R82-10

AGRICULTURAL EXPANSION PLANNING: INCORPORATING WATER REUSE

by

Mohamed Najr Allam
and
David Hunter Marks

RALPH M. PARSONS LABORATORY
HYDROLOGY AND WATER RESOURCE SYSTEMS

Report Number 269

Prepared Under the Support of The
Technology Adaptation Program

MARCH 1982

MIT

[redacted]

DEPARTMENT
OF
CIVIL
ENGINEERING

SCHOOL OF ENGINEERING
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Cambridge, Massachusetts 02139

R82-10

AGRICULTURAL EXPANSION PLANNING: INCORPORATING WATER REUSE

by

Mohamed Najr Allam
and
David Hunter Marks

RALPH M. PARSONS LABORATORY
HYDROLOGY AND WATER RESOURCE SYSTEMS

Report Number 269

Prepared Under the Support of The
Technology Adaptation Program

MARCH 1982

ABSTRACT

A mathematical model has been built to guide decisions required for agricultural expansion planning. Of particular interest is the case when some, or all, of the irrigation sources available have saline water. These decisions generally are quantities and locations of all resource inputs, mixing ratio between different waters, if mixing is possible, irrigation network design, required enlargement in the existing irrigation system, and crop pattern distribution in the new lands. These decisions are based on the maximum net benefit criterion and are carried out in a mathematical optimization framework.

A comprehensive study of the use of this model in a large scale planning problem has been done. This case is based upon the proposed agricultural expansion in the Nile Delta and the Sinai in Egypt. The available irrigation sources in these regions are fresh and saline waters from the River Nile, and from the draines of the existing cultivated lands, respectively. Different alternative schemes for irrigating the new lands have been obtained. An economic approach for enabling the decision makers to analyze the different alternatives has been presented. In addition, the equity concerns in scheduling and cost allocation have been discussed.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS
(continued)

LIST OF TABLES

LIST OF TABLES
(continued)

LIST OF TABLES
(continued)

LIST OF TABLES
(continued)

LIST OF FIGURES

LIST OF FIGURES
(continued)

LIST OF FIGURES
(continued)

Chapter 1

INTRODUCTION

1.1 Overview

When using low quality water in agricultural practices, various soil and cropping problems are to be expected. The most common problems are salinity, soil permeability and toxicity. The irrigation water salinity causes a physiological draught condition which results in damage to plant growth and yield. The permeability problem is normally associated with irrigation water having a high sodium content relative to the calcium and magnesium concentration. The resulting poor permeability makes it difficult to supply crops with water necessary for growth. The toxicity problem is due to certain soluable (ions) at relatively low concentration which have a direct toxic effect on the growth of certain sensitive crops like trees and woody ornamentals.

However, the results of numerous studies (U.S. Salinity Lab., (1954), Hayward, (1956), Ayers, (1976); and Mass and Hoffman, (1977)) have shown that the main damage to plant growth is usually due to salinity of irrigation water. An increase in the irrigation water salinity causes a decrease in growth and yield of the plants. Also irrigation water has to increase with a leaching fraction which is necessary for keeping a long term salt balance in the root zone. Therefore in general, saline irrigation water causes an increase in the irrigation water requirement, and a decrease in the crops yield.

Goldberg et al., (1971) provided a tool for reducing the irrigation water salinity effects upon crops yield by irrigating more frequently using trickle irrigation methods. Mass and Hoffman, (1977) and Ayers

(1977) used the criteria that crops vary greatly in their salt tolerance in decreasing salinity problems. They evaluated the relative salt tolerance of most agricultural crops and they constructed crop tolerance tables which indicate for each crop the maximum allowable salinity without yield reduction and the percent yield decrease per unit salinity increase beyond the threshold. These tables provide a wide range for crop selection according to their tolerance compatibility with salinity of available irrigation water to obtain maximum possible yield. However, until now, no research had been done to use the trade-off between the crop salt tolerance, water requirement, and economic value as a criteria for crop selection in the context of planning agricultural expansion to new lands.

In this research our main concern is how to develop a planning scheme for an agricultural expansion project when some or all irrigation water resources are saline water. Ramos, (1979) solved a similar agricultural expansion problem as a transshipment problem. He use the minimization cost criteria in determining the planning decision variables which are the capacities of irrigation canals. He did not consider the salinity of available irrigation water resources although the saline water (drainage water) was relatively a high portion of water available in the case study. However, in order to develop this planning scheme a large scale agricultural expansion planning model has been built in which we explicitly consider the salinity effects of irrigation water upon the agricultural crops. The salinity effect upon crops yield has been computed using the equation developed by Mass and Hoffman (1977) in which they assumed that the crops yield decreases linearly as salt concentration increases above the threshold level. This equation and another which computes the leaching fraction as a function of the salt concentration in irrigation water and soil water as proposed by Rhodes, (1974) has been included in the model's constraint set.

The crop selection as one of the planning decisions of this model is based on a trade-off between the crops salt tolerance, irrigation water transmission cost, and their economic values. In addition to the crop pattern distribution this model determines required enlargement to the existing irrigation network in the old cultivated lands for supplying the new lands. Other related planning decisions like quantities and locations of all resources inputs, mixing ratios between different water, and irrigation network design in the new lands are also provided by this model. More important, by using this model we can provide the decision makers with cost and benefits allocations and income distribution through the new land which are extremely useful in preparing a planning schedule for this type of project if there is a budget limitation on the investment and in investigating the needs for differential land pricing or other equity measures.

In order to determine the above planning decisions, a maximum net-benefit criteria is used. The net-benefits resulting from an agricultural expansion are usually the agricultural production revenue less irrigation water transmission cost, new land development cost and some other costs on the farm level like costs of seeds, fertilizer, labor, and machinary. Irrigation transmission cost includes excavation, lining, irrigation structures and maintenance costs of the new canals, enlarging cost of existing canals and water lifting cost. The land development cost usually includes the cost of drainage works, farm machinary, housing, electricity, transportation, communication, land leveling and social services. In order to derive water transmission cost functions, it is assumed that the proposed design of the new canals is the most economical one. This design can be done by minimizing the cross-sectional area of a canal given the amount of flow, or by maximizing the uniform flow velocity given the canal's cross-sectional area. Based on this design method the excavation and lining costs of new irrigation canals have been derived in terms of the canal's capacities. Irrigation structure costs and maintenance costs have been expressed as ratios of a canals' excavation cost. The enlarging cost of the existing canals to provide the new lands with irrigation water has been derived in terms of existing and new capacities. Based on a regression analysis, the pumping capital cost as a function of pumping capacity and lifting head was given by Fu -Lsiung, (1970). Because of economy of scale of most of the above cost functions the model's objective function is non-linear and has the wrong shape, i.e., we are maximizing over a convex function. Fortunately, the decision variables appear separately in both the objective function and the linear constraint set. Therefore separable programming has been proposed for solving this planning model using the δ-method as given in Bradley et al., (1977).

The planning model is then applied to an Egyptian case study, namely the agricultural expansion in the Nile Delta and Sinai. This agricultural expansion is in the order of 1,500,000 feddans. The available irrigation water sources are generally fresh water from the River Nile and drainage water from existing cultivated lands. Two agricultural seasons - the winter and summer seasons - have been considered in the model. Seven crops for each season are used as an input to the model to determine the optimum crop selection for each part of the new lands. This selection is according to the trade-off explained before, and other physical and national agricultural requirement constraints. The physical constraints considered in this model are water budget constraints, sequential planting constraints, and soil type - crop pattern constraints. The water budget constraint is to keep the out-flow from each source less than or equal to the inflow to this water source. The sequential planting constraint is used when some crops are needed to be planted before some other crops for different purposes. As an example, in Egypt, clover has to be planted before cotton for enhancing of soil nitrogen. Soil-type crop pattern constraints have been used because some soils are not appropriate for planting certain crops. The agricultural requirement constraint is to insure that some crops have to be cultivated with certain amounts sufficient to the population requirements or for exportation purposes. The constraint could be relaxed if there is enough information about the shadow prices of the imported and exported crops. However, in our solutions we relaxed this constraint to show how crop pattern distribution is sensitive to this constraint.

The possibility of mixing different water of different salinities to obtain a moderate saline water has been accounted for in this case study.

In different sites, the possibility of using the saline (drainage) water directly or after mixing it with fresh water was one of the model's decision variables. An interesting relationship between the benefit cost ratio of the agricultural expansion which is greater than unity and water mixing ratio has been obtained as a convex function. As was expected we found that by increasing the water salinity (increasing the ratio of drainage water to fresh water) the benefit cost ratio decreased.

The crop pattern distribution through the new land have been obtained and for each part of the new areas the agricultural revenue has been computed. It is found that in the winter large areas have been cultivated with beans which have a high price and moderate water consumption. During the summer the crops of high water requirements like rice are chosen to be cultivated close to water resources to minimize the transmission costs. The crops which have a high salt tolerance like cotton have been selected in the areas which have saline irrigation water. More complicated crop selection has been done when maize has been chosen in areas where the irrigation water is saline. Maize was preferred to the cotton because of its higher price, although the latter has a higher salinity tolerance and a lower water requirement. As will be shown in the case study, cotton will be preferred to the maize whenever there is a shortage in irrigation water.

When computing the agricultural revenue for the new areas we found it is mainly dependent on three main factors. First, the irrigation water salinity which is inversely proportional to the agricultural revenue. Second, irrigation water availability; agricultural revenue increases with the increase of irrigation water availability. Finally, the distance between the areas and irrigation water sources. The crops of high water requirement generally have a high market price and usually are preferred in areas close to water sources for minimizing the transmission costs. Therefore when the distance increases the agricultural revenue decreases. Having this information about the income distribution throughout the new lands, a pricing policy for the areas could be done.

1.2 Scope of the Report

After this brief introduction, Chapter 2 presents a detailed survey of the irrigation water quality related problem. Different solutions and management alternatives are presented.

Chapter 3 introduces the mathematical derivation of the cost functions used. The mathematical formulation of the planning model is made with a nonlinear objective function and some nonlinear constraints. The nonlinearity problem is discussed and a separable programming algorithm is suggested for solving this model.

Chapter 4 presents a comprehensive study of the use of the planning model in a large scale case study in Egypt. Different irrigation schemes are obtained. The equity concerns in scheduling and cost allocation are discussed.

Finally, Chapter 5 presents conclusions that can be made from the research. The chapter ends with recommendations for future research.

Chapter 2

IRRIGATION WATER QUALITY

2.1 Introduction

The term "quality" is most often used as a measure of the suitability of an item for use. Evaluating the quality is in the general case difficult, so that the intended use must first be specified. Once this has been done, the quality can be evaluated in terms related to its specific use. For irrigation, the suitability of water is related to a variety of considerations. One such consideration is its effect on soil and crops; another is the amount of management that may be necessary to control or otherwise compensate for water quality related problems. The quality of irrigation water depends on three main factors (30), which are:

(i) The sodium concentration and the ratio between it and the collective concentration of calcium and magnesium. This ratio affects the soil's physical condition.

(ii) The concentration of boron and other toxic ions. These ions are essential for plant growth as microelements. However, when their concentration in the irrigation water exceeds a certain value, they become toxic to the plants.

(iii) The total salt concentration, its effect is the most important of the water quality considerations. This factor relates to the availability of water for plant consumption. A high content of dissolved salt in the water tends to increase the osmotic pressure of the soil solution, thereby rendering less water available for plant growth. We see, then, that the main damage to growth is due to an excessive amount of total soluble salts in the water.

2.2 Irrigation Water Quality Related Problems

If water of poor quality is used, various soil and cropping problems can be expected to arise. The most common problems (30) are salinity, soil permeability, toxcity, and others which we shall refer to as miscellany.

The Salinity Problem

The results of numerous studies [4] show that plants have been observed to wilt in fields although their supply of water was adequate. This is usually due to a physiological drought condition resulting from high soil salinity. Salinity is usually measured and reported as electrical conductance (EC_w) or total dissolved solids (TDS).

It has been found (36) that the effect of matric tension on plant growth can be added to the effect of osmotic tension, producing what is called "total soil moisture stress." The plant responds to this stress without, of course, differentiating whether it seems from a high salt concentration or from drought, or both. The ability of a plant to extract water from soil is determined by the following relationship (25):

$$TSS = MS + SS, \qquad (2.1)$$

where,

TSS = The total soil suction, which represents the force with which water from the soil is withheld from plant uptake,

MS = The matric suction, or the physical attraction of the soil for water, and

SS = The solute suction, or the osmotic pressure of the soil water.

As the water content of the soil decreases due to evapotranspiration, the water film surrounding the soil particles becomes thinner and the remaining water is held with increasingly greater force (MS). Since only pure water is lost to the astmosphere during evapotranspiration, the salt concentration of soil solution (and hence also SS) increases rapidly during the drying process. Since the matric suction of soil increases exponentially upon drying, the combined effect of these two factors can produce critical conditions with regard to soil water availability for plant growth.

The Soil Permeability Problem

A permeability problem occurs if the irrigation water does not enter the soil rapidly enough during an irrigation to replenish the soil with water needed by the crop before the next irrigation (30). The resulting poor permeability makes it difficult to supply crops with water necessary for growth. The permeability problem is normally associated with irrigation water having either a very low salt content (total dissolved salts less than 0.5 millimhos per centimeter) or a high sodium content relative to the calcium and magnesium concentration. Carbonates and bicarbonates can also affect soil permeability under certain conditions and their concentration must be evaluated. The low salt waters are corrosive and deplete surface soils of readily soluble minerals and salts. They often have the tendency to rapidly dissolve all sources of calcium from surface soils. Soils may then break down and disperse, often resulting in poor water penetration. The usual preventive procedure with low salt water is to use gypsum.

The permeability problems due to excess sodium or limited calcium are evaluated (27) by a modification of the Sodium Adsorption Ratio (SAR) concept. This is called the "Adjusted" Sodium Adsorption Ratio (Adj. SAR). This new concept adds the effect of carbonate and bicarbonate to the older (SAR).

The evaluation of irrigation water quality (4) according to the Adj. SAR depends upon the total soluble salts concentration. If this concentration is low, values of Adj. SAR up to 10 may be acceptable. With an increase in total salinity the acceptable SAR values should be lower to avoid sodium hazards.

The Toxicity Problems

Toxicity problems are due to certain specific solubles (ions) at relatively low concentrations which have a direct toxic effect on the growth of certain sensitive crops like trees and woody ornamentals (29). Boron affects a wide range of crops. The correction of a boron problem (30) specifically and toxicity problems generally is leaching and irrigation more frequently than normal.

Miscellaneous Problems

Miscellaneous problems relate to excessive crop growth or delayed maturity due to nitrogen, white deposits on fruits or leaves, and other occasional abnormalities caused by the poor irrigation water quality. To prevent these problems, a change must be made to night irrigation and number of irrigations should be decreased if possible (30).

2.3 Solutions to Irrigation Water Quality Related Problems

As it has been shown through the discussion of water quality related problems, that as the salt concentration increases, the osmotic tension of the soil solution increases. This, in turn, causes the plant growth to diminish. Thus the main damage to growth is due to the content of total soluble salts, and the specific ion effect becomes less important. For this reason, in this section only the salinity problem and its solution will be considered. In fact, for the same reason, the only water quality problem considered in the development of the mathematical model is the salinity problem.

A salinity problem due to water quality occurs if salts from the applied irrigation water accumulate in the crop root zone and reduce the availability of soil water to the crops. To avoid salt accumulation to an excess level, it must be removed in amounts about equal to the salts applied (salt balance concept). To dissolve and remove the salts adequate water must be applied to allow percolation through the entire roote zone (leaching). This can be done in each irrigation but needs to be done only after the salts have accumulated to near damaging concentrations. So leaching enables us to achieve a long term salt balance. In this state, the average soil salinity of the root zone will be closely associated with the quality of the irrigation water applied as well as with the fraction of water moving in the root zone.

The crop primarily responds to the average salinity (30)and any increase in water salinity will result in an increase in average soil salinity as shown in Figure 2.1. Such an increase may have little practical significance, unless the salt content rises sufficiently to affect the crop yield.

The question that now arises is the following. How much water should be applied for leaching the excess salts out? The answer to this question through a detailed discussion is given in the following subsection.

2.3.1 Leaching Requirement

As mentioned earlier a permanent irrigated agriculture requires that salts brought into the root zone of crops by irrigation water be removed from this zone by the water that percolates or drains from the lower boundary of the root zone, and, to achieve such a salt balance, more irrigation must be applied than is necessary for evapotranspiration alone. This addition quantity of water is the leaching water whose quantity can be calculated simply by using the salt balance equation:

$$D_w \, EC_w = D_{dw} \, EC_{dw} \tag{2.2}$$

where

D_w = depth of irrigation water applied,

D_{dw} = depth of water draining from the root zone,

EC_w = salt concentration of the irrigation water, and

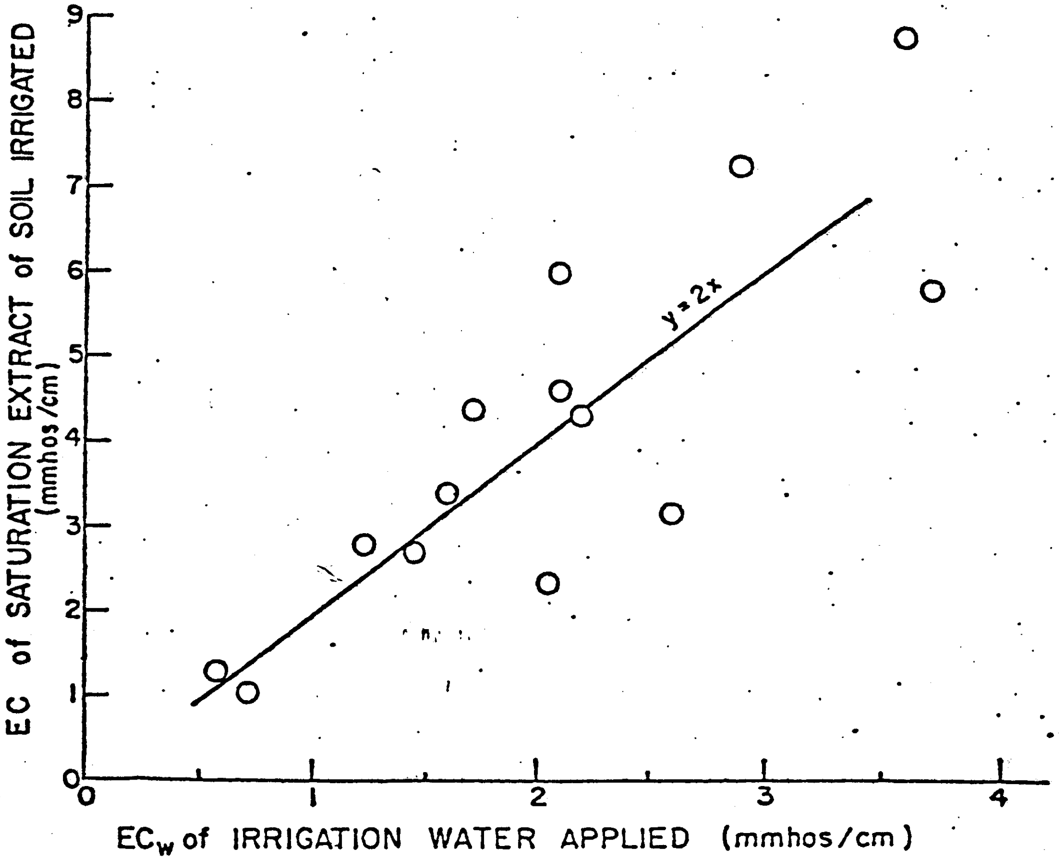

Figure 2.1 Influence of EC_w of Irrigation Water Upon Soil Saturation Extract EC_e

EC_{dw} = salt concentration of the soil water draining from the lower boundary of the root zone.

To calculate EC_{dw} we must take into consideration that some of the irrigation water will move rapidly through the larger pores and reach the lower boundary of the root zone with little increase in salt content. On the other hand, water moving through the finer pores may displace soil water, so that the drainage water from the smaller pores will have about the same salt concentration as that of the soil water in the root zone. Thus, the water draining from the lower boundary of the root zone can be considered as a mixture of irrigation water that has passed unchanged through the root zone and soil solution that has been directly displaced by irrigation water. The hypothetical fraction of the drainage water consisting of displaced soil solution is referred to as the leaching efficiency, with symbol E_ℓ. The fraction of the drainage water consisting of irrigation water that has passed unchanged through the root zone is then $(1 - E_\ell)$, so that the salt concentration of the water draining from the root zone can be calculated as:

$$EC_{dw} = E_\ell \, EC_\ell + (1 - E_\ell) EC_w \, , \tag{2.3}$$

where

EC_ℓ = salt concentration of the soil water in the root zone.

For field soils, however, cracks, root holes, worm holes, and other large-diameter pores, plus the inherent nonuniform distribution of water application in farm irrigation systems cause E_ℓ to be less than one. Then the leaching fraction (LR), which represents the minimum amount of water (in terms of a fraction of applied water) that must pass through the root zone to control salts, can be written in terms of

EC_e as follows:

$$LR = \frac{EC_w}{E_\ell \, EC_e + (1 - E_\ell) EC_w}$$

It has been found [19] that for soils in Iraq, E_ℓ appeared to vary from 0.2 for fine-textured soils (where cracks and larger-diameter pores may abound) to 0.6 for coarse-textured soils. Figure 2.2 shows the effect of different leaching fraction values on soil water salinity.

Some studies [30] on reducing the leaching fraction based on field and laboratory experience were made for different irrigation methods. For surface irrigation (including sprinkler), LR is given by:

$$LR = \frac{EC_w}{5EC_e - EC_w}, \qquad (2.4)$$

where

EC_e = the value of the soil salinity which causes a yield reduction of 10% or less for a given crop (see Table 2.6 page 26).

For a high frequency sprinkler or trickle irrigation (near daily):

$$LR = \frac{EC_w}{2(\max EC_e)}, \qquad (2.5)$$

where

max EC_e = corresponding to 100% yield reduction for given crop (see Table 2.6, page 26).

Besides the leaching procedure there are other management alternatives to help in improving soil water availability to the crop. There are two management alternatives which can be considered more useful.

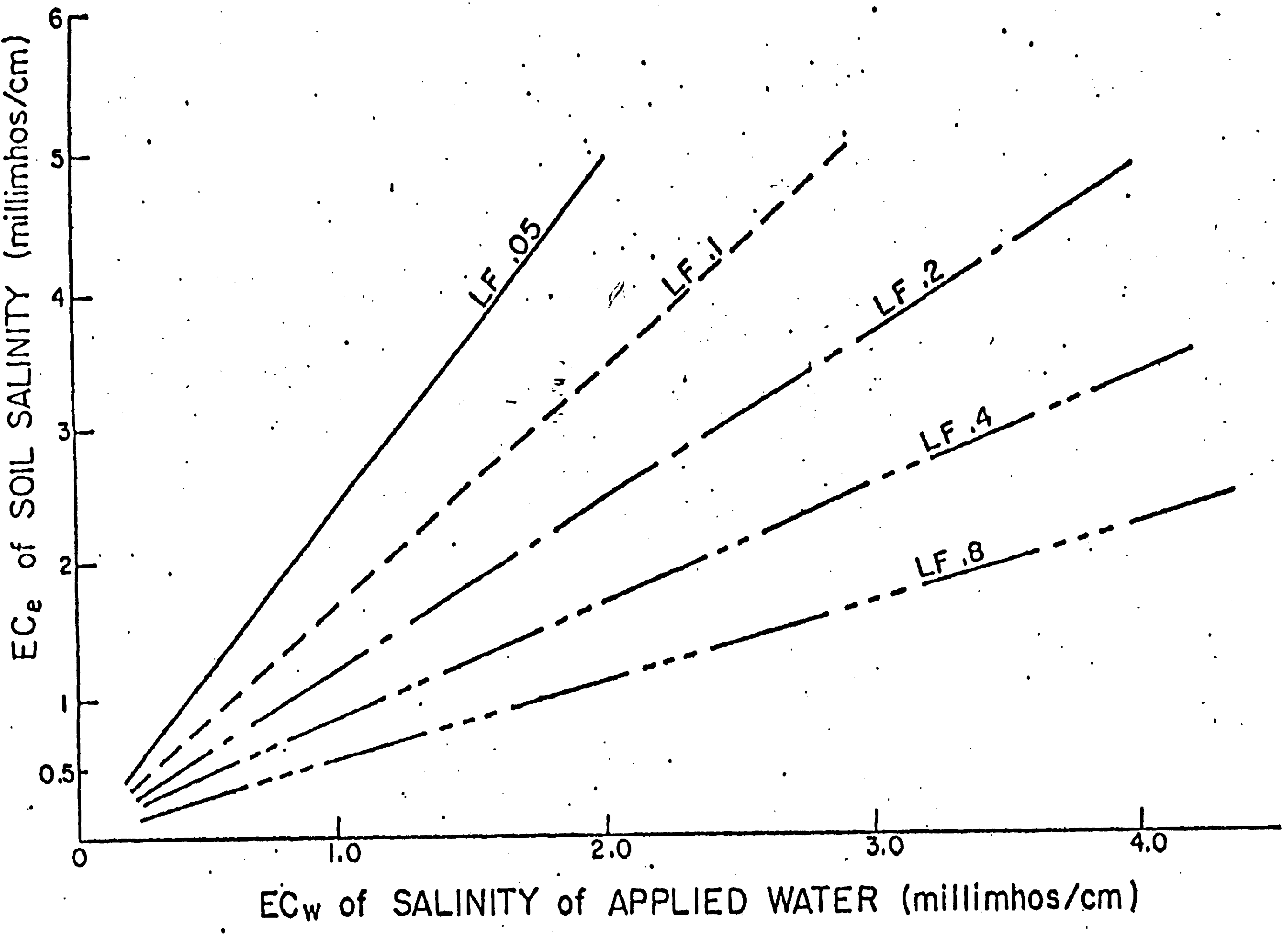

Figure 2.2 Effect of Salinity of Irrigation Water EC_w on Soil Salinity EC_e Under Varying Water Management

The first is to choose the best method of irrigation that will give better salt control, and the second is crop selection according to its tolerance to salinity. Next, we shall consider these management alternatives in more detail.

2.3.2 The Method of Irrigation

As mentioned before (subsection 2.2.1), the plant responds to "total soil moisture stress" without differentiating whether it seems from a high salt concentration or from drought, or both. In this state, as the matric tension decreases, the osmotic tension can be higher than normally acceptable without any resultant change in the effect of the total stress on the plant. Thus, using the trickle irrigation method at very frequent intervals, even daily, we can maintain a low matric tension in the soil and prevent salt accumulation and an increase in osmotic tension between irrigations. This decrease in matric tension and prevention of salt concentration may allow the use of water with a higher salinity level without affecting the relative yield. However, some field experiments have been done [10] using highly saline water. They were applied using both sprinkling and trickle irrigation to determine the effect of the method of water application on the permissible levels of water salinity for different crops. These field experiments were done in two arid regions with saline water resources. The first region was the Arava near the Gulf of Aquaba, and the second was El-Arish district in the northern part of the Sinai desert. The three aspects of these field experiments are:

(i) The effect of the irrigation method on growth and yield when using saline water,

(ii) The effect of the irrigation method on growth and yield when using waters of different qualities, and

(iii) The effect of the irrigation frequency on soil matric suction and yield.

Let us now consider each of these aspects separately.

2.3.2.1 The Effect of the Irrigation Method on Growth and Yield When Using Saline Water

The salt concentrations of the irrigation waters of Arava and El-Arish were 3,000 and 3,600 micromhes per centimeter respectively. The comparative effect of sprinkler and trickle irrigation on vegetative growth and yield of pepper in the two regions is presented in Table 2.1.

Table 2.1

Effect of Irrigation Method on
Vegetative Growth and Yield of Pepper

Region	Arava		El-Arish	
Irrigation Method / Plant Factors	Trickle	Sprinkling	Trickle	Sprinkling
Total no. of leaves	65	47	87	75
Plant embranchment	3	2	4.0	3.6
Plant height (inch)	11.8	6.6	14.0	12.8
Total yield (ton/acre)	3.8	1.9	4.8	2.9

It can be seen that the yield from trickling in the Arava was double that by sprinkling, and at El-Arish it was 70% greater. Similar or greater yield differences were recorded for tomatoes and cucumbers as shown in Table 2.2.

Table 2.2

Effect of Irrigation Method on Tomato and Cucumber Yields

Region	Arava (Yield, tons/acre)		El-Arish (Yield, tons/acre)	
Irrigation Method / Crop	Trickle	Sprinkling	Trickle	Sprinkling
Tomatoes	26.0	15.6	31.6	12.1
Cucumbers	15.7	*	3.0	1.45

*The leaves were burned and subsequently shed, with the result that the plants produced no yield.

2.3.2.2 The Effect of Irrigation Method on Growth and Yield Using Waters of Different Qualities

A field experiment was conducted in the Arava, in which sweet corn was irrigated with water of three salinity levels having the following approximate electrical conductivities: 100, 3000, and 4500 micromillimeters per centimeter. The irrigation were applied by sprinkling and trickling. The rate of the corn irrigated by trickling with the highest salinity level almost was the same as in the case of sprinkling with the non-saline water (100 micromillimeters per centimeter). The effect of the irrigation method on sweet corn is summarized in Table

2.3 The effect of good quality water and of the local saline water on tomatoes was tested with the sprinkling and trickle methods. The results are presented in Table 2.4. It's clear that in the case of trickle irrigation, the good and the saline water produced rather similar results, and with sprinkling, an increase in salinity level resulted in a yield decrease. As shown above, the use of water of high salinity for sprinkling resulted in a drastic reduction in all the parameters measured. In the case of trickling irrigation, there was some reduction in yield and all other parameters of the sweet corn when using a water of higher salinity, but for the development of tomatoes, the good and the saline water produced similar results.

Table 2.3

Effect of Irrigation Method on Development of Sweet Corn

Irrigation Method	Sprinkling			Trickle	
Water Salinity EC_w / Plant Factors	100	3000	4500	3000	4500
Yield (ton/acre	6.8	3.28	2.52	6.56	4.88
No. of ears per plant	.95	.74	.68	1.22	.97
Weight per ear (gm)	221	137	119	246	173

Table 2.4

Tomato Yields (ton/acre) Obtained by Trickle and Sprinkling Irrigation

Region	Arava		El-Arish	
EC_w / Irrigation Method	3000	400	3600	1200
Sprinkling	15.6	20.8	12.1	31.0
Trickle	26.0	26.7	31.6	32.0

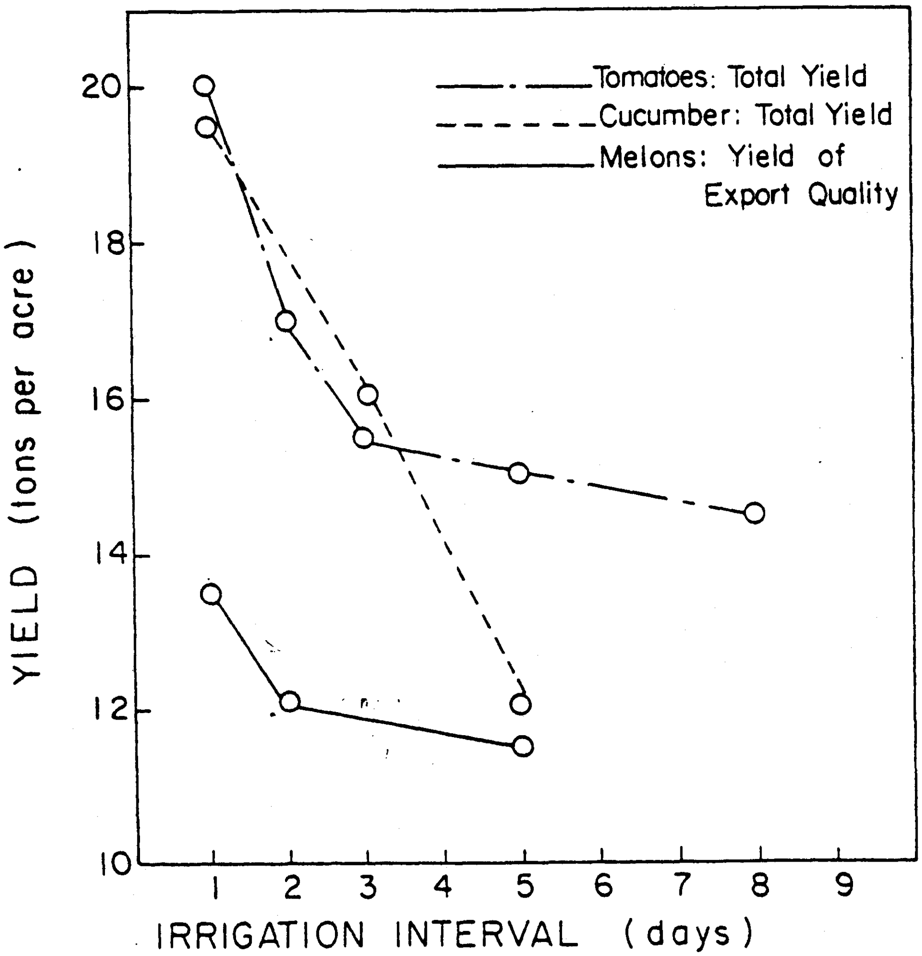

Figure 2.3 Effect of Irrigation Interval on Yield of Tomatoes, Cucumbers and Melons Under Trickle Irrigation

2.3.2.3 Effect of Irrigation Frequency on Soil Suction and Yield

An experiment was conducted [10] in which different frequencies of trickle irrigation was tested on three crops in the Arava which were melons, tomatoes, and cucumbers. The results obtained are presented in Figure 2.3. It's obvious that for all crops, the yield increased as the interval between irrigations was shortened. By shortening the irrigation interval, we can maintain a high soil moisture level between irrigations, which is very important when using a saline water especially for sandy soils. This was emphasized in tomato experiments at El-Arish in which three trickle irrigation treatments were compared. They were irrigation every two days, daily irrigation, and irrigation twice daily. The yields obtained were 23.5, 29.1, and 30.5 tons/acre, respectively.

In coarse-textured soils, daily applications of water by gravitational irrigation methods are not possible [10], and very frequent irrigation by sprinkling caused leaf-burn of the tomatoes and complete destruction of the crop.

Figure 2.4 shows the effect of frequent irrigation on soil water suction when using sprinkling and trickle irrigation.

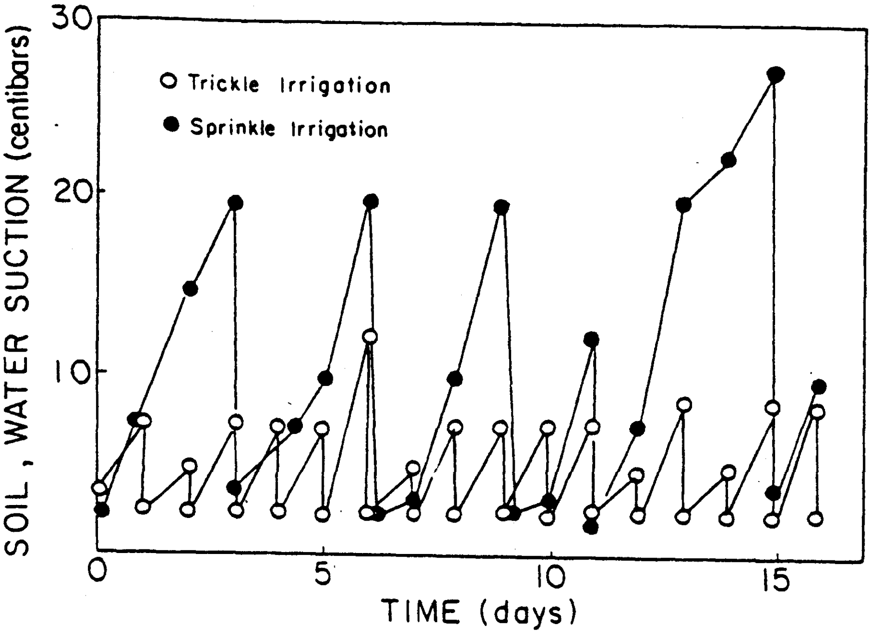

Figure 2.4 Effect of Irrigation on Soil Water Suction at El-Arish

As shown in the figure the frequent irrigation results in a uniform and low soil moisture suction. Except for one unusual hot and dry day, the moisture suction with trickling was below 10 centibars. In the case of sprinkling, the values ranged from 2-3 centibars at the end of an irrigation to 20 centibars before the next irrigation for the 3-day interval, and to almost 30 centibars for the 4-day interval. It's obvious that trickle method of water application has provided the possibility of establishing a moisture regime in which the amplitude of matric and osmotic potential fluctuations during the irrigation cycle are limited and controlled. Therefore, the possibility of using

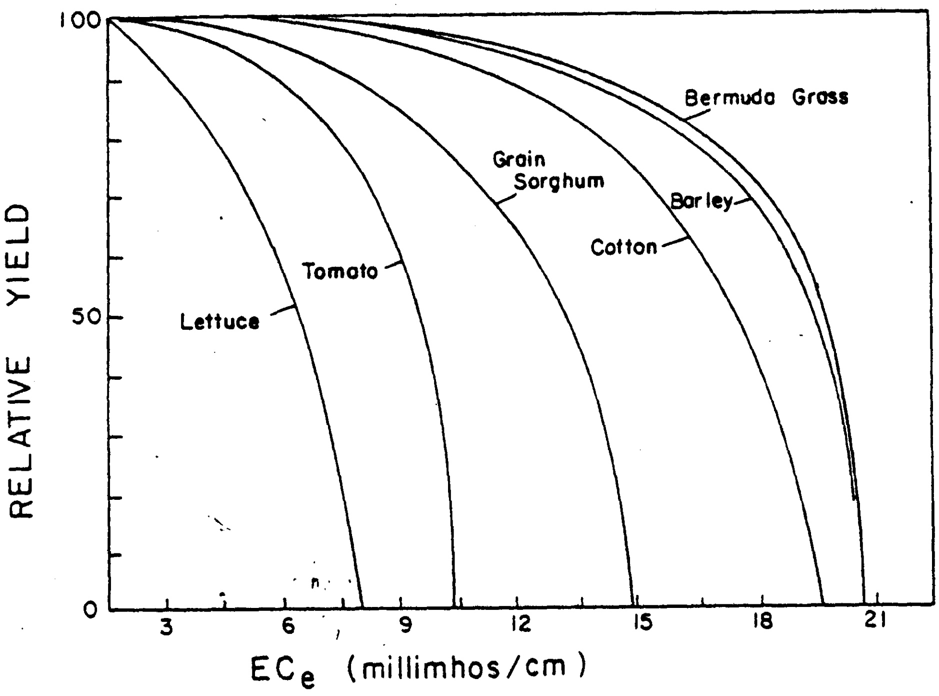

Figure 2.5 Effect of Soil Salinity on Crops Yield

water of medium and high salinity (3,000 ppm, or more) for irrigation has been suggested (mmhos/cm x 640 = approximate total dissolved solids, TDS, in parts per million, ppm).

2.3.3 The Crop Selection

As shown in Figure 2-5, crops vary greatly in their salt tolerance, and therefore the suitability of a water for irrigation will also vary with crops (14). This gives us a wide choice of crops and expands the usable range of water salinity for irrigation. An evaluation of the relative salt tolerance of agriculture crops has been done by Mass and Hoffman [14], and the results are presented in Table 2.5. The crop list provides two essential parameters sufficient for expressing salt tolerance. They are:

(i) The maximum allowable salinity without yield reduction; and

(ii) The percent yield decrease per unit salinity increase beyond the threshold.

All the salinity levels are reported as ECe, in millimhos per centimeter at 25°C.

This table is based on the assumption that yields decrease linearly as salt concentration increases above the threshold level. The relative yield, Y, for any given soil salinity exceeding the threshold, can be calculated by using the formula:

$$Y = 100 - B\,(ECe - A), \qquad (2.7)$$

where

A = the salinity threshold, in millimhos per centimeter, and

Table 2.5 Crops Tolerance Table (Mass and Hoffman)

Crop (1)	Salinity at initial yield decline (threshold) A (2)	Yield decrease per unit increase in salinity beyond threshold B (3)	Salt tolerance rating (4)
Alfalfa	2.0	7.3	MS
Almond	1.5	19	S
Apple	---	---	S
Apricot	1.6	24	S
Avocado	---	---	S
Barley (forage)	6.0	7.1	MT
Barley (grain)	8.0	5.0	T
Bean	1.0	19	S
Beet, garden	4.0	9.0	MT
Bentgrass	---	---	MS
Bermudagrass	6.9	6.4	T
Blackberry	1.5	22	S
Boysenberry	1.5	22	S
Broadbean	1.6	9.6	MS
Broccoli	2.8	9.2	MT
Bromegrass	---	---	MT
Cabbage	1.8	9.7	MS
Canarygrass, reed	---	---	MT
Carrot	1.0	14	S
Clover, alsike, ladino	1.5	12	MS

(1)	(2)	(3)	(4)
Clover, berseem	1.5	12	MS
Corn (forage)	1.8	7.4	MS
Corn (grain)	1.7	12	MS
Corn, sweet	1.7	12	MS
Cotton	7.7	5.2	T
Cowpea	1.3	14	MS
Cucumber	2.5	13	MS
Date	4.0	3.6	T
Fescue, tall	3.9	5.3	MT
Flax	1.7	12	MS
Grape	1.5	9.6	MS
Grapefruit	1.8	16	S
Hardinggrass	4.6	7.6	MT
Lemon	—	—	S
Lettuce	1.3	13	MS
Lovegrass	2.0	8.4	MS
Meadow Foxtail	1.5	9.6	MS
Millet, Foxtail	—	—	MS
Okra	—	—	S
Olive	—	—	MT
Onion	1.2	16	S
Orange	1.7	16	S
Orchardgrass	1.5	6.2	MS
Peach	1.7	21	S

(1)	(2)	(3)	(4)
Peanut	3.2	29	MS
Pepper	1.5	14	MS
Plum	1.5	18	S
Potato	1.7	12	MS
Radish	1.2	13	MS
Raspberry	—	—	S
Rhodesgrass	—	—	MS
Rice, paddy	3.0	12	MS
Ryegrass, perennial	5.6	7.6	MT
Safflower	—	—	MT
Sesbania	2.3	7.0	MS
Sorghum	—	—	MT
Soybean	5.0	20	MT
Spinach	2.0	7.6	MS
Strawberry	1.0	33	S
Sudangrass	2.8	4.3	MT
Sugarbeet	7.0	5.9	T
Sugarcane	1.7	5.9	MS
Sweet potato	1.5	11	MS
Timothy	—	—	MS
Tomato	2.5	9.9	MS
Trefoil, Big	2.3	19	MS
Trefoil, Birdsfoot	5.0	10	MT
Vetch, common	3.0	11	MS

(1)	(2)	(3)	(4)
Wheat	6.0	7.1	MT
Wheatgrass, crested	3.5	4.0	MT
Wheatgrass, fairway	7.5	6.9	T
Wheatgrass, slender	—	—	MT
Wheatgrass, tall	7.5	4.2	T
Wildrye, Altai	—	—	T
Wildrye, Beardless	2.7	6.0	MT
Wildrye, Russian	—	—	T

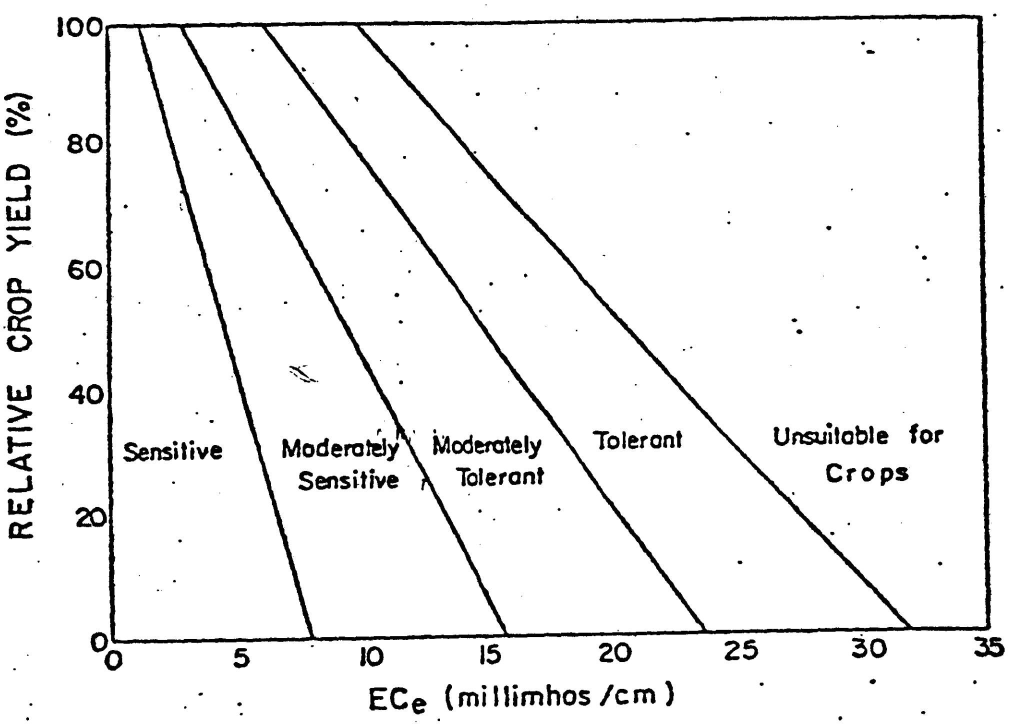

Figure 2.6 Divisions for Classifying Crop Tolerance to Salinity

B = the percent yield decrease per unit salinity increase

(a qualitative salt tolerance rate).

Qualitative salt tolerance ratings are defined by the boundaries shown in Figure 2.6.

Based on the results of Mass and Hoffman, the crop tolerance tables of U.S. salinity laboratory (U.S.D.A., 1954), and the results of some other studies, new crop tolerance tables were obtained [29] for representative field, forage, vegetable, and tree crops. The union of these tables is presented in Table 2.6.

These tables include the expected yield reduction of 0, 10, 25, or 50% due to effects of either increasing soil salinity [ECe] or to comparable increases in irrigation water salinity (ECw) assumes that the salinity of the irrigation water increases threshold in becoming soil water (ECw x 3 $\approx$ ECsw), or in terms of soil salinity, the salinity of irrigation water is concentrated $1\frac{1}{2}$ times in terms of the soil saturation extract (ECw x 1.5 = ECe). This conversion from water salinity to comparable soil salinity assumes a leaching fraction 15-20%. We must notice that the relationship of irrigation water salinity to soil salinity varies with management and local condition of use. Then, if the conditions of use or local experience indicate a different relationship than 1:1.5 concentration factor for water salinity to soil salinity, the values for crop tolerance to salinity (Table 2.6) can be changed and new tables can be prepared.

However, these tables give us a wide range for selecting the crops according to its tolerance compatible with the salinity of available

TABLE 2.6

CROP TOLERANCE TABLE

Yield Decrement to be expected for Certain Crops due to Salinity of Irrigation Water when Common Surface Irrigation Methods are Used

FIELD CROPS

CROP	0%		10%		25%		50%		MAXIMUM
	ECe[1/]	ECw[2/]	ECe	ECw	ECe	ECw	ECc	Ecw	ECe[3/]
Barley	8.0	5.3	10	6.7	13	8.7	18	12	28
Cotton	7.7	5.1	9.6	6.4	13	8.4	17	12	27
Sugarbeet	7.0	4.7	8.7	5.8	11	7.5	15	10	24
Wheat	6.0	4.0	7.4	4.9	9.5	6.4	13	8.7	20
Safflower	5.3	3.5	6.2	4.1	7.6	5.0	9.9	6.6	14.5
Soybean	5.0	3.3	5.5	3.7	6.2	4.2	7.5	5.0	10
Sorghum	4.0	2.7	5.1	3.4	7.2	4.8	11	7.2	18
Groundnut	3.2	2.1	3.5	2.4	4.1	2.7	4.9	3.3	6.5
Rice (paddy)	3.0	2.0	3.8	2.6	5.1	3.4	7.2	4.8	11.5
Sesbania	2.3	1.5	3.7	2.5	5.9	3.9	9.4	6.3	16.5
Corn	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10
Flax	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10
Broadbean	1.6	1.1	2.6	1.8	4.2	2.0	6.8	4.5	12

TABLE 2.6 (continued)

	0%		10%		25%		50%		MAXIMUM
	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe
Cowpea	1.3	0.9	2.0	1.3	3.1	2.1	4.9	3.2	8.5
Beans	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	6.5
FRUIT CROPS									
Date Palm	4.0	2.7	6.8	4.5	10.9	7.3	17.9	12	32
Fig Olive Pomegranate	2.7	1.8	3.8	2.6	5.5	3.7	8.4	5.6	14
Grapefruit	1.8	1.2	2.4	1.6	3.4	2.2	4.9	3.3	8
Orange	1.7	1.1	2.3	1.6	3.2	2.2	4.8	3.2	8
Lemon	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8
Apple Pear	1.7	1.0	2.3	1.6	3.3	2.2	4.8	3.2	8
Walnut	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8
Peach	1.7	1.1	2.2	1.4	2.9	1.9	4.1	2.7	6.5
Apricot	1.6	1.1	2.0	1.3	2.6	1.8	3.7	2.5	6
Grape	1.5	1.0	3.5	1.7	4.1				
Almond	1.5	1.0	2.0	1.4	2.8	1.9	4.1	2.7	7
Plum	1.5	1.0	2.1	1.4	2.9	1.9	4.3	2.8	7

TABLE 2.6 (continued)

	0%		10%		25%		50%		MAXIMUM
	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe
Blackberry	1.5	1.0	2.0	1.3	2.6	1.8	3.8	2.5	6
Boysenberry	1.5	1.0	2.0	1.3	2.6	1.8	3.8	2.5	6
Avocado	1.3	0.9	1.8	1.2	2.5	1.7	3.7	2.4	6
Raspberry	1.0	0.7	1.4	1.0	2.1	1.4	3.2	2.1	5.5
Strawberry	1.0	0.7	1.3	0.9	1.8	1.2	2.5	1.7	4
VEGATABLE CROPS									
Beets	4.0	2.7	5.1	3.4	6.8	4.5	9.6	6.4	15
Broccoli	2.8	1.9	3.9	2.6	5.5	3.7	8.2	5.5	13.5
Tomato	2.4	1.7	3.5	2.3	5.0	3.4	7.6	5.0	12.5
Cucumber	2.5	1.7	3.3	2.2	4.4	2.9	6.3	4.2	10
Cantaloupe	2.2	1.5	3.6	2.4	5.7	3.8	9.1	6.1	16
Cabbage	1.8	1.2	2.8	1.9	4.4	2.9	7.0	4.6	12
Potato	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10
Sweet Corn	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10
Sweet Potato	1.5	1.0	2.4	1.6	3.8	2.5	6.0	4.0	10.5
Pepper	1.5	1.0	2.2	1.5	3.3	2.2	5.1	3.4	8.5
Lettuce	1.3	0.9	2.1	1.4	3.2	2.1	5.2	3.4	9

TABLE 2.6 (continued)

	0%		10%		25%		50%		MAXIMUM
	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe
Radish	1.2	0.8	2.0	1.3	3.1	2.1	5.0	3.4	9
Onion	1.2	0.8	1.8	1.2	2.8	1.8	4.3	2.9	7.5
Carrot	1.0	0.7	1.7	1.1	2.8	1.9	4.6	3.1	8
Beans	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	6.5
FORAGE CROPS									
Tall Wheat Grass	7.5	5.0	9.9	6.6	13.3	9.0	19.4	13	31.5
Wheat Grass (fairway)	7.5	5.0	9.0	6.0	11	7.4	15	9.8	22
Bermuda grass	6.9	4.6	8.5	5.7	10.8	7.2	14.7	9.8	22.5
Barley (hay)	6.0	4.0	7.4	4.0	9.5	6.3	13.0	8.7	20
Perennial Rye Grass	5.6	3.7	6.9	4.6	8.9	5.9	12.2	8.1	19
Trefoil, Birdsfoot Narrow Leaf	5.0	3.3	6.0	4.0	7.5	5.0	10	6.7	15
Harding Grass	4.6	3.1	5.9	3.9	7.9	5.3	11.1	7.4	18
Tall Fescue	3.9	2.6	5.8	3.9	8.6	5.7	13.3	8.9	23
Crested Wheat Grass	3.5	2.3	6.0	4.0	9.8	6.5	16	11	28.5
Vetch	3.0	2.0	3.9	2.6	5.3	3.5	7.6	5.0	12
Sudan Grass	2.8	1.9	5.1	3.4	8.6	5.7	14.4	9.6	26

TABLE 2.6 (continued)

	0%		10%		25%		50%		MAXIMUM
	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe
Wildrye, Beardless	2.7	1.8	4.4	2.9	6.9	4.6	11.0	7.4	19.5
Trefoil, Big	2.3	1.5	2.8	1.9	3.6	2.4	4.9	3.3	7.5
Alfalfa	2.0	1.3	3.4	2.2	5.4	3.6	8.8	5.9	15.5
Lovegrass	2.0	1.3	3.2	2.1	5.0	3.3	8.0	5.3	14
Corn (forage)	1.8	1.2	3.2	2.1	5.2	3.5	8.6	5.7	15.5
Clover Berseem	1.5	1.0	3.2	2.1	5.9	3.9	10.3	6.8	19
Orchard Grass	1.5	1.0	3.1	2.1	5.5	3.7	9.6	6.4	17.5

water for getting maximum possible yield.

2.4 Summary and Conclusion

In this chapter, irrigation water quality related problems and their solutions were discussed. These problems generally occur in the four general categories previously discussed: Salinity, Permeability, Toxicity, and Miscellaneous. It was clear that the main damage to the plants resulting from poor irrigation water quality is due to salinity. A simple procedure is presented for calculating the amount of water necessary for leaching salt out the root zone of irrigated field to maintain an acceptable level of agriculture production with the available saline water supply. As discussed before, by selecting crops compatible with the salinity of available water, and by choosing the suitable method of irrigation, a water user may obtain better yields with available water or may find that water considered "Unusable" under his prior concept of quality may really be usable under certain situations.

CHAPTER 3

A MATHEMATICAL FORMULATION OF THE PLANNING MODEL

3.1 Introduction

The purpose of this model is to provide decisions required for planning of an agricultural expansion project, when the available irrigation sources have different salinities. These decisions generally are quantities and locations of all resources inputs, mixing ratio between different waters if mixing is possible, irrigation network design, and crop pattern distribution in the new land. These decisions are based here on the maximum net benefit criteria. The net benefit resulting from an agricultural expansion is the agricultural production revenue less irrigation water transmission cost, new land development cost, and some other costs on farm level like costs of seeds, fertilizer, labor, and machinery. Mathematical derivations of these benefit-cost functions are presented in following sections.

In this chapter also, a mathematical formulation of this planning model is presented with a nonlinear objective function and some nonlinear constraints. The nonlinearity problem is discussed and an algorithm for solving this planning problem is introduced.

3.2 Cost Functions

3.2.1 Land Development Cost

This cost includes the costs of the drainage works, farm machinery, housing, electricity, equipment and machinery for cultivation; transportation, communication, land leveling, and social services.

3.2.2 Irrigation Water Transmission Cost

Excavation, Lining, Irrigation Structures and Maintenance Costs of the New Canals

These types of costs per unit length of a canal depend on the dimensions of the canal's cross-section, which sequentially depend on the method of its design. In this work, it is assumed that the proposed design of the new canal is the most economical one. This method of design can be done by minimizing the cross-sectional area of a canal, given the amount of flow, or by maximizing the uniform flow velocity, given the cross-sectional area of this canal. For more details, let us have a trapezoidal section as shown in Fig. 3.1 as the general case of the artificial cross-sections. The uniform flow velocity through this section is given by Chezy as

$$V = C\sqrt{R\,S_o} = C\sqrt{\frac{A}{P}\,S_o} \qquad (3.1)$$

where

$A = by + t_1 y^2$

$P = b + 2y\sqrt{1 + t_1^2}$

It is obvious from Eq. (3.1) that the maximum uniform velocity occurs at the minimum value of the wetted parameter. Replacing b in Eq. (3.3) by $(\frac{A}{y} - t_1 y)$ from Eq. (3.2), we get

$$P = \frac{A}{y} - t_1 y + 2y\sqrt{1 + t_1^2}$$

Taking the first derivative of P with respect to the water depth (y)

$$\frac{dP}{dy} = -\frac{A}{y2} - t_1 + 2\sqrt{1 + t_1^2}$$

Replacing A by Eq. (3.2), and equating the first derivative to zero

$$b = 2y(\sqrt{1 + t_1^2} - t_1) \qquad (3.4)$$

The above equation represents the required condition for getting the maximum uniform velocity, or on the other hand, it is the condition for getting the most economical cross-section area. This condition can be written in another form as

$$B = 2y\sqrt{1 + t_1^2} \qquad (3.5)$$

Using Eq. (3.5), the hydraulic radius can be expressed as

$$R = A/P = (by + t_1 y^2)/(b + 2y\sqrt{1 + t_1^2}) = y(b + B)/2(b + B) = Y/2 \qquad (3.6)$$

The uniform flow through a canal is

$$Q = VA = CA\sqrt{R\ S_o} = C(by + t_1 y^2)\sqrt{P\ S_o}$$

Replacing b_1 and R by Eq. (3.4), and Eq. (3.5) respectively, we got

$$Q = K\ y^{5/2}$$

where

$$K = C\ S_o^{1/2}\ (2\sqrt{1 + t_1^2} - t_1)\Big/\sqrt{2}$$

Excavation Cost

From Fig. 3.1, the excavation volume is

$$V = by + t_1 y^2 + (B + B + 2\ t_1\ h_1)\ h_1/2$$
$$+ (2B + 4\ t_1\ h_1 + 4\ b_o + 2\ h_2\ t_2) h_2/2$$

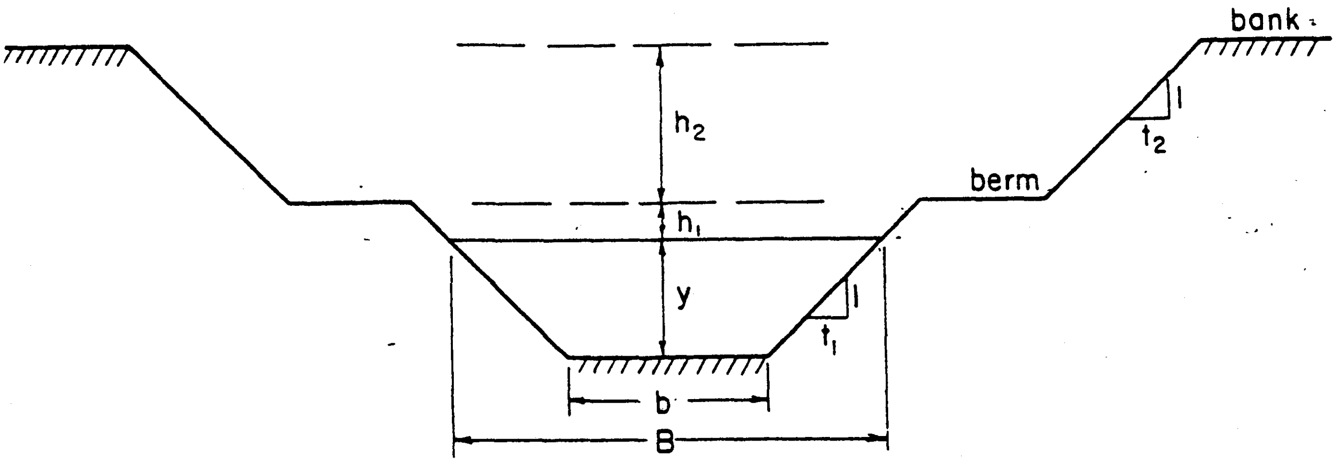

Figure 3.1 A Trapezoidal Cross-Sectional Area

Definitions:

b = bed width

t = side slope

B = top width

y = water depth

A = cross-sectionsl area

P = wetted parameter

R = hydraulic radius

S_o = bed slope

b_o = berm width

h_1 = clearance between the water surface and the berm level

h_2 = difference in elevation between the berm and the bank

C = Chezy's coefficient

Assuming that

$$h_1 = 0.5 \text{ m}$$

$$h_2 = 1 \text{ m, and}$$

$$t_1 = t_2 = t$$

$$b_o = 1.5 \text{ m}$$

we get

$$\rlap{-}V = ty^2 + by + 2B + 4t + 3$$

Replacing b, and B by Eqs. (3.6) and (3.8), the above equation becomes

$$\rlap{-}V = y^2(2\sqrt{1 + t^2} - t) + 4y\sqrt{1 + t^2} + 4t + 3 \quad \text{m}^3 \tag{3.8}$$

For simplicity, let us assume some approximate values for the bed slope, side slope, and Chezzy's coefficient as

$$t = 1.5$$

$$S_o = .001, \text{ and}$$

$$C = 100$$

then

$$\rlap{-}V = 2.1\, y^2 + 7.2\, y + 9 \tag{3.9}$$

From Eq. (3.7), the water depth can be expressed in terms of the discharge as

$$Y = .85\, Q^{.4} \tag{3.10}$$

Substituting Eq. (3.10) into Eq. (3.9), then

$$\rlap{-}V = 1.5\, Q^{.8} + 6.12\, Q^{.4} + 9 \tag{3.11}$$

The excavation cost function in terms of the excavated volume in its general form is

$$\text{Cost} = A(V)^{B}(L)$$

where

A = unit cost of excavation per unit length of a canal in (L.E.)

B = economy-of-scale

L = canals' length in meters

Using Eq. (3-11) the above cost function can be written in terms of the flow (Q) as

$$\text{Cost} = A(1.5\ Q^{.8} + 6.12\ Q^{.4} + 9)^{B}(L) \quad \text{L.E.} \qquad (3.12)$$

Lining Cost

The lining area is the surface area of a given canal's cross-section. From Fig. 3.1 this area can be expressed as follows:

$$A_L = b + 2y\ \sqrt{1 + t_1^2} + 2\ h_1\ \sqrt{1 + t_1^2} + 2\ b_o + 2\ h_2/(1 + t_2^2)$$

Substituting h_1, h_2, t_1, and t_2 by their assumed values, we obtain

$$A_L = b + 3.6\ y + 9.2$$

Replacing b by Eq. (3.8), the above equation becomes

$$A_L = 4.2\ y + 9.2 \qquad (3.13)$$

or

$$A_L = 3.57\ Q^{.4} + 9.2$$

Then the lining cost can be expressed as a function of the channel flow as:

$$\text{Cost} = C\ (3.57\ Q^{.4} + 9.2)^{D}(L) \quad \text{L.E.} \qquad (3.14)$$

where

C = unit cost per unit length of a canal in L.E.

D = economy-of-scale

Irrigation Structures and Maintenance Costs

It is found (4) that structures in open drains cost about 70% of the total excavation cost. In the case of the irrigation canals the irrigation structures cost more, and its cost could be considered as 100% of the excavation cost as provided by the Public Directory of the Horizontal Expansion Project in Eastern Delta (32). Generally this cost can be expressed in terms of excavation cost as:

$$\text{Irrig. struct. cost} = \alpha A(1.5\ Q^{.8} + 6.12\ Q^{.4} + 9)^{B}(L) \quad \text{L.E.} \quad (3.15)$$

where

α = the ratio of irrigation structure cost to the excavation cost

Also, the annual maintenance cost could be assumed as a ratio of the total cost of excavation and irrigation structures, and could be written in the following form:

$$\text{Maintenance costs} = B\ A(1 + \alpha)(1.5\ Q^{.8} + 6.12\ Q^{.4} + 9)^{B}(L) \quad (\text{L.E.}) \quad (3.16)$$

Cost of Engineering the Existing Canals:

Excavation Cost:

As shown from Fig. 3.2 the excavation volume per unit length can be expressed in terms of V_1, V_2, and V_3 as

$$V = V_1 + 2\ V_2 + 2\ V_3$$

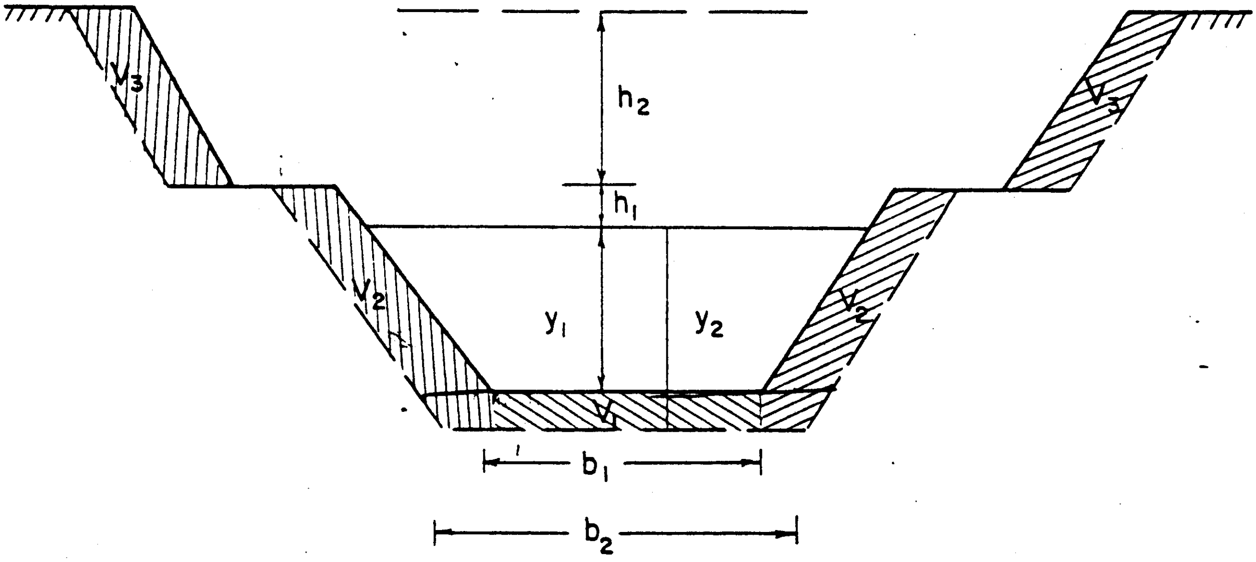

Figure 3.2 The Englargement of Canal's Cross-section

where

$$\text{Ꝟ}_1 = [b_2 + b_2 + 2\ t\ (y_2 - y_1)]\ (y_2 - y_1)/2 = [b_2 + t\ (y_2 - y_1)]\ (y_2 - y_1)$$
$$\text{Ꝟ}_2 = [b_2 + t\ (y_2 - y_1) - b_1]\ (y_1 + h_1),\ \text{and}$$
$$\text{Ꝟ}_3 = [b_2 + t\ (y_2 - y_1) - b_1]\ h_2$$

Substituting with the assumed values of t, h_1, and h_2, and replacing b_1, and b_2 by Eq. (3.8), these above volumes can be written as

$$\text{Ꝟ}_1 = 2.1\ y_2^2 - 3.6\ y_1 y_2 + 1.5\ y_1^2$$
$$\text{Ꝟ}_2 = 2.1\ (y_1 y_2 - y_1^2) + (y_2 - y_1)$$
$$\text{Ꝟ}_3 = 3.1\ (y_2 - y_1)$$

Then the total excavation volume is

$$V_t = 2.1\ y_2^2 - 2.7\ y_1^2 + 6\ y_1 y_2 + 8.4\ (y_2 - y_1) \qquad (3.18)$$

Then the excavation cost function using Eqs. (3.15) and (3.17) can be written as

$$\text{Cost} = A(1.5\ Q_2^{.8} - 1.95\ Q_1^{.8} + .4\ Q_1^{.4}\ Q_2^{.4} + 7(Q_2^{.4} - Q_1^{.4}))^{B}\ (L)\ \text{L.E.} \qquad (3.19)$$

where:

Q_1 = The existing capacity of a canal, and

Q_2 = a new capacity of this canal.

The lining, irrigation structures enlargement, and maintenance costs still the same as they are for the new canals.

Pump Cost Function:

The pump cost function as given in (23) is consisting of three parts: capital cost; operation, maintenance, and replacement (OMR) costs and energy cost.

Capital Cost:

Transforming the given cost function (23) which is based on sum regression analysis, according to ENR cost index for July 1979, we got

$$\text{Capital Cost} = 3735.6\ HP^{.66} \text{ dollars} \qquad 30. \leq HP \leq 400$$

or in terms of Egyptian Pounds

$$\text{Capital Cost} = 26.5\ HP^{.66} \text{ L.E.} \qquad (3.20)$$

The required horse power for lifting the water Δh meters is

$$H.P. = \gamma_\omega . Q .\ \Delta H / 75\eta \qquad (3.21)$$

where γ_ω = the specific weight of water (1000 kg/m^3), and

η = the pumping efficiency.

Replacing H.P. in Eq. (3.21) by Eq. (3.20), and putting $\eta = .75$ we get

$$\text{Capital Cost} = 24962\ .\ (Q\ .\ \Delta H)^{.66} \text{ L.E.} \qquad (3.22)$$

OMR Cost:

This cost could be assumed (23) as 8% of the capital cost so it can be expressed as

$$\text{OMR Cost} = 1997.\ (Q.\ \Delta H)^{.66} \text{ L.E.} \qquad (3.23)$$

Energy Cost:

The pumps are driven by electrical motors which consume electrical energy. If there are 180 days per season, the seasonal energy cost of a pump station is

$$\text{Cost of Energy} \quad 180 \times 24 \times \xi \times C_E \times K \times H.P \qquad (3.24)$$

where:

ξ = a load factor $\simeq$ .2

C_E = per unit cost of the electrical energy $\doteq$ .025 L.E.

K = conversion factor from horse power into kilowatt/hr. $\simeq$ .74

Substituting these values in Eq. (3.24), then

$$\text{Cost of Energy} = 16.\ H.P. \qquad (3.25)$$

Replacing H.P. by Eq. (3.21), Eq. (3.25) can be written as

$$\text{Cost of Energy} = 284\ (q.\ \Delta H)\ \text{L.E.} \qquad (3.26)$$

where q is the seasonal flow.

3.3. The Mathematical Model Formulation

Before going through the model formulation, it is more convenient to divide the whole area of the new land into sub-areas. Each sub-area should be confined to a single soil type for determining the appropriate crop pattern, and to a relatively local and homogeneous region. The later restriction is to insure that the costs of transporting any resource input are essentially uniform. An example of dividing the whole agricultural area into small sub-areas is shown in Figure 3.3, and a network representation for the irrigation system is shown in Figure 3.4.

3.3.1. Notations and Definitions:

Let

$A(j)$	size of a sub-area j in feddans
N	number of the total sub-areas
I	number of the irrigation water resources
K	number of the agricultural seasons per year
H	number of the agricultural crops per season
C_h^k	h^{th} crop in season k
$A(C_h^k,i,j)$	Size of an area in feddans, which is planted with a crop C_n^k in a sub-area j and takes its irrigation water requirements from source i.

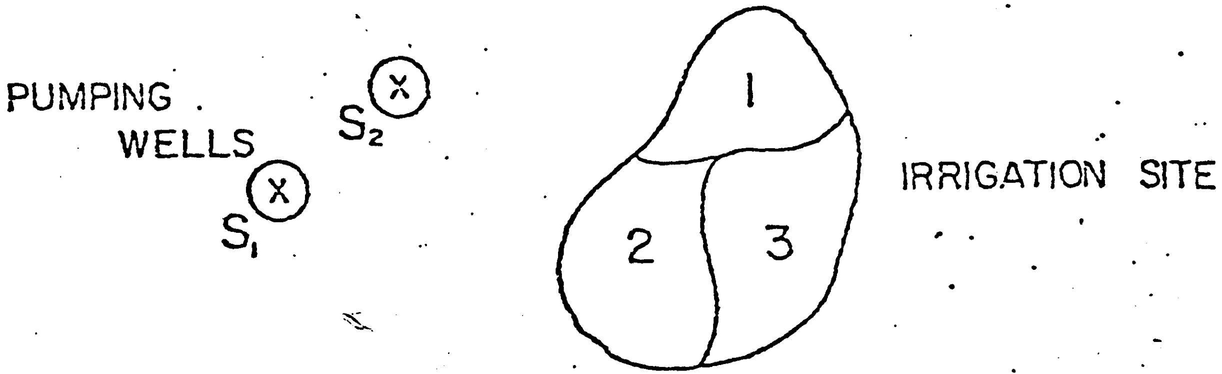

Figure 3.3 An Irrigation Site and Its Water Sources

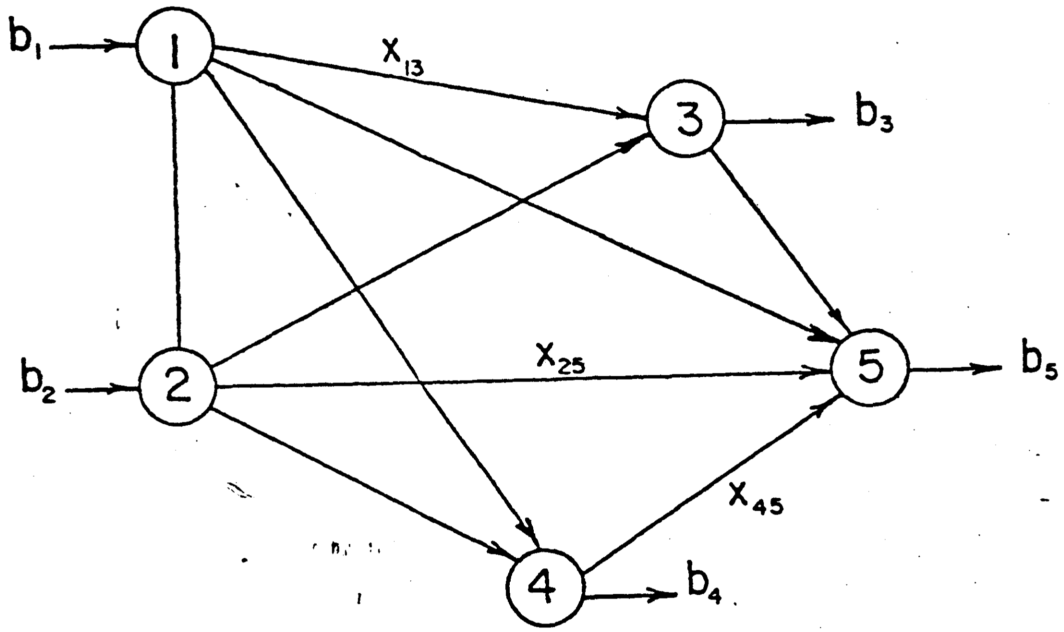

Figure 3.4 A Network Presentation for the Irrigation System

$q(C_h^k,i,j)$ -- average water requirement from source i for a crop C_h^k in a sub-area j (m_1^3/sec)

$Y(C_h^k,i,j)$ -- average yield (Kg./fd.) of a crop C_h^k which is planted in a sub-area j, and takes its water requirements from source i

$P(C_h^k)$ ------ unit price (L.E./Kg.) of a crop C_h^k

$S(C_h^k,i,j)$ and $F(C_h^k,i,j)$ -- amounts of seeds and fertilizer which are required for planting a crop C_h^k in sub-area j, which are functions of the irrigation water salinity

$L(C_h^k,j)$ and $M(C_h^k,j)$ ---- amounts of man-hours and machinery-hour (hrs./fed.) which are required for developing a crop C_h^k in sub-area j,

$C^s(C_h^k,j)$ and $C^f(C_h^k,j)$ --- per unit costs (L.E./Kg.) of seeds and fertilizer which are required for crop C_h^k in sub-area j

$l(i,j)$ ----- length of a canal i-j from source i to a sub-area j

$x(i,j,k)$ --- average flow (m^3/sec.) through a canal i-j during season K

$C(i,j)$ ----- capacity of a canal i-j (m^3/sec.)

$CE(C(i,j))$ and $CL(C(i,j))$ - unit cost (L.E./m.) of excavation and lining respectively of a canal i-j with capacity $C(i,j)$

$CIRS(C(i,j))$ unit cost (L.E./m/) of required irrigation structures along a canal i-j with a capacity $C(i,j)$

$CM(C(i,j,k)$ unit seasonal maintenance cost (L.E./m.) of a canal i-j with a capacity $C(i,j)$

D ---------- number of pump stations

$CPC(Q_d)$ ---- construction cost (L.E.) of a pump station with a capacity Q_d(m^3/sec.)

$CPM(Q_d,k)$ -- seasonal maintenance cost (L.E.) of a pump station with a capacity Q_d (m^3/sec.)

$CEP(q_d,k)$ -- seasonal energy cost (L.E.) which is required to lift discharge q_d (m^3/sec.) during season k

$CD(j)$ ------ unit cost (L.E./fed.) of land development of sub-area (j)

$b(i,k)$ ----- available average water flow (m^3/sec.) at source i, during season k

$CL(i,j,k)$ -- the conveyance losses through a canal i-j during season k as a function of the canal's flow

α_h^k --------- the required ratio of the planted area with crop C_h^k to the total area of the new land

$\underline{C}_L(i,j)$ ---- is the lower permissible capacity of a canal i-j

r ---------- annual discount rate

e ---------- annual interest rate on the capital costs

T ---------- planning time horizon

The models decision variables are the seasonal flows $x(i,j,k)$, and the capacities $C(i,j)$ of the irrigation canals, the areas of different crops $A(C_h^k,i,j)$; the seasonal discharges $q_d(k)$, and capacities Q_d of pump stations; and the mixing ratio (EC_{wi}) at the mixing sites.

3.3.2. Model's Assumptions:

In order to derive a mathematical formulation for the planning model, the following assumptions are made:

(1) The economic planning time horizon is finite and is given.

(2) The discount rate remains constant and is given over the planning time horizon.

(3) The cost functions remain stationary over time.

(4) The agriculture will start in the new land after time t_1, which is required for finishing the land development; irrigation and drainage works.

(5) The whole new land is reclaimed in the same time.

(6) Surface irrigation method is used.

3.3.3. Objective Function:

Agricultural Production Revenue:

The total present value of the agricultural revenue is the present value of the sum of all unit prices times the total yields, which can be expressed in terms of the model's parameters as

$$\sum_{t=t_1+1}^{T} \sum_{i=1}^{I+N-1} \sum_{j=1}^{N} \sum_{k=1}^{K} \sum_{h=1}^{H} \frac{1}{(1+r)^r} A(C_h^k,i,j)\ P(C_h^k)\ Y(C_h^k,i,j) \qquad (3.28)$$

Total Costs on Farm Level:

These costs are the costs of seeds, fertilizer, labor, and machinary. The present values of these costs can be written mathematically as

$$\sum_{t=t_{1+1}}^{T} \sum_{i=1}^{I+N-1} \sum_{j=1}^{N} \sum_{k=1}^{K} \sum_{h=1}^{H} \frac{1}{(1+r)^r}\ A(C_h^k,i,j)\ [C^S(C_h^k,j)\ S(C_h^k,i,j) +$$

$$C^F(C_h^f,j)\ F(C_h^k,i,j) + C^L(C_h^k,j)\ L(C_h^k,j) + C^M(C_h^k,j)\ M(C_h^k,j)] \qquad (3.29)$$

Costs of Excavation, Lining, Irrigation Structures, and Maintenance of the New Canals:

The present value of excavation, lining, and irrigation structures costs which are subject to a compound interest rate $(1+e)^t$ is the present value of the sum of the unit cost functions times the compound interest rate times the canal's length. These costs can be expressed as

$$\sum_{t=1}^{t_1}\ \sum_{i=1}^{I+N-1}\ \sum_{j=1}^{N} \left(\frac{1+e}{1+r}\right)^{t} [CE(C(i,j)) + CL(C(i,j)) + CIRS(C(i,j))]\ \ell_{(i,j)} \qquad (3.30)$$

Replacing CE(C(i,j)), CL(C(i,j)), and CIRS(S(i,j)), by equation 3.12, 3.14, and 3.15 respectively, we obtain

$$\sum_{t=1}^{t_1}\ \sum_{i=1}^{I+N-1}\ \sum_{j=1}^{N} \left(\frac{1+e}{1+r}\right)^{t} [(1+\alpha)\ A(1.5\ Q_{ij}^{.8} + 6.12\ Q_{ij}^{.4} + 9\ )^{B} +$$

$$C(3.57\ Q_{ij}^{.4} + 9.2)^{D}]\ l(i,j) \qquad (3.31)$$

where Q_{ij} is the capacity of a canal i-j. The present value of the annual maintenance cost in terms of the model's parameters is

$$\sum_{t=t_{1+1}}^{T}\ \sum_{k=1}^{K}\ \sum_{i=1}^{I+N-1}\ \sum_{j=1}^{N} \frac{1}{(1+r)^{r}}\ CM(C(i,j))\ l(i,j) \qquad (3.32)$$

or in terms of equation 3.16, we get

$$\sum_{t=t_{1+1}}^{T}\ \sum_{k=1}^{K}\ \sum_{i=1}^{I+N-1}\ \sum_{j=1}^{N} \frac{1}{(1+r)}\ \beta A(1+\alpha)\ \ (1.5\ Q_{ij}^{.8} + 6.12\ Q_{ij}^{.4} + 9)^{B}\ l(i,j) \qquad (3.33)$$

Enlargement Costs of the Existing Canals:

The present value of the costs of excavation, lining, and irrigation structures can be written in terms of equations 3.14 and 3.19 as

$$\sum_{t=1}^{t_1}\ \sum_{i=1}^{I+N-1}\ \sum_{j=1}^{N} \left(\frac{1+e}{1+r}\right)^{t} \{(1+\alpha)\ A[1.5\ Q_{a(i,j)}^{.8} - 1.95\ Q_{b(i,j)}^{.8} + .4\ Q_{b}(i,j)\ Q_{a}(i,j)$$

$$+\ 7(Q_{a(i,j)} - Q_{b(i,j)})]^{B} + C(3.57\ Q_{a(i,j)}^{.4} + 9.2)^{D}]\ l(i,j) \qquad (3.34)$$

where,

Q_a = canal's capacity after the enlargement

Q_b = canal's capacity before the enlargement

and the present value of the increament in the maintenance cost is

$$\sum_{t=t_{1+1}}^{T} \sum_{k=1}^{K} \sum_{i=1}^{I+N-1} \sum_{j=1}^{N} \frac{1}{(1+r)}^{t} \beta A(1+\alpha) [1.5 Q_{a(i,j)}^{.8} - 1.95 Q_{b(i,j)}^{.8}$$

$$+.4 Q_{b(i,j)} Q_{a(i,j)} + 7(Q_{a(i,j)} - Q_{b(i,j)}]^{B} l(i,j) \qquad (3.35)$$

Capital, Operation, and Maintenance Costs of Pump Stations:

The capital cost is subjected to a compound interest rate $(1+e)^t$. The present value of this cost equals in terms of equation 3.22

$$\sum_{t=1}^{t_1} \sum_{d=1}^{D} (\frac{1+e}{1+r})^{t} \ 24962 \ (Q_d \Delta H_d)^{.66} \qquad (3.36)$$

The present values of the annual costs of energy and maintenance can be written in terms of equations 3.23, and 3.26 as

$$\sum_{t=t_{1+1}}^{T} \sum_{k=1}^{K} \sum_{d=1}^{D} \frac{1}{(1+r)}^{t} [1997 \ (Q\Delta H)^{.66} + 284 \ q\Delta H] \qquad (3.37)$$

Land Development Cost:

This cost also is subjected to a compound interest rate $(1+e)^t$. This cost is equal to the unit cost (L.E./fedd.) times the total developed area times the compound interest rate. Then the present value of this cost is

$$\sum_{t=1}^{t_1} \sum_{j=1}^{N} (\frac{1+e}{1+r})^{t} \ CD(j) \ A(j) \qquad (3.38)$$

Notice that the unit cost is a function of the soil type.

In short, the objective function to this maximization problem is composed of equation 3.28 minus equations 3.29, 3.31, 3.33, 3.34, 3.35, 3.36, 3.37, and 3.38.

3.3.4. Constraints:

Flow Balance Constraint:

This constraint is to keep the conservation-of-flow low at each area. This constraint can be expressed mathematically as

$$\sum_{d=1}^{N-1} X(j,d,k) + \sum_{i=1}^{I+N-1} \sum_{h=1}^{H} q(C_h^k,i,j)\ A(C_h^k,i,j) - \sum_{i=1}^{I+N-1} X(i,j,k)$$

$$(1-CL(i,j,k)) = 00 \quad \forall_{j,k} \qquad (3.39)$$

where:

$\sum_{d=1}^{N-1} X(j,d,k)$ = the total outflow from a sub-area j during season k

$\sum_{i=1}^{I+N-1} \sum_{h=1}^{H} q(C_h^k,i,j)\ A(C_h^k,i,j)$ = the total water requirement to a sub-area j during season k.

$CL(i,j,k)$ = the conveyance losses through a canal i-j during season k as a function of the canal's flow.

$\sum_{i=1}^{I+N-1} X(i,j,k)\ (1-CL(i,j,k)$ = the total inflow to a sub-area j during season k.

Area Budget Constraints:

Within each sub-area, the sum of planted areas of the different crops should be less than or equal to the size of the sub-area itself. This contraint can be written as

$$\sum_{i=1}^{I+N-1} \sum_{h=1}^{H} A(C_h^k,i,j) \leq A(j) \quad \forall_k \tag{3.40}$$

Water Budget Constraint:

This constraint is to keep the outflow from each source less than or equal to the inflow to this source. This limit may be stated mathematically as

$$\sum_{j} X(i,j,k) \leq b(i,k) \quad \forall_{i,k} \tag{3.41}$$

Sequential Planting Constraint:

Some crops are needed to be planted before some other crops for different purposes. As an example, in Egypt clover has to be planted before the cotton for enhancing of soil nitrogen. As an example let crop a be planted before crop b, then this constraint can be written as

$$\sum_{i=1}^{I+N-1} A(C_b^k,i,j) \leq \sum_{i=1}^{I+N-1} A(C_a^{k-1},i,j) \quad \forall_{\substack{j,k \\ k\neq 1}} \tag{3.42}$$

where:

$\sum_{i=1}^{I} A(C_b^k,i,j)$ = the planted area of crop b in sub-area j, during season k.

$\sum_{i=1}^{I} A(C_a^{k-1},i,j)$ = the planted area of crop a in sub-area i, during season k-1.

Agricultural Requirements Constraint:

Some crops have to be cultivated with certain amounts sufficient to the population requirements or for exportation purposes. This constraint can be written in terms of the model parameters as

$$\sum_{i=1}^{I+N-1} \sum_{j}^{N-1} A(C_h^k,i,j) - \alpha_h^k \sum_{j=1}^{N} A(j) \geq 0 \qquad \forall_{k,h} \tag{3.43}$$

where:

α_h^k = the required ratio of the planted area with crop C_h^k to the total area of the new land

Soil Type - Crop Pattern Constraint:

There are some soils, not appropriate for planting certain crops. For example, if crop C_h^k, can not be cultivated in sub-area J, this contraint can be written as

$$\sum_{i=1}^{I+N-1} A(C_h^k,i,J) = 0 \tag{3.44}$$

Salt Concentration Constraint:

By mixing different water of different salinities we may have a moderate saline water. This moderate saline water may give better results for the agricultural practices than a water with a high salinity in its status-quo. A constraint on the salt concentration of the resulting mixed water can be formulated as

$$\sum_{i=1}^{I+N-1} EC_{wi} [X(i,j,k) (1-CL(i,j,k) - \sum_{h=1}^{H} q(C_h^k,i,j) A(C_h^k,i,j)]$$

$$EC_{wj} \sum_{\substack{\ell=1 \\ \ell \neq j}}^{N-1} X(j,\ell,k) \qquad \forall_{j,k} \qquad (3.45)$$

where:

EC_{wi} = the salt concentration of the inflow to the mixing site

EC_{wj} = the salt concentration of the outflow from the mixing site to the sub-areas

A Constraint to the Yields of the Crops:

This constraint is to compute the yields of the different crops according to the salinity degree of the water supply. From Chapter (2). This constraint can be written as

$$Y(C_h^k,i,j) = [100-B(C_h^k)(1.5\ EC_{wi}-A(C_h^k)]\ \overline{Y}\ (C_h^k) \qquad (3.46)$$

where:

$\overline{Y}(C_h^k)$ = the standard yield of a crop C_h^k,

$B(C_h^k)$ = the qualitative salt tolerance rate which is a function of the crop pattern, (Table 2.5), and

$A(C_h^k)$ = the salinity threshold, in millimhos per centimeter, which also is a function of the crop pattern, (Table 2.5).

A Constraint on a Crop's Water Requirement:

From Chapter (2), this constraint when using surface irrigation method is given by

$$LR_i = \frac{EC_{wi}}{5EC_e - EC_w} \tag{3.47}$$

where:

EC_e = the soil salinity which causes a 10% or less yield reduction for a given crop (Table (2.6)).

and for trickle irrigation is given by

$$LR_i = \frac{EC_{wi}}{2(\max EC_e)} \tag{3.48}$$

where:

$\max EC_e$ = the soil salinity which causes 100% yield reduction for a given crop (Table (2.6)).

Therefore a water requirement of a crop C_h^k can be written as

$$q(C_h^k,i,j) = (1 + LR_i(EC_{wi},EC_e))\,\bar{q}(C_h^k,i,j) \quad \forall_{h,k,i,j} \tag{3.49}$$

where:

$\bar{q}(C_h^k,i,j)$ = the water requirement of a crop C_h^k when using fresh irrigation water.

Upper Capacity Constraint:

This constraint is to keep the flow through a canal lower than an upper limit. This upper limit is the upper capacity of a canal which is one of the decision variables of the model. This capacity is equal to the maximum seasonal flow. The upper limit constraint can be expressed mathematically as

$$X(i,j,k) \leq C(i,j) \quad \forall_{i,j,k} \tag{3.50}$$

$$q_d(k) \leq Q_d \quad \forall_{k,d} \tag{3.51}$$

Lower Capacity Constraint:

The lower capacity can take different values rather than zero for different purposes like navigation, power generation, etc. Generally this constraint can be expressed in the following form:

$$X(i,j,k) \geq \underline{C}_L(i,j) \quad \forall_{i,j,k} \tag{3.52}$$

where:

$\underline{C}_L(i,j)$ is the lower permissible capacity of a canal i-j.

Non Negativity of the Decision Variables

The decisions variable are required to be non-negative. Since the flows and capacities of the irrigation canals are taken care of by equation (3.50), and (3.52), we need only add the following constraints on the areas of different crops, and the discharges of the pump stations.

$$A(C_h^k,i,j) \geq 0.0 \qquad \forall_{i,j,k,h} \tag{3.53}$$

$$Q_d \geq 0.0 \qquad \forall_d \tag{3.54}$$

3.3.5 Summary of the Model Formulation

From the previous deviation of objective functions, and the constraints, the agricultural expansion problem can be formulated as the following mathematical programming problem.

Maximize:

$$\sum_{t=t_{1+1}}^{T}\ \sum_{i=1}^{I+N-1}\ \sum_{j=1}^{N}\ \sum_{k=1}^{K}\ \sum_{h=1}^{H} \frac{1}{(1+r)}t\ A(C_h^k,i,j)\ P(C_h^k)\ Y(C_h^k,i,j)\ +$$

$$\sum_{t=t_{1+1}}^{T}\ \sum_{i=1}^{I+N-1}\ \sum_{j=1}^{N}\ \sum_{k=1}^{K}\ \sum_{h=1}^{H} \frac{1}{(1+r)}t\ A(C_h^k,k,j)[C^s(C_h^k,j)\ S(C_h^k,i,j)\ +$$

$$C^F(C_h^k,j)\ F(C_h^k,i,j) + C^L(C_h^k,j)\ L(C_h^k,j) + C^M(C_h^k,j)\ M(C_h^k,j)]$$

$$-\sum_{t=1}^{t_1}\ \sum_{i=1}^{I+N-1}\ \sum_{j=1}^{N} \left(\frac{1+e}{1+r}\right)^t [(1+\alpha)\ A(1.5\ Q_{ij}^{.8} + 6.12\ Q_{ij}^{.4} + 9.)^B\ +$$

$$C(3.57\ Q_{ij}^{.4} + 9.2)^D]\ L(i,j)$$

$$-\sum_{t=t_{1+1}}^{T}\ \sum_{k=1}^{K}\ \sum_{i=1}^{I+N-1}\ \sum_{j=1}^{N} \frac{1}{(1+t)t} + \beta\ A(1+\alpha)\ (1.5\ Q_{ij}^{.8} + 6.12\ Q_{ij}^{.4} + 9)^B\ L(i,j)$$

$$-\sum_{t=1}^{t_1}\ \sum_{i=1}^{I+N-1}\ \sum_{j=1}^{N} \left(\frac{1+e}{1+r}\right)^t \{(1+\alpha)\ A[1.5\ Q_a^{.8}(i,j)\ +$$

$$.4\ Q_b(i,j)\ Q_a(i,j) + 7(Q_a(i,j) - Q_b(i,j)]^B\ +$$

$$C(3.57\ Q_a^{.4}(i,j) + 9.2)^D\ \ L(i,j)$$

$$-\sum_{t=t_{1+1}}^{T}\ \sum_{k=1}^{K}\ \sum_{i=1}^{I+N-1}\ \sum_{j=1}^{N} \frac{1}{(1+r)}t\ \ \beta A(1+\alpha)\ [1.5\ Q_a^{.8}(i,j) - 1.95\ Q_b^{.8}(i,j)\ +$$

$$.4\ Q_b(i,j)\ Q_a(i,j) + 7.(Q_a(i,j) - Q_b(i,j)]^B\ L(i,j)$$

$$-\sum_{t=1}^{t_1}\ \sum_{d=1}^{D} \left(\frac{1+e}{1+r}\right)^t 24962\ (Q.\Delta H)^{.66}$$

$$\sum_{t=t_{1+1}}^{T}\ \sum_{k=1}^{K}\ \sum_{d=1}^{D} \frac{1}{(1+r)}t\ [1997(Q.\Delta H)^{.66} + 284\ q.\Delta H]$$

$$\sum_{t=1}^{t_1}\ \sum_{j=1}^{N} \left(\frac{1+e}{1+r}\right)^t CD(j)\ A(j) \tag{3.55}$$

Subject to:

$$\sum_{d=1}^{N-1} X(j,d,k) + \sum_{i=1}^{I+N-1} \sum_{h=1}^{H} q(C_h^k,i,j)\ A(C_h^k,i,j)$$

$$- \sum_{i=1}^{I+N-1} X(i,j,k)\ \left(1-CL(i,j,k)\right) = 0.0 \quad \forall_{j,k} \qquad (3.39)$$

$$\sum_{i=1}^{I+N-1} \sum_{h=1}^{H} A(C_h^k,i,j) \le A(j) \quad \forall_{j,k} \qquad (3.40)$$

$$\sum_{j}^{N} X(i,j,k) \le b(i,k) \quad \forall_{i,k} \qquad (3.41)$$

$$\sum_{i=1}^{I+N-1} A(C_b^k,k,j) - \sum_{i=1}^{I+N-1} A(C_a^{k-1},i,j) \le 0 \quad \forall_{\substack{j,k \\ k\neq 1}} \qquad (3.42)$$

$$\sum_{i=1}^{I+N-1} \sum_{j}^{N-1} A(C_h^k,i,j) - \alpha_h^k \sum_{j}^{N} A(j) \ge 0 \quad \forall_{k,k} \qquad (3.43)$$

$$\sum_{i=1}^{I+N-1} A(C_h^k,i,j) = 0 \qquad (3.44)$$

$$\sum_{i=1}^{I+N-1} EC_{wi}\ [x(k,j,k)\ (1-CL(i,j,k)) - \sum_{h=1}^{H} q(C_h^k,k,j)\ A(C_h^k,i,j)]$$

$$- EC_{wj} \sum_{\substack{\ell=1 \\ \ell\neq j}}^{N-1} X(j,\ell,k) = 0 \quad \forall_{j,k} \qquad (3.45)$$

$$Y(C_h^k,i,j) - [100 - B(C_h^k)(1.5\ EC_{wj} - A(C_h^k)]\ \bar{Y}\ (C_h^k) = 0 \quad \forall_{i,k,h} \qquad (3.46)$$

$$LR(EC_{wi}) - EC_{wi}/(5\ EC_e - EC_{wi}) = 0 \quad \forall_i \qquad (3.47)$$

$$q(C_h^k,i,j) - (1 + LR\ (ECwi)\ \bar{q}(C_h^k,i,j) = 0 \qquad \forall_{i,j,h,k} \tag{3.49}$$

$$X(i,j,k) - C(i,j) \leq 0. \qquad \forall_{i,j,k} \tag{3.50}$$

$$q_d(k) - Q_d \leq 0. \qquad \forall_{k,d} \tag{3.51}$$

$$X(i,j,k) - \underline{C}_L(i,j) \geq 0. \qquad \forall_{i,j,k} \tag{3.52}$$

$$A(C_h^k,i,j) \geq 0. \qquad \forall_{h,k,i,j} \tag{3.53}$$

$$q_d \geq 0. \qquad \forall_d \tag{3.54}$$

3.4 Nonlinearity Problems:

From the above formulation, we can see that the model has a nonlinear convex objective function. This leads to difficulties in seeking the global optimum solution because many local optimum are likely to exist. Also there is a nonlinear constraint (3.45) where two decision variables EC_{wj}, and $X(i,\ell,k)$ are multiplied. If we forget the constraint nonlinearity for a while, we get a mathematical model with a nonlinear objective function and a linear constraint set, in which the decision variables appears separately. In this case instead of solving the problem directly with a nonlinear programming which is a difficult way, we can make an appropriate approximation, so the linear programming can be utilized. In practice, two ways of approximations, called the δ-method and λ-method (7), are often used. Only δ-method will be introduced here.

3.4.1 δ-Method for Separable Programming:

The separable program generally is in the following form:.

$$\text{Max (Min)} \sum_{j=1}^{n} f_j(X_j)$$

$$\text{Subject to} \sum_{j=1}^{n} g_{ij}(X_j) \overset{<}{\underset{>}{=}} 0. \quad \forall_{i=i,2} \ldots ,m$$

where each of the functions f_j and g_{ij} are known. Assume now that one of f(X) is piece wise linearly approximated as shown in Figure (3.11)

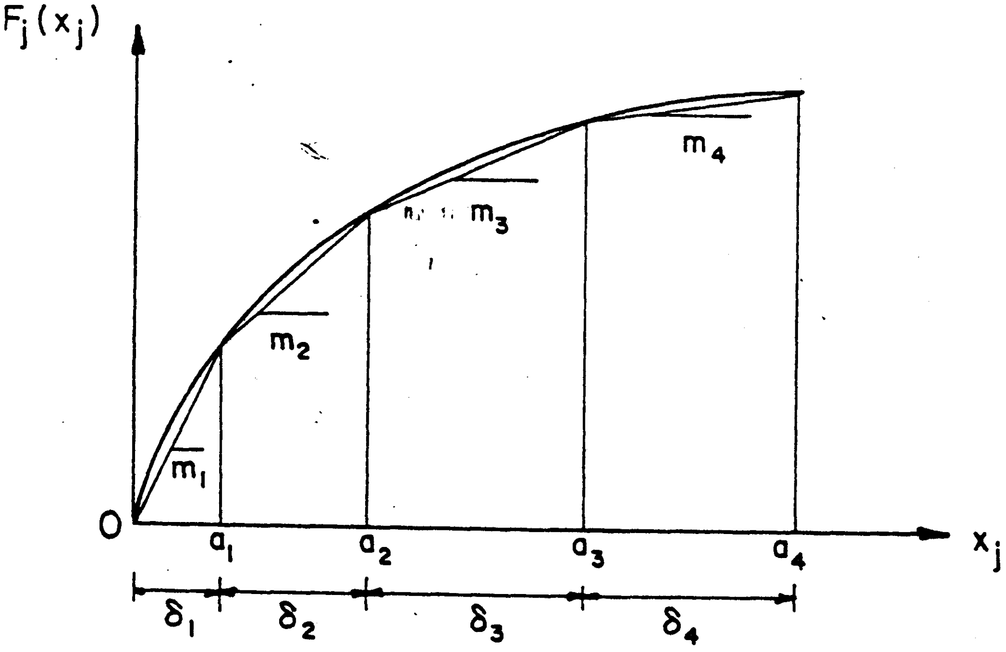

Figure 3.5. A Piecewise Linear Approximation of $f_j(x_j)$

Any value of X can be expressed as the sum of the variables δ_s, so that the cost for each of these variables (δ) is linear and the total approximated cost is given by

$$f(x) = m_1 \delta_1 + m_2 \delta_2 + m_3 \delta_3 + m_4 \delta_4 \tag{3.56}$$

where

$$X = \delta_1 + \delta_2 + \delta_3 + \delta_4, \text{ and} \tag{3.67}$$

$$0. \leq \delta_1 \leq a_1$$

$$0. \leq \delta_2 \leq a_2 - a_1$$

$$0. \leq \delta_3 \leq a_3 - a_2 \tag{3.58}$$

But if we have to minimize over a concave function or to maximize over a convex function we must require that $\delta_1 = a_1$ whenever $\delta_2 > 0.$, and that $\delta_2 = a_2 - a_1$ whenever $\delta_3 > 0.$ and so on. Otherwise, when $X \leq \delta_1$, say, the cost would be minimized by selecting $\delta_1 = \delta_2 = \delta_3 = 0.$ and $\delta_4 = X$, since m_4 has the smallest variable cost ($m_4 < m_3 < m_2 < m_1$). However, these restrictions on the variables are simply conditional constraints and can be modeled by introducing binary variables as follows:

$$w_1 = \begin{cases} 1 & \text{If } \delta_1 \text{ is at its upper bound} = a_1 \\ 0 & \text{Otherwise} \end{cases}$$

$$w_2 = \begin{cases} 1 & \text{If }_2 \text{ is at its upper bound} = a_2 - a_1 \\ 0 & \text{Otherwise} \end{cases}$$

and in the general case:

$$w_j = \begin{cases} 1 & \text{If } \delta_j = a_j - a_{j-1} \\ 0 & \text{Otherwise} \end{cases} \qquad (3.59)$$

So, the constraints on the δ-variables can be written as:

$$\begin{aligned} a_1\, w_1 &\le \delta_1 \le a_1 \\ (a_2-a_1)\, w_2 &\le \delta_2 \le (a_2-a_1)\, w_1 \\ (a_3-a_2)\, w_3 &\le \delta_3 \le (a_3-a_2)\, w_2 \\ 0. &\le \delta_4 \le (a_4-a_3)\, w_3 \end{aligned}$$

and, in the general form:

$$a_k\, w_k \le \delta_k \le (a_k-a_{k-1})\, w_{k-1} \qquad k = 1,2,\ldots,k \qquad (3.60)$$

where a_0 is equal to zero, and w_0 equals one.

<u>Fixed Cost Problem</u>:

The excavation, irrigation structures, or lining costs of a canal as shown before includes a constant term. This term is called a fixed cost, which is not a function of a canal's capacity. When a canal's capacity goes to zero, instead of getting a zero cost of excavation, as an example, we will get this fixed term. This problem can be solved by introducing a binary variable as follows:

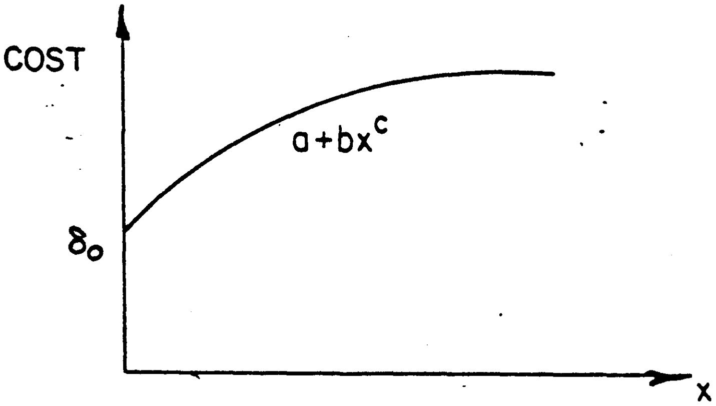

Figure 3.6. A Fixed Cost

Assume we have a concave cost function as shown in Figure 3.12, and we need to get a zero cost when X goes to zero, and $\delta_o + bX^c$ cost when X is greater than zero. Define w_o to be a binary variable, so that $w_o = 1$ when $X > 0.$ and $w_o = 0.$ when $X = 0$. Then the contribution to cost due to X may be written as:

$$\delta_o \, w_o + bX^c$$

subject to

$$X \leq U \, w_o$$

$$X \geq 0.$$

where:

U = the upper limit of X.

Finally, to indicate how we can solve nonlinearity, and fixed cost problems together, let us apply both selections to the excavation cost shown in Figure 3.2. A piecewise linearly approximations of the cost is shown in Figure 3.12.

From the latter figure $m_1 = .37$, $m_2 = .14$, $m_3 = .12$, and $m_4 = .1$, then the cost function can be written as

$$C^E(C) = 2.17\ w_o + .37\ \delta_1 + .14\ \delta_2 + .12\ \delta_3 + .1\ \delta_4 \qquad (3.61)$$

subject to

$$C = \delta_1 + \delta_2 + \delta_3 + \delta_4 \qquad (3.62)$$

$$30\ w_1 \leq \delta_1 \leq 30\ w_o,$$
$$30\ w_2 \leq \delta_2 \leq 30\ w_1,$$
$$30\ w_3 \leq \delta_3 \leq 30\ w_2,$$
$$0. \leq \delta_4 \leq 50\ w_3, \text{ and}$$

$$w_o,\ w_1,\ w_2, \text{ and } w_3 \text{ are binary variables} \qquad (3.63)$$

Then replacing C from the constraint set by Equation 3.60. As shown in equation 3.54 and in equation 3.57, that the number of the constraints will increase at more with N(1+K) constraints, and we will have (NK) decision variables rather than the introduced binary variables. The disadvantage of this programming technique is the great increase of the constraints numbers, especially if we know that the computations for linear programs are quite sensitive to m, the number of constraints, in practice growing proportionally to m^3.

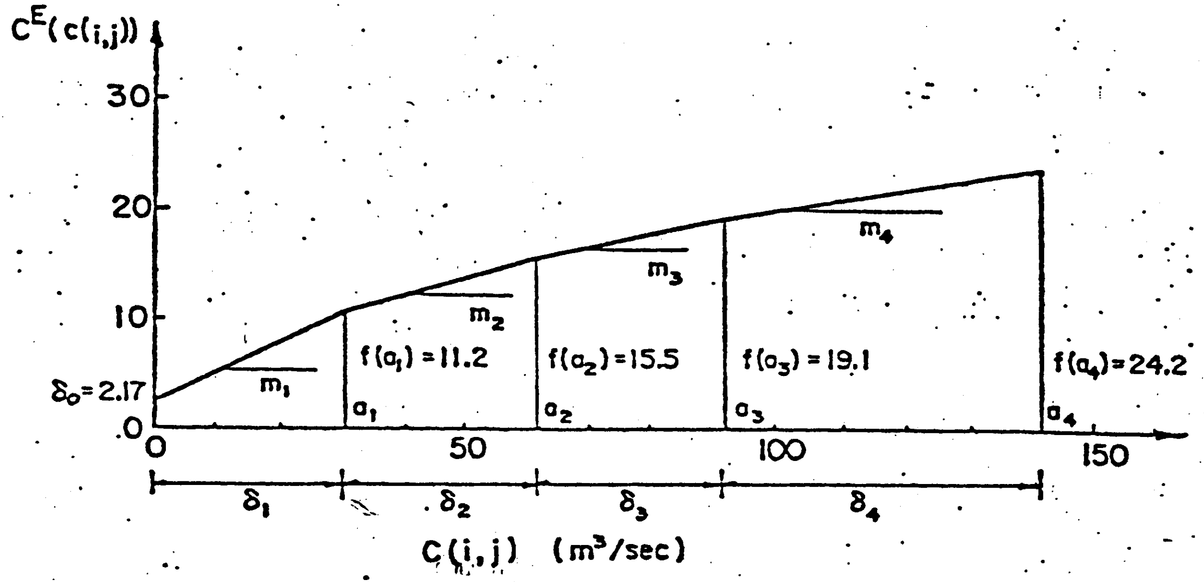

Figure 3.7 A Piece Wise Linear Approximation of the Excavation Cost us with an approximate solution close to the actual solution (global optimum solution) to this type of nonlinear problem. A better solution can be obtained by introducing more break points near the optimal solution given by the original approximation.

In this work the separable programming is chosen for solving this agricultural exapnsion problem. But before using this algorithm constraint (3.43) has to be transformed to a linear form. In the following chapter an approach for dealing with this nonlinearity problem is presented.

3.4.2 Constraints Nonlinearity Problem:

The nonlinearity of constraint (3.43) is due to a multiplication of two random variables EC w_j, and $\sum_{\ell=1}^{N-1} X(j,\ell,k)$. One way of solving this nonlinear problem is by assuming one variable and solving for the other one. In our case it is much easier to assume a certain magnitude for EC w_j instead of assuming (N-1) magnitudes for $X(i,\ell,k)$. After assuming some value for EC_{wj}, we solve the whole problem using the separable programming algorithm and getting the optimum net benefit, then assuming another value for EC w_j, and getting another value for the net benefit, repeating the trails until it reaches the global optimum solution, or close to it.

3.5 Summary:

In this chapter a mathematical deviation of all types of costs used in the model objective function is presented. A mathematical formulation of this agricultural expansion problem is done. The model's nonlinearity problems are discussed and solutions are introduced. The separable programming technique is suggested to be used for solving this agricultural expansion problem.

CHAPTER 4

CASE STUDY: THE AGRICULTURAL EXPANSION IN THE NILE DELTA AND SINAI

4.1 Introduction

This chapter presents a comprehensive study of the use of the planning model presented in the last chapter in a specific planning problem. This problem is based upon the preposed agricultural expansion in the Nile Delta and Sinai where the available irrigation sources are fresh and saline waters from the River Nile, and the drains of the existing cultivated lands respectively.

4.2 The Agricultural Expansion in Nile Delta and Sinai

The Nile Delta is naturally divided by the two major branches of the River Nile - Domietta and Rosetta Branches - into three main regions. These regions are the Eastern Delta, Middle Delta, and Western Delta. This natural decomposition is used here by working only on the Eastern Delta beside the Sinai.

The agricultural expansion in this region is in order of 1,548,500 feddans. This expansion is proposed in twenty-two sub-areas [31]. A soil classification to these sub-areas is presented in Table 4.1.

The irrigation water resources available for these new areas are: (1) El Salam canal which is now under planning. Its water is of a fresh water from Domietta branch and a drainage water from El. Sarw pump Station and Bahr Hadus drain. There are two proposed pump stations on this canal. The first pumping station is to lift the water after being

Table 4-1

A Soil Classification for the New Areas in the Eastern Delta and Sanai

Area No.	Size in feddans	Soil Classification
1	265,000	sandy clay
2	130,000	sand
3	30,000	sand
4	90,000	salty clay
5	135,000	salty clay
6	50,000	salty clay
7	65,000	salty clay
8	29,000	salty clay
9	70,000	salty clay
10	40,000	salty clay
11	32,000	sandy clay
12	70,000	sandy clay
13	120,000	sand
14	20,000	sand
15	15,000	sand
16	10,000	sand
17	100,000	sand
18	40,000	sand
19	85,000	sand
20	47,000	sand
21	5,500	salty clay
22	100,000	sand

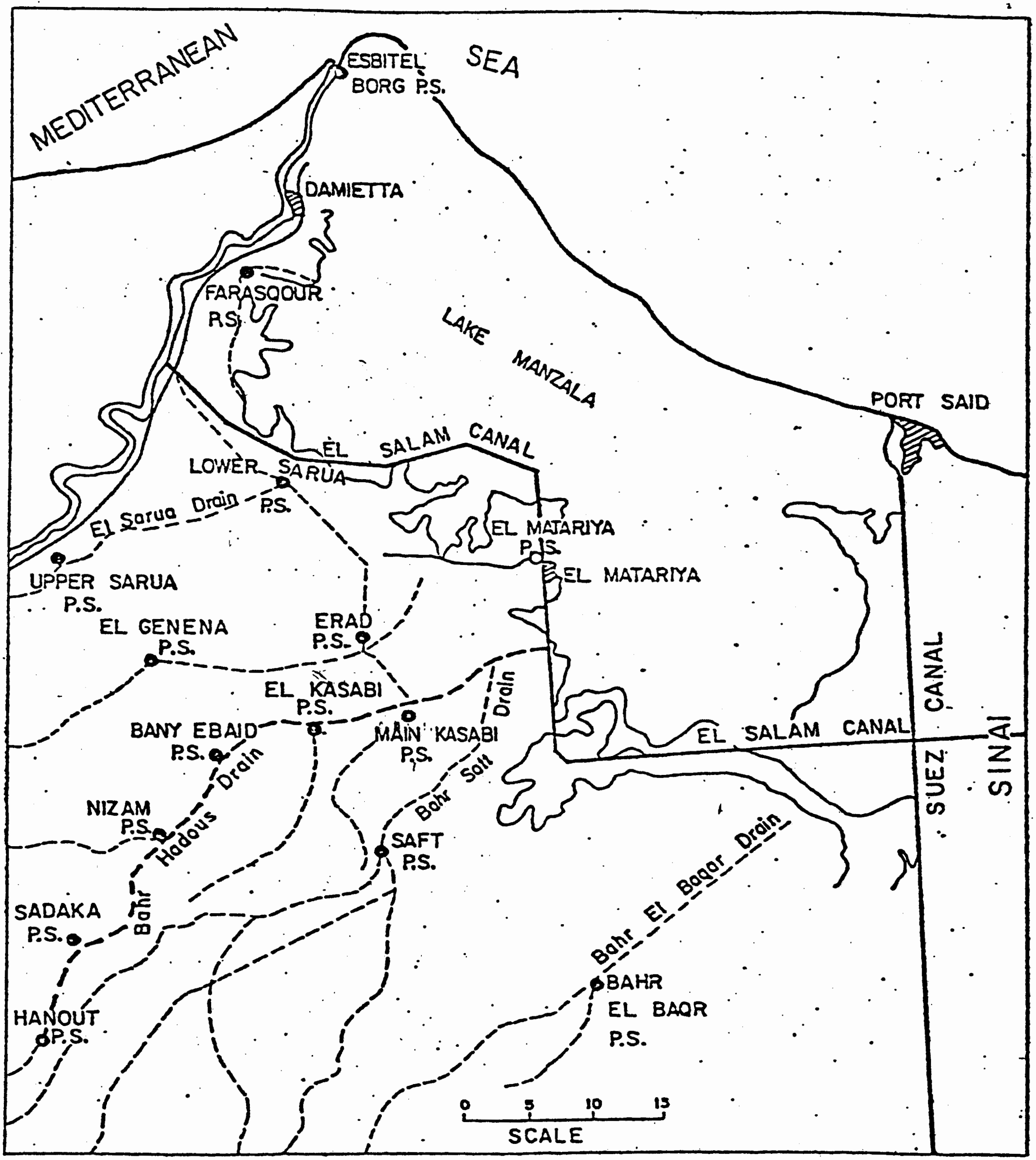

Figure 4.1 The Proposed El-Salam Canal

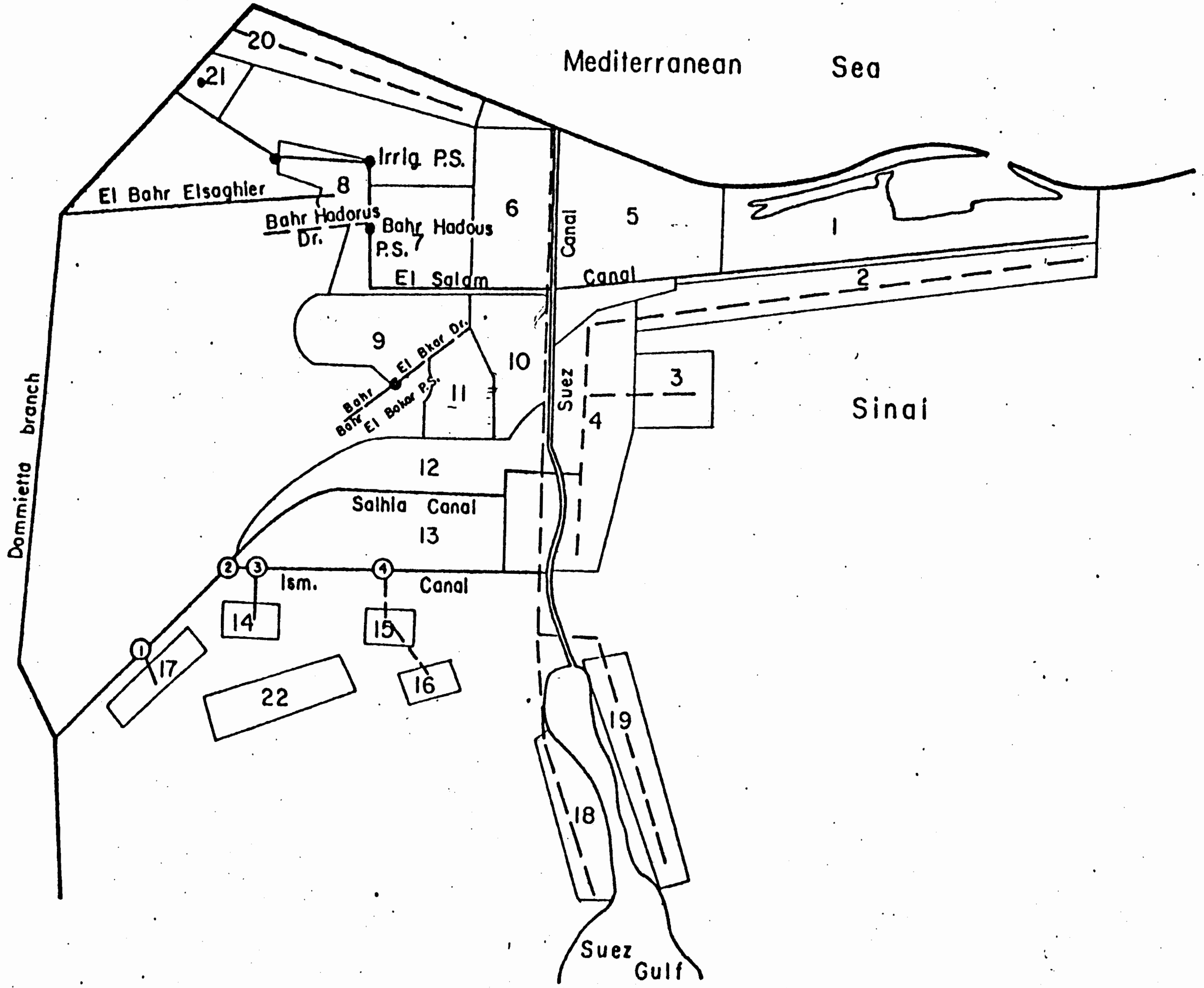

Figure 4.2 A Schematic Map of the New Lands and the Irrigation Water Sources in the Eastern Delta and Sinai Regions

mixed with El. Sarw drainage water. The second one is at the end of Bahr Hadus to lift the drainage water to be mixed with the canal's water. This canal extends from its intake at Domietta branch to Sinai across the Suez Canal as shown in Figure 4.1.

(2) Ismailia Canal, after some enlargement, is proposed to feed directly some new areas close to it rather than two new canals. These canals are the irrigation Suez Canal for supplying the new lands in both west and east of the Suez Gulf, and El Salhia Canal which is planned to feed new areas in the east and west of the Suez Canal as shown in Figure 4.2.

(3) El Bahr El-Saghier after an expansion to its cross-section.

(4) A new canal takes its water from the Domietta branch to supply the sub-area (20) with irrigation water in the northern part of the Eastern Delta as shown in Figure 4.2

(5) A drainage water from Faraskour pump station.

(6) A drainage water from either the pump station or sub-drain of Bahr El Bakar.

(7) A treated sewage water for feeding 100,000 feddans south to Ismailia Canal (sub-area (22)).

Figure 4.2 shows a schematic map of this region. A network representation of the irrigation system in the new land is shown in Fig. 4.3. Node definitions and arcs (canals) lengths are presented in Table C.1 and Table C.2 respectively.

4.3 The Cropping System in Egypt

In Egypt, the agricultural year is divided into two main seasons, winter which starts at the beginning of November and, summer which

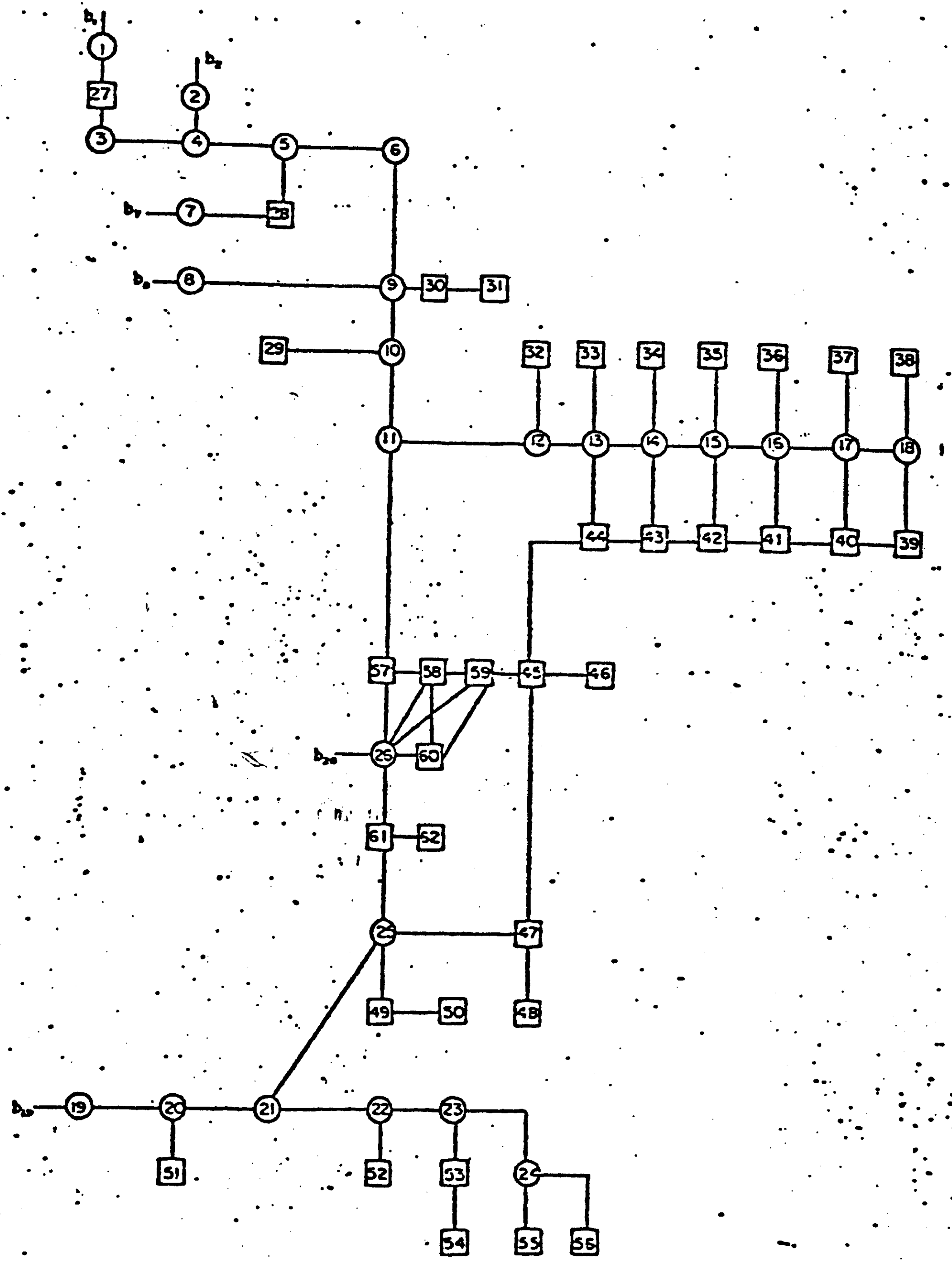

Figure 4.3 A Network Presentation of the Irrigation System in the Eastern Delta and Sinai Regions

starts at the beginning of March. The main winter crops are short-season clover, wheat, vegetables, barley, beans and long-season clover. During the summer, cotton, maize, rice and summer vegetables are grown. In general, there are two traditional cropping patterns in the old lands -- namely, the two - and three-year rotations as shown in Table C.3 and C.4 respectively.

4.4 Data Used in Case Study

To apply the mathematical model, some data has to be prepared as an input to the model. Some of this data is collected and the other part is assumed.

The collected Data:

(1) Monthly discharges and salinities of all drains and drainage pump stations in the Eastern Delta in the last four years are provided by the drainage institute, Cairo, Egypt. Some analysis is carried out to this data in Appendix A to calculate the seasonal average flows and salinities of the drain irrigation resources and the computed values are shown in Table 4.2.

(2) The crops'water requirements based on surface irrigation method are shown in Table 4.3.

(3) The lifting heads of the two pump stations on El-Salam Canal are 1.60 m and 2.4 m, respectively, as provided by the public directory of the horizontal expansion projects in the Eastern Delta (32).

The Assumed Data:

(1) Yields and unit prices of the crops as shown in Table C.5.

(2) Amounts and unit costs of seeds, fertilizer, labor-hours, and machinery hours required for the crops as presented in Table C.6.

Table 4.2 Seasonal Discharges and Salinities of the Irrigation Water Resources

Agricultural Season	Winter		Summer	
Irrigation Source	Discharge (m/sec)	EC_w (mmhos/m)	Discharge (m/sec)	EC_w (mmhos/cm)
El-Salam Canal*	30.3	.2	37.2	.2
El-Sarw Pump Station	13.4	1.6	20.5	1.2
Bahr Hadus	85.7	2.3	114.0	2.0
Ismailia Canal	115.4	.2	162.6	.2
El-Bahr El-Saghier	6.0	.2	7.6	.2
Faraskour Pump Station	5.1	1.2	10.4	1.6
Bahr El-Bakar Pump Station	13.8	1.1	14.5	1.8
Bahr El-Bakar Sub-Drain	37.6	1.2	37.6	1.2

* These seasonal discharges and salinities are computed at the intake of El-Salam Canal at Domietta branch.

Table 4.3 Water Requirements of the Agricultural Crops Based on Surface Irrigation Method

Crop	Growing Season (days)	Water Duty m^3/fed/season	Water Duty $10^{-4}m^3$/fed/sec
Short-Season Clover	100	1910	2.20
Wheat	170	1600	1.10
Barley	120	2200	0.95
Beans	170	1400	1.04
Long Season Clover	150	1350	2.11
Cotton	195	3400	2.02
Maize	130	2700	2.40
Rice	100	8800	10.20
Water Melon	140	4000	3.30
Vegetables	170	3100	2.14

(3) The interest and discount rates on 8% and 6%, respectively.

(4) The A and B coefficients of the excavation cost function are .2 and .9 and the coefficient C and D of the lining ast function are 4. and .95, respectively.

(5) The unit cost of land development is 1200.L.E per feddan as shown in Table C.7.

(6) The water conveyance losses is 10% of the canal's flow for every 100 kms of the canal's length.

(7) The period required for land reclaimation, t_i is equal to 10 years.

(8) The time horizon of this expansion project is 100 years.

4.5 The Seperable Programming Model Application

4.5.1 Objective Function

Agricultural Revenue

In this specific problem, the agricultural revenuw can be written as

$$\sum_{t=11}^{100} \sum_{i=1}^{62} \sum_{j=1}^{61} \sum_{k=1}^{2} \sum_{h=1}^{6} \frac{1}{(1+.06)^t} A(C_h^k,i,j)\ P(C_h^k)\ Y(C_h^k,i,j)$$

where:

C_h^1 = short season clover, wheat, vegetables, barley, beans and long season clover respectively $h=1,\dots,6$

C_h^2 = cotton, maize, rice, melon and vegetables respectively $h=1,\dots,5$

For more illustration, let us compute the agricultural revenuw for node (58) as follows:

$$\begin{aligned}
&[5.\{A(C_1^1,26,58)\ Y(C_1^1,26,58) + A(C_1^1,57,58)\ Y(C_1^1,57,58)\} \\
&+ 60.\{A(C_2^1,26,58)\ Y(C_1^1,26,58) + A(C_2^1,57,58)\ Y(C_2^1,57,58)\} \\
&+ \dots\dots. \\
&+ 5\{A(C_6^1,26,58)\ Y(C_6^1,26,58) + A(C_6^1,57,58)\ Y(C_6^1,57,58)\} \\
&+ 186.\{A(C_1^2,26,58)\ Y(C_1^2,26,58) + A(C_1^2,57,58)\ Y(C_1^2,57,58)\} \\
&+ \dots\dots \\
&+ 170.\{A(C_5^2,26,58)\ Y(C_5^2,26,58) + A(C_5^2,57,58)\ Y(C_5^2,57,58)\}]
\end{aligned}$$

$$\sum_{t=11}^{100} \frac{1}{(1 + 106)^t}$$

where

$$\sum_{t=11}^{100} \frac{1}{(1+.06)^t} = \sum_{t=1}^{100} \frac{1}{(1+.06)^t} - \sum_{t=1}^{10} \frac{1}{(1+.06)^t}$$

$$= \frac{(1+.06)^{100}-1}{.06(1+.06)^{100}} - \frac{(1+.06)^{10}-1}{.06(1+.06)} = 9.3$$

Total Farm Costs

The present value of these costs for this expansion problem are

$$\sum_{t=11}^{100} \sum_{i=1}^{62} \sum_{j=1}^{61} \sum_{k=1}^{2} \sum_{h=1}^{6} \frac{1}{(1+.06)^t} A(C_h^k,i,j)[C^s(C_h^k)S(C_h^k)+C^F(C_h^f)F(C_h^k)$$
$$+ C^L(C_h^k)L(C_h^k)+C^M(C_h^k)M(C_h^k)]$$

The costs for node (58) are

$$9.3[37.9\{A(C_1^1,26,58)+A(C_1^1,57,58)\}+97.75\{A(C_2^1,26,58)+A(C_2^1,57,58)\}$$
$$+ \ldots\ldots$$
$$+168\{A(C_1^2,26,58)+A(C_1^2,57,58)\}+..+158.5\{A(C_5^2,26,58)+A(C_5^2,57,58)\}]$$

The Excavation, Irrigation Structures, Lining and Maintenance Costs

Substituting $\alpha=1$ in the excavation and irrigation structures cost, we get

$$\sum_{t=1}^{10} \sum_{i=1}^{62} \sum_{j=1}^{61} \left(\frac{1+.08}{1+.06}\right)^t \{.6(1.5\ Q_{ij}^{.8}+6.12\ Q_{ij}^{.4}+9)^{.9}\}\ell_{ij}$$

or

$$\sum_{i=1}^{62} \sum_{j=1}^{61} .6(1.5\ Q_{ij}^{.8}+6.12\ Q_{ij}^{.4}+9.)^{.9}\ \ell_{ij} \sum_{t=1}^{10} (1.02)^t$$

or

$$\underset{i=1}{\overset{62}{}} \ \underset{j=1}{\overset{61}{}} \ 6.7(1.5\ Q_{ij}^{.8}+6.12\ Q_{ij}^{.4}+9.)^{.9}\ \ell_{ij}$$

and from the piece wise linear approximation in Figure C-1, the cost can be written as

$$\sum_{i=1}^{62}\sum_{j=1}^{61}(48.4\, w_o+11.1\, \delta_1+5\, \delta_2+4\, \delta_3+3.6\, \delta_4+3.2\, \delta_5+2.9\, \delta_6+2.6\, \delta_7+2.35\, \delta_8+2.15\, \delta_9)_{ij}\, \ell_{ij}$$

By the same way the lining cost (Figure C.2 can be written as:

$$\sum_{i=1}^{62}\sum_{j=1}^{61} 11.2(3.57\, Q_{ij}^{.4}+9.2)^{.95}\, \ell_{ij}$$

or in linear form as

$$\sum_{i=1}^{62}\sum_{j=1}^{61}(90.3\, w_o+8.70\, \delta_1+2.60\, \delta_2+1.9\, \delta_3+1.5\, \delta_4+1.3\, \delta_5+1.1\, \delta_6+.9\, \delta_7+.8\, \delta_8+.7\, \delta_9)_{ij}\, \ell_{ij}$$

From Equation 3.33, the maintenance cost with β=8% is equal to

$$\sum_{i=1}^{62}\sum_{j=1}^{61} .05(1.5\, Q_{ij}^{.8}+6.12\, Q_{ij}^{.4}+9.)^{.9}\, \ell_{ij} \sum_{t=11}^{100}\frac{1}{(1+r)^t}$$

or

$$\sum_{i=1}^{62}\sum_{j=1}^{61} .45(1.5\, Q_{ij}^{.8}+6.12\, Q_{ij}^{.4}+9.)^{.9}\, \ell_{ij}$$

Using the piece wise approximation as shown in Figure C.3 we obtain

$$\sum_{i=1}^{62}\sum_{j=1}^{61}(3.25\, w_o+.75\, \delta_1+.33\, \delta_2+.28\, \delta_3+.24\, \delta_4+.22\, \delta_5+.28\, \delta_6+.18\, \delta_7+.16\, \delta_8+.14\, \delta_9)_{ij}^{.9}\, \ell_{ij}$$

Enlargement Costs of the Existing Canals

From Equation 3.34, the excavation and irrigation structures costs can take the following form:

$$\sum_{i}\sum_{j} 6.7[1.5\ Q_a^{.8}\ (i,j)-1.95\ Q_b^{.8}\ (1,j)+.4\ Q_b^{.4}\ (i,j)\ Q_a^{.4}\ (i,j)$$
$$+7.\ (Q_a^{.4}\ (i,j)-Q_b^{.4}(i,j))]^{.9}\ \ell_{ij}$$

For Ismailia Canal which consists of four reaches, each one has an average Q_b as shown in Figure C.4.

The cost function for these reaches can be linearly approximated as shown in Figures C.5, C.6, C.7 and C.8 and they can be respectively written as:

$$(3.4\ \delta_1+2.93\ \delta_2+2.56\ \delta_3+2.31\ \delta_4+2.1\ \delta_5)_{19,20}\ \ \ell(19,20),$$

$$(4.28\ \ {}_1+3.2\ \delta_2+2.74\ \delta_3+2.46\ \delta_4+2.24\ \delta_5)_{20,21}\ \ \ell(20,21),$$

$$(5.7\ \delta_1+3.83\ \delta_2+3.14\ \delta_3)_{21,22}\ \ \ell(21,22),\text{ and}$$

$$(6.82\ \delta_1+4.62\ \delta_2+3.57\ \delta_3)_{22,23}\ \ \ell(22,23)$$

For El-Bahr El-Saghier, when $Q_b = \frac{Q\ \text{man}}{2} = 32.2\ m^3/\text{sec.}$, the excavation cost as shown in Figure C.9 can be linearly expressed as

$$(6.1\ \delta_1+5\ \delta_2+1.2\ \delta_3)_{7-28}\ \ \ell(7,28)$$

Capital, Operation and Maintenance Costs of Pump Stations

El Sarw Pump Station

From Equation 3.36, the capital cost is equal to

$$381{,}256\ (Q)^{.66}$$

or linearly from Figure C.10 as

$$10^3(175\ \delta_1+100\ \delta_2+.85\ \delta_3+.75\ \delta_4+.65\ \delta_5)$$

In the same manner, and from Figure C.11 the maintenance cost is equal to

$$10^3(10.2\ \delta_1+5.9\ \delta_2+4.9\ \delta_3+4.5\ \delta_4+4.\ \delta_5)$$

Therefore the total cost of El-Sarw Pump Station is equal to

$$10^3(185.2\ \delta_1+105.9\ \delta_2+89.9\ \delta_3+79.5\ \delta_4+69.\ \delta_5)+454\ q_1\text{..L.E.}$$

Bahr Hadus Pump Station

From Figure C.12 the capital cost can be written as

$$10^3(228\ \delta_1+132\ \delta_2+110\ \delta_3+99.\ \delta_4+90\ \delta_5+81\ \delta_6+74.5\ \delta_7+67.7\ \delta_8)$$

and the maintenance cost from Equation 3.37 and Figure C.13

$$10^3(15.1\ \delta_1+8.8\ \delta_2+7.3\ \delta_3+6.5\ \delta_4+6\ \delta_5+5.4\ \delta_6+4.9\ \delta_7+4.5\ \delta_8)$$

Therefore the total pumping cost is equal to

$$10^3(243.1\ \delta_1+140.8\ \delta_2+117.3\ \delta_3+105.5\ \delta_4+96\ \delta_5+86.4\ \delta_6$$
$$+\ 79.4\ \delta_7+72.2\ \delta_8)+681\ q_2$$

4.5.2 Constraints

Flow Balance Constraint

To indicate how this constraint can work, let us apply it for node (58) as follows

$$\text{for } k=1\ ,\quad x(58,59,1)+x(58,60,1)+\sum_{h=1}^{6}[q(C_h^1,26,58)A(C_h^1,26,58)+$$
$$q(C_h^1,57,58)A(C_h^1,57,58)]-x(26,58,1)(1-.01)-x(57,58,1)(1-.01)=0$$

and for k=2

$$x(58,59,2)+x(58,60,2)+\sum_{h=1}^{5}[q(C_h^2,26,58)A(C_h^2,26,58)+$$

$$q(C_h^2,57,58)A(C_h^2,57,58)]-x(26,58,2)(1-.01)-x(57,58,1)(1-.01)=0$$

Area Budget Constraint

For node (58), this constraint (for the winter season) can be written as

$$\sum_{h=1}^{6} A(C_h^1,26,58)+A(C_h^1,57,58) \leq A(58)$$

and for the summer season

$$\sum_{h=1}^{5} A.(C_h^2,26,58)+A(C_h^2,57,58) \leq A(58)$$

Water Budget Constraint

Applying this constraint to node (3) for example, we get when x k=1 that

$$x(3,4,1)+x(3,27,1) \leq b(3,1)\text{, and}$$

and for k=2

$$x(3,4,2)+x(3,27,2) \leq b(3,2)$$

Sequential Planting Constraint

In Egypt, the short season clover has to be planted before the cotton and this condition can be written for node (58) as

$$A(C_1^2,26,58)+A(C_1^2,57,58)-A(C_1^1,26,58)-A(C_1^1,26,58) \leq 0$$

Agricultural Requirements Constraint

In this specific problem it is assumed that each planted area as is the case with cotton, rice or wheat has to be greater than or equal to the tenth of the whole reclaimed area. Also it is assumed that the planted area with maize has to be equal to or greater than 5% of the whole new land. Some other constraints also are assumed to keep the areas of vegetables, melon and clover less than some ratios of the total reclaimed lands. These constraints are

$$\sum_i \sum_j A(C_2^1,i,j) \geq 154850 \text{ feddans}$$

$$\sum_i \sum_j A(C_3^1,i,j) \leq 154850 \text{ feddans}$$

$$\sum_i \sum_j A(C_6^1,i,j) \leq 38712.5 \text{ feddans}$$

$$\sum_i \sum_j A(C_1^2,i,j) \geq 154850 \text{ feddans}$$

$$\sum_i \sum_j A(C_2^2,i,j) \geq 77425 \text{ feddans}$$

$$\sum_i \sum_j A(C_3^2,i,j) \geq 154850 \text{ feddans}$$

$$\sum_i \sum_j A(C_4^2,i,j) \leq 77425 \text{ feddans}$$

$$\sum_i \sum_j A(C_5^2,i,j) \leq 154850 \text{ feddans}$$

<u>Salt Concentration Constraint</u>

From Table 4.6 and for node (57), this constraint can be written as

$$EC_{w_{11}}[x(11,57,k)(1-.005)-\sum_{h=1}^{H} q(C_h^k,11,57)A(C_h^k,11,57)]+$$

$$EC_{26}[x(26,57,k)(1-.01)-\sum_{h=1}^{H} q(C_h^k,26,57)A(C_h^k,26,57)]$$

$$-EC_{57}[x(57,58,k)] = 0 \qquad k = 1,2$$

where EC_{11} depends on the mixing ratio at node (9), which has to be assumed as will be shown later, and EC_{26} is 1.15 in the summer and 1.75 in the winter in mmhos/cm.

A Constraint on a Crop's Water Requirement

As an example, let us apply this constraint for crop C_5^1 (beans) at node (61) using surface irrigation methods

$$LR_{25} = \frac{.2}{5x1.5-.2} = 27\%, \text{ and}$$

$$LR_{26} = \frac{1.15}{5x1.5-.2} = 15.75\%$$

then

$$q(C_5^1,25,61)=(1.027)1.04x10^{-4}=1.07x10^{-4}\ m^3/sec./fed., \text{ and}$$

$$q(C_5^1,26,61)=(1.1575)1.04x10^{-4}=1.2x10^{-4}\ m^3/sec./fed.$$

A Constraint to the Yield of the Crops

For the same crop and the same node as shown above, this constraint can be written for beans as

$$Y(C_5^1,25,61)=[100-.16(1.5x.2-1.)]x1=1\ ton/fed.$$

$$Y(C_5^1,26,61)=[100-.16(1.5x1.15-1.)]x1\ =.998\ ton/fed.$$

Upper Capacity Constraint

For a canal i-j, this constraint can be written as

$$x(i,j,k) \quad \leq \quad \sum_{\ell}(\delta_{\ell})_{i,j} \qquad \forall_{i,j,k}$$

4.6. The Solutions to the Case Study

The model was applied three times using three different mixing ratios of the drainage water to the fresh water. These ratios were

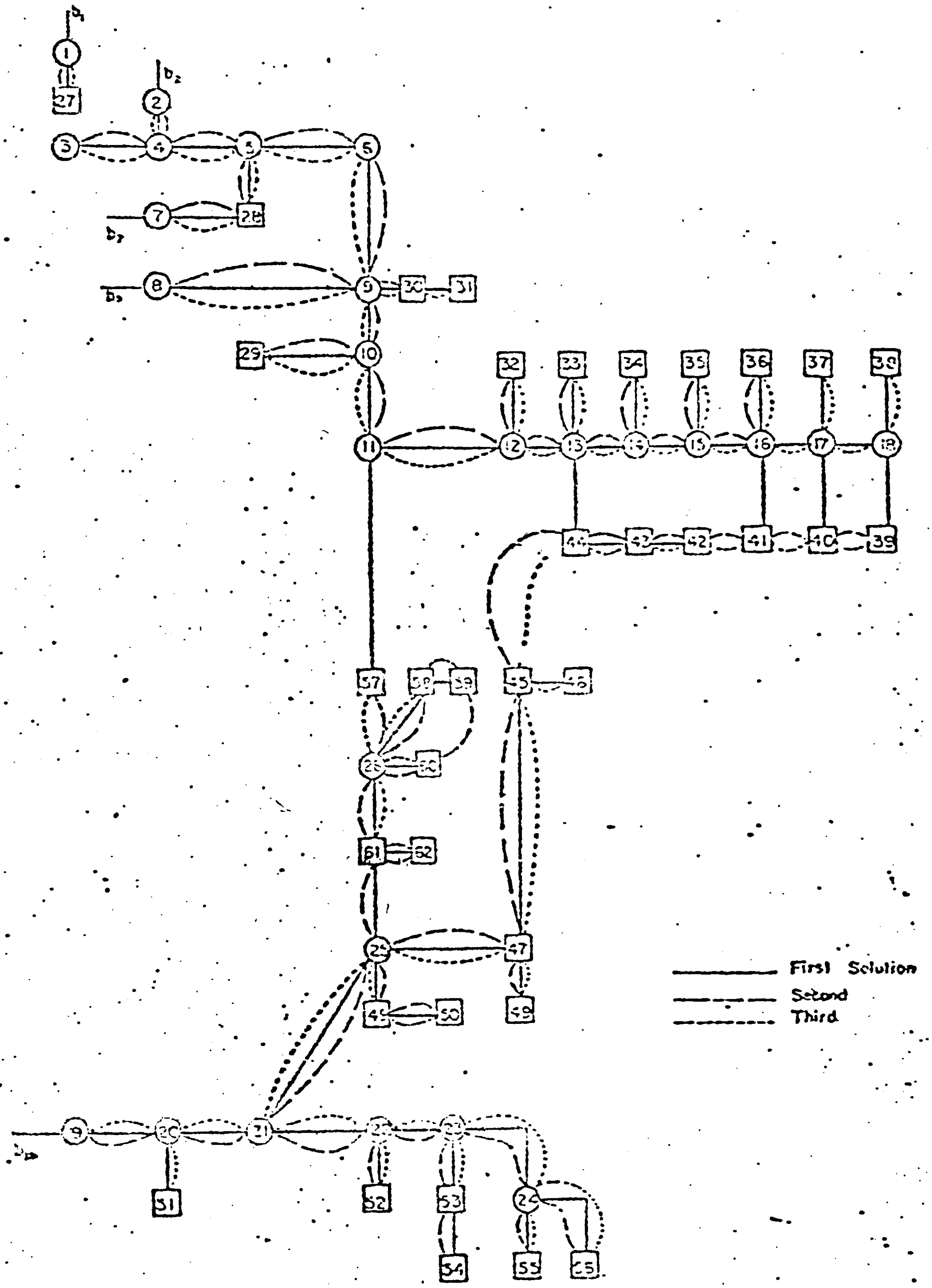

Figure 4.4 A Network Presentation of the Irrigation Systems for the Three Different Solutions

2.5, 1.4, and .8 through the winter; and 2.5, 1.3, and .7 through the summer. In the following a detailed dicussion of each solution and an economic comparison between them is presented.

First Solution

Using the first mixing ratio 2.5 and 2.5 during the winter and summer seasons respectively and dropping the agricultural requirements constraints, the irrigation network was obtained as shown by continuous lines in Figure 4.4. The capacities, cross-sectionsl areas, seasonal water discharges and the total costs of the new canals are presented in Table B.1 (Appendix B). The crop pattern distribution in the new lands is introduced in Table B.4.

The following remarks about the crop pattern distribution when using the above mixing ratio can be observed:

1. Large areas are cultivated with beans which have a high price and at the same time are economical in water consumption.
2. During the summer, the crops of high water requirements like rice are chosen to be cultivated close to the water sources for minimizing the transmission costs.
3. The crops which have a high salinity tolerance are cultivated in the sub-areas which have saline irrigation water like the cotton in the sub-areas (29), (30) or (31). The saline sensitive crops are located in the sub-areas which have fresh irrigation water, like the rice with high intensity in the sub-area (51).
4. More complicated crop selection was done, when the maize

had been chosen in the sub-areas (57), (58), (59) and (60) where the irrigation water is very saline.

The maize was preferred to the cotton because of its higher market price, although the latter has a higher salinity tolerance and a lower water requirement. However as will be shown in the second solution that the cotton was preferred to the maize whenever we have a shortage in irrigation water.

Another run was performed using the same mixing ratio but after holding the constraint set (3-4) to the equality (i.e., all the new lands have to be reclaimed), and after satisfying the agricultural requirement constraint set. The output of this run is presented in Table B.7 which gives the design of the irrigation network, and in Table B.8 which shows the crop pattern distribution in the new lands. The major remark which can be seen from Table B.8, is that the barley is chosen for large areas instead of the beans in the first solution. This selection is done because the barley has a very low water requirement which is appropriate with the resulting shortage of irrigation water after satisfying the agricultural requirements.

The irrigation network remarks will be discussed later through a comparison with the other two solutions.

Second Solution

By decreasing the mixing ratio to 1.4 and 1.3 through the winter and summer seasons, the potential irrigation water decreases. Therefore when we hold the constraint set (3-4) to the equality and keep the agricultural requirement constraint we got an infeasible solution. To find an optimum solution we dropped the agricultural requirement constraint and we converted the equality sign in (3-40) into less than or equal sign (i.e., it is not necessarily to reclaim all the new lands). The irrigation network of this solution is presented with the dotted lines in Figure 4.4 . The design of this irrigation network is introduced in Table B.2 Looking at the crop pattern distribution (Table B.5) we observe that

1. During the winter and as shown in the first solution, large areas are cultivated with the beans.
2. The summer vegetables are selected in sub-area (51) instead of the rice in the first solution. This happens because of the reduction in the irrigation due to the decrease in the mixing ratio.
3. The cotton is chosen in the sub-areas (57), (58), (59) and (60) instead of the maize in the first solution and as mentioned before, this is due to the shortage of the irrigation water.
4. While all the new lands are cultivated in the winter, the only completely cultivated sub-areas during the summer are (27), (28), (51), (58), (59), (60), (61) and (62) because they are very close to the irrigation water sources. The other sub-areas are either partially cultivated or not cultivated at all. This happens because of the high water requirements of the summer crops which are not appropriate with the available irrigation water after decreasing the mixing ratios.

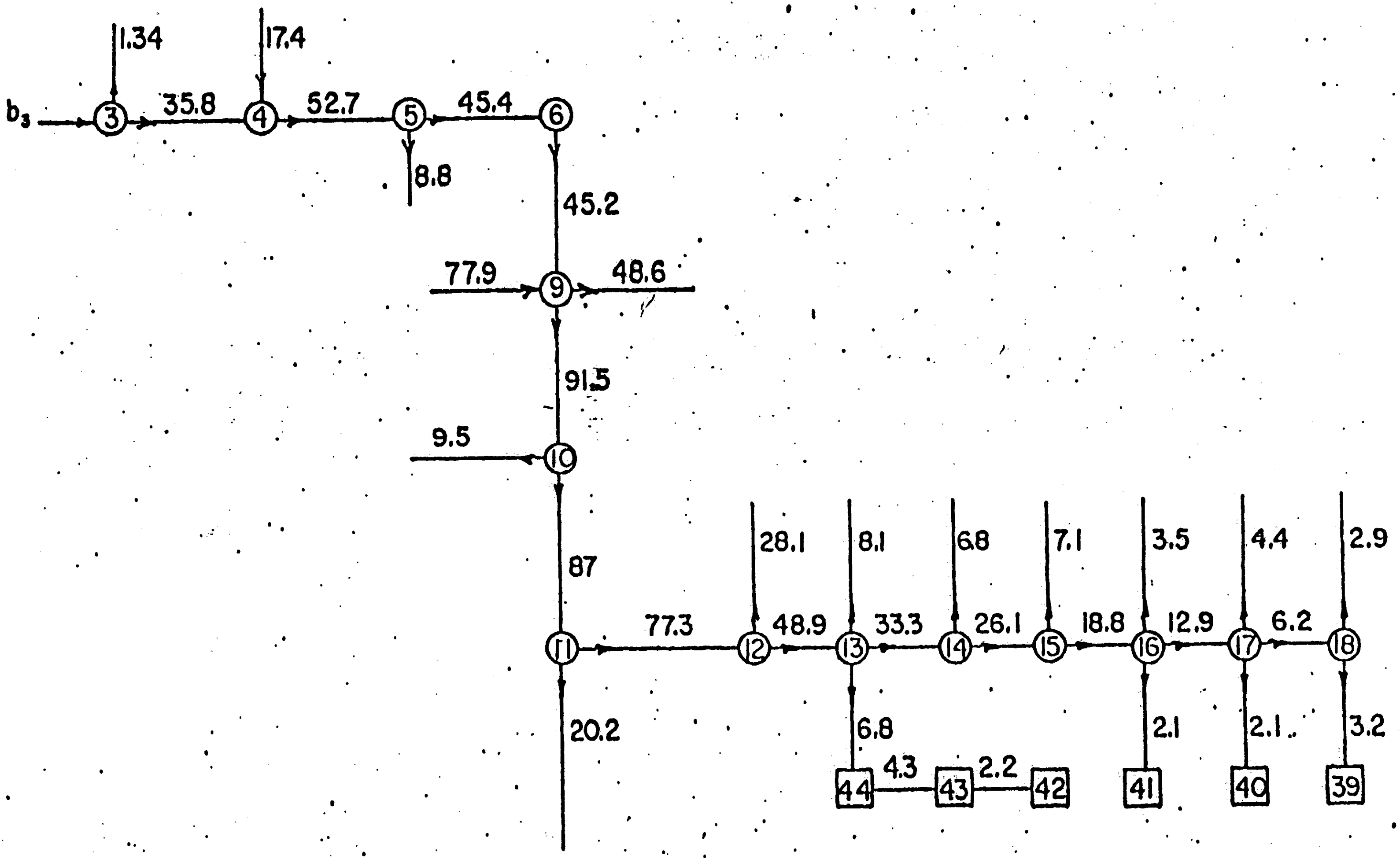

Figure 4-5 .A Schematic Presentation of El-Salam Canal (First Solution)

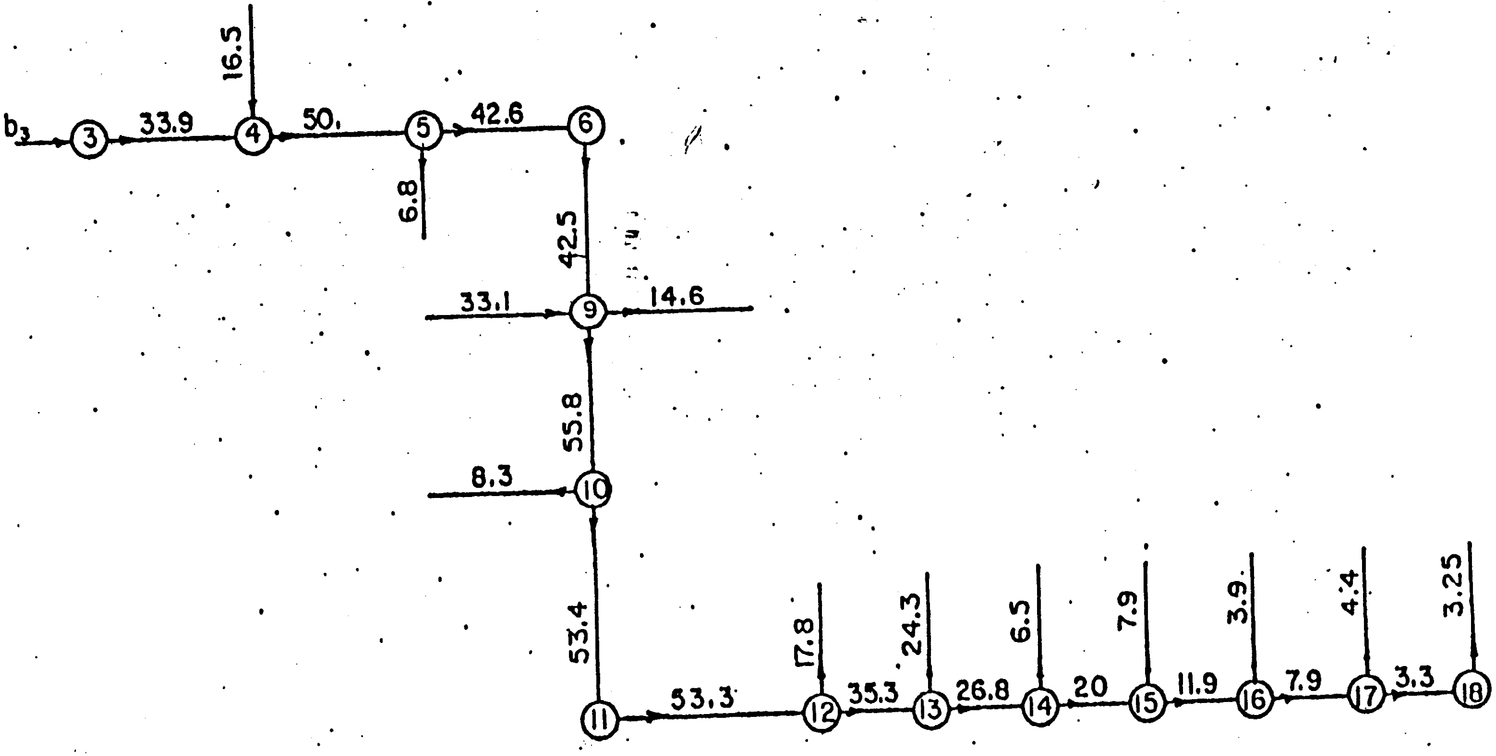

Figure 4-6 A Schematic Presentation of El-Salam Canal (Second Solution)

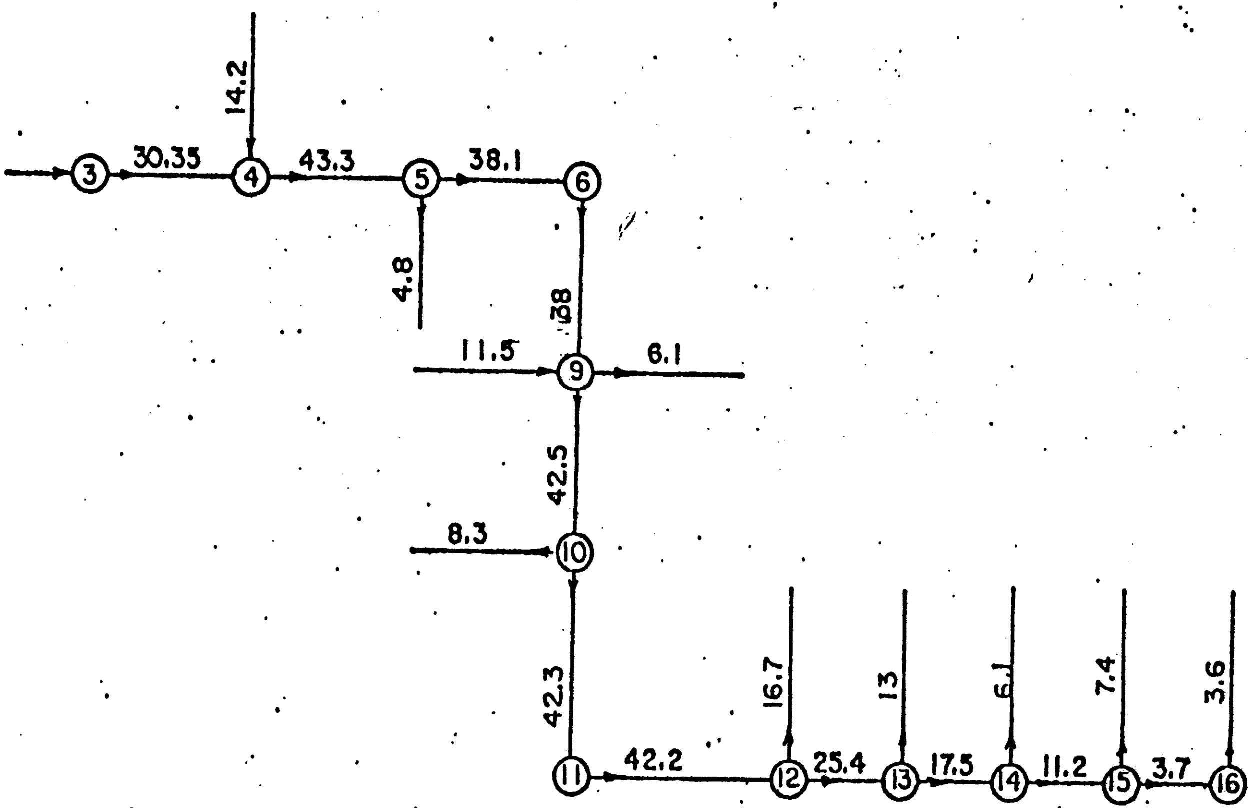

Figure 4-7 A Schematic Presentation of El-Salam Canal (Third Solution)

Third Solution

Using the third mixing ratio we got the irrigation network shown in Figure 4.4 as dashed lines. It is clear from Table B.6, that the winter crop pattern distribution is very similar to the last one obtained from the second solution. The difference is that some lands are not cultivated at all like the sub-areas (37) and (38), and others are partially cultivated like the sub-areas (29) and (45). During the summer the greatest part of the new lands is not cultivated, however, the crop pattern in the cultivated sub-areas are close to the one presented in the latter solution.

To compare the irrigation networks of the three solutions, a schematic presentation of El-Salam Canal were done for each solution in Figures 4.5, 4.6, and 4.7 respectively. Similar presentations of El-Salhia Canal are shown in Figures 4.8, 4.9, and 4.10. These schemes show the different design capacities of these two canals obtained from the three different solutions.

4.7 Economic Analysis

In general there are three parameters usually used to indicate the economic desirability of a project. These parameters are

1. The net benefits (NB).
2. The benefit-cost ratio (B/C).
3. The rate of return (RR).

The first parameter is usually used when comparing different projects and their costs are identical. The second and third parameters are normally used when the benefits as well as the costs of alterna-

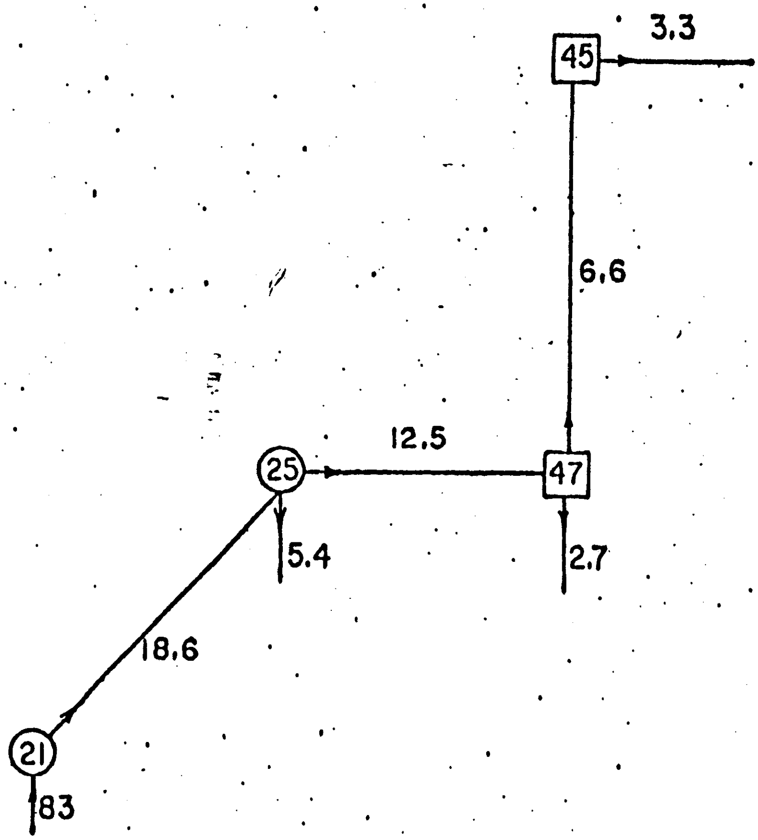

Figure 4-8 A Schematic Presentation of El-Salhia Canal (First Solution)

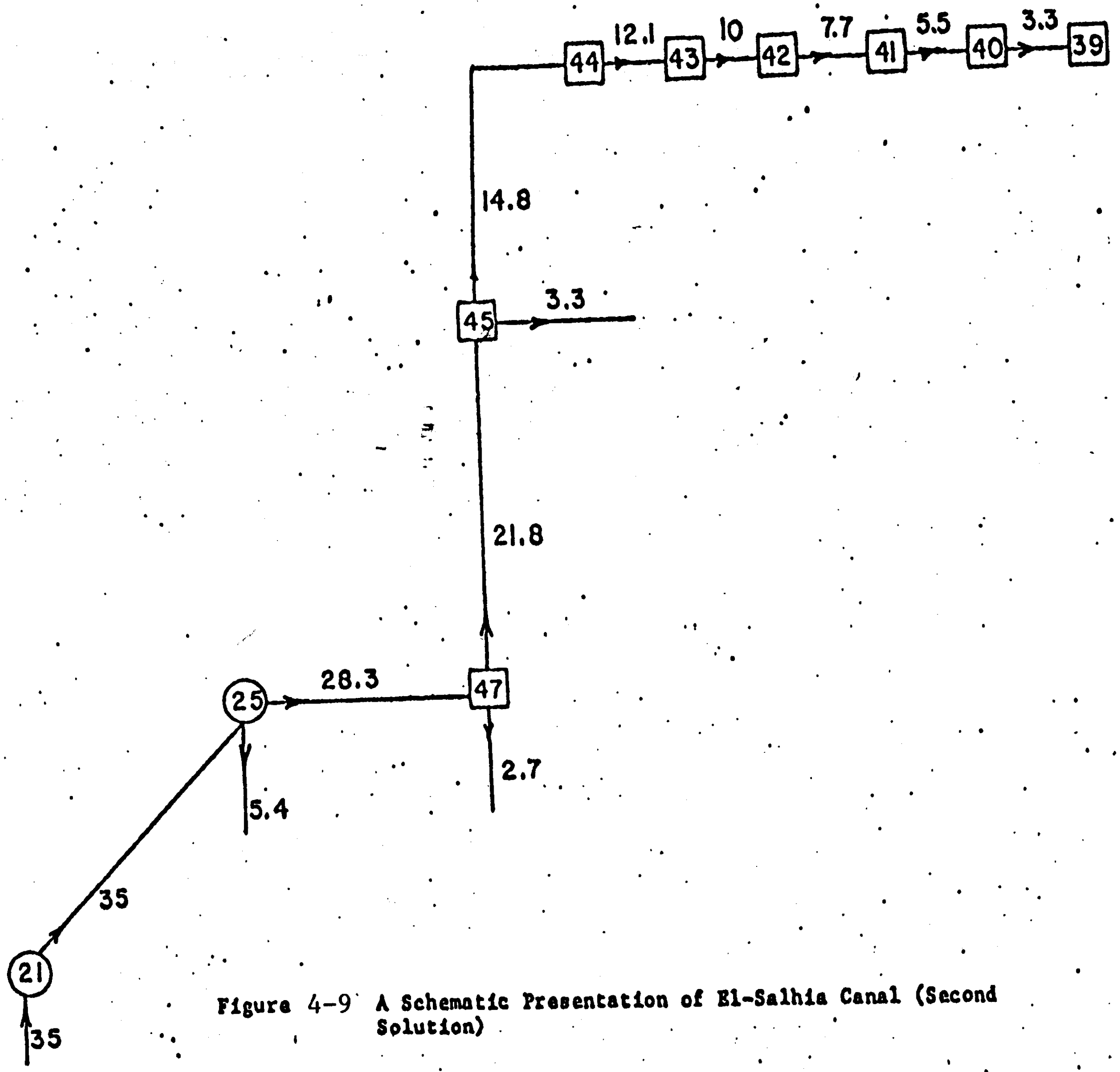

Figure 4-9 A Schematic Presentation of El-Salhia Canal (Second Solution)

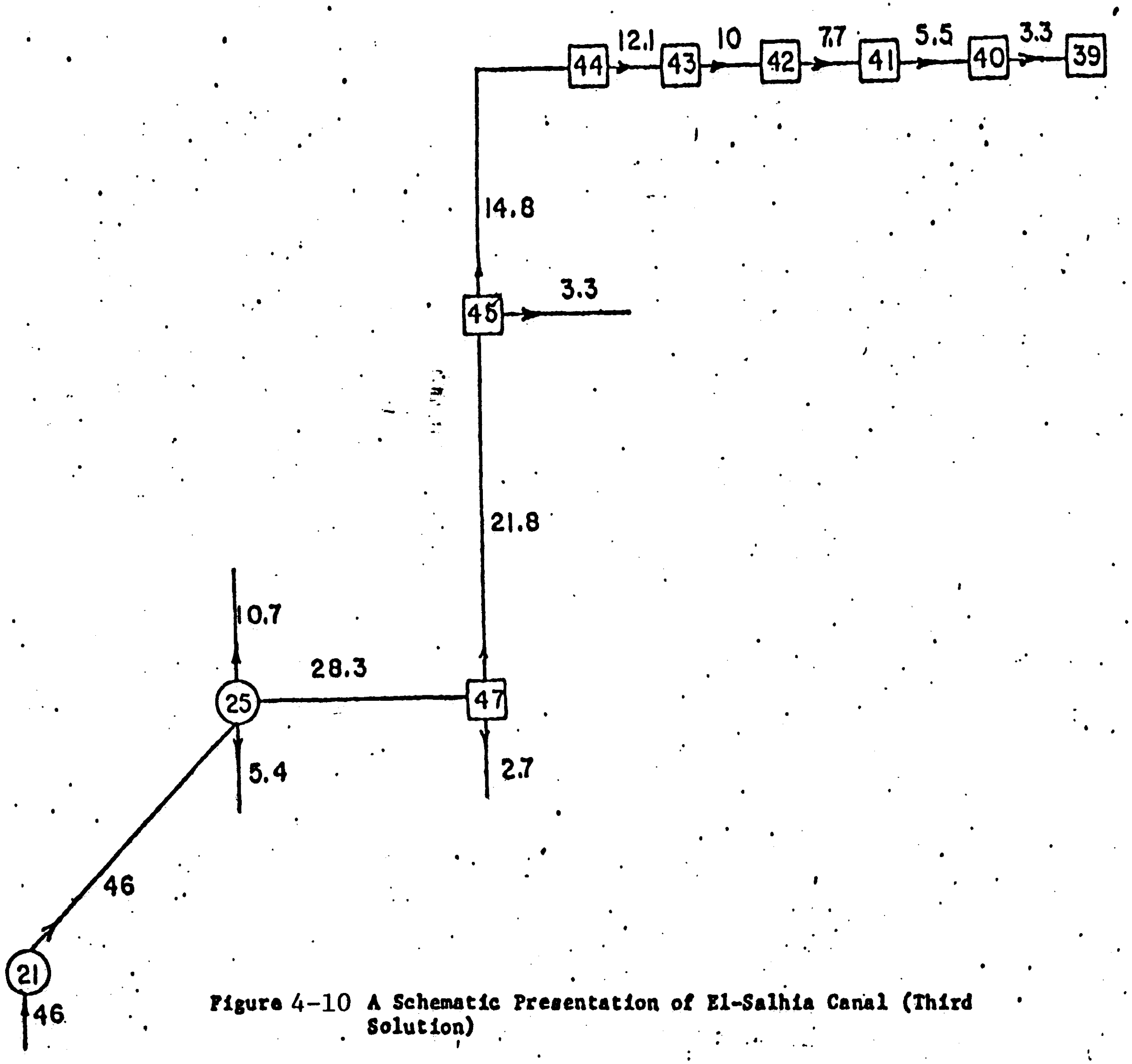

Figure 4-10 A Schematic Presentation of El-Salhia Canal (Third Solution)

Table 4.4 The Computations of B C for the Three Solutions (a)

Solution No.	Benefit in 10^6 L.E. (B)	Cost in 10^6 L.E. (C)	B-C
1	5788.6	4800.3	1.21
2	5730.6	4862.3	1.18
3	5691.72	3900.	1.46

Table 4.5 The Computations of B C Values for the Three Solutions (b)

Solution No.	Benefit in 10^6 L.E. (B)	Cost in 10^6 L.E. (C)	B-C
1	5353.96	4135.36	1.27
2	4997,67	3639.9	1.37
3	4801.72	3236.87	1.46

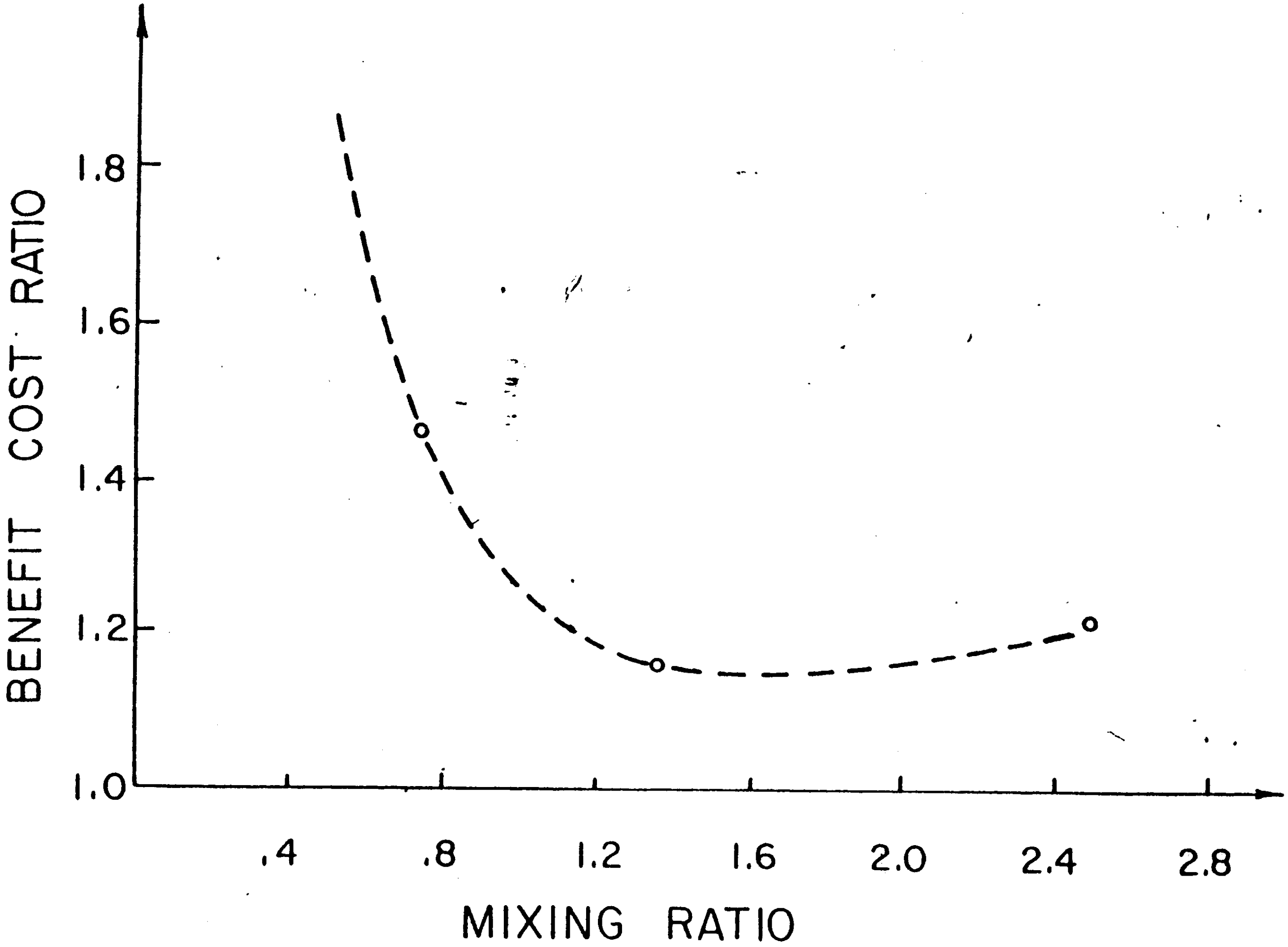

Figure 4-11 The Effect of Water Mixing of B/C (a)

tive projects are different. In this work the benefit-cost ratio (B/C) was used for comparing the different solutions. Table 4.4 presents the computed values of the (B/C) for the three solutions. A graphical presentation of these computed values is shown in Figure 4.11. This figure shows that when the mixing ratio increases, the benefit cost ratio decreases until reaching its minimum value 1.18 corresponding to 1.35 mixing ratio. The (B/C) starts to increase again with the increase of the mixing ratio until reaching to 1.21 value at 2.5 mixing ratio. To explain this behavior of (B/C) with the mixing ratio we have to go back to the latter section. In the third solution when using the lowest mixing ratio we got two main canals for supplying the north part of the Sinai with irrigation water. These canals were El-Salam Canal carrying the mixed water and El-Salhia Canal which takes its irrigation water from Ismailia Canal. As shown in Table B.6 the sub-areas served with El-Salam Canal were mainly cultivated with beans during the winter; rice and maize during the summer. Then by increasing the mixing ratio to 1.4 and 1.3 during the winter and summer seasons respectively the irrigation water increased and we were able to irrigate two more sub-areas (37) and (38). Therefore the total cost and the gross benefit were increased, but due to the increase of the water salinity and its bad effect on the water requirements and the yields of the crops we got a lower (B/C) equal to 1.18. With more increase in the mixing ratio it is supposed to get a (B/C) lower than the latter one due to the increase of the water salinity which has a bad effect on the agricultural crops. This did not happen because the excess in the irrigation water enabled us to irrigate all the new lands in the north part of the Sinai

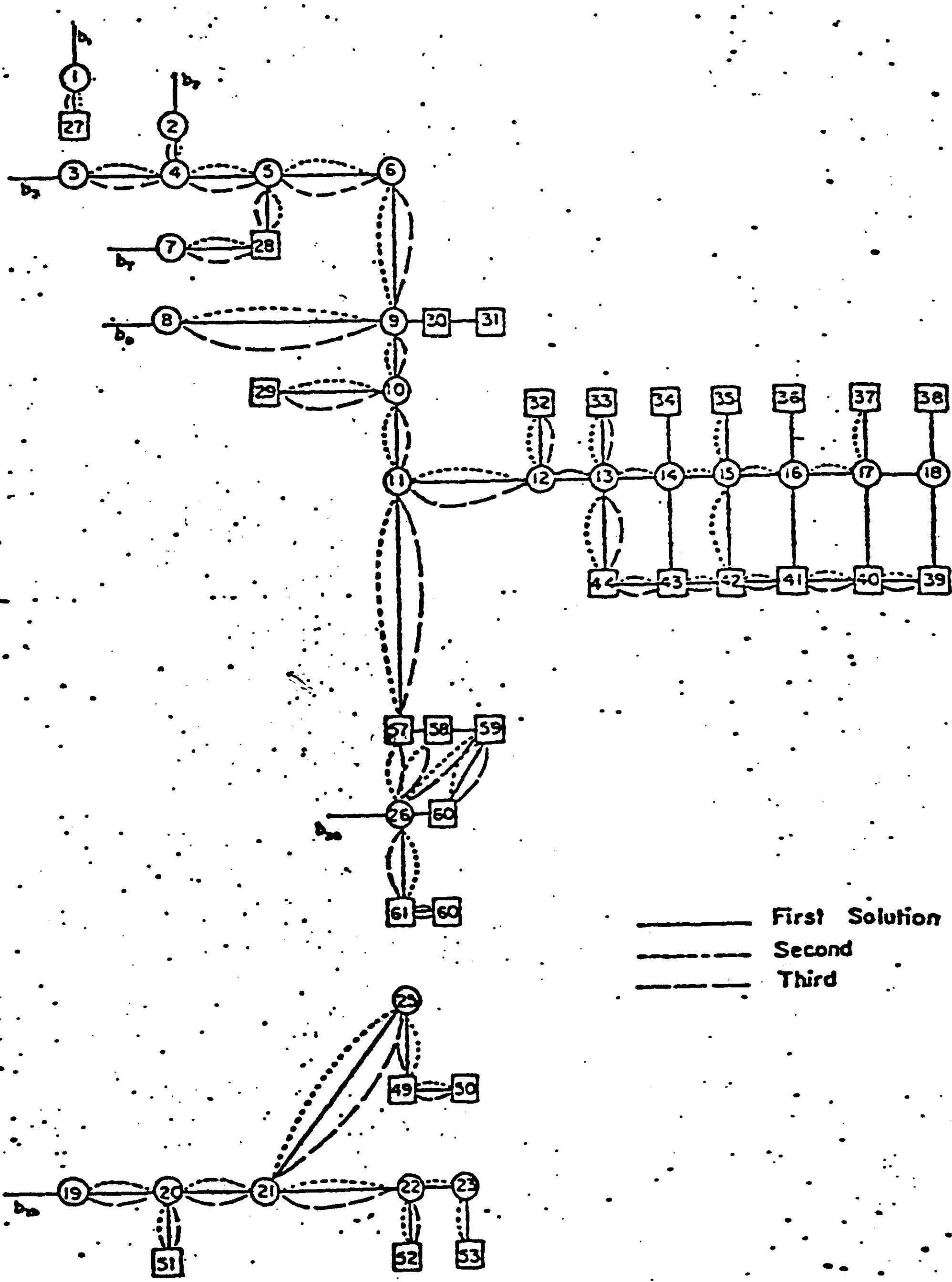

Figure 4-12 A Schematic Presentation of the Irrigation Systems for the Three Different Solutions

using only El-Salam Canal where El-Salhia Canal stopped at Sub-Area (45) as shown in Figure 4.19 and 4.20, so the transmission costs decreased. On the other hand, this excess irrigation water gave us the chance to extend a new canal from El-Salam Canal to sub-area (57) as shown in Figure 4.19. This canal improved the crop pattern in this area from clover and cotton to vegatables, maize and rice which have higher market prices. Then we received an increase in the gross benefit. Therefore, the final result of this solution is an increase in (B/C) from 1.18 to 1.21 which still is less than the highest value of 1.46.

In comparison between the three solutions, the third one is the best alternative to verify the maximum (B/C). But in fact we could get a higher (B/C) if we use a lower mixing ratio, or when no mixing is done at all, which results in leaving more lands without relcaimation. Therefore to get the optimum mixing ratio we have to determine the minimum areas desired to be reclaimed.

4.8 Irrigation Water Availability

The model was applied again three times using the three different mixing ratios, after decreasing the winter and summer potential flows of Ismailia Canal from 115.4 and 162.6 m^3/sec. to 30 and 50 m^3/sec. respectively. The irrigation networks of the three solutions are presented in Figure 4.12. As shown from this figure (whatever the mixing ratio was) due to the reduction made in Ismailia Canal's flow, El-Salhia Canal stopped at node (25) before reaching the Sinai. The crop pattern distribution in the new land obtained from each solution is presented in Tables B.12, B.13 and B.14 respectively. As shown in these tables more areas were left without reclamation because of the irrigation water shortage. The cross-sectional designs, seasonal

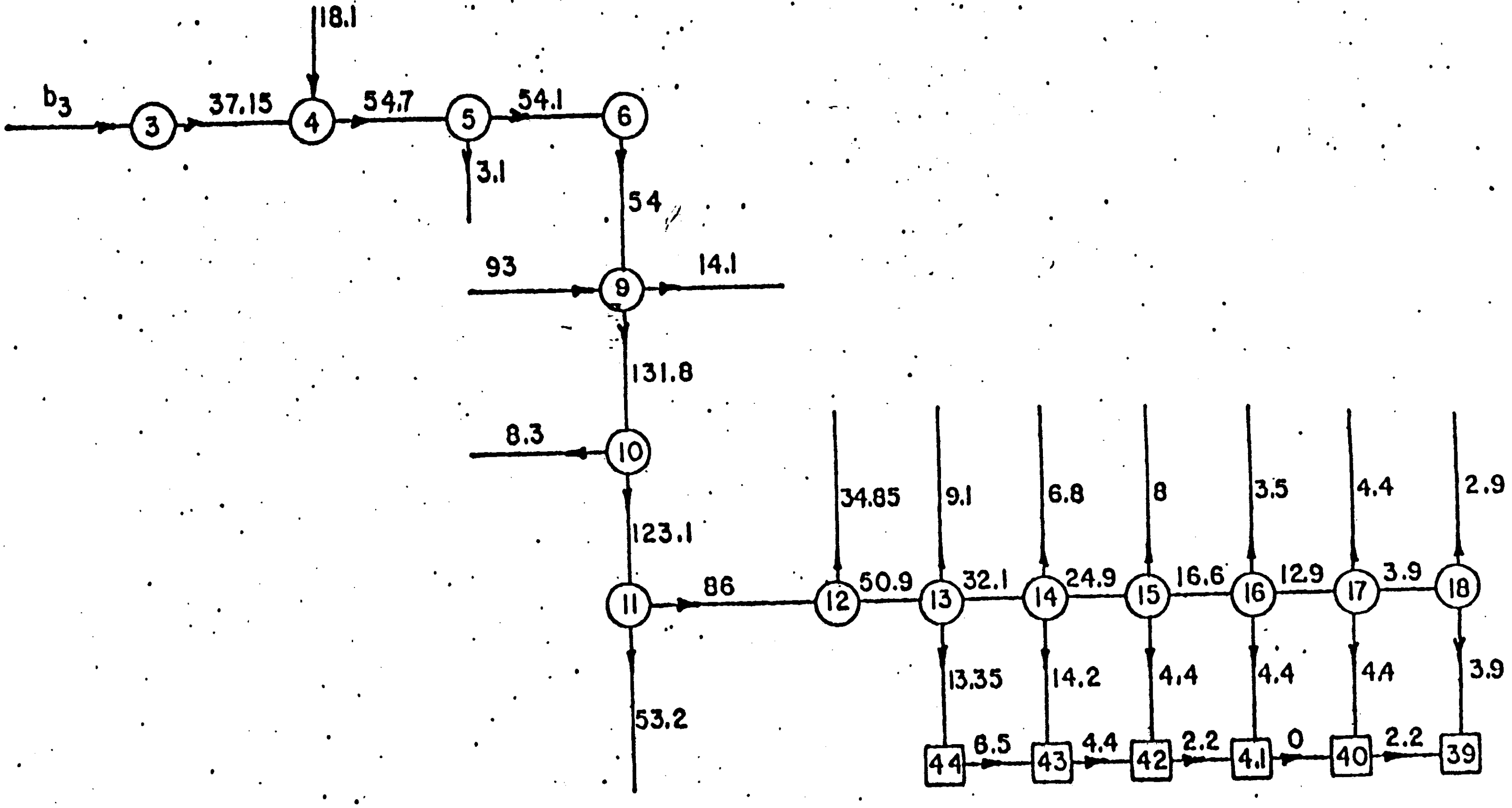

Figure 4-13 A Schematic Presentation of El-Salam Canal (First Solution)

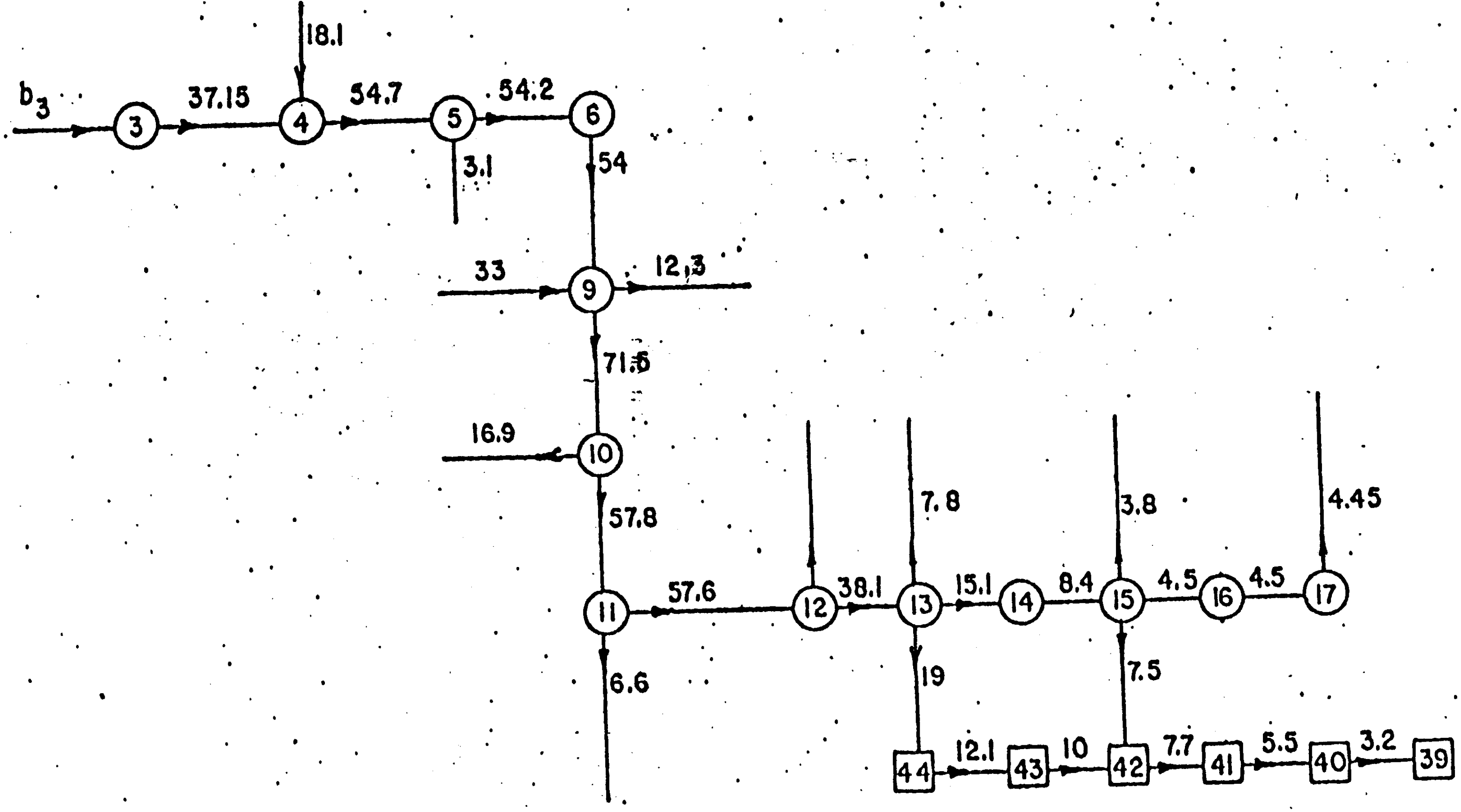

Figure 4-14 A Schematic Presentation of El-Salam Canal (Second Solution)

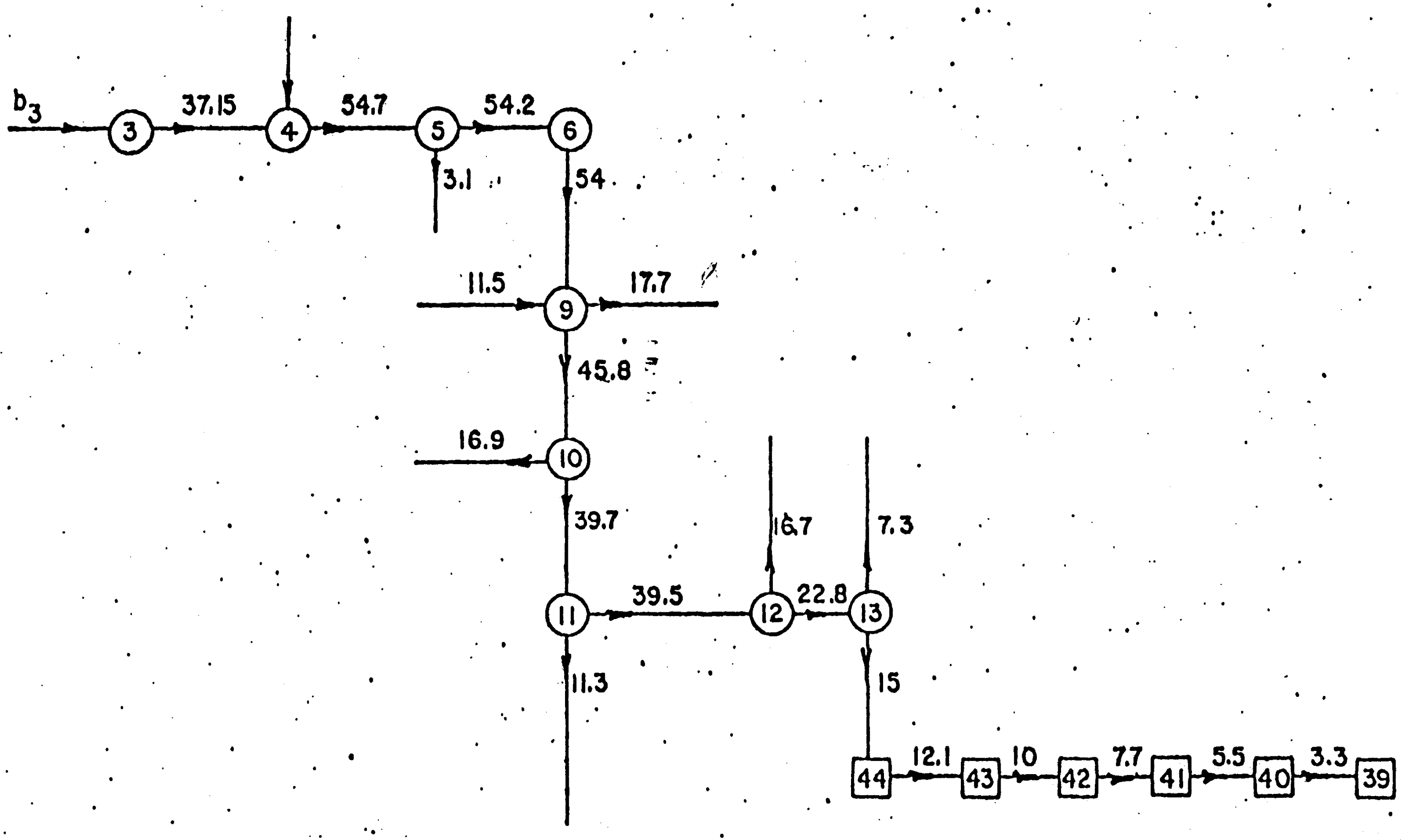

Figure 4-15 A Schematic Presentation of El-Salam Canal (Third Solution)

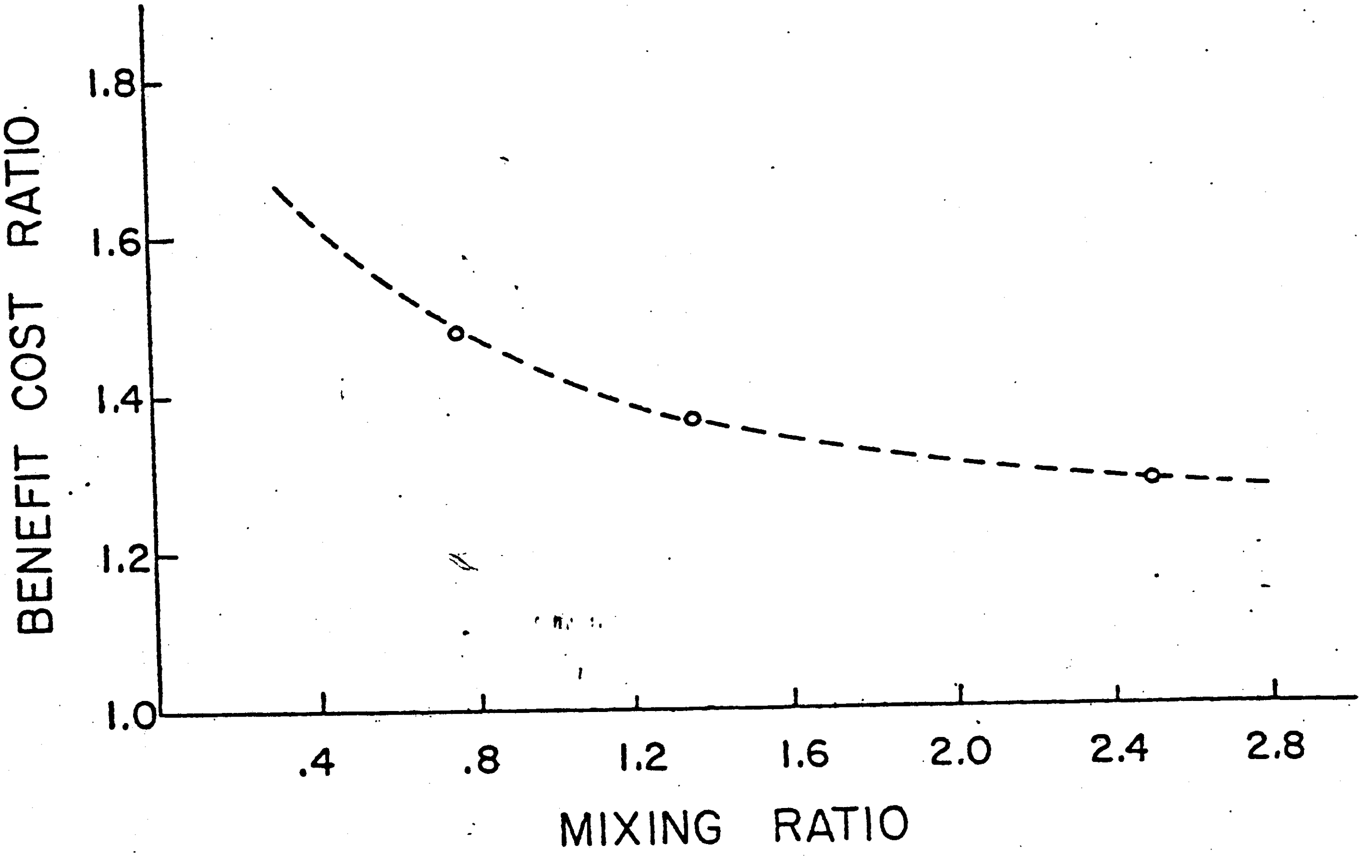

Figure 4-16 The Effect of Water Mixing of B/C (b)

discharges and the total costs of the irrigation canals are introduced in Tables B.9, B.10 and B.11 for each selection. A schematic presentation of El-Salam Canal design obtained while using the different mixing ratios are presented in Figures 4.13, 4.14 and 4.15 respectively.

The benefit-cost ratio (B/C) were computed for the three runs as shown in Table 4.5 and graphically presented in Figure 4.16. Looking at the latter figure we observe that the (B/C) and the mixing ratio are inversely proportional. This happens because of the bad effect of the high salinity on the yields and the water requirements of the crops. Also we can observe from this figure that (B/C) ratios are increased here comparing to the other solutions obtained before decreasing Ismailia Canal's inflows. This occured because of ending El-Salhis Canal at node (25), which results in a decrease in the transmission cost, also because of excluding El-Suez irrigation canal which was feeding the sub-areas (55) and (56) which were having a lower (B/C). The third solution with the lowest mixing ratio is the best one which has the highest (B/C) compared to the other two solutions.

4.9 The Income Distribution

As shown in the last two sections, the crop pattern distribution in a sub-area depends on three major factors which are:

1. The irrigation water salinity which in general is inversely proportional to the agricultural revenue.
2. The irrigation water availability. From Table B.4, B.5, and B.6 it can be observed that when the irrigation water

water increased, the crops in sub-area (57) were changed from clover and cotton to vegetables, maize and rice which have a higher price, i.e., the agricultural revenue is increased.

3. The distance between this sub-area and the irrigation water source. As observed before the crops of high water requirements, which generally have high market prices, were preferred in the sub-areas close to the water sources for minimizing the transmission costs. Therefore when the distance increases the agricultural revenue decreases.

For more illustration, the unit annual return (L.E./Year/Feddan) was computed for different sub-areas using the crop pattern distribution given in Table B.8 according to the following relationship:

Unit Annual Return (UAR) = Agricultural Revenue - total costs on the farm level

where:

Agricultural revenue = (yield of each cultivated crop) (market price for each crop)

The computed values of the annual return for the different sub-areas are presented in Table 4.6 . From this table we can observe how the water salinity can affect the UAR. Then while using fresh irrigation water in sub-area (51), we got 390 L.E./Year/Feddan, and on the other hand we got 234 L.E./Year/Feddan while using saline irrigation water in the sub-areas (45) and (56), or sub-area (29) to sub-area (37) we can see clearly how the water transmission distance

Table 4.6 The Computations of the Unit Annual Return of the New Lands

Sub-Area No.	Water Salinity/mmhos		Crop Pattern		Annual Return (L.E.)
	Winter	Summer	Winter	Summer	
29	2.06	1.86	Barley	Vege.	210
37	2.06	1.86	Wheat	Maize	146
45	0.2	0.2	Wheat	Maize	165
49	0.2	0.2	Vege.	Maize	330
51	0.2	0.2	Vege.	Rice	390
56	0.2	0.2	Clover & Beans	Cotton & Maize	140
58	1.15	1.5	Clover & Wheat	Cotton & Maize	90

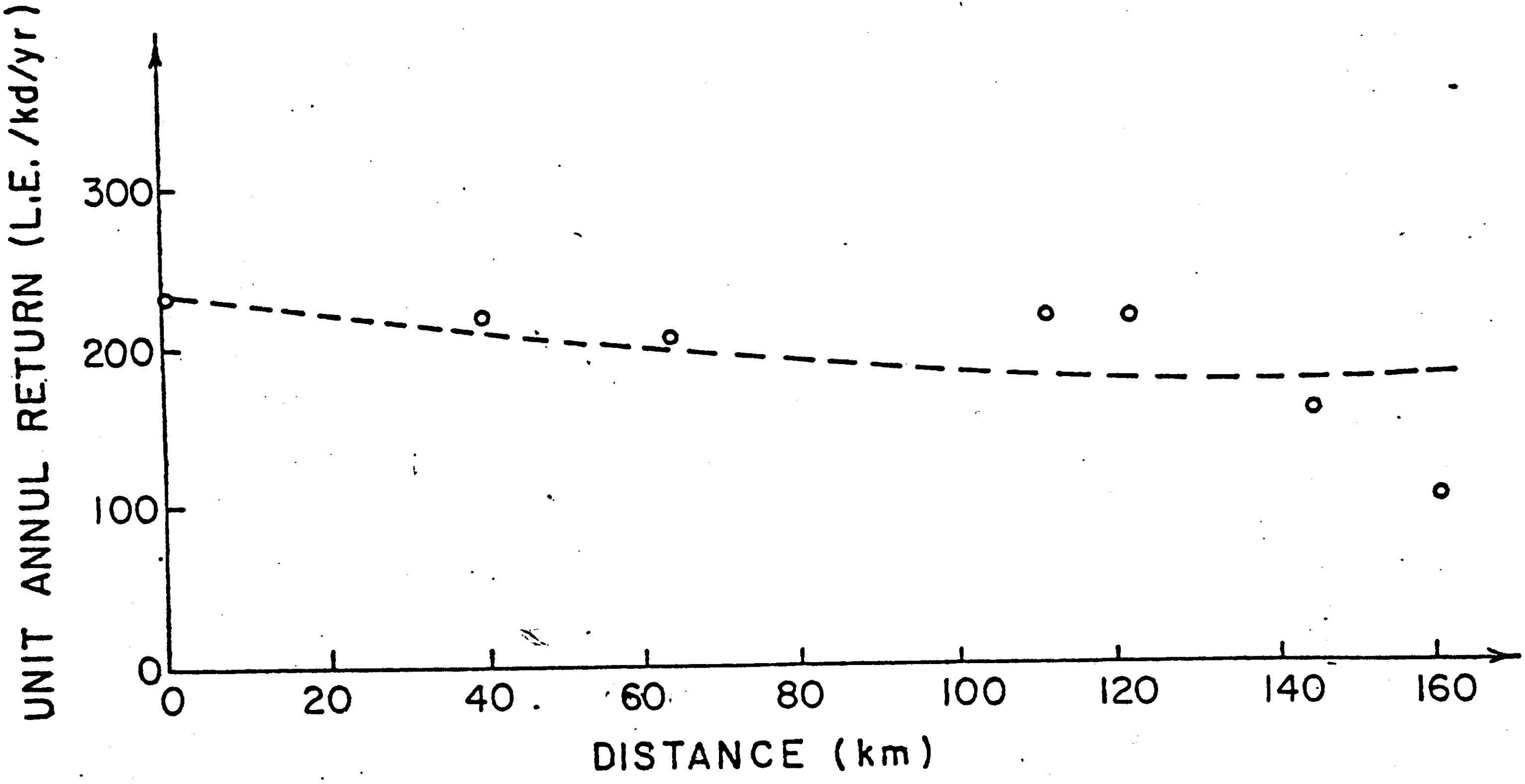

Figure 4-17 The Effect of Water Transmission Distance on U.A.R. (El-Salhia Canal)

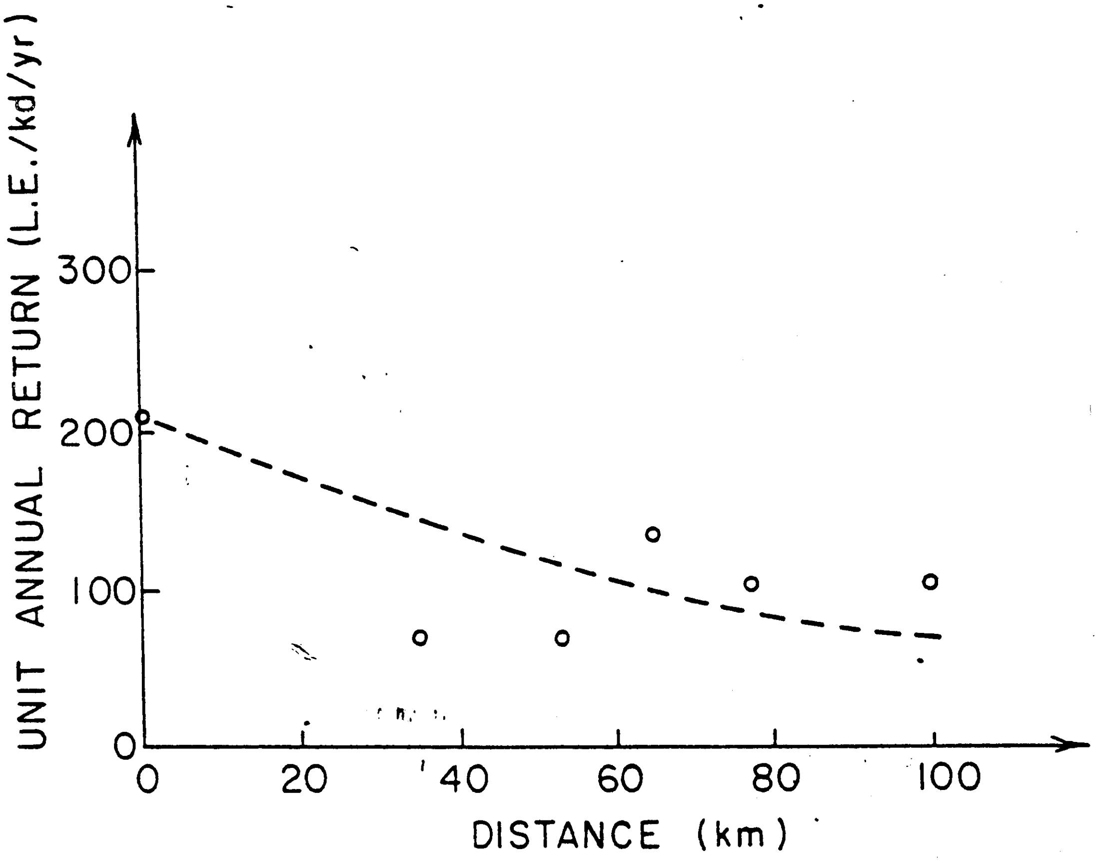

Figure 4-18 The Effect of Water Transmission Distance on U.A.R. (El-Salhia Canal)

affected greatly these annual returns. Looking at the unit annual return of sub-area (58), we observe that it is very low and less than the other one of sub-area (37) although the latters irrigation water is more saline. This happend because the irrigation water available at either Bahr El-Bakar sub-drain or Bahr-El-Bakar Pump Station is not enough to irrigate agricultural crops of high water requirements in all the surrounding areas.

According to the above discussion and while using only one source to supply different areas with irrigation water, the UAR of these areas will be a function of their topographic position with respect to this source. To identify this functional relationship between the topographic position and the UAR, the UAR values of the different areas along El-Salam Canal and El-Salhia Canal are computed from Table B.8. These values are presented in Figures 4.17 and 4.18 as a function of the transmission distances for El-Salam Canal and El-Salhia Canal respectively.

CHAPTER 5

SUMMARY AND CONCLUSIONS

This study has provided a working mathematical model for analyzing and optimizing the conjunctive use of fresh and saline water sources in agricultural practices. Using this model, water mixing can be considered and its impact on the expansion's economics and planning can be computed. Also, the effect of the topographic position and soil type of the new lands on irrigation network planning and on crop pattern distribution can be obtained.

The model's formulation is flexible enough to link the existing cultivated lands with proposed new areas in the eastern Delta and the Sinai. This is useful in guidance for improving irrigation efficiency in the old areas and in computing the required enlargement of the irrigation system for supplying the new lands. Frequently, the crops can be redistributed in such a way as to obtain the maximum economic return and to satisfy the national agricultural requirements.

This mathematical model gives the decision makers qualitative information of cost tradeoffs involved in the irrigation method chosen: surface, sprinkling or dripping irrigation. This choice depends on the irrigation water available and on the minimum desirable size of the areas to be reclaimed. This is shown in the case study when Ismailia Canal's inflow has been reduced by more than 50% and large areas were left without reclamation.

Having applied the model, we found that the agricultural income of the new land is inversely proportional to both irrigation water salinity and water transmission distance. This trend can be considered in scheduling of agricultural expansion planning when there is a budget limitation and as a guidance for estimating rents or prices of the new lands. The model's output can be used to estimate water prices in the system which can give a guidance to irrigation water management and an evaluation to conveyance water losses.

The model presented is more concerned with the planning of large scale agricultural expansion on a national level. It reflects the impact of economical, social and political factors on this type of project. This factor is considered in the model by including their effects on national agricultural requirements either for internal consumption or for export and on agricultural policy regarding agricultural rotations. The model can evaluate the repercussions of these effects on the economy and feasibility of land development. As an example, we obtained an infeasible solution for the case study where we tried to satisfy both national agricultural requirements and agricultural policy.

The separable programming algorithm has demonstrated its effectiveness in solving this type of planning problem. Although the case study had more than 600 constraints, the computer time spent for each run was less than one minute. The approximated solutions obtained were generally accurate enough for planning purposes.

It is recommended that future research be focussed on agricultural expansion scheduling which should include time sequences as a decision variable. Factors, such as constraints on available funds during a time period as well as benefits that increase with calendar time have to be considered.

REFERENCES

1. Abul-Atta, A. A. "The Water Policy of Egypt," Ministry of Irrigation, Cairo, A. R. E., 1977.

2. Academy of Scientific Research and Technology; and Michigan University "Agricultural Implications of Water Quality--River Nile and Lake Nasar Project," Cairo, March 1979.

3. A.D. Dotzenko, M. Zanati, A. A. Abdel-Waked and A. M. Keleg, "Preliminary Soil Survey Report for the Beni Magdoul and El-Hammami areas," EWUP TR. No. 2, A. R. E., Cairo, March 1979.

4. Advisory Panel for Land Drainage in Egypt, "Re-use of Drainage Water for Irrigation," Report No. 77.III.04, A. R. E., Cairo, May 1977.

5. Agricultural Rural Development Division, "Appraisal of Nile Delat Drainage Project," Document of the World Bank, A. R. E., Cairo, May 1977.

6. Amer, M. H., "Re-use of Drainage Water Program," Drainage Research Institute, Ministry of Irrigation, A. R. E., Cairo, April 1979.

7. Bradley, Hax ad Magnanti, Applied Mathematical Programming, Addison Wesley, Menlo Park, California, 1977.

8. C. V. Moore, J. H. Snyder, and Peter Sun, "Effects of Colorado River Water Quality and Supply on Irrigated Agriculture," Water Resources Research, Vol. 10, No. 2, April, 1974.

9. Drainage Research Institute, "Re-use of Drainage Water," Annex IV, A. R. E., Cairo, January 1979.

10. D. Goldberg, B. Gorant, M. Schueli, Ben-Asher, and M. Rinet, "Increasing the Agricultural Use of Saline Water by Means of Trickle Irrigation," Paper No. 71071 of the Water Resources Bulletin, August 1971.

11. Edward Kuiper, Water Resources Project Economics, Butterworths, London, 1976.

12. Elwyn S. Krons, Joseph P. Wagner, Harold L. Parkinson, and Milton S. Sachs, "Desalting Saline Water for Irrigation," Water Research Bulletin, August 1971.

13. Engineering Consultants, Inc., "Irrigation Model of Egypt," Denver, Colorado, April 1975.

14. E. V. Mass and G. J. Hoffman, "Crop Salt Tolerance--Current Assessment," Journal of the Irrigation and Drainage Division, Vol. 103, No. IR2, June, 1977.

15. E. V. Richardson, W. Clyma, W. R. Schmehl, W. W. Shaner, R. S. Candliss, "On-Farm Water Management Project for Egypt," A. R. E., Cairo, April 1976.

16. Gamal Nasr and Quencmoen, "Economic Feasibility of Concrete Lining for Beni Magdoul Canal and Branch Canal," EWUMP Staff Paper No. 1, Cairo, Arpil, 1978,

17. Habashy N. T., "The Economic Classification of the Agricultural Lands," Institute of Economic Agricultural Research, Ministry of Agriculture, A. R. E., Cairo, 1976.

18. Harman Bouwer, "Salt Balance, Irrigation Efficiency, and Drainage Design," Journal of Irrigation and Drainage Division, American Society of Civil Engineers, March 1969.

19. Hayward, H. E., "Plant Growth Under Saline Conditions," Arid Zone Research IV.UNESCO, 1956.

20. Hunting, Technical Services Limited, and Darwish A. Ismail, "Suez Canal Region, Integrated Agricultural Development Study," U.N. Development Programme Report No. 2, April 1979.

21. "Irrigation, Drainage and Salinity," UNESCO/FAO, 1973.

22. James L. Douglas, and Robert R. Lee, Economics of Water Resrouces Planning, McGraw-Hill, New York, 1971.

23. Lai, Fu-hsiung and John C. Schaeke Jr., "A Model for Capacity Expansion Planning of Water Distribution Networks," R70-71, TR No. 131, M.I.T., Cambridge, MA., U. S. A.

24. "Nation Program in Irrigation and Drainage," Ministry of Irrigation, A. R. E., Cairo, September 1978.

25. Report of the National Technical Advisory Committee, "Water Quality Consideration for Irrigation," Washington, D. C., Journal of Water Quality Criteria, Washington, April 1, 1968.

26. R. Fabio and D. H. Marks, "Formulation and Computational Considerations for a General Irrigation Network Planning Model," Masters Thesis, M.I.T., March, 1979.

27. Rhoades, J. D., "Quality of Water for Irrigation," Proceedings, Soil Science Society of America, Vol. 113, 1972, pp. 277-284.

28. Richard W. Ribbens and Marvin J. Shaffer, "Irrigation Return Flow Modeling for the Souris Loop," U.S. Department of the Interior, Bureau of Reclaimation, Denver, Colorado, July 1976.

29. R. S. Ayers, "Quality of Water for Irrigation," Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 103, No. IR2, June 1977.

30. R. S. Ayers, "Water Quality for Agriculture," Food and Agriculture Organization of the United Nations, Rome, 1976.

31. "The Horizontal Expansion and Land Reclaimation Policy," Ministry of Irrigation and Land Reclaimation, A. R. E., Cairo, November 1977.

32. The Public Directory of the Agricultural Expansion Projects in the Eastern Delta, "The Estimated Cost of El Salam Canal Project," A. R. E., Cairo, 1979.

33. U. S. Department of the Interior, Bureau of Reclaimation, "Linings for Irrigation Canals," Second Printing, 1976.

34. U. S. Salinity Laboratory Staff, "Diagnosis and Improvement of Saline and Alkal Soils," U. S. D. A. Agricultural Handbook, No. 60, 1954.

35. Volker, A., "Re-use of Drainage Water; Measurement and Inventory Advisory Panel for Land Drainage in Egypt," Report of a mission to Egypt, January 1979.

36. Wadleigh, C. H., A. D. Ayers, "Growth and Biochemical Composition of Bean Plants as Conditioned by Soil Moisture Tension and Salt Concentration," Plant Phys., 20:106-132, 1945.

Appendix A

The Seasonal Discharges and Salinities of the Irrigation Water Resources

Bahr Hadus Drain

A schematic presentation of Bahr Hadus drain and its tributaries is shown in Figure 1.2.

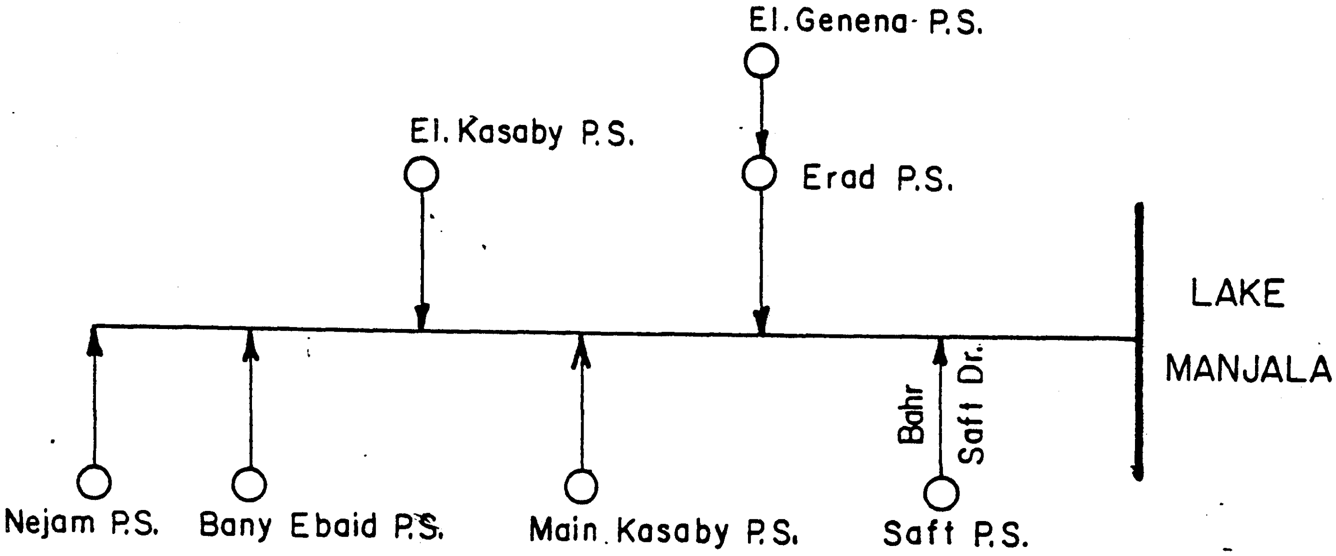

Figure 1.2 Schematization of Bahr Hadus Drain

Assuming no water losses in the tributaries of Bahr Hadus, and using the continuity equation, the outflow of Bahr Hadus can be computed as

$$\overline{Q} = \sum_{L=1} \overline{Q}_i$$

where

$\overline{Q}$ = average seasonal discharge of Bahr Hadus

I = number of Bahr Hadus tributaries

$\overline{Q}_i$ = average seasonal flow of tributary i knowing that the salts are conservative substances, the salinity of Bahr Hadus outflow can be computed as

$$\overline{EC}_w = \sum_{i=1}^{I} \overline{Q}_i \cdot \overline{EC}_{w_i} / \overline{Q}$$

where

$\overline{EC}_w$ = average seasonal salinity of Bahr Hadus outflow

$\overline{EC}_{w_i}$ = average seasonal salinity of tributary i

The discharges and water salinity of each tributary are considered here as deterministic values by taking the mean values of the available previous record for each agricultural season as shown in Tables A.1, A.2, A. , and A.16. Then the average winter outflow of Bahr Hadus equals

$$65.23 + 10.1 + 39.5 + 12.86 + 30. + 15.34 + 7.54 + 37.9$$

$$= 208.37 \times 10^6 \text{ m}^3/\text{month} = 88.39 \text{ m}^3/\text{sec.}$$

The average summer outflow of Bahr Hadus equals

$$77.50 + 17.2 + 61.4 + 22.20 + 47.48 + 20.33 + 9.95 + 37.9$$

$$= 293.96 \times 10^6 \text{ m}^3/\text{month} = 113.41 \text{ m}^3/\text{sec.}$$

The average winter water salinity of Bahr Hadus outflow equals

$$\frac{65.23 \times 1.53 = 10.1 \times 1.89 + 39.5 \times 3.75 + 12.86 \times 2.87 + 30.00 \times 2.725 + 15.34 \times 3.32 + 7.54 \times 1.95 + 37.9 \times 1.53}{208.37}$$

= 2.4 mmhos/cm

The average summer water salinity of Bahr Hadus outflow equals

$$\frac{77.5 \times 1.9 + 17.2 \times 1.143 + 61.4 \times 1.66 + 22.2 \times 3.53 + 47.48 \times 2.725 + 20.33 \times 2.33 + 9.95 \times 1.34 + 37.9 \times 1.72}{293.96}$$

$$= 2.04 \text{ mmhos/cm}$$

The same procedure is repeated again to compute the seasonal discharge and salinity for Bahr El-Bakar pump station, Bahr El-Bar sub-drain, lower Sarn pump station and Faraskaur pump station. The computed values are presented in Tables A.17, A.18, A. , and A.24.

Table A.1. Monthly Discharges of Soft Pump Station

		Discharge in 10^6 m^3/Month		
Month	1975	1976	1977	1978
November	70.66	88.02	86.32	67.00
December	79.65	92.75	97.83	73.00
January	39.45	40.5	73.50	56.00
February	20.67	57.62	37.90	50.00
March	64.6	62.38	75.67	64.00
April	58.14	72.44	81.05	56.00
Total	333.17	413.71	452.27	366.
Average	55.50	69.00	75.40	61.00
May	48.13	70.67	78.19	54.00
June	66.28	-	86.89	44.00
July	81.44	-	81.08	78.00
August	81.76	-	78.00	77.00
September	76.30	94.66	77.17	75.00
October	79.3	103.21	91.56	69.00
Total	433.21	-	492.89	397.00
Average	72.20	89.50	82.10	66.20

Average Winter Flow = 65.225 x 10^6 m^3/month

Average Summer Flow = 77.50 x 10^6 m^3/month

Table A.2. Monthly Discharges of El-Genana Pump Station

Month	Discharge in m³/sec. 1975	1976	1977
November	13.67	12.91	13.83
December	9.88	11.55	11.00
January	2.46	7.90	13.04
February	7.06	-	7.35
March	8.94	13.22	9.80
April	3.16	11.31	13.3
Total	44.87	-	68.32
Average	7.50	11.40	11.40
May	7.54	12.32	14.10
June	5.38	-	17.50
July	26.72	-	25.84
August	22.33	-	26.49
September	21.05	21.37	24.55
October	13.68	11.54	14.46
Total	96.7	-	122.94
Average	16.10	15.1	20.4

Average Winter Flow = 10.1 x 10^6 m^3/month

Average Summer Flow = 17.2 x 10^6 m^3/month

Table A.3. Monthly Discharges of El-Erad Pump Station

Month	Discharge in m^3/sec. 1975	1976	1977
November	51.85	46.84	51.03
December	37.76	38.23	39.12
January	-	29.26	36.78
February	21.33	34.45	26.79
March	49.12	38.00	41.38
April	44.27	42.43	41.12
Total	-	229.21	236.22
Average	40.9	38.20	39.4
May	45.58	44.29	40.64
June	56.88	-	53.44
July	82.74	-	66.56
August	72.84	-	76.03
September	68.63	72.07	71.86
October	58.52	58.96	61.12
Total	385.19	-	369.65
Average	64.2	58.4	61.6

Average Winter Flow = $39.5 \times 10^6\ m^3$/month

Average Summer Flow = $61.4 \times 10^6\ m^3$/month

Table A.4. Monthly Discharges of Main Kasaby Pump Station

Month	1975	1976	1977	1978
	Discharge in 10^6 m^3/month			
November	12.64	15.14	15.84	19.00
December	14.82	13.63	16.38	15.00
January	9.46	10.58	14.12	18.77
February	5.41	12.42	7.54	8.60
March	11.12	10.31	14.47	13.75
April	10.77	11.8	11.94	15.00
Total	64.22	73.88	80.29	90.12
Average	10.7	12.3	13.4	15.02
May	9.23	13.7	10.28	12.93
June	17.68	-	20.48	20.06
July	25.07	-	26.39	30.90
August	-	-	27.67	35.00
September	24.15	27.44	29.20	31.00
October	19.14	22.49	23.34	25.00
Total	-	-	137.36	154.89
Average	19.05	21.03	22.9	25.8

Average Winter Flow = 12.86 x 10^6 m^3/month

Average Summer Flow = 22.20 x 10^6 m^3/month

Table A.5. Monthly Discharges of El-Kasaby Pump Station

Month	1975	1976	1977	1978
	Discharge in 10^6 m^3/month			
November	31.25	41.72	36.69	33.00
December	32.65	39.64	40.72	34.00
January	27.41	19.44	38.34	46.97
February	13.53	33.08	21.92	21.00
March	32.83	39.32	43.61	43.39
April	31.53	36.37	43.04	35.00
Total	169.2	209.57	224.32	213.36
Average	28.2	34.9	37.4	35.56
May	29.97	42.84	33.29	31.29
June	42.12	-	47.3	43.98
July	58.21	-	57.29	44.63
August	42.28	-	57.65	48.00
September	42.85	55.5	65.12	47.00
October	42.5	51.95	52.27	53.00
Total	257.93	-	312.92	267.9
Average	43.0	50.1	52.15	44.65

Average Winter Flow = 30.00 x 10^6 m^3/month

Average Summer Flow = 47.48 x 10^6 m^3/month

Table A.6. Monthly Discharges of Bany Ebaid Pump Station

Month	1975	1976	1977	1978
	Discharge in 10^6 m^3/month			
November	17.10	16.37	19.64	16.78
December	17.34	14.24	7.10	17.95
January	14.44	12.20	15.69	18.13
February	8.50	14.44	12.15	9.96
March	19.74	14.74	17.99	23.94
April	15.78	14.93	14.47	14.41
Total	92.9	86.92	87.04	101.17
Average	15.48	14.49	14.5	16.87
May	18.98	11.7	12.87	15.30
June	16.50	-	16.25	17.57
July	27.88	-	22.97	26.51
August	24.93	-	27.88	25.88
September	21.8	21.43	28.43	21.57
October	20.51	18.64	21.82	16.67
Total	130.6	-	130.17	123.5
Average	21.77	17.26	21.7	20.6

Average Winter Flow = 15.34 x 10^6 m^3/month

Average Summer Flow = 20.33 x 10^6 m^3/month

Table A.7. Monthly Discharges of El-Nejam Pump Station

Month	1975	1976	1977
	Discharge in 10^6 m^3/month		
November	7.23	9.00	6.31
December	6.22	7.46	6.58
January	6.63	6.29	8.05
February	5.86	7.76	4.75
March	9.75	9.24	7.26
April	9.20	8.56	9.46
Total	44.89	48.31	42.41
Average	7.50	8.05	7.07
May	9.00	7.82	8.34
June	7.74	-	8.00
July	12.57	-	12.10
August	10.07	-	10.40
September	9.31	12.4	12.20
October	8.06	10.4	10.09
Total	56.75	-	-
Average	9.46	10.2	10.2

Average Winter Flow = 7.54 x 10^6 m^3/month

Average Summer Flow = 9.95 x 10^6 m^3/month

Table A.8. Annual Discharge of Bahr Saft Drain

Year	1973	1974	1975	1976
Discharge in 10^6 m^3/year	450	450	450	450
Average m^3/month	37.5	37.5	37.5	39.1

Average Winter Flow = Average Summer Flow = 37.9 x 10^6 m^3/month

Table A.9. Drainage Water Salinity at Saft Pump Station

Date	EC_w in mmhos/cm at 25°C
March 19, 1978	1.8
April 5, 1978	1.6
April 22, 1978	1.2
Total	4.6
Average	1.53
May 5, 1978	1.80
May 17, 1978	1.30
June 7, 1978	3.70
June 16, 1978	2.00
July 11, 1978	2.00
July 24, 1978	1.40
August 2, 1978	1.80
August 15, 1978	1.75
August 31, 1978	1.60
September 17, 1978	1.85
October 5, 1978	1.7
Total	20.9
Average	1.9

Table A.10. Drainage Water Salinity at El-Genana Pump Station

Date	EC_w in mmhos/cm at 25°C
January 2, 1977	1.35
January 15, 1977	0.80
February 2, 1977	2.95
February 27, 1977	3.40
March 3, 1977	1.67
March 15, 1977	1.46
April 3, 1977	1.60
Total	13.23
Average	1.89
May 15, 1977	1.1
June 16, 1977	1.13
July 3, 1977	
August 4, 1977	1.33
August 16, 1977	1.62
September 3, 1977	0.20
September 16, 1977	1.10
September 19, 1977	1.40
October 3, 1977	1.19
Total	10.29
Average	1.143

Table A.11. Drainage Water Salinity at El. Eraa Pump Station

Date	EC_w in mmhos/cm at 25°C
January 2, 1977	2.30
January 15, 1977	1.13
February 2, 1977	4.86
February 27, 1977	10.00
March 3, 1977	2.62
March 15, 1977	2.45
April 3, 1977	2.90
Total	26.26
Average	3.75
May 8, 1977	0.70
May 15, 1977	1.90
June 16, 1977	1.65
July 3, 1977	2.23
August 4, 1977	2.67
September 3, 1977	1.80
October 3, 1977	1.30
October 20, 1977	1.05
Total	13.30
Average	1.66

Table A.12. Drainage Water Salinity at Main Kasaby Pump Station

Date	EC_w in mmhos/cm at 25°C
March 19, 1978	2.20
April 5, 1978	3.40
April 24, 1978	3.00
Total	8.6
Average	2.87
May 5, 1978	2.85
May 17, 1978	2.90
June 7, 1978	3.70
June 10, 1978	3.90
July 11, 1978	4.30
Total	17.65
Average	3.53

Table A.13. Drainage Water Salinity at El-Pasaby Pump Station

Date	EC_w in mmhos/cm at 25°C
July 24, 1978	2.35
August 2, 1978	3.00
August 15, 1978	2.85
August 31, 1978	1.60
September 17, 1978	3.35
October 5, 1978	3.25
Total	16.35
Average	2.725

Table A.14. Drainage Water Salinity at Bay Ebid Pump Station

Date	EC_w in mmhos/cm at 25°C
January 2, 1977	1.50
January 15, 1977	1.57
February 2, 1977	4.13
February 27, 1977	8.65
March 3, 1977	2.75
February 15, 1977	1.47
April 3, 1977	3.20
Total	23.27
Average	3.32
May 8, 1977	0.40
May 15, 1977	2.20
June 16, 1977	2.11
July 3, 1977	2.93
July 19, 1977	2.30
August 4, 1977	3.00
August 16, 1977	2.22
September 3, 1977	2.30
September 16, 1977	1.90
October 3, 1977	1.60
October 20, 1977	4.70
Total	25.66
Average	2.33

Table A.15. Drainage Water Salinity at El-Negam Pump Station

Date	EC_w in mmhos/cm at 25°C
November 2, 1977	1.50
November 23, 1977	2.40
Total	3.90
Average	1.95
May 8, 1977	.97
May 15, 1977	.63
August 4, 1977	1.20
August 16, 1977	2.00
September 3, 1977	1.30
September 16, 1977	1.20
October 3, 1977	1.44
October 20, 1977	2.00
Total	10.74
Average	1.34

Table A.16. Drainage Water Salinity at Bahr Saft Drain

Date	EC_w in mmhos/cm at 25°C
March 19, 1978	1.80
April 5, 1978	1.60
April 22, 1978	1.20
Total	4.60
Average	1.53
May 5, 1978	1.70
May 17, 1978	1.30
June 7, 1978	1.65
June 16, 1978	2.00
July 11, 1978	2.00
July 24, 1978	1.40
August 2, 1978	1.90
August 13, 1978	1.60
August 15, 1978	1.80
September 17, 1978	1.85
October 5, 1978	1.70
Total	18.9
Average	1.72

Table A.17. Monthly Discharges of Bahr El-Baker Pump Station

Month / Discharges 10^6 m^3/month	1976	1977	1978
November	34.80	39.00	38.70
December	32.90	36.00	12.00
January	63.60	54.00	38.70
February	33.00	15.00	21.00
March	39.00	39.60	36.48
April	39.00	30.00	38.70
Total	242.3	213.6	185.58
Average	40.40	35.60	30.93
May	39.00	38.88	34.20
June	38.70	42.00	28.50
July	38.88	31.62	38.70
August	38.88	38.80	38.70
September	38.88	38.80	38.70
October	39.00	38.70	34.50
Total	233.34	228.8	213.3
Average	38.90	38.13	35.55

Average Winter Flow = 35.64 x 10^6 m^3/month = 13.75 m^3/sec

Average Summer Flow = 37.53 x 10^6 m^3/month = 14.48 m^3/sec

Table A.18. Drainage Water Salinity at Bahr El-Baker Pumping Station

Date	EC_w in mmhos/cm at 25°C
March 19, 1978	.61
April 5, 1978	.31
April 22, 1978	2.45
Total	3.37
Average	1.12
May 5, 1978	.80
May 17, 1978	2.50
June 7, 1978	2.00
June 16, 1978	.65
July 11, 1978	2.60
July 24, 1978	2.00
August 2, 1978	2.10
August 13, 1978	1.50
August 15, 1978	1.85
September 17, 1978	2.10
October 5, 1978	1.50
Total	19.60
Average	1.78

Table A.19. Monthly Discharges of Bahr El-Bakar Sub-Drain

Month Discharges 10^6 m^3/month	1976	1977	1978
November	99.00	105.00	117.00
December	105.00	108.00	114.00
January	89.40	90.00	108.00
February	87.00	84.00	96.00
March	90.00	84.00	99.00
April	84.00	81.00	115.50
Total	554.40	552.00	649.50
Average	92.40	92.00	108.17
May	84.00	87.00	110.10
June	84.00	60.00	117.00
July	81.00	75.60	120.00
August	99.00	90.08	120.00
September	115.50	90.08	120.00
October	101.70	75.00	123.00
Total	565.20	477.76	710.1
Average	94.20	79.63	118.35

Average Winter Flow = 97.5 x 10^6 m^3/month = 37.6 m^3/sec.

Average Summer Flow = 97.4 x 10^6 m^3/month = 37.58 m^3/sec.

Table A.20. Drainage Water Salinity at Bahr El-Bakar Sub-Drain

Date	EC_w in mmhos/cm at 25°C
March 19, 1978	1.10
April 5, 1978	1.20
April 22, 1978	1.30
Total	3.6
Average	1.2
May 5, 1978	1.30
May 17, 1978	1.20
June 7, 1978	1.40
June 16, 1978	1.20
July 11, 1978	1.60
July 24, 1978	1.12
August 2, 1978	1.20
August 13, 1978	0.75
August 15, 1978	1.00
September 17, 1978	0.80
October 5, 1978	1.10
Total	12.67
Average	1.15

Table A.21. Monthly Discharges of Lower Sarn Pumping Station

Month Discharges 10^6 m^3/month	1975	1976	1977	1978
November	43.05	50.79	39.27	-
December	33.39	42.41	13.62	-
January	34.39	26.825	35.58	38.25
February	19.05	36.99	23.22	21.11
March	45.58	14.56	45.19	42.94
April	41.63	38.89	38.64	38.64
Total	217.09	-	195.52	-
Average	36.12	35.1	32.59	35.24
May	47.51	55.67	58.55	54.39
June	44.03	-	49.15	56.84
July	57.63	-	64.80	17.87
August	53.46	-	68.23	-
September	50.4	73.77	67.39	-
October	42.48	53.55	49.76	-
Total	295.51	-	357.88	-
Average	49.25	61.00	59.64	43.03

Average Winter Flow = 34.8×10^6 m^3/month = 13.4 m^3/sec.

Average Summer Flow = 53.2×10^6 m^3/month = 20.5 m^3/sec.

Table A.22. Drainage Water Salinity at Lower Sarn Pump Station

Date	EC_w in mmhos/cm at 25°C
January 15, 1977	1.10
February 2, 1977	1.56
February 11, 1977	2.00
March 3, 1977	2.27
March 15, 1977	1.00
April 3, 1977	1.70
Total	8.63
Average	1.605
May 15, 1977	0.78
September 16, 1977	1.80
October 3, 1977	1.35
October 20, 1977	1.00
Total	4.93
Average	1.23

Table A.23. Monthly Discharges of Fauskour Pump Station

Discharges Month 10^6 m^3/month	1975	1976	1977	1978
November	17.55	17.55	20.61	-
December	12.43	13.36	15.63	-
January	10.59	9.38	9.69	17.07
February	7.20	12.01	9.61	12.65
March	9.23	10.32	12.38	17.12
April	9.46	12.54	13.01	-
Total	66.46	75.16	71.32	-
Average	11.08	12.53	13.49	15.61
May	14.76	20.66	22.7	23.16
June	14.71	-	28.0	31.46
July	26.77	-	34.34	36.77
August	28.21	-	35.61	-
September	26.56	32.99	38.66	-
October	19.47	20.77	25.22	-
Total	130.48	-	184.53	-
Average	21.75	24.80	30.76	30.46

Table A.24. Drainage Water Salinity at Farskour Pump Station

Date	EC_w in mmhos/cm at 25°C
January 1977	.84
February 1977	.72
February 1977	1.64
March 1977	1.43
March 1977	1.50
April 1977	1.70
Total	7.83
Average	1.30
September 1977	1.45
October 1977	1.40
October 1977	2.00
Total	4.9
Average	1.63

Appendix B

Table B.1

Canal	Length (km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
1-27	-	-	-	-	-	-	-	-
3-27	7.0	-	1.34	.6	1.	.58	1.34	1.19
3-4	13	-	35.8	2.2	3.6	29.8	35.8	6.73
2-4	.5	-	17.4	1.6	2.7	11.46	17.4	.2
4-5	10.	-	52.7	2.5	4.2	40.8	52.7	6.
5-6	3	-	45.4	2.4	3.9	37.3	45.4	1.7
5-28	7.5	-	8.8	1.2	2.0	3.1	8.8	2.42
7-18	35	37.2	39.8	2.2	3.7	6.	7.6	4.94
6-9	20	-	45.2	2.4	3.9	37.2	45.2	16.3
8-9	-	-	77.9	*	*	77.9	77.9	9.44
9-30	7.5	-	48.6	2.4	4.	26.8	48.6	4.36
30-31	8.75	-	14.1	1.5	2.4	14.1	11.4	3.3
9-10	3.5	-	91.5	3.1	5.2	91.5	73.7	2.63
10-29	2	-	9.5	1.3	2.1	4.1	9.5	.67
10-11	3	-	87	3.1	5.1	87.	63.9	2.2
11-57	5.0	-	20.2	1.7	2.8	9.5	20.2	2.1
11-12	30	-	77.3	2.9	4.8	77.3	43.5	20.95

Table B.1 (continued)

Canal	Length (km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
18-39	4.0	-	3.2	.8	1.4	3.2	-	.83
40-39	-	-	-	-	-	-	-	-
41-40	-	-	-	-	-	-	-	-
42-41	-	-	-	-	-	-	-	-
43-42	12.5	-	2.2	.7	1.2	2.2	-	2.34
44-43	12	-	4.3	.9	1.5	4.3	-	2.76
45-44	-	-	-	-	-	-	-	-
45-46	20	-	3.3	.8	1.4	3.3	-	4.2
47-45	24	-	6.6	1.1	1.8	6.6	-	6.67
47-48	6	-	2.7	.8	1.3	2.7	-	1.18
25-47	40	-	12.5	1.4	2.3	12.5	12.5	14.64
25-61	-	-	-	-	-	-	-	-
25-49	5	-	5.4	1.0	1.7	5.4	5.4	1.26
49-50	15	-	12.8	1.5	2.4	7.6	12.8	5.5
21-75	36	-	18.6	1.6	2.7	18.6	18.6	14.9
20-21	30	49	89.4	3.1	5.1	40.4	40.4	14.9
19-20	45	104	209.4	4.4	7.2	53.6	105.4	42.6

Table B.1 (continued)

Canal	Length (km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
20-51	10	-	60.2	2.7	4.4	10.8	60.2	6.3
21-22	3	24	44.7	2.4	3.9	20.7	20.7	1.
22-52	3	-	6.8	1.1	1.8	2.1	6.8	.85
22-23	15	11	29.4	2.0	3.3	18.4	13.8	5.2
23-53	5	-	2.7	.8	1.3	2.7	2.7	.99
53-54	5	-	1.1	.5	.9	1.1	-	.82
23-24	60	-	15.5	1.5	2.5	15.5	10.9	23.38
24-55	60	-	4.6	1.0	1.6	4.6	4.6	14.2
24-56	90	-	10	1.3	2.1	10	5.7	31.3
57-58	-	-	-	-	-	-	-	-
26-57	-	-	-	-	-	-	-	-
26-58	10	-	16.8	1.6	2.6	16.8	16.8	4
58-59	15.	-	9.6	1.3	2.1	9.6	-	5.09
26-59	-	-	-	-	-	-	-	-
26-60	7	-	25.4	1.9	3.1	7.6	25.4	3.2
58-60	-	-	-	-	-	-	-	-
60-59	-	-	-	-	-	-	-	-
26-61	15	-	9.9	1.3	2.1	9.9	9.9	5.18
61-62	15	-	6.5	1.1	1.8	6.5	-	4.13

Table B.2

Canal	Length (km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
1-27	8.	-	1.2	.5	.9	1.2	1.2	1.33
3-27	-	-	-	-	-	-	-	-
3-4	13.	-	33.9	2.1	3.5	30.4	33.9	6.6
2-4	.5	-	16.5	1.6	2.6	11.7	16.5	.2
4-5	10	-	50.	2.4	4.0	41.6	50.0	5.88
5-6	3.	-	42.6	2.3	3.8	38.1	42.6	1.66
5-28	7.5	-	6.8	1.1	1.8	3.1	6.8	2.13
7-28	35.	32.2	39.8	2.2	3.7	6.0	7.6	4.8
6-9	20	-	42.5	2.3	3.8	38.0	42.5	15.85
8-9	*	-	33.1	-	-	33.1	24.4	5.35
9-30	7.5	-	14.6	1.5	2.5	14.6	14.6	2.87
30-31	8.75	-	7.1	1.2	1.9	7.1	4.1	2.54
9-10	3.5	-	55.8	2.5	4.2	55.8	51.4	2.14
10-29	2.	-	8.3	1.2	2.0	2.1	8.3	.6
10-11	3.	-	53.4	2.5	4.2	53.4	43	1.8
11-57	-	-	-	-	-	-	-	-
11-12	30.	-	53.3	2.5	4.2	53.3	42.7	18.06
12-32	12.	-	17.8	1.6	2.7	17.8	17.8	4.9

Table B.2 (continued)

Canal	Length (km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
12-13	20.	-	35.3	2.1	3.5	35.3	24.8	10.3
13-33	2.5	-	24.3	1.2	1.9	7.8	24.3	1.47
13-44	-	-	-	-	-	-	-	-
13-14	12	-	26.8	1.9	3.2	26.8	-	5.61
14-34	2.5	-	6.5	1.1	1.8	6.5	-	.69
14-43	-	-	-	-	-	-	-	-
14-15	12.5	-	20	1.7	2.8	20.	-	5.3
15-35	5.	-	7.9	1.2	1.9	7.9	-	1.52
15-42	-	-	-	-	-	-	-	-
15-16	12.5	-	11.9	1.4	2.3	11.9	-	4.44
16-36	1	-	3.9	.9	1.5	3.9	-	.22
16-41	-	-	-	-	-	-	-	-
16-17	10.	-	7.9	1.2	1.9	7.9	-	3.04
17-37	1	-	4.4	.9	1.5	4.4	-	.23
17-40	-	-	-	-	-	-	-	-
17-18	16.	-	3.3	.8	1.4	3.3	-	3.36
18-38	1.	-	3.75	.8	1.4	3.75	-	.208
18-39	-	-	-	-	-	-	-	-

Table B.2 (continued)

Canal	Length (km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
40-39	16.	-	3.3	.8	1.4	3.3	-	3.35
41-40	10.	-	5.5	1.0	1.7	5.5	-	2.55
42-41	12.5	-	7.7	1.2	1.9	7.7	-	3.75
43-42	12.5	-	10.	1.2	2.0	10.	-	4.33
44-43	12.	-	12.1	1.4	2.3	12.1	-	4.35
45-44	36.	-	14.8	1.5	2.5	14.8	7	13.83
45-46	20.	-	3.3	.8	1.4	3.3	-	4.2
47-45	24.	-	21.8	1.8	2.9	21.8	13.1	10.47
47-48	6.	-	2.7	.8	1.3	2.7	2.7	1.18
25-47	40.	-	28.3	1.9	3.2	28.3	27.4	19.1
25-61	3.	-	-	-	-	-	-	-
25-49	5.	-	5.4	1.0	1.7	5.4	5.4	1.26
49-50	15.	-	3.0	1.8	1.3	3.0	3.0	3.05
21-25	36.	-	35	2.1	3.5	35	35.	18.5
20-21	30.	.49	108	3.3	5.5	59	59	20.54
19-20	45.	104	266.6	5.7	9.3	859	162.6	61.5
20-51	10.	-	95.3	3.2	5.3	22	25.3	7.63
21-22	3.	24	47.25	2.4	4.0	23.75	23.75	1.04

Table B.2 (continued)

Canal	Length (km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
22-52	3.	-	6.7	1.1	1.8	4.4	6.7	.84
22-23	15.	11	39.8	2.2	3.7	18.8	16.4	2.23
23-53	5.	-	3.	.8	1.3	3.	3.	7.45
53-54	5.	-	-	-	-	-	-	-
23-24	60.	-	15.5	1.5	2.5	15.5	13.1	23.38
24-55	60.	-	4.55	1.0	1.6	4.55	4.55	14.13
24-56	90.	-	10.	1.3	2.1	10.	7.8	31.27
57-58	-	-	-	-	-	-	-	-
26-57	10.	-	7.2	1.2	1.9	7.2	7.2	2.9
26-58	10.	-	17.5	1.6	2.7	17.5	16.	4.06
58-59	15.	-	10.	1.3	2.1	10.	8.5	5.2
26-59	-	-	-	-	-	-	-	-
26-60	7.	-	12.1	1.4	2.3	2.9	12.1	2.54
58-60	-	-	-	-	-	-	-	-
60-59	15.	-	-	-	-	-	-	-
26-61	15.	-	16.75	1.6	2.6	16.75	16.75	6.0
61-62	15.	-	10.	1.3	2.1	10.	8.4	5.2

Table B.3

Canal	Length (km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
1-27	8	-	1.2	.5	.9	1.2	1.2	1.33
3.27	-	-	-	-	-	-	-	-
3-4	13.	-	30.35	2.0	3.3	30.35	29.4	6.35
2-4	.5	-	14.2	1.5	2.5	11.7	14.2	.19
4-5	10.	-	43.4	2.3	3.8	41.6	43.4	5.56
5-6	3.	-	38.1	2.2	3.6	38.1	38.1	1.6
5-28	7.5	-	4.8	1.0	1.6	3.1	4.8	1.8
7-28	35.	32.2	39.8	2.2	3.7	6.0	7.6	4.8
6-9	20	-	38	2.2	3.6	38.	38.	15.0
8-9	*	-	11.5	1.4	2.3	11.5	7.5	2.6
9-30	7.5	-	6.1	1.1	1.8	6.1	6.1	2.0
30-31	-	-	-	-	-	-	-	-
9-10	3.5	-	42.5	2.3	3.8	42.5	38.5	1.93
10-29	2.	-	8.3	1.2	2.0	-	8.3	.625
10-11	3.	-	42.3	2.3	3.8	42.3	30.1	1.65
11-57	-	-	-	-	-	-	-	-
11-12	30.	-	47.2	2.3	3.8	42.2	30.	16.5
12-32	12.	-	16.7	1.6	2.6	16.7	16.7	4.80

Table B.3 (continued)

Canal	Length (km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
12-13	20	-	25.4	1.9	3.1	25.4	13.3	9.18
13-33	2.5	-	13	1.5	2.4	7.3	13	.92
13-44	-	-	-	-	-	-	-	-
13-14	12	-	17.5	1.6	2.7	17.5	-	4.87
14-34	2.5	-	6.1	1.1	1.8	6.1	-	.67
14-43	-	-	-	-	-	-	-	-
14-15	12.5	-	11.2	1.3	2.2	11.2	-	4.44
15-35	5	-	7.4	1.2	1.9	7.4	-	1.47
15-42	-	-	-	-	-	-	-	-
15-16	12.5	-	3.7	.8	1.4	3.7	-	2.72
16-36	1	-	3.6	.8	1.4	3.6	-	.21
16-41	-	-	-	-	-	-	-	-
16-17	10	-	-	-	-	-	-	-
17-37	1	-	-	-	-	-	-	-
17-40	-	-	-	-	-	-	-	-
17-18	16	-	-	-	-	-	-	-
18-38	1	-	-	-	-	-	-	-

Table B.3 (continued)

Canal	Length (km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
18-39	-	-						
40-39	16	-	3.3	.8	1.4	3.3	-	3.36
41-40	10	-	5.5	1.0	1.7	5.45	-	2.54
42-41	12.5	-	7.7	1.2	1.9	7.7	-	3.75
43-42	12.5	-	10	1.3	2.1	10	-	4.34
44-43	12	-	12.1	1.4	2.3	12.1	-	4.35
45-44	36	-	14.8	1.5	2.5	14.8	-	13.8
45-46	20	-	3.3	.8	1.4	3.3	-	4.2
47-45	24	-	21.8	1.8	2.9	21.8	-	10.47
47-48	6	-	2.7	0.8	1.3	2.7	2.7	1.18
25-47	40	-	28.3	1.9	3.2	28.3	28.3	19.07
25-61	3	-	10.7	1.3	2.2	10.7	10.7	1.05
25-49	5	-	5.4	1.0	1.7	5.4	5.4	1.26
49-50	15	-	3.0	.8	1.3	3.0	3.0	3.05
21-25	36	-	46	2.4	3.9	46	46	20.48
20-21	30	49	122	3.5	5.8	73	73	24.55
19-20	45	104	266.6	4.8	7.9	99.65	162.6	61.5
20-51	10	-	87.3	3.0	5	22.2	82.3	7.17

Table B.3 (continued)

Canal	Length (km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
21-22	3	24	48.8	2.4	4	24.8	24.8	1.77
22-52	3	-	4.5	1.0	1.6	4.5	4.5	.7
22-23	15	11	31.2	2.0	3.4	20.2	20.2	5.67
23-53	5	-	4.4	.9	1.5	4.4	4.4	1.16
53-54	5	-	1.1	.5	.9	1.1	1.1	.82
23-24	60	-	15.5	1.5	2.5	15.5	15.5	23.38
24-55	60	-	4.55	1.0	1.6	4.55	4.55	14.13
24-56	90	-	10	1.3	2.1	10	10	31.27
57-58	-	-	-	-	-	-	-	-
26-58	10	-	7	1.2	1.9	7	7	2.86
58-59	10	-	-	-	-	-	-	-
26-59	-	-	-	-	-	-	-	-
26-60	7	-	34.5	2.1	3.5	33.8	34.5	3.58
58-60	7	-	-	-	-	-	-	-
60-59	15	-	16.6	1.6	2.6	9.5	16.6	6
26-57	15	-	5	1.0	1.6	5	5	3.67
26-61	15	-	5.4	1.0	1.7	5.4	5.4	3.8
61-62	15	-	10	1.3	2.1	10	8.4	5.2

Table B.4

Sub-area No.	Areas of Winter Crops					
	Short Season Clover	Wheat	Veg.	Barley	Beans	Long Season Clover
27					5,500	
28					29,000	
29	5,517					9,483
30	20,770					29,230
31	50,000					
32	78,563				56,437	
33	60,000					
34					50,000	
35		59,850			150	
36		30,000				
37		40,000				
38		25,000				
39					30,000	
40					20,000	
41					20,000	
42					20,000	
43					20,000	
44					20,000	
45					30,000	
46					30,000	
47					25,000	
48					25,000	
49					50,000	
50					70,000	
51					100,000	
52					20,000	
53					15,000	
54					10,000	
55					40,000	
56					85,000	

Table B.4 (continued)

Sub-area No.	Areas of Winter Crops					
	Short Season Clover	Wheat	Veg.	Barley	Beans	Long Season Clover
57			40,000			
58			30,000			
59			40,000			
60			32,000			
61					30,000	
62			12,850		27,150	

Table B.4 (continued)

Sub-area No.	Areas of Summer Crops				
	Cotton	Maize	Rice	Melon	Veg.
27		5,500			
28		29,000			
29	5,517		9,483		
30	20,770		29,230		
31	50,000				
32	78,563		10,313		
33			7,284		
34	-	-	-	-	-
35	-	-	-	-	-
36	-	-	-	-	-
37	-	-	-	-	-
38	-	-	-	-	-
39	-	-	-	-	-
40	-	-	-	-	-
41	-	-	-	-	-
42	-	-	-	-	-
43	-	-	-	-	-
44	-	-	-	-	-
45	-	-	-	-	-
46	-	-	-	-	-
47			11,661		
48	-	-	-	-	-
49	-	-	-	-	24,541
50				37,425	
51			47,637		48,397
52				20,000	
53					12,290
54					
55					19,633
56					

Table B.4 (continued)

Sub-area No.	Areas of Summer Crops				
	Cotton	Maize	Rice	Melon	Veg.
57		10,191	15,559		23,888
58		20,333	9,667		
59	-	-	-	-	-
60		12,400	19,600		
61			3,900		26,100
62	-	-	-	-	-

Table B.5

Sub-area No.	Areas of Winter Crops					
	Short Season Clover	Wheat	Veg.	Barley	Beans	Long-Season Clover
27			5,500			
28					29,000	
29					15,000	
30					42,279	7,721
31					50,000	
32					135,000	
33					60,000	
34					50,000	
35					60,000	
36					30,000	
37		40,000				
38					25,000	
39					30,000	
40					20,000	
41					20,000	
42					20,000	
43					20,000	
44					20,000	
45					20,000	
46					30,000	
47					25,000	
48					25,000	
49					50,000	
50					70,000	
51	3,841		96,159			
52			20,000			
53			3,191		11,808	
54					10,000	
55					40,000	

Table B.5 (continued)

Sub-area No.	Areas of Winter Crops					
	Short Season Clover	Wheat	Veg.	Barley	Beans	Long-Season Clover
56					85,000	
57	16,478					23,522
58	28,684					1,316
59	40,000					
60	25,847					6,153
61			30,000			
62	40,000					

Table B.5 (continued)

Sub-area No.	Areas of Summer Crops				
	Cotton	Maize	Rice	Melon	Veg.
27		5,500			
28		29,000			
29	-	-	-	-	-
30			13,293		
31					
32			16,145		
33			22,271		
34	-	-	-	-	-
35	-	-	-	-	-
36	-	-	-	-	-
37	-	-	-	-	-
38	-	-	-	-	-
39	-	-	-	-	-
40	-	-	-	-	-
41	-	-	-	-	-
42	-	-	-	-	-
43	-	-	-	-	-
44				20,000	
45					26,509
46	-	-	-	-	-
47			6,253		18,745
48	-	-	-	-	-
49					24,541
50				37,425	
51	3,841		89,416		6,743
52				20,000	
53					13,915
54	-	-	-	-	-
55				19,633	
56	-	-	-	-	-

Table B.5 (continued)

Sub-area No.	Areas of Summer Crops				
	Cotton	Maize	Rice	Melon	Veg.
57	16,478	12,925			
58	28,684		1,316		
59	40,000				
60	25,847				6,153
61		30,000			
62	40,000				

Table B.6

Sub-area No.	Areas of Winter Crops					
	Short Season Clover	Wheat	Veg.	Barley	Beans	Long Season Clover
27			5,500			
28					29,000	
29					521	
30					50,000	
31	-	-	-	-	-	-
32					135,000	
33					60,000	
34					50,000	
35					60,000	
36					30,000	
37	-	-	-	-	-	-
38	-	-	-	-	-	-
39					30,000	
40					20,000	
41					20,000	
42					20,000	
43					20,000	
44					20,000	
45					30,000	
46					30,000	
47					25,000	
48					25,000	
49					50,000	
50						70,000
51	26,003		73,997			
52	16,879		3,121			
53	10,887		4,113			
54					10,000	
55					40,000	

Table B.6 (continued)

Sub-area No.	Areas of Winter Crops					
	Short Season Clover	Wheat	Veg.	Barley	Beans	Long Season Clover
56					85,000	
57	1,288					38,712
58	29,130		870			
59	30,664		9,336			
60			32,000			
61			25,913		4,088	
62	40,000					

Table B.6 (continued)

Sub-area No.	Areas of Summer Crops				
	Cotton	Maize	Rice	Melon	Veg.
27			5,500		
28		23,055	5,945		
29	-	-	-	-	-
30				17,330	
31	-	-	-	-	-
32		54,370	2,181		
33				36,861	
34	-	-	-	-	-
35	-	-	-	-	-
36	-	-	-	-	-
37	-	-	-	-	-
38	-	-	-	-	-
39	-	-	-	-	-
40	-	-	-	-	-
41	-	-	-	-	-
42	-	-	-	-	-
43	-	-	-	-	-
44	-	-	-	-	-
45	-	-	-	-	-
46	-	-	-	-	-
47			23,434		1,566
48					12,271
49					24,541
50				6,605	17,683
51	26,003		27,997		
52	16,879			3,121	
53	10,887		295		3,819
54					4,908
55					19,633
56					41,720

Table B.6 (continued)

Sub-area No.	Areas of Summer Crops				
	Cotton	Maize	Rice	Melon	Veg.
57	1,288			13,509	
58	29,130		870		
59	30,664		9,336		
60			32,000		
61			1,292		28,708
62	40,000				

Table B.7

Canal	Length in K_{ms}	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
1-27	8	-	5.7	1.2	2	1.3	5.7	2
3-27	-	-	-	-	-	-	-	-
3- 4	13	-	37.15	2.2	3.5	30.35	37.15	6.8
2- 4	.5	-	19.2	1.7	2.75	11.7	19.2	.21
4- 5	10	-	55.9	2.6	4.25	41.6	55.9	6.1
5- 6	3	-	46.6	2.5	4.0	38.4	46.6	1.7
5-28	7.5	-	8.7	1.2	2.0	2.8	8.7	2.4
7-28	35.0	32.2	39.8	2.2	3.7	6.0	7.6	4.94
6- 9	20	-	46.4	2.5	4.0	38.3	46.4	16.47
8- 9	-	-	80	-	-	68.85	80	9.45
9-30	7.5	-	25.6	2.0	3.25	18.4	25.6	3.45
30-31	8.75	-	15	1.5	2.5	5.4	15	3.37
9-10	3.5	-	99.9	3.3	5.50	88	99.9	2.6
10-29	2	-	11.3	1.7	2.75	1.6	11.3	.71
10-11	3	-	88.2	3.2	5.25	86	88.2	2.2
11-57	-	-	-	-	-	-	-	-
11-12	30	-	87.9	3.2	5.25	85.8	87.9	22.10

Table B.7 (continued)

Canal	Length in K_{ms}	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
12-32	12	-	35.1	2.2	3.50	35.1	28.4	6.10
12-13	20	-	59.2	2.8	4.50	50.4	59.2	12.5
13-33	2.5	-	15.1	1.5	2.50	15.1	12.7	.96
13-44	-	-	-	-	-	-	-	-
13-14	12	-	45.4	2.5	4.0	34.3	45.4	6.8
14-34	2.5	-	13.7	1.5	2.5	5.8	13.7	.94
14-43	-	-	-	-	-	-	-	-
14-15	12.5	-	31.1	2.25	3.5	28.1	31.1	6.16
15-35	5	-	16.5	1.7	2.75	6.4	16.5	2.0
15-42	-	-	-	-	-	-	-	-
15-16	12.5	-	21.4	1.8	3.0	21.4	14.2	5.4
16-36	1	-	7.75	1.2	2.0	3	7.75	.30
16-41	-	-	-	-	-	-	-	-
16-17	10	-	18.1	1.7	2.75	18.1	6.3	4.1
17-37	1	-	15.4	1.5	2.50	15.4	-	.38
17-40	-	-	-	-	-	-	-	-
17-18	16	-	6.2	1.1	1.75	2.5	6.2	4.3

Table B.7 (continued)

Canal	Length of K_{ms}	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
18-38	1	-	6.1	1.1	1.75	2.5	6.1	.25
18-39	-	-	-	-	-	-	-	-
40-39	16	-	6.3	1.1	1.75	6.3	6.3	4.3
41-40	10	-	10.9	1.4	2.25	9.8	10.9	3.5
42-41	12.5	-	16.0	1.7	2.75	14.9	16.0	4.9
43-42	12.5	-	21.2	1.8	3.0	17.3	21.2	5.4
44-43	12	-	26	2.0	3.25	19.5	26	5.55
45-44	36	-	34	2.2	3.50	22.4	34	18.30
45-46	20	-	7.5	1.2	2.0	3.3	7.5	5.9
47-45	24	-	57.6	2.6	4.25	29.6	52.6	14.30
47-48	6	-	6.1	1.1	1.75	2.7	6.1	1.5
25-47	40	-	67.6	2.9	4.75	36.4	67.6	26.4
25-61	3	-	1	6	1	1	-	.48
25-49	5	-	12.3	1.5	2.5	5.9	12.3	1.8
49-50	15	-	8.5	1.2	2.0	3.1	8.5	4.75
21-25	36	-	83	3.0	5.0	4.5	8.3	25.9
20-21	30	49	179	4.1	6.8	88	130	38

Table B.7 (continued)

Canal	Length in K_{ms}	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
19-20	45	104	266.6	4.8	7.9	115.4	162.6	61.5
20-51	10	-	24.7	1.8	3.0	22	24.7	4.5
21-22	3	24	67.7	2.8	4.6	40.6	43.7	1.84
22-52	3	-	6.8	1.25	2.0	4.3	6.8	.85
22-23	15	11	47.8	2.4	4	36.1	36.8	9.1
23-53	5	-	6.1	1.1	1.75	5.5	6.1	1.6
53-54	5	-	2.5	.75	1.25	2.2	2.45	.96
23-24	60	-	30	2.2	3.5	30	30	29.2
24-55	60	-	8.8	1.2	2.0	8.8	8.8	19.3
24-56	90	-	19.4	1.7	2.75	19.4	19.4	37.85
57-58	-	-	-	-	-	-	-	-
26-57	10	-	13.8	1.5	2.5	5.6	13.2	3.7
26-58	10	-	6.75	1.2	2.0	6.75	6.75	2.8
58-59	-	-	-	-	-	-	-	-
26-59	-	-	-	-	-	-	-	-
26-60	7	-	27.6	2	3.25	27.6	6.7	3.3
58-60	-	-	-	-	-	-	-	-

Table B.7 (continued)

Canal	Length in K_{ms}	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6 L.E.
60-59	15	-	13.3	1.5	2.5	6.2	13.3	5.6
26-61	15	-	25.4	1.8	3.0	11.4	25.4	6.9
61-62	15	-	9	1.2	2.0	9	9	4.9

Table B.8

Sub-area No.	Areas of Winter Crops					
	Short Season Clover	Wheat	Veg.	Barley	Beans	Long Season Clover
27			5,500			
28				29,000		
29				15,000		
30	50,000					
31				50,000		
32	135,000					
33	57,720	2,280				
34		50,000				
35		23,239		36,761		
36				30,000		
37		40,000				
38				25,000		
39	25,875				4,125	
40	10.387				9,613	
41						20,000
42					20,000	
43					20,000	
44					20,000	
45		10,000			30,000	
46					30,000	
47					25,000	
48					25,000	
49			4,350		45,650	
50				70,000		
51			100,000			
52			20,000			
53			15,000			
54			10,000			
55	34,500				5,500	

Table B.8 (continued)

Sub-area No.	Areas of Winter Crops					
	Short Season Clover	Wheat	Veg.	Barley	Beans	Long Season Clover
56	73,312				11,688	
57	1,287					38,713
58	25,000	5,000				
59	12,335	27,665				
60	32,000					
61					30,000	
62	33,333	6,667				

Table B.8 (continued)

Sub-area No.	Areas of Summer Crops				
	Cotton	Maize	Rice	Melon	Veg.
27			5,500		
28					29,000
29					15,000
30	25,000		25,000		
31			10,000		40,000
32	135,000				
33	57,720	2,280			
34		50,000			
35		60,000			
36		14,150			15,850
37		40,000			
38					25,000
39	25,875	4,125			
40	10,387	9,613			
41		20,000			
42		20,000			
43		20,000			
44				20,000	
45		40,000			
46		30,000			
47		25,000			
48		25,000			
49		50,000			
50					70,000
51			100,000		
52				20,000	
53		15,000			
54		10,000			
55	34,500	5,500			

Table B.8 (continued)

Sub-area No.	Areas of Summer Crops				
	Cotton	Maize	Rice	Melon	Veg.
56	73,312	11,688			
57	1,287	22,808		15,905	
58	25,000	5,000			
59	12,335	24,764	2,901		
60	32,000				
61			8,479	21,521	
62	33,333	6,667			

TABLE B.9

Canal	Length(km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6L.E.
1-27	8	-	5.7	1.0	1.7	1.2	5.7	2.07
3-27	-	-	-	-	-	-	-	-
3-4	13	-	37.15	2.2	3.6	30.35	37.15	6.83
2-4	.5	-	18.1	1.6	2.7	11.7	18.1	.21
4-5	10	-	54.7	2.5	4.9	41.6	54.7	6.08
5-6	3	-	54.1	2.5	4.2	38.1	54.1	1.82
5-28	7.5	-	3.1	.9	1.3	3.1	-	1.54
7-28	35	32.2	39.8	2.2	3.7	6	7.6	4.94
6-9	20	-	54	2.5	4.2	38	54.	17.7
8-9	-	-	93	-	-	85.7	93	10.62
9-30	7.5	-	14.1	1.5	2.4	13.1	14.1	2.84
30-31	8.75	-	6.3	1.1	1.8	6.3	-	2.37
9-10	3.5	-	131.8	3.6	6.0	109.7	131.8	3.08
10-29	2	-	8.3	1.2	2.0	2.2	8.3	.63
10-11	3	-	123.1	3.5	5.8	107.1	123.1	2.56
11-57	5	-	53.2	2.5	4.2	20.8	53.2	3
11-12	30	-	86	3.0	5	86	69.5	21.9
12-32	12	-	34.85	2.1	3.5	34.83	22.9	6.16
12-13	20	-	50.9	2.5	4.1	50.9	46.4	11.84

TABLE B.9 (continued)

Canal	Length(km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6L.E.
13-33	2.5	-	9.1	1.3	2.1	9.1	-	.82
13-44	7.5	-	13.35	1.5	2.4	8.7	13.35	2.8
13-14	12	-	37.1	2.1	3.4	32.1	32.1	6
14-34	2.5	-	6.8	1.1	1.8	6.8	-	.7
14-43	6.5	-	14.2	1.6	2.6	-	14.2	2.47
14-15	12.5	-	24.9	1.9	3.1	24.9	17.5	5.7
15-33	5	-	8	1.2	2.0	8	-	1.53
15-42	6	-	4.4	.9	1.5	-	4.4	1.4
15-16	12.5	-	16.6	1.6	2.6	16.6	13	5
16-36	1	-	3.5	.8	1.4	3.5	-	.21
16-41	3	-	4.4	.9	1.5	-	4.4	.7
16-17	10	-	12.9	1.5	2.4	12.9	8.4	3.7
17-37	1	-	4.4	.9	1.5	4.4	-	.23
17-40	4	-	4.4	.9	1.5	4.4	4.4	.93
17-18	16	-	3.9	.9	1.5	3.9	3.9	3.55
18-38	1	-	2.9	.8	1.3	2.9	-	.2
18-39	4	-	3.9	.9	1.5	1	3.9	.89
40-39	16	-	2.2	.7	1.2	2.2	-	3.0
41-40	-	-	-	-	-	-	-	-

TABLE B.9 (continued)

Canal	Length(km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^{6}L.E.
42-41	12.5	-	2.2	.7	1.2	2.2	-	2.33
43-42	12.5	-	4.4	.9	1.5	4.4	-	2.9
44-43	12	-	6.5	1.1	1.8	6.5	6.5	3.3
45-44	-	-	-	-	-	-	-	-
45-46	-	-	-	-	-	-	-	-
47-45	-	-	-	-	-	-	-	-
47-48	-	-	-	-	-	-	-	-
23-47	-	-	-	-	-	-	-	-
25-61	3	-	-	-	-	-	-	-
25-49	5	-	5.4	1.0	1.7	5.4	-	1.26
49-50	15	-	7.6	1.2	1.9	7.6	3.5	4.47
21-23	36	-	12.4	1.4	2.3	12.4	-	13.14
20-21	30	49	66.8	2.7	4.6	17.8	7	7.4
19-20	45	104	154	3.8	6.4	30	50	22.58
20-51	10	-	40.75	2.3	3.75	10.8	40.75	5.44
21-22	3	24	30.8	2.0	3.3	4.9	6.8	.35
22-52	3	-	6.8	1.1	1.8	2.1	6.8	.85
22-23	15	11	13.7	1.5	2.4	2.7	-	.91
23-53	5	-	2.7	1.8	1.3	2.7	-	1

TABLE B.9 (continued)

Canal	Length(km)	Existing Capacity $(m^3/sec.)$	New Capacity $(m^3/sec.)$	Bed Width b(m)	Water Depth y(m)	Winter Flow $(m^3/sec.)$	Summer Flow $(m^3/sec.)$	Cost 10^6L.E.
53-54	5	-	-	-	-	-	-	-
23-24	60	-	-	-	-	-	-	-
24-55	60	-	-	-	-	-	-	-
24-56	90	-	-	-	-	-	-	-
57-58	10	-	11.3	1.3	2.2	11.3	9	3.56
26-58	10	-	-	-	-	-	-	-
58-59	15	-	4.1	.9	1.5	4.1	-	3.4
26-60	7	-	42.1	2.3	3.8	42.1	18.9	3.85
58-60	-	-	-	-	-	-	-	-
60-59	15	-	28.8	2.0	3.3	5.5	28.8	7.2
26-59	-	-	-	-	-	-	-	-
26-54	-	-	-	-	-	-	-	-
26-61	15	-	33.1	2.1	3.4	9.2	33.1	7.55
61-62	15	-	5.9	1.0	1.7	5.9	1.7	3.95

TABLE B.10

Canal	Length(km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^{6}L.E.
1-27	8	-	5.7	1.0	1.7	1.2	5.7	2.07
3-27	-	-	-	-	-	-	-	-
3-4	13	-	37.15	2.2	3.6	30.35	37.15	6.83
2-4	.5	-	18.1	1.6	2.7	11.7	18.1	5.33
4-5	10	-	34.7	2.5	4.2	41.6	54.7	6.08
5-6	3	-	54.2	2.5	4.2	38.1	54.2	1.82
5-28	7.5	-	3.1	.8	1.3	3.1	-	1.54
7-28	35	32.2	39.8	2.2	3.7	6	7.6	4.94
6-9	20	-	54	2.5	4.2	38	54	12.14
8-9	-	-	33	2.1	3.4	33	31	5.35
9-30	7.5	-	12.3	1.39	2.3	12.3	12.3	2.73
30-31	8.75	-	-	-	-	-	-	-
9-10	3.5	-	71.5	2.9	4.7	58	71.5	2.37
10-29	2	-	16.9	1.6	2.6	-	16.9	.8
10-11	3	-	57.8	2.6	4.3	57.8	54.4	1.86
11-57	5	-	6.6	1.1	1.8	-	6.6	1.39
11-12	30	-	57.6	2.6	4.3	57.6	47.6	18.6
12-32	12	-	19.3	1.7	2.8	19.3	19.3	5.04
12-13	20	-	38.1	2.7	3.6	38.1	28.1	10.6

TABLE B.10 (continued)

Canal	Length(km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6L.E
13-33	2.5	-	7.8	1.2	1.9	7.8	-	.76
13-14	12	-	15.1	1.5	2.5	15.1	8.5	4.64
14-44	7.5	-	19	1.7	2.8	14.4	19	3.13
14-34	2.5	-	-	-	-	-	-	-
14-43	-	-	-	-	-	-	-	-
14-15	17.5	-	8.4	1.4	2.3	8.4	8.4	3.93
15-35	5	-	3.8	.9	1.5	3.8	-	1.1
15-42	6	-	7.5	1.2	1.9	-	7.5	1.78
15-16	12.5	-	4.5	1.0	1.6	4.5	-	2.93
16-36	1	-	-	-	-	-	-	-
16-41	-	-	-	-	-	-	-	-
16-17	10	-	4.5	1.0	1.6	4.5	-	2.34
17-37	1	-	4.45	1.0	1.6	4.45	-	.23
17-40	-	-	-	-	-	-	-	-
17-18	16	-	-	-	-	-	-	-
18-38	1	-	-	-	-	-	-	-
18-39	-	-	-	-	-	-	-	-
40-39	16	-	3.2	.8	1.4	3.2	-	3.32
41-40	10	-	5.5	1.0	1.7	5.5	1.9	2.55
42-41	12.5	-	7.7	1.2	1.9	7.7	5.5	3.75

TABLE B.10 (continued)

Canal	Length(km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6L.E.
43-42	12.5	-	10	1.3	2.1	10	2.4	4.34
44-43	12	-	12.1	1.4	2.3	12.1	12.1	4.35
45-44	36	-	-	-	-	-	-	-
45-46	20	-	-	-	-	-	-	-
47-45	24	-	-	-	-	-	-	-
47-48	6	-	2.7	.8	1.3	2.7	-	1.18
25-47	40	-	6.6	1.1	1.8	6.6	-	11.1
25-61	3	-	-	-	-	-	-	-
25-49	5	-	5.4	1.0	1.7	5.4	-	1.26
49-50	15	-	15.5	1.5	2.5	15.5	3.5	5.85
21-25	36	-	12.4	1.4	2.3	12.4	-	13.4
20-21	30	49	67.8	2.8	4.6	17.8	9.8	7.4
19-20	45	104	154	3.8	6.4	30	50	22.58
20-51	10	-	37.9	2.2	3.6	10.8	37.9	5.3
21-22	3	24	33.5	2.1	3.5	4.9	9.5	.49
22-52	3	-	6.8	1.1	1.8	2.1	6.8	.850
22-23	15	11	13.7	1.5	2.4	2.7	2.7	.91
23-53	5	-	2.7	.8	1.3	2.7	2.7	.99
53-54	5	-	-	-	-	-	-	-
23-24	60	-	-	-	-	-	-	-

TABLE B.10 (continued)

Canal	Length(km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6L.E.
24-55	60	-	-	-	-	-	-	-
24-56	90	-	-	-	-	-	-	-
57-58	-	-	-	-	-	-	-	-
26-57	10	-	5.4	1.0	1.7	5.4	4	2.53
26-58	10	-	7.4	1.3	2.2	7.4	6.3	2.94
58-59	-	-	-	-	-	-	-	-
26-60	7	-	16.6	1.6	2.6	16.6	5.3	2.8
26-59	15	-	5.5	1.0	1.7	5.5	5.1	3.82
58-60	-	-	-	-	-	-	-	-
60-59	10	-	4.4	.9	1.5	4.4	4.4	2.32
26-61	15	-	16.4	1.6	2.6	16.4	31.4	3.9[illegible]
61-62	15	-	9.6	1.3	2.1	9.6	-	5.09

TABLE B.11

Canal	Length(km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6L.E.
1-27	8	-	5.7	1.0	1.7	1.2	5.7	2.07
3-27	-	-	-	-	-	-	-	-
3-4	13	-	37.15	2.2	3.6	30.35	37.15	6.89
2-4	.3	-	18.1	1.6	2.7	11.7	18.1	.21
4-5	10	-	54.7	2.5	4.2	41.6	54.7	6.08
5-6	3	-	54.2	2.5	4.2	38.1	54.2	1.82
5-28	7.5	-	3.1	.8	1.3	3.1	-	1.54
7-28	35	37.2	39.8	2.2	3.7	6	7.6	4.94
6-9	20	-	54	2.5	4.2	38	54	17.7
8-9	-	-	11.5	1.4	2.3	11.5	10.6	2.65
9-30	7.5	-	17.7	1.6	2.7	8.8	17.7	3.05
30-31	8.75	-	-	-	-	-	-	-
9-10	3.5	-	45.8	2.4	3.9	39.8	45.8	2
10-29	2	-	16.9	1.6	2.6	-	16.9	3.05
10-11	3	-	39.7	2.2	3.7	39.7	28.8	1.62
11-57	5	-	11.3	1.4	2.3	-	11.3	1.78
11-12	30	-	39.5	2.2	3.7	39.5	17.4	16.13
12-32	12	-	16.7	1.9	3.1	16.7	3.4	4.8
12-13	20	-	22.8	2.1	3.5	22.8	14	8.86

TABLE B.11 (continued)

Canal	Length(km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6L.E.
23-24	60	-	-	-	-	-	-	-
24-55	60	-	-	-	-	-	-	-
24-56	90	-	-	-	-	-	-	-
57-58	-	-	-	-	-	-	-	-
26-37	10	-	5.1	1.0	1.6	5.1	-	2.47
26-58	10	-	7.1	1.2	1.9	7.1	5.2	2.9
58-59	7	-	-	-	-	-	-	-
26-60	7	-	18.5	1.6	2.7	18.5	7	2.9
26-59	15	-	4	.9	1.5	4	-	1.57
58-60	-	-	-	-	-	-	-	-
60-59	10	-	5.45	1.0	1.7	5.45	5.45	2.54
26-61	15	-	40	2.2	3.7	16.75	39.95	8.1
61-62	15	-	10	1.3	2.1	10	8.45	5.2

TABLE B.11 (continued)

Canal	Length(km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6L.E.
43-42	12.5	-	10	1.3	2.1	10	2.7	4.34
44-43	12	-	12.1	1.4	2.3	12.1	7.1	4.35
45-44	-	-	-	-	-	-	-	-
45-46	-	-	-	-	-	-	-	-
47-45	-	-	-	-	-	-	-	-
47-48	-	-	-	-	-	-	-	-
25-47	-	-	-	-	-	-	-	-
25-61	3	-	10	1.3	2.1	-	10	1.04
25-49	5	-	5.4	1.0	1.7	5.4	-	1.26
49-50	15	-	15.5	1.5	2.5	15.5	6	5.85
21-25	36	-	12.4	1.4	2.3	12.4	-	13.14
20-21	30	49	67.8	2.8	4.6	17.8	4.5	7.4
19-20	45	104	154	3.8	6.4	30	50	22.58
20-51	10	-	43.2	2.3	3.8	10.8	43.2	5.56
21-22	3	24	28.9	2.0	3.3	4.9	4.4	.25
22-52	3	-	4.4	.9	1.5	2.1	4.4	.7
22-23	15	11	13.7	1.5	2.4	2.7	-	.91
23-53	5	-	2.7	.8	1.3	2.7	-	1
53-54	5	-	-	-	-	-	-	-

TABLE B.11 (continued)

Canal	Length(km)	Existing Capacity (m^3/sec.)	New Capacity (m^3/sec.)	Bed Width b(m)	Water Depth y(m)	Winter Flow (m^3/sec.)	Summer Flow (m^3/sec.)	Cost 10^6L.E.
13-33	2.5	-	7.3	1.3	2.2	7.3	-	.73
13-14	12	-	-	-	-	-	-	-
13-44	7.5	-	15	1.5	2.5	15	13.75	2.9
14-43	-	-	-	-	-	-	-	-
14-15	-	-	-	-	-	-	-	-
15-35	-	-	-	-	-	-	-	-
15-42	-	-	-	-	-	-	-	-
15-16	-	-	-	-	-	-	-	-
16-36	-	-	-	-	-	-	-	-
16-41	-	-	-	-	-	-	-	-
16-17	-	-	-	-	-	-	-	-
17-37	-	-	-	-	-	-	-	-
17-40	-	-	-	-	-	-	-	-
17-18	-	-	-	-	-	-	-	-
18-38	-	-	-	-	-	-	-	-
18-39	-	-	-	-	-	-	-	-
40-39	16	-	3.3	.8	1.4	3.3	-	3.36
41-40	10	-	5.5	1.0	1.7	5.5	-	2.55
42-41	12.5	-	7.7	1.2	1.9	7.7	-	3.75

Table B.12

Sub-area No.	Areas of Winter Crops					
	Short Season Clover	Wheat	Veg.	Barley	Beans	Long Season Clover
27			5,500			
28					29,000	
29					15,000	
30	45,990					4,010
31		50,000				
32	108,860					26,140
33					51,438	8,562
34					50,000	
35		9,850			50,150	
36		30,000				
37		40,000				
38		25,000				
39					30,000	
40					20,000	
41					20,000	
42					20,000	
43					20,000	
44					20,000	
45					8,742	
46	-	-	-	-	-	-
47					25,000	
48					25,000	
49					50,000	
50						70,000
51					100,000	
52					20,000	
53					15,000	
54					10,000	
55	-	-	-	-	-	-

Table B.12 (continued)

Sub-area No.	Areas of Winter Crops					
	Short Season Clover	Wheat	Veg.	Barley	Beans	Long Season Clover
56	-	-	-	-	-	-
57			40,000			
58			30,000			
59			40,000			
60			32,000			
61					30,000	
62			7,350		32,650	

Table B.12 (continued)

Sub-area No.	Areas of Summer Crops				
	Cotton	Maize	Rice	Melon	Veg.
27			5,500		
28		1,900		27,100	
29					
30	45,990		4,010		
31					
32	108,800				
33	-	-	-	-	-
34	-	-	-	-	-
35	-	-	-	-	-
36	-	-	-	-	-
37	-	-	-	-	-
38	-	-	-	-	-
39					17,700
40					20,000
41					20,000
42					20,000
43			20,000		
44				20,000	
45	-	-	-	-	-
46	-	-	-	-	-
47	-	-	-	-	-
48	-	-	-	-	-
49	-	-	-	-	-
50				10,325	
51			77,153		
52				20,000	
53	-	-	-	-	-
54	-	-	-	-	-
55	-	-	-	-	-
56	-	-	-	-	-

Table B.12 (continued)

Sub-area No.	Areas of Summer Crops				
	Cotton	Maize	Rice	Melon	Veg.
57			40,000		
58		30,000			
59		19,400	20,600		
60		20,405	11,595		
61			30,000		
62		5,720			

Table B.13

Sub-area No.	Areas of Winter Crops					
	Short Season Clover	Wheat	Veg.	Barley	Beans	Long Season Clover
27			5,500			
28					29,000	
29	-	-	-	-	-	-
30	47,898				2,102	
31						
32	13,015				121,985	
33					60,000	
34					50,000	
35					28,803	
36	-	-	-	-	-	-
37		40,000				
38	-	-	-	-	-	-
39					30,000	
40					20,000	
41					20,000	
42					20,000	
43					20,000	
44					20,000	
45					8,742	
46	-	-	-	-	-	-
47					25,000	
48					25,000	
49					50,000	
50			70,000			
51					100,000	
52					20,000	
53					15,000	
54					10,000	
55	-	-	-	-	-	-

Table B.13 (continued)

Sub-area No.	Areas of Winter Crops					
	Short Season Clover	Wheat	Veg.	Barley	Beans	Long Season Clover
56	-	-	-	-	-	-
57			1,287			38,713
58	30,000					
59	38,838		1,162			
60	25,100		6,900			
61			30,000			
62			40,000			

Table B.13 (continued)

Sub-area No.	Areas of Summer Crops				
	Cotton	Maize	Rice	Melon	Veg.
27			5,500		
28		1,900		27,100	
29	-	-	-	-	-
30	47,898		2,102		
31	-	-	-	-	-
32	13,015	35,525	6,431		
33	-	-	-	-	-
34	-	-	-	-	-
35	-	-	-	-	-
36	-	-	-	-	-
37	-	-	-	-	-
38	-	-	-	-	-
39	-	-	-	-	-
40	-	-	-	-	8,489
41					20,000
42					20,000
43			6,528		13,472
44				20,000	
45	-	-	-	-	-
46	-	-	-	-	-
47	-	-	-	-	-
48	-	-	-	-	-
49	-	-	-	-	-
50				10,325	
51			19,400		80,600
52				20,000	
53					12,290
54	-	-	-	-	-
55	-	-	-	-	-
56	-	-	-	-	-

Table B.13 (continued)

Sub-area No.	Areas of Summer Crops				
	Cotton	Maize	Rice	Melon	Veg.
57		40,000			
58	30,000				
59	38,838		1,162		
60	25,100				
61			30,000		
62	-	-	-	-	-

Table B-14

Sub-area No.	Areas of Winter Crops					
	Short Season Clover	Wheat	Veg.	Barley	Beans	Long Season Clover
27			5,500			
28					29,000	
29	-	-	-	-	-	-
30			24,131		25,869	
31	-	-	-	-	-	-
32					135,000	
33					60,000	
34					4,934	
35	-	-	-	-	-	-
36	-	-	-	-	-	-
37	-	-	-	-	-	-
38	-	-	-	-	-	-
39					30,000	
40					20,000	
41					20,000	
42					20,000	
43					20,000	
44					20,000	
45					8,742	
46	-	-	-	-	-	-
47					25,000	
48					25,000	
49					50,000	
50			70,000			
51					100,000	
52					20,000	
53					15,000	
54					10,000	
55	-	-	-	-	-	-

Table B.14 (continued)

Sub-area No.	Areas of Winter Crops					
	Short Season Clover	Wheat	Veg.	Barley	Beans	Long Season Clover
56	-	-	-	-	-	-
57		1,288				38,713
58	24,660		5,340			
59	25,801		14,199			
60	27,607		4,393			
61			30,000			
62	40,000					

Table B.14 (continued)

Sub-area No.	Areas of Summer Crops				
	Cotton	Maize	Rice	Melon	Veg.
27			5,500		
28		29,000			
29	–	–	–	–	–
30				50,000	
31	–	–	–	–	–
32				12,736	
33	–	–	–	–	–
34	–	–	–	–	–
35	–	–	–	–	–
36	–	–	–	–	–
37	–	–	–	–	–
38	–	–	–	–	–
39	–	–	–	–	–
40	–	–	–	–	–
41	–	–	–	–	–
42	–	–	–	–	12,201
43					20,000
44				18,721	
45	–	–	–	–	–
46	–	–	–	–	–
47	–	–	–	–	–
48	–	–	–	–	–
49	–	–	–	–	–
50					27,227
51			25,857		74,143
52					20,000
53	–	–	–	–	–
54	–	–	–	–	–
55	–	–	–	–	–
56	–	–	–	–	–

Table B.14 (continued)

Sub-area No.	Areas of Summer Crops				
	Cotton	Maize	Rice	Melon	Veg.
57		31,296		8,704	
58	24,660				
59	25,801				
60	27,607	4,393			
61			30,000		
62	40,000				

Appendix C

Table C.1 The Nodes Definition

Node	State	Node	State
1	Faras Kour P.S.	23	Divergent Node
2	Lower Sarrow P.S.	24	" "
3	Domietta Branch	25	" "
4	Mixing Node	26	Bahr El-Bakar
5	Divergent Node	27	Sub-Area (21)
6	Divergent Node + P.S.(I)	28	Sub-Area (8)
7	El-Bahr El-Saghia	29	15,000 fd. of (7)
8	Bahr Hadaus Dr.	30	50,000 fd. of (7)
9	Divergent Node + P.S.(II)	31	Sub-Area (6)
10	Divergent Node	32	Sub-Area (5)
11	Divergent Node	33	60,000 Feddan (1)
12	Divergent Node	34	50,000 Feddan (1)
13	Divergent Node	35	60,000 Feddan (1)
14	Divergent Node	36	30,000 Feddan (1)
15	Divergent Node	37	40,000 Feddan (1)
16	Divergent Node	38	25,000 Feddan (1)
17	Divergent Node	39	30,000 Fd. From (1)
18	Divergent Node	40	20,000 Fed.
19	Israitia Canal	41	20,000 Fed.
20	Divergent Node	42	20,000 Fed.
21	Divergent Node	43	20,000 Fed.
22	Divergent Node	44	20,000 Fed.

Table C.1 (Continued)

Node	State	Node	State
45	40,000 Fed. from (4)	54	Sub-Area (16)
46	Sub-Area (3)	55	Sub-Area (18)
47	25,000 Fed. from (4)	56	Sub-Area (19)
48	25,000 Fed. from (4)	57	40,000 Fed. from (9)
49	50,000 Fed. from (13)	58	30,000 Fed. from (9)
50	70,000 Fed. from (13)	59	Sub-Area (10)
51	Sub-Area (17)	60	Sub-Area (11)
52	Sub-Area (14)	61	30,000 Fed. from (12)
53	Sub-Area (15)	62	40,000 Fed. from (12)

TABLE C.2

The Arcs Definitions

Arc	Length in Kilemeters
1-27	8.0
3-27	7.0
3-4	13.0
2-4	0.5
4-5	10.0
5-28	7.5
7-28	35.0
5-6	3.0
6-9	20.0
8-9	---
9-30	7.5
30-31	8.75
9-10	3.5
10-29	2.0
10-11	3.0
11-57	5.0
57-58	10.0
58-60	10.0
58-59	15.0
11-12	30.0
12-32	12.0

Table C.2 Continued

Arc	Length in Kilometers
12-13	20.0
13-33	2.5
13-44	7.5
44-43	12.0
13-14	12.0
14-43	6.5
14-34	2.5
14-15	12.5
15-35	5.0
15-42	6.0
43-42	12.5
15-16	12.5
42-41	12.5
16-36	1.0
16-41	3.0
16-17	10.0
41-40	10.0
17-37	1.0
17-40	4.0
17-18	16.0
40-39	16.0
18-38	1.0
18-39	4.0
45-44	36.0
45-46	20.0
47-45	24.0
47-48	6.0
25-47	40.0
25-49	5.0
49-50	15.0
21-25	36.0

Table C.2 Continued

Arc	Length in Kilometers
19-20	45.0
20-21	30.0
20-51	10.0
21-22	3.0
22-52	3.0
22-23	13.0
23-53	5.0
53-54	5.0
23-24	20.0
24-55	60.0
24-56	90.0
25-61	3.0
61-62	15.0
26-61	15.0
26-57	10.0
26-60	7.0
60-59	15.0
26-59	10.0
26-58	10.0

TABLE C.3 Two-Year Agricultural Rotation

Year	Season	Crops
1	Winter	Short-season clover
	Summer	Cotton
2	Winter	Long-season clover, wheat, barley, vegetables, beans
	Summer	Rice, maize, vegetables

TABLE C.4 Three-Year Agricultural Rotation

Year	Season	Crops
1	Winter	Short-season clover
	Summer	Cotton
2	Winter	Long-season clover
	Summer	Rice
3	Winter	Wheat, barley, vegetables, beans
	Summer	Maize, vegatables

Table C.5 Yields and Unit Prices of the Agricultural Crops

Crops	Yield in Ton/Feddan	Unit Price L.E./Ton
Short Season		
lover	6.50	15.00
Wheat	1.45	120.00
Barley	1.20	90.00
Beans	1.00	200.00
Long Season		
Clover	26.00	15.00
Cotton	.30	450.00
Maize	1.65	120.00
Rice	2.30	120.00
Water Melon	11.20	50.00
Vegetables	4.00	100.00

Table C.6 Amount and Unit Costs of Fertilizer, Seeds, Labor-Hours, Machinary Hours Required for the Crops

	Fertilizer (PO)		Fertilizer (N)		Seeds or Stocks		Labor-Hours		Machinary Hours	
Crop	Amount Kg.	Unit Price L.E./Kg.	Amount Kg.	Unit Price L.E./Kg.	Amount Kg.	Unit Price L.E./Kg.	Amount Hours	Unit Price L.E/hr.	Amount Hours	Unit Price L.E./hr.
Short Season										
Clover	60	.04	-	.05	10.	.05	200	.10	10	1.5
Wheat	100	.04	400	.05	75.	.05	400	.10	20	1.5
Barley	100	.04	400	.05	75.	.05	300	.10	20	1.5
Beans	100	.04	50	.05	78.	.10	350	.10	10	1.5
Long Season										
Clover	100	.04	-	.05	10.	.05	400	.10	15	1.5
Cotton	100	.04	400	.05	30.	.02	600	.10	10	1.5
Maize	-	.04	400	.05	30.	.07	500	.10	25	1.5
Rice	100	.04	200	.05	40.	.05	600	.10	35	1.5
Water Melon	200	.04	200	.05	50.	.02	400	.10	15	1.5
Vegetables	220	.04	500	.05	50.	.2	1000	.10	10	1.5

Table C.7 Average Cost of Land Reclamation

Item	Unit Cost (L.E./Feddan)
Irrigation and Drainage*	500
Housing and Utilities	200
Electricity	150
Transportation and Communications	200
Equipment and Machinary for Cultivation	50
Local Lifting Stations	50
Social Services	50
TOTAL	1,200

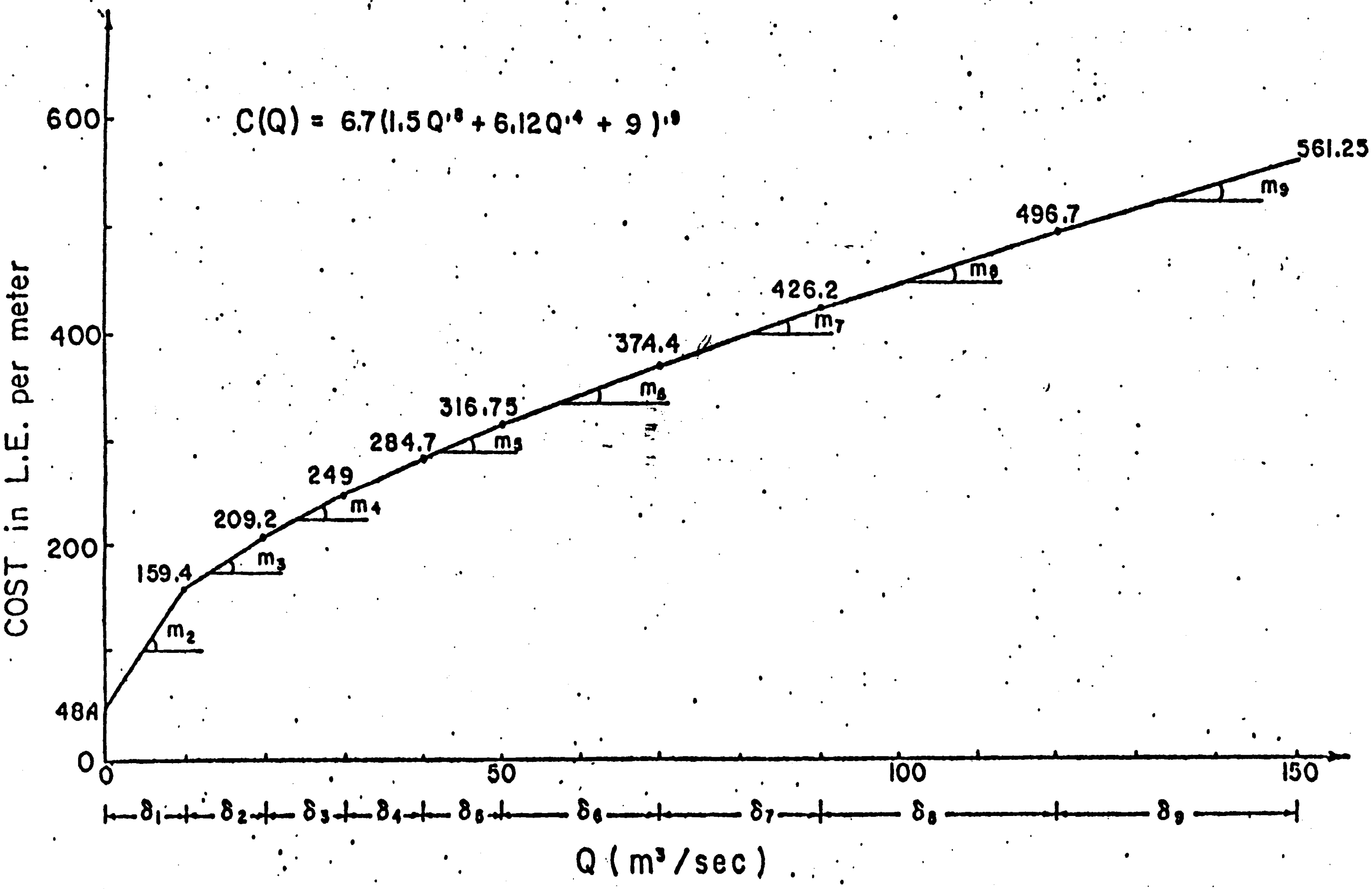

Figure C.1 **A Piece Wise Linear Approximation of the Excavation and Irrigation Structure Cost Function**

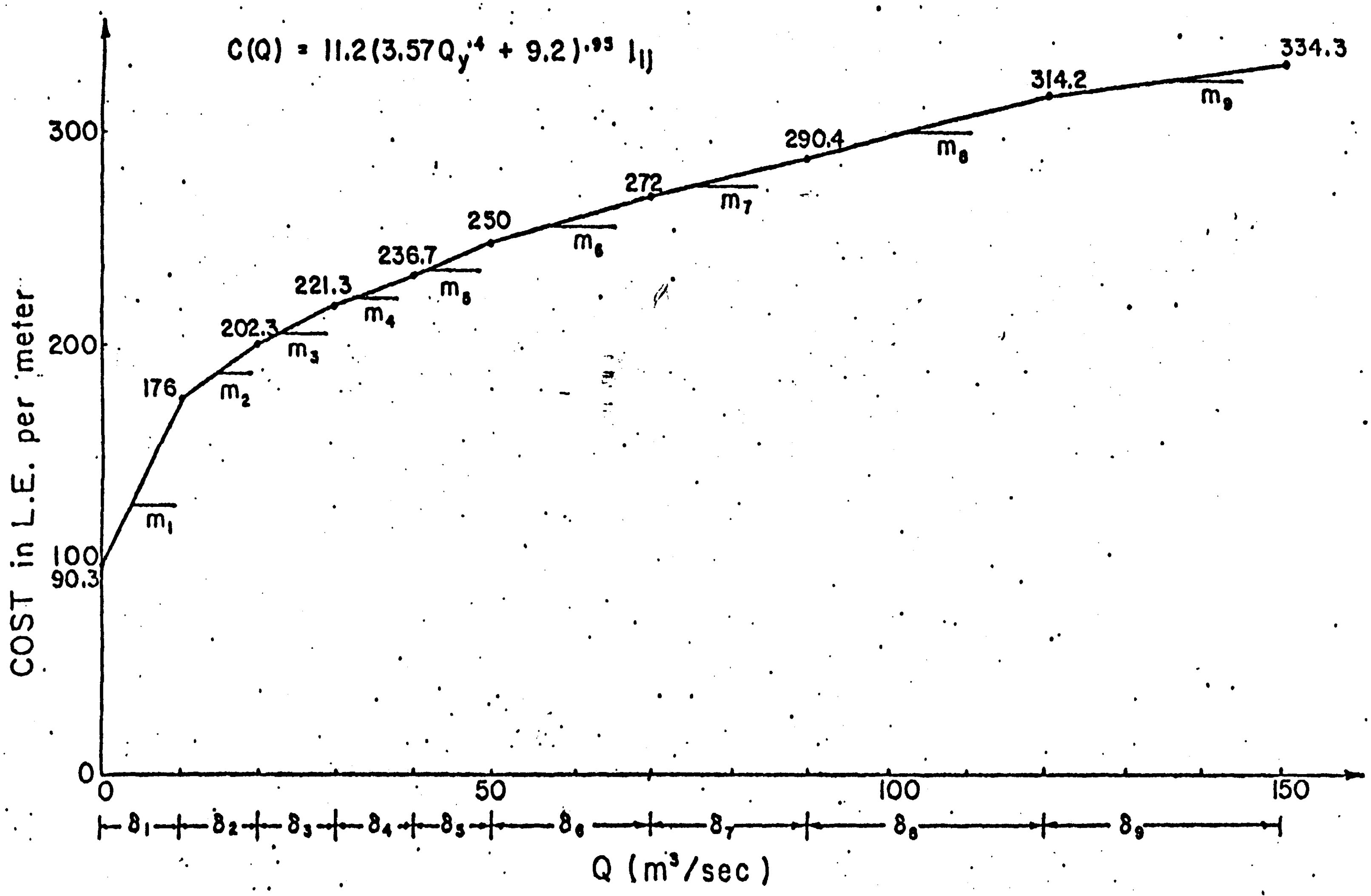

Figure C.2 **A Piece Wise Linear Approximation of the Lining Cost Function**

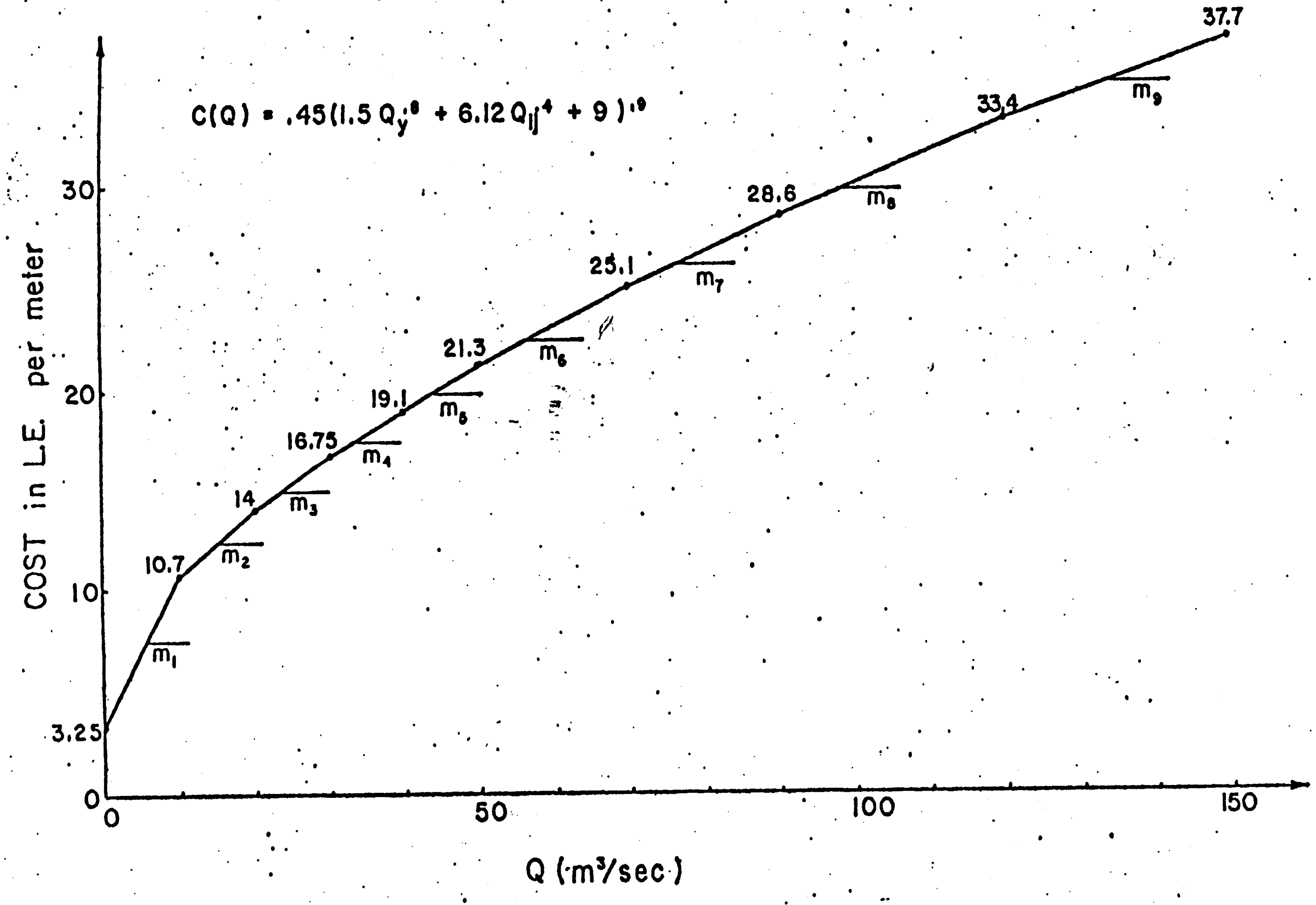

Figure C.3 **A Piece Wise Linear Approximation of the Maintenance Cost Functions**

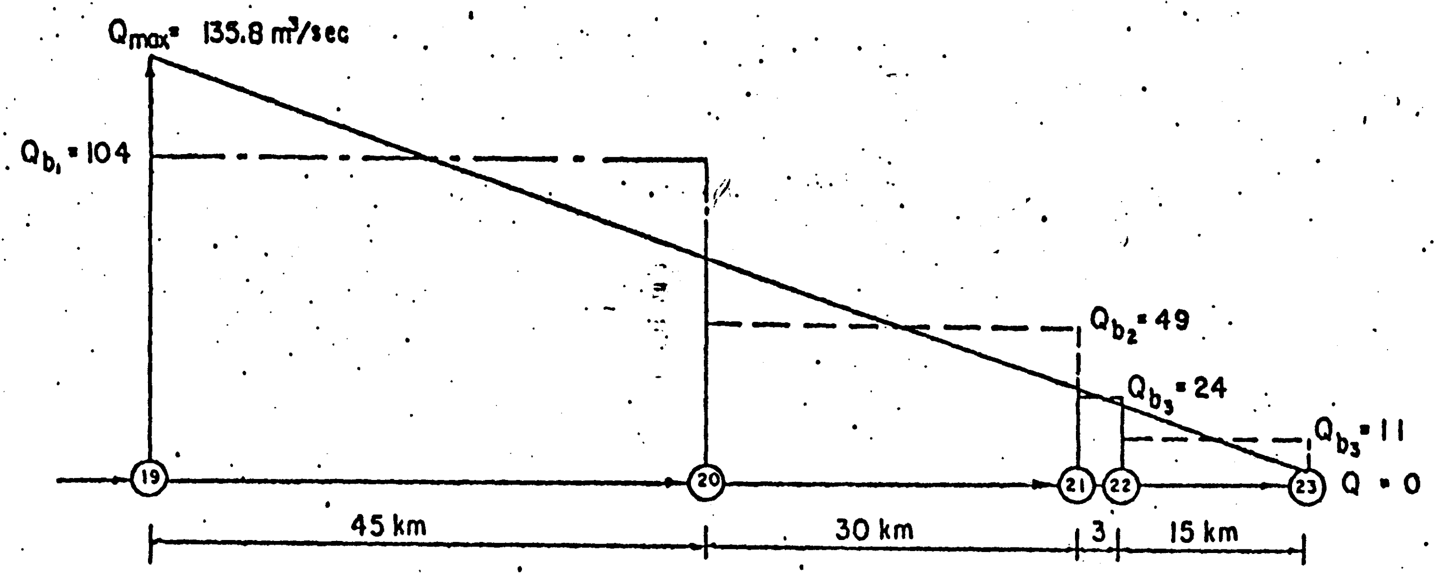

Figure C.4 **A Schematic Presentation of the Capacity Variation of Ismailia Canal**

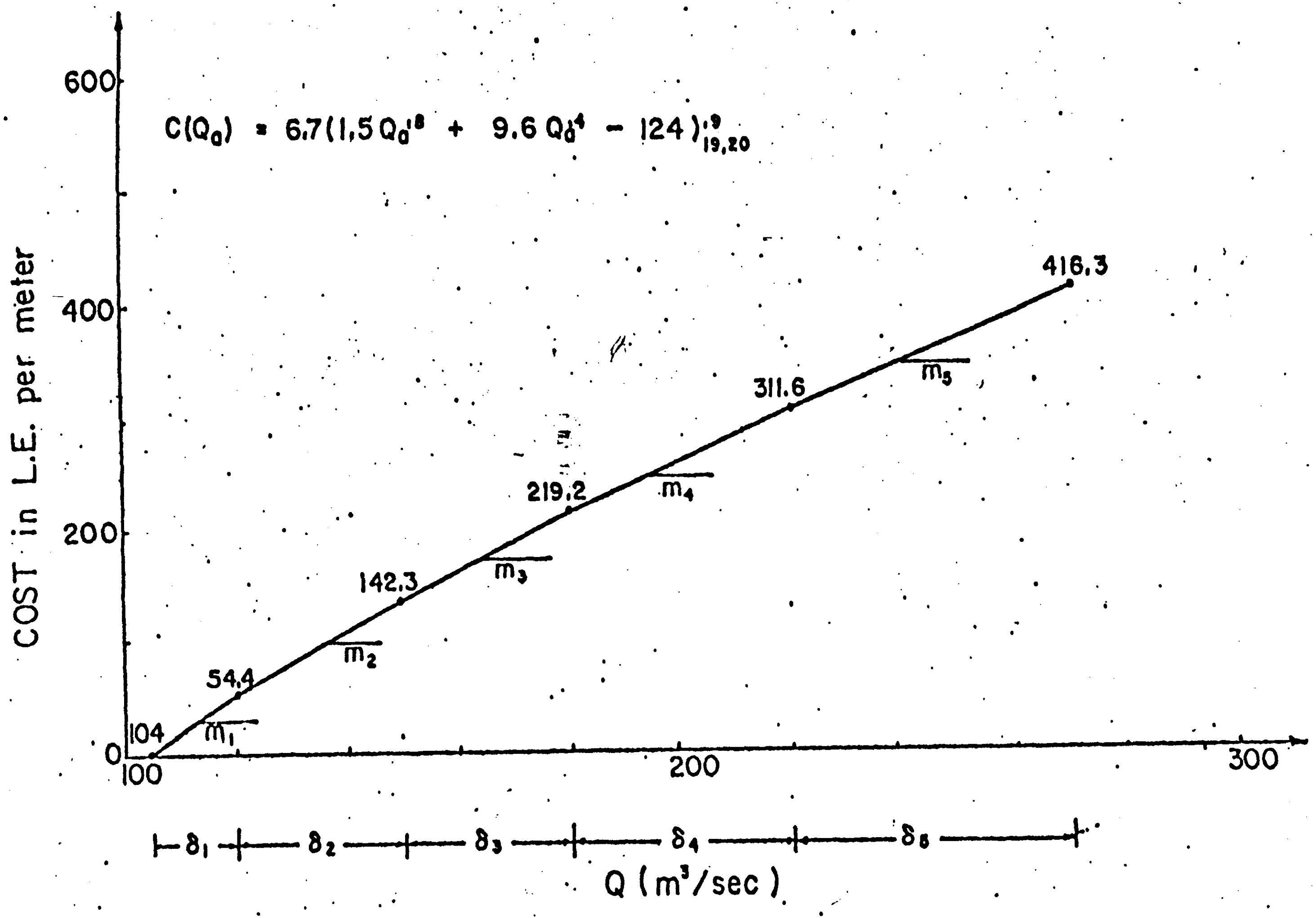

Figure C.5 **A Piece-Wise Linear Approximation of the Enlargement Cost of the First Reach of Ismailia Canal**

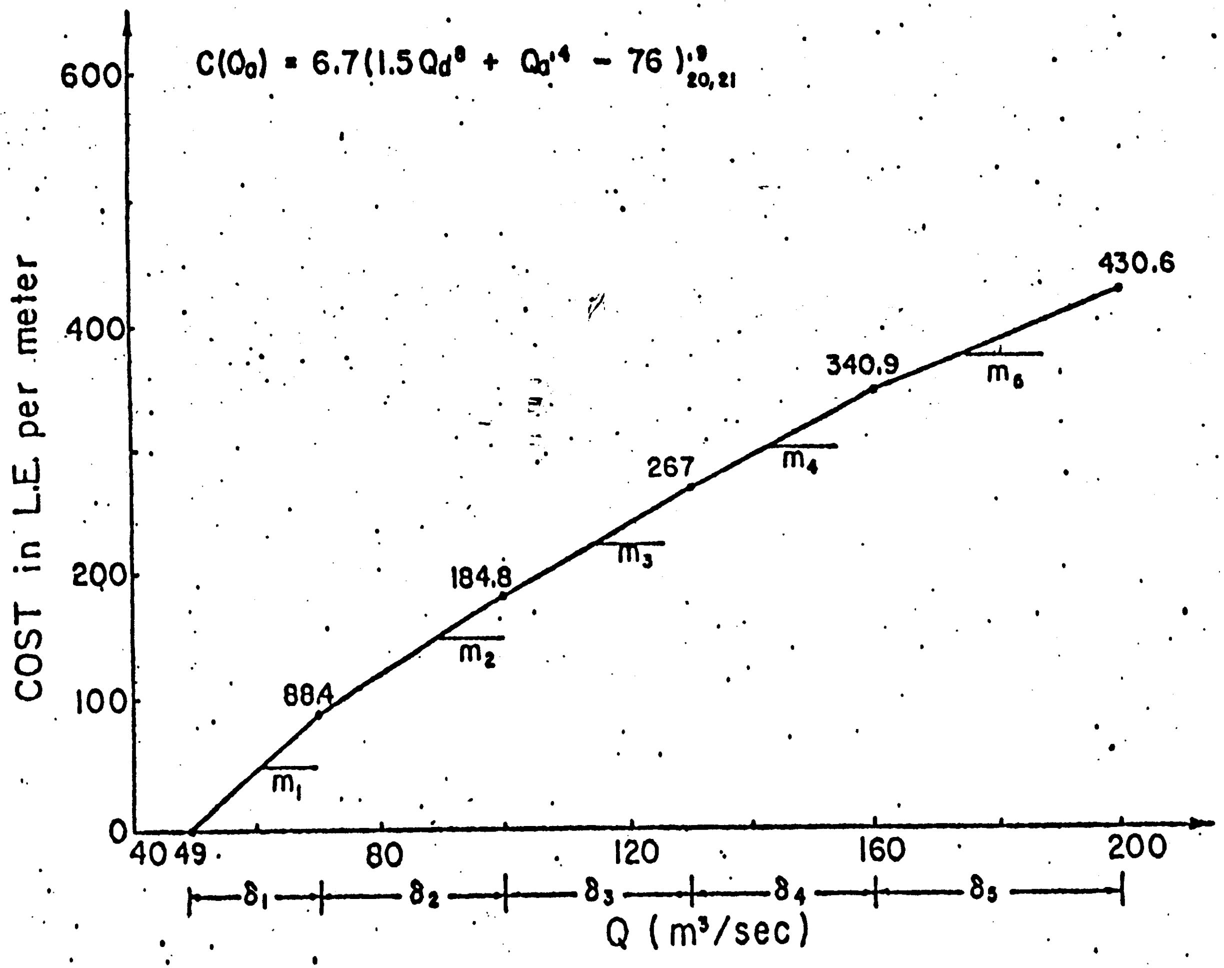

Figure C.6 **A Piece Wise Linear Approximation of the Enlargement Cost of the Second Reach of Ismailia Canal**

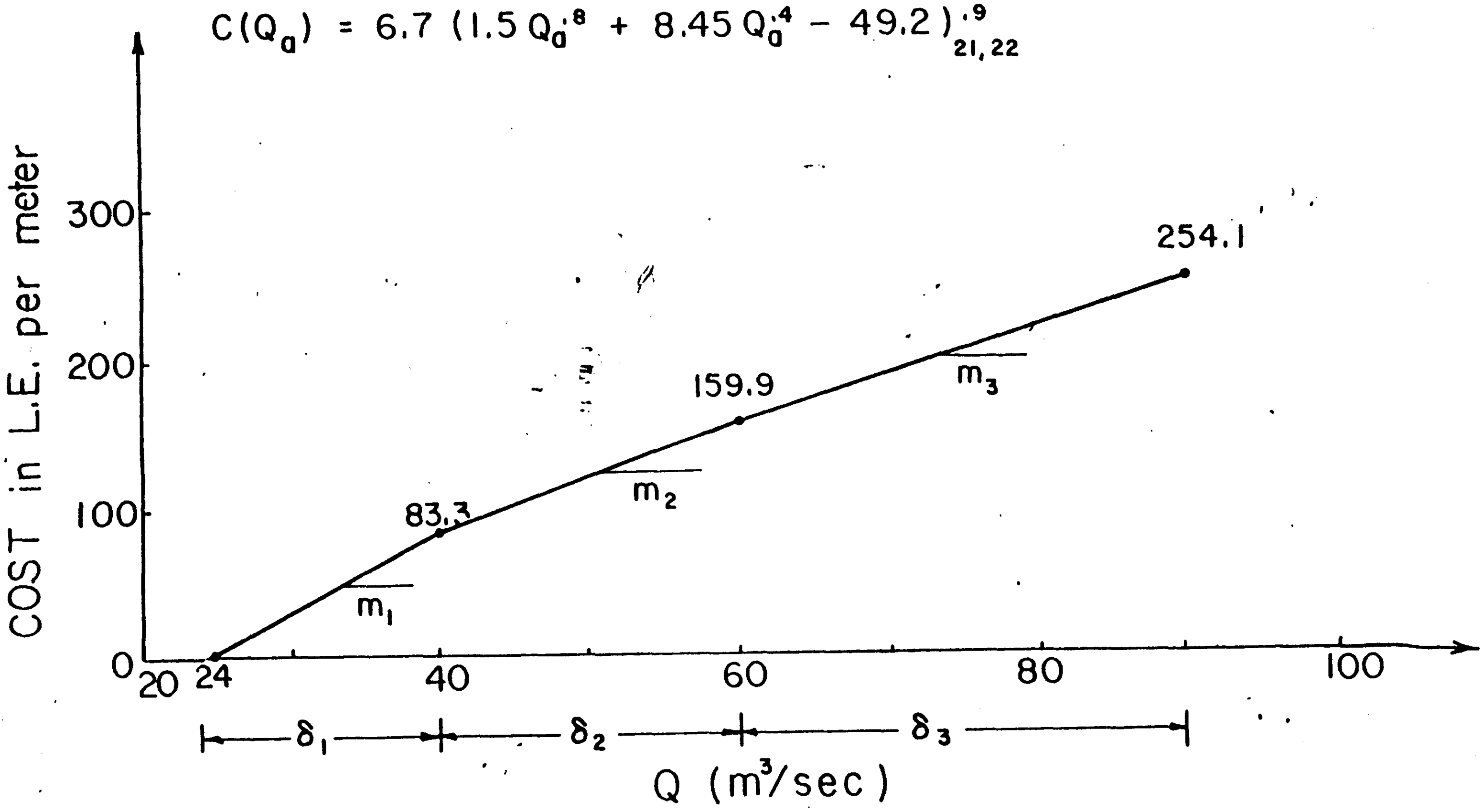

Figure C.7 A Piece Wise Linear Approximation of the Enlargement Cost of the Third Reach of Ismailia Canal

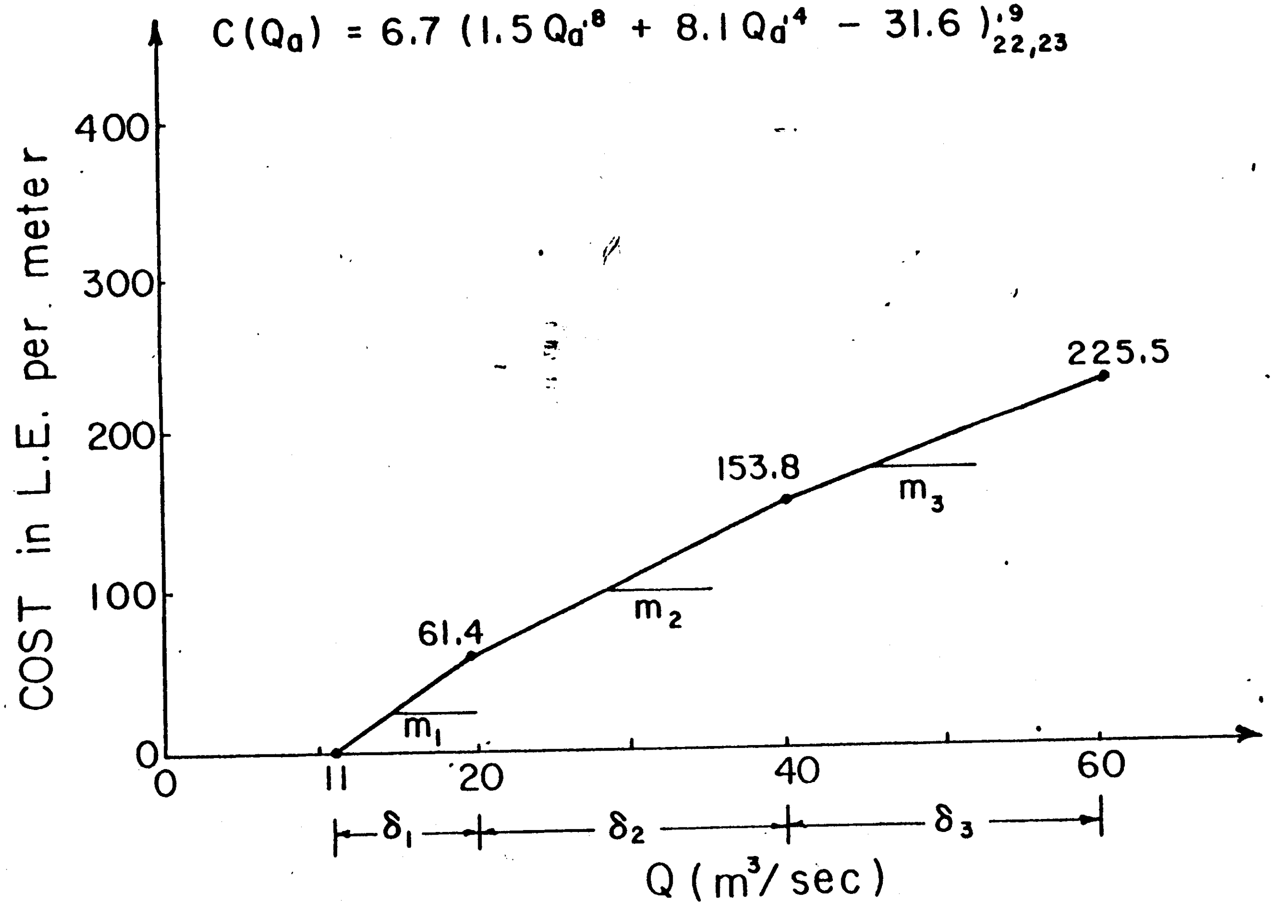

Figure C.8 A Piece Wise Linear Approximation of the Enlargement Cost of the Fourth Reach of Ismailia Canal

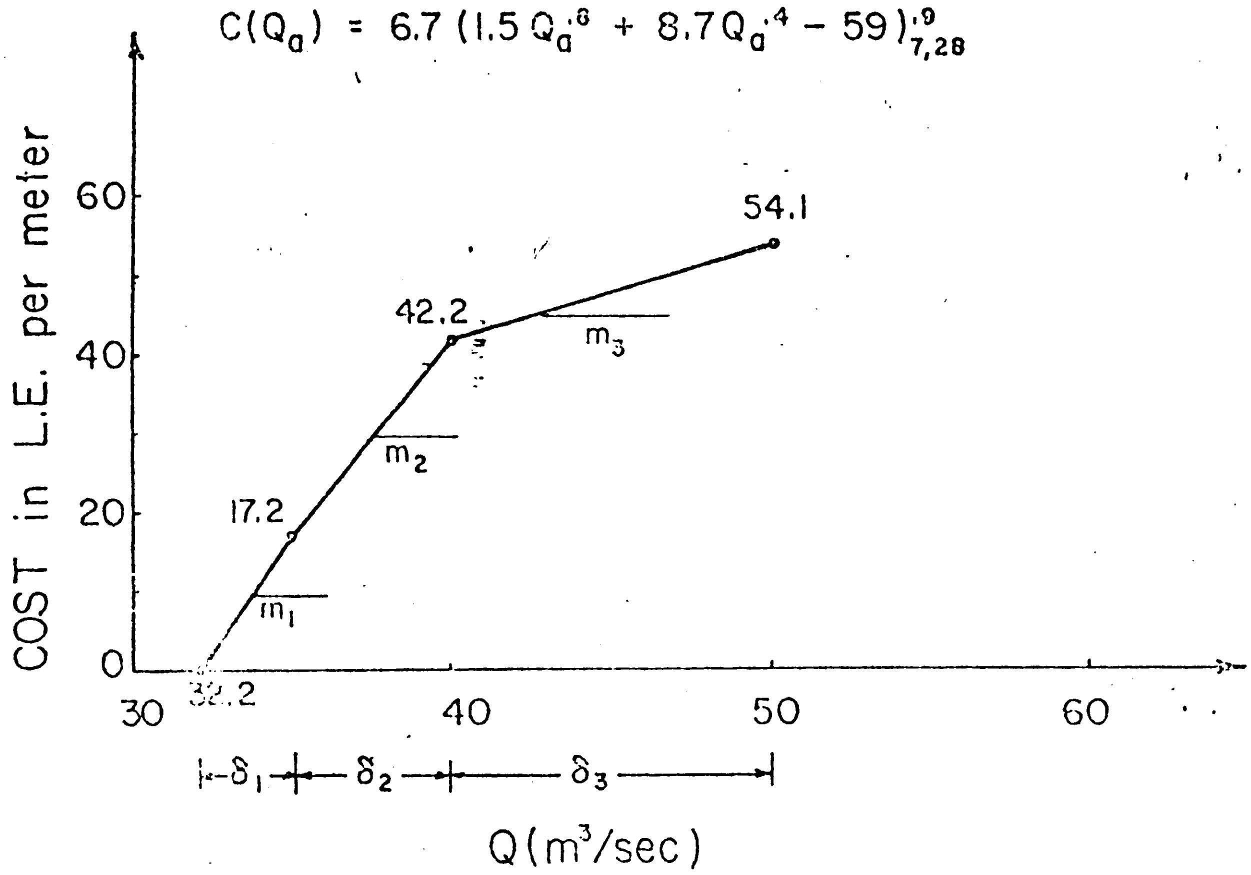

Figure C.9 A piece Wise Linear Approximation of the Enlargement Cost of El-Bahr El-Saghier

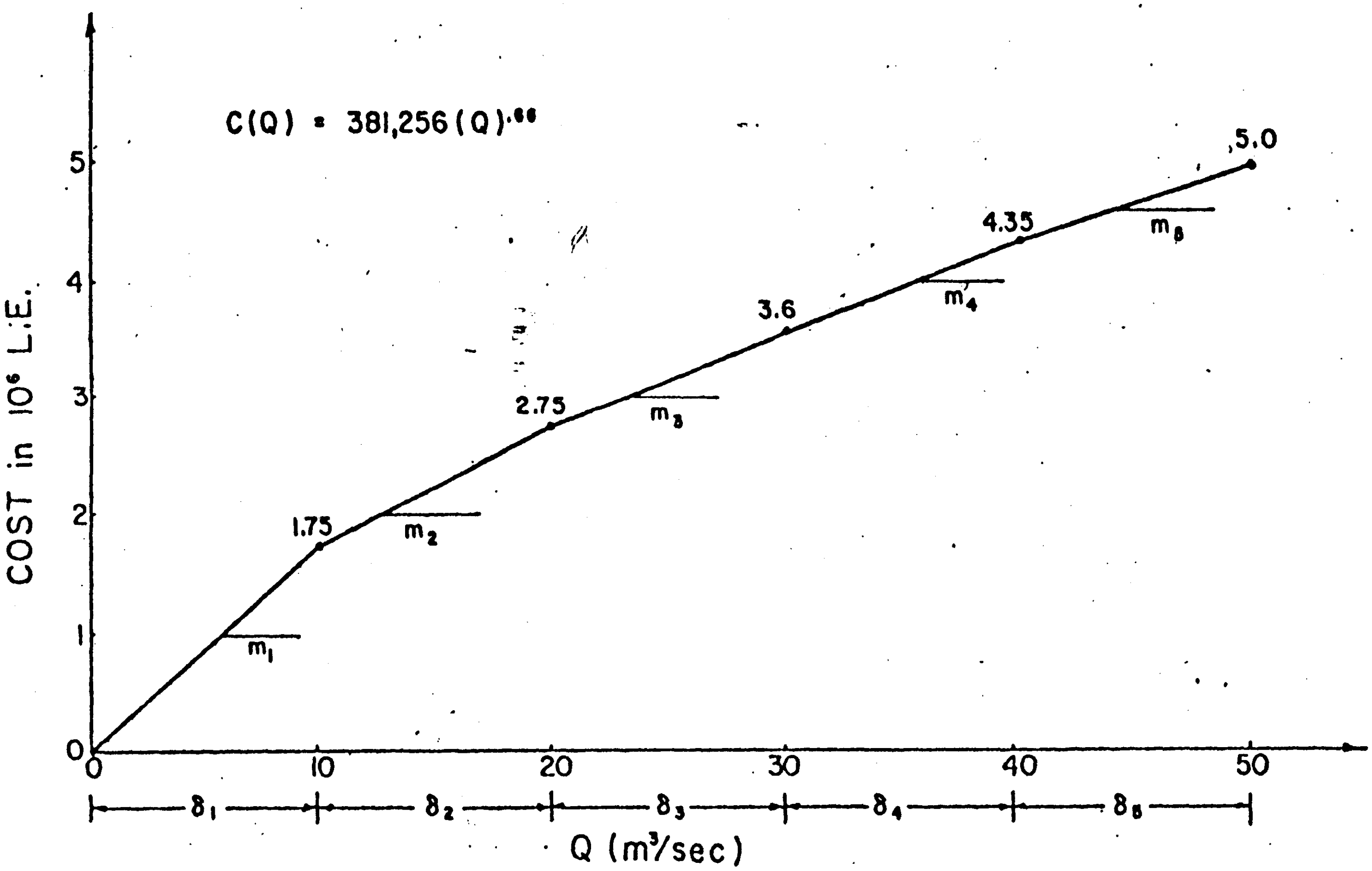

Figure C-10 A Piece Wise Linear Approximation of the Capital Cost of El Sarw Pump Station

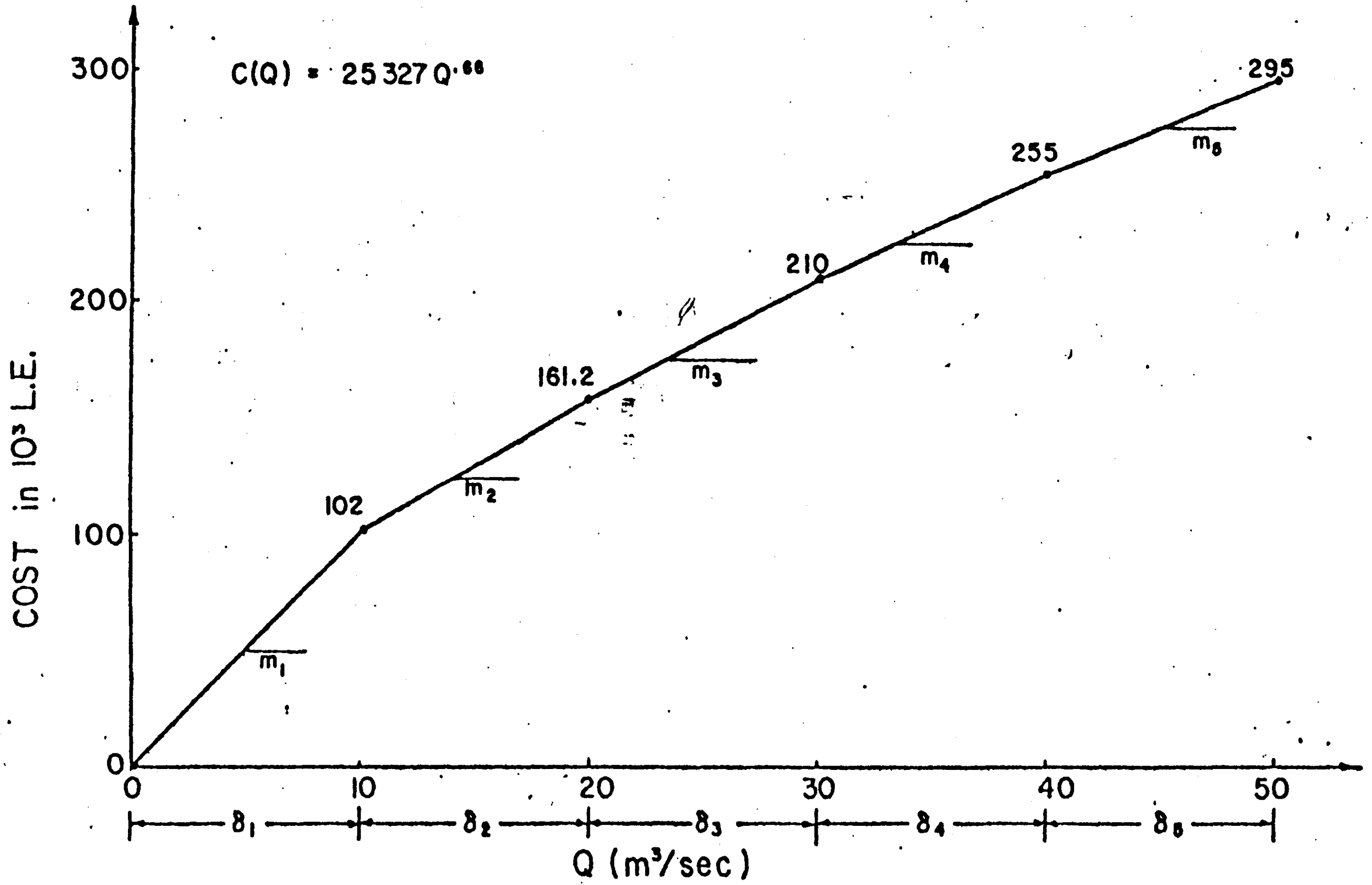

Figure C-11 A Piece Wise Linear Approximation of the Maintenance Cost of El Sarw Pump Station

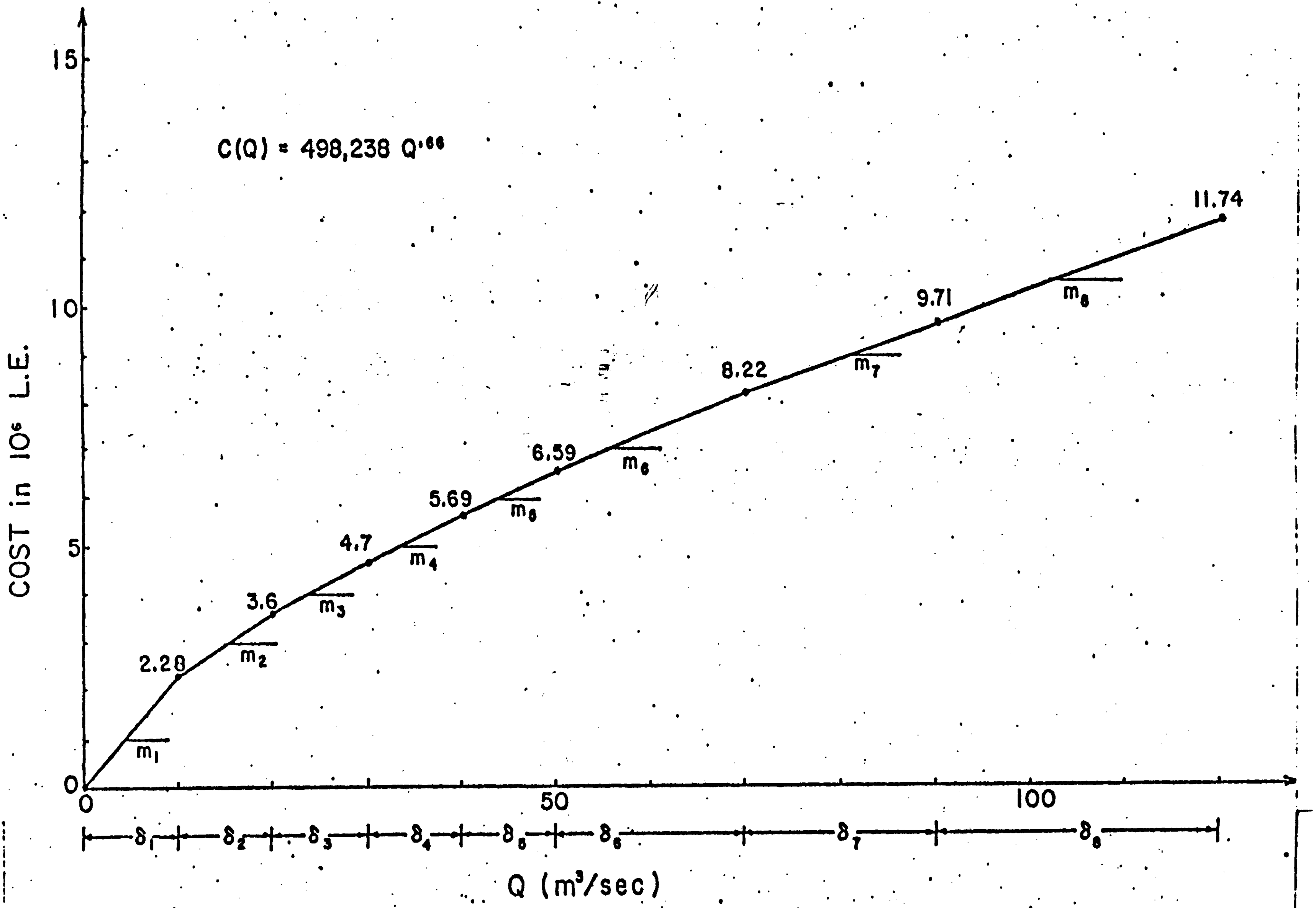

Figure G-12 A Piece Wise Linear Approximation of the Capital Cost of Bahr Hadus Pump Station

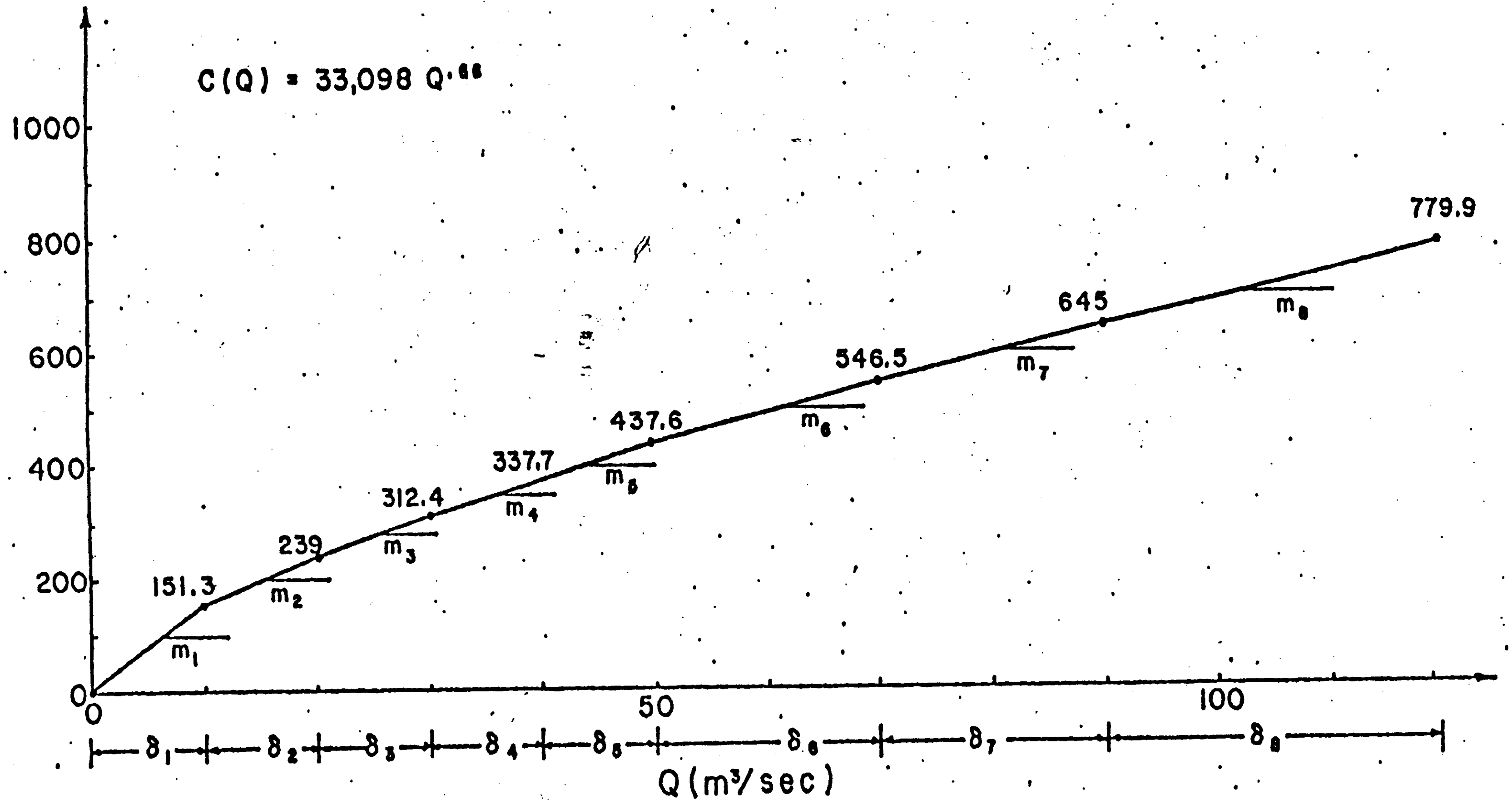

Figure C-13 **A Piece Wise Linear Approximation of the Maintenance Cost of Bahr Hadus Pump Station**