needed.

A mathematical programming model which includes these components is formulated. The model is applied to the Ramla region which includes one town and several farms on the coastal plain of Israel. The cost allocation among the participants is considered in the following paper (Dinar et al., 1985). As will be shown later, the regional optimization problem can be separated from the cost allocation problem.

A MODEL FOR REGIONAL OPTIMIZATION OF WASTEWATER TREATMENT AND REUSE

The objective is to maximize the region's income subject to a given supply of wastewater, health regulations and the capability of the farms to utilize the effluent, subject to their land and other resource endowments, and the prevailing price system and technology.

The following entities, or "players" (using game theory semantics) are involved:

1) The municipal authority(s) that delivers the effluent (effluent supply);
2) The farmers interested in using effluent in irrigation (effluent demand); and
3) A public organization, such as the government or a regional authority which serves public interests (e.g., environmental quality) and which can control the related activities via regulations and subsidized financing.

Apparently, economic potential exists for regional cooperation in the treatment of wastewater and the use of effluent in irrigation. The farmers might be able to increase their irrigated acreages and benefits. The treatment cost could rise, as the result of a treatment level higher than required by health regulations for discharge to the sea, but a share of the cost would be borne by the farmers, and by a government subsidy if needed. Environmental considerations and fresh water savings may provide the motivation for the subsidy.

The economic analysis refers to a one-year period, with all long-run costs and revenues expressed on an annual basis. It does not account for the effect of present irrigation decisions on the future from the standpoint of salt accumulation in the soil, because, with reference to the particular region studied, it is not significant, due to salt leaching by winter rainfall.

The model deals with one urban authority, several farms, and incorporates government environmental-quality regulations. It neglects seasonal differences in wastewater quality and assumes a uniform quality throughout the year. In addition, the model assumes only one possible treatment level throughout the year; this level is chosen in order to maximize the regional income.

ELEMENTS OF THE MODEL

The Town and the Treatment Plant

Municipal wastewater supply and quality are viewed as predetermined exogenous variables. For each month, the following balance equation holds:

$$(1) \qquad \overline{S}_t = D_t + S_t \qquad t = 1,\dots,12$$

where

$\overline{S}_t$ is the municipal wastewater supply (m^3) in month t;

D_t is the quantity (m^3) of wastewater discharged after necessary treatment in month t (discharged to the sea through a wadi (riverbed, dry most of the year));

S_t is the quantity (m^3) of wastewater diverted to a pretreatment storage in month t.

The cost of wastewater discharge is d ($\$/m^3$) and it is lower than the cost per unit of treatment required for irrigation use. Discharge costs include minimum wastewater treatment (required by law) and the conveying expense to the discharge site. The supply of wastewater is continuous over the year while the agricultural demand for effluent is mainly restricted to the summer months. To match agricultural demand, wastewater is stored in a pretreatment reservoir until needed. Although some quality improvement (oxidation) does take place in the stored wastewater during winter, its extent with regard to the conditions studied is not known, and for the purpose of this study it will be considered as negligible. (In general, there is a problem whether wastewater should be stored before treatment or after treatment, as effluent. In the first case, there is the benefit of quality improvement before treatment which reduces treatment costs; on the other hand, this implies that the treatment will take place at the appropriate time of effluent use, and a larger treatment plant is required. In the second case, the opposite holds. In this study, pretreatment storage in a large abandoned quarry conveniently located in the region was assumed with a small operational reservoir for the treated wastewater (effluent).)

Denoting by t the index of the month, we distinguish between the group of the fall-winter months w, w = {9,10,11,12,1,2,3,4} and the peak summer months, t = 5,6,7,8. The fall-winter months will be treated as one group, w. We will also define $T = \{5,6,7,8\} \cup w$.

The fall-winter storage treatment balance is

$$(2) \qquad U_{w5} + \sum_{j=1}^{3} Z_{wj} = (1-\alpha) \sum_{t \in w} S_t$$

where α is the loss coefficient due to evaporation and infiltration during fall-winter;

j is the index of treatment level for use in irrigation; three discrete treatment levels are assumed (j=1,2,3); j = 0 denotes the discharge option before storage, without a treatment plant;

U_{w5} is the quantity (m^3) of wastewater transferred from fall-winter storage during May (t=5); and

Z_{wj} is the quantity (m^3) of wastewater designated for treatment at level j during fall-winter.

The balance equation of storage and treatment in peak month t is:

$$(3) \quad U_{t,t+1} + \sum_{j=1}^{3} Z_{tj} = (1-\beta)\,[S_t + U_{t-1,t}] \qquad t = 5,6,7,8$$

$U_{t,t+1}$ is the quantity (m^3) of stored wastewater transferred at the end of month t to month t+1;

Z_{tj} is the quantity (m^3) of wastewater removed from storage to the treatment plant for treatment level j in month t;and

β is the loss coefficient for peak months.

Defining q_j as the maximal quantity of wastewater treated in the plant during any of the peak months t at treatment level j:

$$q_j = \max Z_{tj} \qquad t=5,6,7,8; \quad j=1,2,3$$

In the mathematical programming model applied, this relationship is expressed as:

$$(4) \qquad q_j \geq Z_{tj}$$

Note that q_j is linked to a negative coefficient in the objective function which maximizes the region's income; therefore, it should be as small as justified.

The region can choose one of the three levels of treatment and/or the discharge option (j=0,1,2,3). This is expressed by relationships (5)-(7):

(5) $$\sum_{j=0}^{3} \delta_j = 1$$

with

(6) $$\delta_j = 0,1 \qquad j=0,1,2,3$$

(7) $$q_j \leq \delta_j M \qquad j=1,2,3$$

with M being an arbitrary large number. Thus, in the case of j=1,2,3

For $\delta_{j*} = 0$, $q_{j*} \leq 0$, which implies $q_j = 0$, for $j \neq j*$.

For $\delta_{j*} = 1$, $q_{j*} \leq M$; with M being sufficiently large, q_{j*} is practically unlimited and continuous for each j (j=1,2,3) which is chosen.

Notice that for j=0 the town discharges all its wastewater; no treatment plant is established. Equation (7) allows, for j≠0, the treatment of part of the effluent and discharge of the other part. The model assumes certainty in the agricultural demand for water; therefore the quantity of treated effluent is determined by the demand for water in the irrigation season; the remainder is discharged after minimal treatment which costs d ($/m^3). The quantity which was stored (after losses) is being treated in a treatment plant and devoted to irrigation.

For each month, there are balance equations of supply (Z_{tj}) and uses of treated effluent:

(8) $$Z_{tj} \geq \sum_{n=2}^{N} R_{tj}^{n} \qquad j = 1,2,3;\ t \epsilon T$$

where

N is the number of "players" in the region (N = number of farms plus one, the town);

R_{tj}^{n} is the effluent amount (m^3) at treatment level j acquired by farm n(n=2,3...,N) during month t. (Index n=1 stands for the town).

The plant's capacity Q_j (m^3/month) is determined by q_j, defined above (4), with the addition of a safety factor γ:

(9) $$Q_j = \gamma q_j \qquad j = 1,2,3$$

The wastewater treatment cost is a non-linear function (Loehman et al., 1979; Dinar, 1984).

A rate r of government subsidy of the treatment cost and conveying capital cost is assumed so that the actual cost function to the region is:

(10) $$P_j = (1-r)F_j(Q_j) \qquad j=1,2,3$$

The following estimate (Dinar, 1984) was used:

$$F_j(Q_j) = 2006\ Q_j^{0.633}\ E_j^{-0.094}$$

where

E_j is the index of treatment level represented by the percentage of BOD remaining in effluent out of the pretreatment original 400 mg/l. For j=1,2,3, these percentages are 15, 8.75 and 4 (60, 35 and 15 mg/l), respectively.

The non-linear cost function (10) is incorporated into the programming model by a separable programming routine (CDC, 1977).

The last equation of the town expresses the cost of transporting wastewater from the town to the treatment plant with the site of the treatment plant being predetermined. Wastewater transport cost to the plant comprises (a) capital cost, and (b) variable cost (mainly energy). Specifically, the following conveying cost function was assumed:

$$(11) \qquad m^1 = (1-r)B^1(K^1) + \nu^1 \sum_{t=1}^{12} S_t$$

where

m^1 is the overall annual cost (\$) of conveying wastewater from the town to the reservoir;

B^1 is the capital cost (\$) as a function of K^1;

ν^1 is the cost of energy per unit of wastewater conveyed from the town to the storage (\$/m^3); and

K^1 is the town's maximal periodic supply (m^3).

K^1 is determined by $K^1 = \max S_t$ (t=5,6,7,8), which is formulated in the programming model as:

$$(12) \qquad K^1 \geq S_t \qquad t=5,6,7,8$$

K^1 has a negative coefficient in the objective function which is being maximized.

When the town operates alone, its goal is to minimize the treatment and conveying costs:

$$f^1 = d \sum_{t=1}^{12} D_t + \sum_{j=1}^{3} P_j + m^1$$

Within the regional framework which is aimed at regional optimization, the town increases its expenses, assuming that the farmers will contribute their share. The above cost function multiplied by (-1) is one component in the regional objective function, which is maximized.

The Farms

The farms in the region differ in their production factors, their technology and their cropping pattern as they relate to the possible regional treatment plant. Their major characteristics are presented in this section along with the relevant components of the programming model.

We denote the farms' group by G. It consists of N-1 farms, $G = \{2,3,\ldots,N\}$. Farm n ($n \in G$) is characterized by L^n land sections and Y^n crop alternatives. Each land section of each farm can be irrigated with effluent, but due to sanitary regulations, it is not possible to irrigate the same land section with both effluent and freshwater during a season, nor to shift, over the years, from effluent to freshwater irrigation, unless special sanitary prevention measures are taken and permission is granted. Each farm can freely transfer freshwater among its land sections as long as its water quota allotments are not exceeded.

The farms can also install irrigation equipment on their nonirrigated areas and grow their irrigated crops. Each farm may have two out of four types of irrigation water at its disposal: k=1,2,3,4, namely effluent at treatment level k=1,2,3, and freshwater k=4, according to the farm's quota allotment. Recall that only one level of treatment of effluent throughout the season is possible.

Farm n's productive capacity is described by the following equations and inequalities:

Land use:

(13) $$I_l^n \geq \sum_{y \varepsilon Y^n} \sum_{k=1}^{4} X_{ylk}^n \qquad l = 1,\ldots,L^n$$

where

X_{ylk}^n is the area (ha) of crop y grown in land section l and irrigated with water of quality k by farm n, $l=1,\ldots,L^n$; $k=1,2,3,4$; $y=1,\ldots Y^n$

For k=1,2,3 water quality used in irrigation is equal to quality of wastewater treated up to the j^{th} level (j=1,2,3); k=4 denotes freshwater supplied from the conventional water system.

I_l^n is the area of farm n's section l (ha).

Water-use balance:

(14) $$\bar{W}_{tk}^n \geq \sum_{l=1}^{L^n} \sum_{y \varepsilon Y^n} A_{yltk}^n X_{ylk}^n - R_{tj}^n \qquad t \varepsilon T,\ k=1,2,3,4;\ j=1,2,3;\ n \varepsilon G$$

where

A_{yltk}^n is the irrigation water amount (m^3) of quality k applied in period t per ha of activity y in farm n's section l; and

$\bar{W}_{tk}^n$ is the farm n's irrigation-water supply and use (m^3) of quality k, in period t.

Effluent supply and use:

(8) $$Z_{tj} \geq \sum_{n \epsilon G} R^{n}_{tj} \qquad j = 1,2,3; \quad t \epsilon T$$

Farm n's site in the region determines effluent conveying costs from the treatment plant (whose site is given) to its fields. The capacity of the effluent conveying system is determined by the maximum periodic effluent supply that must be transported from the plant to these fields:

(15) $$\sum_{j=1}^{3} R^{n}_{tj} \leq K^{n} \qquad t \epsilon T, \ n \epsilon G$$

where

K^n is the farm n's maximal periodic effluent supply (m^3). Note that (15) is equivalent to $R^n_{tj} \leq K^n$ for j=1,2,3.

Conveying cost function from the plant to farm n's fields is:

(16) $$m^{n} = (1-r)B^{n}(K^{n}) + \nu^{n} \sum_{t \epsilon T} \sum_{j=1}^{3} R^{n}_{tj}$$

where

ν^n is the energy costs ($\$/m^3$) of conveying effluent from the treatment plant to farm n.

The characteristics of m^n are identical to those of m^1, which were already discussed in the section concerning the town. The m^n function is also treated with the aid of separable programming. We assume that the energy component in conveying costs depends linearly on the amount of effluent.

Additional restrictions for farm n are represented as follows:

(17) $$H^{n} \underline{\tilde{x}} \leq \underline{b}^{n}$$

where

H^n is the matrix of input factors (other than water) for farm n;

$\underline{X}^{n}$ is the vector of activities not using water and not generating income, to farm n; and

$\underline{b}^n$ is the vector of restrictions not related to irrigation, specific to farm n.

The objective of farm n is to maximize f^n;

$$(18) \qquad f^n = \sum_{l=1}^{L^n} \sum_{y \varepsilon Y^n} \sum_{k=1}^{4} C^n_{ylk} X^n_{ylk} - m^n$$

where

C^n_{ylk} is the gross income ($/ha) for activity unit y in farm n's land section l irrigated by water of quality k (market value net of marketing cost, minus variable cost not including freshwater cost).

The regional objective function f^N is composed of such N-1 individual functions, and the town's effluent treatment cost.

The regional problem is to maximize f^N;

$$(19) \quad f^N = - f^1 + \sum_{n \varepsilon G} [\sum_{l=1}^{L^n} \sum_{y \varepsilon Y^n} \sum_{k=1}^{4} C^n_{ylk} X^n_{ylk} - m^n]$$

subject to restrictions (1)-(17) described above, and the non-negativity restriction on the decision variables.

The model makes it possible to determine the amount of regional income when the town's wastewater is used for irrigation within the framework of regional cooperation.

The decision variables in this model are:

j - treatment level of effluent or the discharge option;

K^n - capacity of the conveying system of wastewater or effluent to/from participant n (n=1,2,3,4);

Q_j - treatment plant capacity for treatment level j; (Note that the capacity and treatment level are determined simultaneously.)

X^n_{ylk} - level of activity y in block l of producer n, irrigated by water of quality k.

Decision variables determined exogenously to the model are the site of the treatment plant, and r -- the rate of government subsidy for treatment and conveying.

Cooperative and Non-Cooperative Solutions

As stated,

f^N denotes the regional gross income when the farms and the town in the region cooperate ($N = \{1\} \cup G$);

f^n denotes the gross income or the cost generated by the n^{th} participant when acting independently ($n = 1,2,\ldots,N$).

A necessary condition for regional cooperation is that:

(20) $$f^{N^o} > \sum_{n=2}^{N} f^{n^o} - f^{1^o}$$

where o denotes the optimal values of f^N and f^n.

Other conditions for cooperation deal with the related cost benefit allocation schemes among the farms and the town. These are discussed in the following paper (Dinar et al., 1985).

The model is able to solve for both the cooperative and the non-cooperative situation. In the first situation the town and all the farms in the region cooperate to treat the municipal wastewater and use the effluent for irrigation (a "grand coalition" is formed using game theory semantics); in the second situation the town and each of the farms operate independently. In this case, the town disposes the wastewater and the farms use their freshwater quota allotments only.

Intermediate situations, namely cooperation among the town and some of the farms, are also possible ("partial coalitions" in game theory terms). Note that any cooperation, a grand or a partial coalition, is possible only if the town participates and supplies effluent.

The model includes the options to treat or not to treat wastewater for irrigation, and for each farm, to use or not to use the effluent. This formulation leads to the following result:

$$\xi^{1^o} \leq f^{1^o}; \quad \xi^{1^o},\ f^{1^o} < 0$$

(21)

$$\xi^{n^o} \geq f^{n^o}; \quad \xi^{n^o},\ f^{n^o} > 0; \quad n=2,3,\ldots,N$$

where

f^{1^o} and ξ^{1^o} are the town's treatment cost in the non-cooperative and the cooperative optimal solutions, respectively; f^{n^o} and ξ^{n^o} are the n^{th} farm income in the noncooperative (= no use of effluent for irrigation) and cooperative (= reuse of effluent) solutions, respectively.

Relationship (21) holds because the objective function (19) is to maximize the region's income which is the sum of the town's treatment cost and of the (N-1) farms' incomes. If wastewater treatment is not profitable from the region's standpoint (its objective function), i.e., $\delta_1 = \delta_2 = \delta_3 = 0$, then the programming problem (1) - (17) and (19) becomes a set of N independent programming problems and the solution represents the individualistic solutions of the town and each of the farms, with $\xi^{n^o} = f^{n^o}$ for all n.

If the use of effluent for irrigation is profitable from the region's point of view for any subset of farms $s \subseteq G$, then a coalition s* between the town and that subset will be created, $s^* = s \cup \{1\}$, with the other farms (N-s) acting independently. (In terms of the model solution this is obtained by allocating effluent to the farms $n \varepsilon s^*$.) The optimal value of the regional objective function is

$$f^{N^o} = f^{\{s^*\}^o} + \sum_{n \not\varepsilon s^*} f^{n^o}$$

where $f^{\{s^*\}^o}$ is the s*th coalition income. Notice that

$$f^{\{s^*\}^o} = \sum_{n \varepsilon s^*} \xi^{n^o} \geq \sum_{n \varepsilon s^*} f^{n^o}, \qquad \xi^{1^o},\ f^{1^o} < 0$$

and $\xi^{n^o} \geq f^{n^o}$ for all $n \varepsilon s \ \varepsilon\ s^*$. The value of the regional objective function is not optimized if for some farm n, $n \varepsilon s^*$, $\xi^{n^o} < f^{n^o}$. In game theory terms, "individual rationality" holds for each farm.

The difference $\sum_{n \varepsilon s} (\xi^{n^o} - f^{n^o})$ can be used for the compensation to the town for its additional treatment cost.

Notice that $\sum_{n \varepsilon s} (\xi^{n^o} - f^{n^o}) \geq f^{1^o} - \xi^{1^o}$ and the compensation is possible.

EMPIRICAL ANALYSIS

Data and Description of the Region

The empirical analysis is being applied to a real case in the Ramla region on the coastal plain of Israel. The regional system consists of three farms, a town, and a wastewater treatment plant.

The town supplies wastewater of a given quality - 400 mg/l BOD - and a constant quantity - 100,000 m^3/month. The cost of disposing wastewater to non-farm sites (in this case -- the sea) is 0.30 \$/m^3. (All monetary values are constant October 1980 dollars.) If a regional treatment plant is set up, the town operates the plant with the understanding that the effluent will be distributed among the agricultural producers, who will purchase the effluent and pay at least for the additional treatment costs.

Conveyance and treatment cost functions were described in the model section, for detailed data see Dinar (1984). Wastewater storage loss coefficient for fall-winter (α) is 16% and for each peak month (β) is 4% (Berezik, 1982). The sanitary requirements for effluent quality are presented in Table 1. In addition to the sanitary restrictions governing effluent use, there is also the problem of salinity damage resulting from effluent irrigation (the salt concentration is higher in effluent than in freshwater). Soil salinity levels were calculated using a modification (Yaron, et al. 1974, 1979) to a model proposed by Bresler (1967). The soil salinity level used in this study to calculate yield losses of crops is the average between the spring and the fall soil salinity assuming that winter rains leached salt from the root zone. Yield losses are calculated according to coefficients proposed by Maas and Hoffman (1977) and Yaron, et al. (1979), crop budgets are based on Israel Ministry of Agriculture (1980). Basic data for representative crops is reported in Table 2.

The farms differ in their land area, soil quality, irrigation technology, cropping pattern, freshwater quota, salt concentration of irrigation water, and distance from the suggested plant (Table 3). Farm A must participate in any coalition established because of its location.

From the point of view of water use, the crops grown on the farms can be classified into four categories:

1. Intensively irrigated field crops, such as cotton (using alternative irrigation technologies, including drip irrigation), tomatoes and corn for canning.

2. Extensively irrigated field crops, such as wheat (for grain), sorghum, and sunflower.

3. Field crops not requiring irrigation, such as wheat (grain) and forage crops grown for hay or silage.

4. Perennial fruit crops, such as citrus, avocado and vineyards.

Some of these crops are sensitive to salinity (especially citrus and avocado). Detailed data on the technology applied in their growing, and the estimates of their yield losses due to salinity can be found in Dinar (1984).

Results

The optimization model is first solved for the non-cooperative conditions, and offers the optimal solutions for each of the participants when they act independently. This is achieved by imposing $\delta_1 = \delta_2 = \delta_3 = 0$. Table 4 presents the results with respect to the treatment costs of the town, the income of the farms and the shadow prices of freshwater.

Scrutiny of the shadow prices of freshwater in the non-cooperative situation (Table 4) suggests that the month of July is the most effective water constraint for each farm. The annual water constraint is effective for Farms A and B, while the June water quota constrains Farm A only. The high shadow prices of freshwater in July for all farms justify consideration of an additional water source to the region.

Regional cooperation in wastewater treatment for irrigation can arise among the town and some or all of the farms. the model solution for the region studied, suggests that no cooperative agreement will be justified for a government subsidy less than 15% of the overall treatment and the capital component of effluent conveying costs. If less, there is no incentive for any of the farms to use effluent in irrigation and no cooperative treatment plant will be set up. When the subsidy is 15%, cooperation between the town and Farm A is justified, but Farms B and C will be excluded. Only a 50% subsidy provides for a full cooperation ("grand coalition") among all the potential participants.

A comparison of major results for cooperative situations, given 15% and 50% governmental subsidies, is shown in Table 5. It suggests that with a subsidy of 50% a plant of treatment level 2 (see Table 1, column 2) will be established. The 50% subsidy amounts to $497,000 and the regional income is increased by only $365,000. The environmental effects of such a subsidy are quite significant because the share of the regional wastewater used in irrigation (a good solution from the sanitary point of view) is 100% as compared with only 75% at a 15% subsidy level. At a 15% subsidy level only Farm A uses effluent, while at 50% - all three farms participate. A comprehensive and conclusive discussion of the subsidy issue falls beyond the scope of this study. On the basis of (a) the positive environmental effects and (b) the fact that freshwater is significantly subsidized too, a 50% subsidy was assumed for the continuation of the analysis.

Comparisons of other results for the non-cooperative and cooperative situations are presented in Tables 6 through 8. The optimal cooperative solution enables each farm to efficiently reallocate the freshwater quota among the different land sections, to cultivate new land areas and to expand the irrigated crops by irrigating part of them with effluent.

The changes occurring due to the cooperative solution can be summarized as follows:

1. Expansion of Farm A's irrigated areas, no change in Farm B's irrigated area and reduction in Farm C's irrigated areas;

2. Substitution of effluent for freshwater by all producers; the quantity of freshwater use in the region is decreased by 330,000 m^3 per year;

3. Increase in water input per land unit area; decrease in the area of unirrigated crops in the region;

4. Expansion of certain crops and crops' irrigation procedures (new schedules of cotton irrigation, drip irrigation); and

5. Reallocation of freshwater among each farm's various land sections, according to the cropping patterns and the demand of sensitive crops for freshwater.

Tables 7 and 8 present the major changes induced by the cooperation for each farm: Farm A increases the irrigated area from 110 ha to 250 ha of which 170 are irrigated with effluent, substituting effluent

250 ha of which 170 are irrigated with effluent, substituting effluent for freshwater. Farm B does not increase its irrigated area but changes the cropping pattern by increasing cotton's area to 180 ha. Farm C decreases its irrigated area but increases cotton's area to 100 ha, Farm C also equips 10 ha with drip irrigation for cotton. A substantial decrease of 330,000 m^3 of freshwater in the region is another result of the cooperative solution (Table 8, row 1). This quantity remains at the disposition of the national system and can be supplied to another region.

Results in Table 8 line 3 show that for some of the Farms (B and C) there is an increase of the intensity rate of using water as is reflected by the ratio of total applied water per ha. The high ratio for Farms B and C explains the decrease or stability of their irrigated area; for Farm A the ratio decreases because the irrigated area expands so much.

The relatively large source of irrigation water also enables the farms to transfer fresh water from blocks which can be irrigated with effluent to blocks which are limited only to fresh water or that are being cropped with sensitive crops. These results are not presented.

SUMMARY

The paper presents a regional optimization model of municipal wastewater treatment and reuse in irrigation. Maximization of the regional income is constrained by the available production factors, given technologies of agricultural production, wastewater treatment technologies, prices and environmental regulations.

The model was applied to a case study in a small region on the coastal plain of Israel. The empirical results show that without a subsidy, there is no incentive to the farms in the region to use treated wastewater. Partial cooperation between the town and Farm A is

established when a subsidy level of 15% is given. In this case only 75% of the town's wastewater is treated in a treatment plant while the remainder may cause environmental hazards. Comprehensive regional cooperation is possible only with a subsidy level of 50%. In this case all the town's wastewater is treated and all the farms in the region use the effluent for irrigation. The town bears the increased treatment cost for all the other participants, while the farms increase their gross income, and then compensate the town. This is discussed in the following paper (Dinar et al., 1985).

The town and the farms in the region derive direct benefits from cooperation. The environmnent and the national water system which are indirectly involved in the model, also benefit from the cooperative solution. Environmental regulations are being followed in the cooperative solution. The total subsidy of $559,000 to the region provides 330,000 m^3 freshwater to the national water system and the average of 1.69 $\$/m^3$ can be considered as a per m^3 substitute for investment in new water resources. Shadow prices in Table 4 give a comparable range for this investment.

In accordance with the prevailing regulations in Israel the regional optimization model assumes that inter-farm transfers of freshwater quotas are not permissible, and therefore redistribution of the additional regional income should be carried out only through monetary "side payments" by the farms to the town.

The acceptability of the regional cooperative solution depends on the establishment of a redistribution system which is acceptable to all participants. Viewing the regional problem as a cooperative game with "side payments" allows the regional optimization problem and the income problem to be treated separately. This is an important feature of the problem and the model from the point of view of the computational burden.

The problems of redistribution of income and specifically the payments to the town are treated in the following paper.

REFRENCES

Asano, T., and R. S. Mandancy, Water Reclamation Efforts in the United States. In: Water Reuse, edited by E. Joe Middlebrooks, Ann Arbor Science Publishers, Ann Arbor, Mich., 277-281, 1982.

Berezik, S., Nesher-Ramla Reservoir (Hebrew), Planning Report, April 1982.

Bresler, E., A Model for Tracing Salt Distribution in the Soil Profile and Estimating the Efficient Combinations of Water Quality and Quantity under Varying Field Conditions, Soil Science, 104, 227-233, 1967.

California State Water Resources Control Board, Irrigation with Reclaimed Municipal Water, A Guidance Manual, Edited by G. S. Pettygrove and T. Asano, Report Number 84-1 WR, 1984.

Control Data Corporation (CDC), APEX-3 Reference Manual Version 1.1, 1977.

Dinar, A., Economic Analysis of Regional Wastewater Treatment and Use of Effluent in Irrigation and Related Cost Benefit Allocation Schemes (Hebrew), Ph.D. Dissertation, 190 pp., The Hebrew University of Jerusalem, Israel, 1984.

Dinar, A., D. Yaron, and Y. Kannai, Municipal Wastewater Treatment and Reuse: II. Sharing Regional Cooperative Gains from Reusing Effluent for irrigation. W.R.R., Manuscript submitted, 1985.

Dorfman, R., Conceptual Model of a Regional Water Quality Authority, In: Models for Managing Regional Water Quality, edited by R. Dorfman, H. D. Jacoby, and H. A., Thomas, Jr., Harvard Univ. Press, 42-83, 1972.

Feigin, E., H. Bielorai, T. Kipniss, and M. Gal, Use of Municipal Effluent for Irrigating Agricultural Crops (Hebrew), Agricultural Research Organization, The Institute of Soil and Water, Special Publication No. 86, Israel, 1977.

Giglio, R. J., and R. Wrightington, Methods for Apportioning Costs among Participants in Regional Systems, Water Resources Research, 8(5), 1133-1144, 1972.

Goodwin, H. L., Jr., R. F. Victurine, and R. L. Lacewell, Economic Implications of Rural Wastewater Treatment Alternatives, Western Agricultural Economic Association Conference, San Diego, California, 1984.

Israel Ministry of Agriculture, Extension Service, Computerized Budgets for Agricultural Crops, 1980.

Loehamn, E., J. Orlando, J. Tschirhart, and A. Whinston, Cost Allocation for a Regional Wastewater Treatment System, Water Resources Research, 15(2), 193-202, 1979.

Maas, E. V., and G. J. Hoffman, Crop Salt Tolerance--Current Assessment. ASCE, J. of the Irrigation and Drainage Division, IR2 103, 115-134, 1977.

Messer, Jay, International Developments and Trends in Water Reuse, In: Water Reuse, edited by E. Joe Middlebrooks, Ann Arbor Science Publishers, Ann Arbor, Mich., 549-576, 1982.

Moore, C. V., K. D. Olson, and M. A. Marino, On-Farm Economics of Reclaimed Wastewater Irrigation, Chap. 3, In: Irrigation with Reclaimed Municipal Water, A Guidance Manual, edited by G. S. Pettygrove and T. Asano, California State Water Resources Control Board, Report Number 84-1 WR, 1984.

Nakamura, M., and D. Brill, Jr., Generation and Evaluation of Alternative Plans for Regional Wastewater Systems: An Imputed Value Method, Water Resources Research, 15(4), 1979.

Papke, G. R., J. A. Smedile, and Greeley and Hansen, Engineers, Wastewater Treatment Processes and Cost Estimating Data, Staff Paper No. 20, Northeastern Illinois Planning Commission, Chicago, Illinois, April 1977.

Rinaldi, S., R. Soncini-Sessa, and A. R. Whinston, Stable Taxation Schemes in Regional Environmental Management, Journal of Environmental Economics and Management, 6, 29-50, 1979.

Tahal, Unrestricted Use of Effluent in Agriculture (Hebrew), Department of Effluent Reuse, Progress Report No. 2, Israel, 1978.

Victurine, R. F., R. D. Lacewell, and H. L. Goodwin. Economic Implications of Applying Effluent for Irrigation, Western Agricultural Economic Association Conference, San Diego, California, 1984.

Water Commission, Treated Wastewater Designated for Irrigation (Hebrew), Advisory Committee for Establishing Rules on the Quality of Reclaimed Wastewater Used for Irrigation, Israel, 1978.

Yaron, D., J. Shalhevet, and E. Bresler, Economic Evaluation of Water Salinity in Irrigation, Research Report submitted to Resources for the Future, The Hebrew University of Jerusalem, Faculty of Agriculture, 1974.

Yaron, D., A. Dinar, and S. Shamla, First Estimates of Prospective Income Losses Due to Increasing Salinity of Irrigation Water in the South and Nagev Regions of Israel (Hebrew), The Center for Agricultural Economic Research, Working Paper No. 7902, Rehovot, Israel, 1979.

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Table 1: Effluent Quality Requirement for Major Crops

Crop Group	A	B	D
BOD level (mg/l)	<60	<35	<15
Coliforms (bacteria/100 ml)	--	<250	<12[a]
Treatment level index, j	1	2	3
Crops	- Cotton - Sugar beet - Seed crops - Cereal - Hay crops - Silage crops	- Fodder crops - Peanuts - Olives - Dates - Almonds - Citrus - Pecans - Other fruits with inedible peels - Deciduous fruit crops irrigated under canopy - Fruits and vegetables for canning - Vegetables consumed after cooking - Vegetables eaten without peels	UNRESTRICTED IRRIGATION

[a]For 80% of the samples.

Source: Water Commission (1978).

Table 2: Basic Data for Representative Crops

Crop	Loss coefficient		Var. cost not inclu. water and labor ($/ha)	Labor (day/ha)		Yield price minus marketing cost ($/ton)	Water (c.m./ha)					Common yield with good water (ton/ha)
	b	a		cultiv.	harvest		May	June	July	Aug	Annual	
Cotton 3 irrig. sprinkl.	5.2	7.7	1196	8	3	747.5		1000	2200		3200	4.8[a]
Cotton 4 irrig. sprinkl.	5.2	7.7	1245	9	4	747.5		900	2200	900	4000	5.3[a]
Cotton drip	5.2	7.7	1329	10	5	747.5	400	600	1400	1200	4300	5.8[a]
Tomato industry sprinkl.	9.9	2.5	1561	21	9	73.1		1800	1700		5000	100.0
Peanut	2.9	3.2	1345	15	9	1013.2	400	2800	1200	600	5000	6.0
Wheat grain dried	7.1	6.0	615	2	1	299						4.0
Wheat grain irrigated	7.1	6.0	689	3	1	299					2400	6.0
Wheat silage	7.1	6.0	681	3	1							30.0
Avocado	30.0	1.3	2835	35	26	2032.7	600	1500	1800	1800	9000	12.0
Wine grapes	10.6	1.2	5814	36	25	1328.9	800	1000	900		3100	20.0
Pecan	30.0	1.3	498	10	20	1528.2	1000		800		2500	2.5
Citrus	30.0	1.3	6644	35	9	573.1	900	900	1000	1000	9000	45.0

Monetary values are constant 1980 dollars.

[a] Lint and grain yield.

Table 3. Farms' Major Water and Land Characteristics

Participant	Total Irrigated Land Area (ha)	Fruit Crops Included in Total (ha)	Total Unirrigated Land (ha)	Annual Fresh-Water Allotment (000 m3)	Peak Months Water Quota (000 m3)	Water Per Land Unit[a] Irrigated Only (m3/ha)	Water Per Land Unit[a] Total (m3/ha)	Water Per Land Unit[a] Peak Month (m3/ha)
Farm A	240.0	108.4	58.0	1600	159	6660	5360	660
Farm B	350.0	20.0	372.6	902	300	2580	1330	850
Farm C	196.9	42.5	91.1	850	138	4320	2930	700

[a]Without effluent.

Table 4. Cost, Gross Income and Shadow Prices of Freshwaster under the Optimal Non-Cooperative Solution

	Town	Farm A	Farm B	Farm C	Region's Total
Cost/Income ($000)	-368	1,940	1,285	440	3,297
		Shadow prices of water ($/m^3)			
June quota		0.515	0	0	
July quota		1.074	0.559	1.161	
Annual quota		0.191	0.139	0	

Monetary values are constant 1980 dollars.

Table 5. A Comparison of Major Results in the Regional Optimization Solution at Different Subsidy Levels

Variables	15% Subsidy	50% Subsidy
Farms participating	A only	all region's farms
Regional income ($000)[a]	3,255	3,622
Level of treatment	2	2
Wastewater to be treated (000 m^3)	900	1200
Effluent used in irrigation (000 m^3)[b]	700	1015
% of regional wastewater	58	85
% of regional treated wastewater	7	100
Total Treatment Costs ($000)	749	993
Subsidy ($000)	113	496[c]
Treatment Costs to Region ($000)	636	497

Monetary values are constant 1980 dollars.

[a]Regional income with the subsidy included.

[b]Gap between used effluent and treated wastewater is due to evaporation and infiltration in the storage site (model eqs. (2)-(3)).

[c]Rounded values.

Table 6: Average Treatment and Conveying Costs in a "Grand Coalition" Cooperative Setting

	Town	Farm A	Farm B	Farm C	Region
cost/income in non-cooperative solution ($000)[a]	-368	1,940	1,285	440	3,297
cost/income in cooperative solution ($000)[a]	-497	2,266	1,365	488	3,622
Overall treatment cost ($000)[b]	993	-	-	-	
Subsidy for treatment ($000)	497	-	-	-	
Treatment cost net of subsidy($000)	497	-	-	-	
Total effluent purchased (000 m^3)	-	680	273	62	1015
Average treatment cost net of subsidy ($\$/m^3$)	0.489	0.489	0.489	0.489	
Subsidy for transportation ($000)		25	33	3.8	
Transportation cost net of subsidy ($000)	-	27	38	4	
Average transportation cost net of subsidy ($\$/m^3$)	-	0.039	0.143	0.068	
Overall average cost net of subsidy ($\$/m^3$)	-	0.528	0.623	0.557	

Monetary values are constant 1980 dollars.

[a]Before redistribution of income.

[b]Includes towns' transport cost.

[c]Only for the capital component.

Table 7: Land Use and Cropping Patterns under the Non-cooperative and Cooperative Situations

Farm Situation	A		B		C		Region	
	Non-Coop.	Coop.	Non-Coop.	Coop.	Non-Coop.	Coop.	Non-Coop.	Coop.
(1) Irrigated field crop area (ha)	110.4	251.6	230.9	230.9	153.2	108.3	494.5	590.5
(2) Irrigated fruit crops (ha)	108.4	108.4	40.5	40.5	20.0	20.0	168.9	168.9
(3) Total irrigated area (ha)	218.8	360.0	271.4	271.4	173.2	128.3[a]	663.4	759.7
(4) Effluent irrigated area (ha)[b]	-	167.8	-	94.9	-	20.0	-	282.7
(5) Percent of effluent irrigated (%)[c]	-	47	-	35	-	16	-	37
(6) Unirrigated crop area (ha)	183.5	113.3	424.3	424.3	-	59.0	607.8	596.6

[a]Including 100 ha newly equipped for irrigation

[b]Included in (3)

[c]100·(4)/(3)

Table 8: Use of Water under the Non-Cooperation and Cooperative Situations (rounded numbers).

Farm	A		B		C		Region	
Situation	Non-Coop.	Coop.	Non-Coop.	Coop.	Non-Coop.	Coop.	Non-Coop.	Coop.
1. Total freshwater use (000 m3)	1450	1280	760	700	500	400	2710	2380
2. Total effluent use (000 m3)	-	680	-	273	-	62	-	1015
3. Total applied per irrigated ha (m3)	6600	5440	2800	3600	2900	3600	4100	4470
4. Total water use (000 m3)	1450	1960	760	973	500	462	2710	3395
5. Change in water use (%)	+35		+28		-8		+25	
6. Use of fresh water in June (000 m3)	219	318	104	275	51	79	374	672
7. Use of effluent in June (000 m3)	-	210	-	34	-	20	-	264
8. Use of fresh water in July (000 m3)	241	209	183	182	90	118	514	509
9. Use of effluent in July (000 m3)	-	221	-	65	-	18	-	304

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