77

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United States - Israel Binational Agricultural Research and Development Fund

FINAL REPORT

PROJECT. No. I-101-79

Analysis of Efficient Regional Allocation of Irrigation Water with Emphasis on Salinity and the Related Cost Sharing Scheme

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1984

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Date 25 April, 1984

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P.O. Box 6
Bet Dagan, ISRAEL

BARD Project No. I-101-79

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Names of Investigators:

Principal Investigator: Dan Yaron

Cooperating Investigator(s): Robert A. Young

Name and Address of Affiliated Institutions:

Principal Institution: The Center for Agricultural Economic Research

P.O. Box 12, Rehovot, Israel

Cooperating Institution(s): Colorado State University

Fort Collins, Colorado, USA

Project's starting date: March 1, 1980

Type of Report: 1st Annual _____ 2nd Annual _____ Final x

Signatures:

Principal Investigator

Dan Yaron

Institution's Authorizing Official

Joel Hsieh

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b. Table of Contents

c. Abstract

d. Scientific Report

Chapter 1: The Background and the Motivation for the Study.

Part One

Chapter 2: Optimal Allocation of Water Quantity and Quality
in a Region and the Related Income Distribution

Part Two - Regional Cooperation in Treatment of Municipal Waste Water
and Use of Effluent in Irrigation.

Chapter 3: Use of Municipal Waste Water for Irrigation - an
Introductory Review

Chapter 4: Optimization of Municipal Waste Water Treatment and
Use in Regional Irrigation

Chapter 5: Cost/Benefit Allocation Schemes

References: a) English

b) Hebrew

Part Three - Supporting Studies

Chapter 6: Evaluation of Irrigation Water Quality for a
Spatially Variable Field

e. Description of Cooperation

f. Benefits to Agriculture

g. List of Publications

c. Abstract

Irrigation with low quality (saline) water is a major problem in Western USA and Israel. This is due to the relative scarcity of good quality water and the necessity to develop and use low quality water resources. These prospects provided the motivation for the study.

The report presents two case studies. The first one refers to a small region and analyzes the potential of cooperation in water use with emphasis on water salinity. The second case study deals with the analysis of regional cooperation in treatment of municipal waste water and the use of effluent (with higher salinity than fresh water) in irrigation. The use of effluent in irrigation is subject to sanitary regulations and government control.

These two case studies deal with essentially the same problem - efficient use of water resources within a region, with emphasis on water quality, (salinity), and the evaluation of the economic potential of regional cooperation in water use. The problems faced by a region are: a) Determination of water quantity and quality for the region; b) Water allocation among the farms; and c) The related scheme of allocation of costs and benefits. Alternative schemes of cost/benefit allocations were derived with the aid of Game Theory approaches.

The models developed in the study may provide a useful framework for the analysis of similar problems in Israel and the US. The major empirical findings (which apply to the conditions studied in Israel) are: a) There is a considerable economic potential in regional cooperation in water use; b) Regional cooperation in waste water treatment and use in irrigation depends on government subsidy; its extent determines the extent of cooperation; c) The game theoretic approaches do not generally provide acceptable and undisputable solutions to the cost/benefit allocation problem.

Chapter 1
INTRODUCTION

THE BACKGROUND AND THE MOTIVATION FOR THE STUDY

Soil salinity problems and irrigation with saline water are widespread - it is estimated that they affect about one third of all irrigated land (Yaron et al., (1969)). According to Evans (1974), about 28% of irrigated land in the U.S. suffers from depressed yields due to salinity. Furthermore, the salinity problem of the Colorado River is considered as one of the most troublesome issues in U.S.-Mexican relations in recent years (Oyarzabal and Young (1978)).

Irrigation with saline water is, as well, a major problem in Israel. This is due to: a) the relative scarcity of good quality water and the necessity to utilize water resources of poor quality (including large scale utilization of reclaimed sewage); b) existing potential for development of brackish water resources; c) the process of gradual deterioration in quality of natural flows and aquifers, and d) existing plans for desalinization of brackish and/or sea water on an experimental or large scale basis. The safe yield of all sources of good quality water is estimated at 1,600 million c.m. (Greenwald, (1980, Hebrew)), while the projected water use for the end of the century is above 2,000 million c.m. The gap would be covered by brackish water, with estimated potential of 150-175 million c.m., reclaimed sewage (=effluent) and other "marginal" sources with estimated potential of 250-300 million c.m. (Greenwald, (1980, Hebrew)). This implies that nearly one half of the water supply to agriculture by the end of the century would be from the above low quality sources.¹⁾ In some regions the projected water supply situation might be even more severe as reflected by Table 1.

¹⁾ In effect in 1979 140 million c.m. of brackish water and 45 million c.m. of effluent were already in use in agriculture (Greenwald, (1980, Hebrew), Dinar (1983, Hebrew)).

Table 1: The Share of "Marginal" Sources in Water Supply to Agriculture in Selected Regions in 1976 and Projection for the Year 2000

Region	1976			2000		
	Supply mill. c.m.	Effluent %	Brackish water %	Supply mill. c.m.	Effluent %	Brackish water %
Rehovot	179	3	1	174	48	1
Negev	268	2	1	306	46	11
Arava	17	12	41	38	39	61

Source: Tahal (1979, Hebrew)

The above prospects call for a comprehensive analysis of optimal utilization of irrigation water of different quality levels.

The problems involve all levels in the hierarchy extending over a single crop - single farm - and regional and multiregional entities. This study is concerned with the issue of efficient utilization of irrigation water at the regional level with emphasis on quality, and attempts to develop an analytical framework for an economic analysis of:

- 1) The optimal level of water quality of the water supply to a region.
- 2) Optimal allocation of the irrigation water among farms.
- 3) Related schemes for the allocation of costs and benefits among the farms and the determination of the extent of government support, if necessary.

The issues involved can be viewed as having two dimensions: a) economic, and b) institutional. On most farms in the U.S. and Israel, on which water is scarce relatively to other resources, the intra-farm water allocation is subject to economic considerations. However, the inter-farm and the inter-regional water allocation is dominated by institutional considerations. The understanding of the issues involved and the knowledge of guides for optimal inter-farm water allocation with emphasis on the parameter of quality, and the related schemes for cost/benefit sharing are important to agriculture and water institutions

for the sake of: a) determining the quality level(s) of the irrigation water, and b) for planning changes in the institutional allocation of water with both parameters of quantity and quality taken into consideration.

SUBJECTS OF STUDY AND CONTENTS OF THE REPORT

This report presents two case studies. The first one refers to a small region and analyzes the potential of cooperation in water use with emphasis on water salinity. The regional cooperation focusses on:

- a) the determination of water salinity supplied to the region by the Regional Project, with the option presented to the region to increase the quantity of water supplied, along with increasing its salinity content;
- b) inter-farm water allocation providing for efficiency in water use; and
- c) allocation of the gains derived from the regional cooperation among the region's farms, with emphasis on game theoretic approaches.

Several alternative background scenarios for the regional cooperation are assumed; all scenarios assume inter-farm water mobility, namely transfers of institutionally allotted water quotas from one farm to another, according to efficiency criteria, and contrary to the current institutional regulations. This study is presented in Part One, Chapter Two. It is based on an M.Sc thesis by Ratner (1983, Hebrew) in which additional details can be found.

The second case study deals with the analysis of regional cooperation in treatment of municipal waste water and the use of effluent in irrigation. A small region in the Coastal Plain of Israel (the Ramla region, east to Tel-Aviv), with one town - the source of the waste water - and agricultural periphery with several farms, provides the empirical background for the analysis. The issue faced by the region is the option to use treated waste water (=effluent) in irrigation with the specific decision variables being:

- a) Determination of the capacity of the regional treatment plant (it is assumed that its location is exogenously predetermined);
- b) Decision on the waste water treatment level;
- c) Allocation of the effluent to the region's farms;
- d) Choice of an optimal crop mix and the allocation of effluent to the various land blocks of the region's farms;
- e) Cost allocation to the participants.

The region's farms have at their disposable institutionally allotted quotas of freshwater. Effluent, if used, is considered in this study as a supplementary source, not as a substitute for fresh water.¹⁾ The use of effluent in irrigation is subject to sanitary regulations and government control. Furthermore the study assumed that quotas of fresh water are not transferable among the region's farms. Again, this is in accordance with the prevailing regulations and practice in Israel. The farms can only reduce their use of fresh water supplied by a regional project (linked to the National Water Carrier), and thus save this resource in nationally controlled ground water reservoirs.

The second case study is presented in Part Two, Chapters 3 through 5, on the basis of a Ph.D thesis by A. Dinar (1983, Hebrew) in which more details on the subject can be found.

The above two case studies deal with essentially the same problem - efficient use of water resources within a region, with emphasis on water quality, evaluation of the economic potential of regional cooperation in water use and analysis of alternative schemes of costs and benefits among the prospective participants. The scenarios and the background details of the two studies are different; and numerous other scenarios can be assumed, as well.

The attitude towards the issue of regional cooperation in water use for irrigation is that with reference to small regions (15-25 settlements) viewing the supply-demand relationships as a competitive market is inappropriate due to the following reasons: a) The farms in the region are not anonymous; there are "close neighbourhood" relationships; partial "cooperation agreements" are possible; b) The decision on water quality for the region (salinity level in the first case study, effluent quality in the second) necessitates an agreement by all region's farms,²⁾ and c) Treatment of waste water, as considered in the second case study, is subject to increasing economies and decreasing marginal cost. In such a case marginal cost pricing leads to a deficit, which should be covered either by the users or some external agency (e.g. government) or both.

¹⁾ This is in accordance with the current conditions in Israel which would probably change in the future. It is likely, however, that in the future fresh water quotas would be, in part, substituted by effluent.

²⁾ A dual quality water supply to a region, whereby each farm would be able to choose its preferred quantity-quality mix invalidates this argument. Further study is needed to learn the costs and benefits of such systems. Note that an elaborate multi-salinity supply system exists in the Beissan Valley in Israel.

Accordingly, the pricing of water, the level of other decision variables and the related income redistribution should be negotiated and agreed upon. Several approaches from the field of Cooperative Games Theory, were applied to derive alternative schemes of cost/benefit allocations among the participants in the regional cooperation (Core and Nucleolus, Shapley Value, Modified Shapley Value, Nash solution).¹⁾ Pricing of water according to its shadow cost was also applied. Both case studies conclude with an attempt to evaluate the acceptability, reasonableness and fairness of these alternative cost/benefit allocation schemes.

The effect of water salinity in irrigation on crop yields, was estimated according to procedures described by Yaron et al. (1979, Hebrew), and Yaron and Ratner (1982). An attempt to evaluate the effect of spatial soil variability under conditions of saline irrigation water was undertaken during the study. Its product is an expositional type paper presented in Part Three, Chapter 6 (reproduced from WRR); due to lack of sufficient "hard" data it is not presently possible to apply the approach developed in an empirical or quasi empirical, more realistic, study.

Acknowledgements

E. Bresler provided advice on issues related to irrigation with saline water, and S. Berzik - on the technology of waste water treatment. Their assistance is highly appreciated.

¹⁾ An introductory discussion of these approaches along with related references is given in Chapter 5.

PART ONE

Chapter 2

OPTIMAL ALLOCATION OF WATER QUANTITY AND QUALITY IN A REGION AND THE RELATED INCOME DISTRIBUTION

THE BACKGROUND

Water rights in Israel have been determined in the early fifties. Since then significant technological progress in Israeli agriculture has occurred and has induced changes in the types of farms and their derived demand for water. With water rights kept unchanged and interfarm water mobility being restricted by the institutional regulations ¹⁾ the result is inefficiency in the interfarm and interregional water allocation, with significant differences in the marginal value product of water on farms in the same region.

The case for increasing efficiency in water allocation advocated by economists and agricultural economists has had limited results (see Yaron (1966)). In the early seventies a system of differential pricing for irrigation water was introduced ²⁾ but due to political pressures it was essentially abandoned, after a short life time of 3 years approximately.

The inefficiency of the institutional water allocation system is being recently exacerbated by the rising importance of the quality dimension of water for irrigation. With one water quality level, the allotment of water quotas to farms involves two parameters only - the annual and the peak season ³⁾ quantities. With a dual water supply, namely with good quality and low quality water being supplied to a region - and this is the trend for the future - there are four allocation parameters to be considered. The growing complexity of the water allocation problem in such situations, would, necessarily, increase the inefficiency of the institutional allocation system and emphasize the need for interfarm water mobility.

¹⁾ Interfarm water transfers are officially forbidden.

²⁾ Increasing prices for increasing quantities of water, with the average price for the average user being unchanged.

³⁾ Defined on monthly, weekly, daily or even hourly basis, depending on the specific conditions.

A recent trend in Israeli agriculture which may support the case for increased efficiency in water use is the emergence of regional farmers' organizations established with the aim to utilize treated urban wastewater or brackish water. With the farmers sharing investment in the development of these "marginal" water sources it is likely that increased efficiency in water use would be on the agenda of the regional farmers' organizations.

The problem addressed in this chapter refers to a region with several farms, with a given water quota allotment of given quality (qualities) to each farm. The major source of water supply to the region is a Regional Project (linked to the National Water Carrier) with water salinity content of 220 ppm Cl. The region can negotiate the receipt of a higher quota allotment from the Regional Project at the cost of increasing its salinity content (substitution of quantity for quality), according to a quantity-salinity transformation curve (1) specified to the region by the national authorities (see (1) below).

Some of the region's farms have at their disposition wells with relatively highly saline water (above 1000 ppm Cl). Pumping from these wells is subject to quotas too. The farms owning such wells include them in their consideration regarding the water supply from the Regional Project.

THE WATER ALLOCATION MODEL

Consider a region with a given allotment of water ($\bar{G}\bar{W}$) of given salinity level (R_0). $\bar{G}\bar{W}$ is the sum of the individual farm quotas ($G\bar{W}_i$),

$$(\bar{G}\bar{W} = \sum_{i=1}^I G\bar{W}_i).$$

Assume that the National Water Carrier can supply the region with a larger water quantity at the cost of increasing its salinity. For a given $\bar{G}\bar{W}$, the substitution between water quantity $\bar{W}$ and its salinity R is subject to a transformation curve determined by the national authority.

$$(1) \quad F(\bar{W}, R | \bar{G}\bar{W}) = 0$$

1) For simplicity, a single quality water supply to the region from the Regional Project is assumed. Conceptually, the analysis can be easily extended to a dual supply situation.

We further assume that the quality of water R must be the same for the region and all of its farms. Obviously $\sum_i W_i = \bar{W}$ with W_i denoting the quantity of water quality R allocated to farm i .

Farms' i income y_i is a function of W_i and R :

$$(2) \quad y_i = y_i(W_i, R) \quad i = 1, 2, \dots, I$$

The problem faced by the region is to determine simultaneously:

- a) The optimal quantity-quality ($\bar{W}$ - R) mix for the region with reference to the transformation curve (1).
- b) The quantity of water W_i of quality R ($R \geq R_0$) allotted to each of the region's farms.

This is a classical problem of equilibrium in the supply and use of "public" and "private" goods. In our context we refer to water quality R as a "public good" which "all enjoy in common, in the sense that each individual's consumption of that good leads to no substitution from any other individual's consumption of that good" (Samuelson (1964)). This is opposed to "a private good" (in our context - the quantity of water) which can be parceled among different individuals and the consumption of that good by one individual does reduce the quantity remaining for the consumption of the others.

The optimality conditions involving the relationship between $\bar{W}$ and R , are obtained from the following problem:

$$(3) \quad \text{Maximize } U = \sum_{i=1}^I \lambda_i y_i$$

subject to

$$(4) \quad \begin{aligned} F(\bar{W}, R | G\bar{W}) &= 0 \\ \sum_{i=1}^I W_i - \bar{W} &= 0 \end{aligned}$$

with U being the region's welfare function and λ_i - relative weights assigned to the i -th farm income ($\lambda_i > 0$; $\sum \lambda_i = 1$). The optimality conditions satisfy:

$$(5) \quad \sum_{i=1}^I \frac{\partial y_i}{\partial R} / \frac{\partial y_i}{\partial W_i} = \frac{F_R}{F_{\bar{W}}}$$

with F_R and $F_{\bar{W}}$ being the partial derivative of F with respect to R and $\bar{W}$, respectively. Relationship (5) implies that the sum of the individual farms' marginal rate of substitution between water quantity for quality in water use should equal the technical marginal rate of substitution between water quantity for quality in supply. By parametrically varying the λ_i weights, the "efficiency frontier" in the I farms' income space can be derived. The efficiency frontier is the locus of Pareto-optimal points with the property that any move from such a point aimed at improving the income of one farm must necessarily reduce the income of some other farm(s).

The above model can be written alternatively as:

(6) Maximize y_1
subject to (4) above and restrictions on incomes of the $(I-1)$ remaining farms.

(7) $y_i \geq K_i \quad i = 2, \dots, I$

By parametrically varying the K_i values in (7) the interfarm income efficiency frontier is obtained.

For the case of two farms in the region ($I=2$), the problem and its solution can be graphically presented (Fig. 1, 2, and 3).

Fig. 1 presents (a) the $\bar{W}$ - R transformation curve (TT) confronted by the region; (b) iso-income curve of farm 2 at level y_2^* obtainable at various combinations of W_2 and R ; (c) iso-income curve of farm 2 at level y_2^{**} .

Fig. 2 shows two residual W - R transformation curves confronted by farm 1 (T_1^* and T_1^{**}) in correspondence with the two iso-income curves of farm 2. For each level of R , the corresponding W_1 value is obtained by vertical subtraction of y_2^* (or y_2^{**}) iso income curve from the TT curve. Fig. 2 shows also two iso-income curves y_1^* and y_1^{**} for farm 1 and the optimal combination of water quantity and quality for farm 1 (and for farm 2, as well), obtained at the points of tangency (C and D) of curves y_1^* to T_1^* , and y_2^* to T_2^{**} , respectively. Each point of tangency represents the incomes of farms 1 and 2 and the corresponding optimal levels of $\bar{W}$ and R (on the transformation curve $\bar{W}$ - R). By parametrically varying the level of farm's 2 income a family of similar tangency points is obtainable. The locus of all such points is the interfarm income transformation curve (TY) shown in Fig. 3.

Fig. 1 $\bar{W}$ - R transformation curve (TT) and farm 2's iso-income curves Y_2^* and Y_2^{**} .

Fig. 2 Residual $\bar{W}$ - R transformation curves confronted by farm 1 and optimal W_1 - R combination points C and D .

Fig. 3 Income transformation curves between farms 1 and 2.

The Operational Model

Ratner (1983) has applied a linear programming model to the empirical estimation of an income efficiency frontier such as TY in Fig. 3 for a quasi-empirical region in the Negev area of Israel. In the transition from the theoretical model to the operational one, it was decided, for computational convenience, to refer to R as an exogenous, parametrically varying variable,¹⁾ R = 260, 300, 350, 400 ppm Cl with the water quality of GW being 220 ppm (R_0 , the current salinity level). The essentials of the model are presented below.

(8) Maximize f

$$f = \sum_{ij} c_{ij}^R x_{ij}^R$$

subject to

Shadow price
notation

$$(9) \quad \sum_j w_{ij}^R x_{ij}^R - w_i^R \leq 0 \quad i = 1, 2, \dots, I$$

$$\sum_j d_{ij}^R x_{ij}^R - sw_i^R \leq 0$$

$$(10) \quad \sum_i w_i^R - \bar{w}^R \leq 0 \quad \underline{u}^0$$

$$(11) \quad \sum_i sw_i^R - \bar{sw}^R \leq 0 \quad \underline{v}^0$$

$$(12) \quad \frac{1}{\alpha} \bar{w}^R \leq \bar{Gw} \quad \underline{w}^0$$

$$(13) \quad \frac{1}{\alpha} \bar{sw}^R \leq \bar{Gw} \quad \underline{z}^0$$

$$(14) \quad \sum_j a_{pij} x_{ij}^R \leq b_{pi} \quad \begin{matrix} i = 1, 2, \dots, I \\ p = 1, 2, \dots, p \end{matrix}$$

$$(15) \quad \sum_j c_{ij}^R x_{ij}^R \geq K_i \quad i = 2, 3, \dots, I$$

¹⁾ Feinerman (1980) and Feinerman and Yaron (1983) have incorporated R into a linear programming model as an endogenous continuous decision variable, along with the quantities of water to be applied to the farms' crops. However, their approach is computationally cumbersome and has not been applied here.

where c_{ij} = income per activity unit j on farm i [\$];

x_{ij} = level of activity j on farm i ;

W_i^R, SW_i^R = annual and high season water of quality R allocated to farm i ;

$\bar{SW}^R$ = high season water of quality R used by the region;

w_{ij}, d_{ij} = respectively, total and high season water inputs per activity unit j ;

α^R = regional coefficient of substitution between good quality water (GW) for water of quality R ($\alpha > 1$);

β = maximal share of high season water used out of the annual total ($0 < \beta < 1$);

a_{pij} and b_{pi} = respectively, input coefficient and availability level of restriction p other than water;

K_i = restriction level on the i -th farm income $i = 2, \dots, I$.

Assuming that restrictions (10) - (13) are binding, denoting their shadow prices at the optimal solution by $\bar{u}^0, \bar{v}^0, \bar{w}^0$ and $\bar{z}^0$, respectively, and substituting $\bar{SW}^R = \beta \bar{W}^R$, we get from the optimality conditions:

$$(16) \quad \bar{w}^0 = \frac{1}{R} \bar{w}^0 \text{ or } \bar{w}^0 = \alpha^R \bar{u}^0$$

$$\bar{u}^0 = \frac{1}{R} \bar{z}^0 \text{ or } \bar{z}^0 = \alpha^R \bar{v}^0$$

and

$$(17) \quad - \frac{d\bar{W}^R}{d\bar{GW}^R} = \frac{f/\partial \bar{GW}^R}{f/\partial \bar{BW}^R} = \frac{\bar{w}^0 + \beta \bar{z}^0}{\bar{w}^0 + \beta \bar{v}^0} = \alpha^R$$

Relationship (17) implies that the marginal rate of substitution between water of quality R and water of current quality $\bar{GW}$ in use on all farms should equal the technical rate of substitution α^R in the regional supply transformation relationship.

When restriction (15) is deleted, the optimal solution of (8) through (14) determines the highest income obtainable for the region, for water quality R . By incorporating (15) and parametrically varying the K_i levels, interfarm income efficiency frontier is obtained. Note that restriction (15) does not affect the Pareto-optimality conditions (16) and (17) which hold for any point on the income efficiency frontier. For any given set of K_i levels $i = 2, \dots, I$ the optimal R can be found by solving (8) through (15), parametrically for the discrete R levels considered. ¹⁾

¹⁾ Since R is discrete, this is a "nearly optimal" R level.

For simplicity of presentation the saline wells owned by some of the farms were not included in the model formulation presented. They were included in the empirical analysis in the following way: (a) Annual and peak season pumping restrictions were defined; (b) Activities using water from these sources only, and activities using mixed-saline wells' and the Regional Project water - were specified according to the prevailing practices on the farms.

A QUASI EMPIRICAL APPLICATION

The Derivation of the Income Transformation Curve for a Two Farms Case

The above model has been applied to the analysis of a small region, in the Negev, southern Israel. A small "region" with two kibbutz farms and one moshav¹⁾ was addressed; such a small, somewhat artificially defined region, enables to expand the analysis in several directions, formulate alternative underlying scenarios and attempt various approaches.

We commence the presentation of the results with reference to a "subregion" comprising the two kibbutz farms only. The farms, hereafter kibbutzim A and B, have at their disposal certain annual and high season quotas of water from the Regional Project, (with a current salinity of 220 ppm Cl), self owned wells of saline water (salinity content of above 1000 ppm Cl) with annual and high season pumping quotas, and, certain areas of irrigable land. The major differences between these two adjacent farms are:

- (a) The land of kibbutz A is practically unlimited while on B it does limit the cropping area;
- (b) The soil type is different; on kibbutz A it is mostly sandy soil, on B it is sandy loess or loess. Accordingly the mix of crops on the two kibbutzim is different too.
- (c) The share of the high season water supplied from the Regional Project out of the annual total, is 20% and 12%, respectively, for farms A and B;
- (d) The high season pumping quota from the self-owned wells is 10% and 30% respectively, for the two farms.

¹⁾ Moshav - a cooperative village of 60-100 family farms. The village cooperative acts as a credit organization and maintains production and marketing services.

The regional cooperation model was applied to the two farms using the following assumptions:

- 1) The regional supply transformation relationship between water quality R and quantity $\bar{W}$ is:

R ppm Cl	Compensational $\bar{W}$ as % of GW
220	0
260	3.0
300	5.5*
350	8.0
400	10.0

- 2) The income of each farm under cooperation must be equal to or higher than its income before cooperation ("individual rationality" assumption);

- 3) The $\bar{W}$ - R combination for the region is determined as part of the cooperative arrangement; so are the quantities of water allocated to each farm;

- 4.1) The cooperation is restricted to the Regional Project only;

or

- 4.2) The cooperation in water use involves both the Regional Project and the saline wells' water. Regarding the latter case, the recipient of the other's well water covers the cost of water pumping and conveying;

- 5.1) The cooperation involves both water and direct income transfers ("side payments");

or

- 5.2) The cooperation is restricted to transfers of water only. The distribution of income between the farms is determined by water transfers.

The difference between 5.1 and 5.2 is that under 5.2 the income of a farm due to cooperation is totally generated on the farm; under 5.1, part of the income may be generated on the other farm and then transferred.

On both farms labor was considered as a variable input. It was also assumed that under conditions of no cooperation water salinity remains unchanged (at 220 ppm Cl level).

The results of four runs of the model involving combinations of the above assumptions are shown in Table 1 and Fig. 4. As the table indicates, the additional income varies within the range of 5 - 22% depending on the scenario and the interfarm income allocation.

The major share of the additional income is due to water and income transfers (under scenarios 1 and 3); only a minor share, up to 3.4% at maximum is attributable to other factors - increased water quantity and increased water salinity, as well as water and income transfers.

This is an important finding. While the issue of water quality (salinity) and the increasing complexity of interfarm and interregional water allocation may shake the rigid and inefficient institutional water rights, the major share of the regional benefits in the case studied, is derived from the assumed interfarm water mobility and not so much from changing water quality. (The latter finding is not surprising in view of the assumed compensation of the farms by a larger water quantity for the deteriorating quality (increasing salinity)).

Fig. 4 presents the computed transformation curves of income between the two farms. The point Q represents the income obtainable with no cooperation and the feasible region for income allocation lies "north-east" to Q. Points M and N correspond to the maximal "regional" income under scenarios 1 and 3, respectively, but they are outside of the feasible region; the feasible parts of the income transformation curves are $\bar{MT}$ and $\bar{NS}$. For scenarios 2 and 4 they are CD and EF.

Table 4: Additional Income Generated by the Cooperation of Farms A and B Under Alternative Scenarios Regarding Cooperation¹⁾

Scenario No.	1	2	3	4
<u>Elements of cooperation</u>				
<u>Water resources included</u>	Regional Project only	Regional Project only	Regional Project and saline wells(4.2)	Regional Project and saline wells(4.2)
Water and income transfers	(4.1)	(4.1)	Water transfers and income transfers (5.1)	Water transfers only (5.2)
Optimal water salinity ppm Cl	350	300 - 350	350	300 - 350
<u>Additional income</u> ¹⁾ , %	<u>18</u>	<u>5-11</u>	<u>22</u>	<u>6-15</u>
of the above:				
a) due to water and income transfers ²⁾	14.6	4.6 - 8.7	19.1	5.1 - 11.6
b) due to other factors ³⁾	3.4	0.4 - 2.3	2.9	0.9 - 3.4

¹⁾ Additional income as percent of income with no cooperation.

²⁾ Maximum income obtained with reference to 200 ppm Cl (=R₀) salinity level.

³⁾ The other factors being increased salinity and increased water quantity; water and income transfers.

Figure 4: Income Transformation Curves Between Farms A and B Under Alternative Scenarios

(One IS (Israel Shekel at January 1982 price level = 6 US cents))

Extending the "Region" to Include a Moshav Village

In this section the analysis is extended to a "region" comprising three farms - two kibbutzim (discussed above) and a moshav village. As a simplification, the moshav - a cooperative village of 80 family farms - is referred to as an aggregate. The unique feature of the moshav in the context of our analysis is its high sensitivity to salinity, due to a high share of salinity sensitive fruit crops - 40% - of the total cultivated area, as compared with 5% on kibbutz B and none on A. The kibbutzim grow certain salinity sensitive vegetable crops (e.g. carrots, potatoes, raddish) but the degree of sensitivity of these crops is lower. The difference in sensitivity to salinity among the three settlements is reflected by Table 2.

Table 2: Optimal Level of Salinity for the Regions' Settlements Under a Non-Cooperative Situation¹⁾

Farm	Preferred salinity level ppm Cl
Kibbutz A	350
Kibbutz B	300
The Moshav Village	220

¹⁾ Assuming compensation by quantity for quality according to the W-R regional transformation curve (see text).

The following scenarios were assumed as the background for the analysis:

Scenarios 3 and 4 - as previously specified (see text and Table 1)

Scenario 5 - similar to scenario 4 with the addition of "group rationality" assumption, stating that the income under regional cooperation of any two farms in the region cannot be lower than that of a partial cooperation ("coalition") of these two farms.

The additional income generated by the three farms' cooperation under scenarios 3 and 4 is shown in Table 3. ¹⁾ There is no feasible solution to the regional problem with reference to the assumptions underlying scenario 5. This is an interesting result with, possibly, important implications for regional cooperation organizations. It is due to the high income potential of the partial cooperation of the two kibbutzim and the inability of the region to provide this income without lowering the income of the moshav below the level achieved with no cooperation.

It should also be noted that there is an inherent conflict of interest between the moshav and the two kibbutzim - the kibbutz farms prefer higher salinity and larger quantities of water, while the moshav prefers the current salinity level (see Table 2). If these results reflect a general situation, as we tend to believe, then regional water associations with membership of both kibbutzim and moshavim might face considerable difficulties if the water supplied to the region would be of one salinity level only. On the other hand a dual salinity water supply to a region may open opportunities for exchange of quantity for quality (salinity) between kibbutz and moshav settlements and thus be beneficiary to the region.

Scenario 6 - Same as scenario 5, except for the relaxation of a restriction on the acreage of a certain crop (watermelon) in the moshav, thereby increasing its income generating potential and enabling a feasible solution.

Table 3 presents the additional regional income generated by the cooperation of the three settlements under scenarios 3, 4 and 6.

¹⁾ Additional income in comparison to the no-cooperation situation. Note that with no cooperation the salinity level must remain unchanged.

Table 3: Additional Income Generated by the Cooperation of the Three Farms in the Region Under Scenarios 3, 4, and 6¹⁾

Scenario No.	3	4	6 ¹⁾
<u>Elements of cooperation</u>			
Water resources included	Regional Project and saline wells	as in (3)	as in (3)
Water and income transfers	Water and income transfers	Water transfers only	Water transfers only
Optimal water salinity ppm Cl	300	260 ³⁾	300 ³⁾
<u>Additional income, %²⁾</u> of the above	16.6	10.5	17.4
a) due to water and income transfers	15.7	10.1	15.7
b) due to ⁴⁾	0.9	0.4	1.7

1) Scenario 6, assumed "group rationality" and an increased acreage limit on watermelons in the moshav. Scenario 5, without the last assumption leads to an infeasible solution (see text).

2) Percent of regional income with no cooperation.

3) Highest regional income point on the interfarm income transformation function. The whole transformation function was not computed.

4) The other factors being increased water quantity and increased salinity, and water and income transfers.

Scrutiny of Table 3 suggests that: a) there is a considerable income generating potential in the regional cooperation under the scenarios assumed; b) the major share of the additional income is due to water and income transfers. These results are similar to those regarding the cooperation between the two kibbutz farms (Table 1). The details of the interfarm water transfers and the related changes in the cropping patterns of the region's farms are detailed by Ratner (1983, Hebrew).

ALLOCATION OF BENEFITS GENERATED BY THE REGIONAL COOPERATION

Viewing the region and its water supply demand relationships as a competitive market is considered here as inappropriate due to the following reasons: a) The number of farms in the region is small,¹⁾ the farms are not anonymous and partial cooperation agreements ("partial coalitions") are possible; b) It is assumed that deliberate increasing of water salinity in the region necessitates an agreement by all the farms in the region and the National Water Authority.

The above assumptions are considered by the authors as reasonably representing the prevailing institutional background for the allocation of benefits (income) among the farms. It is further assumed that the share of the Regional Project in the regional benefits is zero; its terms for the agreement are expressed by the $\bar{W}$ -R transformation curve (1). With these assumptions as the terms of reference it is evident that the pricing of water, the level of other decision variables and the related income redistribution must be negotiated and agreed upon.

In the following several allocation schemes of the benefits generated will be presented and discussed. The first scheme (natural for economists to start with) is pricing of water according to its shadow cost. It is followed by several approaches originating in Cooperative Game Theory. The discussion will be restricted to Scenario 3 only (see Ratner (1983, Hebrew) for the extension of the discussion to other scenarios).

¹⁾ In this statement a region of 20-25 kibbutzim and/or moshav villages is in mind, well above the size of the model-region discussed in this chapter.

Payment for water transfers according to its shadow cost

The first scheme assumes that water transferred from one farm to another is paid for according to its shadow cost with an adjustment for the conveying costs. Table 4 presents the redistribution of income in a three farms' region under the shadow cost pricing scheme.

Table 4: The Redistribution of Income in a Three Farms' Region under Conditions of Scenario 3 and Shadow Cost Pricing Scheme

Million IS				
	Kibbutz A	Kibbutz B	Moshav	Total
(1) Income generated on farm	26.322	9.461	9.302	45.085
(2) Income transfer (payment for water)	- 9.680	+8.905	+0.775	0
(3) Net income ²⁾	16.642	18.366	10.077	45.085
(4) Income with no cooperation	<u>15.766</u>	<u>12.822</u>	<u>10.082</u>	<u>36.670</u>
(5) Gains from cooperation ³⁾	0.876	5.544	0.005	6.415

Footnotes

¹⁾ At January 82 price level; One IS = 6 US cents.

²⁾ (3) = (1) + (2).

³⁾ (5) = (3) - (4).

As shown by Table 4 the net gains from regional cooperation are 0.876, 5.544 and 0.005 million IS for kibbutzim A and B and the moshav respectively, with the total gain for the region being 6.415 million IS or 17% of the income with no cooperation. Referring to a region comprising the two kibbutzim only the net gains are 0.758 and 5.676 million IS or 22% of the income with no cooperation. Table 4 reflects inequality in the allocation of the regional gains among the farms; moreover Kibbutz A, which generates most of the additional income in the region receives only a minimal amount, while Kibbutz B which transfers a considerable share of his water quota to Kibbutz A, receives the major share of the regional incremental income. Therefore, the shadow cost pricing seems to be unacceptable.

It can also be argued that the incremental income of kibbutz B, originating in the payment for the use of its water rights, is unduly received because under the Israeli conditions water from the National Carrier is not a private property of the farms; they are allowed to use it but not to sell it at profit. There is, however, a counterargument to the above. Some water resource specialists and policy makers claim that it is worthwhile for a regional or a national water authority to lease water quotas for cash from "owners" of the water rights rather than invest in the development of costly marginal water sources. Transfers of water for cash are consistent with this point of view.

Game Theoretical Approaches - the Core, the Nucleolus Shapley Value and the Nash Solution¹⁾

With reference to each of the four scenarios assumed the core of the two kibbutz farms' game is the corresponding income transformation curve shown in Fig. 4.

The core the the three farms' game is defined by relationships (18) and (19) and is graphically presented by Fig. 5.

¹⁾ The concepts of Core and Nucleolus are presented by Luce and Raiffa (1957), Owen (1968) Schmeidler (1969) and others. The Nash Solution is presented by Nash (1950, 1953), Luce and Raiffa (1957), Owen (1968) and others. Shapley Value concept was first presented by Shapley (1953) and is discussed by Luce and Raiffa, and Owen. They are, as well, reviewed in Chapter 5.

Fig. 5 The Core of the Three Farms' Game under Assumptions of Scenario 3.

$$\begin{array}{ll}
 (18) & 15.766 \leq y_1 \leq 21.020 \quad (\text{million IS}) \\
 & 12.822 \leq y_2 \leq 19.188 \quad " \\
 & 10.082 \leq y_3 \leq 13.189 \quad "
 \end{array}$$

$$(19) \quad y_1 + y_2 + y_3 = 45.086$$

It is evident that the core, while setting reasonable bounds on the claims of each of three settlements is far from determining a unique allocation solution. To obtain a unique solution within the core, the Nucleolus approach was applied (see e.g. Schmeidler (1969), Kohlberg (1971)) with the following results: $y_1 = 17.641$; $y_2 = 15.809$; $y_3 = 11.635$, with the increments of income above the non-cooperative situation being $\Delta y_1 = 1.875$; $\Delta y_2 = 2.987$; $\Delta y_3 = 1.533$. Again the incremental income received by kibbutz B is higher than that received by kibbutz A contrary to the ranking of their relative contributions to the regional income under cooperation.

The income allocation schemes according to Shapley Value and according to the Nash solution are shown in Table 5, which summarizes the alternative schemes. Note that the axioms underlying the Nash solution imply that the share of each settlement in the regional incremental income be equal-2.139 mill I.S. The Shapley Value implies that each settlement receives the weighted average of its contribution to the regional income in all possible coalitions it may join in all possible sequences.

Table 5: Comparison of Alternative Schemes of Allocation of Income Generated by Regional Cooperation with Reference to Scenario 3.

	Kibbutz A	Kibbutz B	Moshav Village	Total
(1) Income with no cooperation, Million I.S. ¹⁾	15.766	12.822	10.082	38.670
(2) % of regional income	41	33	26	100
(3) Income generated on farms under cooperation, mill I.S.	26.322	9.461	9.302	45.086
(4) % of regional income	58	21	21	100
<u>Allocation scheme</u>	<u>Allocation of regional gains</u>			
<u>Shadow cost pricing</u> , mill I.S.	0.876	5.544	0.005	6.415
Shadow cost pricing %	14	86	negl.	100
<u>Nucleolus</u> , mill I.S.	1.875	2.987	1.553	6.415
Nucleolus, %	29	47	24	100
<u>Shapley value</u> , mill I.S.	2.655	3.230	.530	6.415
Shapley value, %	41	51	8	100
<u>Nash</u> , mill I.S.	2.139	2.139	2.139	6.417
Nash, %	33.3	33.3	33.3	100

Footnotes:

1) At January 1982 price level. One I.S. = 6 US cents.

Table 5 summarizes the alternative schemes of allocation of income, generated by regional cooperation. Scrutiny of this table raises questions with respect to the reasonableness, the fairness and the acceptability of the schemes examined. It is evident that:

(a) Kibbutz A generates the major part (58%) of the regional income under cooperation;

(b) Kibbutz A's share in the regional gains is at most equal to that of kibbutz B (Nash solution); under the shadow cost pricing the Shapley and the Nucleolus solutions it receives considerably less than kibbutz B;

(c) The moshav village whose weighted average contribution to the regional gains according to Shapley Value is 8% only, is allotted 24% and 33.3% of the regional gains in the Nucleolus and Nash solutions.

These results do not seem to serve as a sound basis for a regional agreement on the redistribution of income.

CONCLUDING COMMENTS

In this chapter the potential of cooperation in water use in a small model region was studied. The regional cooperation focusses on a) the determination of water quality (salinity) supplied to the region by the Regional Project and the extent of substitutions of quantity for quality (salinity); b) interfarm water allocation providing for efficiency in water use; and c) allocation of the gains derived from the regional cooperation among the region's farms, with emphasis on game theoretic approaches. Several alternative background scenarios for the regional cooperation were assumed.

The results point to a significant income generating potential of the regional cooperation. They also suggest that conflict of interest may arise between the Kibbutz and the Moshav settlements concerning the level of salinity preferred by the region (with increasing salinity being compensated by increased quantity).

The application of several game theory schemes to the allocation of the regional cooperation gains among the region's settlement lead to generally unacceptable results. The only firm and acceptable contribution of game theory to the case presented in this chapter is the core concept. Apparently, some combination of the core and of conventional economic approaches to the cost/benefit allocation problem might perhaps lead to more acceptable proposals.¹⁾ The search and the examination of such proposals is a subject *for* the continuation of this study.

¹⁾ This conclusion is similar to that of Heany and Dickinson (1982).

PART TWO

REGIONAL COOPERATION IN TREATMENT OF
MUNICIPAL WASTE WATER AND USE OF
EFFLUENT IN IRRIGATION

USE OF MUNICIPAL WASTEWATER FOR IRRIGATION

AN INTRODUCTORY REVIEW

BACKGROUND

Municipal wastewater, which originates for the most part in households, may constitute an environmental and health hazard, if adequate removal of the pollutants is not ensured.

The final use of effluent dictates the level of its treatment. In Europe and in the United States, the treated wastewater (hereafter referred to as effluent) is usually discharged to lakes and rivers, which in many instances are used as sources of drinking water for the urban population. In Israel, municipal effluent is used for irrigation and in certain circumstances this use provides one of the most efficient solutions for wastewater removal.

For most municipal wastewater, secondary treatment (defined in the following) makes the effluent suitable for irrigation. Discharging effluent to lakes and rivers, which serve as drinking water sources, requires a higher level of treatment and is considerably more expensive.

This chapter will survey the conditions of Israel, a country typified by a scarcity in water sources, which justify the use of effluent for irrigation. The chapter will also stress other aspects of effluent irrigation.

QUALITY OF WASTEWATER AND EFFLUENT ¹⁾

Wastewater originating in households is composed of 99.9% water and 0.1% solids. It contains organic and mineral materials and microorganisms, some of which are pathogenic. Household wastes are greenish in color, and are characterized by unpleasant odors emanating from the decomposition of nitrogen and sulphur. The chemical characteristics of household wastewater stems from a variety of organic and inorganic components.

¹⁾ In accordance with Tebbitt (1973) and the National Council of Research and Development (1975).

In general, the concentration of pollutants in wastewater depends on how the water is used for urban needs. The typical pollutants found in household wastewater are usually identical, but their concentration, which determines the method of treatment for effluent removal or reuse, may differ.

The quality of wastewater and effluent is generally characterized by the following indices, measured in milligram/liter units (except for 6):

1. Biochemical Oxygen Demand (B.O.D.) - an index of the concentration of organic materials that consume oxygen during the process of biological decomposition;
2. Chemical Oxygen Demand (C.O.D.) - an index of total organic elements subject to oxidation;
3. Suspended Solids (S.S.) - an index of the concentration of suspended solids whose particles cause problems in effluent use.

These three indices indicate the "organic load" found in wastewater; their high values indicate low quality. In wastewater treatment, emphasis is already placed during the first stage of the process on lowering the levels of these parameters.

4. Nitrogen Compounds - their concentration constitutes an index of the load of nutritive elements found in wastewater and effluent. Total nitrogen promotes algae growth in lakes and rivers; nitrates cause serious pollution problems in aquifers, and ammonia salts cause corrosion to industrial equipment.

5. Phosphorus Compounds - their concentration also constitutes an index of the load of nutritive elements in wastewater and effluent. When effluent is used for cooling in industrial processes, phosphates create stonelike sediments; they also serve as a source of food for algae in lakes and rivers.

These last two indices (4 and 5) indicate the load of nutritive elements found in wastewater. Their high concentrations attest to low quality. Their reduction is generally more complicated than the reduction of the organic load, and is usually carried out by advanced chemical treatment.

6. Coliform Bacteria - an index for the presence of pathogenic organisms like bacteria, protozoa, and viruses. This index is measured by the number of bacteria in 100 cubic centimeters of water.

7. Heavy Metals - are usually found in industrial wastewater; their concentration is determined by the type of industry. A high concentration of heavy metals can make conventional treatment difficult; because of high toxicity of certain metals, the effluent may not be used for irrigation.

8. Total Salts and Chlorides¹ - households discharge salts into wastewater, thereby increasing its salinity level. These salts are a restricting factor both in the use of effluent for irrigation and in uses for cooling in industry. Chlorides are often used as an index of mineral salinity in Israel, because chloride ions are harmful to citrus and other major fruit crops.

TABLE 1: TYPICAL COMPOSITION OF MUNICIPAL WASTEWATER AT DIFFERENT CONCENTRATION LEVELS (mg/l)

	High Concentration	Medium Concentration	Low Concentration
Suspended Solids	350	200	100
B.O.D.	300	200	100
C.O.D	1,000	500	250
Total Nitrogen	85	40	20
Ammonia Nitrogen	50	25	12
Total Phosphorus	20	10	6
Chlorides *)	100< **)	50	30

SOURCE: Feigin et al (1976).

Notes:

*) Another measure of salinity is the electrical conductivity of the water (milli-mhos/centimeter).

**) Note that wastewater quality surveys (Ministry of Agriculture, 1978, 1980, and 1983) point to a high chloride concentration of up to 250-400 mg/l, depending on the source of fresh water and the nature of its use (households, industry).

WASTEWATER TREATMENT PROCESSES

In wastewater treatment, physical, chemical, and biological processes come into play to remove various compounds. A wastewater treatment plant is based on a sequence of several fundamental processes.

The various stages of the treatment can be classified as follows (National Council of Research and Development (1975)):

1. Pre-treatment - removal of coarse elements from wastewater;
2. Primary treatment - gravitational removal of crude filtration removal of suspended particles;
3. Secondary treatment - biological decomposition of unstable organic compounds through providing for aerobic and anerobic conditions for bacteria and other microorganisms (primarily algae);
4. Tertiary treatment - removal of phosphorus, colloids and heavy metals; conversion of nitrates into elementary nitrogen (denitrification); dispersing ammonia chemically; removal of stable organic residue; and removal of dye elements, odors, detergents, and toxic organic materials;
5. Disinfection - during the treatment processes, a residual called sludge, is formed and must be removed. The sludge is treated through drying (which decreases its weight and volume) chemical or physical treatment (e.g., burning), or disposal.

The treatment systems can be classified according to the following categories:

1. Biochemical treatment;
2. Chemical-physical treatment;
3. Soil treatment.

The treatment processes prevalent in Israel are mostly biological and include primary and secondary treatment stages of the following types:

1. Aerated ponds;
2. Extended aeration;
3. Trickling filters
4. Activated sludge.

In general, effluent treated biologically by the secondary level (stages 1 through 3) may be used for irrigation of certain crops. To meet the sanitary standards and enable unlimited use of effluent in irrigation, a higher treatment is needed.

The prevailing quality of primary, secondary, and tertiary effluent is shown in Table 2.

TABLE 2: QUALITY OF PRIMARY, SECONDARY (BIOLOGICAL TREATMENT), AND TERTIARY EFFLUENT (mg/l)

TREATMENT	PRIMARY	SECONDARY BIOLOGICAL TREATMENT				TERTIARY
LEVEL :		Oxidation	Aerated	Trickling	Activated	
Index		Ponds	Ponds	Filters	Sludge	
BOD	120-150	25-70	25-40	50-70	5-35	6-15
COD	600-800	250-400	200-250	70-80	40-60	10-90
SS	<350	60-250	50-80	20-60	15	2-30
N	37-60	15-45	20-45	50-80	10-20	
P	11-20	10-15	10-12	7-10	5-12	0.1-1.3

SOURCE: Tahal (1977, 1978).

Advanced Treatment

Advanced treatment of wastewater for discharge to lakes and rivers, which are used as drinking water sources, focuses on:

1. Reducing the concentration of phosphorus;
2. Reducing the concentration of nitrogen;
3. Removing heavy metals;
4. Removing pathogens.

Advanced treatment can be classified into three groups:

1. Chemical treatment - through the addition of chemical elements (lime, magnesium, alum and chloride), aimed at the removal of certain pollutants, such as phosphorus, ammonia, heavy metals and organic residue.
2. Biological methods - through a modification in the conventional biological treatment process, nitrogen can be removed from wastewater by converting ammonia into nitrate (nitrification) and by removing the nitrates (denitrification).
3. Physical methods - a combination of sand filtration treatment, activated charcoal, and ultraviolet rays.

Land applications for wastewater treatment

One of the methods of wastewater treatment is effected through its transfer, after primary and secondary treatment, to the soil. Various methods of land application are (Papke et al., 1977):

1. Irrigation - allocation of water in relatively small quantities per land units, according to plant needs;
2. Overland flow - this method applies primarily when the soil is impervious to water. The essence of this method lies in the existence of a physical treatment process (filtration), activated by the contact of effluent with soil particles.
3. High-rate applications - one of the applications in this category is achieved by effluent infiltration and percolation in large quantities per land units (5000 c.m./ha) and subsequent aeration.¹⁾
4. Ground water recharge - this method is used in Israel in the Dan Region Treatment Plant (Tahal, 1978a). Effluent that underwent secondary treatment and advanced chemical treatment is discharged into ground water and remains there for a sequence of years. In the discharging process, sand dunes (at the site of effluent infiltration) provide additional filtration, and actually, the effluent's suspension in closed reservoirs for an extended period of time uproots and prevents the development of pollutants.

A comparison between the quality of wastewater and effluent at different treatment levels is shown in Tables 3 and 4 and in Figure 1.

¹⁾ In Israel, the first method of treatment - use of effluent for irrigation - is the one most accepted with respect to wastewater originating in small towns. The composition of effluent allocated to irrigation still differs from the composition of effluent used for drinking water ; thus, one must be aware of and prevent the possible influences of effluent quality and soil type, on the environment and on aquifer pollution.

TABLE 3: QUALITY OF WASTEWATER AND EFFLUENT AT DIFFERENT TREATMENT LEVELS -
DAN REGION PLANT (mg/l)*

INDEX	WASTEWATER	PLANNED QUALITY			AVERAGE QUALITY, 1977			
		Secondary Treatment	Tertiary Treatment	Tertiary Treatment + Disinfection	Eff- luent	Secondary Treatment	Tertiary Treatment	Ground- Water Discharge
BOD	200-450	30-120	10-20	10-15	300	50	8.5	8.5
COD	400-1,000	150-450	40-80	40-80	800	350	78	78
SS	150-450	100-300	10-20	10-20	350	150	20	20
N	70-100	20-60	2-5	2-5	80	45	8.5	8.5
P	10-20	5-15	0.5-1	0.5-1	11	11	15	1.5
Chlor- ides	100-300	150-350	150-350	150-350	?	?	?	204
Coli*	10^7 - 10^9	10^6 - 10^8	10 - 10^2	10-500	10^8	10^8	10^2	70

SOURCE: a) Amir and Idelovitch (1974).

b) Tahal, 1977 averages (1978a).

Notes:

*The coli index is expressed by the number of bacteria in 100 cc of water.

Due to the concern over losing control of effluent quality, the Dan Region Plant, which is designed to treat 120 MCM¹ of effluent yearly for Dan cities, incorporates the tertiary treatment stage and purifies the water to drinking quality. Currently, the plant discharges treated effluent into aquifers (Tahal, 1978a).

In the United States (Table 4), various land treatment methods are applied such as overland flow and large-scale flooding, in addition to irrigation after secondary treatment, which is customary in Israel.

¹MCM - million cubic meters. Dan Region = Tel-Aviv metropolitan area.

TABLE 4: QUALITY OF WASTEWATER AND EFFLUENT AT DIFFERENT TREATMENT LEVELS PREVAILING IN THE UNITED STATES (mg/l)

INDEX	WASTEWATER	SECONDARY TREATMENT		TERTIARY TREATMENT	LAND TREATMENT		
		Aerated Ponds	Activated Sludge	Lime Treatment	Irrigation after Secondary Treatment	Over-land Flow	Infiltration+ Percolation
BOD	150	35	20	5	1	5	5
SS	200	40	25	5	1	5	1
N	30	30	20	30	3	3	10
P	10	8	8	0.5	0.1	5	2

SOURCE: a) EPA (1975).

Both from Tables 3 and 4, it can be concluded that land treatment methods can to a certain degree, serve as cheap and efficient substitute for treatment plants.

FIGURE 1: PARAMETERS OF EFFLUENT QUALITY AT DIFFERENT TREATMENT LEVELS

TREATMENT AND USE OF MUNICIPAL WASTEWATER FOR IRRIGATION IN ISRAEL¹

In Israel, there is a perennial trend of degradation in the quality of water sources, and a depletion of fresh water sources available to agriculture (Water and Irrigation, 1983).

TABLE 5: GENERATION, TREATMENT, AND USE OF MUNICIPAL WASTEWATER (MCM)

YEAR	1963	1971	1978	1980	1982
WASTEWATER DISCHARGED	135	177	215	226	251
WASTEWATER TREATED	32	57	101	133	137
EFFLUENT IN USE	14	24	43	52	57

SOURCE: The Ministry of Agriculture. (1978, 1980, 1983).

The depletion of fresh water sources available to agriculture and the deterioration in their quality have given rise to the development of "marginal water" sources, such as flood waters, brackish water, and municipal wastewater (see Chapter 1, p.1.1).

The development of effluent use in Israeli agriculture is shown in Tables 5 and 6. By looking at Table 7, one can also learn about the development of secondary and tertiary treatment plants in Israel during two recent years (80-82).

In the last 20 years, the volume of treated wastewater and utilized effluent grew fourfold; during the years 1978-82. the land area irrigated with effluent grew by 50%. The number of plants, primarily aerated ponds grew as well.

TABLE 6: LAND AREA IRRIGATED WITH EFFLUENT (THOUSANDS OF DUNAMS)*

Crops	1978		1980		1982	
	Dunam	%	Dunam	%	Dunam	%
COTTON	41	60	68.0	77	86	87.0
FODDER	9.4	14	5.8	7	3.0	3.0
CITRUS	6.1	9	6.2	7	6.5	7.0
FRUIT CROPS	2.0	3	3.4	4	2.5	2.0
OTHERS	10	14	4.5	5	1.2	1.0
TOTAL	68.6	100	87.9	100	99.2	100.0

SOURCE: The Ministry of Agriculture (1978, 1980, 1983).

Notes: *) One dunam = 1/10 hectare

TABLE 7: MAJOR MUNICIPAL TREATMENT PLANTS IN ISRAEL

TYPE OF PLANT	NO. OF PLANTS	
	80	82
Activated Sludge	2	2
Trickling Filters	2	2
Extended Ventilation	2	4
Aerated Pond	13	23
Advanced Treatment (Tertiary)	1	1
TOTAL	20	32

SOURCE: The Ministry of Agriculture (1980, 1983).

ALTERNATIVE USES OF EFFLUENT AND CORRESPONDING QUALITY REQUIREMENTS IN ISRAEL

The alternative uses of effluent can be classified as follows (The National Council of Research and Development (1975)):

1. Restricted agricultural irrigation of plants which are not used directly for human consumption, such as cotton, wheat, sorghum, seed plants, sugar beet, and forage plants not fed directly to livestock, such as hay, and silage;
2. Selective agricultural irrigation I of a) fruits with inedible peels such as pecans, almonds, citrus, banana and dates, and (b) forage crops;
3. Selective agricultural irrigation II of a) fruit crops with edible peels which are irrigated below canopy, b) fruits and vegetables consumed after cooking or used for canning, and c) lawns;
4. Unrestricted agricultural irrigation, including fruits and vegetables eaten raw;
5. Various industrial production processes (e.g. refrigeration and other purposes);
6. Recharge to aquifers classified as drinking water sources;
7. Direct reuse as drinking water through intermediate reservoirs for dilution and for quality control.

For every designated use there are specific quality requirements determined on the basis of international standards (The Advisory Committee for Establishing Rules on the Quality of Reclaimed Wastewater Used for Irrigation, (1978)). Legislation on water quality is not yet official and these requirements can somewhat change in the future.

Table 8 details maximum standard levels determined by the Advisory Committee for Establishing Rules on the Quality of Reclaimed Wastewater Used for Irrigation in a coordance with the designated uses of effleunt. An emptyentry indicates that there are no maximum standards for the appropriate index.

TABLE 8: QUALITY REQUIREMENTS FOR EFFLUENT IN DIFFERENT USES

QUALITY INDICES	DESIGNATED USE						
	RESTRICTED IRRIGATION	SELECTIVE IRRIGATION I	SELECTIVE IRRIGATION II	UNRESTRICTED IRRIGATION	INDUSTRIAL USE	RECHARGE AQUIFERS	DIRECT REUSE
BOD (mg/l)	60	45	35	15	10	5	1
COD (mg/l)					60	60	30
SS (mg/l)	50	40	35	20	5	1	0.5
Coliform (bacteria/100cc) water			100	12	2	10	2
Salinity (chlorides mg/l)	Depending on crop's sensitivity				Depending on use	300	300
N (mg/l)					10	0.5	0.5
P (mg/l)					0.5	0.5	0.5

- SOURCES:
1. For irrigation use: Israel Water Commission, The Advisory Committee for Establishing Rules on the Quality of Reclaimed Wastewater Used for Irrigation, Final Report, (May, 1978).
 2. For industrial uses, discharge and direct reuse: The National Council of Research and Development (1975).

Heavy metals and other toxic elements

Heavy metals, toxic elements, various organic compounds, detergents, and nitrates found in effluent can infiltrate through the rootsystem to plants, livestock, and the human population as a result of effluent irrigation, or through infiltration to aquifers used for irrigation or as drinking water. These polluting factors accumulate and could also cause a negative effect on soil structure, despite that in small concentration, some of these pollutants (micro-elements) are vital to the plant's nutrition.

The treatment process decreases, to a certain degree, although not significantly, the toxic concentration in effluent. Part of the heavy metals found in effluent remains in the sludge, which is separated in the treatment process.

Table 9 shows the typical concentration of heavy metals in wastewater, typical effluent, and drinking water standards.

TABLE 9: HEAVY METAL CONCENTRATION IN WASTEWATER AND EFFLUENT, AND DRINKING WATER STANDARDS (mg/l)

ELEMENT	WASTEWATER		TYPICAL EFFLUENT	DRINKING WATER STANDARDS
	LOW CONCENTRATION	HIGH CONCENTRATION		
CADMIUM	below 0.005	0.15	0.01	< 0.005
CHROME	" 0.01	1.46	0.20	0
COPPER	" 0.01	1.30	0.20	0.10
MERCURY	" 0.0002	0.001	0	0
NICKEL	" 0.02	5.4	0.20	0.02
LEAD	" 0.02	1.3	5.00	0.05
ZINC	" 0.03	4.7	2.00	0.15

SOURCE: Feigin (1976).

THE EFFECT OF EFFLUENT IRRIGATION ON YIELD AND QUALITY OF CROPS YIELD

Generally, positive responses and few failures were found in the literature surveyed by Feigin et al (1977) on the effect of effluent on plant yield. There is still however, paucity of information based on controlled experiments. Nevertheless, with the current knowledge at hand, it is clear that the use of effluent in irrigation can bring about a savings, primarily in nitrogenous fertilizers, but also in phosphorus and potassic fertilizers. By taking into consideration the nutrient contents of effluents, excess fertilizer use is prevented, and the leaching of nutrients to aquifers and their subsequent pollution is controlled (Borstein, 1978).

1. Nitrogen. In secondary household effluent, nitrogen turns up primarily in the form of ammonium, whereas the concentration of organic nitrogen and nitrogen oxides (nitrites and nitrates) is negligible.

Nitrogen in effluent is absorbed by plants and constitutes a good substitute for nitrogen fertilizers. The concentration of nitrogen in secondary effluent wavers between 30-60 mg/l.

Feigin et al (1977) examined the response of cotton and to nitrogen in effluent. Their conclusions were that nitrogen in effluent raises the yield of these crops; the quality of cotton fibers is decreased by excess nitrogen.

Hausenberg et al (1977) found that citrus absorption of nitrogen from effluent is higher than from mineral fertilizers and irrigation with regular water.

2. Phosphorus. Phosphorus is found in secondary effluent in concentrations of about 20 mg/l and is readily available to plants.

In their experiments, Feigin et al (1977) found higher phosphorus absorption by cotton and Rhodes grass when they were irrigating them with secondary effluent, as compared to irrigation with regular water, to which phosphoric fertilizer is added. The amount of phosphorus in effluent is not sufficient for cotton, but is sufficient for pasture and forage crops.

3. Potassium. The concentration of potassium in effluent wavers between 15-30 mg/l. The effect of potassium in effluent on crops is statistically insignificant, while the amount found in effluent constitutes 50% of the crops' fertilizer needs.

An economic appraisal of the fertilizer content in effluent can be found in Yogeve and Kloner (1976).

The effect of effluent irrigation on soil salinity and crop yields

A. Accumulation and Leaching of Salts

During the irrigation season, effluent with a given salt concentration infiltrates the soil solution. Following evapotranspiration, the soil solution becomes more concentrated. The process increases soil salinity, and unless leaching occurs it can cause losses in crop yields.

Salt accumulation in the soil occurs gradually during the irrigation season. Under usual irrigation conditions and for most crops, a high share of the salts found in the irrigation water accumulates in the 0-90 centimeters root layer. Some (or all, depending on the specific conditions) of the accumulated salt is leached in winter by rainwater, whose salt concentration is nil.

Accordingly, in the spring, soil salinity is lower than at the end of the summer (after a period of effluent irrigation). 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.

Yaron et al (1974, and 1979) adopted a modification to a model proposed earlier by Bresler (1967) that explains and forecasts the accumulation and leaching process of salts in soils, as follows:

$$(1) \quad Q_W CL_W - \beta Q_W \frac{CLS_1 + CLS_2}{2} = (CLS_2 - CLS_1) \cdot V$$

where

Q_W - quantity of irrigation water (mm)

CL_W - salinity of irrigation water (chloride milliequivalents/liter) ¹⁾

β - leaching factor (an empirical parameter);

CLS_1 - chloride concentration in the root layer before irrigation season (chloride milliequivalents/liter at saturated paste soil moisture content);

CLS_2 - chloride concentration in the root layer after irrigation season (chloride milliequivalents/liter at saturated paste soil moisture content)

V - water content in the root layer at saturated paste soil moisture contents (mm).

From (1) one can derive

$$(2) \quad CLS_2 = [Q_W CL_W + CLS_1 (V - \frac{1}{2} \beta Q_W)] / (V + \frac{1}{2} \beta Q_W)$$

CLS_2 in (2) is expressed by measurable variables. The parameter β should be empirically estimated for the various types of soils, crops, and irrigation practices.

Yaron et al (1979) verified the applicability of this model by adapting it to different empirical data. They also estimated the parameter β for sprinkler irrigation of several crops grown in different types of soil.

*1) Chloride concentration can also be expressed in units of mg/l. The relationship is: 1 chloride milliequivalent = $\frac{1 \text{ mg/l}}{35.9}$, when the molecular weight is 35.9.

A compilation of information from different sources throughout the world on crop yield losses due to salinity can be found in Bernstein (1964, 1965) and in Mass and Hoffman (1977). In Israel several studies on the subject were published, mostly on citrus (Hausenberg et al (1977) and Shalhevet et al (1974)); tomatoes (Shalhevet and Yaron (1973)); potatoes and peppers (Meiri and Shalhevet (1973)); autumn potatoes (Sadan and Berglas (1980)); several fruit crops (Shalhevet et al (1976)); and eggplants (Hoyer (1983)).

Mass and Hoffman's approach to the specification of the crop response to salinity was adopted by several researchers. The model for calculating crop damage is

$$(3) \quad y = \begin{cases} 100 - b(EC - a), & \text{if } EC \geq a \\ 100, & \text{if } EC < a \end{cases}$$

where

y = relative yield (%)

EC = average electrical conductivity of the soil solution in the root layer (milli-mhos/centimeter) during the growing season.

a = critical threshold of electrical conductivity, beneath which no damage occurs (milli-mhos/centimeter)

The essence of Mass and Hoffman's approach is that, until the critical threshold of salinity in the soil solution is reached, there is no effect on yield and anything above the threshold causes a linear decrease in yield. The values of the parameters a and b of the response function used in this study follow Yaron et al (1979).

SUMMARY

This chapter reviewed the factors relating to wastewater treatment and the use of effluent for irrigation.

The use of effluent is restricted from a sanitary standpoint, due to potential health hazards and environmental damage. Uncontrolled use of effluent for irrigation could impair the quality of drinking water in aquifers and could cause salinity damage to soils and crops.

Strict government imposed quality controls, (as practiced in Israel), on the one hand, and the development of proper technology for effluent use in irrigation on the other, can aid Israeli agriculture in making treated wastewater one of the most important sources for improving its water balance in the coming decades.

Chapter 4

OPTIMIZATION OF MUNICIPAL WASTE WATER TREATMENT AND USE IN REGIONAL IRRIGATION

BACKGROUND

Municipal wastewater warrants increased attention as an environmental pollution source and as a possible irrigation source.

Public health regulations require municipal authorities to treat urban wastewater before its removal as effluent (effluent = treated wastewater).

Under certain conditions, use of municipal effluent for irrigation, treated only up to the level required by health regulations, is an effective solution for wastewater removal. Distinctions are made between a) a local initiative, where small towns and villages set up regional wastewater treatment plants, and the farmers in the region use effluent for irrigation, as opposed to b) initiatives at the national level aimed at setting up inter-regional plants to treat metropolitan centers' wastewater and which would convey effluent to distant agricultural regions.¹⁾

Such distinction is practiced in Israel. It is justified by the fact that as the volumes of wastewater become larger, larger areas, beyond the boundaries of a single "region", should be incorporated into the planning and implementation of its treatment and use or discharge.

A regional wastewater treatment system and its distribution to farms within the region can offer economic advantages to the potential participants, but it requires the establishment of a special organization to encourage regional cooperation.

As previously mentioned in Western Europe and the United States, municipal wastewater is generally treated for discharge to streams and lakes, which might be used as sources of drinking water. Accordingly, the international professional literature centers primarily on the choice of a treatment plant (or plants) that fulfills given quality requirements for removing

¹⁾ E.g., the Dan Region (=Tel Aviv Metropolitan area) and Haifa City in Israel.

effluent to streams at minimal cost and on a related cost-sharing scheme among the polluting agents such as towns and out of town factories (Dorfman (1972), Giglio and Wrightington (1972), Papke et al (1977), Loehman et al (1979), Nakmura and Brill (1979) and Rinaldi et al (1979)).

In Israel, a good deal of effort is devoted toward coordinating effluent quality with agricultural crop requirements, and toward adapting environmental-quality regulations for using effluent in irrigation as a cheap outlet of removal (Feigin et al (1977), Tahal (1978), Borstein (1978), Yaron et al (1979), Minsker (1982)).

The chapter deals with a proposed regional solution for municipal wastewater removal through treatment and irrigation, with an emphasis on preserving environmental quality. A region involved in such endeavor faces the following interrelated problems:

- a) Determination of the regional boundaries for cooperation and the corresponding capacity of the regional treatment plant;¹⁾
- b) Determination of the wastewater treatment level;
- c) Allocation of the effluent (treated wastewater) to the region's farms;
- d) The selection of an optimal crop mix and the allocation of effluent to the various land blocks of the region's farms.
- e) Cost allocation to the participants.

A MODEL FOR REGIONAL OPTIMIZATION OF WASTEWATER TREATMENT AND USE

Preliminaries

In the following section a mathematical programming model for the joint optimization of wastewater treatment and use in irrigation within a region is presented. The objective is to maximize the region's income subject to a given supply of wastewater, health regulations and the capacity of the farms to utilize the effluent, given their land and other resource endowments, price system and technology. The problem of the distribution of the income generated by this activity is discussed in Chapter 5.

¹⁾ The above mentioned decisions involve the determination of the capacity and layout of the wastewater and effluent conveying system, as well.

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

- 1) The municipal authority(s) that delivers the wastewater (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 may be able to increase their irrigated acreage and income. The treatment cost could rise, as the result of a higher treatment level but the share of the cost actually borne by the town would be lower than if the town would have treated the wastewater by itself. The other share would be borne by the farmers. However, as shown later, under the conditions existing in Israel, a government subsidy is needed to support such cooperation in the region actually studied.

The study presented below deals with one urban authority, three large farms (kibbutzim), and applies environmental-quality regulations determined by the government.

The economic analysis refers to a one-year period, with all 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 leaching by winter rains.

The model overlooks seasonal differences in wastewater quality and assumes a uniform quality throughout the year. In addition, the model assumes only one possible treatment level in the plant throughout the year.

ELEMENTS OF THE MODEL

The town and the treatment plants---

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

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

where

$\bar{S}_t$ = municipal wastewater supply in month t (c.m.);

D_t = quantity of wastewater removed from the system in month t (c.m.);¹⁾

S_t = quantity of wastewater diverted to a pretreatment reservoir in month t (c.m.).

The cost of wastewater removal is d IS/c.m.; it is lower than the cost per unit of treatment required for irrigation use. Removal costs include minimum wastewater treatment (required by law) and the conveying expense to the removal site.

The effluent is generally not used in winter (September-April), while in the summer there is an excess of demand. To meet this demand, wastewater is stored in the pretreatment reservoir until needed (sometimes, toward the end of winter; in general, in the peak summer months).

Although some quantity 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.²⁾

¹⁾ Discharged to the sea through wadis.

²⁾ 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 close to the use of effluent, and a larger treatment plant is required. In the second case the opposite is true.

In this study pretreatment storage in a large cave 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 differentiate between the group of the fall and winter months, W , $W = \{9, 10, \dots, 12, 1, 2, \dots, 4\}$, and the peak summer months, $t = 5, 6, 7, 8$. All the fall and winter months will be treated as one group, W . We will also define $T = \{5, 6, 7, 8\} \cup W$.

Let α be the loss coefficient due to evaporation and infiltration for fall and winter [16% according to Berezik (1982)];

j = index of treatment level for use in irrigation; three discrete treatment levels are assumed ($j=1, 2, 3$) with $j = 0$ denoting the treatment necessary for wastewater removal.

U_{w5} = quantity of wastewater transferred from winter storage in May ($t=5$), (c.m.);

Z_{wj} = quantity of wastewater designated for treatment at level j during fall and winter (c.m.);

The storage-treatment balance during winter will be

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

Similarly, let

$U_{t,t+1}$ = quantity of stored wastewater transferred in month t to month $t+1$ (c.m.);

Z_{tj} = quantity of wastewater removed from reservoir to the treatment plant for treatment level j in month t (c.m.);

β = loss coefficient for peak months [4% per month according to Berezik (1982)]. The balance equation of storage treatment in peak month t will be:

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

Define q_j as the maximal quantity of wastewater treated in any of the peak months t ($t=5, 6, 7, 8$) at treatment level j :

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

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

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

Note that q_j is linked to a negative value in the objective function aimed at maximizing the region's income; therefore it would be as small as possible.

The region can choose only one among the three levels of treatment ($j=1,2,3$). This is expressed by relationships (5) - (7):

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

with

$$(6) \quad \delta_j = 0,1 \text{ (binary variables) } \forall j$$

$$(7) \quad q_j \leq \delta_j M$$

with M being an arbitrary large number. Thus:

For $\delta_j^* = 0$, $q_j \leq 0$, which implies $q_j = 0$.

For $\delta_j^{**} = 1$, $q_j^{**} \leq M$; with M being sufficiently large, q_j is practically unlimited.

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

$$(8) \quad Z_{tj} \geq \sum_{n=2}^4 R_{tj}^n \quad t \in T; j = 1,2,3$$

where

R_{tj}^n = effluent at treatment level j acquired by farm n ($n=2,3,4$) during t (c.m.). Index $n=1$ stands for the town.

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

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

Following Berezik (1982), γ is assumed to be 1.2.

The wastewater treatment cost is a non-linear function (Loehman et al. (1979), Dinar (1983)). The following estimate (Dinar (1983)) was used:

$$(10) \quad F_j(Q_j) = 12,076 Q_j^{0.633} E_j^{-0.094}$$

where

E_j = 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.

A government subsidy of $r\%$ of the treatment and conveying costs is assumed so that the actual cost function to the region is (I.S.):

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

As was found later in the empirical analysis a subsidy of 50% is necessary to provide incentives to all the farms in the region for joining the regional cooperative organization.

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

The last equation characterizing the town system relates to the cost of transporting wastewater from the town to the treatment plant. The site of the treatment plant is assumed to be 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:

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

where

m^1 = overall annual cost of conveying wastewater from the town to the reservoir [IS];

B^1 = capital costs as a function of K^1 [IS];

v^1 = cost of energy per unit of wastewater conveyed from town to storage.

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

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

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

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

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

Within the regional framework which is aimed at regional optimization, the town increases its spending, on the assumption that the farmers will contribute their share. The above cost function multiplied by (-1) appears as 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 crop mix, as they relate to the possible cooperative effluent plant. Their major characteristics are described in this section along with the relevant components of the programming model.

We denote the farms' group by G . It consists of three kibbutz farms, $G = \{2,3,4\}$.

Producer n has L^n land blocks and Y^n crop alternatives at his disposal. Each land block of each producer can be irrigated with effluent, but due to sanitary regulations, it is not possible to irrigate the same block with both effluent and freshwater during a season, neither to shift, over the years, from effluent to freshwater irrigation, unless a special permission is granted. Each farm can freely transfer freshwater among its land blocks as long as its water quota allotments are not exceeded.

The farms can as well install irrigation equipment on their dry areas and grow there irrigated crops. Each producer may have two out of four types of irrigation water at his disposal: $k = 1,2,3,4$, namely effluent at treatment level 1,2,3, respectively, 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.

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

Land use:

$$(13) \quad I_1^n \geq \sum_{y \in Y} \sum_{k=1} X_{ylk}^n \quad l = 1, \dots, L^n$$

where

X_{ylk}^n = area of crop y grown in land block l and irrigated with water of quality k by producer n (dunam) $l=1, \dots, L^n$; $k=1, 2, 3, 4$; $y = 1, \dots, Y^n$

I_1^n = the area of producer n's block l (dunam).

Water-use balance:

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

where

A_{yltk}^n = amount of irrigation water of quality j, in period t per dunam of activity y in producer n's block k (c.m.);

R_{tj}^n = producer n's amount of acquired effluent of k-th quality during period t (c.m.);

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

Effluent supply and use:

$$(15) \quad Z_{tj} \geq \sum_{n \in G} R_{tj}^n \quad j = 1, 2, 3; \quad t \in T$$

Producer n's site in the region determines effluent conveying costs from the treatment plant (whose site is given) to his 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:

$$(16) \quad \sum_{j=1} R_{tj}^n \leq K^n \quad t \in T, n \in G$$

where

K^n = producer n's maximal periodic effluent supply.¹⁾

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

$$m^n = (1-r) B^n (K^n) + v^n \sum_{t \in T} \sum_{j=1} R_{tj}^n$$

where

v^n = energy costs of conveying one c.m. of effluent from the treatment plant to producer n (IS/c.m.).

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 producer n would be represented as follows:

$$(17) \quad H^n \underline{\hat{X}} \leq \underline{b}^n$$

where

H^n = matrix of input factors (other than water) for producer n;

$\underline{\hat{X}}^n$ = vector of activities not using water and not generating income, specific to producer n;

$\underline{b}^n$ = vector of restrictions not related to irrigation, specific to producer n.

The objective of producer n is to maximize ζ^n :

$$(18) \quad \zeta^n = \sum_{y \in Y} \sum_{k=1}^4 C_{ylk}^n X_{ylk}^n - m^n$$

where

C_{ylk}^n = income for activity unit y in producer n's block l irrigated by water of quality k.

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

¹⁾ Note that (16) is equivalent to $R_{tj}^n \leq K^n$ for $j=1,2,3$.

The regional problem is to maximize f^N :

$$(19) \quad f^N = -m^1 + \sum_{n \in G} \left[\sum_{y \in Y} \sum_{k=1}^4 C_{ylk}^n X_{ylk}^n - m^n \right]$$

subject to restrictions (1) - (18) described above.

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.

As stated f^N - denotes the regional income when the farms and the town in the region cooperate;

ζ^n - denotes the income (or the cost in the case of the town) generated by the n-th participant in the regional cooperation ($n=1,2,3,4$);

Let f^n - indicate the income or the cost of the n-th potential participant when acting independently ($n=1,2,3,4$).

A necessary condition for regional cooperation is that:

$$(20) \quad f^{N^0} > \sum_{n=1}^4 f^{N^0}$$

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

Other conditions for cooperation deal with the related cost benefit allocation scheme among the town and the farms. These are discussed in the following chapter.

EMPIRICAL MODEL

The Regional System

The regional system consists of three farms, a town, and a potential wastewater treatment plant.

The town supplies wastewater of a given quality - 400 mg/l BOD - and a constant quantity - 100,000 c.m./month. If the town itself must dispose of the wastewater, it does so at a cost of 1.85 IS/c.m. (All monetary values apply to the October 1980 price level).¹⁾

¹⁾ One IS (Israel Shekel) at 1980 price level = 16 US cents.

If the 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 for the additional treatment costs.²

The farms differ in their land areas and their characteristics and in their freshwater quotas (see Table 1).

Table 1: FARMS' MAJOR WATER AND LAND CHARACTERISTICS

FARM	TOTAL IRRIGATED LAND AREA (DU) ¹⁾	TOTAL, LESS FRUIT CROPS (DU)	TOTAL UNIRRIGATED LAND (DU)	ANNUAL FRESH- WATER ALLOTMENT (000 c.m.)	PEAK MONTHS WATER QUOTA (000 c.m.)	WATER PER LAND UNIT IRRIGATED ONLY (c.m./du)	LAND UNIT TOTAL (c.m./du)
A	2400	1084	580	1600	159	666	536
B	3500	200	3726	902	300	258	133
C	1969	425	911	850	138	432	293

Notes:

- 1) One dunam (du) = 1/10 hectare

Table 1 suggests that the farms face a freshwater shortage, in general, and especially when the peak months quota allotments are considered. The regional treatment plant can offer an additional supply at a quality level below that of freshwater. The sanitary requirements for effluent quality as formulated in this study are presented in Table 2. 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).

The physical layout of the town, the treatment plant and the farms is schematically presented in Figure 1.

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 methods of irrigation, including drip irrigation), and 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 (1983).

Characteristics of Regional Solutions

The non-cooperative situation leads to independent, individually optimal solution for the town and for the region's farms. In this situation, the town removes the wastewater by itself, and the agricultural producers use their freshwater quota allotments only.

The regional optimization model - maximization of (19), subject to (1) through (18) - refers to a situation of regional cooperation in the treatment of municipal wastewater and in its use for irrigation.

The decision variables in this model are;

δ_j = treatment level of effluent;

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

R_{ylk}^n = effluent quantity of quality j in period t , supplied to producer n ($n=2,3,4$);

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

x_{ylk}^n = level of activity y in block l belonging to producer n , irrigated by water of quality k .

Figure 1: Schematic Diagram of Participants' Sites, Cooperative Treatment Plant, and Conveying Network

Note: The numbers in the right bottom corner of each rectangle indicate the elevation of the farm's site (meters above sea level); the numbers of the arrows connecting the rectangles indicate the users' and the town's distances (km) from the treatment plant.

TABLE 2: EFFLUENT QUALITY REQUIREMENT FOR MAJOR CROPS

Crop group	A	B	C	D
BOD level mg/l	<60	<45	<35	<15
Crops:	<ul style="list-style-type: none"> - Cotton - Sugar beet - Seed crops - Cereals - Hay crops - Silage crops 	<ul style="list-style-type: none"> - Fodder crops - Peanuts - Olives - Dates - Almonds - Citrus - Pecans - Other fruits with inedible peels 	<ul style="list-style-type: none"> - Deciduous fruit crops irrigated under canopy - Fruits and vege- tables for canning - Vegetables consumed after cooking - Vegetables eaten without peels 	UNRESTRICTED IRRIGATION

SIMPLIFYING AGGREGATION USED IN MODEL

Crop group	A	B + C	D
BOD level mg/l	<60	<35	<15
Treatment level index, j	1	2	3

Source: Based on The Advisory Committee for Establishing Rules on the Quality of Effluent Used for Irrigation (1978).

It is clear from the model that the non-cooperative solution is a special case of the regional optimization solution, and can be solved by imposing $\delta_j = 0$, for all j , which implies that wastewater is not treated for irrigation use.

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

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. Table 3 presents the results with respect to the costs of the town, the income of the farms and the shadow prices of freshwater.

Table 3: COST, INCOME AND SHADOW PRICES OF FRESHWATER UNDER THE OPTIMAL NON-COOPERATIVE SOLUTION

	Town	<u>Farm</u>			Region's total
	A	B	C		
Cost/Income mill/IS ¹⁾	-2.22	11.68	7.74	2.65	19.85
	<u>Shadow prices of water</u>				
	I.S./c.m.				
June quota	3.10	-	-		
July quota	6.47	3.37	6.99		
Annual quota					

¹⁾ At 10/80 price level One IS = 16 US cents.

Scrutiny of the shadow prices of freshwater in the non-cooperative situation (Table 3) 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 constraints farm A only.

The high shadow prices of freshwater in July on all farms justify the consideration to develop an additional water source in the region.

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

A comparison of major results in cooperative situations, given 15% and 50% governmental subsidies, is shown in Table 4. It suggests that a subsidy of 50% which amounts to 2.99 million IS increases the regional income by 2.2 million IS only, but the environmental effect 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 85% as compared with 58% only at 15% subsidy level. At 15% subsidy level Farm A only uses effluent, while at 50% - all three region's 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 analysis.

Comparisons of major results for the non-cooperative and cooperative situations are presented in Tables 5 through 8. Table 5 shows that land use and cropping patterns of each farm in the cooperative as opposed to the non-cooperative situations. Table 6 presents the major changes induced in water use.

Table 4 : 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 (Millions IS) ¹⁾	19.6	21.8
Effluent (000 c.m.) Used in Irrigation	700	1,015
% of regional wastewater	58	85
Total Treatment Costs (Million IS)	4.51	5.98
Subsidy (Million IS)	0.68	2.99
Treatment Costs to Region (Million IS)	3.83	2.99

Notes:

¹⁾ Regional income with the subsidy included. Prices at 10.80 price level. One IS = 16 US cents.

Table 5: LAND USE AND CROPPING PATTERNS UNDER THE NON-COOPERATIVE AND COOPERATIVE SITUATIONS

Farm	<u>A</u>		<u>B</u>		<u>C</u>	
	Non-Coop.	Coop.	Non-Coop.	Coop.	Non-Coop.	Coop.
1. Irrigated Field Crop area (du)	1104	2516	2309	2309	1532	1083
2. Irrigated Fruit Crops (du)	1084	1084	405	405	200	200
3. Total Irrigated Area (du)	2188	3600	2714	2714	1732	1283 ²⁾
4. Effluent Irrigated Area (du) ₁₎	-	1678	-	949	-	200
5. Percent of Effluent Irrigated (%)	-	47	-	35	-	16
6. Unirrigated Crop Area (du)	1835	1133	4243	4243	-	590

Footnotes:

¹⁾ Included in (3)

²⁾ Including 100 du newly equipped for irrigation.

Table 6: USE OF WATER UNDER THE NON COOPERATION AND COOPERATIVE SITUATIONS

Farm	<u>A</u>		<u>B</u>		<u>C</u>	
	Non-Coop.	Coop.	Non-Coop.	Coop	Non-Coop.	Coop.
1. Total Freshwater Use (Thousands of cm)	1450	1280	760	700	500	400
2. Total Effluent Use (thousands of cm)	----	680	----	270	---	60
3. Total Water Use (thousands of cm)	1450	1960	760	970	500	460
4. Change in Water Use (%)	+35		+28		-8	

The changes occurring due to the cooperative solution can be summarized as follows (for more details see Dinar (1983)):

- A. Expansion of farms A and B's irrigated areas, and reduction in farm C's area;
- B. Substitution of freshwater for effluent by all producers; the quantity of freshwater use in the region is decreased by 300,000 c.m. per year;
- C. Increase in water input per land unit area; decrease in the area of unirrigated crops in the regions.
- D. Expansion of certain crops and crops' irrigation procedures (new schedules of cotton irrigation, drip irrigation); and
- E. Reallocation of freshwater among the farm's various land blocks, according to the demand of sensitive crops in each block.

These changes can explain the additional income accrued to the farms and to the region (Table 7).

In the cooperative situation, before the redistribution of income, the town bears the increased treatment cost for all the other participants, while the farms increase their gross income (Table 7). Obviously, in order to preserve the region's incentive for cooperation, the farms who benefit from the use of effluent should compensate the town.

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 stability of the regional cooperative solution depends on the establishment of a redistribution system 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 fact from the point of view of the computational burden.

The problem of redistribution of income and specifically the payments to the town are dealt with in Chapter 5.

Table 7: WASTEWATER TREATMENT COST AND THE FARMS' INCOME IN NON-COOPERATIVE AND COOPERATIVE SITUATIONS (MILLIONS IS)¹⁾

Participant	Cost/Income in Non-Cooperative Solution	Cost/Income in Regional Cooperative Solution ²⁾
Town	-2.22	-2.99
Farm A	11.68	13.64
Farm B	7.74	8.22
Farm C	2.65	2.94
Total for Region	19.85	21.81

1) October 1980 Price Index, One IS = 16 US cents

2) Before redistribution of income.

APPENDIX TO CHAPTER 4Table A: AVERAGE TREATMENT AND CONVEYING COSTS IN A COOPERATIVE SETTING

	Town	A	Farm B	C
Overall Treatment Cost (million IS) 1)	5.98	-	-	-
Treatment Subsidy (million IS)	2.99	-	-	-
Actual Treatment Cost (IS)	2.99	-	-	-
Total Effluent Purchased (000 c.m.)	1,015	-	-	-
Actual Average Treatment Cost (million IS)	2.95	2.95	2.95	2.95
Transport Cost After Subsidy (million IS)	-	0.164	0.231	0.025
Effluent Purchased (thousnads c.m.)	-	680	273	62
Transport Cost per c.m. (IS/c.m.)	-	0.24	0.86	0.41
Overall Average Cost (IS/c.m.)	-	3.18	3.80	3.35

1) October 1980 price level. One IS = 16 US cents

Chapter 5

COST/BENEFIT ALLOCATION SCHEMES

FOREWORD

The previous chapter presented the regional optimization model of municipal wastewater treatment and use in irrigation. It maximizes the regional objective function f^N :

$$(1) \max f^N = -\zeta^1 + \sum_{i=2}^4 \zeta^i$$

subject to the availability of production factors and other constraints, given technology and prices,¹

where

f^N = objective function of the entire region;

$N = \{1,2,3,4\}$;

$-\zeta^1$ = the town's expenses;

ζ^i = the i -th farm's income.

$i = 2,3,4$.

The maximization is constrained by the available production factors, given technology and prices, and institutional restrictions including environmental regulations.

Cooperative use of municipal wastewater in irrigation is linked to the incentive for increasing the region's farms' income by augmenting their irrigation potential. The town, which owns and operates the treatment plants, bears increased treatment costs ($-\zeta^1$). If the additional cost (the difference between ζ^1 and the cost of treatment with no cooperation - a necessary expenditure if all the wastewater is to be removed from the region) is smaller than the additional benefits, then regional cooperation is economically feasible.

The question then arises: How should the regional net benefits of the cooperative enterprise be allocated among the town and the farms? This chapter deals with this issue within the framework of a cooperative game with side payments. The regional optimization model ensures efficiency in the treatment of wastewater (quantity treated and treatment level), and its allocation among the farms. Based on the prevailing regulations, it is assumed that freshwater farms' quotas are not transferrable, and the only way to compensate the participants in the regional project is through income transfers, or more specifically-farms' payments for effluent to the town.

ALTERNATIVE SCHEMES FOR COST/BENEFIT ALLOCATIONS WITHIN THE REGION

The conventional competitive rule that each user of effluent should pay according to the marginal treatment cost is not applicable in this case: a) the number of participants in the wastewater-effluent "market" is small; they are not anonymous and agreements and coalitions among some of the potential participants are possible; and b) the treatment costs are subject to increasing economies and decreasing marginal cost. In such a case, marginal cost pricing leads to a deficit, which should be covered either by the users or some external agency (e.g., government), or both.

Marginal cost pricing of public utilities and other publicly supplied goods has been extensively discussed in the economic literature (e.g., Hotelling (1938), Ruggles (1949)). As indicated by Lerner (1944), Coase (1946), Samuelson (1947), and others while it leads to efficient use of resources, the problem of covering the deficit generated under the decreasing marginal cost situation has not been satisfactorily solved.

One of the methods used in the USA for the allocation of costs in public enterprises, is the SCRB - Separable Cost Remaining Benefits (Giglio and Wrightington (1972), Loughlin (1977), and Heany and Dickinson (1982)). However, this method is unsatisfactory because (a) it does not effectively charge the users with the additional costs accrued to the enterprise by their participation, and (b) it may violate the individual and group rationality assumption, (see below).

The difficulties encountered by the above cost allocation (pricing) schemes lead to a search for solutions in axiomatic approaches. The essence of these approaches is that once the users of a public utility or the participants in a regional enterprise (as in our case) agree on certain axioms believed to satisfy selected criteria, such as efficiency, fairness, and reasonableness, the cost allocation solution is uniquely determined (e.g. Hardwood (1950, 1951), Loehman and Whinston (1971, 1974), Nash (1950), Shapley (1951) and Schmeidler (1969)).

Cooperative games theory offers several axiom-based models for solving cost/benefit allocation problems. They have been applied to a variety of issues, such as water resource development (Young et al (1981)), charging for airfield use (Littlechild, (1974)), telephone switchboard use (Billera et al (1978)) and others. This chapter will deal with the application of the axiom-based models to regional wastewater treatment and its use in irrigation. It will also attempt to determine to what extent the schemes based on a priori reasonable assumptions (axioms) lead to reasonable and acceptable results. Besides the axiomatic game theory approaches, the application of the Core concept (Owen (1968)), Shapley and Shubik (1969b, 1969c) and Varian (1978)) and a variant of marginal costs pricing will be presented and tested.

APPLICATION OF ALTERNATIVE COST/BENEFIT ALLOCATION SCHEMES TO REGIONAL WASTEWATER TREATMENT AND USE OF EFFLUENT IN IRRIGATION

The problem of cost/benefit allocation is referred to within the framework of a cooperative game.¹ $N(=4)$ players participate in the game - the town and the farms. The players are assumed to be rational, in the sense that each attempts to maximize its income. Side payments are possible; that is, income is transferrable among the players. In the following, we will refer to the town as player 1, and to the farms as players 2, 3, and 4, or interchangeably as farms A, B, and C.

The Core Solution

The core of a game of N cooperative players can be defined as a group of all the feasible allocations of the cooperative game income (or utility) which fulfill the following assumptions:

a) Individual rationality - no player participating in the game receives less than in the non-cooperative situation; i.e. when he operates on his own.

¹ Luce and Raiffa (1957) or Rappoport (1970) are good introductions to the subject. More advanced treatment can be found in the books by Owen (1968) or Varian (1978) and in journal articles cited throughout the text.

- b) Group rationality - every subset of players with the potential to create a "partial coalition" does not receive less than what would be given in the partial coalition situation.
- c) Joint efficiency - no one can increase his income without reducing someone else's income (Pareto optimality).

Let $N = \{1, 2, \dots, n\}$ be the grand coalition of all the players participating in the game.

A subgroup of players will be noted as S , $S \subseteq N$; $S = \{1\}, \{2\}, \dots, \{1, 2\}, \dots, \{1, 2, 3\}, \dots$, with $S = \{1\}$ denoting player 1 (the town) operating on its own; $S = \{1, 2\}$ representing the partial coalition of 1 and 2 (the town and farm A), etc.

The "characteristic function" of subgroup S , $v(S)$, denotes the collective income of group S in a cooperative setting. For the empty set, $v(\{\emptyset\}) = 0$.

The collective income $v(N)$ must be distributed among the members of N in a manner that will motivate them to set up coalition N .

Let w_i = player i 's allocation, and let $\underline{w} = (w_1, \dots, w_n)$ be the vector of income allocations (the town's income is negative - it indicates the cost of wastewater treatment).

Using the above notation, the core is the set of income allocations satisfying the following conditions:

- (2) $w_i \geq v(\{i\})$ for all $i \in N$.
- (3) $\sum_{i \in S} w_i \geq v(S)$ for all $S \subseteq N$
- (4) $\sum_{i \in N} w_i = v(N)$

In the region under study, the town, which operates the treatment plant, is essential to any coalition. Similarly essential is farm A's (player 2) participation due to its location relative to the town and to the other farms. Accordingly, the number of feasible coalitions is eight.

Columns one and two in Table 1 show respectively the feasible coalitions and the income of each coalition $v(S)$ (or $v(\{i\})$, in the case of non-cooperation). Column four in the table presents the incremental income of a coalition $v(\cdot)$, above the sum of the incomes of the players participating in the coalition, which is achievable under non-cooperation (column 3). Formally, the data in column four present $\rho(S)$:

$$(5) \quad \rho(S) = v(S) - \sum_{i \in S} v(\{i\})$$

where $\rho(S)$ can be regarded as the "normalized" income of coalition S .

The gross income of the players derived under the various coalition combinations is shown in Table 2; it represents the composition of the income (characteristic function) of each coalition. For example, $v\{1,2,3\} = 18.95$ (row 6 in Table 1) is the sum of $-3.00 + 13.70 + 8.25$ in row six of Table 2. (Note that the figures are rounded).

Table 1: Values of the Characteristic Function (Income) of Possible Coalitions in the Region in Millions I.S. ¹⁾

Coalition $\{S\}, \{i\}$	Characteristic Function $v(S), v(\{i\})$	$\sum_{i \in S} v(\{i\})$	Incremental Income of Coalition S $\rho(S)$
(1)	(2)	(3)	(4)
{1}	-2.22	-2.22	0
{2}	11.68	11.68	0
{3}	7.74	7.74	0
{4}	2.65	2.65	0
{1,2}	11.18	9.46	1.72
{1,2,3}	18.95	17.20	1.75
{1,2,4}	13.84	12.11	1.73
{1,2,3,4}	21.81	19.85	1.96

Source: Optimal solution values of Chapter 4's programming model, solved for the respective coalitions.

Footnotes:

¹⁾ Income in millions IS, at October 1980 price level (rounded figures).
One IS = 16 U.S. cents.

Table 2: Gross Income (ζ^i) of players in the Optimal Solution for Various Coalition Combinations¹

Coalition	Player	1	2	3	4	Total
{1}		-2.22				-2.22
{2}			11.68			11.68
{3}				7.74		7.74
{4}					2.65	2.65
{1,2}		-2.47	13.65			11.18
{1,2,3}		-3.00	13.70	8.25		18.95
{1,2,4}		-2.38	13.28		2.94	13.84
{1,2,3,4}		-2.99	13.64	8.22	2.94	21.81

Source: Solutions of Chapter 4's programming model.

Footnotes:

¹⁾ Income in millions IS at October 1980 price level (rounded figures).

One IS = 16 U.S. cents.

Scrutiny of Tables 1 and 2 suggests that the incremental income of a coalition generated by players 1 and 2 is 1.72 million IS; the gross income generated by farm A (player 2) rises from 11.68 to 13.66 million IS (about 2 million IS), while the treatment cost rises by only 0.25 million IS. Players 3 and 4's individual entry to {1,2} increases the income by a negligible amount. When they both join {1,2}, the additional net income generated is only 0.24 million IS (=1.96-1.72 = 0.24 in normalized values).

These observations imply that farm A is the significant contributor to the regional income, while farms B and C fall far behind. Common sense suggests that this fact should be considered in any income allocation scheme. This point will be discussed again later in the chapter.

Referring to the last column of Table 1, the core of the game with all players cooperating can be defined as follows (in terms of the incremental income $\rho(\cdot)$):

$$\begin{array}{ll}
 w_i & \geq 0 \\
 w_1 + w_2 & \geq 1.72 \\
 (6) \quad w_1 + w_2 + w_3 & \geq 1.75 \\
 w_1 + w_2 + w_4 & \geq 1.73 \\
 w_1 + w_2 + w_3 + w_4 & = 1.96
 \end{array}$$

The core of this game is a four-dimensional polyhedron. A method of calculating the extreme points of the core of a convex game was used (Shapley, 1971).¹⁾ The essence of the method is to refer to a sequence of growth of any feasible coalition and to allocate the incremental income generated by each players's entry into an existing coalition.

Table 3 presents the extreme points of the core of the regional game. The first four columns indicate the contribution of each player when he joins an existing coalition, and these are in effect the maximal allocations payable to the players. The right-hand side of the table shows the corresponding coalition formation sequences. For example, the sequence corresponding to the first row is 1,2,3,4, with:

$$v(\{1\}) = 0$$

$$v(1,2) = 1.72 \text{ and } w_2 = 1.72$$

$$v(1,2,3) = 1.75, \text{ and } w_3 = 0.03$$

$$v(1,2,3,4) = 1.96, \text{ and } w_4 = 0.21$$

Note that certain extreme points allocations correspond to several alternative sequences (e.g., row 3), because

$$v(1,3) = v(1,4) = 0$$

$$v(\{i\}) = \text{all } i$$

$$v(S) = 0 \quad i \in S$$

¹⁾ The definition of convex games is given in Shapley. See Dinar (1983) for proof of convexity of this game.

Table 3: Extreme Points of the Core in the Regional Game

Maximum Profit Allocation to Player i (Mill. IS) ¹⁾				Coalition Formation Sequences allowing This Allocation					
Player									
1	2	3	4						
0	1.72	.03	.21	1234					
0	1.72	.23	.01	1243					
0	1.75	.0	.21	1324	3124				
0	1.96	0	0	1342	1432	3142	3412	4132	4312
0	1.73	.23	0	1423	4123				
1.72	0	.03	.21	2134					
1.72	0	.23	.01	2143					
1.75	0	0	.21	2314	3214				
1.96	0	0	0	2341	2431	3241	3421	4231	4321
1.73	0	.23	0	2413	4213				

Footnotes:

1) October 1980 price level; 1 IS = 16 US cents

Table 3 suggests that the bargaining set consistent with the assumptions underlying the core is quite large. Players 1 and 2 can each claim up to 1.96 million IS - the total additional regional income generated by the cooperation - because each is essential to any coalition. On the other hand, the claims of players 3 and 4 consistent with the core are bound to be modest, less than 0.23 and 0.21 million IS for 3 and 4, respectively. This is consistent with their modest contributions to the regional cooperation under the present conditions. Note that farms B and C (players 3 and 4) are considerably younger and less developed than farm A. In the future, their productive capacity may increase. This prospect serves in effect as the reason for their inclusion in the regional cooperation, in spite of their present modest contribution.

To summarize, in the particular case studied, the core provides bounds only on the claims of the participants in the regional cooperation. While logically and morally easily acceptable, it is not conclusive, and therefore only partly useful. It may serve as a starting point for the continuation of the analysis; a direct progression is the application of the Least Core and Nucleolus concepts is discussed in a later section. Also, the computations of the extreme points of the core are incorporated into the Shapley Value, discussed in the following section.

The Shapley Value and the "Revised" Shapley Value

The Shapley Value is a uniquely defined solution to a cooperative game with n players, expressed in terms of the characteristic function (Shapley, 1953).

The solution is a system of allocations among the players of the income (utility) generated by the grand coalition. The allocation system takes into account a) the potential contribution of each player to each a priori possible coalition, (possible in a combinatorial sense); and b) their possible sequences of formation. The solution allocation to each player $\theta_i(v)$ is the weighted average of his contributions to all possible coalitions and sequences:

$$(7) \quad \theta_i(v) = \sum_{\substack{S \subseteq N \\ i \in S}} \frac{(n-s)!(s-1)!}{n!} [v(S) - v(S - \{i\})] \quad i \in N$$

where

$\theta_i(v)$ = the allocation to player i ;
 n = the number of players in the game;
 s = the number of members in coalition S .

The expression in the square brackets denotes the marginal income of coalition S due to player i 's entry in a certain sequence; it is multiplied by the probability of player i joining the coalition $\{S - \{i\}\}$.

The Shapley Value assumes that there is a common denominator for comparing the utilities among the players, with a media for their transfer (money). It complies with the following axioms:

- a) Anonymity (or symmetry);
- b) The "dummy" axiom - player i whose contribution to a coalition formed in a given sequence is zero (i.e., $v(S) = v(S - \{i\})$) will be assigned a zero value for this particular sequence; and
- c) The sum of allocations to all the players is equal to the value of the grand coalition ($\sum_{i \in N} \theta_i(V) = v(N)$).

The Shapley Value does not account for the bargaining power of the potential participants in the potential coalitions. It assumes equal probability for the formation of any coalition theoretically possible. The last assumption has been criticized by Loehman and Whinston (1976), referred to in the following.

The Shapley Value does not necessarily satisfy the assumptions underlying the core; it may lie outside the core (Maschler et al, 1979). Moreover, it exists when the core is empty. When the game is convex, the Shapley Value is the center of gravity of the core (Shapley, 1971).¹

The vector of allocations of the regional incremental income among the four players according to the Shapley Value is, in millions IS:

$$\underline{\theta}(V) = [.92; .92; .07; .05]$$

The anonymity property of the Shapley Value is demonstrated by the allocation of players 1 and 2, whose values are identical. The Shapley Value does not differentiate between players 1 and 2 because they appear symmetrically in each coalition, whose characteristic function is not zero (symmetric players).

Loehman and Whinston (1976) claimed that the use of the Shapley Value in games where some of the coalitions are not realistically possible causes a certain distortion in allocation, resulting from assigning greater weight to players also appearing in coalitions whose

values are zero. As an alternative, Loehman and Whinston proposed the "Revised" Shapley Value, which differs from the original in two major aspects.

- a) It refers only to coalitions that are practically possible, (rather than possible from a theoretical combinatorial point of view), and
- b) The probability of a coalition occurring depends on a logical sequence of its formation. (See Figure 1; note that the number of possible sequences of the grand coalition is only 4, as compared to 24 combinatorial possibilities).

In a manner similar to Shapley, Loehman and Whinston (1976) assign to each player the weighted average of his contributions to any coalition realistically formed. The probabilities of the realistically possible coalitions are computed with the aid of Figure 1. The allocation to player i is $\hat{\theta}_i(V)$:

$$(8) \quad \hat{\theta}_i(V) = \sum_{\substack{S^* \subseteq N \\ i \in S^*}} P(S^*, S^* - \{i\}) [V(S^*) - v(S^* - \{i\})]$$

where

$$P(S^*, S^* - \{i\}) = P(S^* | S^* - \{i\}) \cdot P(S^* - \{i\})$$

is the probability of player i joining coalition S^* . For further computational details, refer to Loehman and Whinston (1976) or to Dinar (1983).

Figure 1: Coalition Formation Sequences in the Regional Cooperative Game

The vector of allocations according to the "Revised" Shapley Value is (in millions IS):

$$\hat{\theta}(v) = [.86; .86; .13; .11]$$

Again players 1 and 2 - the town and farm A - are assigned equal allocations, because their roles are symmetrical. Their allocations are lower than in the (nonrevised) Shapley Value, while those of players 3 and 4 are higher.

The incorporation of the "Revised" Shapley allocations into the regional income distribution is summarized in Table 4.

The Least Core and the Nucleolus

In cooperative games in the form of the characteristic functions, the core of a game can be empty because certain colations provide greater incentives than the grand coalition, i.e.,

$$\sum_{i \in S} w_i \leq v(S) \text{ for some } S, S \subseteq N$$

Conversely, conditions may arise where the core does exist, but is too large and leaves the cost/benefit allocation problem open for further bargaining (as in this study). A possible approach for the derivation of a unique solution in both cases is by limiting or expanding the core and then obtaining the "least core" (Ω - core), (Mashler et al, 1979), which still satisfies the conditions of individual and group rationality. When the core is empty, the Ω core is defined as the solution of the following problem:

(9) Minimize Ω

Subject to

$$\begin{aligned} \sum_{i \in S} w_i + \Omega &\geq v(S) & S \subseteq N \\ \sum_{i \in N} w_i &= v(N) & \Omega > 0 \end{aligned}$$

This formulation can be interpreted as levying minimal penalty (Ω) on partial coalitions S to make them less attractive and thus to enable the formation of the grand coalition.

Table 4: Calculation of the Charges for Cooperative Treatment Costs,
Using the "Revised" Shapley Value (million IS)

Player	1 Town	2 Farm A	3 Farm B	4 Farm C	Total
1. Cost/Income in non-Cooperative Solution	-2.22	11.68	7.74	2.65	19.85
2. Allocation of incremental regional Income ¹⁾	<u>.86</u>	<u>.86</u>	<u>.13</u>	<u>.11</u>	<u>1.96</u>
3. Total net Income in Regional Cooperation ²⁾	-1.36	12.54	7.87	2.76	21.81
4. Gross Income in Regional Cooperation before Re-Distribution ³⁾	<u>-2.99</u>	<u>13.64</u>	<u>8.22</u>	<u>2.94</u>	<u>21.81</u>
5. Income Transfers ⁴⁾	+1.63	-1.10	-3.5	-1.8	0

1) "Revised" Shapley Value allocations.

2) Row 3 = row 1 + row 2 = net income after income redistribution.

3) Results of the regional optimization model (see Table 2).

4) Row 5 = row 3 - row 4.

In the case of the core being too large, the least core is generated by the solution of (11) and (12), which can be interpreted as subsidizing the partial coalitions to make them more attractive, while not refuting the individual and the group rationality conditions:

(11) Minimize Ω

Subject to

$$(12) \quad \sum_{i \in S} w_i - \Omega \geq v(S)$$

$$\sum_{i \in N} w_i = v(N) \quad \Omega > 0$$

Note that alternative approaches to reducing the core and obtaining a unique solution can be formulated (Young et al, 1979).

The least core solution of (11) and (12) for the regional problem studied is obtained when $\Omega = 0.08$; however, the optimal vector of allocations of $\underline{w}^0$ is not unique. To illustrate, two alternative optimal solutions are $\underline{w}_1^0 = [1.72; .08; .08; .08]$, $\underline{w}_2^0 = [.08; 1.72; .08; .08]$.

Any convex combination of $\underline{w}_1^0$ and $\underline{w}_2^0$ is an optimal solution, too, because players 1 and 2 are "symmetrical", in the sense that they both are essential to any coalition formed and are jointly included in each of (12)'s restrictions.¹⁾

The Nucleolus of a cooperative game expressed in terms of the characteristic function is a unique selection of the preferred allocation vector $\hat{\underline{w}}^0$ (Schmeidler, 1969). The Nucleolus can be interpreted as the allocation, which minimizes the maximal possible objection to the allocations to any of the coalitions; it is a minimax selection. The extent of the objection is measured by the "excess" or the difference

¹⁾ This is evident from the detailed formulation of (11) and (12) for the regional problem:

Minimize Ω

$$w_i - \Omega \geq 0 \quad i = 1, 2, 3, 4$$

$$w_1 + w_2 - \Omega \geq 1.72$$

$$w_1 + w_2 + w_3 - \Omega \geq 1.75$$

$$w_1 + w_2 + w_4 - \Omega \geq 1.73$$

$$w_1 + w_2 + w_3 + w_4 = 1.96$$

$$\sum_{i \in S} w_{ij} - v(S) \geq 0$$

where w_{ij} is the allocation to player i in solution j to (11) and (12).

The properties of the Nucleolus solution (Maschler et al, 1979), derived from its definition and computational methods are:

- a) It is an unique allocation in the core, when the core is not empty.
- b) It is an anonymous allocation; and
- c) It accounts for the bargaining power of the players.

The Nucleolus solution of the regional cooperative problem is (millions IS): $\hat{w}_1 = \hat{w}_2 = 0.90$; $\hat{w}_3 = \hat{w}_4 = 0.08$

For computational details of the Nucleolus, refer to Maschler (1979) or to Dinar (1983).

Charging the Farms for Effluent According to its Shadow Prices

It can be shown that charging the farms for effluent according to its shadow prices in the various months does not affect the optimality of the regional solution, nor does it affect the value of the objective function. It has the effect of income redistribution only, in the form of payment by the farms to the town (Dinar, 1983).

Table 5 presents the payments by farms A through C according to this rule. As shown by the table, the total payments amount to 1.91 million IS, out of 2.99 million IS (the cost to town after deducting the 50% subsidy), leaving 1.08 million IS to be borne by the town. Recall that the town's costs with no cooperation total 2.22 million IS; that is, the net gain of the town due to cooperation is 1.14 million IS. This might be considered by the town leaders as a reasonable gain. On the other hand, the payment by farm A - 1.40 million IS - might be considered as too high in comparison to its contribution to cooperation (Table 3). The net gain to the town is 0.56 million IS.¹⁾

¹⁾ Computed as: 13.64 - 1.40 - 11.68 = 0.56
 (Gross income at optimal solution) (Payment for effluent) (Income with no cooperation) (Net Cooperation gain)

We will return to this point later when we discuss the net gains due to cooperation according to the various schemes.

Table 5: Payments for Effluent by Farms A, B, and C According to the Shadow Cost Rule (Millions IS)

Farm	A	B	C	Total
Payment	1.40	.40	.11	1.91
Treatment costs				2.99
Costs not covered				1.08

While the relative gains to the various players resulting from cooperation might be subject to criticism, a strong point against shadow cost pricing is that the cost/benefit allocation does not lie in the core, as it does not satisfy the conditions of group rationality. The sum of players 1 and 2's net gains in the grand coalition is smaller than the value of their partial coalition: $1.14 + .56 < v(1,2) = 1.72$.

COMPARISON OF THE ALTERNATIVE ALLOCATION SCHEMES

Table 6 presents the allocation of the regional cooperative gains to the town and to the farms according to the alternative schemes. Table 7 presents a more comprehensive view of the effects of these cost/income allocation schemes on the costs/incomes of the regional participants.

Using Tables 6 and 7 as background, we will attempt to evaluate the various allocation schemes.

Table 6: Allocation of Regional Cooperation Gains among the
Players according to Various Approaches (mill.IS.)

Allocation Scheme	Player:	1	2	3	4	
		Town	Farm A	Farm B	Farm C	
Shapley Value		.92	.92	.06	.05	1.95 ¹⁾
Revised Shapley Value		.86	.86	.13	.11	1.96
Nucleolus		.90	.90	.08	.08	1.96
Shadow Cost Pricing		1.14	.55	.09	.18	1.96

Footnotes

1) Rounding error.

The first note worthy observation is that the allocations based on shadow cost pricing are quite divergent from the others. The allocation to the town is considerably higher, and that to farm A - considerably lower. Furthermore, there is a large difference in the town's and farm A's allocations. In view of the symmetry of these players and the large income generated by Farm A, such inequality might be considered as unacceptable. Also, as previously shown, the shadow cost pricing allocation vector, does not lie in the core, another reason for its rejection by players 1 and 2.

The apparent inacceptability of the shadow cost pricing system may raise doubts and questions. It is proper to note, therefore, that prices of fresh water paid by the farmers in the region are in general considerably lower than its on-farm shadow cost. The application of shadow cost pricing with respect to effluent only, introduces a "strange" element into the system which may partly explain its inacceptability.

Table 7: Distribution of the Incremental Income among the Participants in the Regional Cooperation According to Alternative Allocation Schemes

Allocation Scheme	Player	1 Town	2 Farm A	3 Farm B	4 Farm C
Shapley Value	Allocation, Mill. IS	.92	.92	.06	.05
	% of regional incremental income ¹⁾	47	47	3	3
	% of income with no cooperation ¹⁾	42	8	1	2
Revised Shapley Value	Allocation, Mill. IS	.86	.86	.13	.11
	% of regional incremental income	44	44	7	6
	% of income with no cooperation	31	7	2	1
Nucleolus	Allocation, Mill. IS	.90	.90	.08	.08
	% of regional incremental income	46	46	4	4
	% of income with no cooperation	41	8	1	3
Shadow Cost Pricing	Allocation, Mill. IS	1.14	.55	.09	.18
	% of regional incremental income	58	28	5	9
	% of income with no cooperation	51	5	1	7

Footnotes:

¹⁾ Rounded figures.

The other three systems of allocation of the regional cost/income were derived on the basis of a priori acceptable axioms. Do the results derived from these axioms (i.e. the actual allocations) meet, as well, common criteria such as fairness, reasonableness and acceptability?

If acceptability means satisfying the assumptions underlying the core solution, and we tend to accept this interpretation, then all three allocations—Nucleolus, Shapley and Revised Shapley are acceptable (the nucleolus by its computation, Shapley and Modified Shapley - due to the fact that the game is convex).

Regarding the criteria of fairness and reasonableness, no objective way to measure them is known to us (see also Rawls (1971), Arrow (1971), Yaari (1981), and Shapley (1976b)). We'll therefore restrict ourselves to several observations and questions.

Considering the allocations to the town and farm A - players 1 and 2 - in all schemes their shares are equal. This reflects their symmetry as players and their bargaining power. However, the increase in income of farm A ranges between 7.4 - 7.9 % as compared to the non cooperative situation, while the decrease in cost of the town is in the range of 31-42%. Is it fair? Is it reasonable?

The entry of player 3 to any coalition contributes to the regional income more than that of player 4 (Table 3) but the percentage wise increase in income of player 3 is lower than player 4's under all three axiomatic schemes. Would player 3 consider this situation as fair and reasonable?

Other similar questions could be asked with no clear cut answers.

To summarize - in the case studied, game theoretic approaches do not provide an objective, undisputable solution to the income distribution problem. The various approaches presented, and, especially the core, provide a) the bounds on the claims by the participants, and b) better understanding of the grounds for these claims and of possible objections to them. This information might be helpful in bargaining aimed to reach an agreement.