NILE VALLEY REGIONAL PROGRAM
PHASE II

Resource Management Series

Volume 3

INVENTORY STUDIES

Old Irrigated Lands of Egypt

Water Management

Editors
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Volume 3

Resource Management in the Old Irrigated Lands of Egypt: Water Management

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Weights and Measures

1 feddan (fed) = 0.42 hectare = 1.037 acres
1 hectare (ha) = 2.38 feddans
1 ardab maize = 157.5 kg

Acronyms

ARC = Agricultural Research Center
ASM = Available Soil Moisture
AWQI = Average Water Quality Index
bcm = Billion cubic meters
BOD = Biological Oxygen Demand
CFO = Cumulative Frequency of Occurrence
COD = Chemical Oxygen Demand
CU = Water Consumptive Use
DM = Dry Matter
DRI = Drainage Research Institute
EC = Electrical Conductivity
EC_w = Electrical Conductivity of Irrigation Water
EC&D = Efficiency of Conveyance and Distribution
ESP = Exchangeable Sodium Percentage
ET = Evapotranspiration
ETc = Crop ET
ETp = Potential ET
EU = European Union
EWUP = Egypt Water Use Project
FAO = Food and Agriculture Organization
IAS = Irrigation Advisory Service
IBRD = International Bank for Reconstruction and Development
ICARDA = International Center for Agricultural Research in the Dry Areas
IFAD = International Fund for Agricultural Development
IIP = Irrigation Improvement Project
ISAWIP = Integrated Soil and Water Improvement Project
Kc = Crop coefficient
MPN = Most Probable Number
NPV = Net Present Value
NVP = Nile Valley Project
NVRP = Nile Valley Regional Program

NWRC = National Water Research Center
PMA = Phenyl Mercuric Acetate
RIGW = Research Institute of Groundwater
S = Surfactant
SAR = Sodium Adsorption Ratio
SEV = Summation Exceedance Value
SEW = Sum of Exceedance in Winter
SD = Standard Deviation
SP = Soluble Protein
SWD = Soil Water Depletion
SWERI = Soil, Water and Environment Research Institute
TDS = Total Dissolved Salts
TP = Total Phosphorus
UNDP = United Nations Development Programme
WCP = Winter Closure Period
WR = Water Requirements
WUA = Water Users Association
WUE = Water-Use Efficiency

Foreword

Limited soil and water resources and threatened sustainability of agricultural production call for an effective resource management strategy and farming systems approach in agricultural research. Implementing a long-term research program where more emphasis would be on systems-oriented rather than commodity-oriented agricultural research would represent such a strategy. Therefore, the Resource Management Component of the Nile Valley Regional Program (NVRP) of the International Center for Agricultural Research in the Dry Areas (ICARDA) was developed. The Component, which started in 1994 in one of the Nile Valley countries, Egypt, and is expected to be extended to the others, aims at achieving sustainable production at a high level, based upon the need to protect the resource base (land and water) through good management. This would be achieved through basic intensive technical research (long-term on-station trials) and on-farm extensive monitoring of resources in farmers' fields and farmers' decision making logic.

Preparatory studies were carried out prior to conducting the trials and monitoring activities. The objectives of these studies were to define and characterize the major farming systems of the main agroecological environments; to identify and prioritize—with respect to the natural resources—the constraints to optimum utilization and the threats to sustainable production; and to provide an outline for the strategy, design and implementation of the long-term research activities.

The preparatory studies involved three procedures for information collection: **Inventory Studies**, in which existing information and details of the ongoing research and development, related to soil and water management, agronomy and cropping systems, and socioeconomics were collected; **Rapid Rural Appraisals**, which included qualitative sampling of farmers and extension views concerning current limitations, constraints, dangers, and opportunities in the utilization of soil, water, and inputs; and **Multidisciplinary Surveys**, which employed short-focused questionnaires to fill some important information gaps. In general, information collected in the preparatory studies dealt with resource description, resource utilization and management, productivity, and threats to sustainability. This knowledge was used in planning the long-term research activities at selected locations by identifying high-priority researchable resource management problems, in the context of realistic cropping sequences and farm level economics.

The outcome of these studies is hence presented in what is called the **Resource Management Series**. The series includes a total of 18 volumes on Inventory Studies, Rapid Rural Appraisals, and Multidisciplinary Surveys in the Old Irrigated Lands, New Lands, and Rainfed Areas. In the Inventory Studies, five volumes on the research and development activities and findings in each of the Old and New Lands were compiled. These volumes were on Agronomy, Soil Fertility and Management, Water Management, Socioeconomic Studies, and a Synthesis of all the latter. The Inventory Studies of the Rainfed Areas included two volumes, one on the Northwest Coast and the other on North Sinai.

These studies were conducted in Egypt with the involvement of the Agricultural Research Center (ARC), Desert Research Center (DRC), National Water Research Center (NWRC), National Research Center (NRC), Ain Shams University and ICARDA within the NVRP with financial support from the European Commission. Appreciation is expressed to all those who contributed to these important reviews and studies.

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Introduction

Egypt is a country in which land is an ample resource, while water is a very limited resource. The inhabited area in Egypt does not exceed 3.5% of the total area, and is confined to the narrow strip which borders the main course of the River Nile from Aswan in the south to Cairo in the north, plus the Nile Delta, which includes the area from Cairo to the shoreline of the Mediterranean Sea between the cities of Damietta in the east and Rosetta in the west. It is well known that Egypt has one of the oldest agricultural societies in the world, thanks to the relatively regular flow of the River Nile.

Throughout history, the area of cultivated land progressively increased. Then, at the beginning of the Twentieth Century, the addition of New Lands was halted, primarily because of the desire of the nation to convert from an agriculture-oriented society into a small industrial country. The secondary reason is the inadequacy of the water supply.

At that time, the country depended almost totally on Nile water, which flooded during a short period in the summer months. Regulation of the Nile flow started in the 1830s with the construction of the Delta Barrage. This enabled the conversion of some of the Delta lands from basin irrigation, in which a single crop was raised, to perennial irrigation of more than one crop per year.

Early in the Twentieth Century (1902) the construction of the Aswan Dam marked the second stage of controlling the River Nile flow in Egypt. The dam was raised twice to increase its storage capacity from the original one billion cubic meters (bcm) to five bcm. Control of the Nile flow led to the construction of new barrages on the Delta branches (1935), barrages on the main course of the Nile in Upper Egypt (Esna, Naga Hammadi and Assiut) and two barrages on the Nile branches in the Delta, namely, Zefta Barrage on the Damietta Branch and Edfina Barrage on the Rosetta Branch.

The construction of these major control structures was accompanied by the construction of an even larger number of smaller control structures needed to regulate the flow in lower level irrigation canals.

The effort of the Egyptians to control the Nile flow inside their country was crowned in the 1960s by the construction of the country's water bank: the Aswan High Dam.

The Aswan High Dam is not the nation's only storage water reservoir, but it is also the first line of defense against severe flood and drought. This fact was fully realized during the 1978–1987 drought which hit the African continent and caused famine and starvation in many countries, especially in the Sahel region. Yet Egypt enjoyed a more or less steady supply of water, except during a state of emergency in 1988, after which an above average flood restored the reservoir to its normal levels.

The High Dam enabled the country to convert its land from basin to perennial irrigation, to generate an appreciable amount of clean hydropower, to cultivate 1 million fed (420,000 ha) of rice and, most importantly, to start an ambitious plan for land reclamation projects. The area reclaimed following the construction of the High Dam is almost (or will reach in the very near future) 2 million fed (840,000 ha).

However, population growth in Egypt skyrocketed in the 1970s at a rate of 3% per year or more. After sincere efforts from both official and unofficial organizations, this rate has recently declined to 2.2%. This means that the number of inhabitants has doubled more than four times since the beginning of the Nineteenth Century. The population has risen from 2.5 million in 1800 to 5 million in 1850, to 10 million in 1900, to 20 million in 1950 to 40 million in 1978, to 57 million in 1993, and to an anticipated 66 million by the year 2000.

This increased population has made many demands on agriculture, with a pressing need for food and natural fiber, as well as a pressing demand for domestic water supply and industrial requirements. Water specialists have realized that the supply of water is being put under greater and greater pressure.

In 1990, the country reached the so called poverty line with a per capita water share of almost 1000 cubic meters per year. This is expected to fall to less than 500 cubic meters by 2030, when the population reaches an estimated 100 million. Given this state of affairs, the only available solutions for the crisis are:

- To add new water resources.
- To improve water management techniques in order to save wasted water.

New water resources for Egypt means either the implementation of Upper Nile projects where large quantities of water are lost in evaporation through the spreading of water over huge areas of marches and swamps, and/or the introduction of new technologies in seawater desalinization using cheap energy sources such as solar radiation, wind or waves.

Improvement of water management was, is, and will continue to be the major concern of those who are involved in the country's water budgeting. This is simply because competition between different users is becoming stronger and stronger. Agriculture, as a main user, presently consumes more than 85% of the total water budget. This is not likely to continue, because domestic and industrial requirements are rapidly increasing along with the increase in population. This means that irrigation of agricultural fields has to be within the most economic limits, and efficiency of water use should be kept at very high levels.

Irrigation water-use efficiency is composed of two elements:

- Conveyance and distribution efficiency.
- On-farm irrigation efficiency.

These two efficiencies are the only means of evaluating the performance of the irrigation system. However, new criteria have recently been developed to allow for:

- The economic value of water estimated by the price of the crop produced per unit volume of irrigation water supplied.
- Assessment of the system performance not only with respect to water saving mechanisms but also with respect to socioeconomic and environmental impact.

This assessment is particularly evident in Egypt since it is extremely difficult, at least at the present time, to price water because of the socioeconomic implications of such pricing. In the meantime, the high efficiency of the irrigation system is attributed to the recycling and reuse of land drainage water, which certainly entails some negative environmental impacts.

The objective of this report is to throw some light on the irrigation and drainage systems in the Old Lands, their merits, and their drawbacks. The two systems will first be described in terms of the farm, and in terms of the main systems. This detailed description will enable the identification of the major problems which affect the performance of the two systems.

Reference will be made to two major research programs conducted during the last twenty years, both of which adopted the integrated approach in the field of irrigation water management. These two programs are: Egypt Water Use Project (EWUP) and the Integrated Soil and Water Improvement Project (ISAWIP). Reference will also be made to one of the leading projects in the field of irrigation improvement, the Irrigation Improvement Project (IIP), which is the major pilot project in this field in Egypt. This project is under implementation at the present time and will be completed late in 1995.

The aim of this study is increased production of cereals and legumes, which is the overall target of the Nile Valley Regional Program. This report constitutes part of a general report on the proper management of different resources and the effect on the improvement of production of the above-mentioned crops.

General Overview of the Irrigation System

The irrigation system in Egypt is a closed system, which starts with one single inlet of irrigation water at the Aswan High Dam and ends in the north with the coastal lakes, which are in direct connection with the Mediterranean sea.

The irrigation system can be best described if the Nile system is divided into stretches. These stretches are:

- From the Aswan High Dam to the Esna Barrage.
- From the Esna Barrage to the Naga Hammadi Barrage.
- From the Naga Hammadi Barrage to the Assiut Barrage.
- From the Assiut Barrage to the Delta Barrage.
- The Damietta Branch.
- The Rosetta Branch.

The River Nile from Aswan in the south to the Esna Barrage in the north is scattered with floating pumping stations lifting water to the main irrigation canals, which serve the cultivated area. This cultivated area is about 170,000 fed (71,400 ha), most of which is planted to sugarcane, the major perennial crop in the area. Beside sugarcane, the dominant crops are wheat and berseem (a fodder crop) in winter, and grain sorghum and sweet maize in summer.

The cultivated areas in this stretch are irrigated by gravity and drainage water returned back by gravity to the River Nile. An exception to gravity irrigation is the reclaimed area in Wadi Abbadi and Radisia, where water is lifted to irrigate high elevations of originally desert lands.

Irrigation is carried out on the Kom Ombo plateau, which was reclaimed from desert lands at the beginning of this century. Extension of land reclamation projects is still taking place in this area.

From the Esna Barrage to the Naga Hammadi Barrage, the River Nile feeds two main canals which run parallel to it: the Asfon Canal and the Kallabia Canal. The summer, winter, and perennial crops in the area are similar to those of the previous segment.

The area downstream from the Naga Hammadi Barrage is irrigated by the East and West Naga Hammadi Canals, which run parallel to the River Nile.

The stretch from Naga Hammadi to the Assiut Barrage is marked by gradual conversion from sugarcane cultivation to the cultivation of ordinary farm crops. In the Governorate of Assiut, wheat, faba bean, berseem, and vegetables are the major winter crops.

The total cultivated area from Aswan in the south to Assiut in the north, which is usually called Upper Egypt, is about 1.108 million fed (0.465 million ha) divided between winter and perennial crops as follows:

- Wheat and barley — 0.379 million fed (0.159 million ha)
- Faba bean and lentil — 0.114 million fed (0.048 million ha)

- Berseem 0.204 million fed (0.085 million ha)
- Vegetables 0.091 million fed (0.038 million ha)
- Sugarcane 0.269 million fed (0.113 million ha)
- Orchards 0.051 million fed (0.021 million ha)

This means that the area planted to cereals, legumes, and berseem is almost two-thirds the total cultivated area.

Upstream of the Assiut Barrage, the Ibrahimia Canal, one of the largest man-made canals in the world, takes its water from the River Nile. This canal irrigates the lands north of the city of Assiut in Assiut, Minia, Beni Sueif, and Giza Governorates. About sixty kilometers north of Assiut, the Dairut head regulator was constructed to feed Bahr Yousef, a large irrigation canal which feeds the agricultural lands in Fayoum with water. The irrigated area in Fayoum is about 0.350 million fed (0.147 million ha), while the total area cultivated from the intake of the Ibrahimia Canal to the Delta Barrage is about 1.296 million fed (0.544 million ha). This area is divided between different winter and perennial crops as follows:

- Wheat and barley 0.284 million fed (0.119 million ha)
- Faba bean 0.158 million fed (0.066 million ha)
- Berseem 0.399 million fed (0.167 million ha)
- Vegetables 0.263 million fed (0.110 million ha)
- Sugarcane 0.038 million fed (0.016 million ha)
- Orchards 0.154 million fed (0.065 million ha)

The Nile Valley downstream from the Aswan High Dam varies in width from zero (north of Aswan), two kilometers (near the town of Daraw), and 26 kilometers (near the city of Beni Sueif).

The irrigation and drainage systems in the Delta are usually divided according to their location into three parts:

- The part east of the Damietta Branch, usually called the East Delta.
- The part confined between the two Delta Branches, known as the Middle Delta.
- The part located west of the Rosetta Branch, called the West Delta.

Each of these areas depends mainly on a major canal which is directly fed from one of the Nile branches called a *rayah* branch. The major irrigation canals are the *rayah* Tawfiki in the East Delta, the *rayah* Menoufi in the Middle Delta, and the *rayah* Beheiri in the west. Table 1 shows the area grown with winter and perennial crops in each of the Delta regions in 1990 in million fed (0.420 million ha).

Note that almost half of the total area is grown with berseem; the other half is more or less divided between cereals on the one hand and vegetables and perennials on the other.

Table 1. Distribution of winter and perennial crops in the Delta region (1990).

Crop	Area (million fed)			
	East Delta	Middle Delta	West Delta	Total
Wheat and barley	0.513	0.410	0.270	1.193
Food legumes	0.061	0.052	0.061	0.174
Berseem	0.592	0.786	0.571	1.949
Vegetables and others	0.192	0.202	0.242	0.636
Perennials	0.250	0.127	0.153	0.530
Total	1.608	1.577	1.297	4.482

Table 2 gives the distribution of winter and perennial crops in the Delta, Middle and Upper Egypt.

Table 2. Distribution of winter and perennial crops in the Delta, Middle and Upper Egypt.

Crop	Area (million fed)			
	Delta	Middle Egypt	Upper Egypt	Total
Cereals	1.193	0.284	0.379	1.850
Food legumes	0.174	0.158	0.114	0.446
Berseem	1.949	0.399	0.204	2.552
Vegetables and others	0.636	0.263	0.091	0.990
Perennials	0.530	0.192	0.320	1.042
Total	4.482	1.296	1.108	6.886

The policy, adopted by the Egyptian Government since the late 1980s, of freeing the prices of the majority of farm crops has resulted in an increase in the area of cereals at the expense of berseem.

Table 3 gives the water requirements of cereals, food legumes, and berseem in the three regions of Egypt, and the total seasonal water requirements of the three crops. Total water requirement of cereals, food legumes, and berseem is about 9112 million m^3 or almost 20% of the total irrigation water budget.

Table 3. Water requirements of winter and perennial crops in the Delta, Middle (ME) and Upper Egypt (UE).

Crop	Cultivated area (million fed)			Crop water requirements (m^3/fed)			Gross water requirements (million m^3)		
	Delta	ME	UE	Delta	ME	UE	Delta	ME	UE
Cereals	1.193	0.284	0.379	1,280	1,568	1,827	1,527	445	692
Food legumes	0.174	0.158	0.114	1,609	1,097	2,195	280	316	250
Berseem	1.949	0.399	0.204	2,106	2,843	3,421	4,105	1,245	254

1 ha = 2.38 fed.

Characteristics of the Conveyance and Distribution Systems

Irrigation water is distributed through an intensive network of irrigation canals, which varies according to function between:

- Carrier canals from which extraction of water is not allowed.
- Distributary canals which divert water either to lower order canals or directly to the irrigated fields.

Distribution is also made between irrigation canals according to their size, or the area they serve as follows:

- Principal (Public First Order Canals or *rayahs*): receive water directly from the River Nile or its branches and convey it to the main canals.
- Main Canals or Second Order Canals: take water from first order canals and pass it to branch canals.
- Branch Canals: receive water from first or second order canals and convey it to distributary canals. Direct irrigation at the lower reaches of branch canals is sometimes permitted.
- Distributary Canals: receive water from branch canals for distribution to field ditches called *mesqas* through legal outlets. Irrigation rotations are normally applied at this level.

In most cases, direct irrigation is not permitted from the first two classes of irrigation canals.

On-farm irrigation from distributary canals is carried out in about 80% of the area by lifting. Gravity irrigation takes place only in Aswan and Fayoum Governorates.

Almost all irrigation canals in the Old Lands are unlined. The problems associated with these types of canals are:

- Aquatic weed growth includes three different types: emergent, submerged, and floating. Despite the mechanical cleaning which takes place twice a year in every irrigation canal, aquatic weeds cause severe problems with respect to their high water consumption on the one hand and the restriction of flow to the downstream reaches on the other. Cleaning of farm *mesqas* has traditionally been the responsibility of the farmers. All other higher orders of canals are cleaned by the Irrigation Departments. Mechanical cleaning causes the cross section of the irrigation canals to become larger than the design section. If the same discharge passes through the canal, velocities will be smaller, which encourages more aquatic weeds to grow. In the meantime, cleaning removes part of the top layer, which has very low permeability, thus creating higher seepage rates.
- Seepage from irrigation canals is a function of the water level with respect to the adjacent land levels and the groundwater elevation. It is also a function of soil type. Seepage rates are higher in distributary canals, which crack during off-periods allowing more water losses to take place.

- Unstable and oversized cross sections are caused by sedimentation, erosion of canal banks by water scoring and animal traffic, soil removal for brick making, and enlargement from cleaning operations to remove weeds and sediments.

Estimates of the total length of the conveyance and distribution networks differ. The figures which can be stated with confidence are in the realm of 40–45 thousand kilometers, excluding private *mesqas*. The basic formula used in the design of these canals is the well known Manning Equation, based on the area served, the area of each crop, water duty of each crop, soil type, conveyance, and on-farm losses.

Major structures in the delivery system include: 5623 intake structures, 2887 head regulators, 162 weirs, 1761 tail escapes, 153 spillways, 9955 bridges, and 567 crossing structures.

Losses from the conveyance and distribution systems

The main losses from the conveyance and distribution systems are:

- Evaporation from free water surfaces. This type of loss is unavoidable in open canals where water is directly exposed to the atmosphere. It is obvious that evaporation losses are higher with hot, windy, and dry climates, and lower with cool, still, and humid climates.
- Seepage losses. Water lost by seepage depends on water levels in the canal with respect to the adjacent lands, groundwater table elevation, and soil type. In some cases water is lost by seepage from irrigation canals to the agricultural land, to the drains and/or to the shallow groundwater aquifer. If the water level in the canal is low, seepage losses might be converted into gains.
- Evapotranspiration by water plants and aquatic weeds. Water plants and aquatic weeds consume approximately twice the quantity of water consumed by evaporation from free water surfaces (Khattab, personal communication). As mentioned earlier, water plants do harm not only by their excessive water consumption, but they also restrict water supply to lower ends.
- Tail end losses. In order to avoid the risk of over-topping the banks of irrigation canals, which might cause flooding of lands, damage of property and loss of life, the tail end of irrigation canals must not be a dead end. Almost all ends of canals are either connected to higher order canals or to drains by means of spillways. This allows water to continue rising in the canal up to a certain elevation, after which it spills into the connected canal or drain. Since the irrigation system does not include, according to design, any storage capacity, withdrawal of water should be continuous (i.e. 24 hours a day). If farmers do not irrigate at night, fresh water from irrigation canals moves along unused by the drainage system, creating tail-end losses. This phenomena takes place frequently during winter, when demand is low and the weather at night is cold. Tail end losses are minimal in summer when demand is at its peak and extraction of water from the system lasts for longer hours.
- Leakage of gates and faulty operation of gates. Most of the control and off-take structures are equipped with the traditional heavy steel gates of the "Botcher" or Fahmy Hunien type, which were introduced to the irrigation system 50–70 years ago and are

operated manually. When the fit between the edges of the gate and the groove in which the gate moves up and down is not tight, water leaks from the gate to the downstream side, even if the gate is completely closed. When water is closed in a branch canal during an off-rotation period, any leakage from the feeding canal is considered a loss.

Again, failure of the gate operator to maintain the required upstream water level causes the quantity of water delivered to the downstream side to be either more than necessary or less than the actual requirements. In the first case, surpluses are considered a loss. In the second case, part of the area served will not receive adequate water.

Conveyance and distribution efficiency

Conveyance and distribution efficiency (EC&D) is defined as the ratio between the quantity of water which reaches the distributary canal (q_d) to the quantity of water diverted from the source (q_s), i.e.:

$$EC\,\&\,D = \frac{q_d}{q_s} = \frac{q_s - (C\,\&\,D)l}{q_s}$$

where (C&D)l refers to the conveyance and distribution losses.

Conveyance and distribution losses depend on the above-named five elements (evaporation, seepage, water plants, tail-end losses, and leakage from gates). They are also a function of the distance between the locality where efficiency is required to be determined and the source of water.

This means that conveyance and distribution losses are expected to be smaller in Upper Egypt than in Middle Egypt and smaller in Middle Egypt than in the Nile Delta. In other words, conveyance and distribution efficiency is higher to the south.

Estimates of conveyance and distribution efficiency are 95, 85, and 80% in Upper, Middle, and Lower Egypt, respectively. The "Irrigation Efficiency Indicator" as given by ISAWIP for the total research area, 80,000 fed (33,613 ha), served by the Bahr El Sahir Canal, range between 67 and 72%. For El Nazl pilot area within the same project, the range is 55–62%.

Irrigation Rotation

The region served by a number of distributary canals fed from a branch canal is divided into approximately two equal areas with water delivered by a dual (or two turn) rotation, or into approximately three equal areas with water delivered by a three turn rotation.

Space and time allocation of any type of rotation is a function of soil type, cropping pattern, season, and boundary conditions. For example:

- Two turn rotation
    - 4 days on and 6 days off (rice).
    - 7 days on and 7 days off (cotton).
- Three turn rotation
    - 4 days on and 8 days off (general crops/summer).

- 5 days on and 10 days off (general crops/winter/Upper and Middle Egypt).
- 7 days on and 14 days off (general crops/winter/Delta).

The nationwide system has recently changed to 7 days on and 7 days off in summer and 5 days on and 10 days off in winter, except for rice areas where the rotation is 4 days on and 6 days off.

The main reason for the application of the rotation system is water saving. When water does not flow in half or two thirds of the distributary canals (in the cases of two and three turn rotation respectively), evaporation and seepage losses are reduced. In the meantime, when farmers realize that if they do not irrigate during their designated rotation, they will only be allowed to irrigate in the following period—which might be a long time resulting in production losses—they will do their best to irrigate during their rotation. Third, if only half (or one third) of the area is irrigated at a time, the drainage system will be relieved and will perform better. Fourth, the off period can be used to carry out small repairs and maintenance on the system. Finally, the off period gives farmers the opportunity to do other work such as fertilizing, applying pesticides, etc.

However, the rotation system has the disadvantage of eliminating the possibility of scheduling irrigation. For instance, if three winter crops—namely wheat, faba bean, and berseem—are grown in the same rotation area, wheat needs to be irrigated only once every month, faba bean needs an irrigation once every three or four weeks, and berseem requires irrigation once every two weeks. If water is delivered in a 7 days on and 7 days off rotation, then the first two farmers will irrigate once every 14 days, which is, in fact, more than the actual crop water requirement and results in a loss to the system.

The situation is even worse with summer crops during peak demand because many farmers, especially those at the heads of the canals, those who grow crops sensitive to moisture deficit, and/or those who have sandy soils, occasionally irrigate both at the beginning and at the end of the on period to be certain that there will be adequate soil moisture until the next on period.

When the rotation continues although farmers have little demand for water, canal water flows unused through the system to the nearest drain. Because of this state of affairs, the conversion from a rotation system to a continuous flow system is strongly recommended. With continuous flow, water will pass through irrigation canals continuously and farmers will abstract water when they feel that their crops need it and will thus withdraw the amount of water the crop actually needs and no more.

Upstream Water Control

Measurements of discharges in the irrigation system in Egypt take place only at the highest levels. Water passing from the Aswan High Dam and the old Aswan Dam is measured accurately. Also, the barrages on the main course of the River Nile and the two branches are carefully measured. Off-take structures of first, second, and third order canals are normally calibrated and their discharges determined by the upstream and downstream water levels and the opening of the gate. Below this level, no measurements take place and discharges are determined by the upstream water level of the head regulators.

Head regulators are normally located just downstream from the off-take of branching canals, and therefore the upstream water level of the head regulator indicates how much water passes through it and how much water is diverted to the branch canal. Obviously, flow in both cases is a function of the gate opening.

Adjustment of upstream and downstream water levels and the gate opening is done by the gate operator, who receives his operating instructions from the engineer in charge. In this process, mistakes might be committed either on purpose or innocently. The result is either excessive quantities of water going to the wrong users or the right users not getting their fair share, or both.

This problem can be solved in one of three ways:

- Installation of automatic gates which operate either mechanically or electrically when a certain downstream water level is reached. The limitation of this type of gate is that a supply of electricity is not necessarily available in remote areas where control structures are located.
- Installation of automatic gates which are self-operated and adjusted according to the difference in elevation between the upstream and downstream water levels according to pre-set conditions. This type of gate is the state-of-the-art in this field. However, being a very modern technology, the operation and maintenance of these gates also needs sophisticated and skilled technicians.
- For smaller-sized canals, the Nyrbic gate provides a reasonable solution, in which manual operation is combined with accuracy of flow measurement and ease of operation and maintenance.

The advantage of these gates, in addition to what is mentioned above, is their tightness which reduces losses due to leakage to almost nil.

Downstream control in general has an additional advantage over upstream control, which is the possibility of creating a storage capacity in the system. This storage zone could prove useful when withdrawal is at a halt, and thus fresh water can be kept in the irrigation canals instead of flowing unused to the drainage network.

Winter Closure

The whole irrigation system in Egypt is closed for a certain period during low water demand, and when there is a possibility of rainfall, which compensates for the unavailability of irrigation water.

The winter closure was introduced at the beginning of the century with a duration of 40 days, plus 5 days before and 5 days after for gradual closure and gradual opening of the system.

The objectives of the winter closure are as follows:

- To clean the irrigation canals from sediments and aquatic weeds.
- To conduct repairs and maintenance of control and other structures.
- To build new structures.

- To allow the soil to drain and get rid of surplus moisture.

A number of alternatives and changes in the timing and duration of the winter closure have since taken place.

The winter closure is now 25 days long, and is staggered between the various regions: from 5 to 30 January in Upper and Middle Egypt, 11 January to 5 February in Fayoum, and from 19 January to 12 February in the Delta. Complete closure of the whole system only takes place during the period 10–30 January.

However, despite the objectives of the winter closure mentioned above, other factors which are not in favor of closure are:

- Water has to be released to meet municipal, domestic, and industrial requirements as well as for hydropower generation.
- Water is required for navigation in the upstream reaches. It should be noted here that the closure period corresponds with the high season of tourism in which five star hotel ferries navigate between Luxor and Aswan.
- Water is needed for safe heading between the upstream and downstream reaches of the main barrages.
- Water is needed to keep the banks of the River Nile from slipping if the flow is extremely low.
- Water is needed to keep a continuous flow through the mouths of the river so that seawater does not intrude during high tides and consequently affect the salt balance of the Delta.
- Water is needed to flush toxic and harmful substances into the sea and keep the environment of the irrigation network clean.
- Water is needed to irrigate crops which suffer during this particular period from ground frost (e.g. sugarcane and vegetables grown in Upper and Middle Egypt).
- Water is needed for the irrigation of newly reclaimed lands where modern irrigation systems are used and the soil is light in texture. The moisture storage capacity of this types of lands cannot tolerate the deficit caused by prolonged periods of drought.
- Water is needed to conserve the media of fresh-saline water interaction at the mouth of the river branches where special species of fish breed.
- Finally, water is needed to provide the tail ends with fresh water supply for coastal cities like Port Said, Damietta, and Alexandria.

In view of the above reasons the whole idea of winter closure becomes questionable, especially since the improvement program calls for the continuous flow to be put into general use. In the meantime, the original objectives of the winter closure, which were the cleaning of canals, repair and maintenance of structures and the construction of new control works, can be done with the water running into the canals. Otherwise, the specific branch or main canal in which works have to be carried out can be closed, as is the case with the domestic water supply and sewage network. It should also be stated that drainage of the soil in the root zone during the winter closure is no longer valid, especially in areas installed with field drainage systems. Other areas which are provided with open secondary and main drains also help parts of these lands get rid of their surplus moisture.

It is therefore recommended that winter closure be subject to in-depth investigation to decide whether or not the practice should be continued.

The above indicators reveal that winter closure should be ended. If this is the case, cancellation should be gradual, i.e., it should be canceled first in one region only. Upper Egypt is nominated because of the very low possibility of rainfall and its position at the head of the system, which means that any surplus water can be used beneficially downstream.

If the exercise in Upper Egypt is successful, the plan should be extended to Middle Egypt and then to the Delta.

In the meantime, the duration of the off period in the Delta's winter rotation should be extended to 2–3 weeks instead of 1 week); this should gradually be applied to Middle and then Upper Egypt.

Reuse of Drainage Water

In view of the shortage of fresh water in Egypt and also since large quantities of land drainage water of relatively good quality is released every year into the Mediterranean Sea and the coastal lakes, reuse of drainage water has become a major strategy of the Egyptian authorities.

Reuse of drainage water is not new to Egypt. It started as early as 1928 when the Upper Serw Pumping Station was constructed to lift water from the Serw Drain to the Damietta Branch of the River Nile. This pumping station was followed by a large number of stations in which fresh and drainage water were mixed and used for irrigation. These stations are mainly concentrated in the southern part of the Nile Delta.

Table 4 shows the amount of reused water used from 1984/85 to 1990/91 for the three Delta regions (East, Middle and West), the total annual amount for the Delta ranging from 2.659 bcm to 4.223 bcm.

Table 4. Reused drainage water (million m^3) in the Delta.

Region	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91
East Delta	1,300	1,263	1,420	1,381	1,400	1,504	1,585
Middle Delta	764	747	766	693	704	1,506	1,999
West Delta	814	789	807	629	555	625	639
Total	2,878	2,799	2,993	2,703	2,659	3,635	4,223

Moreover, all drains in Upper and Middle Egypt disperse their water either by gravity or by lifting to the main course of the Nile. Measurements which are carried out on the drainage network in the Delta are not carried out in Upper and Middle Egypt. The quantity of drainage water which is gained by the river in these two regions is estimated at 2.3 bcm/year.

There are two reuse projects under construction:

Al Salam Canal Project, in which mixed fresh and drainage water at a ratio of (1:1) will be used to irrigate an area of about 600,000 fed (252,000 ha) on either side of the Suez Canal.

The area to the west of the Suez Canal is almost 200,000 fed (84,000 ha) and includes:

- 50,000 fed (21,000 ha) south of Port Said.
- 62,000 fed (26,050 ha) north of Hussienia.
- 73,000 fed (30,663 ha) south of Hussienia.
- 15,000 fed (6,300 ha) south of Materia.

The area east of the Suez Canal in Sinai Peninsula is about 400,000 fed and includes:

- 60,000 fed (25,200 ha) in the Tina Plateau.
- 75,000 fed (31,500 ha) south of East Qantara.
- 70,000 fed (29,400 ha) in Rabaa.
- 70,000 fed (29,400 ha) in Beer El Abd.
- 125,000–135,000 fed (52,500–56,700 ha) in El Ser and El Qwareer.

Fresh water will be taken from the Damietta Branch upstream from the Farskour Head regulator. Drainage water will be obtained from the Lower Serw Pumping Station and the Bahr Hadous Drain.

The Nubaria Canal project feeds the canal with drainage water from the Omoum Drain at kilometer 46.0, upstream from the off-takes of El Nasr and El Bustan Canals. The mixed water will be used for land reclamation projects on the two canals, which may total as much as 500,000 fed (210,000 ha).

When these two large projects are completed, the total drainage water reused in the Nile Delta will be about 7.0 bcm/year.

However, in spite of the fact that the reuse of drainage water increases water-use efficiency, it has a number of limitations. These are:

- Good quality drainage water that can be used for irrigation either separately or after mixing with fresh water is a direct result of large-scale on-farm operations and tail-end losses. It would be better if these losses could be prevented, and the cost of pumping from the drainage system to the irrigation system saved.
- If these losses are saved in the future due to the implementation of improvement projects, the areas served by drainage or mixed water will suffer from severe water shortages. Improvement projects not only reduce the quantity of drainage water but they also deteriorate the quality of this water, and therefore sustainability of these projects is questionable.
- Drainage water is a collection of a number of waters that: i) pass above the soil as surface runoff; ii) pass through the soil until reaching the field drain; and iii) flow upward to the field drain by capillary action from shallow groundwater aquifers. This water is, therefore, expected to be loaded with salts, fertilizers (nitrogen and phosphorous), and other chemicals such as pesticides, insecticides, and herbicides.

Sometimes raw sewage and industrial waste water is added to drainage water, adding another dimension from a pollution point of view. Drainage water reuse has, therefore, to be treated with care to avoid pollution of soil, crop, and the environment at large.

Drainage water reuse is not only practiced on an "official" level, i.e., by mixing projects implemented by official authorities, it is also practiced unofficially by individual farmers. When the fresh water supply is short and farmers—especially those at the tail ends of irrigation canals—feel that if they did not irrigate at a certain time they will lose their crop, they would rather irrigate with drainage water than not irrigate at all and sustain a loss. This can happen occasionally during periods of high demand, but it is also continuously practiced in areas where the fresh water supply is always short (e.g. tail ends of irrigation canals).

The extent of drainage water reuse is clear in the ISAWIP area, where measurements made in El Nazl pilot area show that drainage water is being reused on 11% of the total land area. Computations made using SIWARE (a water management model developed by the Drainage Research Institute) revealed that in the eastern Nile Delta almost 23% of the drainage water generated is unofficially recycled into the system. Similar to the reuse of drainage water is the use of ground and fresh water. This is frequently practiced in areas where cash crops are grown. It is also frequent in areas with high value orchards (like mangoes). This type of plantation is sensitive to moisture stress during certain stages of growth (e.g. flowering). Growers usually make sure that irrigation water can be made available in the required quantities during these stages. With the existing rotation system, this can never be guaranteed and, therefore, growers opt to withdraw water from the shallow groundwater aquifers which underlie most of the areas in the Nile Valley and the Delta. These aquifers are completely dependent, as is the case with drainage water, on irrigation practices, since they are formed as a result of excessive irrigation on the farm and seepage losses from the conveyance and distribution system. Any reduction in the level of such losses which might be realized by improvement projects will certainly affect shallow groundwater in the Nile Valley and the Delta. Excessive pumping from these aquifers could result in salinization caused by deeper saline groundwater reservoirs or, in the case of the northern strip parallel to the sea shore, seawater intrusion,.

For this reason, digging wells is permitted only by the relevant authority within the Ministry of Public Works and Water Resources, which also fixes withdrawal rates that do not affect groundwater levels, quantity or quality.

Conjunctive use of groundwater is also similar to the reuse of drainage water in the fact that both waters are vulnerable to pollution caused by irrigation water, soil salinity, fertilizers, and other chemicals used in agriculture. The advantage of groundwater over drainage water is twofold:

- Its slow motion enables degradation of some of the chemical constituents.
- Water filtration keeps suspended substances in the soil.

Whether to continue the reuse of drainage water and the conjunctive use of shallow groundwater is a subject of prolonged discussion when it comes to the country's water budget. Excluding these practices should be considered based on their negative environmental impact on the one hand and the fact that they will vanish when losses from the irrigation system are fully under control on the other.

On-farm Irrigation

As stated earlier, on-farm irrigation is carried out by lifting water from canals to fields on more than 80% of the agricultural land in Egypt. After lifting the water, the farmer is free to distribute it over his field as he likes. Generally, water is distributed through a field ditch called *marwa* to small basins of not more than 10 × 10 m. The surface of the field may be furrowed for row crops or smoothed for sod crops.

The basins provide the farmer with fairly good control of the water and allow for application of uniform amounts even when fields are relatively uneven. Excess irrigation water may be surface drained into open field drains or sometimes back to the irrigation canals. However, both the small basins and short furrows which are in use hinder mechanization, particularly the operation of the large four-wheel tractors commonly used in agricultural processes.

The best environment for crop production is achieved when the plants' root zone is kept adequately moist. Both inadequate and excessive water in the root zone cause plant stress and reduce yield. Proper irrigation management should maintain optimum moisture in the root zone without using excessive irrigation water.

Poor irrigation management causes the waste of water, the waste of plant nutrients, the rise of the groundwater table, and the overloading of drains.

Appropriate on-farm water management requires level fields, well designed on-farm distribution systems, and most important, the knowledge of when to irrigate and how much water to supply. It also requires a dependable source of water, available when needed, in a quantity which can be distributed efficiently over the field.

Consequently, there must be close communication and interaction among all farmers served by a distributary canal or a *mesqa* and with the district irrigation engineer who regulates the water upstream from the intake of both canals.

The following sections will describe the advantages and limitation of the on-farm irrigation system in Egypt in the light of the above-mentioned merits and credits of an ideal system.

Irrigation Practices

Up until the last 20 or 30 years, the *tambour* and *shadouf*, small water lifting devices inherited from the ancient Egyptians, were still in common use in Egypt. Both devices are operated by hand. For larger heads, *sakias* (water wheels) operated by farm animals, were in common use; some of them are still in operation.

This highlights two important facts:

- The on-farm irrigation system in Egypt is as old as the country itself.
- Lifting water is an inherited process, the possibility of wasting water after exerting such effort either by humans or animals is slim.

When the prices of meat and dairy products increased, farmers realized that the animal has more value when not working and many farmers switched from *sakias* to small diesel pumps. Obviously, this was not the only reason, other reasons were: saving time in irrigation, competition between manufactures of diesel pumps which brought their prices down; and the credit system provided by the village banks to the farmers which enabled them to purchase the pumps and pay in small installments.

According to EWUP, the number of irrigations the farmers apply is generally consistent with the number specified by the irrigation authorities. The difference is only in the designated planting and harvesting dates which vary considerably between farmers in one location and farmers in another, and between one farmer and another in the same locality.

The gap between the last irrigation of one crop and the first irrigation of the next also varies between groups of farmers in different localities and between individual farmers in the same place. While some farmers use intercropping in order to make use of every single day of the year, it is reported that other farmers have gaps as long as 83 days between wheat and rice, and 118 days between cotton and wheat in Abu Raya, Kafr El Sheikh. Even though these irrigation gaps are prolonged, the individual crops receive appropriate initial, and final irrigations when viewed separately.

The gaps represent periods of general decline in irrigation demand, when large volumes of water are released during these periods, much of this water flows unused directly to the drains. Irrigation planning should therefore be based on the entire cropping pattern rather than on individual crops.

Extraction normally starts at 4:00 a.m. in summer and 8:00 a.m. in winter, and irrigation ends around 1:00 p.m. except during periods of peak demand, when farmers in some locations, especially those at the tail ends of the canals, are forced to irrigate at night. As soon as irrigation ceases, canals refill, and any excess water flows unused into the drains.

The amount of water applied during an irrigation depends largely on whether or not it is the first or a subsequent irrigation. The first irrigation after a long dry gap requires 150–200 mm of water. Subsequent irrigations, which only replace depleted moisture, require 70–100 mm.

Puddling of rice fields requires 250 mm of water. In all cases each irrigation usually recharges the soil moisture profile or even exceeds this level. The presence of prolonged irrigation gaps and the difference between initial and subsequent irrigations indicates a need to determine irrigation requirements over the entire crop rotation rather than considering just the irrigation demands of individual crops.

Over-irrigation, defined as the application of more water than a crop requires, occurs for one or more of the following reasons:

- Farmers irrigating under poor land leveling conditions apply more water than necessary to assure that high spots receive adequate amounts.
- Uncertainty concerning delivery schedules.
- The lack of knowledge of actual soil moisture status.
- Poor water management, especially during night irrigation.
- Softening of the top layer of the soil in order to easily remove remains of crops after harvesting.

Despite the above factors, which favor low application efficiency, the actual efficiencies measured in EWUP areas were mostly in the 60–90% range. This was attributed to the low infiltration properties of the soil. In sandy soil the application efficiency is much lower. Figures ranging between 14 and 40% were reported by EWUP. In some areas of shallow groundwater, the estimated consumptive use of water applied is considerably higher, which indicates a substantial contribution of groundwater. The overall average application efficiencies in Upper Egypt, Middle Egypt, and the Delta are in the range of 72, 75, and 75%, respectively. These figures were obtained from intensive experiments carried out in a number of research stations.

The Irrigation System Efficiency Indicator, as given by ISAWIP on the farm level for the area served by the Bahr El Saghir canal (80,000 fed/33,600 ha), lies in the range of 53–58%. The margin of efficiency in El Nazl pilot area (6,000 fed/2,520 ha) within the same research project is between 53 and 60%.

However, all the above figures should be handled with the utmost care, since efficiency depends on three factors. First, it depends on its definition, which is still a matter of controversy among research workers and executives working in the fields of irrigation and agriculture. Second, on-farm efficiency depends on the location of the field with respect to the feeding canal. Fields at the tail ends are expected to have higher efficiencies because of the tight water supply. Again, areas which lie at the tail end of the overall irrigation system (i.e., the most northern part of the agricultural area near the coast) can be considered as tail end areas. Third, on-farm efficiency is a function of surface runoff and deep percolation, if evaporation on the farm level is neglected. In the ISAWIP area, it is reported that runoff and percolation account for 49% of the amount of water delivered at the farm gate; 34% for percolation, and the remaining 15% for surface runoff. However, the water which percolates out of the soil is not considered a loss because it also represents the leaching component of the farm delivery requirement.

Condition of Structures and Channels

Normally, distributary canals have an off-take structure at the inlet and a check structure (tail escape) at the outlet. In some cases when the canal is too long, head regulators are located in the intermediate sections along its course. The number of these structures depends upon the length of the distributary canal. Most of these structures are made of concrete, masonry, and bricks. They normally have heavy steel gates and/or timber block gates. Maintenance of head regulators is minimal and takes place only when severe damage affecting its function is observed.

Different conditions at the entrance cause the flow through the outlet to vary. A pipe extending into the canal with the entrance not flush with the bank could have a lower discharge than one with the entrance recessed into the canal bank. The difference in flow rates may be as high as 10% or even more. Flow from canals to *mesqas* is intended to be delivered 24 hours per day through legal turnouts 10 m long, with a head loss of 0.25 m. The allowable water duty per day is 50 m^3/fed/day (i.e. 12 mm/day)

In order to irrigate only during daylight hours many farmers install pipes of larger diameter to deliver adequate flow rates with smaller heads. Sometimes, extra pipes are illegally installed. Because of the low flow rates through turnouts into *mesqas*, farmers irrigate extensively from *mesqa* storage. When the storage is depleted faster than the inflow rate, water levels in the *mesqas* fall and cause an increase at the pumping head and a decline in flow rate. Often irrigation ends by midday because of insufficient water remaining in the *mesqas*.

During peak water-use periods such as rice transplanting, some irrigation occurs at night, after the inflow has refilled the *mesqa* with water. Farmers at the downstream end of *mesqas* often have to wait until upstream farmers finish irrigating, which makes their irrigation schedule more uncertain. The major problems of maintenance in unlined channels are weeds, seepage and unstable cross sections.

Removal of weeds and the general cleaning and maintenance of private *mesqas* is traditionally the responsibility of the farmers. However, in view of the excessive weed growth in some cases, and the blocking of canal cross sections by sediments and other material such as garbage and debris—especially those running through villages—in others, flow to farms can be restricted. Seepage of water from the canal to the adjacent strips running parallel to it from both sides and the over-topping of water above the banks of the canals can impede farm operations due to wet or flooded conditions.

Unstable and oversized cross sections are caused by the accumulation of sediments, erosion of the canal banks by water scoring and animal traffic, soil removal for brick manufacturing, and enlargement resulting from cleaning operations to remove weeds and sediments.

In the EWUP project areas, it is estimated that 1% of the cropped area was lost because of oversized canals. In the ISAWIP area it was observed that farmers frequently cross-connect *mesqas* and drains when the water supply is insufficient. While this cross connection improves supply during peak demand, it also results in excessive losses during non-irrigation periods. Over-excavation is common at withdrawal points, which leads to erosion, hydraulic inefficiencies and low water levels at the downstream end of the *mesqa*. Erosion is also common at bends in the *mesqas*, due to lack of maintenance and steep unprotected side slopes.

The ISAWIP report goes on to explain that no formal *mesqa* operating programs exist. Farmer coordination usually occurs only when withdrawal from one point vertically eliminates supply at another. The water balance in the ISAWIP area indicates that 7% of the net external inflow to the project area is lost as direct spillage to the drainage system, primarily through *mesqas* and their direct and uncontrolled connection to the drainage system.

Operation

Flow in any distributary canal is assumed to be based on crop needs as determined by:

- Cropping pattern.
- Water requirements of each crop.
- Area served, divided into separate areas occupied by each crop.
- Soil type.
- The expected conveyance, distribution and on-farm losses.

In practice, water delivery to distributary canals is based on the water surface elevation on the downstream side of the off-take structure control gate. Regulation of the flow to distributary canals is usually related to the available head in the district branch or main canal. There is no determination or allocation of a specific flow rate at any point within the district. The more water a group of farmers use on a canal, the lower the water surface in the canal becomes. This increases the difference in the head at the inlet control gate and subsequently the inflow rate. The internal distribution within one or more irrigation districts is accomplished by maintaining adopted water levels in the branch and distributary canals. Most of the intake structures of the first order and main canals and those of the main distribution sites between governorates are calibrated, and water flowing through them is measured.

During on periods, water flows through canals 24 hours a day. With no gates on the farm outlets, water flows from the canals into the *mesqas* continuously, day and night.

Daytime irrigation is preferred by farmers, thus during the night water either flows through the system to the drains or is stored in the channels.

Water balance studies in the EWUP project showed high losses to drains: 30–45% of total water delivered for irrigation at Abyuha (Minia), and 46–58% at Abu Raya (Kafr El Sheikh). It should be noted here that following the crisis in 1988, when the water level in the Aswan High Dam Lake fell to its minimum, deliveries were tightened; consequently, night irrigation was increased, and losses to the drainage system were considerably reduced.

Water deliveries in summer and winter in the three EWUP project areas are described in Table 5. Again, the reader is reminded of the fact that the EWUP project was implemented during the period 1978–1984 when the control on water supply was not as tight as it is at the present time.

Table 5. Water deliveries in summer and winter in the three EWUP project areas.

Location	Water delivery (m^3/fed)	
	Winter	Summer
Abyuha (Minia)	4,419–4,440	7,175–10,419
Beni Magdoul (Giza)	2,685–3,174	3,601–4,271
Abu Raya (Kafr El Sheikh)	4,887	6,810

Water-use efficiency in the summer months (June, July, and August) is relatively high. When it comes to winter, efficiency is either low or extremely low. This applies to the two sites in Middle Egypt (Abyuha) and the Delta (Abu Raya). The site near Giza (Beni Magdoul) has better efficiencies in general, yet, this reflects the strong competition for water between different users. Beni Magdoul is subject to creeping urbanization. Most of the water from the feeding canal is used for domestic and other purposes. The remaining portion is used efficiently by farmers for the irrigation of their fields.

Most of the existing canals are constructed to provide a water surface in the *mesqa* at an elevation of 50–75 cm below the ground surface, which requires farmers to lift the water. Originally, the *tambour* and *shadouf* were operated. When the lifting head is larger, *sakias* operated by farm animals were used.

Recently, small diesel pumps have become common. They are owned either by one farmer who rents his machine to other farmers or owned by a group of farmers who use it to irrigate their fields on the basis of pre-set rotation.

The advantage of manual or animal-operated devices over diesel pumps is that the rate of withdrawal is proportional to the rate of supply, and therefore the drop in water surface elevation is gradual. With diesel pumps, water surface elevation drops fast, especially when the number of pumps in operation at the same time is large.

The flow rates of *sakias*, on the other hand, are not always adequate for long furrows and wide basins, especially when the channel storage is depleted and lifting heads become excessive. This is not the case when diesel pumps are in use.

Obviously, the time required to irrigate a specific field is much smaller when using a diesel pump than when irrigated with *sakias*.

The government policy has favored lift irrigation on the assumption that gravity flow would result in excessive water application. However, the EWUP reported that this assumption was not necessarily true under full control and proper management.

Farmers do understand that excessive water, applied to fields which contain slowly permeable clay soils, will pond on the surface, prevent seed germination, and damage mature plants. Less caution was observed where surface drains were available. Crop damage resulting from excessive irrigation on sandy soils was not readily evident to farmers due to the high infiltration and permeability rates. The major drainage in this case would be soil leaching and the increase in water table elevation, which can diminish soil nutrients, rooting depth and crop yields. Sandy soils comprise approximately 10% of the irrigated land along the River Nile and the Nile Delta (Old Lands).

When *mesqas* have dead (closed) ends, water levels periodically become too high, and farmers have to release water to the nearest open field drain to prevent flooding of their cropped land.

The only two governorates in which gravity irrigation is practiced are Aswan and Fayoum. In Aswan this is meant to provide sugarcane with sufficient water. In the meantime, discharges and water levels in the area are sufficiently high to meet requirements. Even if excessive irrigation takes place, drainage water of the cultivated area comes back to the main course of the River Nile, bringing the efficiency of the system in the area to as high as 100%.

The situation in Fayoum is different; irrigation in this area is dependent on control structures (*nasbas*) which are not used in any other place in the country. The reason for this is the natural ground slope, which is more than 250 cm per kilometer, compared with an average slope of less the 10 cm per kilometer in the Nile Valley and Delta. Control of flow in *nasbas* (which are free-fall broad crested weirs) is dependent upon the depth of water above the crest and the width of the weir opening. The flow is given to a specific area on the assumption that withdrawal takes place 24 hours a day.

Farmers have their sharing water system (*moutarfa*) in which every field is allowed to withdraw water for a certain period of time, depending upon its size and the crop.

Efficiency in Fayoum, because of this system, is generally higher than in any other place in the country. However, there are other reasons for this high efficiency. Water management in the area is better controlled, because excessive use of water is immediately reflected on the water levels of Lake Qaroun, the only exit for drainage water other than the Wadi El Rayan depression. High water levels in the lake affect tourist resorts on its shore, and inundate the coastal strip running parallel to the shoreline.

Irrigation Improvement Project

Water is the key constraining input in Egypt's agricultural production system. Improving water-use efficiency in the Old Lands helps save the water needed to irrigate the newly reclaimed lands and for the increasing domestic and industrial demand.

The main reasons for reduced efficiency in the irrigation system are:

- General deterioration of the system caused by age and inadequate maintenance.
- Water losses from the conveyance and distribution systems as well as from the on-farm system.
- Poor operation, management, and maintenance caused by shortage of capital.
- Shortage in skilled and trained professional staff and labor.
- Weak institutional capacity for organizing, managing, and administrating the system, as well as the operational policies and procedures and equipment to carry out the mammoth job of improving and modernizing the system.

The major problems experienced with the irrigation system in the Old Lands are:

- Fixed irrigation intervals represented by the rotation system. which might be too short or too long, and is generally inflexible. This type of system may well be the reason for over-irrigation in some cases and may result in crop water stress in others.
- Inequity of distribution between the head and tail reaches of distributary canals and *mesqas*.
- Poor maintenance of different orders of irrigation canals and *mesqas*.
- Inefficient control on water due to the manual operation of gates and the leakage from closed gates.
- Excessive fresh water loss to drains due to over-irrigation, poor land leveling, non-gated off-take pipes, avoidance of night irrigation, and upstream control.

The Irrigation Improvement Project (IIP) has initiated several changes in the operation of the command area canal delivery systems. These changes, or improvements, provide for rational distribution of water, effective management, and a regular monitoring system. The improvements provide water users with the necessary flexibility for irrigating crops at the proper time, rate, and duration required for optimum crop production. These improvements include:

- Renovation and improvement of the main delivery system including new water control structures, restoring design channel cross sections, tone pitching (both dry and mortar), bank protection, concrete lining, bridges, crossings, access roads, etc. These elements help to improve operation and maintenance of canals. Conversion from rotation delivery to continuous flow enables users to select the irrigation intervals that suit crop and soil needs.

  Upstream control is replaced by downstream control, which provides water on demand. With downstream control, off-takes from canals can be opened, closed or adjusted at any time without advance notice. Downstream control has the additional advantage of providing the wedge storage represented by the area confined between the hydraulic slope at maximum flow and the flat pool surface at zero flow. This storage builds up at night when water is not used for irrigation.

- Improvement of the *mesqa* system. This is carried out mainly through the introduction of single points lifted or pumped from the canal at the head of the *mesqa* rather than at each farm or *marwa*. Water flows from the head of the *mesqa* to the farm by gravity. Users take water by opening their gates or valves.

  The elevated *mesqa* can be lined with concrete or low pressure pipeline. The hydraulic capacity of the improved *mesqas* is based on continuous flow and an operating time of 16 hours per day. This provides for economic design, uniformity of withdrawal, reduced maintenance cost, and minimum seepage losses.

- Water Users Association (WUA): *Mesqas* are the private property of water users who own, control and manage the WUAs for the benefit of improving *mesqa* water delivery and on-farm use of water. WUAs are responsible for the following activities:
  - Developing roles, responsibilities, and rules for operation, maintenance, and management of WUA and *mesqas*.
  - Appointing a treasurer, record keeper, pump operator, guard, etc.
  - Coordinating with engineers in planning and design of the improved *mesqas*.
  - Purchase of pumps and/or obtaining their acquisition.
  - Operation of single point lifting pumping plant.
  - Maintenance of improved *mesqas* and pumping plant.
  - Scheduling of irrigation among water users.
  - Resolving disputes and issues.
  - Developing financial plans, fee schedules, and bank accounts.
  - Recovery of costs of *mesqa* improvement.
  - Election of leaders and officers.
  - Any other activities that are deemed important.
- Irrigation Advisory Service (IAS). The main objective of the IAS is to provide technical assistance to the water users; it has three major functions which are:
  - Assist water users to improve *mesqa* water delivery.
  - Assist water users in irrigation water management by helping them to determine the appropriate irrigation rate, frequency, and duration.
  - Assist water users to establish sustainable private WUAs.

  The IAS carries out its activities in a flexible systematic strategy which includes seven phases:

- Entry of information collection.

- Organization.
- Preparation for *mesqa* improvement.
- Participation in *mesqa* improvement.
- Regular operation and maintenance.
- Federation to canal level.
- Monitoring and evaluation.

The IAS engineers are trained as trainers of field agents on water delivery, water use and organizational development of WUAs. Both field agents and engineers conduct regular two or three day short training courses for WUA council members.

The major effects and benefits of the Irrigation Improvement Project are:

- Increase of water delivery efficiency, reduction of operation, and management losses and improvement of on-farm irrigation efficiency.
- Equity of water distribution between head and tail reach farmers.
- Continuous flow allows for a flexible irrigation interval to suit crop and soil conditions, increases the number of days in which canals and *mesqas* are in operation, and allows for greater volume for night or temporary storage in streams. The hydraulic capacity of canals under continuous flow is only one half the capacity needed under rotation flow.
- Downstream control provides additional flexibility in terms of timing, rate of flow and the duration required for irrigating different crops.
- The improved *mesqas* (lined or pipelines) reduce seepage losses.
- Buried pipelines and smaller hydraulic size of *mesqas* result in saving of land requirements.
- Timed application of irrigation water at the appropriate quantity increases crop yields.
- The technical assistance of the IAS provides water users with the knowledge and skills needed for the efficient use of irrigation water and optimum crop production.
- Fewer numbers of pumps needed per *mesqa* and lower pumping cost are associated with single point lifting.
- The system is more convenient for farmers, who only need to open a gate or a valve to get water.
- Irrigation time is reduced.

On-Farm Water Management

Water resources in Egypt depend mainly on:

- The Nile water, since rainfall is scarce both in amount and distribution. Egypt's share from the Nile water is 55.5 billion cubic meters per/year.
- The second water resource is the water drained into the Nile between Aswan and Cairo (4.6 billion cubic meters per year). Drainage water from the Nile Delta is also used in irrigation.
- Underground water (2.6 billion cubic meters per year) is the third water source in Egypt, but its use is limited.
- Rainfall in the coastal areas (normal amounts are 100–200 mm/year increasing to 304 mm at Rafah (North Sinai). Rainfall values are 60–70 mm in the North Delta, i.e., enough for one irrigation received by winter crops.

Water Consumptive Use (ET) and Water Requirements (WR)

Water consumptive use is the water consumed by plants in evapotranspiration (evaporation from the soil and plant surface as well as transpiration by plants). Water consumptive use can be measured by sampling soil from the root zone and calculating the difference between the soil moisture content after irrigation and the moisture content before the next irrigation. A summation of ET for all irrigation intervals gives the seasonal value of ET per crop in mm (many methods can be used in this estimation). Multiplying ET in mm by 4.2 gives the seasonal ET crop per feddan in cubic meters. Dividing ET crop per feddan by the irrigation efficiency gives the water requirement (WR) of the crop per feddan. The importance of adjusting ET estimations is to justify the water balance and save water and/or to be used as a guide to proper water management in Egypt.

Crop Water Use and Management Studies

Research activities carried out on the farm level will be reviewed. The main results and recommendations are summarized below.

On-farm water requirements

Results obtained from the different collaborative projects as well as local efforts can be summarized as follow:

- The estimation of crop water consumptive use in Egypt was calculated according to Blaney and Criddle formula for all crops at 24 billion cubic meters per year. Water required for the New Lands is not included. Considering an irrigation efficiency of 60% all over the country, the total irrigation requirements have been estimated at 44 billion cubic meters per year for crop production. This value includes the water needed to wash out the accumulated salts from the soil (El Gibali and Badawy, 1978).
- The Water Master Plan project (PL-480 150) on the water requirements of the major crops in three areas in Egypt, namely, the Delta and Middle and Upper Egypt, was funded by the United States Department of Agriculture (USDA) and the Ministry of Agriculture from 1975 to 1981. Through the project, ET values and rates for wheat,

berseem (Egyptian clover), cotton, maize, and sorghum were calculated, and the crop coefficients (Kc) at different stages of plant growth were estimated. The following are the main findings and recommendations:

- Water planning requires a knowledge of anticipated demand, potential supply, and the capability of a system to deliver that supply according to demand. This is the general idea of successful water planning. However, a complete water plan should take into consideration other aspects, such as economy, social, and other factors.
- The Ministry of Irrigation in Egypt, IBRD, and UNDP developed models to serve agricultural development both in the Old and New Lands, as well as municipal and industrial water, and all other water uses.
- Many scenarios were considered and compared on the basis of economic performance, investment needs, effective use of land and water, social effectiveness, and energy requirements.
- The project published these studies in 20 reports including physical water planning components, economic analysis, planning and evaluation items, environmental elements, and other tasks.
- The Water Use Committee of the project suggested that the Water Requirement staff members of the Soil and Water Research Institute, ARC, Ministry of Agriculture be assigned to assemble and analyze Egyptian experimental work on consumptive use. The results of their work were reported in Technical Report No. 17: Consumptive Use of Water by Major Field Crops in Egypt (Tables 9, 10, and 12).
- The agro-economic model was used to determine whether the present allocation of water to Old Lands was reasonable. It was used to identify trends in cropping pattern changes for the future, with various constraints assumed on water supply, and with various agricultural policies. For all cases, the model computed the shadow price of water and the net economic returns.
- Finally, the project described scenarios for growth during the next 20 years and how water development plans should be assembled to serve that growth. The first plan started with the water supply projects to which Egypt is committed, and showed the expansion in agricultural production that could be supported after satisfying other uses. The other two plans envisaged high and low growth rates in agricultural development.

- Within the project called EMCIP (funded by USAID to improve the production of wheat, maize, and sorghum crops), the long furrow method was used in comparison with the traditional method (in small basins). Results indicated that the long furrow method caused a 17% increase in maize production and saved 10% more water. The water-use efficiency was also increased. The same result was found in the sorghum crop.
- The NVP/ICARDA/IFAD project focused on faba bean. The following results were obtained:

- The optimum time for life watering, i.e., the first watering after planting, was after four weeks in Upper Egypt, and five weeks in Middle Egypt.
- The flowering and seed filling stages are the critical stages for water in faba bean.
- The favorable triggering point for irrigation is when 40% of the available soil moisture (ASM) has been consumed.

- Experiments in many of these projects were conducted on most of the field crops under study.
- A general survey and calculations for the ET of all crops at three main regions in Egypt were carried out. Field data were collected, and estimates were made using the Blaney and Criddle as well as the Penman formulae and approved by the Research Committee of the Water Requirements and Agro-meteorology Research Department (Table 6).

Tables 6, 7, and 8 indicate the ET, total crop areas and total water requirements for 1990/91.

- Total annual ET of crops in Egypt is about 28 billion cubic meters.
- Total crop area in 1990/91 was about 11.4 million fed.
- Total water requirement of all crops was about 47 billion cubic meters.

The symbols used in the following tables are: A= Abscission trees, C = Cutting, F = Fahl or one cut, N = Nili, P = Perennial trees, S = Summer, Av = Average, and W = Winter.

Table 6. Seasonal ET (m^3/fed) of crops.

Crop	Delta	Middle Egypt	Upper Egypt	Average
Wheat	1470	1701	1827	1666
Faba bean	1218	1470	1747	1478
Barley	1165	1444	1702	1437
Fenugreek	1402	1447	1507	1450
Lupine	1533	1558	1642	1577
Chickpea	1402	1442	1507	1450
Lentil	990	1151	1379	1173
Clover C	2000	2352	2772	2375
Clover F	818	1169	1300	1095
Flax	1407	1407	1512	1442
Onion W	1310	1413	1588	1437
Garlic W	1453	1541	1642	1545
Sugar beet	1867	2381	2594	2280
Vegetables W	1611	1691	1808	1703
Others W	1255	1281	1378	1305
Cotton	2142	2772	3192	2702
Rice	4542	----	----	4542
Maize S	2430	2612	2802	2615
Sorghum S	----	2058	2226	2142
Soybean	2543	2772	3204	2840
Sugarcane	----	756	08274	7917
Sesame	1705	2130	2358	2064
Peanuts	2982	3154	3326	3154
Sunflower	2070	2319	2539	2309
Onion S	1866	----	----	1866
Vegetables S	2093	2174	2286	2184
Others S	1869	1974	2079	1974
Maize N	2249	2315	2473	2346
Sorghum N	----	1974	2142	2058
Vegetables N	2016	2084	2110	2070
Orchards P	4909	5027	5329	5088
Orchards A	3977	4145	4376	4166
Orchards (avg)	4493	4586	4853	4644

Source: Data were prepared and reported by the Water Requirements and Field Irrigation Research Department Committee from studies in the 1992 inventory.
1 ha = 2.38 fed.

Table 7. Average crop areas (1000 fed) in 1990/91.

Crop	Middle Delta	East Delta	West Delta	Middle Egypt	Upper Egypt	Total
Wheat	305.6	459.6	192.4	333.5	413.5	1704.6
Faba bean	41.0	63.9	39.7	125.2	72.9	342.7
Barley	2.1	36.2	28.0	9.5	11.0	86.8
Fenugreek	0.1	1.2	0.0	8.8	4.6	14.7
Lupine	0.0	3.0	0.0	3.2	1.4	7.6
Chickpea	0.0	0.4	2.0	0.2	10.7	13.3
Lentil	2.1	5.1	0.0	0.3	6.0	13.5
Clover C	441.7	515.0	239.9	390.9	149.9	1737.4
Clover F	230.3	291.7	131.9	80.9	61.4	796.2
Flax	11.7	13.1	5.3	0.5	0.0	30.6
Onion W	6.5	3.2	0.5	8.7	6.0	24.9
Garlic W	1.8	1.7	0.7	9.0	1.6	14.8
Sugar beet	32.0	2.1	0.0	0.0	0.0	34.1
Vegetables W	88.4	89.2	104.9	102.3	50.6	435.4
Others W	1.0	0.9	0.3	27.3	11.0	40.5
Total	1166.3	1486.3	745.6	1100.5	800.4	5297.1
Cotton	278.7	294.4	131.7	170.0	118.2	993.0
Rice	328.6	520.2	186.7	0.0	0.0	1035.5
Maize S	464.9	321.3	177.4	358.1	221.4	1543.1
Sorghum S	0.0	0.0	0.0	35.5	274.7	310.2
Soybean	19.7	3.2	6.9	55.9	12.9	98.6
Sugarcane	0.0	0.0	0.0	38.6	224.6	263.2
Sesame	0.1	8.3	0.2	9.1	24.4	42.1
Peanuts	0.5	13.6	1.5	9.8	3.8	29.2
Sunflower	0.0	0.0	0.0	0.0	0.0	0.0
Onion S	2.0	1.6	5.8	0.0	0.0	9.4
Vegetables S	37.2	52.3	110.4	75.8	25.2	300.9
Others S	45.3	33.6	35.6	60.3	27.8	202.6
Total	1177.0	1248.5	656.2	813.1	932.9	4827.9
Maize N	27.7	78.3	28.2	225.8	68.5	428.5
Sorghum N	0.0	0.0	0.0	6.3	1.3	7.6
Vegetables N	20.8	20.7	42.6	65.4	11.3	160.8
Others N	9.6	11.1	8.0	26.0	11.0	65.7
Total	58.1	110.1	78.8	323.5	92.1	662.6
Orchards (avg)	147.1	170.0	96.3	98.6	52.1	564.1
Total	205.2	280.1	175.1	422.2	144.2	1226.8
Grand total	2546.7	3015.1	1576.9	2335.9	1877.6	11352.3

1 ha = 2.38 fed.

Table 8. Total ET (million m^3) of crops at different regions.

Crop	Middle Delta	East Delta	West Delta	Middle Egypt	Upper Egypt	Total
Wheat	449.166	675.562	282.791	567.346	755.448	2730.313
Faba bean	49.938	77.852	48.319	184.085	127.402	487.596
Barley	2.479	42.221	32.594	13.740	18.639	109.673
Fenugreek	0.136	1.738	0.000	12.812	6.896	215.820
Lupine	0.021	4.528	0.000	5.004	2.318	11.871
Chickpea	0.000	0.489	2.818	0.264	15.182	18.753
Lentil	2.093	5.057	0.000	0.306	8.273	15.729
Clover C	883.526	102.991	479.830	919.507	415.545	2801.399
Clover F	188.345	238.667	107.914	94.597	79.749	601.358
Flax	16.549	18.485	7.468	0.727	0.000	43.229
Onion W	8.497	4.267	0.6291	2.345	9.518	35.256
Garlic W	2.685	2.434	0.103	13.852	2.558	21.632
Sugar beet	59.647	3.930	0.000	0.083	0.000	63.660
Vegetables W	142.458	143.741	169.029	173.016	91.438	719.682
Others W	1.251	1.191	0.319	35.023	15.132	52.916
Total	2250.1	1132.7	1806.8	2032.7	1549.1	8771.4
Cotton	597.025	630.545	282.181	471.304	377.269	2358.324
Rice	1492.578	2362.689	848.182	0.000	0.000	4703.449
Maize S	1129.648	780.868	431.067	935.339	620.310	3897.232
Sorghum S	0.000	0.000	0.000	73.110	611.371	684.481
Soybean	50.199	8.010	17.478	154.922	41.242	271.851
Sugarcane	0.000	0.000	0.000	291.937	1858.125	2150.065
Sesame	0.172	14.186	0.169	19.492	57.606	91.625
Peanut	1.467	40.639	4.545	30.821	12.622	90.094
Sunflower	0.000	0.000	0.000	0.000	0.000	0.000
Onion S	3.818	3.010	10.892	0.000	0.000	17.720
Vegetables S	77.876	109.380	231.027	164.837	57.612	640.732
Others S	84.662	62.896	66.473	118.947	57.87	390.851
Total	3437.445	4012.223	1892.014	2260.709	3694.030	15296.4
Maize N	62.288	176.047	63.332	522.664	169.405	993.736
Sorghum N	0.000	0.000	0.000	124.381	2.780	127.161
Vegetables N	42.003	41.770	85.960	136.342	23.877	329.952
Others N	15.731	18.144	13.081	42.681	19.369	109.006
Total	120.022	235.961	162.373	826.068	215.441	1559.855
Orchards (avg)	645.176	746.025	419.653	233.559	297.732	2451.145
Total	765.198	981.986	582.026	1123.800	449.000	4011.000
Grand Total	6468.5	6145.1	4293.8	5459.9	5711.5	28078.8

1 ha = 2.38 fed.

Cereals

Wheat

Water consumptive use. Eid *et al.* (1966) calculated the water consumptive use (CU) for Lower, Middle, and Upper Egypt and the values were found to be 21.2, 22.0, and 23.7 inches, respectively. El Gibali and Badawi (1978) computed ET rates for wheat, using the Blaney and Criddle formula, as 37.9, 40.5, and 42.1 cm for Lower, Middle, and Upper Egypt, respectively.

Serry *et al.* (1980) found that water consumptive use values were 38.31, 47.54, and 52.27 cm for Lower, Middle, and Upper Egypt, respectively. Average daily use was 0.23, 0.29, and 0.33 cm, respectively. Badawi *et al.* (1984) found that water consumptive use of wheat, under field conditions, was 36.71 cm at Sakha, 43.13 cm at Gemmeiza, 43.65 cm at Sids, and 47.45 cm at Shandaweel for Sakha 8, Giza 157, Sakha 69, and Giza 155, respectively, at 50% depletion of available soil moisture (ASM) and 60 kg N/fed. The PL-480 project (1975–1981) estimated mean values of water consumptive use by wheat. ET values were 18.18, 15.73 and 13.70 inches for the wet (25%), medium (50%) and dry (75%) soil, respectively. The high yielding variety Chenap 70 consumed more water than the local wheat variety Giza 156. Ibrahim *et al.* (1987) at Sakha found that values of water use ranged between 39.96 and 49.10 cm. Daily rates of ET were 0.22–0.27 cm. Closer results were obtained by Badawi (1970) at Gemmeiza, Seif El Yazal (1971) at Giza, Talha (1975) at Kalyubia, Abdel-Hafez (1976) at Sakha, Eid (1977) at Giza, Abdel-Mottaleb (1978) at Mallawy, Metwally *et al.* (1984), at Sakha, Giza and Mallawy, and Yousef and Eid (1994) at Fayoum.

Khafagi *et al.* (1967) showed that the consumptive use of water can be estimated using any formula based on climatic data with a proper monthly coefficient. For the same crop, this coefficient changes with time during the growing season. They also found that the maximum rate of moisture removal takes place in the top 10 cm of the soil. Over 80% of the total extraction is confined to the uppermost 50 cm of soil. Shahin (1980) showed that the daily consumptive use value of Chenap 70 wheat varied according to the growth stage. The peak CU was obtained between 91 and 119 days after sowing. Shahin also found that the crop coefficient was 0.664.

Serry *et al.* (1980) showed that the crop coefficient for wheat is 0.50, 0.72, 0.74, 0.76, 0.80, 0.58, and 0.42 for the months from November to May, respectively, with an average of 0.65. Ibrahim *et al.* (1987) at Sakha found that the seasonal Kc for wheat is 0.6.

Water stress in wheat. El Nadi (1969) reported that water stress during the four-leaf stage to the appearance of the first inflorescence in Sudan significantly reduced plant length and tillers per plant.

Mohamed (1976) found that increasing soil moisture stress by decreasing the amount of available water in the soil before irrigation depressed spike length, grain and straw yields, 1000-grain weight, and number of spikes. He showed that grain protein content tended to increase by delaying the period the plant is exposed to soil moisture stress. He added that the same trend was found with regard to gluten content. In the PL-480 project, results showed the importance of irrigation at the different stages of plant growth (in descending order) as follows: tillering, booting, heading, milk. El Sayed (1982) found that exposing wheat plants to high moisture stress depressed seasonal consumptive use and grain and straw yields. He also found that maximum consumptive use as well as crop coefficient (Kc) of wheat plants were obtained during March. The same results were found by Seif El Yazal (1971). Also, Seif El Yazal, *et al.* (1984), on the study of withholding irrigation on wheat at Sakha, Giza, Sids, and Mallawy, found that withholding one irrigation either at the milk, heading, or booting stage or at the tillering stage decreased grain production by 11, 14, 16, and 20%, respectively, as compared to the check treatment receiving six irrigations. Withholding two or three irrigations decreased yield by 25 and 34%, respectively, less than the yield produced in the check treatment. Gad El Rab *et al.* (1988a) found that the best water-use efficiency at Sakha was obtained when system C (four irrigations) or D (five irrigations) were used, compared to three or six irrigations.

Water management of wheat. From the final report of the PL-480 project, it could be concluded that wheat should be irrigated at 50% depletion. Badawi *et al.* (1984) indicated that consumptive use data can be used for irrigation scheduling. Since differences in grain yield between the 25 and 50% irrigation treatments were not significant, five to six irrigations proved adequate for wheat irrigation. Eid *et al.* (1988) compared the long furrows in controlled irrigation by land leveling and a slope of 0.1% with the surrounding fields under traditional methods. They found that the method showed practical advantages, especially in land and labor saving. One of the greatest advantages is the real potential for fully mechanizing all operations of crop production. Water use by wheat was 1508 m^3/fed, while the quantity of applied water was 2,420 m^3/fed. Wheat yield was increased by 17% by using long run irrigation. Water application efficiency was 65% using this method, compared to the traditional one. This technique can be recommended. Mitkees *et al.* (1991) reported that treatments receiving their irrigation 20 days after sowing gave significantly higher grain yields compared to those receiving the first irrigation after 40 days. Ghanem *et al.* (1990), in an ICARDA report (1989/90), indicated that application of three, four, five, and six successive irrigations to wheat at Sohag, Qena, Aswan, and Fayoum governorates affected grain yield significantly in all Upper Egypt governorates but not in Fayoum. Also, five irrigations increased grain yield by 17–28%. They concluded that irrigation should be stopped after five irrigations to obtain the highest yield under Upper Egyptian conditions.

Water-use efficiency of wheat. Eid (1977) found that delaying the sowing date from Nov. 10 or Nov. 24 till Dec. 8 or Dec. 22 decreased CU and increased water-use efficiency. The PL-480 project found that water-use efficiency ranged between 115.3 and 137.3 kg/inch. Seif El Yazal (1984) found that the highest water-use efficiency was obtained by soaking the wheat grains in GA3 (gibberellic acid; 1000 ppm) and spraying the plants when 50 days old with chlorocholine chloride (CCC) at a concentration of 150–200 ppm. Metwally *et al.* (1984), at Sakha, Giza, and Mallawy, studied the effect of soil moisture depletion of 25, 50, and 75% from the ASM on Giza 156 and Chenap 70. They found that irrigation at 50% from ASM is the best for yield and water-use efficiency. Hassanein *et al.* (1986) at Sakha found that irrigation with a field capacity above 20% ASM gave higher WUE values without decreasing wheat grain yield. Ibrahim *et al.* (1987) at Sakha indicated that water-utilization efficiency reached 0.89 kg/m^3. Results obtained by many researchers indicate that water-use efficiency of wheat is increased by increasing soil moisture content. Table 9 shows the water-use efficiency of wheat.

Table 9. Water-use efficiency (WUE) values of wheat.

Author	WUE values	Unit
PL-480, 1975–1981 at *different sites*	115.3–137.3	kg grains/inch
Hassanein *et al.* (1986) at Sakha	1.0 and 0.86 for FC + 20% and FC + 40%	kg grains/m^3
Ibrahim *et al.* (1987) at Sakha	0.89	kg grains/m^3
El Refai *et al.* (1988a) at Gemmeiza	50.12, 67.24 and 68.20 for basin, sprinkler, and drip irrigation systems	kg grains/cm

Yousef and Eid (1994) studied the effect on yield of soil moisture stress and splitting nitrogen fertilizer applications on Sakha 69. They found that the highest water-use efficiency was obtained from a 30% depletion and splitting the nitrogen into three equal portions.

Using the new irrigation systems in the Old Lands, El Refai *et al.* (1988a) conducted an investigation to determine the extent to which these irrigation systems could increase water-use efficiency, while maintaining reasonable yield, compared to the basin irrigation method. Wheat was watered by sprinkler, trickle, or basin system when 50% of the available soil water had been extracted from the effective root zone (60 cm deep). Comparable grain yields of wheat and water-use efficiencies were achieved by the sprinkler irrigation method.

Abdel-Maksoud *et al.* (1988) carried out an investigation on Sakha 69 at Gemmeiza using different tillage practices designated as zero, chisel twice and chisel once plus disc tillage. They found that water-use efficiency was increased by tillage. El Refai *et al.* (1988b) studied the effect of soil moisture levels on Sakha 69 under the sprinkler irrigation method. They found that production of wheat increased while increasing the available soil moisture. Water-use efficiency was higher under dry soil levels than under wet conditions; the values of water-use efficiency were 8.33, 9.03, and 10.01 kg/mm for 25, 50, and 75% of soil moisture depletion, respectively.

It is very important to obtain the maximum wheat grain and straw yields with the least amount of water. Wheat crops need four to five irrigations, including one at sowing to obtain the best results. In the Delta, rainfall and groundwater may save one irrigation. Six irrigations are acceptable in Middle and Upper Egypt. The suitable irrigation interval is three to four weeks. A four-week interval is suitable in the Delta, while three weeks is favored in Middle and Upper Egypt as well as in the flowering and grain filling stages in all regions. Seasonal, monthly, and daily average ETs of wheat at the three regions are recorded in Tables 6, 7, and 10.

Table 10. Wheat ET in the Delta, Middle, and Upper Egypt.

Region	Rate	Monthly ET (cm)							Seasonal ET	
		Nov	Dec	Jan	Feb	Mar	Apr	May	cm	m³/fed
Delta	monthly	0.7	4.4	4.4	5.4	8.0	9.5	2.6	35.0	1470
	daily	0.13	0.14	0.14	0.20	0.26	0.32	0.22	0.21	
Middle	monthly	1.1	4.5	5.5	7.3	10.0	10.8	1.2	40.5	1701
Egypt	daily	0.16	0.15	0.14	0.26	0.32	0.36	0.40	0.25	
Upper	monthly	2.2	5.9	6.6	8.2	10.6	10.0	–	43.5	1827
Egypt	daily	0.22	0.19	0.21	0.29	0.34	0.33	--	0.28	

Barley

Water consumptive use of barley. El Gibali and Badawi (1978) calculated the ET of barley using the Blaney and Criddle formula in the three regions of Egypt in cubic meters/fed (Tables 6 and 7). Moursi *et al.* (1983) found that irrigation of barley after depletion of 40% of available water during the vegetative stage increased straw yield, whereas this treatment during the fruiting stage increased grain yield and 100-grain weight compared with irrigation at wilting percentage.

Water stress in barley. El Monayeri *et al.* (1984) indicated that barley plant height was significantly decreased with increasing soil moisture stress, as well as grain number/spike, grain weight and grain yield/plant. They found differences in variety performance under moisture stress, with Giza 121 performing the best. Okaz *et al.* (1988) concluded that some barley genotypes can be more yielding under irrigation water stress, with a suitable chance to reduce the irrigation water used in winter, especially in the wet years. Abd El Rahman (1992) evaluated nine barley genotypes (*Hordeum vulgare* L.) under drought-stress conditions at Gemmeiza. He showed that growth characters such as number of days to heading, number of days to maturity, number of tillers, plant height, spike length, and straw yield were significantly decreased with increasing water stress. The correlation between these characters and the amount of water applied per season were significant and positive for all tested barley genotypes. Grain yield and its components decreased significantly with increasing water stress. Significant differences were found among barley genotypes in grain yield and its components.

Water-use efficiency of barley. Water-use efficiency was significantly affected by irrigation treatment, with values decreasing with increasing drought stress. Barley genotypes differed significantly in water-use efficiency. CR 366, Giza 124, and Giza 123 were recognized for their higher value of water-use efficiency (Okaz *et al.* 1988).

Food legumes

Faba bean

Water consumptive use in faba bean. Metwally (1973) found that increasing irrigations decreased the seed protein percentage at Giza but increased the total carbohydrate percentage. El Mughraby (1980) reported that the decrease in soil moisture content caused a continuous reduction in seed yield. Water consumptive use was decreased by reducing the number of irrigations. Tawadros *et al.* (1993) at Sakha (North Delta), Sids, and Mallawy (Middle Egypt), and Mataana (Upper Egypt) found that the most important period for water demand by faba bean is between flowering and pod-filling, as its crop ET (ETc) is close to potential ET (ETp) for that period of growth. They also reported that mean values of irrigation water amounts were 1780, 1782, 1989, and 2134 m^3/fed for Sakha, Sids, Mallawy, and Mataana, respectively. Wahba *et al.* (1993) at Mallawy (Middle Egypt), Ainer *et al.* (1994) at Sakha and Gemmeiza obtained similar results.

Water management of faba bean. Studies on faba bean irrigation were carried out by El Gibali *et al.* (1968) at Mallawy and Tawadros *et al.* (1969) at Sids. Badawi (1970) found that increasing irrigation water was followed by a marked increase in yield. El Motaz Bleh *et al.* (1970) at Sids and El Nadi (1970) at Khartoum found that the decrease in irrigations decreased seed yield.

El Mughraby (1984) and Eid *et al.* (1988) at Minia compared the long furrows in controlled irrigation by land leveling and a slope of 0.1% with the surrounding fields under traditional methods. They obtained an increase in crop production and a decrease in water consumptive use. The same results were found by Gad El Rab *et al.* (1988b), Shahin *et al.* (1989), and Abd El Mottaleb and Abbas (1992).

Water-use efficiency of faba bean. Faba bean varies in its needs for water throughout the growth season and according to regional temperature. It needs four to six irrigations, including the one at sowing. Five irrigations are the best. The "life" watering is needed after four weeks in Upper Egypt, while five weeks is better in the Delta and Middle Egypt. The other irrigations have to be applied every three to four weeks. Strong wind destroys irrigated plants. WUE values of faba bean are presented in Table 11, while ET is recorded in Tables 6, 8, and 12.

Table 11. Water-use efficiency (WUE) of faba bean.

Author	WUE values	Unit
Ainer *et al.* (1994) at Gemmeiza	1.13–1.47	kg seed/m^3

Table 12. Faba bean ET in the Delta, Middle and Upper Egypt.

Region	Rate	Monthly ET (cm)						Seasonal ET	
		Nov	Dec	Jan	Feb	Mar	Apr	cm	m^3/fed
Delta	Monthly	1.3	4.1	4.9	6.9	8.0	4.3	29.0	1218
	Daily	0.13	0.13	0.16	0.25	0.26	0.22	0.19	
Middle Egypt	Monthly	3.4	5.4	6.1	7.2	10.4	2.4	35.0	1470
	Daily	0.17	0.18	0.20	0.26	0.34	0.24	0.19	
Upper Egypt	Monthly	5.8	7.3	7.4	9.8	11.4	—	41.6	1747
	Daily	0.19	0.24	0.24	0.35	0.37	—	0.28	

Lentil

The lentil crop consumes 990, 1151, and 1379 m^3/fed in the Delta, Middle, and Upper Egypt, respectively. The application of three irrigations is recommended. Water-use efficiency decreases with increasing soil moisture stress. These recommendations were obtained from the work carried out by El Warraky (1978), Abd-El Rahman *et al.* (1980), Khalil (1982), Saleeb (1983), Abd-Alla (1987), Hamdi (1987), El Komos and Basioni (1989), Ezzat (1989), El Rays (1990), Rizk and Hassan (1991), and Azmi *et al.* (1992).

Soybean

Water consumptive use in soybean. Sherif (1978) found that irrigating at 10-day intervals increases total water consumptive use. The peak was found between 50 and 70 days from sowing in both seasons. Studies of the water status of soybean leaves and soil show that the maximum value of relative turgidity is associated with higher soil moisture, while values decrease along with a decrease in soil water. A highly significant correlation was found between relative turgidity and water status of soil. Abbas (1988) found that seasonal ET in soybean ranges between 48.16 and 84.07 cm. Daily ET values start low in the beginning of the growth season and increase gradually to arrive at its peak at 70–100 days, then decline. The Penman formula gave the best ETp. Seasonal Kc ranged between 0.75 and 1.14.

Water stress in soybean. Abbas (1992) studied the effect of some growth regulators both GA3 and N-dimethyl amino succinamic acid (Alar) under water deficit conditions (85, 70, 55% field capacity) on soybean. He found that maximum seed and straw yields and seed oil content are obtained from the wet treatment (85% field capacity).

Water management in soybean. Sherif (1978), used different irrigation intervals at Bahtim (10 days apart, 20 days, 30 days, 10 days in first half, +20 days in the second half, 10+30, 20+10, 20+30, 30+10, 30+20, 10 in the first half only, 20 in the first half only, and 30 in the first half only) to study the effect on soybean growth, yield, and water consumptive use. He found that irrigating every 10 days increases seed yield and yield components, and seed oil content percentage, while protein content percentage decreases. Eid *et al.* (1980) at Giza found that irrigating every seven or 14 days gives the best results. Yousef (1989) at Giza tried to schedule soybean irrigation from pan evaporation. He found that 1.4 is the effective pan coefficient for soybean sown in early May (Crawford cv.) at Giza. The actual seasonal ET was 76.5 cm. The last two parameters can be used in soybean irrigation scheduling depending on the evaporation from the pan.

Water-use efficiency in soybean. El Wakil (1979) found that irrigation at 60% soil moisture depletion produced the highest value of water-use efficiency. Sherif (1983) indicated that frequent irrigation at 25% depletion from ASM decreased the water-use efficiency compared to other irrigation depletion treatments. Abdallah (1984) at Assiut, and Abdel Hamid *et al.* (1985) obtained the same results. Abbas (1988) found that weed control either by hoeing or by chemical herbicides increases water-use efficiency.

Chickpea

Seasonal ET of chickpea is 1402, 1442, and 1507 m^3/fed for the Delta, Middle, and Upper Egypt, respectively (Table 6). Total ET of chickpea for all regions is given in Table 7.

Fodder crops: clover and sorghum

Clover (berseem)

There are many studies on water consumptive use and water management of berseem: Zein El Abdine (1960), El Gibali and Badawi (1978), the PL-480 Final Reports (1975–1981), Eid *et al.* (1982), and Mahrous *et al.* (1984) at Sakha, Giza, Sids and Mallawy.

Berseem is the second major winter crop in Egypt, occupying the largest area. Berseem needs sufficient water throughout its growing season, especially at germination, tillering and at high temperatures (in spring). It needs eight to ten irrigations, every eight to ten days before cutting, and every six to eight days after cutting.

The life watering must be after about 12 days from sowing. The more water at sowing, the lower the germination percentage. (ET of berseem is shown in Tables 6, 7, and 13.)

Table 13. Berseem ET in the Delta, Middle and Upper Egypt.

Region	Rate	Monthly ET (cm)							Seasonal ET	
		Nov	Dec	Jan	Feb	Mar	Apr	May	cm	m^3/fed
Delta	Monthly	4.4	5.0	5.3	6.3	9.4	13.2	4.1	47.6	2000
	Daily	0.15	0.16	0.17	0.23	0.30	0.42	0.40	0.25	
Middle	Monthly	5.6	5.2	5.9	8.4	11.9	14.8	5.1	56.0	2352
Egypt	Daily	0.19	0.17	0.19	0.30	0.38	0.49	0.50	0.29	
Upper	Monthly	5.8	6.5	6.5	10.0	13.9	16.7	7.0	66.0	2772
Egypt	Daily	0.19	0.21	0.21	0.36	0.46	0.56	0.70	0.35	

Fodder sorghum

Al Ramah (1982) and Bakheit and Abd El Rahim (1984) studied fodder sorghum. Tawadros *et al.* (1984) studied the effect of four moisture levels: (a) wet, (b) moist, (c) medium, and (d) dry on the production of Sudan grass (*Sorghum sudanense*) and sordan (sorghum–Sudan grass hybrid) at two sites: Sakha and Shandaweel. They found that the total fresh weight of Sudan grass at Sakha was 16.2, 12.9, 11.4, and 8.6 t/fed at a, b, c, and d, respectively. At Shandaweel, the fresh weight was 33.9, 28.8, 28.4, and 22.5 t/fed. The total DM production ranged from 1.84 to 3.09 t/fed with frequent irrigations. Results were in agreement with those obtained by Marei (1992).

Irrigation Improvement and Water Conservation

Land leveling and long furrows technique

Mesiha *et al.* (1984) and Eid *et al.* (1988) conducted five experiments on wheat, faba bean, corn, cotton, and sugarcane to compare long furrows in controlled irrigation by land leveling and a 0.1% slope with the surrounding fields under traditional methods. Using long furrows in controlled irrigation by land leveling with a 0.1% slope showed practical advantages, especially in saving land and labor. One of the greatest advantages is the potential for fully mechanizing all crop production operations.

Water use by faba bean is calculated at 1,213 m^3/fed with 2,420 m^3/fed of applied water. Its yield increases by 24% when long furrows are used, as opposed to small basins.

Water use by wheat is 1508 m^3/fed, while the quantity of applied water is 2,420 m^3/fed. Wheat yield increases by 17% when using long furrow irrigation compared to the traditional method. For both crops, the irrigation efficiency reaches 65% compared with 50–60% in the traditional method.

Surge flow

A new method for controlling furrow irrigation water has been developed at Utah State University. This method, named surge flow irrigation, uses recent advances in electronics to control the in-flow of water. Surge flow research at Utah State University in 1979 concentrated on field experiments to measure continuous flow, furrow irrigation, and surge flow using the same time average furrow flow.

Ismail *et al.* (1985), Ghalleb (1987), Zein El Abedin (1988), Guirguis (1988), Osman (1991), and Fathi *et al.* (1993) tested surge flow irrigation under different soil conditions in Egypt..

Antitranspirants

It was found that water-use efficiency of wheat was much lower early in the season, increasing to a maximum during grain formation, then decreasing.

Phenyl mercuric acetate (PMA) antitranspirant at a concentration of 1×10^{-4} M increased water-use efficiency from late tillering through the dough stage, while a higher rate decreased it. Abdel Hamid *et al.* (1984) studied the effect of different substances on the marketable grain yield of wheat. It was found that growth promoters and the antitranspirant (PMA) increase water-use efficiency only under wet and medium soil moisture conditions.

Concerning growth retardants, results show that the use of Alar did not cause any increase in values. However, the use of Ethrel did.

Threats to Sustainability

- Changes in water quality and quantity. This will result in reducing crop productivity, and soil degradation.
- Inadequate drainage systems. This will raise the water table and reduce crop productivity.
- Rising water table. This will reduce crop productivity.
- Pollution from fertilizers and pesticides. This will affect human health and crop productivity.
- Global climate change. This will reduce productivity and increase crop water needs as a result of the anticipated global warming (+4°C by the year 2050).

Constraints, Gaps, and Future Research

- ET and water requirement (WR) estimations for cultivated crops, including vegetables and fruits, need to be rechecked.
- Drip and sprinkler irrigation system studies are important and numerous studies are needed in the Valley.
- Lysimeter applications are deficient.
- The agro-meteorological data is still lacking in our studies in Egypt due to the lack of weather stations and their maintenance.
- Irrigation improvement to save water and sustain high yields needs more investigations.
- Studies on alternative cropping patterns should focus on the amount of available water at the national level.
- Reuse of drainage and groundwater needs more intensive study.
- Irrigation studies on chickpea are inadequate in Egypt.

Summary of Irrigation Management in the Old Lands

Water resources in Egypt depend mainly on Nile water, since rainfall is scarce both in amount and distribution. Egypt's share from the Nile water is 55.5 bcm. The second water resource is the water drained into the Nile between Aswan and Cairo. Drainage water from the Nile Delta area is also used in irrigation. Groundwater is the third water source in Egypt and its use is limited.

Water consumptive use is the water consumed by plants in evapotranspiration (evaporation from the soil and the plant surface and the transpiration of plants).

The importance of adjusting ET estimates is to justify the water balance and thus to save water and/or guide the way to proper water management in Egypt. Study topics are discussed below.

Water use and management studies

Wheat

High-yielding varieties consume more water than other wheat varieties. The land leveling and long furrow technique has practical advantages, especially in saving land and labor, along with increasing yield and water application efficiency. It is very important to obtain the maximum wheat grain and straw yields with the least amount of water. Wheat needs four to five irrigations, including the one at sowing, to obtain the best result. In the Delta, rainfall and groundwater may save one irrigation. Six irrigations are acceptable in Middle and Upper Egypt (three to four us suitable). Four weeks is suitable in the Delta, while a three-week interval is favored in Middle and Upper Egypt and during the flowering and grain filling stages in all regions. Seasonal, monthly, and daily averages ETs for wheat in the three regions were estimated.

Barley

Calculated ET of barley using the Blaney and Criddle formula is 1165, 1444, and 1702 m^3/fed for the Delta, Middle, and Upper Egypt, respectively. Studies clarify that water-use efficiency is significantly affected by different irrigation regimes and their values decrease with increasing drought stress. Barley genotypes differ significantly in water-use efficiency. Giza 124 and Giza 123 are recognized for their higher values of water-use efficiency.

Faba bean

Faba bean varies in its need for water throughout the growing season, and with regional temperature. It needs four to six irrigations, including the one at sowing. Five irrigations are best. The life watering is needed after four weeks in Upper Egypt, and after five weeks in the Delta and Middle Egypt. The other irrigations are applied at three to four week intervals. Strong wind destroys irrigated plants. Faba bean ET values are 1218, 1470, and 1747 m^3/fed in the Delta, Middle, and Upper Egypt, respectively.

Lentil

Whenever the soil moisture content reaches 70% field capacity, plant height and the number of branches per plant increase. Maximum yield is obtained with a ten day irrigation interval. It is clear that increasing available soil moisture increases the number of pods per plant, the number of seeds per pod, seed yield per plant, 1000 seed weight, seed yield per feddan, and straw yield per feddan. Water-use efficiency decreases with increasing soil moisture stress. It was found that two to three surface irrigations are best to obtain the maximum yield.

Soybean

Irrigating every 10 days increases plant height, number of pods per plant, number of seeds per plant, seed weight, 100 seed weight, seed yield per fed, and seed oil percentage, while protein content percentage decreases. The best irrigation interval for soybean is 10–14 days.

Chickpea

Seasonal ET values for chickpea are 1402, 1442, and 1607 m^3/fed in the Delta, Middle, and Upper Egypt, respectively.

Berseem

The second major winter crop in Egypt is berseem, which occupied the largest area. The multi-cut berseem needs sufficient water during the growing season, especially at germination, tillering and during high temperatures in spring. It needs eight to 10 irrigations: one eight to ten days before each cut and one six to eight days after each cut. The life watering must be about 12 days after sowing. The more water used at sowing, the lower the germination percentage. ET values of berseem are 2000, 2352, and 2772 m^3/fed for the Delta, Middle, and Upper Egypt, respectively.

Fodder sorghum

To obtain optimum yields of sorghum, available soil moisture should be maintained between 40 and 60%. Water-use efficiency decreases as soil moisture content increases with high irrigation frequency. Increasing soil moisture stress until only a small portion of available water remained (10–15%) resulted in a sharp decrease in the production of sorghum. Seasonal values of water consumptive use per cut range from 103.8 to 105.8, 78.2 to 34.4, 50.2 to 41.3, and 40.2 to 24.7 cm at Ismailia, Shandaweel, Nubaria, and Sakha, respectively.

Irrigation improvement and water conservation

Land leveling and long furrow technique

Using long furrows in controlled irrigation by land leveling with a 0.1% slope showed practical advantages, especially in saving land and labor. One of the greatest advantages is the potential for fully mechanizing all crop production operations.

Surge flow technique

Several scientists used this method in Egypt and concluded that it helps save irrigation water and increase crop yield.

Antitranspirant application

Film-forming antitranspirants improve water-use efficiency. Studies reveal the effect of different substances on the market grain yield of wheat. Growth promoters and antitranspirants (PMA) increase the value of water-use efficiency only under wet and medium soil moisture conditions. As for growth retardants, it is obvious that the use of Alar does not cause any increase.

Land Drainage in Egypt

Historical Background

With the gradual introduction of perennial irrigation since the beginning of this century, more and more open drainage systems were installed. It is the responsibility of the state to construct the main drainage facilities, which are considered a public service. A separate authority for drainage was established in 1959 as part of the Ministry of Irrigation to take the responsibility for implementation of drainage projects in the country. By 1965, nearly five million acres were served, mainly open drains, but farmers did not respond as expected by installing the system of field drains required. They could not afford to lose the area devoted to ditch drains. Consequently, the drainage system was neither complete nor effective in terms of having any significant control on the water table.

Recognizing the inadequacy of the ditch drainage system, research was initiated in 1939 to try tile drainage in different parts of the country. By 1952, pilot projects were extended to an area of 50,000 acres. Encouraged by the results obtained, a law was passed in 1956 giving responsibility to the Government for the execution of field drainage. Between 1961 and 1965, modern techniques of tile drain installation were tested through a pilot project covering five areas, about 2,000 acres each, implemented under the auspices of the United Nations Special Fund, with FAO as the executing agency.

When irrigation water became available from the Aswan High Dam in 1964, it allowed the introduction of perennial irrigation to all areas, thus reclaiming New Lands and increasing cropping intensities. A direct consequence of intensified irrigation has been a rising groundwater table, and increased problems of waterlogging and salinity. Both poor water management and inadequate water table control have contributed significantly to these problems. In response to this challenge, the Government gave high priority for installing subsurface drainage systems to conserve the productivity of agricultural areas.

When the Government was convinced that providing agricultural lands with field drainage would increase crop yield and prevent the development of waterlogging and soil salinity, a national program was initiated. It was started in the southern part of the Nile Delta where salinity and high water table problems were more predominant. The first of these programs was agreed upon in 1970, and provided an area of 950,000 acres in the southern part of the Delta with covered drains, constructed 11 drainage pumping stations and widened and deepened the main open drainage systems in that area to allow for field drainage.

An agreement was signed with the World Bank in 1973 for a loan to install covered field drains in 300,000 acres in Upper Egypt and four pumping stations, reclaim 22,000 acres suffering from salinity and alkalinity problems, and rehabilitate main drains and implement a bilharzia control program in an area of 900,000 acres in Upper Egypt. It was believed that the introduction of an open drainage system in Upper Egypt, after the construction of the High Dam, would help migrate bilharzia snails from the Nile Delta to Upper Egypt.

Subsequently, the program was expanded with the assistance of the World Bank and other donor countries to cover a total area of 3.4 million acres by the end of 1989 (Figs. 1 and 2). Some 2.5 million acres of this area are in the Nile Delta, and the rest in Upper Egypt. A total area of 5.5 million acres is planned for subsurface drainage by the year 2000.

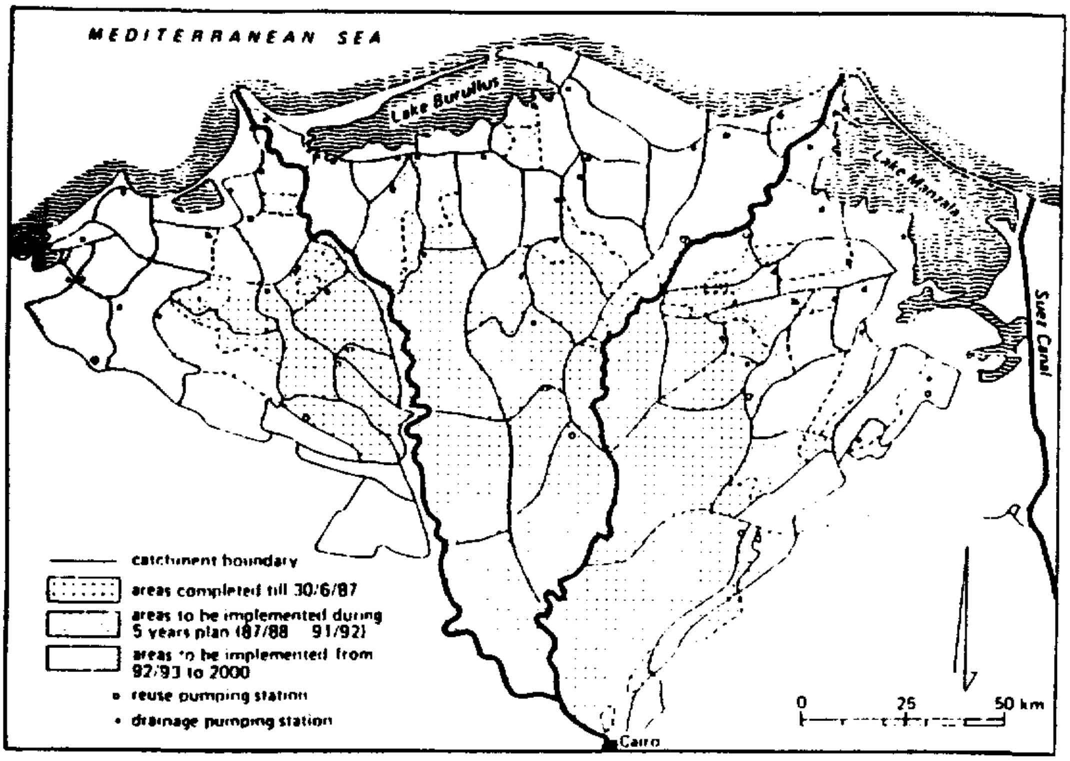


Fig. 1. Drainage implementation program in the Nile Delta.

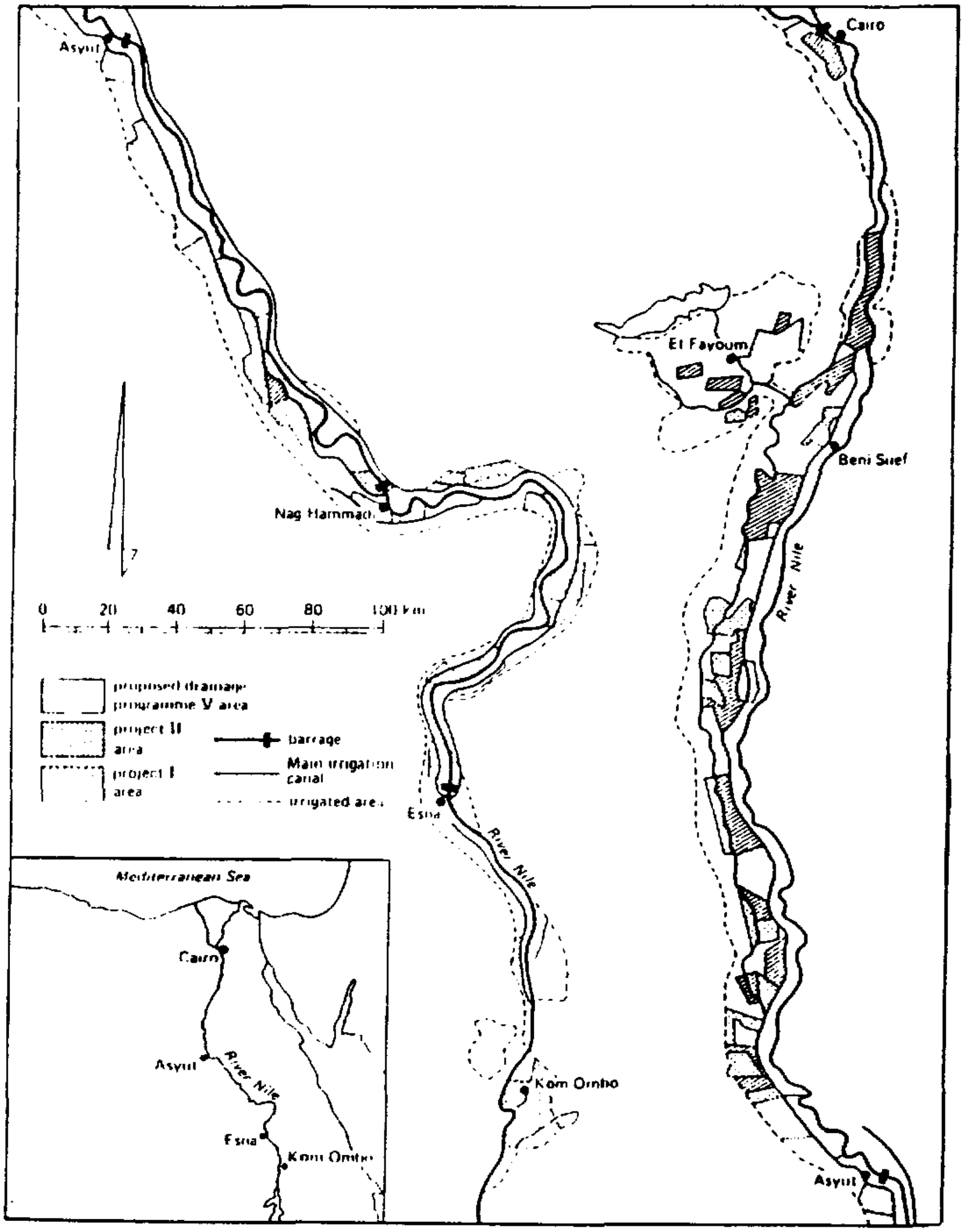


Fig. 2. Location of drainage projects in Upper Egypt.

Layout

The drainage system consists of a tree of drains of different type, depth, length, and size. They are classified into two main groups. The first group is known as the main or open drainage system, and the second group may be called the covered or field drainage system.

The main drainage system includes the branch, the main, and the out-fall drains. They follow an irregular pattern which depends on the topography of the area, the land slope and the location of an outlet facility such as a larger drain, a river, a lake, or the sea.

It is almost impossible to implement a field drainage system without a reliable and efficient main system to evacuate the drainage water. The lack of suitable main drains was the first problem confronting the implementation of the field system in Egypt. Therefore, the construction of new open drains or deepening and remodeling existing drains was necessary and complementary to recent drainage projects.

The construction of open drains requires the sacrifice of fertile land in an already limited agricultural area of the country. The flat nature of the land often requires the use of pumping stations to maintain the water surface level in open drains below the specified level. This increases the overall cost of the drainage system and requires reliable and efficient operation and maintenance.

The covered drainage system, which consists of buried tubes, forms a regular pattern of lateral and collector drains. This system provides for primary drainage in cultivated fields. It has a gridiron layout (Fig. 3). The general rule for the layout is to cross the major infrastructures, such as canals or roads, with collectors only.

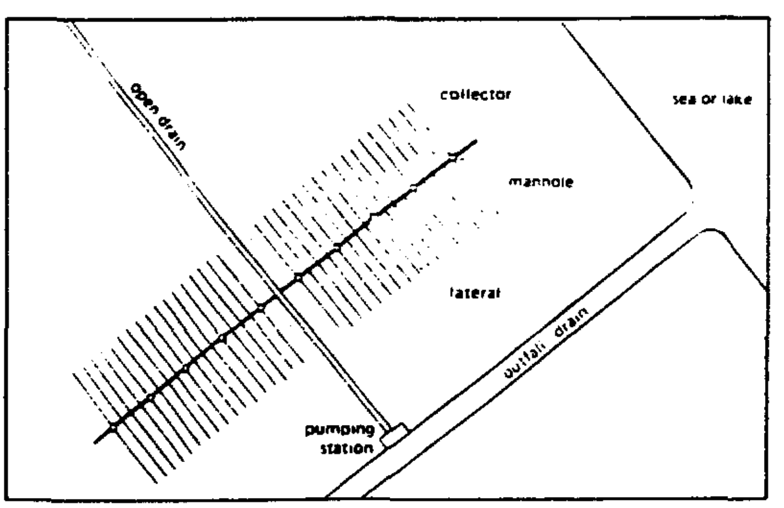


Fig. 3. Covered drainage system used in Egypt.

Open Drainage System

The most affected irrigated lands in Egypt were divided into several drainage units to be served by independent pumping stations. The main open drain project started in 1933, and consisted of a huge system of open drains and pumping stations. Schematic diagrams of the existing drainage system are given in Figs. 4 through 9.

The system is divided into:

- Open and covered drains (collectors and laterals).
- Open collector drains that comprise both branch and sub-branch drains.
- A carrier network of main drains that receive water from a collector system and conveys it to the Nile or discharges it into the coastal lakes or the Mediterranean sea.
- Pumping stations which transfer drainage water to coastal lakes or to the Mediterranean Sea.

The Ministry of Public Works and Water Resources has established a comprehensive drainage program ranging from construction of open collector drains to construction of additional pumping stations for maintenance of the drainage system and weed control. This program resulted in improvement of drainage conditions in the areas involved.

A survey of the pumping stations made in 1977, and showed a total of 80 pumping stations serving a total area of about 4,172,450 fed in both the Nile Delta and Upper Egypt as shown in Table 14. From 1977 to 1987, more pumping stations were constructed, bringing the total to 129, with a capacity of 2459 m^3/sec and serving an area of 6,592,450 fed (2,768,829 ha) as shown in Table 15.

The Drainage Research Institute (DRI) of the National Water Research Center (NWRC) took the lead in establishing a network of measuring stations on the key points of the main drains in the Nile Delta in the late 1970s (DRI, 1987b). The measurement network is composed of 22 drain catchments, each of which either consists of a single or multiple drainage zone as shown in Fig. 10 and Table 16.

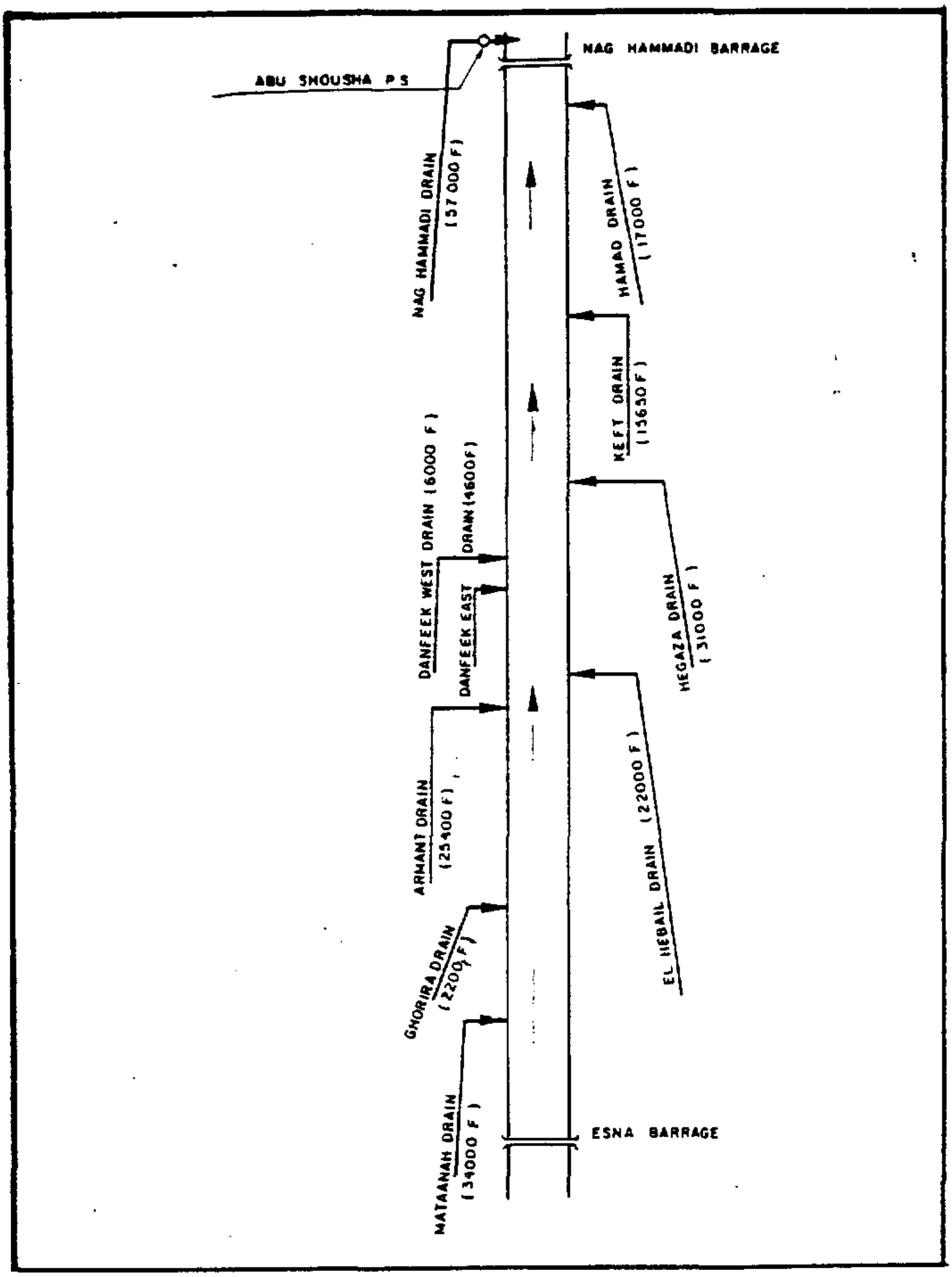


Fig. 4. Drainage system from Esna to Naga Hammadi.

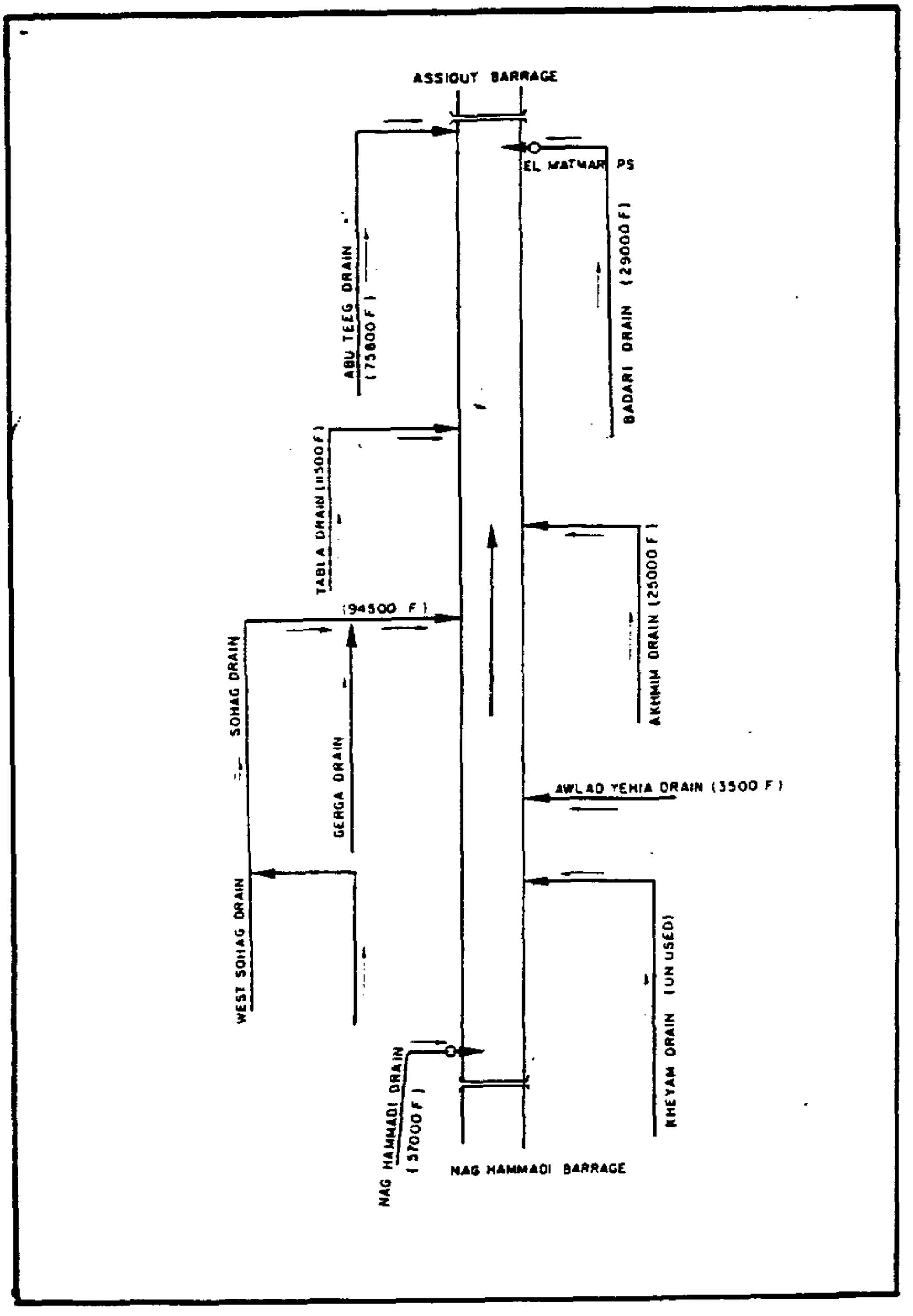


Fig. 5. Drainage system from Naga Hammadi to Assiut.

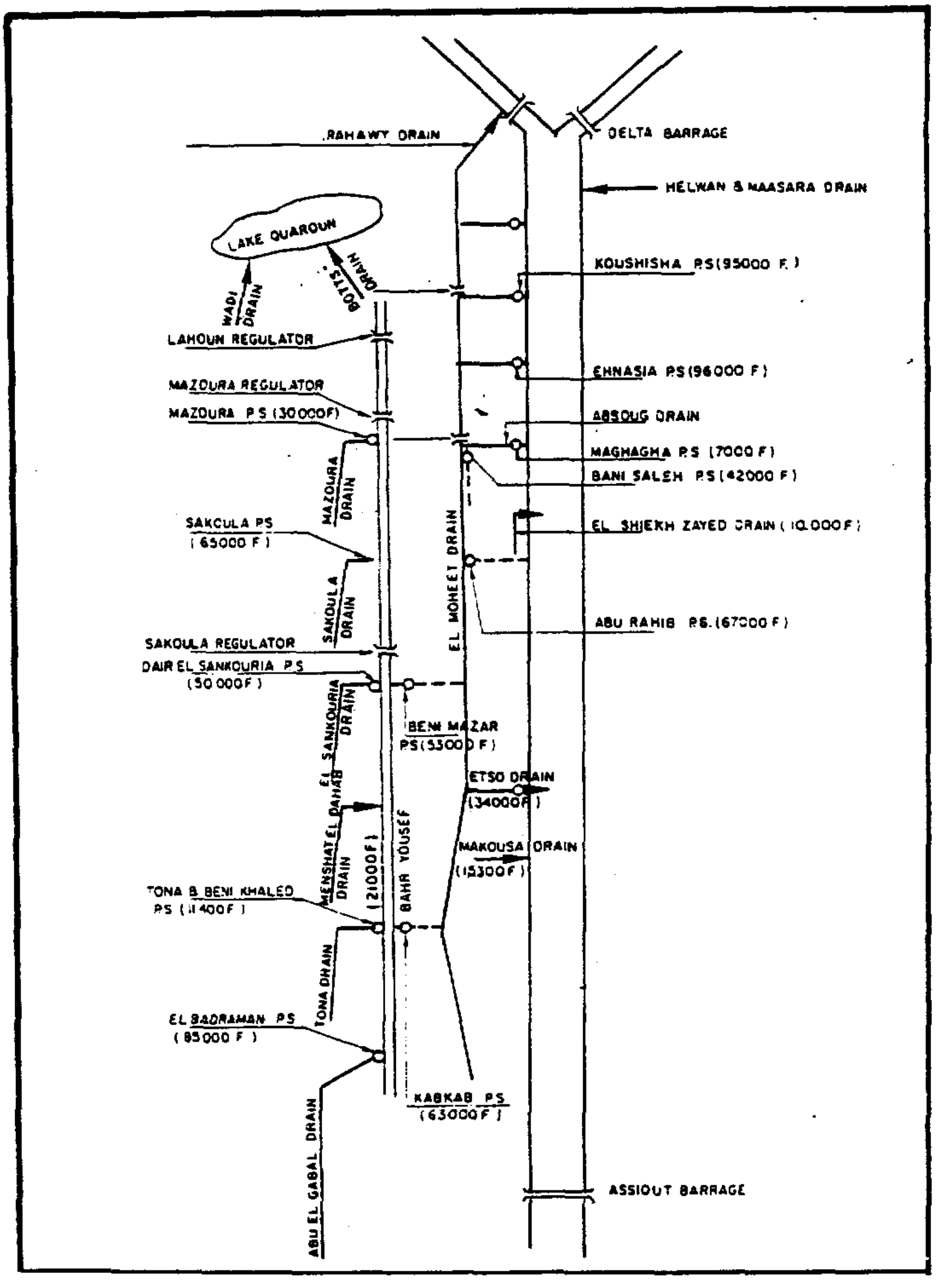


Fig. 6. Drainage system from Assiut to the Delta.

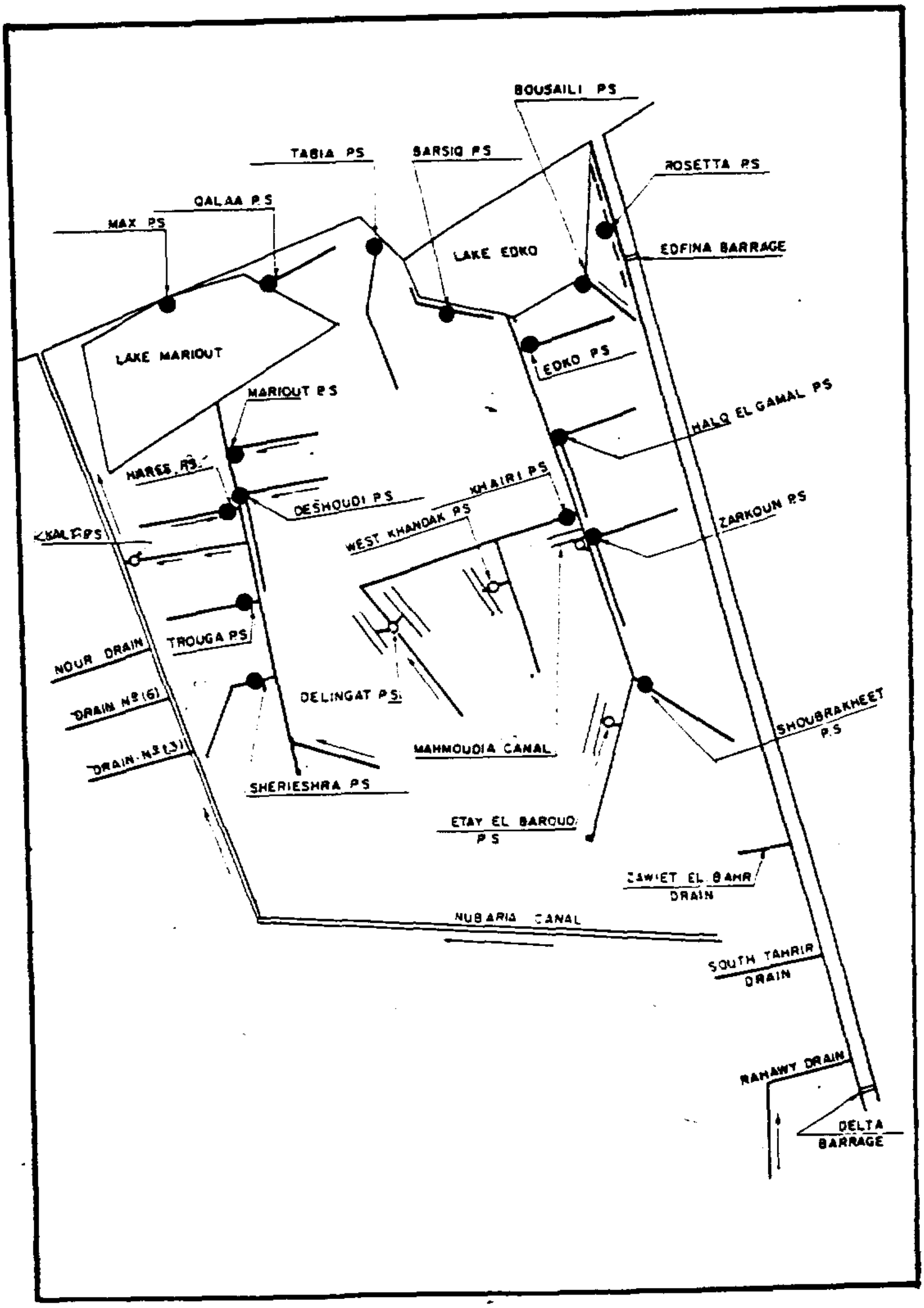


Fig. 7. Drainage system in the West Delta.

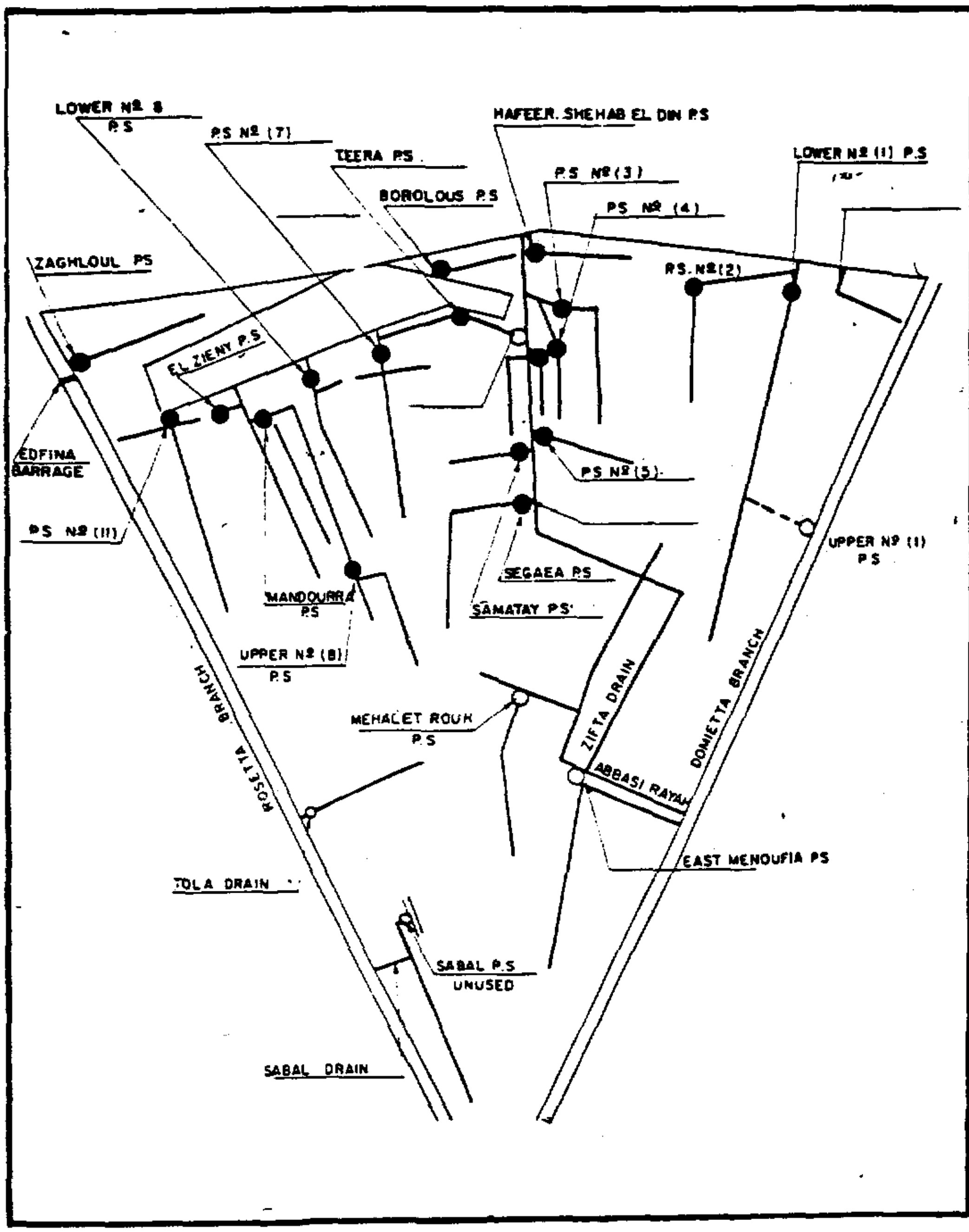


Fig. 8. Drainage system in the Middle Delta.

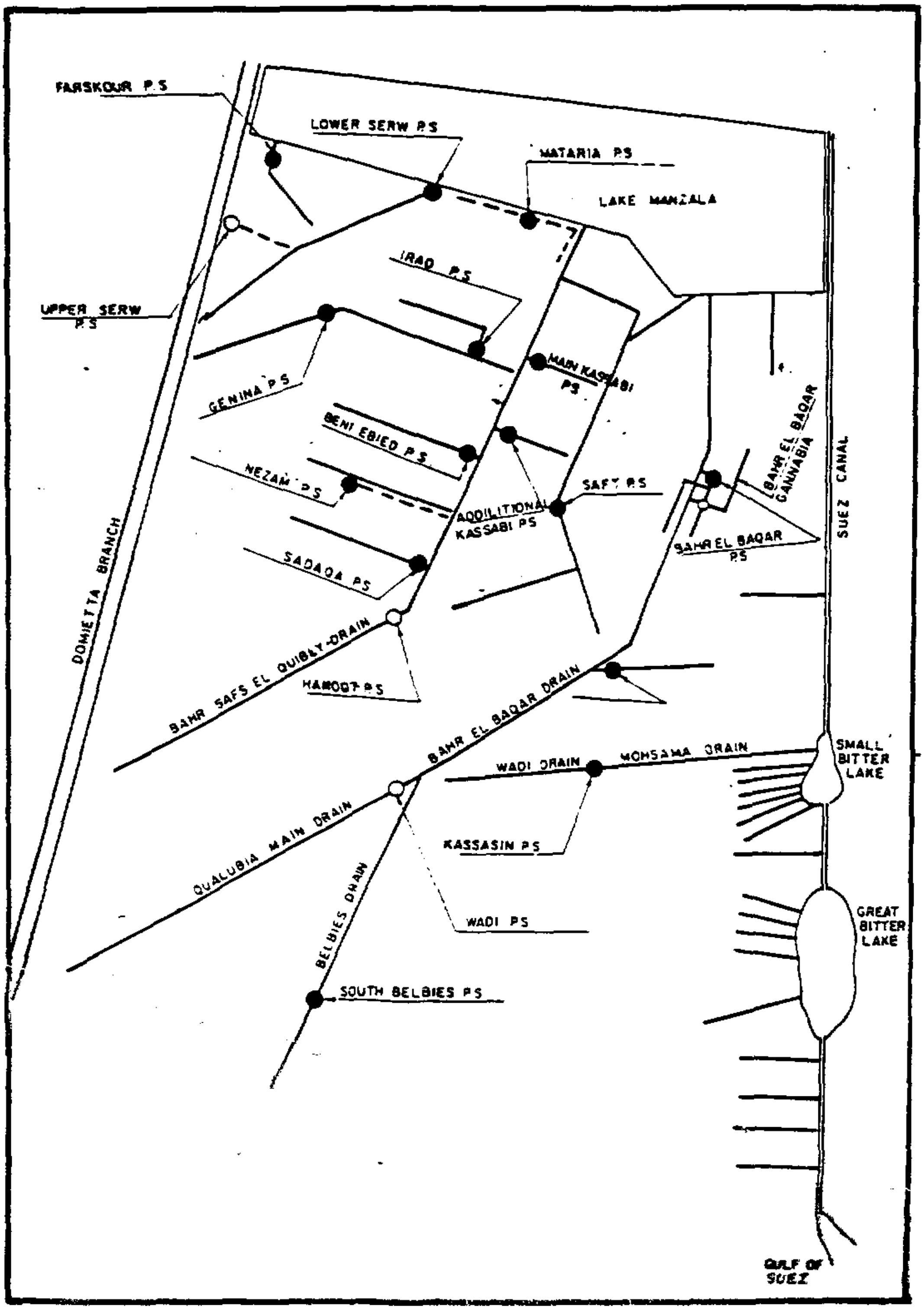


Fig. 9. Drainage system in the East Delta.

Table 14. Number of pumping stations and areas served up to 1977.

Number of stations	Total discharge (m^3/s)	Area served (fed)	Remarks
17	12,960	573,850	Constructed prior to 1952 and not renewed.
13	28,100	813,000	Constructed from 1953 to 1960.
15	23,700	571,000	Constructed from 1967 to 1975.
11	37,350	982,000	Constructed prior to 1952, renewed during first five year plan and completed in 1963–1971.
13	32,125	639,600	Constructed prior to 1952, renewed during second five year plan and completed in 1971–1974.
1	1,180	85,000	Station El Badrman (UE) remodeled in 1975.
1	910	42,000	Station Bani Saleh (UE) remodeled in 1975.
1	10,620	444,000	Station constructed under IDA first agreement, completed in 1975–1977.
1	800		Station El Mahssama, constructed in 1977 to Ismailia Canal from El Mahssama Drain.
1	800	22,000	Station El Saada, Sharkia Governorate, constructed in 1977.
80	1,485,450	4,172,450	

Table 15. Pumping stations constructed between 1977 and 1987.

Number of stations	Total area served (fed)	Remarks
80	4,172,450	Stations constructed up to 1977.
28	880,000	Stations to replace pre-1975 stations and reconstructed pumping stations up to 1979 (Upper Egypt).
11	1,000,000	Stations included in the World Bank First Agreement (1979).
10	450,000	Stations included in the World Bank Agreement (up to 1987).
129	6,592,450	Total discharge 2,459 m^3/s

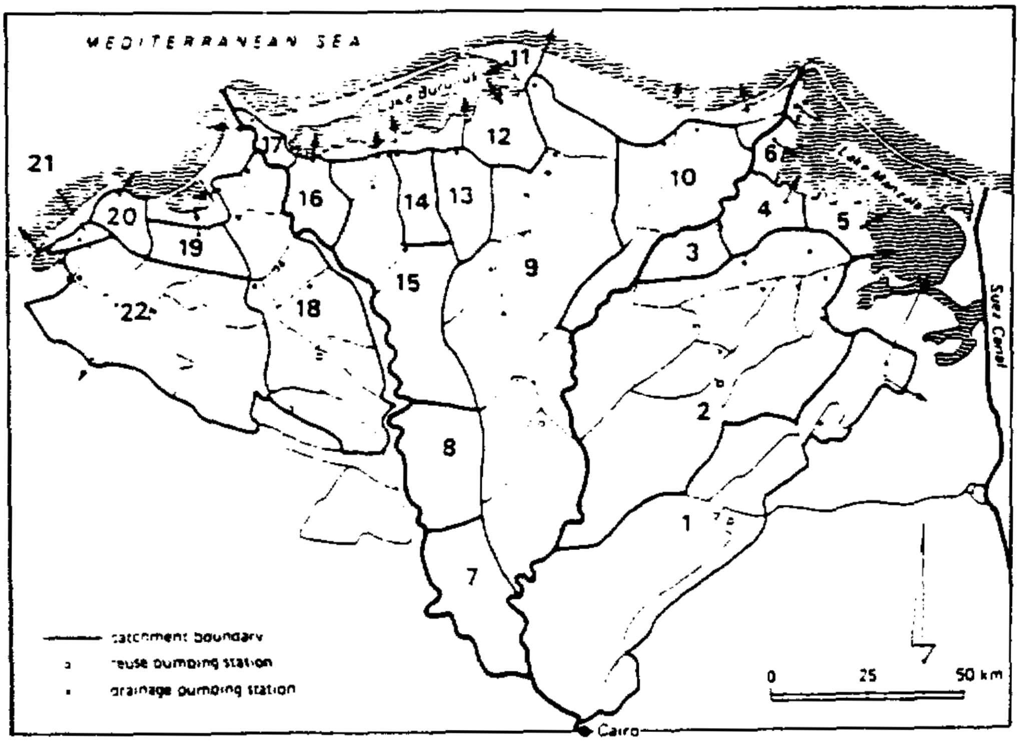


Fig. 10. Drainage catchments in the Delta.

Table 16. Single and multiple zone drains.

Region	Single zone drains	Multiple zone drains
East Delta	Upper Serw (3) Lower Serw (4) Mataria (5) Farskour (6)	Bahr El Baqar (1) Bahr Hadous (2)
Middle Delta	Sabal (7) Tala (8) Burullos (11) Tira (12) No. 7 (13) Lower No. 8 (14) No. 11 (16) Zaghloul (17)	Gharbia Main Drain (9) Drain No. 1 (10) Nashart Drain (15)
West Delta	Barsiq (19) Tabia (20) Qalaa (21)	Edku Drain (18) Omoum Drain (22)

Drainage water flows and their variations

The Nile Delta is physically divided into three well identified regions. The first region is bounded by the Suez Canal to the east, the Damietta branch to the west, Lake Manzala to the north, and the Ismailia Canal to the south. It is known as the East Delta. The Middle Delta is located between the two branches of the Nile and bounded by Lake Burullos and the Mediterranean Sea to the north. The western region is that part of the Delta to the west of the Rosetta Branch. It runs west to the fringes of the Delta and includes the recently reclaimed desert areas.

The drainage water which flows out of the Delta to the sea consists of irrigation water in excess of crop evapotranspiration in addition to canal tail end losses emptied into or collected by the drain through its course. It should be noted that under reuse practices, part of the drainage water is lifted out of the drains and into the irrigation system at certain locations. A part of this water returns to the drainage system, either to the same drain or another drain. Thus the water finally flowing to the sea is the net flow out of the agricultural system. Although against the law, industrial and domestic untreated wastes are dumped into some drains.

The average drainage rate during 1990 per drainage catchment area is shown in Fig. 11. The drainage rate is quite low in the south, where the water table is low and natural drainage high. The situation in the north is different; where the drainage rate exceeds the irrigation rate, a significant part of the Delta is subject to upward seepage of brackish groundwater. This seepage is partly responsible for the high rates in the northern catchments. Another reason is the high intensity of rice in the north of the Delta.

The average regional rates of the eastern, middle and western regions of the Nile Delta are given in Table 17 for the period 1984/85 through 1989/90. This represents the average drain discharges per unit area of each region.

The average drainage rate in the West Delta is slightly higher than the eastern and middle regions. This can be attributed to the lighter soils of this region in addition to the fact that the agricultural area is more concentrated in the northern part of the region, where upward seepage and seawater intrusion are higher. The average drainage rate over the whole Delta during the period 1984–1990 was about 1.8 mm/day. The average annual supply of the Nile water to the Delta during the same period was about 34.6 billion m^3/year. The supply rate per unit area is 4.8 mm/day. Consequently, the overall water-use efficiency can be estimated as 62% during the said period. It should be noted that the calculated efficiency is underestimated, since the drainage water includes a portion which either originates from seawater, deep artisan groundwater, or industrial and urban waste water.

Table 17. Average regional drainage rates to the sea.

Year	Drainage rate (mm/day)		
	East Delta	Middle Delta	West Delta
1984/85	1.85	1.89	2.10
1985/86	1.80	1.80	2.14
1986/87	1.77	1.81	1.95
1987/88	1.60	1.61	1.87
1988/89	1.58	1.56	1.77
1989/90	1.75	1.68	1.74
Average	1.73	1.72	1.93

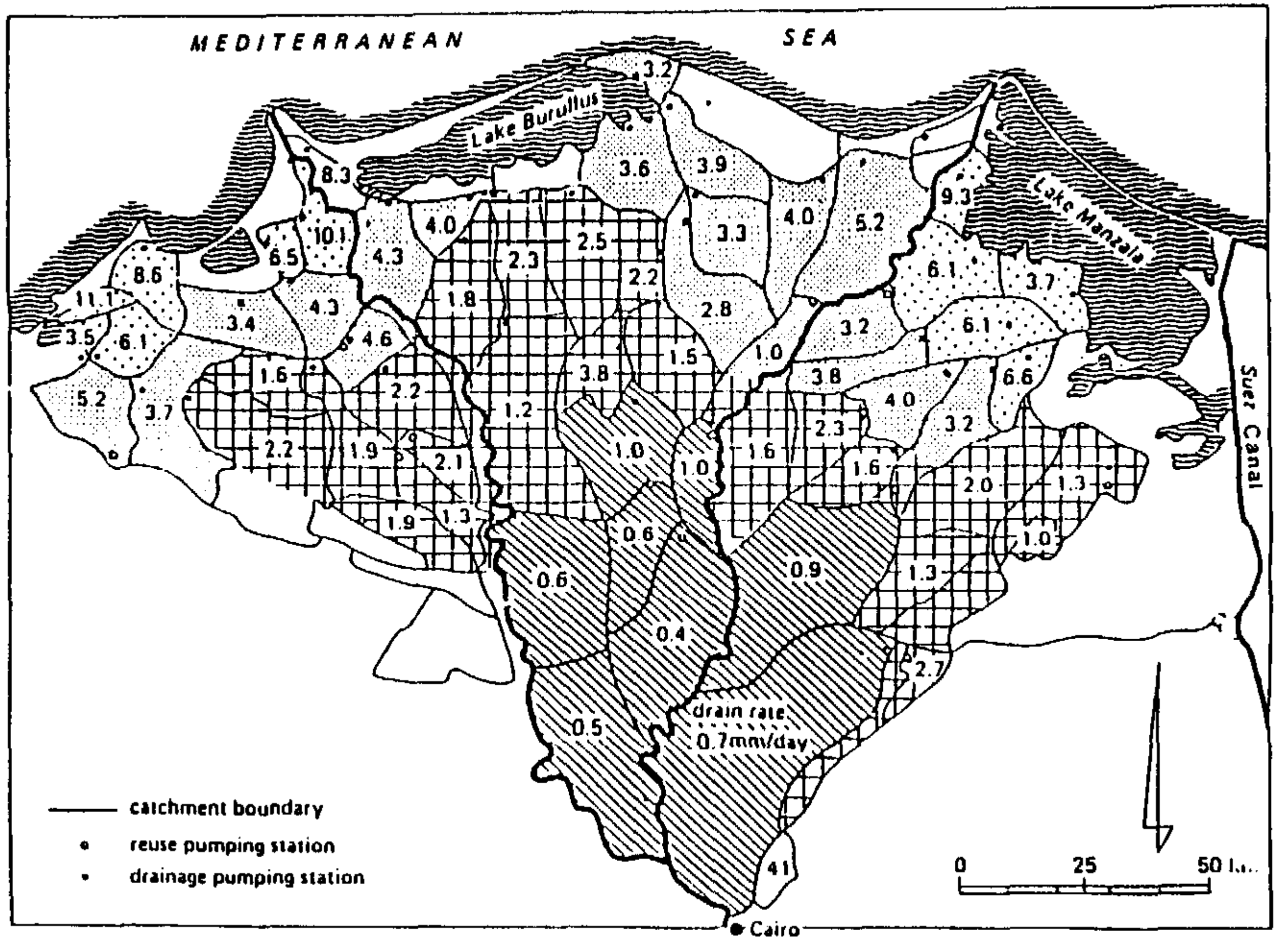


Fig. 11. Average annual (1990) drainage rates in the Delta (mm/day).

The drainage water monitoring program clearly revealed that drainage water quantity changes with time. The variations occur from month to month, season to season and year to year (Tables 18 to 22). The annual variations are primarily dependent on the water use policies and management of the main supply system, especially the releases of the Aswan High Dam. The strict control and reduction of releases associated with the continuation of drought in the Upper Nile basin has resulted in a clear reduction in the drainage water. In 1987/88, a reduction of 1,600 million m^3/year in the water supply to the Nile Delta resulted in a corresponding reduction of 1200 million m^3/year in the drainage water discharged into the sea and northern lakes (Abdel Dayem and Abu-Zeid, 1991).

Table 18. Average annual discharges to the sea (million m^3).

Region	84/85	85/86	86/87	Average 84–87	87/88	88/89	89/90	Average 87–90
East Delta	4,391.49	4,219.36	3,815.31	4,142.05	3,513.19	3,181.10	3,651.17	3,448.49
Middle Delta	5,013.33	4,883.45	4,899.72	4,932.16	4,291.20	4,141.50	4,158.80	4,197.19
West Delta	4,320.86	4,338.93	3,943.37	4,201.05	3,793.69	3,600.02	3,922.05	3,771.92
Overall Delta	13,725.7	13,441.7	12,658.4	13,275.26	11,598.1	10,922.1	11,732.02	11,417.60

Table 19. Average annual officially reused drainage water (million m^3).

Region	84/85	85/86	86/87	Average 84–87	87/88	88/89	89/90	Average 87–90
East Delta	1,300.50	1,262.84	1,419.75	1,327.70	1,381.12	1,400.03	1,503.55	1,428.23
Middle Delta	763.47	747.64	734.45	748.52	652.54	676.28	1,447.48	925.43
West Delta	814.08	778.40	776.10	789.50	590.73	518.58	579.85	563.05
Overall Delta	2,878.0	2,788.88	2,930.3	2,865.72	2,624.39	2,594.89	3,530.88	2,916.71

Fig. 12 shows the total monthly discharges of drainage water to the sea from 1984/85 to 1989/90. In general, the quantity of unused drainage water decreases as it flows to the sea. The maximum drainage water quantity was measured in 1984/85. The annual flow to the sea was 13.7 billion m^3. The minimum quantity was recorded in 1988/89 and reached only about 10.9 billion m^3. The average annual flow to the sea following the tight control on Nile water supply is about 11.4 billion m^3. The annual flow to the sea from different regions of the Delta is summarized in Table 18, which also shows the effect of rationalization as expressed by the averages during the two periods before and after 1987/88.

The tightened supply of Nile water after 1987/88 is associated with a reduction of the total official reuse of drainage water. The amounts of drainage water which were annually reused during the period 1984–1990 varied between 2.9 and 3.5 billion m^3/year. This water was pumped into irrigation canals and mixed with a volume of fresh water depending on the salinity of the drainage water. The highest quantity of drainage water currently reused is in the eastern Nile Delta. Table 19 shows the official reused quantities over the period. In 1989/1990, a considerable increase in the official reused drainage water was measured. This increase is mainly observed in the Middle Delta, an area estimated at 40,000 fed (16,800 ha).

Table 20a. Monthly distribution of drainage water flow to the seas and coastal lakes of the East Delta, 1984–1990 ($Q = 1000\ m^3$, EC in dS/m).

YEAR	1984-1985		1985-1986		1986-1987		OVERALL AVG. 1984-1987		1987-1988		1988-1989		1989-1990		OVERALL AVG. 1987-1990		OVERALL AVG. 1984-1990	
MONTH	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC
AUG	522.10	2.06	494.73	2.20	436.56	2.57	484.46	2.26	439.42	2.71	376.62	2.85	485.25	2.68	433.76	2.74	459.11	2.48
SEP	521.50	2.11	501.14	2.15	512.60	2.37	511.75	2.21	480.97	2.43	437.11	2.71	492.86	2.76	470.31	2.63	491.03	2.41
OCT	475.96	2.07	434.77	2.27	457.83	2.19	456.19	2.17	452.91	2.33	382.42	2.80	388.17	2.86	407.83	2.65	432.01	2.40
NOV	380.92	2.18	369.15	2.32	390.26	2.25	380.11	2.25	328.32	2.53	297.58	2.85	291.25	2.89	305.72	2.75	342.91	2.47
DEC	429.56	2.13	429.69	2.20	378.95	2.31	412.73	2.21	405.04	2.27	386.40	2.31	364.64	2.85	385.36	2.47	399.05	2.33
JAN	372.58	2.62	376.04	2.50	354.71	2.83	367.78	2.65	367.39	2.51	359.88	2.66	341.92	2.45	356.40	2.54	362.09	2.59
FEB	237.10	2.50	233.39	3.74	176.06	3.60	215.52	3.25	149.30	4.15	156.93	3.90	206.06	4.09	170.76	4.06	193.14	3.60
MAR	342.76	2.58	333.60	2.60	371.63	2.37	349.33	2.51	337.07	2.53	322.97	3.07	329.64	2.90	329.89	2.83	339.61	2.67
APR	311.30	2.43	340.38	2.31	288.73	2.47	312.80	2.40	238.33	3.00	257.89	2.92	311.23	2.80	269.15	2.90	290.98	2.63
MAY	318.25	2.24	311.65	2.38	282.81	2.36	303.50	2.33	237.24	2.57	256.48	2.94	322.75	2.53	272.16	2.67	287.83	2.49
JUN	357.40	2.33	323.16	2.69	411.40	2.39	363.99	2.48	268.15	3.14	308.79	2.93	437.62	2.80	338.19	2.93	351.09	2.69
JUL	465.32	2.35	447.83	2.61	481.00	2.41	464.72	2.45	397.39	3.63	510.85	2.64	517.82	2.87	475.35	3.00	470.04	2.73
TOTAL	4732.75	2.27	4595.53	2.44	4540.34	2.45	4622.87	2.38	4101.53	2.72	4053.92	2.81	4489.21	2.82	4214.89	2.79	4418.88	2.58

Table 20b. Monthly distribution of reused drainage water in the East Delta and effect of rationalization strategy, 1984–1990 (Q = 1000 m^3, EC in dS/m).

YEAR	1984-1985		1895-1986		1986-1987		1984-1987 OVERALL AVG.		1987-1988		1988-1989		1989-1990		1987-1990 OVERALL AVG.		1984-1990 OVERALL AVG.	
MONTH	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC
AUG	160.53	1.16	138.97	1.21	143.64	1.36	147.71	1.24	150.77	1.38	130.75	1.49	162.26	2.38	147.92	1.78	147.82	1.51
SEP	137.57	1.20	142.75	1.22	148.25	1.33	142.86	1.25	144.43	1.28	166.19	1.38	164.62	2.40	158.41	1.70	150.63	1.49
OCT	127.64	1.15	114.39	1.30	140.72	1.24	127.59	1.23	142.27	1.39	129.87	1.39	118.00	2.70	130.05	1.79	128.82	1.51
NOV	102.10	1.18	91.25	1.37	126.87	1.29	106.74	1.28	130.82	1.50	109.90	1.55	118.72	2.76	119.81	1.93	113.28	1.62
DEC	85.23	1.35	108.62	1.24	131.43	1.18	108.43	1.24	141.84	1.27	128.02	1.42	112.96	2.77	127.61	1.76	118.02	1.52
JAN	91.65	1.49	82.25	1.35	99.73	1.69	91.28	1.52	107.80	1.60	104.69	1.52	98.32	2.71	103.60	1.92	97.44	1.74
FEB	49.61	1.99	52.52	2.31	47.50	2.49	49.87	2.26	56.63	2.38	50.17	3.86	60.53	4.98	55.78	3.76	52.83	3.05
MAR	112.26	1.33	105.05	1.28	125.31	1.25	114.21	1.28	113.98	1.48	126.45	1.64	134.53	2.65	124.99	1.95	119.60	1.63
APR	90.99	1.38	102.43	1.15	95.49	1.27	96.30	1.26	83.05	1.53	85.38	1.65	106.64	2.67	91.69	2.01	94.00	1.63
MAY	99.42	1.38	101.95	1.09	96.78	1.20	99.38	1.22	91.18	1.27	97.64	1.36	130.05	2.27	106.29	1.70	102.84	1.47
JUN	108.12	1.17	101.20	1.21	122.58	1.18	110.63	1.18	96.56	1.35	106.77	1.27	134.27	2.47	112.53	1.77	111.58	1.48
JUL	135.17	1.20	121.46	1.43	141.45	1.33	132.69	1.32	121.79	1.44	164.21	1.33	162.66	2.43	149.56	1.76	141.12	1.55
TOTAL	1300.50	1.28	1262.84	1.30	1419.75	1.34	1327.70	1.31	1381.12	1.44	1400.03	1.53	1503.55	2.64	1428.23	1.89	1377.96	1.61

Table 21. Monthly distribution of drainage water flow to the sea and coastal lakes of the Middle Delta, 1984–1990 (Q = 1000 m^3, EC in dS/m).

YEAR	1984-1985		1985-1986		1986-1987		OVERALL AVG. 1984-1987		1987-1988		1988-1989		1989-1990		OVERALL AVG. 1987-1990		OVERALL AVG. 1984-1990	
MONTH	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC
AUG	603.39	2.78	507.42	3.18	531.55	3.53	547.45	3.15	468.04	3.45	439.83	3.51	593.46	2.92	500.44	3.26	523.95	3.20
SEP	585.92	2.97	533.87	3.37	564.32	3.46	561.37	3.26	501.81	3.51	474.73	3.68	511.80	3.43	496.11	3.53	528.74	3.39
OCT	475.07	3.29	443.65	3.42	463.37	3.72	460.70	3.47	470.93	3.37	383.10	3.57	357.59	4.03	403.87	3.63	432.29	3.54
NOV	419.69	3.16	365.06	4.04	431.04	3.66	405.26	3.60	333.27	4.32	298.38	4.28	324.47	4.48	318.71	4.36	361.99	3.94
DEC	426.35	3.21	392.95	4.00	376.70	4.11	398.67	3.75	425.47	4.05	409.35	3.39	381.04	4.14	405.29	3.86	401.98	3.81
JAN	316.80	3.87	326.32	4.49	352.46	4.28	331.86	4.22	334.39	4.79	302.01	5.07	367.70	4.59	334.70	4.80	333.28	4.51
FEB	194.44	7.26	227.06	5.48	181.90	5.78	201.13	6.14	200.25	6.09	119.70	6.79	223.83	5.68	181.26	6.08	191.20	6.11
MAR	318.56	3.85	358.07	3.38	385.35	3.60	353.99	3.60	275.76	3.95	252.86	4.66	350.04	3.89	292.89	4.13	323.44	3.04
APR	333.28	3.51	389.71	3.61	306.33	3.77	343.11	3.63	220.99	4.63	228.54	4.29	315.81	3.89	255.11	4.22	293.11	3.88
MAY	339.99	3.41	346.38	3.87	310.73	3.65	332.37	3.65	243.51	3.92	227.27	4.10	272.95	3.72	247.91	3.91	290.14	3.76
JUN	413.73	3.14	407.61	3.34	457.64	3.35	426.33	3.28	302.82	4.09	296.25	3.95	429.05	3.53	342.71	3.81	384.52	3.52
JUL	586.11	2.81	585.35	3.63	538.21	3.32	569.89	3.25	513.96	3.39	619.52	3.06	509.02	3.37	547.50	3.26	558.69	3.25
TOTAL	5013.33	3.35	4883.45	3.71	4899.60	3.72	4932.127	3.93	4291.20	3.96	4051.54	3.91	4636.75	3.83	4326.50	4.23	4629.31	4.07

Table 22. Monthly distribution of drainage water flow to the sea and coastal lakes of the West Delta, 1984–1990 (Q = 1000 m^3, EC in dS/m).

YEAR	1984-1985		1985-1986		1986-1987		OVERALL AVG. 1984-1987		1987-1988		1988-1989		1989-1990		OVERALL AVG. 1987-1990		OVERALL AVG. 1984-1990	
MONTH	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC	Q	EC
AUG	427.18	4.87	422.82	4.81	387.70	3.92	412.57	4.55	412.46	5.04	326.12	4.94	398.56	4.98	379.05	4.99	395.81	4.76
SEP	428.40	4.92	433.12	4.23	418.61	3.74	426.71	4.30	406.15	5.07	355.25	5.13	333.37	4.45	364.92	4.90	395.82	4.57
OCT	412.91	4.83	461.60	5.76	391.95	3.78	422.15	4.87	410.84	5.41	376.51	5.26	298.10	6.05	361.82	5.53	391.99	5.17
NOV	356.26	4.35	387.18	5.06	340.13	4.59	361.19	4.68	330.70	6.00	287.40	5.22	283.68	7.16	300.59	6.12	330.89	5.33
DEC	377.30	6.21	401.67	4.82	287.95	5.05	355.64	5.37	368.16	6.12	313.83	6.54	300.25	7.37	327.41	6.64	341.53	5.98
JAN	325.50	7.53	306.79	5.88	265.93	5.83	299.41	6.46	335.92	7.29	307.62	8.26	314.62	7.09	319.39	7.54	309.40	7.02
FEB	269.99	8.01	215.80	6.74	208.72	6.43	231.50	7.14	249.19	7.56	200.61	8.39	216.78	11.03	222.19	8.94	226.85	8.02
MAR	326.88	6.62	325.45	6.13	317.81	6.02	323.38	6.26	255.86	6.68	292.58	7.44	242.07	6.69	263.50	6.97	293.44	6.58
APR	318.35	6.46	329.46	5.60	270.99	5.95	306.27	6.00	192.43	6.27	210.19	8.23	232.87	6.21	211.83	7.63	259.05	6.67
MAY	329.39	5.79	321.99	4.56	272.62	4.98	308.00	5.12	235.88	5.47	263.33	7.61	252.08	6.98	250.43	6.73	279.22	5.84
JUN	353.18	5.74	330.93	3.80	357.32	4.68	347.14	4.76	281.07	5.10	261.32	6.28	289.57	5.83	277.32	5.72	312.23	5.19
JUL	395.52	5.14	402.12	3.81	423.64	4.59	407.09	4.51	308.53	5.03	389.11	5.23	357.21	5.34	351.62	5.21	379.36	4.83
TOTAL	4320.86	5.76	4338.93	5.02	3943.37	4.81	4201.05	5.21	3787.19	5.84	3583.87	6.35	3519.16	6.54	3630.07	6.24	3915.56	5.69

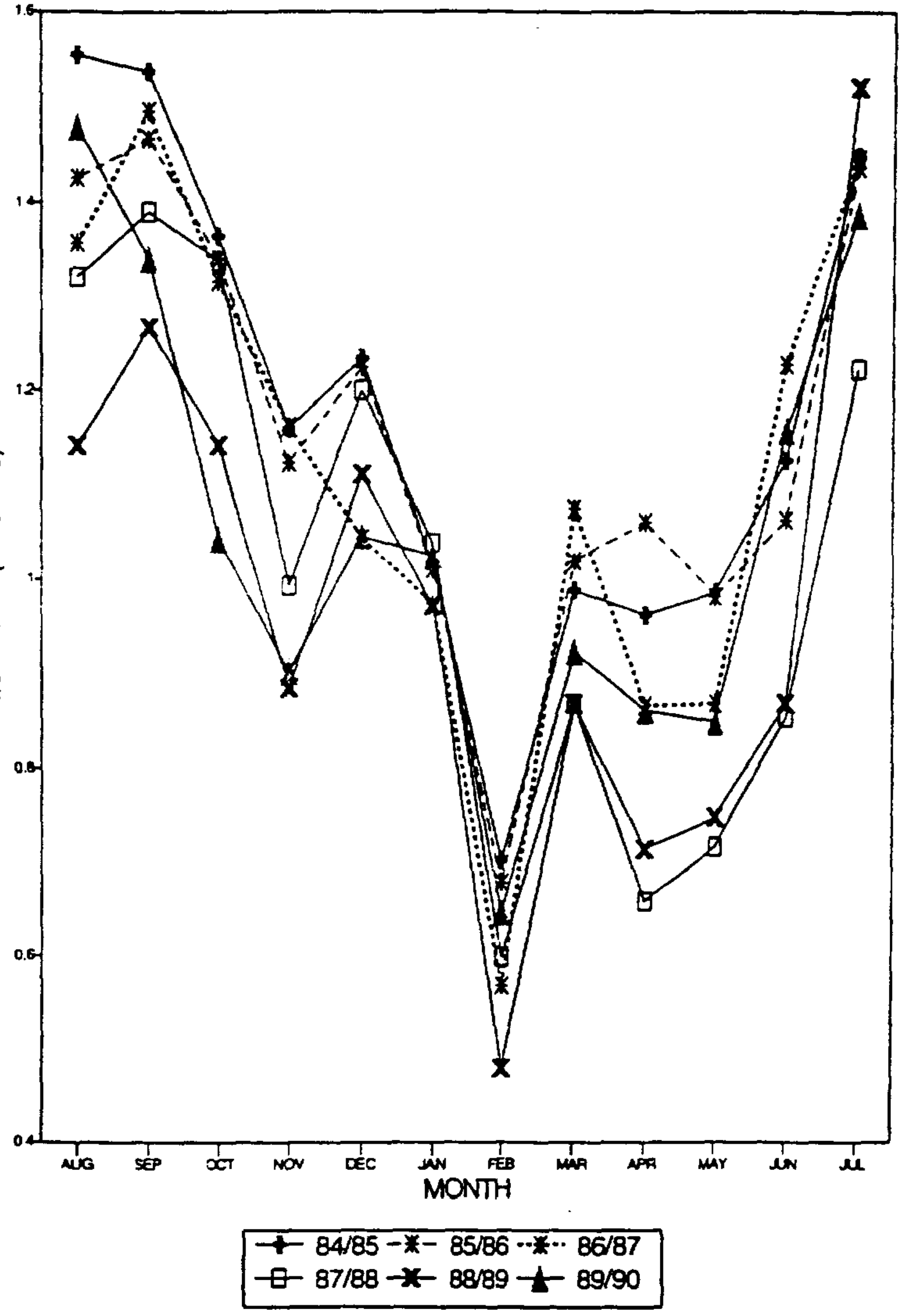


Fig. 12. Monthly drainage water flow (10^9 m^3) to the sea.

Subsurface Drainage System

Actual cost of the tile drainage system

Fahmy (1990) listed the following items and their cost per feddan to describe the economics of land drainage in Egypt.

Item	Cost per fed (LE)
Lateral drains (40 m spacing, 80 mm outer diameter; PVC tubes) without gravel envelope.	220.20
Lateral drains (50 m spacing, 80 mm outer diameter; PVC tubes) with 5 cm gravel envelope.	242.25
Collector drains (concrete tile with diameter varying (15–60 cm).	49.40
Road crossing (RC pipes).	1.70
Operational cost (office, workshop, oil, fuel, etc.).	3.20
Total cost per fed in area without gravel envelope.	286.35
Total cost per fed in area with gravel envelope.	306.40

There is an additional 10% overhead and 10% resale value minus the cost of the PVC tubes. Thus, the cost of subsurface drainage per fed is LE 325 and LE 355 for drains without, and with envelope material, respectively. The cost of gravel per meter of drain length is LE 0.4 for material and LE 0.43 for installation.

Drain design criteria

The drainage criteria have been defined by Bouwer (1974) as the total designed drainage intensity for a given field or region, which includes both natural and artificial drainage. The drainage system should therefore be designed to satisfy the amount in excess of natural drainage. The design requirement (or design criterion) according to this definition expresses the agricultural function of the drainage system in terms which can be used as input information in the design equation. He also added that compared to the existing knowledge on the theory of drainage flow systems, drain spacing equations, soil permeability measurement, drainage materials and methods, etc., the paucity of adequate design criteria currently constitutes the weakest link in rational drainage design. This last statement shows how much work still needs to be done to develop reliable design criteria to improve existing ones.

In arid and semi arid areas, the drainage requirement of a crop is determined by its tolerance to salinity and susceptibility to wetting and drought stress. In these areas the drainage system is designed to maintain favorable moisture levels and prevent salt accumulation in the root zone.

Spacing between laterals

Amer *et al.* (1989), stated that in spite of the theoretical computation, a limit was imposed on the maximum and minimum drain spacing. A minimum spacing of 30 m was justified by economy, and a maximum of 60 m was claimed to be a practical upper limit. However, in 1986, these criteria for spacing were changed to adopt a minimum of 20 m.

Amer (1989) discussed the spacing and drainage criteria used in Egypt and suggested a design drainage rate of 1.0 mm/day, a depth of 1.5 m at the outlet, leading to an average drain depth of 1.40 m. He mentioned that calculated spacing L is rounded off as follows:

Spacing less than 47 m	L = 40 m
47 m < L < 55 m	L = 50 m
Spacing more than 55 m	L = 60 m

He also stated that spacing narrower than 40 m was economically unjustifiable, while spacing wider than 60 m was risky for efficient drainage.

Water table depth

The groundwater table control in irrigated semi-arid and arid regions should primarily ensure aeration of plants during the irrigation season and prevent capillary salinization during the fallow season. Suggested water table depths for steady and non-steady (transient) states in arid and semi arid regions are given in Table 23.

Table 23. Water table during tail irrigation.

Crops	Water table depth (m)			
	Fine soils		Light soils	
	Steady	Non steady	Steady	Non steady
Field crops	1.2	0.9	1.0	0.9
Vegetables	1.1	0.9	1.0	0.9
Trees	1.6	1.4	1.2	1.1

Water table control in fallow areas with irrigated lands is required to minimize salinization due to the capillary rise of saline groundwater. The drains are placed at a depth of not less than 1.2 m in fine and course soil, and 1.8 m in medium-textured soil.

In Egypt, the steady-state criterion requires a de-watering drain 1.0 m below the soil, which is assumed necessary for the cotton crop. An average drain depth of 1.4 m is considered optimum for lateral drains. Thus, the design water table head midway between drains is 0.40 m above the drain canal.

Recent monitoring of crop yields in the Nile Delta showed that cotton yield started to decrease at an average water table depth of less than 90 cm during the growing season (Nijland and El-Guindi, 1984).

A general survey of design practices for covered drains in an agricultural drainage system has been carried out. Studies on the effect of drain spacing and depth (water table fluctuation) at the Mashtoul Pilot area in Sharkia Governorate were reported by Abdel Dayem *et al.* (1989). Results of the monitoring program over a three-year period were as follows:

- Water table fluctuation depends on many factors, such as the irrigation and infiltration rates, moisture content of the soil before irrigation, and the soil's physical properties, such as climatic conditions, root depth, hydrological boundary conditions, size of area irrigated, irrigation conditions in neighboring fields, and depth and spacing of the drains.

- The depth of the water table depends on the water management associated with each crop. Relatively deeper water tables occur under wheat in winter and cotton in summer.
- The effect of drain spacing on the average water table depth for some crops is shown in Tables 24 and 25.

Table 24. Water table under summer crops at Mashtoul pilot area.

Unit	Drain		Year	Crop	Water table depth (m)			
no.	Spacing (m)	Depth (m)			Max.	Min.	Aver.	SD
II	15	1.23	1985	Maize	1.19	-0.01	0.68	0.29
IV	15	1.35	1983	Cotton	1.44	-0.16	1.13	0.23
			1985	Maize	1.45	-0.02	0.87	0.34
XIII	15	1.64	1983	Maize	1.46	0.05	1.01	0.25
			1984	Cotton	1.72	0.11	1.20	0.35
IX	30	1.04	1984	Cotton	1.28	0.04	0.70	0.22
VII	30	1.14	1984	Maize	1.20	-0.02	0.74	0.36
VIII	30	1.39	1984	Maize	1.66	0.01	0.82	0.34
XV	25	1.60	1983	Cotton	1.52	0.44	1.10	0.21
			1985	Maize	1.28	-0.13	0.69	0.24

Negative signs mean pounding water.
Summer crops are cultivated in June and harvested in September.

Table 25. Water table under winter crops at Mashtoul pilot area.

Unit	Drain		Year	Crop	Water table depth (m)			
no.	Spacing (m)	Depth (m)			Max.	Min.	Aver.	SD
I	15	1.18	83/84	Wheat	1.51	-0.02	0.91	0.36
II	15	1.23	84/85	L. Bers	1.34	-0.07	0.84	0.28
IV	15	1.38	82/83	S. Bers.	1.53	0.35	1.06	0.28
			83/84	Wheat	1.73	-0.04	1.15	0.35
			84/85	L. Bers	1.70	-0.15	0.93	0.34
XIII	15	1.64	82/83	L. Bers	1.44	-0.02	0.92	0.42
			83/84	S. Bers.	1.64	-0.14	1.04	0.32
			84/85	Wheat	1.83	-0.15	1.11	0.46
IX	30	1.04	83/84	S. Bers.	1.38	-0.02	0.73	0.34
			84/85	S. Bers.	1.64	-0.14	0.73	0.37
VII	30	1.14	82/83	Wheat	1.43	-0.13	0.83	0.39
			83/84	L. Bers	1.46	0.17	0.77	0.43
			84/85	S. Bers.	1.37	-0.09	0.92	0.41
VIII	30	1.39	82/83	Wheat	1.50	0.03	0.95	0.44
			83/84	L. Bers	1.63	-0.21	0.76	0.40
			84/85	S. Bers.	1.63	-0.12	0.85	0.35
XV	25	1.60	82/83	S. Bers.	1.47	-0.12	0.75	0.34
			83/84	Wheat	1.66	-0.17	0.96	0.44
			84/85	L. Bers	1.31	0.02	0.75	0.27

Negative signs mean pounding water.
Winter crops are cultivated in October and harvested in May the following year.
L. Bers.: Long Berseem; S. Bers: Short Berseem.

Typical examples of water table fluctuation graphs are shown in Fig. 13.

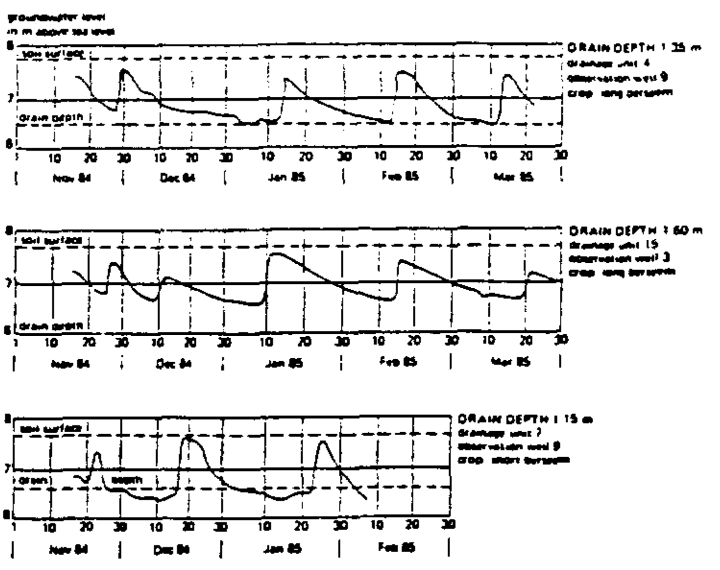


Fig. 13. Water table fluctuation with different drain depths.

El Mowelhi (1989) presented a study on the interaction of land drainage and cropping patterns at the Fourth International Drainage Workshop held in Cairo in 1990. Within this study, the relationship between water table and crop yield was presented using the sum of exceedance values in winter (SEW) concept of the new summation exceedance value (SEV). The SEV value is defined as the sum of the daily height of the water table midway between the drains above a given base level (0.8 m) for a period of seven to 10 days after irrigation. The SEVs presented in Table 26 are valid only for a drainage depth of 1.4 m and drain spacing of 20 m in heavy clay soils.

Table 26. Proposed sum of exceedance values (SEV) of water table depth after irrigation above 0.8 m.

Cotton	Wheat	Berseem	Crop production index
< 55	< 25	< 25	Very good
55–100	25–50	25–50	Good
110–200	50–100	50–250	Moderate
> 200	< 100	< 250	Poor

Drainage coefficient

The drainage coefficient (or drainage rate) is the rate of removal of water at the required water table depth to obtain the desired crop production. It is expressed in mm/day. Amer (1989) stated that in semi arid areas, drainage coefficients are likely to be in the following ranges, if natural drainage or seepage is negligible:

- < 1.5 mm/day for soils having a low infiltration rate.
- 3.0 mm/day for most soil with a higher rate and when cropping intensity is high.
- 3.0–4.5 mm/day for extreme conditions of climate, crop, salinity management, and poor irrigation practice.

The design rate for drain capacity in non-rice growing areas is 2.0 mm/day (UNDP and FAO, 1966), including a safety margin of 100%. When rice exists in a crop rotation the design rate is 4.0 mm/day, but with a margin of only 33% (El Mowelhi, 1989).

Amer (1989) mentioned that the steady design criterion for the de-watering zone is 1.0 m below the surface. Recently, the drainage rate was increased from 1.0 to 1.25 mm/day, especially for the northern parts of the Nile Delta, between contours 5 and 3 m + MSL, and 1.5 mm/day north of contour 3 m + MSL. He also stated that the design discharge rate for collectors in non-rice areas is 3 mm/day, including a safety factor of 2. In rice growing areas a drainage coefficient of 4 mm/day is used, including a safety factor of 33%.

Measurements lasting for more than three years have covered one crop rotation involving berseem, wheat, rice, maize, and cotton. An overall statistical analysis of the lateral drainage rates is shown in Table 27.

Table 27. Lateral discharge rates at Mashtoul pilot area.

Statistical parameter	Discharge (mm/day)					
	Winter crops			Summer crops		
	1983/84	84/85	85/86	1984	1985	1986
Maximum	6.7	5.4	2.6	3.9	2.5	4.8
90% (CFO)†	0.2	0.7	1.1	3.1	1.2	1.5
Median	0.0	0.0	0.2	1.0	0.3	0.2
Mean	0.1	0.2	0.4	1.2	0.5	0.5
SD	0.3	0.4	0.5	1.2	0.7	0.7

† CFO = Cumulative frequency of occurrence.

The results shown in the above table indicate that there is reliability in the drainage rates. The drain discharge stays high for a very short time, then drops sharply as indicated by the 90% discharge frequency.

The overall average drainage discharge rates for each crop are summarized in Table 28. Each figure in this table represents an average value of the statistical parameter calculated separately for each crop season at each location.

Table 28. Lateral drainage rates for different crops.

Crop	Average rate (mm/day)			
	Maximum	90% (CFO)	Median	Mean
Wheat	3.2	0.3	0.0	0.1
Long season berseem	4.0	0.8	0.3	0.3
Short season berseem	3.1	0.2	0.0	0.2
Rice	3.7	2.4	1.3	1.3
Maize	2.4	1.2	0.3	0.4
Cotton	1.5	0.3	0.0	0.1

A zero median value means that the drains were running dry for more than half the number of days between successive irrigations.

Drainage and Crop Production

Installation of drainage systems and crop production

The average increase in yield for various crops after installation of a drainage system is not known accurately. Because of the hot conditions in the different areas, yields are difficult to determine.

Moreover, the yields of crops vary heavily from year to year as a result of mythological conditions and plagues. It was reported that the increase due to drainage varies greatly as follows:

- In cotton, from 0 to 50%, wheat 20 to 32%, and maize 17 to 48%. Measurements of wheat yield in the pilot areas indicated that in the first or second year after drainage, a yield increase of about 10% can be expected. This percentage increases to 20 in subsequent years.
- El Mowelhi (1989) reviewed the relationship between drainage and crop production using different concepts of evaluation. He presented a case study of these relationships in Egypt. A field experiment was conducted for about 10 years in the Nile Delta beginning in 1977 to identify the benefit of subsurface drainage on crop yield. During three crop rotations, subsurface drains at a spacing of 20 m and a depth of 1.5 m doubled the yield of cotton and rice and increased the yield of wheat and berseem by 50%. No significant enhancement of crop yield resulted from placing various envelope materials around the drains
- Crop yield at similar areas in the Nile Delta with and without covered drains were evaluated by the DRI (1987a) at the Mashtoul pilot area for drainage technology. The results are presented in Table 29.

Table 29. Crop yield (t/fed) at Mashtoul pilot Area.

Year	Wheat	Berseem	Maize	Rice
1977–1978	0.8	1.9	0.7	---
1978–1979	1.2	1.9	1.3	---
1979–1980	---	2.7	1.0	2.2
1980–1981	1.2	---	1.6	2.4
1981–1982	2.2	3.2	1.4	2.3
1983–1984	3.5	3.6	2.8	2.8
1984–1985	2.2	3.0	---	--
1985–1986	2.2	3.2	1.3	2.1
Average before drainage	1.0	2.0	1.0	2.2
Average after drainage	2.4	3.1	1.5	2.4

- Although crop yield generally increases after drainage, the amount of increase is not the same for each crop. This is due to the different tolerance levels of crops to salinity and excessive moisture. It can also be attributed to the difference in agricultural inputs.
- Amer and Abu Zeid (1989) reported that the economic evaluation and statistical analysis of crop yields proved after a period of ten years that tile drainage improved crop productivity and was most effective in lowering salinity hazards. As an example, in

the first of two regions (each with an area of 30,000 fed/12,600 ha), 7,300 t/fed of salts were removed within three years. For the second region, 8,350 t/fed of salts were removed. Prior to the introduction of the drainage system, the average maize yield was 5.10 ardab/fed in the first region. It rose to 7.46 ardab/fed after drainage (an increase of 45%). In the second region, the average maize yield before drainage was 4.79 ardab/fed; after drainage it rose to 8.37 ardab/fed (a 75% increase).

Fahmy (1990) presented the results of yield analysis of data collected over 13 years (Table 30). He concluded that drainage has a positive effect on crop yield. Drainage not only increases crop yield but also prevents declines which would occur if the drainage project had not been implemented.

Table 30. Average increase in crop yield due to tile drainage system.

Crop	Yield increase (%)
Wheat	27
Maize	24
Cotton	21
Rice	21

Reuse of drainage water, effect on soil and crop production

Research studies

Agricultural expansion depends on water, which is a limiting factor in Egypt. Hence, attention is directed to alternative resources, i.e. underground and drainage water, to secure better and efficient water utilization.

Huge amounts of drainage water, as well as groundwater containing different quantities of salt, are underutilized in Egypt. A suitability index of drainage waters for irrigation purposes was determined.

Studies on reuse of drainage water revealed positive results about the prospects for using drainage water, and the reduction in yield according to the use of different concentrations of salts in irrigation water (Table 31). More studies need to be made in this area.

Following are some studies on the use of saline water and its effect on soil properties and crop production.

El Sherbeeny *et al.* (1986) conducted a sand culture experiment using wheat cultivars. The medium level of salinity resulted in the highest contents of Fe, Mn, and Zn in shoots and spikes. However, the high level of nitrate gave the highest contents of these elements in both shoots and spikes. No characteristic relationships could be observed between the salt tolerance of the tested cultivars and their Fe, Mn, and Zn contents.

Kamel (1986) grew faba bean seeds on washed sea sand mixed with: (i) 100–1500 mg KNO_3/25 g sand; or (ii) 500 or 1500 mg NH_4NO_3 and watered with 50 ml seawater/liter water. All nutrient treatments decreased seedling, root, and shoot lengths. The rate of seed weight increase was in the following order: control > NH_4NO_3 > KNO_3.

Table 31. Reduction in crop yields as a result of salts in irrigation water.

Crop	Salts (ppm)	Reduction (%)	Crop	Salts (ppm)	Reduction (%)
Berseem	1000	6	Wheat	1000	0
	1500	8		1500	0
	2000	13		2000	18
	3500	18		4000	24
	4000	32		6000	53
	6590	75		8000	100
Food legumes	1000	0	Sugar beet	1000	0
	2000	28		3000	3
	3000	33		5000	14
	4000	45		6500	50
	8000	66			
Soybean	1500	12	Barley	2000	0
	2500	37	2500		10
	3000	74		3000	18
	5000	42			
	6000	47			
	7000	50			
	8000	54			
	9000	66			
	10000	72			

Soliman and Farah (1986) planted wheat (cultivar Giza 157) in a greenhouse in calcareous soil to study the interactive effects of saline irrigation water at 250 or 6000 ppm, Na+$CaCl_2$ (1:1 w/w) with 75, 150, or 225 kg N/ha and 0, 37.5, 75, or 112.5 kg P_2O_5/ha. It was concluded that rates of 150 kg N and 75 kg P_2O_5/ha were effective for increasing grain yield under saline and non-saline conditions.

Abdel-Dayem *et al.* (1987) presented results of a field monitoring program carried out in a pilot area in the Nile Delta to assess the drainage effect on increasing crop yield. Desalinization of soil started as soon as adequate drainage was provided in irrigated fields. Soil salinity reached an equilibrium level of 1.0 mmhos/cm after two years within the top 0.5 m of the soil profile. Meanwhile, crop yield increased and reached a maximum level corresponding to this reduction in soil salinity.

Abdel-Gaffar (1987) found that high yields were obtained with irrigation at 50% depletion of available water. Soil salinity or irrigation with saline water badly affected growth and yield, but nodulation and N fixation were less affected. Seed inoculation proved effective.

Salama and Ahmed (1987) found that increasing salinity decreased wheat plant water content, shoot and root length and soluble carbohydrate content.

Hamdy (1988a, b) showed the influence of irrigation water of different salt concentration levels and its mode of application on the growth of sensitive and moderately salt-tolerant plants. He found that high sodium concentrations not only reduce leaf area and dry matter production, but also decrease the concentration and uptake of the major nutrients, thus exercising a double negative influence.

El Mowelhi *et al.* (1988) conducted a field experiment for 10 years in the Nile Delta to quantify the benefit of subsurface drainage on crop yield. During three crop rotations, subsurface drains spacing at 20 m at a depth of 1.5 m doubled the yield of cotton and rice and increased the yield of wheat and berseem by 50%.

Amer *et al.* (1989) studied the irrigation-water salt concentration and application mode on root development in sensitive and moderately salt-tolerant plants. Under different irrigation treatments, the concentration of different elements in the roots increased with the increase in salinity. However, root water uptake decreased. The accumulation of nutrients, which is mainly a function of root development, was relatively greater with the alternate treatments. The accumulation of K in plants may be seen as an important mechanism of salt tolerance, since sodium is thereby prevented from entering in excessive quantities.

Amer *et al.* (1989) stated that the Alexandria coastal region is characterized by Mediterranean climate with limited rainfall and by soils with shallow water tables. A three-year field study was conducted from 1979 through 1982 to optimize water and N application for wheat (*Triticum aestivum* L.) grown on vertic torrifluvents. The primary objective was to save irrigation water through the advantageous use of the high probability rainfall and the shallow water table. The soil water depletion (SWD) from the top 40 cm that can be allowed without reducing yield was estimated at 50, 75, and 90% of the available water at the tillering, boot, and milk stages, respectively. The SWD decreased with the decrease in the number of irrigations and the depth of the water table. Potential evapotranspiration (ETp) amounted to 53 cm for the entire wheat season.

El Guindy *et al.* (1989), in a study on the use of drainage water for agriculture in Egypt at Fayoum, showed that irrigating with saline water decreases soil salinity as long as the salt concentration in the water is less than in the soil. Tile drainage and gypsum at 2 t/fed reduced exchangeable sodium percentage (ESP) by approximately 30%. Wheat could tolerate salinity in irrigation water up to 1700 ppm, where soil salinity was greater than 4 mmhos, without appreciable decrease in yield, but was affected by ESP higher than 13.

El Sharkawi *et al.* (1989) investigated changes in soluble protein (SP), total free amino acids and calcium and sodium contents in millet (*Sorghum bicolor*) in response to decreased soil osmotic water potential (psi-s) and increased sodicity (SAR level). The importance of such changes in adjustment of plants to salinity and sodicity hazards is discussed.

Hamdy (1989) studied the effects of irrigation water salinity on pH, and salt and ion accumulation in the soil using broad bean and wheat. He found that increasing the salinity of irrigation water caused significant increases in the salt content of the topsoil under beans, while increases occurred in the subsoil under wheat. There was little variation in pH.

Heakal *et al.* (1989a) studied the effect of the interaction between the osmotic effect of Na and the specific ion toxicity of Ni on growth of lettuce cultivars in a completely defined nutrient solution. In seedling lettuce, Na exerted both a specific ion effect and a salinity or osmotic effect. The specific ion effect was exhibited at relative low concentrations of Na and resulted in minimal yield depression.

Ni was toxic at a relatively low concentration of 10 μM and thus by itself contributed only specific ion toxicity. The Ni dose-response curve was biphasic with a toxicity threshold at 10 μM and a phase change at 30 μM, which was associated with an 87% yield reduction. The interaction of Na on the Ni dose-response curve was additive in the first phase.

Heakal *et al.* (1989b) found that dose-response curves were obtained in a background of 1/10 strength Hoagland nutrient solution for lettuce (the cultivar Climax) seedlings with Ni at different background levels of $CaCl_2$ and for $CaCl_2$ at different background levels of Ni. Nickel showed a toxicity threshold at 20 μeq Ni/liter and a 50% reduction in yield at Ni concentrations of about 30 μeq/liter. However, when the available Ca was increased from that in the control 1/10 strength Hoagland solution of 1.0 to 257 μeq/liter, most of the reduction in growth due to Ni toxicity at 30 μeq/liter was reversed, giving a yield increase of more than 90% of the control. These curves also showed a strong alleviation of Ni toxicity at high Ni concentrations in the presence of high background concentrations of Ca.

Salama and Awadalla (1989) carried out a study to clarify the interaction of kinetin and salinity stress on osmotic potential and carbohydrate content in cotton and millet plants. It was concluded that kinetin can alleviate the effect of salinity stress on osmotic pressure. The results also revealed that soluble carbohydrates decreased and reserve sugars increased with increased soil salinity, while kinetin treatment tended to reverse this effect. The interaction between kinetin and salinity stress was more pronounced when kinetin was applied by the presoaking method.

Shehata *et al.* (1989) studied the effect of type and level of salinity on the cooking properties of faba bean (cultivar Giza 1). They showed that the linear effect of Ca was significant for almost all the properties studied. The linear effect of the salt mixture was not significant except for the yield and swelling coefficient of the dry seeds. The salinity levels used had no effect on seed germination. Irrigation with a $CaCl_2$ solution gave harder beans with a lower hydration coefficient. Although phytase, pectic fractions, and mineral contents of dry beans and cooking quality were affected by soil ions, no significant direct correlation was found between them (except certain pectic fractions and K) and the texture of cooked beans. Soil ions may affect cooking properties through changes in functional properties of the bean main constituents.

Abdalla *et al.* (1990) studied the effect of subsurface drainage on soil salinity under normal cropping practices three years after construction in a pilot area in the Nile Delta. Water and salt balances showed that the area has a natural drainage rate of about 0.5 mm/day. The difference between the amount of salts brought in by the irrigation water and the amount of salts leached from the soil indicated that salt leaching from the deeper parts of the clay layer was still continuing.

Abdel-Dayem and Ritzema (1990) conducted a monitoring program to verify the design criteria of subsurface drainage systems in a pilot area in the Nile Delta. The results showed that the yield of all crops (wheat, *Trifolium alexandrinum*, maize, rice, and cotton) increased significantly after the installation of a subsurface drainage system. Optimum growing conditions for the combination of crops that are cultivated in rotation in the area required that the water table midway between the drains had an average depth of 0.8 m. A corresponding drain discharge of 0.4 mm/day was sufficient to cope with the prevailing percolation losses of irrigation water and to maintain favorable soil-salinity levels.

Heakal *et al.* (1990) irrigated wheat and barley seedlings growing in pots in a greenhouse in a non-saline sandy loam soil with saline water. There were different interactions, however, between the crops, indicating some effect of plant species. In both, a decrease in yield with increasing salinity was associated with a corresponding decrease in ET. In the most saline treatments, where the available water to plants was the lowest, ample K supply produced substantial improvements in salinity tolerance of both crops.

Ismail and Gowing (1990) developed a novel computer model for irrigation scheduling decisions when salinity cannot be ignored. The basis of the model is the relationship between relative evapotranspiration and total soil water potential. The model allows considerable flexibility in its operation, either in a simulation model to evaluate alternative irrigation strategies, or in an operational mode to optimize water allocation decisions such as the management of reusing drainage water in a semi-arid area with saline soils.

Abderrahman *et al.* (1991) mentioned that predictions suggest that the earth's temperature may increase 1.5–4.5°C within the next 50 years if the trend of the greenhouse effect continues. The impact of the expected temperature increase on reference crop evapotranspiration, irrigation water demands, soil salinity, crop yield, and desertification were assessed. The same water shortage increases soil salinity by about 1.23 to 17.68 times the original salinity level. This causes a further decrease in crop yield. The increase in water stress and soil salinity have a detrimental effect on desert plants. Some species might be partially or completely damaged. This enhances the desertification processes in the non-irrigated deserts of the peninsula. Similar effects, of varying extent, are expected to occur in arid regions with the increase in temperature. Effective measures should be taken to eliminate the causes of the greenhouse effect, maintaining the global temperature at the natural level.

Hussain *et al.* (1991) carried out a field experiment to quantify the effect of subsurface drainage on soil salinity under normal cropping practices three years after construction in a pilot area in the Nile Delta area of Egypt. Relationships were established between crop type and the discharge characteristics (rate and salt content) of the lateral drains. The lowest rates were associated with wheat (in winter) and cotton (in summer), intermediate rates with berseem (in winter) and maize (in summer), and the highest rates with rice (in summer). Water and salt balances showed that the area has a natural drainage rate of about 0.5 mm/day. The difference between the amount of salts brought in by the irrigation water and the amount of salts leached from the soil profile indicates that salt leaching from the deeper parts of the clay layer was still continuing.

Hussain *et al.* (1991) also investigated the effects of recycling irrigation water on rice and wheat crops in greenhouse studies at the University of Faisalabad in 1988/89. They found that there was no significant residual effect of drainage water irrigation on the growth and yield of the wheat. Drainage water irrigation increased the soil electrical conductivity (EC) and sodium adsorption ratio (SAR) after the rice crop but the values decreased during canal water irrigation of the wheat crop. It was concluded that a cyclic strategy of irrigation with brackish drainage water followed by irrigation with canal water had potential as an additional irrigation water source.

Abdalla (1992) grew the faba bean cultivar Giza 3 inoculated with *Rhizobium leguminosarum* RCR 1001, which later formed an infectious and effective symbiosis with faba bean under saline conditions. A noticeable decline in nitrogenase activity and total nitrogen concentration in the plant under saline conditions could be attributed to nodule senescence, as shown by the lowering of leg hemoglobin, soluble protein and carbohydrate contents of cytosol and bacteroides.

Aldesuquy (1992) found that the growth in the wheat shoot of the saline-treated plants was, in general, stimulated in response to presoaking the grains in kinetin or gibberellic acid (GA3). On the other hand, indole acetic acid (IAA) + salinity had a negligible effect on the growth of wheat plants, particularly at the early stages of growth. The presoaking of grains in NaCl at 33 m*M* + IAA or 66 m*M* + kinetin induced a marked increase in the pigment content of the wheat flag leaf, particularly at the early stages of growth. The interaction between salinity and phytohormones increased the number of chloroplasts; kinetin was the most effective.

Hamada *et al.* (1992) examined the effect of salinity on barley, wheat, and maize. Results show that, with the exception of potassium and nitrogen content, the levels of most inorganic macronutrient elements (sodium, calcium, magnesium, and phosphorus) and micronutrient elements (iron, boron, zinc, manganese, copper, and chloride) increased with increased salinity concentrations. This was true also for osmolality and electrical conductivity but not pH.

Hilal and Koker (1992) found that in a barley field, the total salt topsoil content of sulfur in non-treated plots reached 61 mmhos, whereas in sulfur-treated plots, salinity did not exceed 23 mmhos by the end of the growing season. Salinity control was associated with a 115% increase in yield. Similar effects were seen with wheat, fodder beet, and maize yields. The residual sulfur effect persisted for more than six growing seasons in calcareous and alkaline clay soils. Long-term deeper irrigation has maintained better salt and moisture distribution around plants and significantly increased yield of cucumber and onion as compared to light daily irrigation.

Tube Well Drainage

Groundwater extraction schemes confirm that tube well drainage is a promising technique for water table control to improve saline soils. The experiences also show that the major problems of tube well drainage are related to operation and maintenance of the (often large) well fields, especially in areas where the pumped water cannot be used for irrigation due to its high salinity and has to be disposed of elsewhere.

Studies carried out by the Research Institute for Groundwater (RIGW) between 1986 and 1988 showed that the main economic benefits of groundwater development are:

- Groundwater extraction for irrigation taken from storage during the summer months which is replenished during winter.
- Surface drainage and tube well drainage are attractive alternatives to the tile drainage system.
- Saving in remodeling the irrigation distribution system.

Areas for groundwater development

Attia and Tuinhof (1989) identified the location at which groundwater development is the more attractive alternative to tile drainage systems as follows:

- Areas in the Nile flood plain where implementation of tile drainage is difficult or economically less attractive. These areas are predominantly near the fringes of the Nile Valley and the Delta, adjacent to reclaimed desert area.
- Areas in the Nile flood plain which suffer from shortages of surface water.
- Desert fringes of the Nile Valley and Delta. In these areas, the conjunctive use of groundwater and surface water, or the use of groundwater alone for irrigation may be more economical than the use of surface water.

Attia and Tuinhof (1989) introduced a comparison between the advantages and disadvantage of the tube well and tile drainage systems. Applied tube well research in the Minia pilot area and feasibility studies were described in their work.

Cost of tube well drainage

The cost of installing a drainage system, adjusted with the help of an accounting ratio (World Bank, 1985) was 609 LE/fed in 1985. Operation and maintenance costs were calculated at LE 9.51/fed and 13.5 LE/fed, respectively.

In areas where a tile drainage system has already been installed, benefits are limited to operation and maintenance costs until the tile drainage system has to be replaced. Table 32 summarizes the costs, benefits and net present value (NPV) of the difference.

Table 32. Economic net present value (million LE) of alternative operation schemes of the Minia well field (1984/85).

	Operation scheme (pumping rate in $10^6 m^3$/year)			
	46.5	71.3	91.2	166.0
Costs†				
Installation	6.3	6.4	6.4	6.5
Recurrent	1.3	1.5	1.6	2.5
Total costs	7.6	7.9	8.0	9.0
Benefits†				
Saved on tile drainage				
-Installation	8.2	13.1	14.7	31.8
-Recurrent	0.7	1.1	1.2	2.7
-Total	8.9	14.2	15.9	34.4
Seasonal production of groundwater	0.6	2.8	3.9	0.5
Total benefits	9.5	17.0	19.8	34.9
NPV benefits–costs	1.9	9.2	11.7	26.0

† Discount at 10%.

Areas of Drainage Problems in Egypt

Problem areas are defined as those areas with unusual conditions which require unconventional design and/or a different implementation technique. Unusual conditions may be related to soil or hydrology in the area. When problem areas are encountered within the planned project areas, appropriate design criteria, and new technologies are needed. When necessary, the implementation of subsurface drainage is delayed until careful studies have been carried out to develop appropriate solutions. Some typical examples of such problem areas in Egypt are described below.

Heavy soils

There are about 500,000 acres of heavy soils located in the northern parts of the country, south of Burullos and Manzala lakes, and east of Port Said. The soils in these areas consist of marine clays, which are highly saline and have poor internal drainage properties. The sodicity hazard in these soils is high and their permeability is very low. Their reclamation is very difficult and expensive. They require improvement of their physical and chemical properties through leaching, amendments, subsoiling, and deep plowing. All these methods become ineffective without appropriate drainage. New projects are starting in many of these areas and research is being carried out to develop appropriate reclamation techniques.

Unstable soils

While the alluvial silty clay soils of the Nile Valley are characterized with structural stability, the fringe areas towards the desert on both sides of the Valley consist mainly of unstable subsoils (Fig. 14). They collapse easily, especially under construction of drainage systems. Sometimes it is almost impossible to lay the pipes or to make the connections without first de-watering the construction site. Use of adequate envelopes in these areas is essential, otherwise serious clogging problems occur. About 150,000 acres of future drainage programs in Egypt fall under this category.

Areas under artesian pressures

The soil profile in the Nile Valley consists of a semi-confined sandy aquifer with a clay cap of varying thickness on top. In the north of the Delta near the Ismailia Canal, there is piezometric pressure of groundwater within the aquifer. An upward flux occurs depending on the difference of pressures, the thickness of the clay cap and its permeability. The deep groundwater is usually more saline, and as evaporation from the soil surface or transpiration by plants takes place, the salinity of the top soil increases. Careful water management in these areas should be considered to account for the upward flow. Although drainage may increase the rate of upward flow, it is necessary to intercept the saline groundwater. Drains are usually very closely spaced, and consequently their cost is high (Fig. 15).

Nile Valley fringe areas

The land surface in the Nile Valley and Delta is characterized as flat, while at the edges close to desert, the land surface rises steeply to form high-lying lands. During the past 30 years land reclamation extended to the fringe areas and many of the high-lying lands has been brought under irrigated agriculture. Deep seepage of excess irrigation and canal water causes damage to the adjacent highly productive low-lying lands. Improved water management and interceptor drains are solutions for protecting low-lying lands. In some of these areas vertical drainage is an attractive solution, especially in places where conjunctive use of groundwater is possible. Areas to the west of the Nubaria Canal, and Wadi El Mullak in the east, as well as Samaloot, El Fashn, and Kom Ombo in Upper Egypt, suffer from seepage problems (Fig. 16).

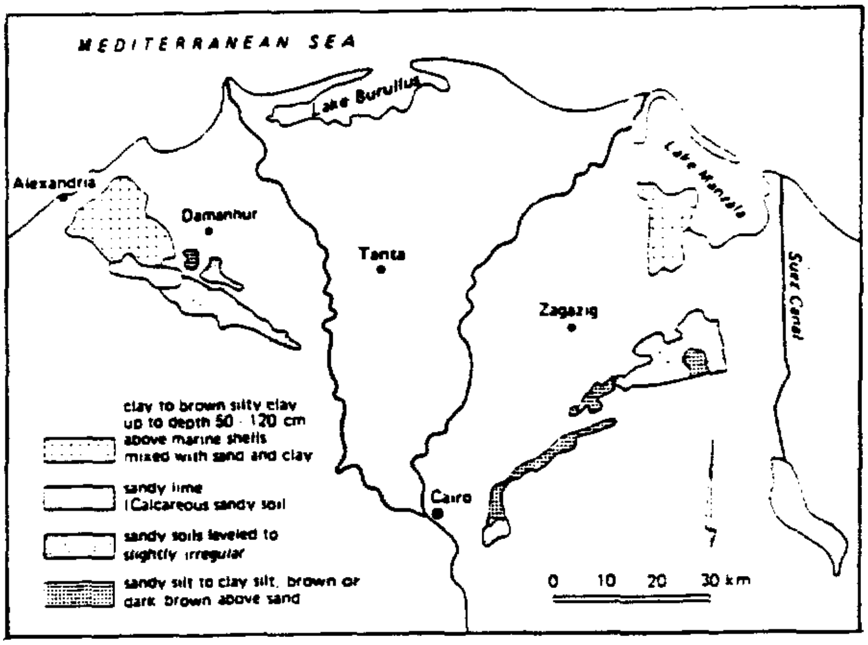


Fig. 14. Areas with sandy subsoil in the Delta.

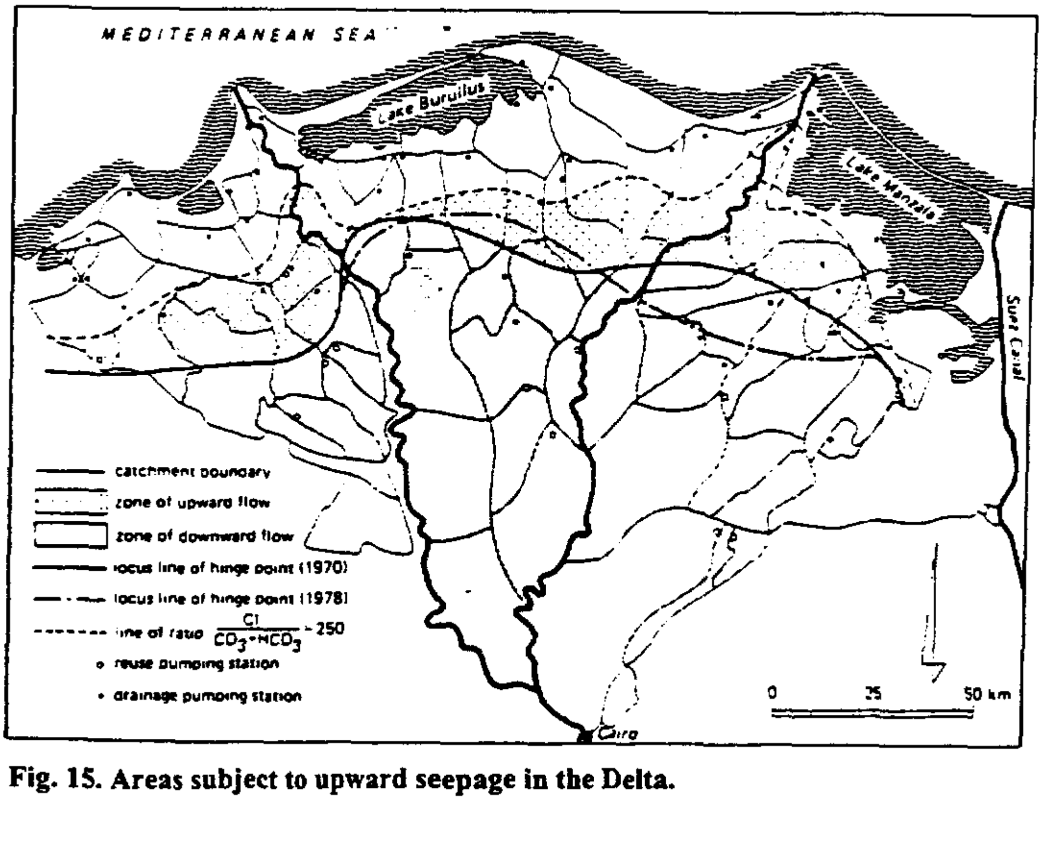


Fig. 15. Areas subject to upward seepage in the Delta.

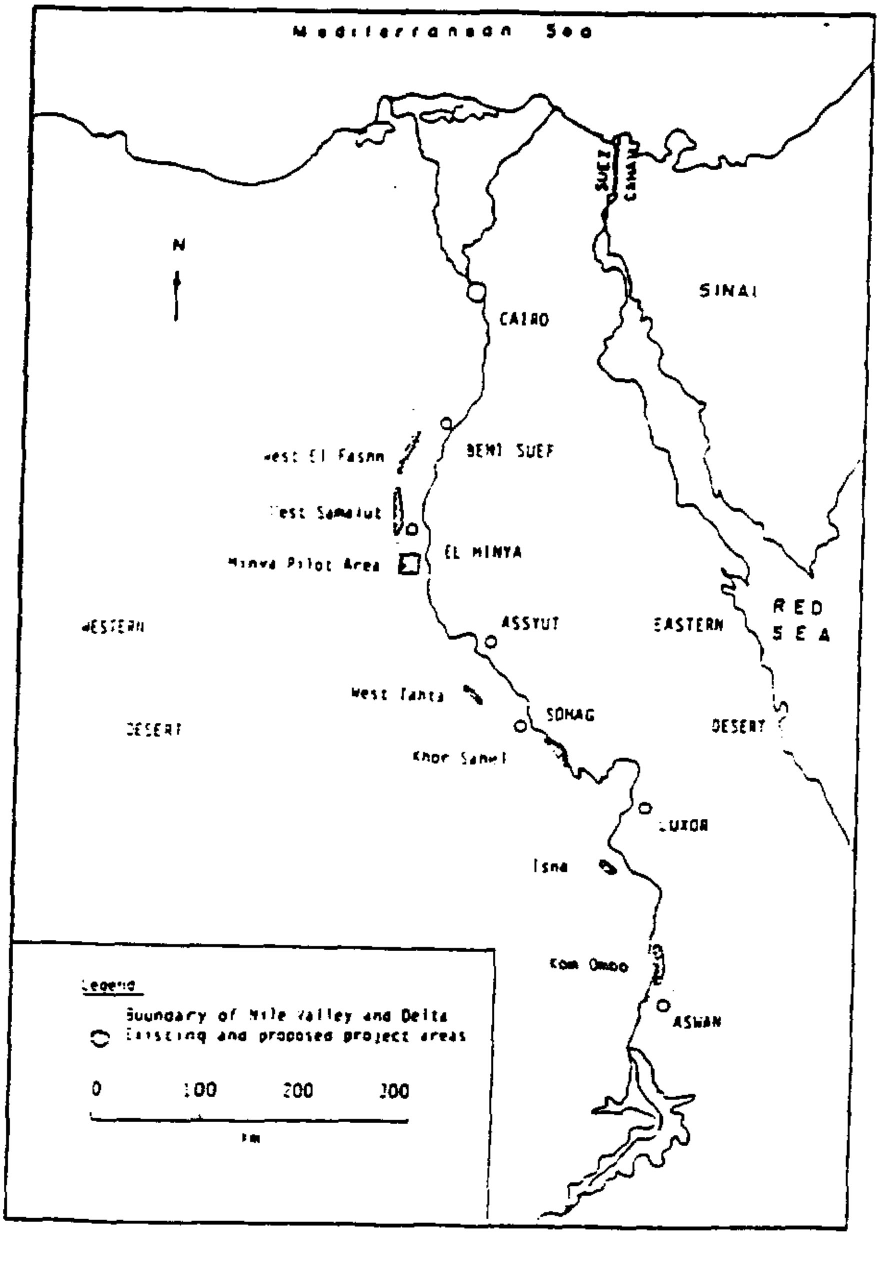


Fig. 16. Areas with seepage problems.

Areas with rice in the crop rotation

Rice is cultivated during the summer in an area of about one million acres in the north of the Nile Delta and Fayoum. Crop rotation includes other crops such as cotton, maize, and beans. While rice requires a permanent wet field surface, the other crops require a well balanced moisture air content in the root zone. These crops usually share the same area served by a uniform composite subsurface drainage system which has a free outlet. Thus, rice fields lose water which has to be compensated through supplementary irrigation or it would run dry and thus contribute to crop damage. A new modified design for subsurface drainage systems has been introduced to provide satisfactory water management for all crops. It depends on controlled outlets of sub-collectors designed to serve well-defined crop units. In each unit, one crop is cultivated at a time. The modified system conserves irrigation water, protects crops from damage and prevents the farmers from blocking the drains, as they do with conventional drainage systems.

Areas with a shallow barrier

Compared with the rest of Egypt, Fayoum Governorate is characterized by unique topographic features. The land surface is very steep and crops are cultivated on terraces. The soil is underlined with limestone which exists at a shallow depth in the western part of the region. The depth of the soil in this area does not exceed 60–80 cm. There is a high water table due to lateral seepage and the presence of excess irrigation water. Salinity is increasing and crop yields are deteriorating. Subsurface drainage may not be feasible in areas with a shallow barrier. Surface drainage and improved water management represent a more efficient approach. Planning and design of subsurface drainage in areas with steep slopes or differences in elevation require the development of new drainage design criteria and methodology.

Sugarcane areas

Sugarcane is grown in southern Egypt in an area of 300,000 acres. It is a high water-consuming crop. In many locations it has been associated with high water table and salinity problems. With respect to the implementation of technology, the following problems have been identified:

- Sugarcane is a dense and tall crop, which complicates most of the field surveys, especially topographical surveys.
- Land is clear for less than two months every year, which means there is little time to implement a drainage system.
- Small machinery is recommended. Besides these physical constraints, sugarcane growing areas are located next to higher reclaimed lands, which further complicates the execution of programs. The execution of some interceptor open drains has not proved successful, and vertical drainage is now under consideration.

Rosetta Branch

In order to evaluate the water quality along the Rosetta Branch, the Water Quality Department of the Nile Research Institute, as a part of its monitoring program, collected data during the winter and summer months of 1990 and 1991. The data were analyzed for physico–chemical parameters including organochlorinated pesticides and biological characteristics along the branch and at agriculture drains and industrial effluent out-falls. Sampling locations along the Rosetta Branch are given in Table 33 and Fig. 17. The *following parameters were evaluated:*

- Nutrient: nitrogen (ammonia), nitrogen (organic), nitrogen (nitrite), nitrogen (nitrate), phosphorus (orth and total).
- Organic pollutants: biological oxygen demand (BOD), chemical oxygen demand (COD), surfactant (S), oil, and grease.
- Major ions: total dissolved salts (TDS), sulfate, calcium, magnesium, sodium, and potassium.
- Organic micro-pollutants: phenols, surfactant, organochlorine pesticides.
- Bacteriological and biological: Total coliform, fecal coliform, algal density, and chlorophyll "a."

Table 33. Total organochlorine pesticide residues (mg/l) calculated for each site at different sampling periods.

Sampling location	Upstream Delta Barrage km 20†	El Rahawy Drain km 35	Sabal Drain km 97	El Tahrir Drain km 112	Zawiet El Bahr km 126	Tala Drain km 146	Upstream Edfina Barrage km 229
Run 1	655.94	—	3401.09	559.99	1546.12	883.94	466.82
Run 2	360.96	969.07	2209.34	1180.09	1825.43	453.68	547.44
Run 3	4915.20	—	1751.09	1747.94	1451.52	1306.03	1274.73
Run 4	716.22	—	259.04	320.55	410.00	1160.54	459.87

† km from El Roda.

The results of this study are as follows:

- Generally the water in the Rosetta Branch has a pH between 7 and 9, and alkalinity ($CaCO_3$) between 150 mg/l during winter closure and 270 mg/l beyond the Rahawy Drain discharge point. The total solids ranged from 246 mg/l to 410 mg/l (closure period). The TDS concentration attained a steady value of 500 mg/l as shown in Fig. 18.
- Surface surfactant concentration along the Rosetta Branch was 0.01 mg/l in winter and summer (Fig. 19).
- Organic pollution: In general, although the Rosetta Branch receives effluent from various sources, it showed a considerable self purification capacity, resulting in water of good quality. This was indicated by BOD and COD, where the two values are matched with the value of dissolved oxygen concentration along the branch. The dissolved oxygen content in water upstream of the Delta Barrage was 8.2 mg/l in winter and 11 mg/l during summer.
- Nutrients: The nitrogen concentration of different components along the Rosetta Branch are shown in Fig. 20. Generally, ammonia and organic nitrogen concentrations were at low levels in the Delta Barrage, then increased downstream from the Rahawy Drain and beyond. Nitrate concentration ranged between 2 and 7 mg/l along the branch, reaching 12 mg/l at Kafr El Zayat.

- Pesticides: Total organochlorine concentration was higher at the Delta Barrage than upstream of the Edfina Barrage. The acceptable value of organochlorine residues should not exceed 0.1 mg/l. The total organochlorine pesticide residues at different locations along the Rosetta Branch are shown in Table 33.

Another similar study was carried out to evaluate River Nile water quality based on pesticide residues along the Rosetta Branch. The organochlorine pesticide residues were monitored in water samples collected from two sites upstream from the Delta Barrage and upstream from the Edfina Barrage. Samples were collected before, during, and after the winter closure period (WCP) and three months later. Samples were analyzed for 15 organochlorinated pesticides, DDT complex, HCH isomers, oxychlordane, endrin, heptachlor epoxide, and dieldrin residues. The results are shown in Figs. 21 through 23. The results show that the highest residue of the total organochlorine pesticides was found after the termination of the closure.

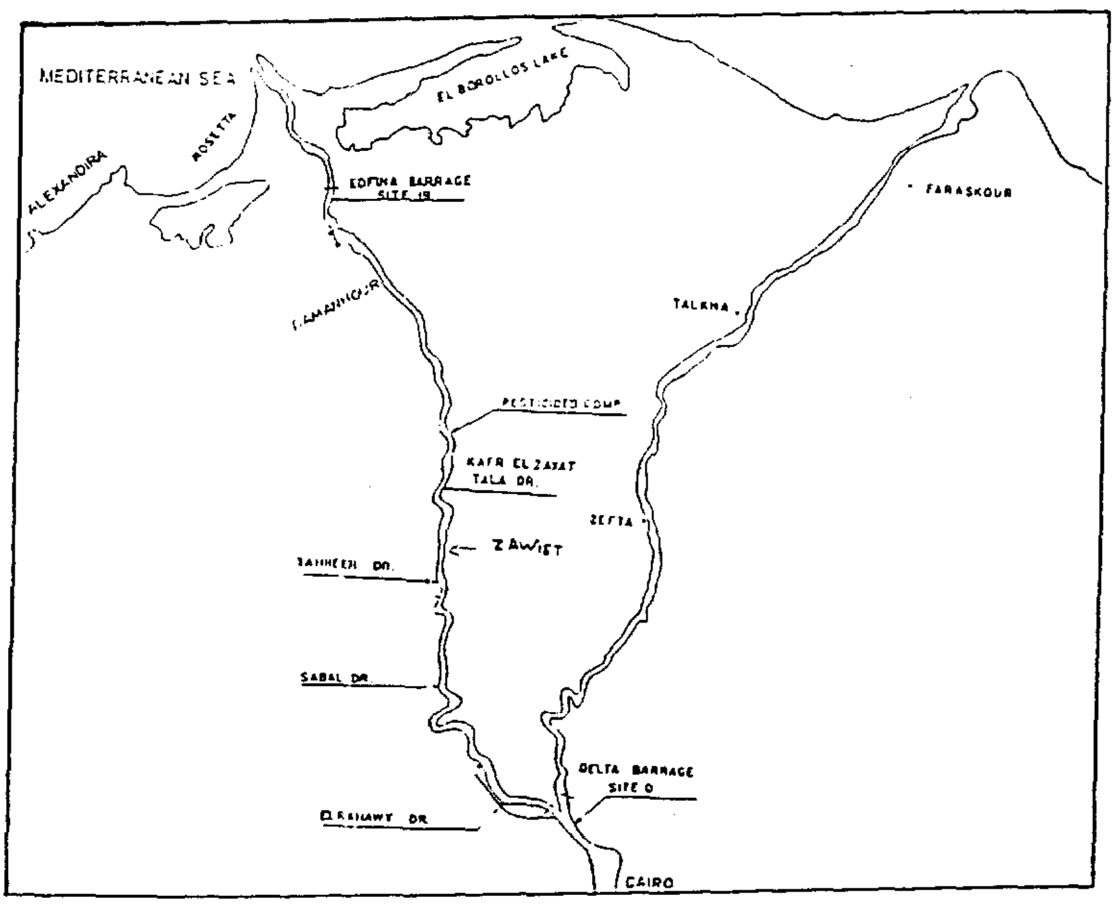


Fig. 17. Sampling locations along the Rosetta Branch.

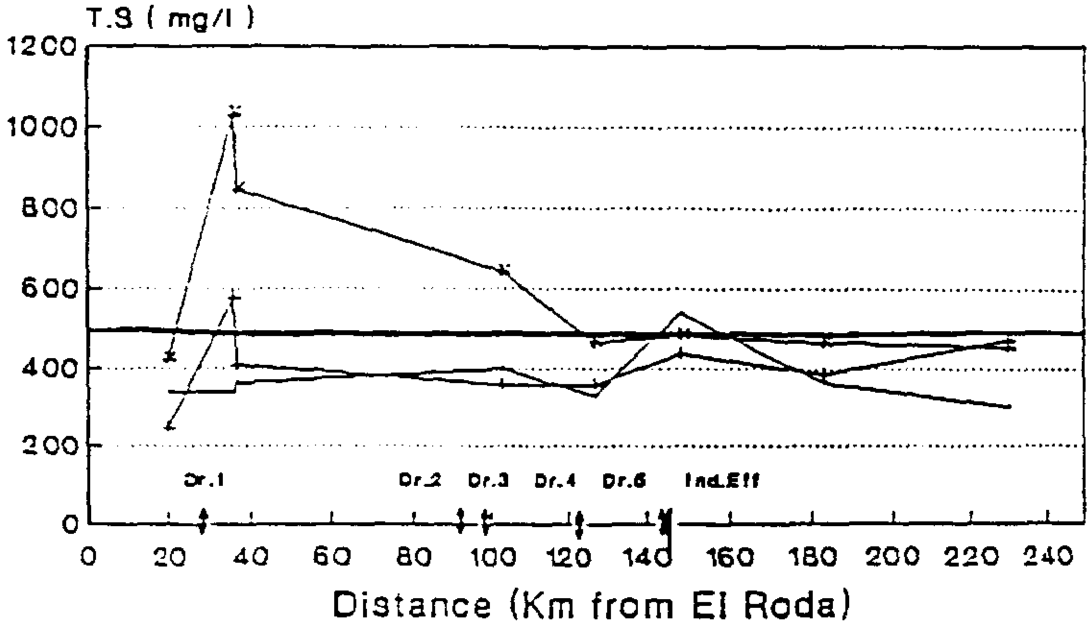


Fig. 18. Changes of total solid concentration along the Rosetta Branch before, during and three months after winter closure.

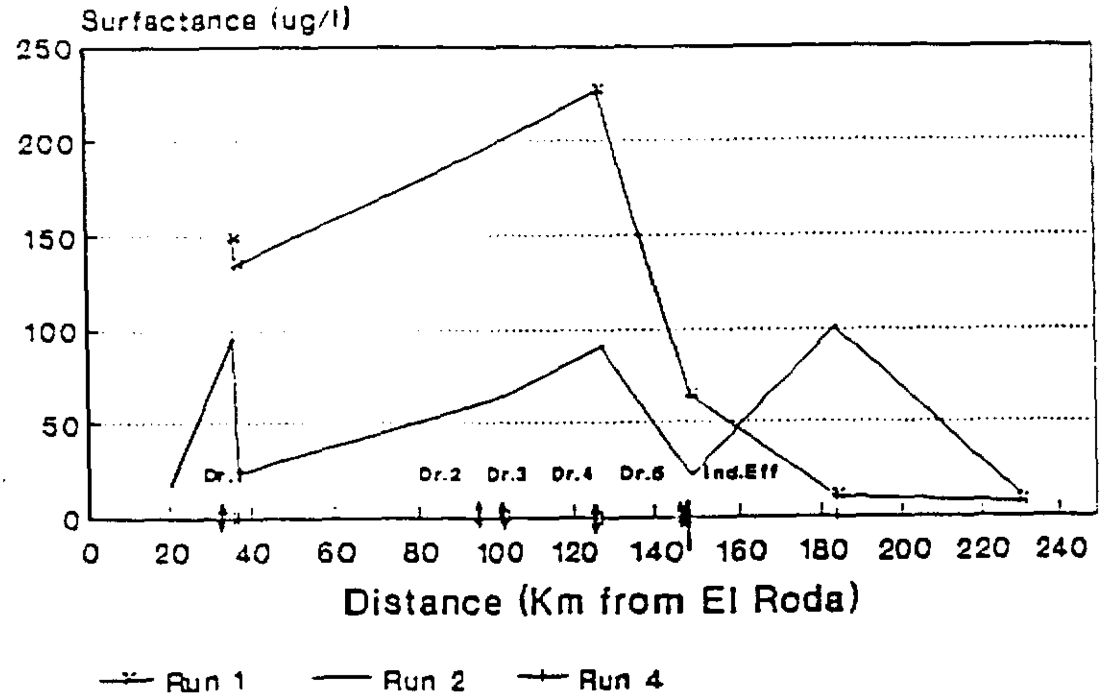


Fig. 19. Changes of surfactant concentration along the Rosetta Branch before, during and three months after winter closure.

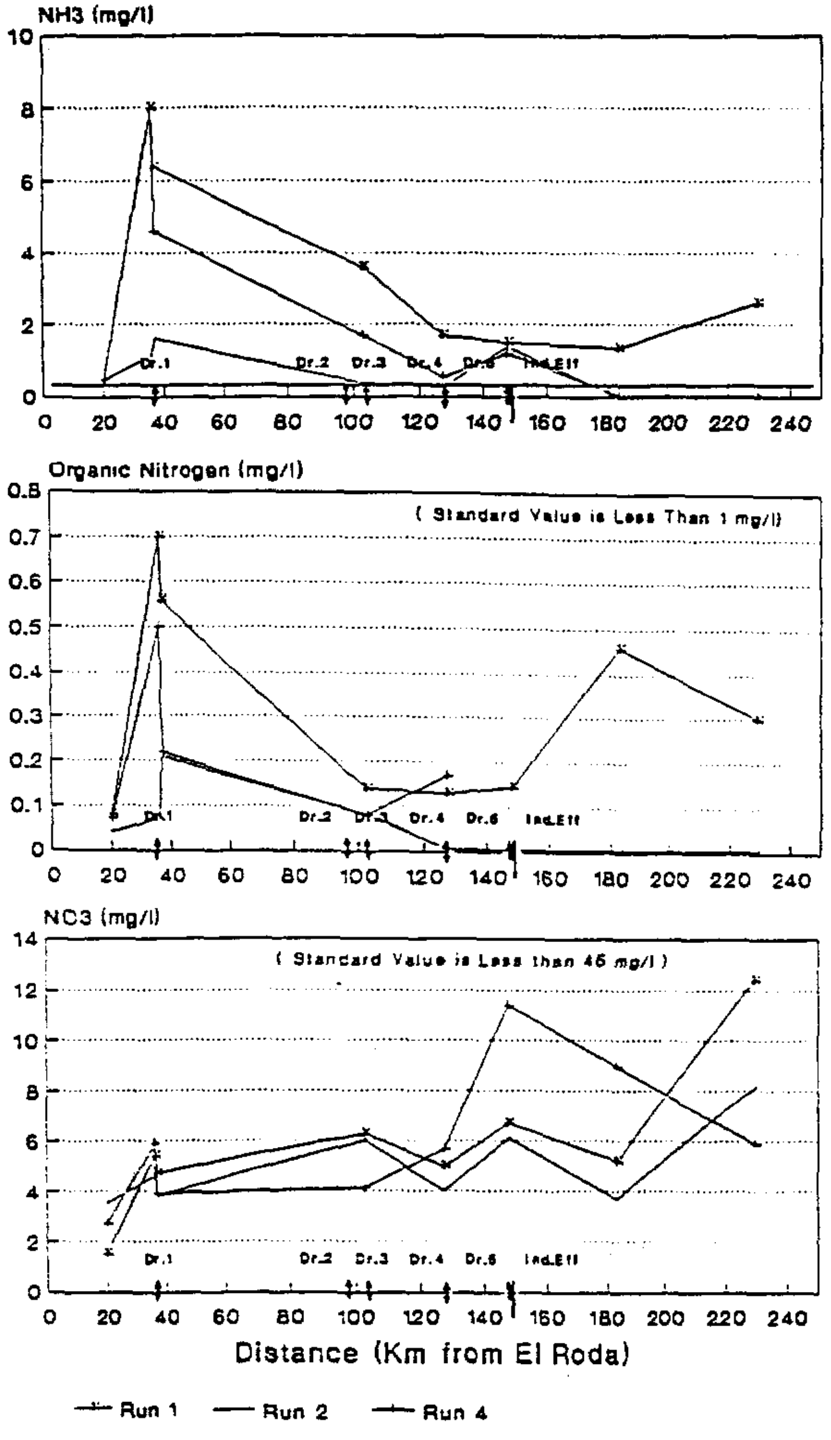


Fig. 20. Changes of nutrient concentration along the Rosetta Branch before, during and three months after winter closure.

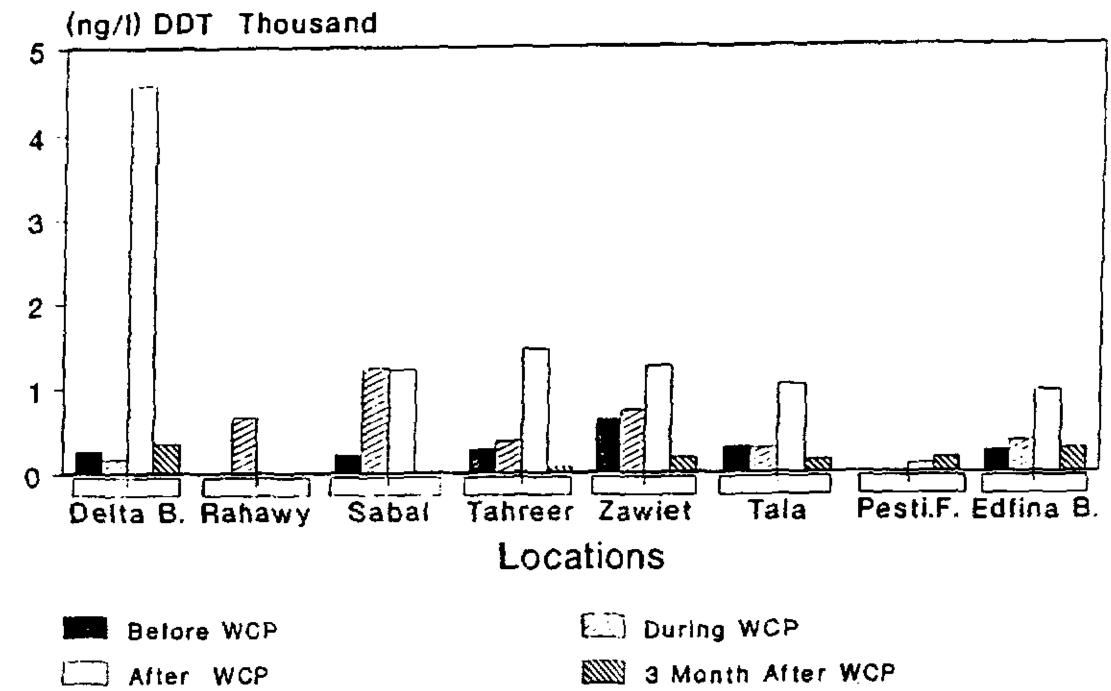


Fig. 21. DDT complex residue levels along the Rosetta Branch related to WCP.

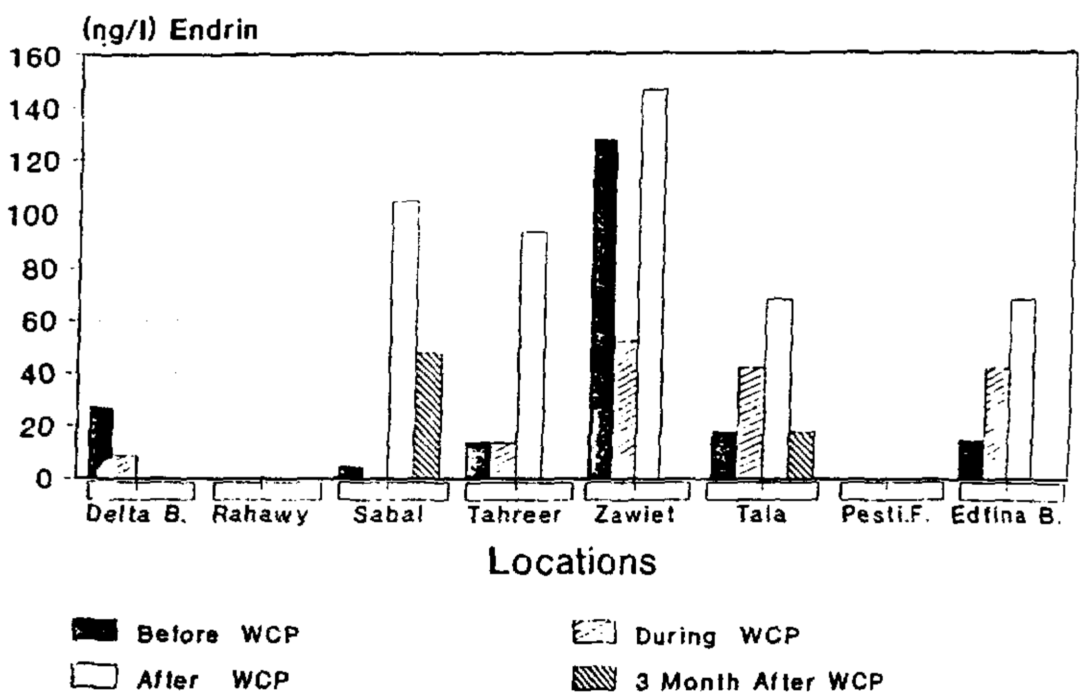


Fig. 22. Endrin residue levels along the Rosetta Branch related to WCP.

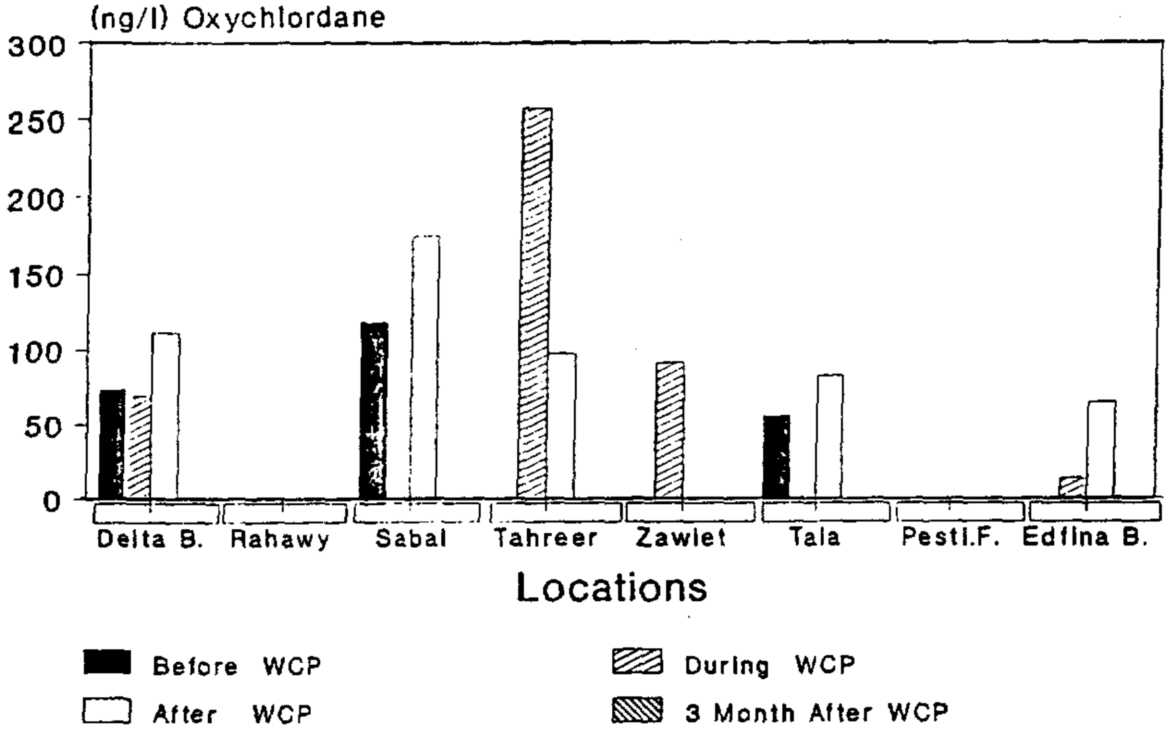


Fig. 23. Oxychlordane residue levels along the Rosetta Branch related to WCP.

Water Quality in Egypt

Nile Water Quality

Salinity status

A good review and evaluation of the guidelines previously used to evaluate water quality for agriculture is given in the FAO/UNESCO international source book on irrigation, drainage, and salinity (1973). Guidelines for evaluating water quality using the problem approach are given in Table 34. These guidelines are used for water quality evaluation in order to assist research work in Egypt.

Table 34. Guidelines for interpretation of water quality for irrigation (after FAO, 1985).

Irrigation problem	Degree of problem		
	None	Increasing	Severe
Salinity (affects water availability to crop)			
EC_w (mmhos/cm)	< 0.75	0.75–3.0	> 3.0
Permeability (affects infiltration rate into soil)			
EC_w (mmhos/cm)	< 0.5	0.5–2.5	< 0.2
Adj. SAR			
Montmorillonite(2:1 crystal lattice)	< 6	6–9	> 9
Illite–vermiculite (2:1 crystal lattice)	< 8	8–16	> 16
Kaolinite–sesqufoxides (1:1 crystal lattice)	< 16	16–24	> 24
Specific ion toxicity (affects sensitive crops)			
Sodium (adj. SAR)	3	3–9	> 9
Chloride (meq/l)	<	4–10	> 10
Boron (mg/l)	< 0.75	0.75–2.0	> 2
Miscellaneous effects (affect susceptible crops)			
NO_3-N (or) NH_4-N (mg/l)	< 5	5–30	> 30
HCO_3 (meq/l)	< 1.5	1.5–8.5	> 8.5
pH	Normal range: 6.5–8.4		
Fe	Permissible limit: 0.3 ppm		
Zn	Permissible limit: 5.0 ppm		

Generally, the water of the River Nile is of good quality with a total salt content not exceeding 350 ppm and an average adjusted SAR value of 4.5. Table 35 shows the average salinity and chemical composition of the water in the main canals in the three major parts of the Delta. The salt content in all irrigation canals in the Delta ranges between 0.35 and 0.7 mmhos. The dominant cations are calcium and magnesium throughout the year, while the prevalent anions appear to be bicarbonate in winter and sulfate in summer.

Table 35. Chemical analysis of irrigation water in the Nile Delta (1987).

Location *	pH	EC at 25°C mmhos/cm	ppm	Cations milligram equivalents/litre				Anions milligram equivalents/litre				SAR	Adj SAR
				Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl		
River Nile at Giza	8.2	0.32	250.0	1.25	1.13	1.15	0.03	—	1.95	0.9	0.71	1.1	1.7
Eastern Delta													
B. Faqus Canal	7.6	0.7	490.0	2.14	2.23	2.5	0.31	0.0	2.31	2.9	1.93	1.7	3.2
Ismailia Canal	9.02	0.6	410.0	2.25	1.86	1.7	0.31	0.0	2.79	1.77	1.48	1.2	2.4
B. Mois	8.06	0.41	200.0	1.52	1.39	1.13	0.2	0.0	1.76	1.31	1.16	0.9	1.5
Abu-khayar	7.88	0.68	410.0	1.93	1.05	2.67	0.24	0.0	2.5	1.79	2.62	1.9	3.6
Farasqur Dam	7.95	0.46	120.0	1.63	1.52	1.22	0.22	0.0	1.85	1.57	1.35	1.0	1.6
Middle Delta													
Edfina Barrage	8.1	0.56	390.0	1.78	1.33	2.2	0.32	0.0	1.88	2.16	1.56	1.8	2.9
East Edfina P. S.	7.99	0.54	370.0	1.82	1.46	1.84	0.28	0.0	2.02	1.8	1.54	1.4	2.5
West Edfina P.S.	7.72	0.52	350.0	1.78	1.35	1.78	0.26	0.0	1.76	1.82	1.58	1.4	2.3
Rayah El-Abasy	8.66	0.48	320.0	1.44	1.43	1.05	0.27	0.0	1.79	1.53	1.46	0.9	1.4
Mit Yazid Canal	8.15	0.50	340.0	1.38	1.36	1.4	0.3	0.0	1.93	1.62	1.46	1.2	2.0
Bahr Basandela	8.99	0.46	320.0	1.2	1.32	1.58	0.25	0.0	1.92	1.45	1.23	1.4	2.3
B. Tira	8.3	0.46	330.0	1.6	1.3	1.57	0.25	0.0	1.74	1.73	1.25	1.3	2.1
Western Delta													
Mahmoudiya C.	7.68	0.55	360.0	1.57	1.87	1.5	0.2	0.0	2.63	1.12	1.75	1.3	2.6
Kafr El-Dawwar B.	7.9	0.56	380.0	1.63	1.48	2.26	0.24	0.0	1.86	1.81	1.92	1.8	3.0
Khandak El-Gharbi Irr.	7.84	0.64	440.0	1.82	1.7	2.66	0.26	0.0	1.94	2.45	2.04	2.0	3.5
Dilingat Bridge	7.92	0.67	460.0	1.95	1.76	2.85	0.24	0.0	2.0	2.88	1.9	2.1	3.7

* For Location refer to Figure 7.2 Chapter 7.

Environmental status of the River Nile

The River Nile is considered as the source of life for Egyptians. It is therefore subject to multiple uses such as domestic, commercial, agricultural, industrial, and navigational, and thus different types of waste material enter the river, affecting its water quality. El Sherbeeny *et al.* (1993) discussed the Water Quality Monitoring Program, which was established in 1976 along the River Nile. Its main objective was to serve and evaluate Nile water quality and the potential effects of some pollutants with respect to different water uses. The historical data show that the quality of Nile water has deteriorated at some locations. The situation is probably getting worse with time as the discharge of waste increases. Fig. 24 shows the monitoring stations along the River Nile. Priorities were given to 13 major sites according to barrage locations and heavily polluted areas. The results of that monitoring program are summarized below.

Average water quality index

The water quality index is defined as a rating reflecting the composite influence of a number of parameters on the overall water quality. The average water quality index (AWQI) along the River Nile from Aswan to the Delta Barrage is given in Fig. 25. The AWQI at site zero is very low (17) increasing downstream from the dam from 21 at site 11 to 108 at site 14.

Ninety percent of the sites have an AWQI below 50. On the other hand, the AWQI varies from site to site according to the specific water quality parameter as shown in Fig. 26. For example, dissolved oxygen and coliform are an important contributing factor in some sites.

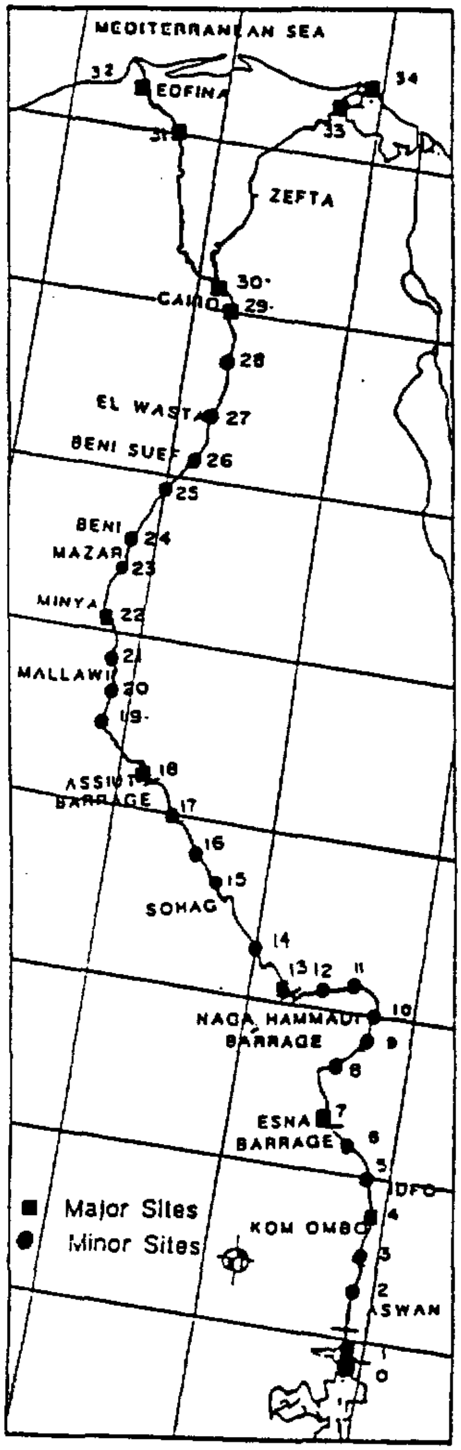


Fig. 24. Sampling locations.

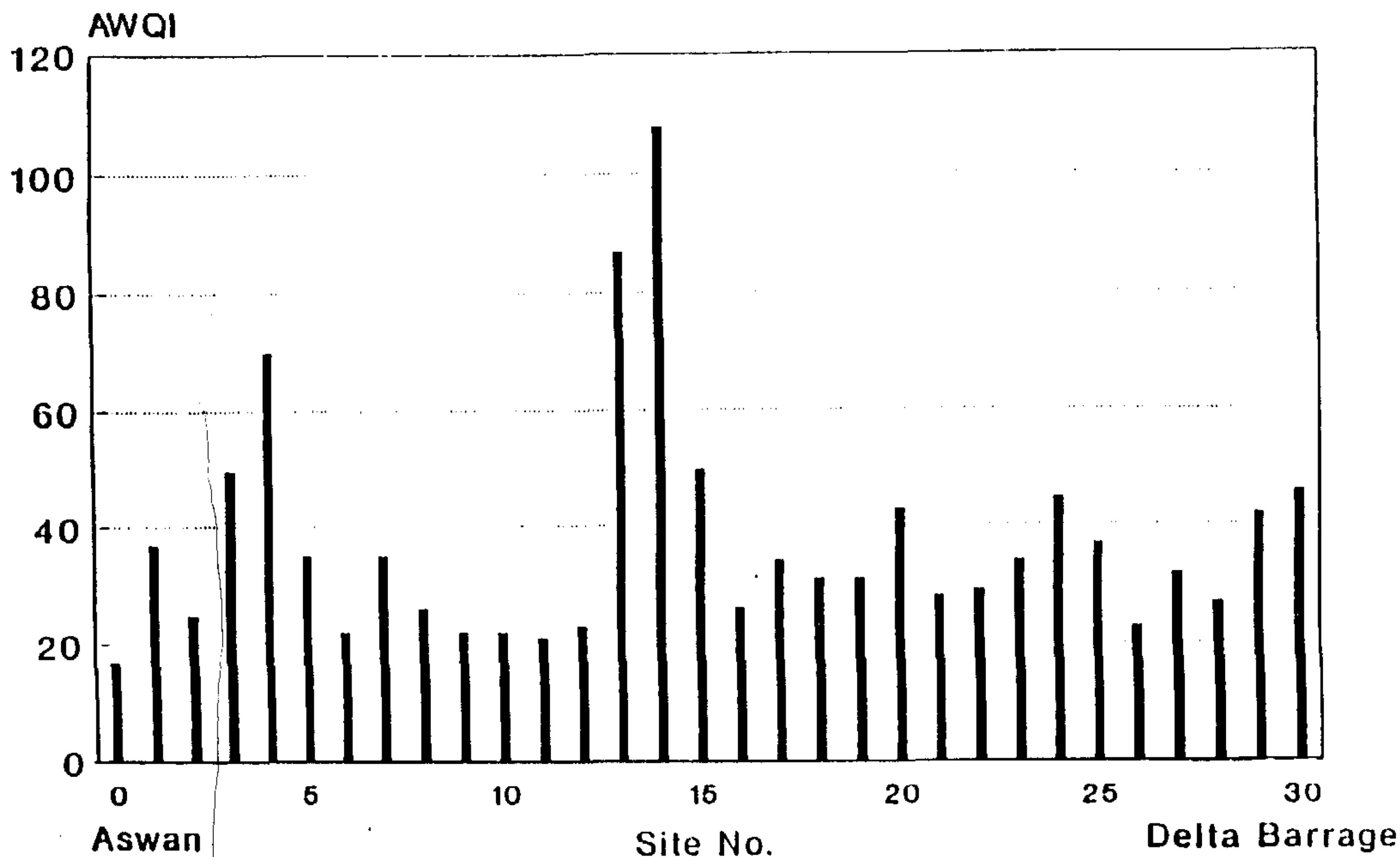


Fig. 25. Average water quality index along the River Nile (July, 1991).

- Total coliform: Total coliform counts fluctuated along the River at 76 MPN/100 ml at standard values (10,000) at only five sites: 4, 3, 4, 5, and 29.
- Ammonia (NH_3): The concentration of NH_3 fluctuated between 0.01 mg/l at sites 1, 2, 11, 12,1 5, 16, 21, 13, 15, and 29 and 0.6 mg/l at site 8. The concentrations were below the standard value (0.5 mg/l) except at site 8 where the standard value was exceeded by 20%.
- Surfactant: Concentrations of surfactant were mainly between 0.008 and 0.06 mg/l with a value of 0.18 mg/l observed at site 27, which is still below the standard of 0.5 mg/l.
- Nitrate (NO_3): The concentration of NO_3 along the River was very low, far below the standard value of 45 mg/l. It ranged from 0.81 mg/l at site 24 to 3.8 mg/l at site 19.
- Organic nitrogen: Organic nitrogen concentration along the River was far below the standard of 1 mg/l. It fluctuated between 0.01 mg/l at sites 3, 5, 7, 8, 10, 22, 25, 27, 28, and 29, and 0.08 mg/l at site 11.

Variations in water quality parameters are illustrated in Fig. 27. Comparisons between organochlorine, dieldrin and hepta-epoxide residue levels are shown in Figs. 28, 29 and 30, respectively.

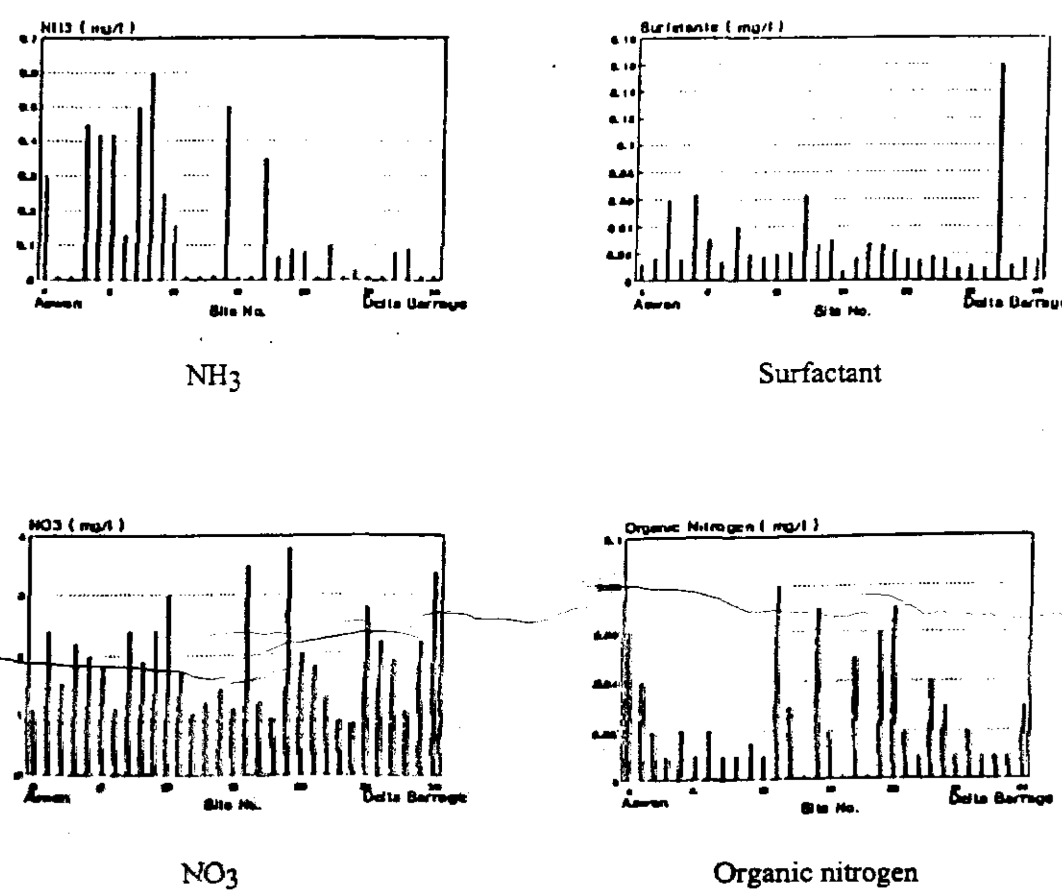


Fig. 27. Levels of some water quality parameters from Aswan to the Delta Barrage.

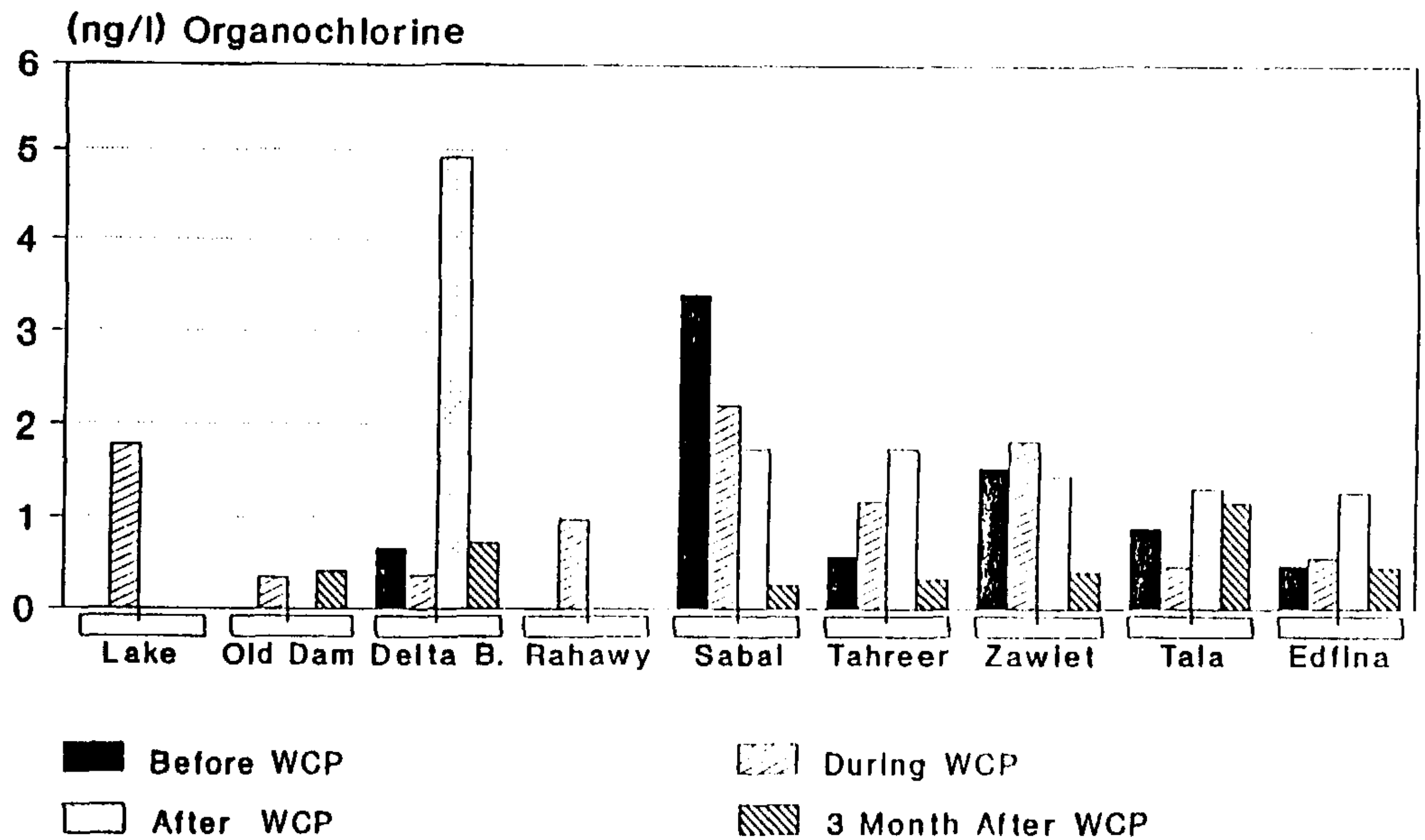


Fig. 28. Comparison of organochlorine residues along the Rosetta Branch and Aswan (samples related to WCP).

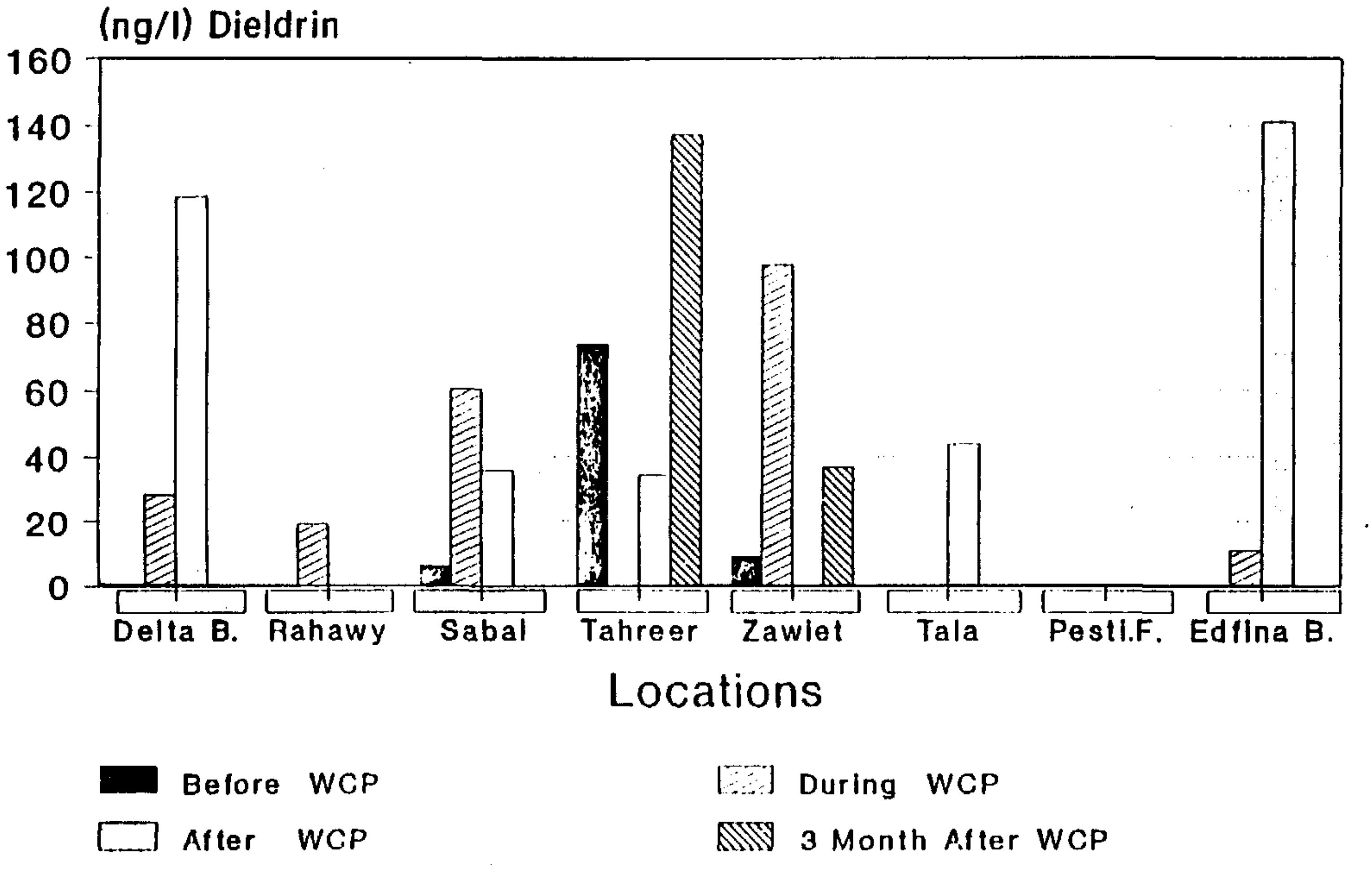


Fig. 29. Dieldrin residue levels along the Rosetta Branch (related to WCP).

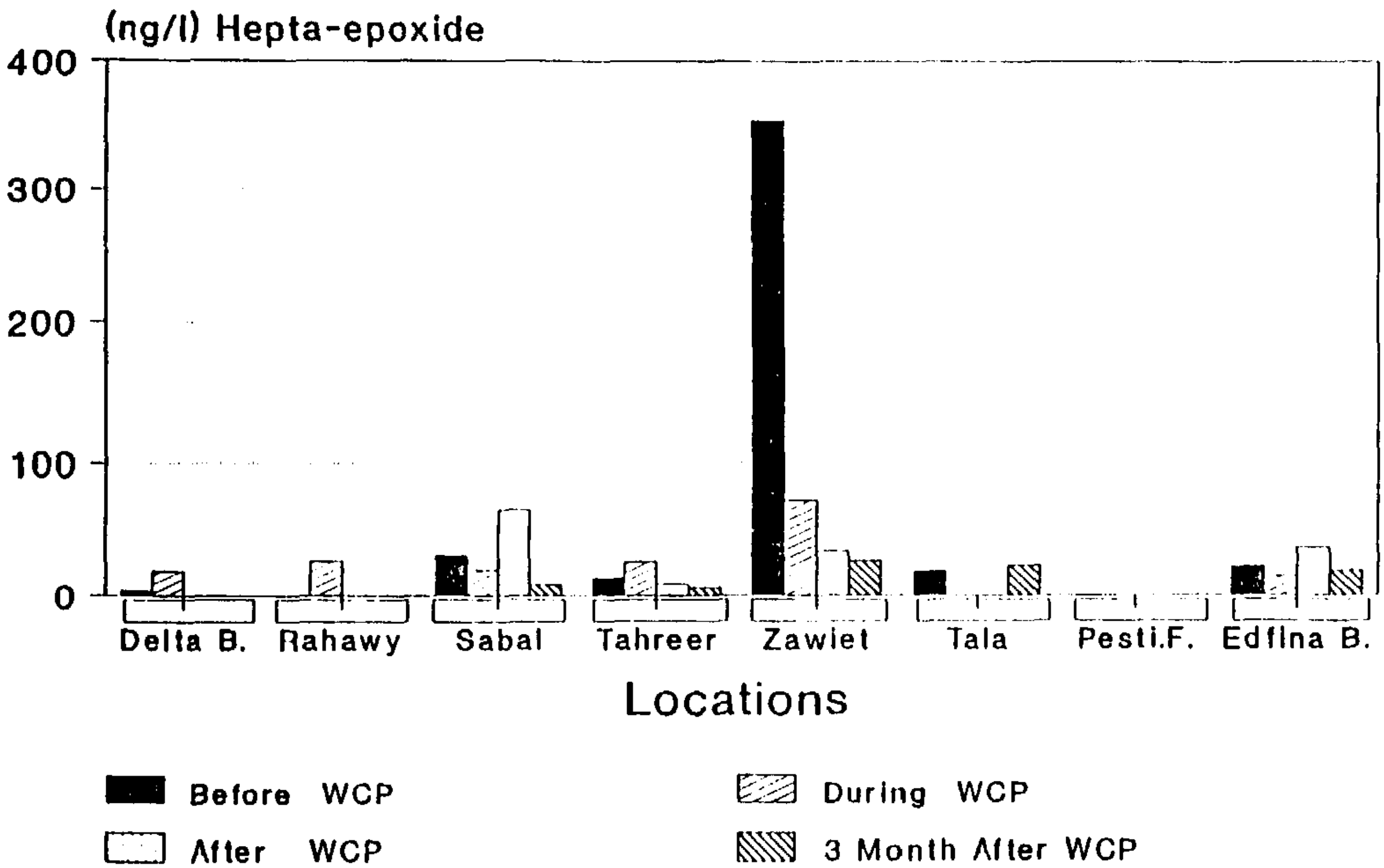


Fig. 30. Hepta-epoxide residue levels along the Rosetta Branch (related to WCP).

Biological index of the River Nile

The degree of eutrophication and pollution along the River Nile was evaluated. The biological evaluation included the compound eutrophication index, trophic state index, autotrophic index, Shannon-Wiener index, Saprobic index, Saprobic quotient and the concept of the indicator of the species. These biological approaches rely mainly on the species composition of phytoplanktons, the distribution of individuals among species, chlorophyll "a" concentration and the dry weight of the organic matter. The study was carried out between autumn 1987 and summer 1988. Water samples were seasonally collected from 16 different sampling stations, three located upstream and 13 downstream from Cairo. The biological approaches revealed a severe deterioration in water quality, *progressing from upstream* to downstream waters. From the biological point of view, the water of the study area is typically eutrophic, and its pollution status ranges between P-mesosaprobic and oligosaprobic conditions. The results of this study are given in Tables 38 to 40.

Table 38. Values of compound eutrophication index, trophic state index, autotrophic index, diversity index, saprobic index, and saprobic quotient, recorded at 16 stations (1987/88).

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Autumn 1987																
Compound eutrophication index	19.5	18.5	18.5	22.0	16.7	24.5	20.0	13.5	23.0	11.5	22.0	26.0	27.0	18.5	19.0	9.0
Trophic state index (Chlorophyll a)*	64.8	61.5	61.3	61.0	61.3	64.3	63.1	55.2	52.3	58.3	55.5	54.7	57.5	56.5	58.2	60.2
Autotrophic index	460	408	480	463	435	379	381	1222	545	891	1106	1197	321	426	357	485
Diversity index (cell number)**	1.5	1.4	1.5	1.7	1.9	1.9	1.8	1.7	3.3	2.9	2.4	2.5	3.1	2.9	3.0	2.4
Diversity index (cell biovolume)***	1.9	1.8	1.9	2.0	2.1	1.3	1.7	2.6	2.3	1.9	1.9	1.9	0.8	2.5	2.0	1.9
Saprobic index (cell number)**	1.3	1.3	1.3	1.4	1.4	1.4	1.5	2.1	2.0	1.8	1.9	1.9	2.1	1.9	1.9	1.7
Saprobic index (cell biovolume)***	1.3	1.3	1.3	1.3	1.4	1.3	1.4	1.9	2.0	1.9	1.9	1.7	2.5	2.0	1.9	1.8
Saprobic quotient	1.18	1.19	1.19	1.23	1.20	1.15	1.12	1.13	1.12	1.11	1.10	1.15	1.07	1.17	1.16	1.26
Winter 1988																
Compound eutrophication index	17.0	13.5	13.5	14.0	14.0	17.0	20.5	16.5	8.0	5.0	30.0	29.0	31.0	15.5	6.8	29.0
Trophic state index (Chlorophyll a)*	59.3	60.6	60.5	60.8	57.2	60.7	57.3	59.7	31.0	73.2	53.0	55.8	55.8	56.6	54.9	53.0
Autotrophic index	534	656	755	731	798	741	788	307	2158	155	812	914	1980	847	1174	1624
Diversity index (cell number)**	2.5	2.4	2.4	2.5	2.6	2.4	2.6	2.8	2.6	1.7	2.5	2.5	2.8	2.5	2.5	2.5
Diversity index (cell biovolume)***	2.5	2.4	2.4	2.6	2.5	2.5	2.9	1.5	1.2	0.5	2.8	2.2	2.2	3.0	3.1	1.3
Saprobic index (cell number)**	1.7	1.8	1.8	1.8	1.8	1.9	2.1	2.0	1.7	2.3	1.7	2.0	1.9	2.0	2.0	1.9
Saprobic index (cell biovolume)***	1.6	1.6	1.6	1.6	1.6	1.5	2.1	1.3	1.6	2.5	1.8	1.8	1.6	1.8	1.8	1.3
Saprobic quotient	1.13	1.16	1.16	1.21	1.15	1.22	1.05	1.15	1.14	1.57	1.00	1.14	1.06	1.20	1.36	1.17
Spring 1988																
Compound eutrophication index	19.0	24.0	40.0	35.0	22.0	30.0	26.0	36.0	28.0	13.0	31.0	25.0	45.0	32.0	22.0	28.0
Trophic state index (Chlorophyll a)*	60.6	60.8	56.5	56.4	51.7	54.1	54.6	56.1	57.0	68.2	55.8	52.8	71.7	54.7	66.3	52.7
Autotrophic index	748	917	1815	1439	1132	2005	866	1338	675	473	611	1867	136	511	157	2304
Diversity index (cell number)**	2.1	2.2	1.9	1.7	2.1	2.2	1.7	1.9	2.1	1.8	1.8	1.8	2.8	2.9	2.4	2.7
Diversity index (cell biovolume)***	1.9	1.3	1.8	2.7	2.2	1.8	1.1	2.3	1.4	2.2	2.5	1.8	1.4	1.7	1.0	1.2
Saprobic index (cell number)**	2.0	1.7	1.9	1.9	1.8	1.9	1.6	1.9	1.6	1.7	1.9	1.9	1.9	1.9	1.9	1.8
Saprobic index (cell biovolume)***	1.3	1.2	1.2	1.8	1.8	1.3	1.7	1.5	1.6	1.9	1.7	1.6	2.4	2.1	2.4	1.3
Saprobic quotient	1.20	1.08	1.14	1.07	1.21	1.14	1.08	1.14	1.07	1.19	1.16	1.11	1.10	1.19	1.20	1.15
Summer 1988																
Compound eutrophication index	13.7	21.0	21.0	24.0	29.0	12.7	10.3	10.5	48.0	7.4	17.0	15.5	34.0	36.0	26.5	34.0
Trophic state index (Chlorophyll a)*	60.2	62.8	63.4	61.9	55.4	65.9	57.3	61.9	57.0	60.1	60.3	59.1	72.1	68.6	66.0	60.5
Autotrophic index	685	150	493	653	959	601	784	736	539	594	580	656	116	219	269	566
Diversity index (cell number)**	1.8	2.1	2.0	1.9	2.4	2.6	2.3	2.1	2.5	2.9	2.4	2.6	2.5	2.5	3.2	2.4
Diversity index (cell biovolume)***	2.5	2.6	2.4	2.7	2.7	2.3	2.4	2.6	2.8	2.4	1.8	1.7	3.2	2.5	2.2	2.3
Saprobic index (cell number)**	1.9	1.9	1.9	1.9	1.9	2.0	1.9	1.9	2.0	2.1	2.0	2.0	2.0	1.9	1.9	2.1
Saprobic index (cell biovolume)***	1.8	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.8	1.7	1.7	1.9	1.9	2.2	2.2
Saprobic quotient	1.16	1.11	1.11	1.09	1.08	1.21	1.24	1.20	1.20	1.55	1.13	1.16	1.10	1.12	1.12	1.07

* Values are computed from concentrations of chlorophyll a

** Abundance of algae was expressed as cell number per liter

*** Abundance of algae was expressed as cell biovolume (cubic milliliter) per liter

Table 39. Biological indices and water quality indications.

	(A) Compound eutrophication index	(B) Trophic state index	(C) Autotrophic index	(D) Shannon-Wiener diversity index	(E) Saprobic index	(F) Saprobic quotient
Maximum	56 (Eutrophic)	73.7 (Hypereutrophic)	2458 (Very poor water quality)	3.17 (3.3)* Slight pollution (Slight pollution)	2.51 (2.26) In the middle between β- and α- mesosaprobity (β- to α- mesosaprobity)	1.57 Oligo- to β- mesosaprobity
Minimum	5 (Eutrophic)	34 (Good water quality ; oligotrophic)	116 (Normal water quality)	0.5 (1.4) Heavy pollution (Moderate pollution)	1.18 (1.31) Univocal oligosaprobity (Oligo- β- mesosaprobity)	1.0 β- mesosaprobity
Average	22.3 (Eutrophic)	59.3 (Eutrophic)	792 (Poor water quality)	2.09 (2.32) Light pollution (Light pollution)	1.73 (1.84) β- to oligosaprobity (β- to oligosaprobity)	1.16 β- to oligosaprobity
Median	21 (Eutrophic)	59.2 (Eutrophic)	656 (Poor water quality)	2.19 (2.42) Light pollution Light pollution	1.77 (1.9) β- to oligosaprobity (Univocal β- mesosaprobity)	1.14 β- to oligosaprobity

* Numbers in and out brackets are the index's values when the algal abundance is expressed as absolute cell density (cells l^{-1}) and cell biovolume (mm^3 l^{-1}), respectively.

Table 40. Biomonitoring of water quality: indicator species.

Taxa	Indicator species (Palmer 1980): E	Indicator species (Palmer 1980): FP	Indicator species (Palmer 1980): Other	Indication of saprobity Sladecek (1973): s	Environmental requirements and pollution tolerance of: diatoms Lowe (1974): Nut.	diatoms Lowe (1974): s	blue-greens Vanlandingham (1982): Nut.	blue-greens Vanlandingham (1982): s
Actinastrum hantzschii		x		beta-meso.				
Ankistrodesmus falcatus		x		beta-alpha-meso.				
Botryococcus braunii				oligo-beta-meso.				
Chlorella vulgaris		x		poly - alpha-meso.				
Coelastrum microporum	x	x		beta-meso.				
Crucigenia rectangularis				alpha-beta-meso.				
C.tetrapedia				oligo-beta-meso.				
Dictyosphaerium ehrenbergianum			SP.T	beta-meso.				
D.pulchellum		x		beta-meso.				
Kirchneriella lunaris				beta-meso.				
Micractinium pusillum	x	x		beta-meso.				
Oocystis borgei	x							
O.lacustris				beta-meso.-oligo				
Pediastrum boryanum		x		beta-meso.				
P.duplex				beta-meso.				
P.simplex				beta-meso.				
P.tetras			T	beta-meso.				
Scenedesmus abundans			T					
S.dimorphus			SP					
S.obliquus		x		beta-meso.				
S.quadricauda		x		beta-meso.				
T. minimum				beta-meso.				
T. muticum		x						
Westella botryoides				beta-meso.				
Anabaena affinis				beta-meso.				
Chroococcus dispersus							E.	
C. limneticus				a.-beta-meso.			E.	Alpha-beta-
C. turgidus							Dis.	
Coelosphaerium dubium				beta-meso.				
Gomphosphaeria aponina	x						E.	beta-
Merismopedia elegans	x	x					E.	
M. glauca							E.	oligo-
Microcystis aeruginosa				beta-meso.			E.	alpha-poly-
Cyclotella meneghiniana				alpha-beta-meso.		Alpha-		
Melosira varians				a.-beta-meso.		Oligo-		
M. granulata	x	x		beta-meso.	E.	oligo-beta-		
Nitzschia palea		x		alpha-meso.	E.	alpha-poly-		
Synedra acus		x		beta-meso.	E.	beta-oligo-		
Cryptomonas cylindrica			SP.T					
C. marssonii				o-beta-meso.				

E = Europhication T = Taste and odor
FP = Freshwater pollution Dis = Dystrophic
SP = Sewage pond Nut. = Nutrient

Drainage Water Quality

Salinity status of drainage water

Agricultural drainage water in Upper Egypt is discharged back into the River Nile. Thus it is mixed with Nile water and becomes part of the flow to the Delta. This slightly affects the quality of the Nile water, as its salinity increases from 250 ppm at Aswan to about 300–350 ppm near Cairo. The quantity of the drainage water from Upper Egypt is relatively small, estimated at about 2 billion m^3 per year. On the other hand, the drainage system in the Delta is rather intensive and serves a total gross area of 4.72 million fed (1.98 million ha) out of the 7.2 million fed (3.025 million ha) of agricultural lands in Egypt. The total length of the main open drains in the Delta is about 1,600 km. The drainage water in these drains is of low quality and thus was previously discharged into the sea or to the coastal lakes. However, a few drains still discharge their drainage water into the two branches of the Nile.

Preliminary investigations showed that substantial amounts of drainage water flowing to the sea have salinity levels suitable for irrigation reuse. However, the inclusion of this type of water requires careful and detailed evaluation of its quantity and quality along with spatial and temporal variations. The Drainage Research Institute of the Water Research Center was entrusted to carry out a long-term monitoring program to determine the time-dependent variables of drainage flow in the Delta. A network of fixed measuring stations at the key points of the drainage system was established in the late 1970s (Amer and de Ridder, 1989). Fig. 31 illustrates the irrigation–drainage water monitoring network in the Delta.

Since then, the network has been continuously maintained and upgraded to furnish reliable measurements. The measuring sites are located at outlets of drainage catchments where there are pumping stations. The current monitoring network consists of 34 measuring stations distributed as shown in Fig. 24.

An important parameter for evaluating the suitability of drainage water for agricultural uses is the salt content of this water. The annual variations are primarily dependent on the water-use policies and management of the main supply system. The strict control and reduction of releases associated with the continuation of droughts in the Upper Nile basin have resulted in a clear increase of salt content in the drainage water and a reduction in the drainage discharges, i.e. the reduction in drainage water quality due to the rationalization policy introduced in 1987/88 resulted in an increase in its salinity.

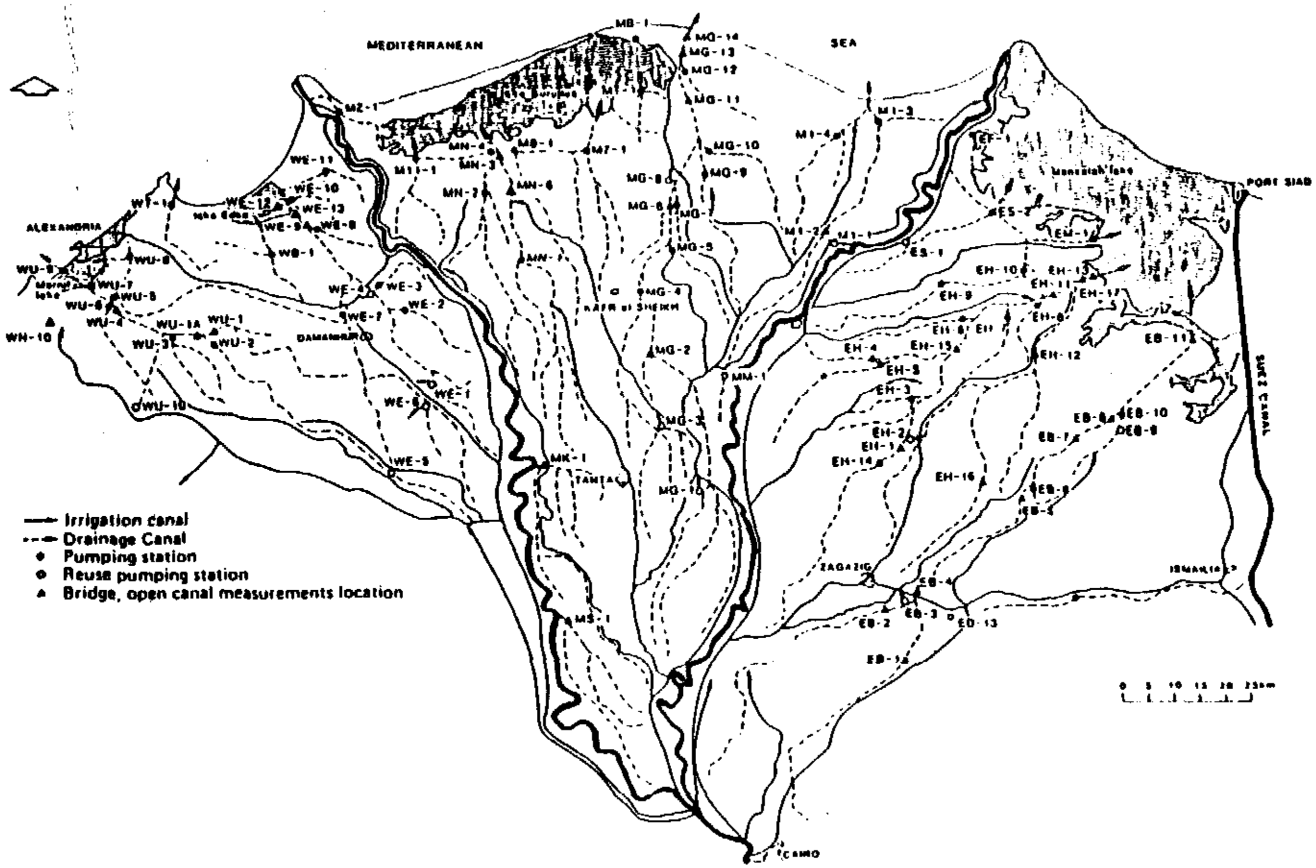


Fig. 31. Delta irrigation and drainage system and drainage water monitoring network.

Tables 41 and 42 show the changes in the drainage water salinity as affected by the rationalization strategy on the regional level, for both drainage water flow to the sea and that reused in irrigation.

Table 41. Average annual salinity (mmhos/cm) of drainage water flowing to the sea.

Region	84/85	85/86	86/87	Avg.	87/88	88/89	89/90	Avg.
East Delta	2.12	2.35	2.43	2.31	2.64	2.76	2.85	2.75
Middle Delta	3.35	3.71	3.72	3.59	3.96	3.88	3.99	3.94
West Delta	5.76	5.02	4.72	5.17	5.65	6.00	5.75	5.30
Overall Delta	3.72	3.71	3.65	3.69	4.14	4.34	4.31	4.26

Table 42. Average annual salinity (mmhos/cm) of reused drainage water.

Region	84/85	85/86	86/87	Avg.	87/88	88/89	89/90	Avg.
East Delta	1.28	1.3	1.34	1.31	1.44	1.53	1.55	1.89
Middle Delta	1.29	1.21	1.25	1.25	1.42	1.46	2.24	1.71
West Delta	1.53	1.51	1.53	1.52	1.49	1.64	1.49	1.54
Overall Delta	1.35	1.33	1.37	1.35	1.45	1.53	1.76	1.58

The salinity of drainage water varies also from one month to another and is influenced by the cropping system, the irrigation system operations and their losses to the main drains. The monthly variation of drainage water salinity is shown in Fig. 32.

The monthly distribution of drainage water flow to the sea or the coastal lakes, and the reused quantities in each Delta region according to salinity class from 1984/85 to 1989/90 are shown in Tables 43 to 54.

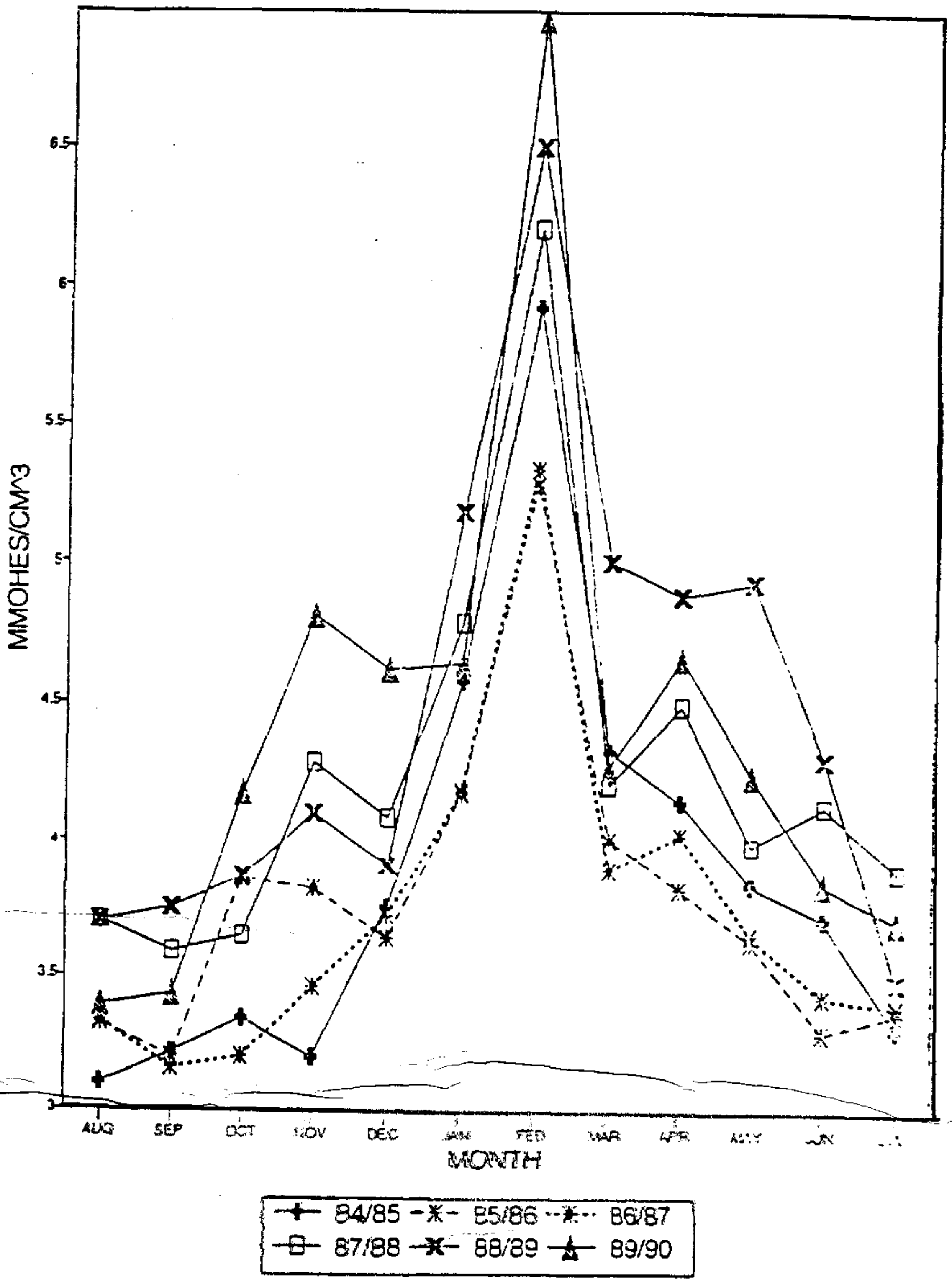


Fig. 32. Monthly variation in drainage water salinity.

Table 43. Monthly distribution of drainage water to the sea, by salinity class (East Delta).

Year	Month		Salinity Class						
		mmhos/cm	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0
		ppm	960-1280	1280-1600	1600-1920	1920-2240	2240-2560	2560-2880	2880-3200
	AUG		-	522.10	-	-	-	-	-
	SEP		-	521.50	-	-	-	-	-
	OCT		-	475.96	-	-	-	-	-
	NOV		-	380.92	-	-	-	-	-
	DEC		-	429.56	-	-	-	-	-
84/85	JAN		-	-	372.58	-	-	-	-
	FEB		-	-	237.10	-	-	-	-
	MAR		-	-	342.76	-	-	-	-
	APR		-	311.30	-	-	-	-	-
	MAY		-	316.25	-	-	-	-	-
	JUN		-	357.40	-	-	-	-	-
	JUL		-	465.32	-	-	-	-	-
	TOTAL		-	3780.31	952.44	-		-	-
	AUG		-	494.73	-	-		-	-
	SEP		-	501.14	-	-	-	-	-
	OCT		-	434.77	-	-	-	-	-
	NOV		-	369.15	-	-	-	-	-
	DEC		-	429.69	-	-	-		-
85/86	JAN		-	376.04	-	-	-		-
	FEB		-	-	-	-	233.39	-	-
	MAR		-	-	333.60	-	-	-	-
	APR		-	340.38	-	-	-	-	-
	MAY		-	311.65	-	-	-	-	-
	JUN		-	-	323.16	-	-		-
	JUL		-	-	447.83	-	-	-	-
	TOTAL		-	3257.55	1104.59	-	233.39	-	-
	AUG		-	-	436.56	-	-	-	-
	SEP		-	512.60	-	-	-	-	-
	OCT		-	457.83	-	-	-	-	-
	NOV		-	390.26	-	-	-	-	-
	DEC		-	378.95	-	-	-	-	-
86/87	JAN		-	-	354.71	-	-	-	-
	FEB		-	-	-	-	176.06	-	-
	MAR		-	371.63	-	-	-	-	-
	APR		-	286.73	-	-	-	-	-
	MAY		-	282.61	-	-	-	-	-
	JUN		-	411.40	-	-	-	-	-
	JUL		-	481.00	-	-	-	-	-
	TOTAL		-	3573.01	791.27	-	176.06	-	-

Values In The Above Table Are Expressed In Million m3

Table 43. (Cont'd)

Year	Month		Salinity Class						
		mmhos/cm	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0
		ppm	960-1280	1280-1600	1600-1920	1920-2240	2240-2560	2560-2880	2880-3200
	AUG		-	-	439.42	-	-	-	-
	SEP		-	480.97	-	-	-	-	-
	OCT		-	452.91	-	-	-	-	-
	NOV		-	-	328.32	-	-	-	-
	DEC		-	405.04	-	-	-	-	-
87/88	JAN		-	-	367.39	-	-	-	-
	FEB		-	-	-	-	-	149.30	-
	MAR		-	-	337.07	-	-	-	-
	APR		-	-	-	238.33	-	-	-
	MAY		-	-	237.24	-	-	-	-
	JUN		-	-	-	268.15	-	-	-
	JUL		-	-	-	-	397.39	-	-
	TOTAL		-	1338.92	1709.44	506.48	397.39	149.30	-
	AUG		-	-	376.62	-	-	-	-
	SEP		-	-	437.11	-	-	-	-
	OCT		-	-	382.42	-	-	-	-
	NOV		-	-	297.58	-	-	-	-
	DEC		-	386.40	-	-	-	-	-
88/89	JAN		-	-	359.88	-	-	-	-
	FEB		-	-	-	-	156.93	-	-
	MAR		-	-	-	322.97	-	-	-
	APR		-	-	257.89	-	-	-	-
	MAY		-	-	256.48	-	-	-	-
	JUN		-	-	308.79	-	-	-	-
	JUL		-	-	510.85	-	-	-	-
	TOTAL		-	386.40	3187.62	322.97	156.93	-	-
	AUG		-	-	485.25	-	-	-	-
	SEP		-	-	492.86	-	-	-	-
	OCT		-	-	388.17	-	-	-	-
	NOV		-	-	291.25	-	-	-	-
	DEC		-	-	364.64	-	-	-	-
89/90	JAN		-	341.92	-	-	-	-	-
	FEB		-	-	-	-	-	206.06	-
	MAR		-	-	329.64	-	-	-	-
	APR		-	-	311.23	-	-	-	-
	MAY		-	-	322.75	-	-	-	-
	JUN		-	-	437.62	-	-	-	-
	JUL		-	-	517.82	-	-	-	-
	TOTAL		-	341.92	3941.23	-	-	206.06	-

Values In The Above Table Are Expressed In Milloin m3

Table 44. Average monthly distribution of drainage water to the sea, by salinity class (East Delta).

Year	Month		Salinity Class						
		mmhos/cm	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0
		ppm	960-1280	1280-1600	1600-1920	1920-2240	2240-2560	2560-2880	2880-3200
AVG 84/87	AUG		-	484.46	-	-	-	-	-
	SEP		-	511.75	-	-	-	-	-
	OCT		-	456.19	-	-	-	-	-
	NOV		-	380.11	-	-	-	-	-
	DEC		-	412.73	-	-	-	-	-
	JAN		-	-	367.78	-	-	-	-
	FEB		-	-	-	215.52	-	-	-
	MAR		-	-	349.33	-	-	-	-
	APR		-	312.80	-	-	-	-	-
	MAY		-	303.50	-	-	-	-	-
	JUN		-	363.99	-	-	-	-	-
	JUL		-	464.72	-	-	-	-	-
	TOTAL		-	3690.25	717.11	215.52	-	-	-
AVG 87/90	AUG		-	-	433.76	-	-	-	-
	SEP		-	-	470.31	-	-	-	-
	OCT		-	-	407.83	-	-	-	-
	NOV		-	-	305.72	-	-	-	-
	DEC		-	385.36	-	-	-	-	-
	JAN		-	-	356.40	-	-	-	-
	FEB		-	-	-	-	-	170.76	-
	MAR		-	-	329.89	-	-	-	-
	APR		-	-	269.15	-	-	-	-
	MAY		-	-	272.16	-	-	-	-
	JUN		-	-	338.19	-	-	-	-
	JUL		-	-	475.35	-	-	-	-
	TOTAL		-	385.36	3658.76	-	-	170.76	-
AVG 84/90	AUG		-	459.11	-	-	-	-	-
	SEP		-	491.03	-	-	-	-	-
	OCT		-	432.01	-	-	-	-	-
	NOV		-	342.91	-	-	-	-	-
	DEC		-	399.05	-	-	-	-	-
	JAN		-	-	362.09	-	-	-	-
	FEB		-	-	-	-	193.14	-	-
	MAR		-	-	339.61	-	-	-	-
	APR		-	-	290.98	-	-	-	-
	MAY		-	287.83	-	-	-	-	-
	JUN		-	-	351.09	-	-	-	-
	JUL		-	-	470.04	-	-	-	-
	TOTAL		-	2411.94	1813.80	-	193.14	-	-

Values In The Above Table Are Expressed In Million m3

Table 45. Monthly distribution of reused drainage water, by salinity class (East Delta).

Year	Month		Salinity Class						
		mmhos/cm	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5
		ppm	640-960	960-1280	1280-1600	1600-1920	1920-2240	2240-2560	2560-2880
84/85	AUG		160.53	-	-	-	-	-	-
	SEP		137.57	-	-	-	-	-	-
	OCT		127.64	-	-	-	-	-	-
	NOV		102.10	-	-	-	-	-	-
	DEC		85.23	-	-	-	-	-	-
	JAN		91.85	-	-	-	-	-	-
	FEB		-	49.61	-	-	-	-	-
	MAR		112.26	-	-	-	-	-	-
	APR		90.99	-	-	-	-	-	-
	MAY		99.42	-	-	-	-	-	-
	JUN		108.12	-	-	-	-	-	-
	JUL		135.17	-	-	-	-	-	-
	TOTAL		1250.89	49.61	-	-	-	-	-
85/86	AUG		138.97	-	-	-	-	-	-
	SEP		142.75	-	-	-	-	-	-
	OCT		114.39	-	-	-	-	-	-
	NOV		91.25	-	-	-	-	-	-
	DEC		108.62	-	-	-	-	-	-
	JAN		82.25	-	-	-	-	-	-
	FEB		-	-	52.52	-	-	-	-
	MAR		105.05	-	-	-	-	-	-
	APR		102.43	-	-	-	-	-	-
	MAY		101.95	-	-	-	-	-	-
	JUN		101.20	-	-	-	-	-	-
	JUL		121.46	-	-	-	-	-	-
	TOTAL		1210.32	-	52.52	-	-	-	-
86/87	AUG		143.64	-	-	-	-	-	-
	SEP		148.25	-	-	-	-	-	-
	OCT		140.72	-	-	-	-	-	-
	NOV		126.87	-	-	-	-	-	-
	DEC		131.43	-	-	-	-	-	-
	JAN		-	99.73	-	-	-	-	-
	FEB		-	-	47.50	-	-	-	-
	MAR		125.31	-	-	-	-	-	-
	APR		95.49	-	-	-	-	-	-
	MAY		96.78	-	-	-	-	-	-
	JUN		122.58	-	-	-	-	-	-
	JUL		141.45	-	-	-	-	-	-
	TOTAL		1272.52	99.73	47.50	-	-	-	-

Values In The Above Table Are Expressed In Million m3

Table 45. (Cont'd)

Year	Month		Salinity Class						
		mmhos/cm	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5
		ppm	640-960	960-1280	1280-1600	1600-1920	1920-2240	2240-2560	2560-288
87/88	AUG		150.77	-	-	-	-	-	-
	SEP		144.43	-	-	-	-	-	-
	OCT		142.27	-	-	-	-	-	-
	NOV		-	130.82	-	-	-	-	-
	DEC		141.84	-	-	-	-	-	-
	JAN		-	107.80	-	-	-	-	-
	FEB		-	-	56.63	-	-	-	-
	MAR		113.98	-	-	-	-	-	-
	APR		-	83.05	-	-	-	-	-
	MAY		91.18	-	-	-	-	-	-
	JUN		96.56	-	-	-	-	-	-
	JUL		121.79	-	-	-	-	-	-
	TOTAL		1002.82	321.67	56.63	-	-	-	-
88/89	AUG		130.75	-	-	-	-	-	-
	SEP		166.19	-	-	-	-	-	-
	OCT		129.87	-	-	-	-	-	-
	NOV		-	109.90	-	-	-	-	-
	DEC		128.02	-	-	-	-	-	-
	JAN		-	104.69	-	-	-	-	-
	FEB		-	-	-	-	-	50.17	-
	MAR		-	126.45	-	-	-	-	-
	APR		-	85.38	-	-	-	-	-
	MAY		97.64	-	-	-	-	-	-
	JUN		106.77	-	-	-	-	-	-
	JUL		164.21	-	-	-	-	-	-
	TOTAL		923.44	426.41	-	-	-	50.17	-
89/90	AUG		-	-	162.26	-	-	-	-
	SEP		-	-	164.62	-	-	-	-
	OCT		-	-	-	118.00	-	-	-
	NOV		-	-	-	118.72	-	-	-
	DEC		-	-	-	112.96	-	-	-
	JAN		-	-	-	89.32	-	-	-
	FEB		-	-	-	-	-	-	-
	MAR		-	-	-	134.53	-	-	-
	APR		-	-	-	106.64	-	-	-
	MAY		-	-	130.05	-	-	-	-
	JUN		-	-	134.27	-	-	-	-
	JUL		-	-	162.66	-	-	-	-
	TOTAL		-	-	753.85	689.17	-	-	-

Values In The Above Table Are Expressed In Million m3

Table 46. Average monthly distribution of reused drainage water, by salinity class (East Delta).

Year	Month		Salinity Class						
		mmhos/cm	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5
		ppm	640-960	960-1280	1280-1600	1600-1920	1920-2240	2240-2560	2560-2880
AVG 84/87	AUG		147.71	-	-	-	-	-	-
	SEP		142.86	-	-	-	-	-	-
	OCT		127.59	-	-	-	-	-	-
	NOV		106.74	-	-	-	-	-	-
	DEC		108.43	-	-	-	-	-	-
	JAN		-	91.28	-	-	-	-	-
	FEB		-	-	49.87	-	-	-	-
	MAR		114.21	-	-	-	-	-	-
	APR		96.30	-	-	-	-	-	-
	MAY		99.38	-	-	-	-	-	-
	JUN		110.63	-	-	-	-	-	-
	JUL		132.69	-	-	-	-	-	-
	TOTAL		1186.54	91.28	49.87	-	-	-	-
AVG 87/90	AUG		-	147.92	-	-	-	-	-
	SEP		-	158.41	-	-	-	-	-
	OCT		-	130.05	-	-	-	-	-
	NOV		-	119.81	-	-	-	-	-
	DEC		-	127.61	-	-	-	-	-
	JAN		-	103.50	-	-	-	-	-
	FEB		-	-	-	-	-	55.78	-
	MAR		-	124.99	-	-	-	-	-
	APR		-	-	91.69	-	-	-	-
	MAY		-	106.29	-	-	-	-	-
	JUN		-	112.53	-	-	-	-	-
	JUL		-	149.56	-	-	-	-	-
	TOTAL		-	1280.77	91.69	-	-	55.78	-
AVG 84/90	AUG		-	147.82	-	-	-	-	-
	SEP		150.63	-	-	-	-	-	-
	OCT		-	128.82	-	-	-	-	-
	NOV		-	113.28	-	-	-	-	-
	DEC		-	118.02	-	-	-	-	-
	JAN		-	97.44	-	-	-	-	-
	FEB		-	-	-	-	52.83	-	-
	MAR		-	119.60	-	-	-	-	-
	APR		-	94.00	-	-	-	-	-
	MAY		102.84	-	-	-	-	-	-
	JUN		111.58	-	-	-	-	-	-
	JUL		-	141.12	-	-	-	-	-
	TOTAL		365.05	960.09	-	-	52.83	-	-

Values In The Above Table Are Expressed In Million m3

Table 47. Monthly distribution of drainage water to the sea, by salinity class (Middle Delta).

Year	Month		Salinity Class						
		mmhos/cm	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	> 5.0
		ppm	1280-1600	1600-1920	1920-2240	2240-2560	2560-2880	2880-3200	> 3200
	AUG		-	603.39	-	-	-	-	-
	SEP		-	585.92	-	-	-	-	-
	OCT		-	-	475.07	-	-	-	-
	NOV		-	-	419.69	-	-	-	-
	DEC		-	-	426.35	-	-	-	-
84/85	JAN		-	-	-	316.80	-	-	194.44
	FEB		-	-	-	-	-	-	-
	MAR		-	-	-	318.56	-	-	-
	APR		-	-	-	333.28	-	-	-
	MAY		-	-	339.99	-	-	-	-
	JUN		-	-	413.73	-	-	-	-
	JUL		-	586.11	-	-	-	-	-
	TOTAL		-	1775.42	2074.83	968.64	-	-	194.44
	AUG		-	-	507.42	-	-	-	-
	SEP		-	-	533.87	-	-	-	-
	OCT		-	-	443.65	-	-	-	-
	NOV		-	-	-	-	365.06	-	-
	DEC		-	-	-	392.95	-	-	-
85/86	JAN		-	-	-	-	326.32	-	-
	FEB		-	-	-	-	-	-	227.06
	MAR		-	-	358.07	-	-	-	-
	APR		-	-	-	389.71	-	-	-
	MAY		-	-	-	346.38	-	-	-
	JUN		-	-	407.61	-	-	-	-
	JUL		-	-	-	585.35	-	-	-
	TOTAL		-	-	2250.62	1714.39	691.38	-	227.06
	AUG		-	-	-	531.55	-	-	-
	SEP		-	-	564.32	-	-	-	-
	OCT		-	-	-	463.37	-	-	-
	NOV		-	-	-	431.04	-	-	-
	DEC		-	-	-	-	376.70	-	-
86/87	JAN		-	-	-	-	352.46	-	-
	FEB		-	-	-	-	-	-	181.90
	MAR		-	-	-	385.35	-	-	-
	APR		-	-	-	306.33	-	-	-
	MAY		-	-	-	310.73	-	-	-
	JUN		-	-	457.64	-	-	-	-
	JUL		-	-	538.21	-	-	-	-
	TOTAL		-	-	1560.17	2428.37	729.16	-	181.90

Values In The Above Table Are Expressed In Milion m3

Table 47. (Cont'd)

Year	Month	Salinity Class mmhos/cm: 2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	> 5.0
		ppm: 1280-1600	1600-1920	1920-2240	2240-2560	2560-2880	2880-3200	> 3200
87/88	AUG	-	-	468.04	-	-	-	-
	SEP	-	-	-	501.81	-	-	-
	OCT	-	-	470.93	-	-	-	-
	NOV	-	-	-	-	333.27	-	-
	DEC	-	-	-	-	425.47	-	-
	JAN	-	-	-	-	-	334.39	-
	FEB	-	-	-	-	-	-	200.25
	MAR	-	-	-	275.76	-	-	-
	APR	-	-	-	-	-	220.99	-
	MAY	-	-	-	243.51	-	-	-
	JUN	-	-	-	-	302.82	-	-
	JUL	-	-	513.96	-	-	-	-
	TOTAL	-	-	1452.93	1021.08	1061.56	555.38	200.25
88/89	AUG	-	-	-	439.83	-	-	-
	SEP	-	-	-	474.73	-	-	-
	OCT	-	-	-	383.10	-	-	-
	NOV	-	-	-	-	298.38	-	-
	DEC	-	-	409.35	-	-	-	-
	JAN	-	-	-	-	-	-	302.01
	FEB	-	-	-	-	-	-	119.70
	MAR	-	-	-	-	-	252.86	-
	APR	-	-	-	-	228.54	-	-
	MAY	-	-	-	-	227.27	-	-
	JUN	-	-	-	296.25	-	-	-
	JUL	-	-	619.52	-	-	-	-
	TOTAL	-	-	1028.87	1593.91	754.19	252.86	421.71
89/90	AUG	-	593.46	-	-	-	-	-
	SEP	-	-	511.80	-	-	-	-
	OCT	-	-	-	-	357.59	-	-
	NOV	-	-	-	-	324.47	-	-
	DEC	-	-	-	-	381.04	-	-
	JAN	-	-	-	-	-	367.70	-
	FEB	-	-	-	-	-	-	223.83
	MAR	-	-	-	350.04	-	-	-
	APR	-	-	-	315.81	-	-	-
	MAY	-	-	-	272.95	-	-	-
	JUN	-	-	-	429.05	-	-	-
	JUL	-	-	509.02	-	-	-	-
	TOTAL	-	593.46	1020.82	1367.84	1063.10	367.70	223.83

Values In The Above Table Are Expressed In Milion m3

Table 48. Average monthly distribution of drainage water to the sea, by salinity class (Middle Delta).

Year	Month		Salinity Class						
		mmhos/cm	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	> 5.0
		ppm	1280-1600	1600-1920	1920-2240	2240-2560	2560-2880	2880-3200	> 3200
AVG 84/87	AUG		-	-	547.45	-	-	-	-
	SEP		-	-	561.37	-	-	-	-
	OCT		-	-	460.70	-	-	-	-
	NOV		-	-	-	405.26	-	-	-
	DEC		-	-	-	398.67	-	-	-
	JAN		-	-	-	-	331.86	-	-
	FEB		-	-	-	-	-	-	201.13
	MAR		-	-	-	353.99	-	-	-
	APR		-	-	-	343.11	-	-	-
	MAY		-	-	-	332.37	-	-	-
	JUN		-	-	426.33	-	-	-	-
	JUL		-	-	569.89	-	-	-	-
	TOTAL		-	-	2565.74	1833.40	331.86	-	201.13
AVG 87/90	AUG		-	-	500.44	-	-	-	-
	SEP		-	-	-	496.11	-	-	-
	OCT		-	-	-	403.87	-	-	-
	NOV		-	-	-	-	318.71	-	-
	DEC		-	-	-	405.29	-	-	-
	JAN		-	-	-	-	-	334.70	-
	FEB		-	-	-	-	-	-	181.26
	MAR		-	-	-	-	292.86	-	-
	APR		-	-	-	-	255.11	-	-
	MAY		-	-	-	247.91	-	-	-
	JUN		-	-	-	342.71	-	-	-
	JUL		-	-	547.50	-	-	-	-
	TOTAL		-	-	1047.94	1895.89	866.71	334.70	181.26
AVG 84/90	AUG		-	-	523.95	-	-	-	-
	SEP		-	-	528.74	-	-	-	-
	OCT		-	-	-	432.29	-	-	-
	NOV		-	-	-	361.99	-	-	-
	DEC		-	-	-	401.98	-	-	-
	JAN		-	-	-	-	-	333.28	-
	FEB		-	-	-	-	-	-	191.20
	MAR		-	-	-	323.44	-	-	-
	APR		-	-	-	299.11	-	-	-
	MAY		-	-	-	290.14	-	-	-
	JUN		-	-	-	384.52	-	-	-
	JUL		-	-	558.69	-	-	-	-
	TOTAL		-	-	1611.38	2493.45	-	333.28	191.20

Values In The Above Table Are Expressed In Million m3

Table 49. Monthly distribution of reused drainage water, by salinity class (Middle Delta).

Year	Month		Salinity Class						
		mmhos/cm	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0
		ppm	320-640	640-960	960-1280	1280-1600	1600-1920	1920-2240	2240-2560
	AUG		-	69.17	-	-	-	-	-
	SEP		-	74.53	-	-	-	-	-
	OCT		-	51.50	-	-	-	-	-
	NOV		-	72.68	-	-	-	-	-
	DEC		69.24	-	-	-	-	-	-
84/85	JAN		-	64.30	-	-	-	-	-
	FEB		-	52.87	-	-	-	-	-
	MAR		-	59.47	-	-	-	-	-
	APR		-	65.33	-	-	-	-	-
	MAY		-	-	54.30	-	-	-	-
	JUN		-	57.19	-	-	-	-	-
	JUL		-	-	72.89	-	-	-	-
	TOTAL		69.24	567.04	127.19	-	-	-	-
	AUG		-	66.34	-	-	-	-	-
	SEP		-	65.72	-	-	-	-	-
	OCT		-	55.68	-	-	-	-	-
	NOV		-	68.16	-	-	-	-	-
	DEC		72.11	-	-	-	-	-	-
85/86	JAN		-	54.76	-	-	-	-	-
	FEB		-	25.22	-	-	-	-	-
	MAR		-	61.01	-	-	-	-	-
	APR		-	63.38	-	-	-	-	-
	MAY		-	66.65	-	-	-	-	-
	JUN		-	69.04	-	-	-	-	-
	JUL		-	78.57	-	-	-	-	-
	TOTAL		72.11	675.53	-	-	-	-	-
	AUG		-	68.07	-	-	-	-	-
	SEP		-	78.20	-	-	-	-	-
	OCT		-	47.42	-	-	-	-	-
	NOV		-	57.51	-	-	-	-	-
	DEC		-	51.97	-	-	-	-	-
86/87	JAN		-	65.17	-	-	-	-	-
	FEB		-	-	23.09	-	-	-	-
	MAR		-	62.43	-	-	-	-	-
	APR		-	60.18	-	-	-	-	-
	MAY		-	59.71	-	-	-	-	-
	JUN		-	75.77	-	-	-	-	-
	JUL		-	84.93	-	-	-	-	-
	TOTAL		-	711.36	23.09	-	-	-	-

Values In The Above Table Are Expressed In Million m3

Table 49. (Cont'd)

Year	Month		Salinity Class						
		mmhos/cm	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0
		ppm	320-640	640-960	960-1280	1280-1600	1920-2240	1920-2240	2240-256(
	AUG		-	62.57	-	-	-	-	-
	SEP		-	72.16	-	-	-	-	-
	OCT		-	44.07	-	-	-	-	-
	NOV		-	50.59	-	-	-	-	-
	DEC		-	57.59	-	-	-	-	-
87/88	JAN		-	82.24	-	-	-	-	-
	FEB		-	-	32.40	-	-	-	-
	MAR		-	64.09	-	-	-	-	-
	APR		-	-	40.26	-	-	-	-
	MAY		-	48.15	-	-	-		-
	JUN		-	-	52.19	-	-	-	-
	JUL		-	-	46.23	-	-	-	-
	TOTAL		-	481.46	171.08	-	-	-	-
	AUG		-	-	55.76	-	-	-	-
	SEP		-	66.13	-	-	-	-	-
	OCT		-	-	47.02	-	-	-	-
	NOV		-	46.60	-	-	-	-	-
	DEC		-	76.63	-	-	-	-	-
88/89	JAN		-	75.57	-	-	-	-	-
	FEB		-	-	36.14	-	-	-	-
	MAR		-	40.66	-	-	-	-	-
	APR		-	-	49.12	-	-	-	-
	MAY		-	-	47.32	-	-	-	-
	JUN		-	-	59.33	-	-	-	-
	JUL		-	76.00	-	-	-	-	-
	TOTAL		-	381.59	294.69	-	-	-	-
	AUG		-	84.93	-	-	-	-	-
	SEP		-	70.95	-	-	-	-	-
	OCT		-	-	41.63	-	-	-	-
	NOV		-	-	40.23	-	-	-	-
	DEC		-	58.62	-	-	-	-	-
89/90	JAN		-	-	65.73	-	-	-	-
	FEB		-	-	-	24.03	-	-	-
	MAR		-	-	38.77	-	-	-	-
	APR		-	-	-	103.69	-	-	-
	MAY		-	-	139.03	-	-	-	-
	JUN		-	-	167.93	-	-	-	-
	JUL		-	196.43	-	-	-	-	-
	TOTAL		-	410.93	493.32	127.72	-	-	-

Values In The Above Table Are Expressed In Milloin m3

Table 50. Average monthly distribution of reused drainage water, by salinity class (Middle Delta).

Year	Month	Salinity Class mmhos/cm / ppm	1.0-1.5 / 640-960	1.5-2.0 / 960-1280	2.0-2.5 / 1280-1600	2.5-3.0 / 1600-1920	3.0-3.5 / 1920-2240	3.5-4.0 / 2240-2560	4.0-4.5 / 2560-2880
AVG 84/87	AUG		67.86	-	-	-	-	-	-
	SEP		72.82	-	-	-	-	-	-
	OCT		51.53	-	-	-	-	-	-
	NOV		66.12	-	-	-	-	-	-
	DEC		64.44	-	-	-	-	-	-
	JAN		61.41	-	-	-	-	-	-
	FEB		34.06	-	-	-	-	-	-
	MAR		60.97	-	-	-	-	-	-
	APR		62.96	-	-	-	-	-	-
	MAY		60.22	-	-	-	-	-	-
	JUN		67.33	-	-	-	-	-	-
	JUL		78.80	-	-	-	-	-	-
	TOTAL		748.52	-	-	-	-	-	-
AVG 87/90	AUG		67.75	-	-	-	-	-	-
	SEP		69.75	-	-	-	-	-	-
	OCT		-	44.24	-	-	-	-	-
	NOV		45.81	-	-	-	-	-	-
	DEC		64.28	-	-	-	-	-	-
	JAN		74.51	-	-	-	-	-	-
	FEB		-	30.86	-	-	-	-	-
	MAR		47.84	-	-	-	-	-	-
	APR		-	64.36	-	-	-	-	-
	MAY		-	78.17	-	-	-	-	-
	JUN		-	93.15	-	-	-	-	-
	JUL		106.22	-	-	-	-	-	-
	TOTAL		476.16	310.77	-	-	-	-	-
AVG 84/90	AUG		67.81	-	-	-	-	-	-
	SEP		71.28	-	-	-	-	-	-
	OCT		47.89	-	-	-	-	-	-
	NOV		55.96	-	-	-	-	-	-
	DEC		64.36	-	-	-	-	-	-
	JAN		67.96	-	-	-	-	-	-
	FEB		-	32.46	-	-	-	-	-
	MAR		54.41	-	-	-	-	-	-
	APR		-	63.66	-	-	-	-	-
	MAY		69.19	-	-	-	-	-	-
	JUN		80.24	-	-	-	-	-	-
	JUL		92.51	-	-	-	-	-	-
	TOTAL		671.61	96.12	-	-	-	-	-

[illegible] The Above Table [illegible] Expressed In Million m3

Table 51. Monthly distribution of drainage water to the sea, by salinity class (West Delta).

Year	Month	Salinity Class							
		mmhos/cm	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	> 5.0
		ppm	1280-1600	1600-1920	1920-2240	2240-2560	2560-2880	2880-3200	> 3200
84/85	AUG		-	-	-	-	-	427.18	-
	SEP		-	-	-	-	-	428.40	-
	OCT		-	-	-	-	-	412.91	-
	NOV		-	-	-	-	356.26	-	-
	DEC		-	-	-	-	-	-	377.30
	JAN		-	-	-	-	-	-	325.50
	FEB		-	-	-	-	-	-	269.99
	MAR		-	-	-	-	-	-	326.88
	APR		-	-	-	-	-	-	318.35
	MAY		-	-	-	-	-	-	329.39
	JUN		-	-	-	-	-	-	353.18
	JUL		-	-	-	-	-	-	395.52
	TOTAL		-	-	-	-	356.26	1268.49	2696.11
85/86	AUG		-	-	-	-	-	422.82	-
	SEP		-	-	-	-	433.12	-	-
	OCT		-	-	-	-	-	-	461.60
	NOV		-	-	-	-	-	-	387.18
	DEC		-	-	-	-	-	401.67	-
	JAN		-	-	-	-	-	-	306.79
	FEB		-	-	-	-	-	-	215.80
	MAR		-	-	-	-	-	-	325.45
	APR		-	-	-	-	-	-	329.46
	MAY		-	-	-	-	-	321.99	-
	JUN		-	-	-	330.93	-	-	-
	JUL		-	-	-	402.12	-	-	-
	TOTAL		-	-	-	733.05	433.12	1146.48	2026.28
86/87	AUG		-	-	-	387.70	-	-	-
	SEP		-	-	-	418.61	-	-	-
	OCT		-	-	-	391.95	-	-	-
	NOV		-	-	-	-	-	340.13	-
	DEC		-	-	-	-	-	-	287.95
	JAN		-	-	-	-	-	-	265.93
	FEB		-	-	-	-	-	-	208.72
	MAR		-	-	-	-	-	-	317.81
	APR		-	-	-	-	-	-	270.99
	MAY		-	-	-	-	-	272.62	-
	JUN		-	-	-	-	-	357.32	-
	JUL		-	-	-	-	-	423.64	-
	TOTAL		-	-	-	1198.26	-	1393.71	1351.40

Values In The Above Table Are Expressed In Million m3

Table 51. (Cont'd)

Year	Month	Salinity Class							
		mmhos/cm	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	> 5.0
		ppm	1280-1600	1600-1920	1920-2240	2240-2560	2560-2880	2880-3200	> 3200
87/88	AUG		-	-	-	-	-	-	412.46
	SEP		-	-	-	-	-	-	406.15
	OCT		-	-	-	-	-	-	410.84
	NOV		-	-	-	-	-	-	330.70
	DEC		-	-	-	-	-	-	368.16
	JAN		-	-	-	-	-	-	335.92
	FEB		-	-	-	-	-	-	249.19
	MAR		-	-	-	-	-	-	255.86
	APR		-	-	-	-	-	-	192.43
	MAY		-	-	-	-	-	-	235.68
	JUN		-	-	-	-	-	-	281.07
	JUL		-	-	-	-	-	-	308.53
	TOTAL		-	-	-	-	-	-	3787.19
88/89	AUG		-	-	-	-	-	326.12	-
	SEP		-	-	-	-	-	-	355.25
	OCT		-	-	-	-	-	-	376.51
	NOV		-	-	-	-	-	-	287.40
	DEC		-	-	-	-	-	-	313.83
	JAN		-	-	-	-	-	-	307.62
	FEB		-	-	-	-	-	-	200.61
	MAR		-	-	-	-	-	-	292.58
	APR		-	-	-	-	-	-	210.19
	MAY		-	-	-	-	-	-	263.33
	JUN		-	-	-	-	-	-	261.32
	JUL		-	-	-	-	-	-	389.11
	TOTAL		-	-	-	-	-	326.12	3257.75
89/90	AUG		-	-	-	-	-	398.56	-
	SEP		-	-	-	-	333.37	-	-
	OCT		-	-	-	-	-	-	298.10
	NOV		-	-	-	-	-	-	283.68
	DEC		-	-	-	-	-	-	300.25
	JAN		-	-	-	-	-	-	314.62
	FEB		-	-	-	-	-	-	216.78
	MAR		-	-	-	-	-	-	242.07
	APR		-	-	-	-	-	-	232.87
	MAY		-	-	-	-	-	-	252.08
	JUN		-	-	-	-	-	-	289.57
	JUL		-	-	-	-	-	-	357.21
	TOTAL		-	-	-	-	333.37	398.56	2787.23

Values In The Above Table Are Expressed In Million m3

Table 52. Average monthly distribution of drainage water to the sea, by salinity class (West Delta).

Year	Month	Salinity Class							
		mmhos/cm	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	> 5.0
		ppm	1280-1600	1600-1920	1920-2240	2240-2560	2560-2880	2880-3200	> 3200
AVG 84/87	AUG		-	-	-	-	-	412.57	-
	SEP		-	-	-	-	426.71	-	-
	OCT		-	-	-	-	-	422.15	-
	NOV		-	-	-	-	-	361.19	-
	DEC		-	-	-	-	-	-	355.64
	JAN		-	-	-	-	-	-	299.41
	FEB		-	-	-	-	-	-	231.50
	MAR		-	-	-	-	-	-	323.38
	APR		-	-	-	-	-	-	306.27
	MAY		-	-	-	-	-	-	308.00
	JUN		-	-	-	-	-	347.14	-
	JUL		-	-	-	-	-	407.09	-
	TOTAL		-	-	-	-	426.71	1950.15	1824.20
AVG 87/90	AUG		-	-	-	-	-	379.05	-
	SEP		-	-	-	-	-	364.92	-
	OCT		-	-	-	-	-	-	361.82
	NOV		-	-	-	-	-	-	300.59
	DEC		-	-	-	-	-	-	327.41
	JAN		-	-	-	-	-	-	319.39
	FEB		-	-	-	-	-	-	222.19
	MAR		-	-	-	-	-	-	263.50
	APR		-	-	-	-	-	-	211.83
	MAY		-	-	-	-	-	-	250.43
	JUN		-	-	-	-	-	-	277.32
	JUL		-	-	-	-	-	-	351.62
	TOTAL		-	-	-	-	-	743.97	2886.10
AVG 84/90	AUG		-	-	-	-	-	395.81	-
	SEP		-	-	-	-	-	395.82	-
	OCT		-	-	-	-	-	-	391.99
	NOV		-	-	-	-	-	-	330.89
	DEC		-	-	-	-	-	-	341.53
	JAN		-	-	-	-	-	-	309.40
	FEB		-	-	-	-	-	-	226.85
	MAR		-	-	-	-	-	-	293.44
	APR		-	-	-	-	-	-	259.05
	MAY		-	-	-	-	-	-	279.22
	JUN		-	-	-	-	-	-	312.23
	JUL		-	-	-	-	-	379.36	-
	TOTAL		-	-	-	-	-	1170.98	2744.59

Values In The Above Table Are Expressed In Million m3

Table 53. Monthly distribution of reused drainage water, by salinity class (West Delta).

Year	Month		Salinity Class						
		mmhos/cm	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5
		ppm	640-960	960-1280	1280-1600	1600-1920	1920-2240	2240-2560	2560-2880
	AUG		84.01	-	-	-	-	-	-
	SEP		-	84.25	-	-	-	-	-
	OCT		86.65	-	-	-	-	-	-
	NOV		76.91	-	-	-	-	-	-
	DEC		-	76.44	-	-	-	-	-
84/85	JAN		43.46	-	-	-	-	-	-
	FEB		-	-	27.86	-	-	-	-
	MAR		-	65.39	-	-	-	-	-
	APR		-	60.57	-	-	-	-	-
	MAY		55.84	-	-	-	-	-	-
	JUN		73.20	-	-	-	-	-	-
	JUL		79.50	-	-	-	-	-	-
	TOTAL		499.57	286.65	27.86	-	-	-	-
	AUG		-	84.02	-	-	-	-	-
	SEP		-	84.84	-	-	-	-	-
	OCT		85.33	-	-	-	-	-	-
	NOV		-	72.21	-	-	-	-	-
	DEC		-	62.44	-	-	-	-	-
85/86	JAN		-	47.20	-	-	-	-	-
	FEB		25.47	-	-	-	-	-	-
	MAR		-	60.01	-	-	-	-	-
	APR		-	60.07	-	-	-	-	-
	MAY		57.23	-	-	-	-	-	-
	JUN		64.51	-	-	-	-	-	-
	JUL		75.07	-	-	-	-	-	-
	TOTAL		307.61	470.79	-	-	-	-	-
	AUG		77.49	-	-	-	-	-	-
	SEP		76.97	-	-	-	-	-	-
	OCT		87.13	-	-	-	-	-	-
	NOV		-	69.65	-	-	-	-	-
	DEC		-	64.31	-	-	-	-	-
86/87	JAN		-	-	-	55.55	-	-	-
	FEB		31.06	-	-	-	-	-	-
	MAR		-	-	61.81	-	-	-	-
	APR		61.84	-	-	-	-	-	-
	MAY		56.14	-	-	-	-	-	-
	JUN		67.86	-	-	-	-	-	-
	JUL		66.29	-	-	-	-	-	-
	TOTAL		524.78	133.96	61.81	55.55	-	-	-

Values In The Above Table Are Expressed In Million m3

Table 53. (Cont'd)

Year	Month		Salinity Class						
		mmhos/cm	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5
		ppm	640-960	960-1280	1280-1600	1600-1920	1920-2240	2240-2560	2560-2880
87/88	AUG		66.36	-	-	-	-	-	-
	SEP		70.96	-	-	-	-	-	-
	OCT		70.31	-	-	-	-	-	-
	NOV		-	59.77	-	-	-	-	-
	DEC		60.61	-	-	-	-	-	-
	JAN		-	35.58	-	-	-	-	-
	FEB		-	26.26	-	-	-	-	-
	MAR		-	-	44.24	-	-	-	-
	APR		-	35.82	-	-	-	-	-
	MAY		-	35.84	-	-	-	-	-
	JUN		-	43.86	-	-	-	-	-
	JUL		41.02	-	-	-	-	-	-
	TOTAL		309.26	237.23	44.24	-	-	-	-
88/89	AUG		-	50.31	-	-	-	-	-
	SEP		-	53.48	-	-	-	-	-
	OCT		-	55.08	-	-	-	-	-
	NOV		-	45.02	-	-	-	-	-
	DEC		-	51.81	-	-	-	-	-
	JAN		-	38.25	-	-	-	-	-
	FEB		-	-	11.21	-	-	-	-
	MAR		-	41.65	-	-	-	-	-
	APR		-	38.56	-	-	-	-	-
	MAY		40.69	-	-	-	-	-	-
	JUN		43.55	-	-	-	-	-	-
	JUL		48.97	-	-	-	-	-	-
	TOTAL		133.21	374.16	11.21	-	-	-	-
89/90	AUG		-	55.09	-	-	-	-	-
	SEP		65.72	-	-	-	-	-	-
	OCT		-	61.43	-	-	-	-	-
	NOV		53.52	-	-	-	-	-	-
	DEC		48.88	-	-	-	-	-	-
	JAN		33.53	-	-	-	-	-	-
	FEB		13.25	-	-	-	-	-	-
	MAR		-	43.25	-	-	-	-	-
	APR		-	47.99	-	-	-	-	-
	MAY		-	47.12	-	-	-	-	-
	JUN		-	50.31	-	-	-	-	-
	JUL		59.79	-	-	-	-	-	-
	TOTAL		274.66	305.19	-	-	-	-	-

Values In The Above Table Are Expressed In Million m3

Table 54. Average monthly distribution of reused drainage water, by salinity class (West Delta).

Year	Month	Salinity Class						
		mmhos/cm 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5
		ppm 640-960	960-1280	1280-1600	1600-1920	1920-2240	2240-2560	2560-2880
AVG 84/87	AUG	81.84	-	-	-	-	-	-
	SEP	82.02	-	-	-	-	-	-
	OCT	86.37	-	-	-	-	-	-
	NOV	72.92	-	-	-	-	-	-
	DEC	-	67.73	-	-	-	-	-
	JAN	-	-	-	-	-	-	-
	FEB	-	28.13	48.74	-	-	-	-
	MAR	-	62.40	-	-	-	-	-
	APR	-	60.83	-	-	-	-	-
	MAY	56.40	-	-	-	-	-	-
	JUN	68.52	-	-	-	-	-	-
	JUL	73.62	-	-	-	-	-	-
	TOTAL	521.70	219.09	48.74	-	-	-	-
AVG 87/90	AUG	57.25	-	-	-	-	-	-
	SEP	-	63.39	-	-	-	-	-
	OCT	62.27	-	-	-	-	-	-
	NOV	-	52.77	-	-	-	-	-
	DEC	53.77	-	-	-	-	-	-
	JAN	35.79	-	-	-	-	-	-
	FEB	-	16.91	-	-	-	55.78	-
	MAR	-	43.05	-	-	-	-	-
	APR	-	40.79	-	-	-	-	-
	MAY	-	41.25	-	-	-	-	-
	JUN	45.91	-	-	-	-	-	-
	JUL	49.92	-	-	-	-	-	-
	TOTAL	304.90	258.15	-	-	-	55.78	-
AVG 84/90	AUG	69.55	-	-	-	-	-	-
	SEP	72.70	-	-	-	-	-	-
	OCT	74.32	-	-	-	-	-	-
	NOV	-	62.85	-	-	-	-	-
	DEC	-	60.75	-	-	-	-	-
	JAN	-	42.26	-	-	-	-	-
	FEB	-	22.52	-	-	-	-	-
	MAR	-	52.73	-	-	-	-	-
	APR	-	50.81	-	-	-	-	-
	MAY	48.83	-	-	-	-	-	-
	JUN	57.22	-	-	-	-	-	-
	JUL	61.77	-	-	-	-	-	-
	TOTAL	384.38	291.91	-	-	-	-	-

Values in [illegible]

Pollution of drainage water

Sometimes, waste generated domestically or industrially in villages or towns finds its way to open drains. Therefore, the drainage water in certain locations is highly polluted (e.g., Bahr El Baquar main drain).

Simple tests, such as biological oxygen demand, chemical oxygen demand, and some microbiological examinations, have been done by the Drainage Research Institute to ascertain the type of pollutants and their incidence in drainage water. Table 55 shows the sources and degree of pollution in some locations in the Nile Delta.

Table 55. Results of some pollution examinations.

Location	Source of pollution	NH_4 (mg/l)	NO_3 (mg/l)	BOD bacteria (mg/l)	COD (mg/l)	Total coliform (per 100 ml)
East Delta						
Belbeis Drain	Sewage + industry	3.9	45.0	-	-	-
Wadi P.S.	Sewage	3.9	49.0	50	336	11×10^6
Bahr El Baquar	Sewage	3.7	46.5	160	952	24×10^6
Nizam P.S.		2.6	31.0	100	660	24×10^6
Middle Delta						
Segaia P.S.	Textile industry + sewage	1.2	13.0	50	336	24×10^5
Sematay P.S.	Textile industry + sewage	3.0	30.0	-	-	-
P.S No. 5	Textile industry + sewage	2.7	29.0	-	-	-
Hamoul Bridge	Textile industry + sewage	1.2	11.8	-	-	-
Drain 1	*Fertilizer industry*	1.2	13.0	-	-	-
West Delta						
Etay Baroud P.S.	Sewage effluent	-	-	85	542	24×10^6
Khandak P.S.	Sewage effluent	-	-	70	282	43×10^5
Khairy P.S.	Sewage effluent	1.6	22.0	-	-	-
Tabia P.S.	Sewage + industry	2.6	32.0	30	56	24×10^3
Dushudi P.S.	Sewage	1.2	11.8	40	56	15×10^3
Max P.S.	Oil industry	2.8	28.0	80	306	23×10^5
Qalaa P.S.	Sewage	-	-	-	-	-

Groundwater Quality

General outline

Hydrogeological information for the Nile Delta is contained in a map prepared by RIGW (1988) and is available mainly through the WRDB for the Quaternary aquifer, and to some extent for the Tertiary aquifer.

The observation wells of the Research Institute for Groundwater (RIGW) are sampled and analyzed regularly for major ions and TDS by the RIGW laboratory. Results used in the compilation of the map refer mainly to 1991. Additional information on quality was obtained from production wells. Screens of sampled wells are located generally in the upper part of the water-bearing zone, usually not deeper than 150 m below the surface.

Distribution of salinity

Salinity is presented as TDS and is indicated on the hydrogeological map by isosalinity lines of 1,000 ppm and 10,000 ppm (Fig. 33). Fresh groundwater (TDS less than 1,000 ppm) is found in the central and southern Nile Delta in the Nile Delta aquifer and in the eastern-most part of the Moghra aquifer, adjacent to the Nile Delta (Wadi El Farigh). In the Nile Delta aquifer, local areas of higher salinity are found. In these pockets the TDS is generally between 1,000 and 5,000 ppm. The increased salinity may be caused by different processes, such as the presence of (salty) clay layers (east and west desert fringes of the Nile Delta) or the rising of deeper saline water due to over-extraction (Ramsis project). In desert areas, the return of flow of excess irrigation water may also result in increased salinity.

Within the Nile Delta aquifer, salinity increases to the north. North of the 31° 15' N latitude the salinity is in excess of 10,000 ppm. It is known that within this aquifer a sharp interface exists between fresh and saline water. The interface is found near the surface at Kafr El Sheikh and is located at approximately 300 m below the surface near Tanta (Fig. 34). The presence of saline water is in the northern part of the subsurface intrusion of seawater.

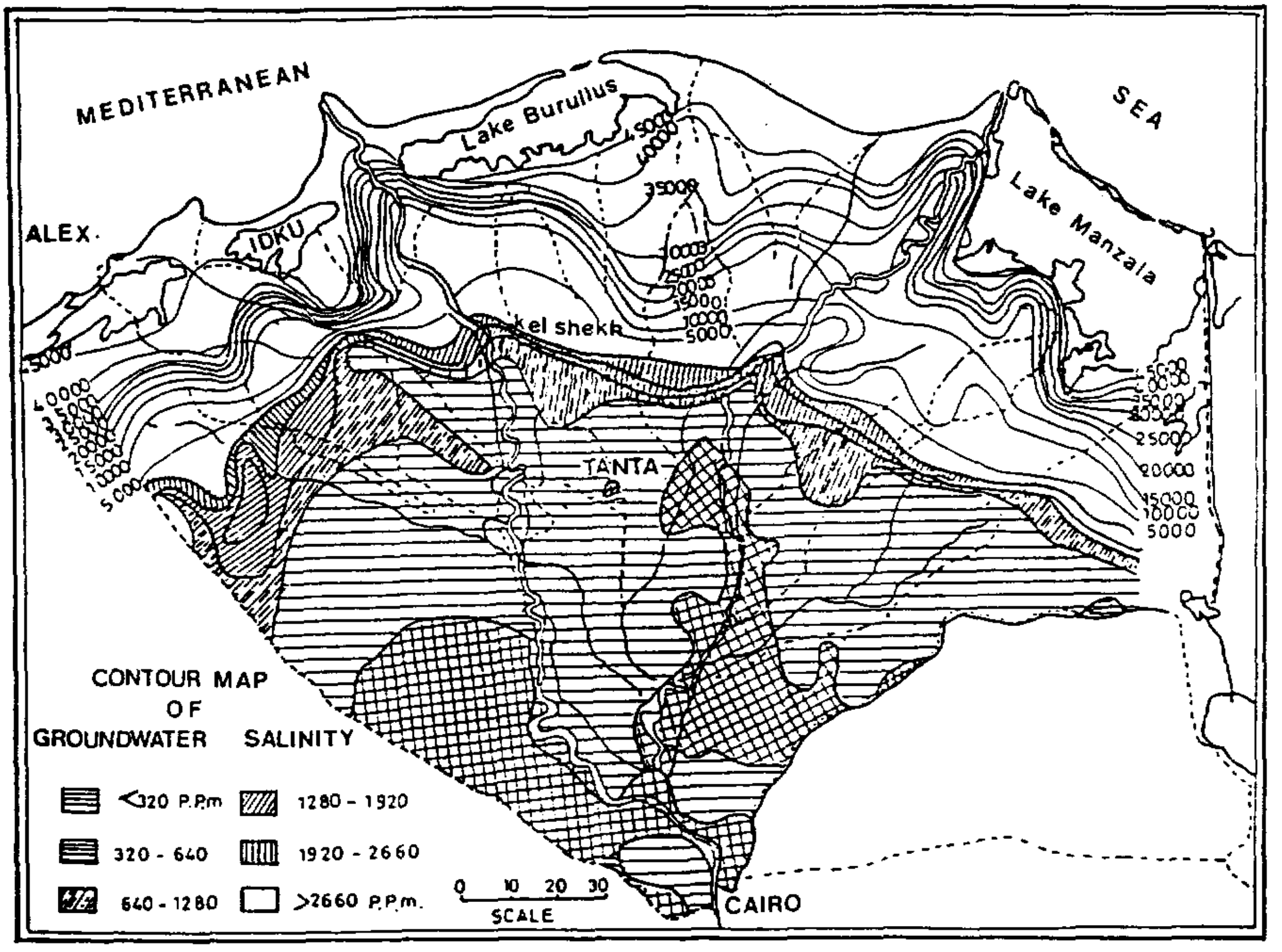


Fig. 33. Groundwater salinity map of the Delta.

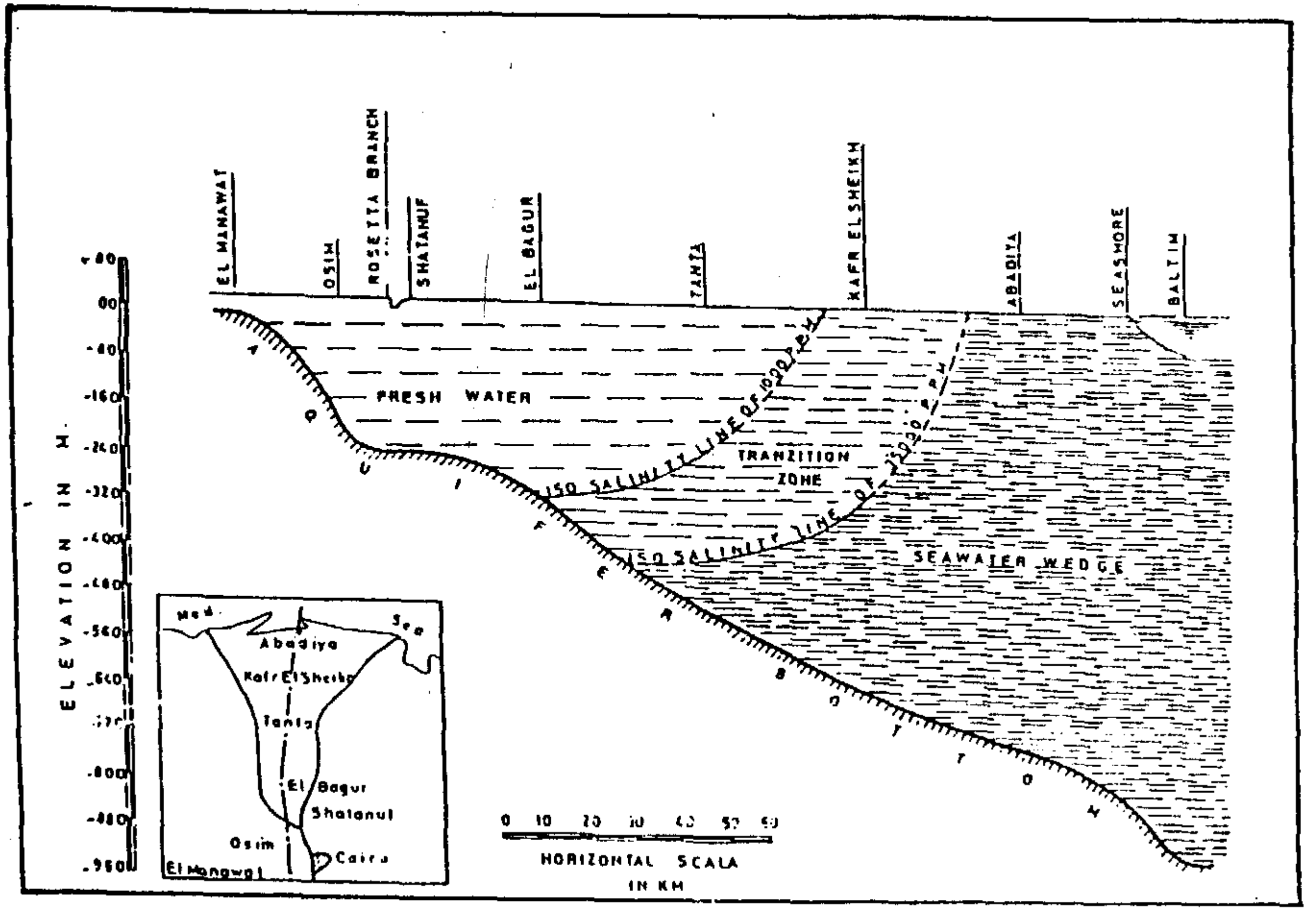


Fig. 34. Seawater intrusion in the Delta aquifer.

An increase in salinity within the Nile Delta aquifer is also found to the west and east. Generally, groundwater salinity exceeds 5,000 ppm outside the Nile Delta border. The increase is due to the limited recharge of water from the aquifer in the desert fringe. The inflow of brackish water from the Tertiary aquifers may also play a role. In the Sinai the groundwater is saline, but local brackish water is found in small quantities in shallow dug wells.

As for the Tertiary Maghra aquifer, salinity increases from very low in Wadi El Farigh to high in the north and west. In the desert of Wadi El Natroun, groundwater quality data are scarce.

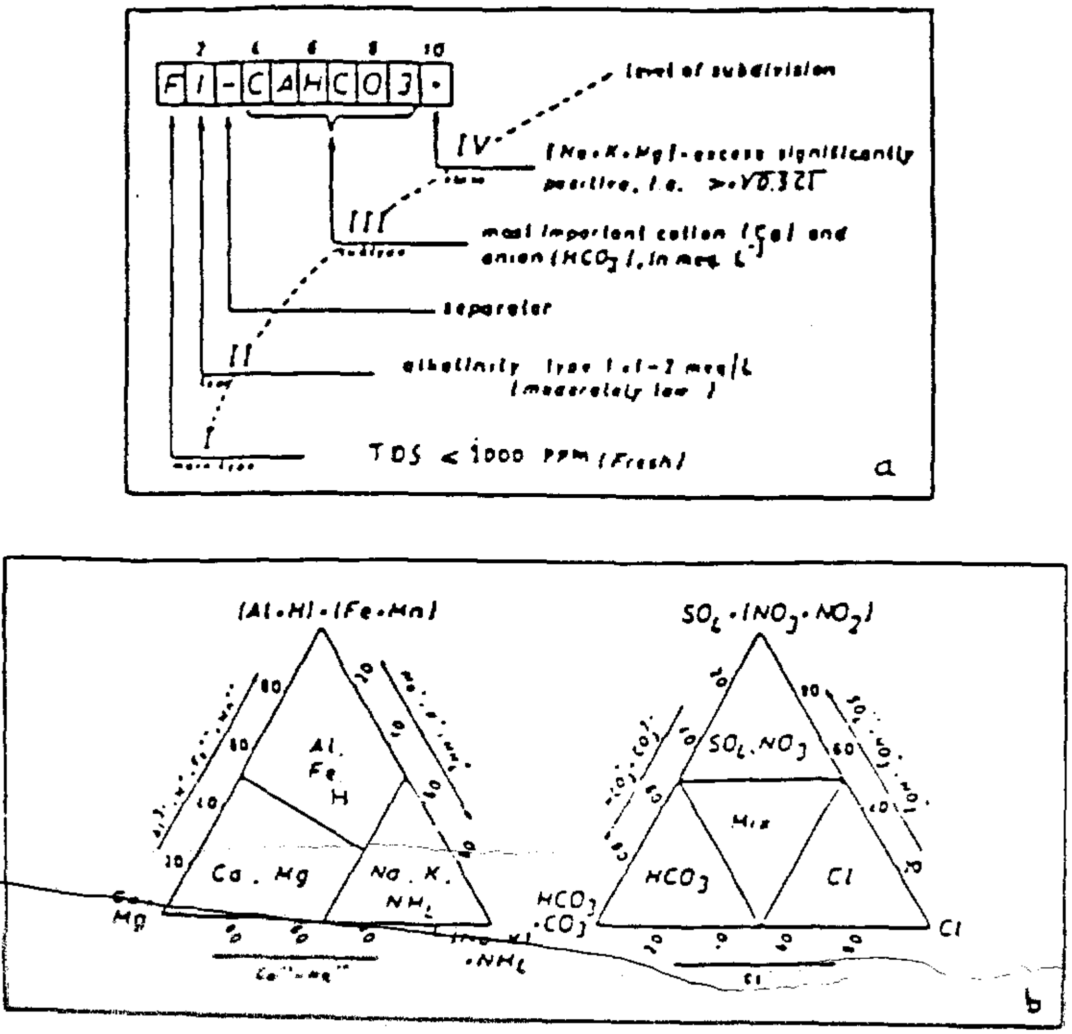
The Tertiary aquifer has low productivity and generally brackish or saline water, with the exception of the Wadi El Natroun aquifer. Local fresh water may be found here, mostly due to the increased recharge caused by reclamation and the use of fresh surface water. Fresh water is also reported from the Oligocene period in the Habashi soil (Sinai) at a depth of 600 m below the surface. This water is confined and probably in contact with a deeper aquifer (Nubian Sandstone complex).

Hydrochemical zonation

The available analyses of groundwater samples have been classified according to a modified version of the Stuyfzand method, which classifies the cation exchange resulting from mixing fresh and saline water.

In the classification as proposed, the water type is determined on the basis of salinity, alkalinity, the most important cation and anion and the [Na + K = Mg] content, corrected for seawater contribution zonation (Fig. 35). In Egypt, salinity and alkalinity have not been used to determine the groundwater type. Therefore, the groundwater type is determined only by the main cation and anion and the [Na+K+Mg] surplus or [Na+K+Mg] deficit. In order to determine the most important cation or anion, the Stuyfzand classification divides the cations and anions into families. Important families are [Ca+Mg] and [$Na+K+NH_4$] for cations and [HCO_3+CO_3], [$SO_4+NO_3+NO_2$], and [Cl] for anions.

Every sample is attributed to one of three classes, indicated by "+", "0", or "–", designating respectively a [Na+K+Mg] surplus, equilibrium, or deficit relative to seawater. A deficit implies seawater intrusion, whereas a surplus is caused by fresh-water encroachment of the aquifer.



(a) Structure of the classification system (Stuyfzand, 1988)
(b) Subdivision in subtype

Fig. 35. Stuyfzand classification.

The results of the chemical classification of the available groundwater samples are summarized as follows:

In the south part of the Nile Delta (Pleistocene and Moghra aquifers), fresh $[Ca\text{-}HCO_3]^+$ and $[Mg\text{-}HCO_3]^+$ groundwater types are found. Both the main cation and anion and the "+" indicate a refreshing of the groundwater taking place. This is caused by the continuous recharge of the aquifer by excess irrigation water.

To the northwest, north, and east of this zone and near Wadi El Natroun, a zone with fresh, sometimes brackish $[Na\text{-}HCO_3]^+$ and $[Na\text{-}mix]^+$ *water is present.*

Refreshing of the aquifer is taking place, because the groundwater belongs to the "+" class of water. The fresh water encroachment is caused by the downward seepage of irrigation water; the fact that Ca^{+2} and Mg^{+2} cations are restored indicates that the aquifer is less flushed than the southern part of the Delta.

More to the north and also to the east, Na^-Cl^+ and Na^-Cl^- type groundwater is found. In this zone the groundwater is brackish to saline, but to some extent the aquifer is still flushed by fresh water.

Only near the coast a Na^-Cl^- water type is found, indicating that fresh water is being replaced by seawater (seawater intrusion). East of Cairo this type of water is also found, suggesting that the saline water in the Tertiary aquifer is being recharged from deeper aquifers.

Suitability of groundwater for irrigation

The suitability of groundwater for irrigation depends on a combination of soil type and groundwater quality. Table 56 shows the suitability criteria for use of groundwater for irrigation on sandy soils (from RIGW/IWACO, 1988). For irrigation on clayey soils, different criteria apply.

Table 56. Guidelines for the interpretation of water quality for irrigation in reclaimed desert areas with sandy soil (from RIGW/IWACO, 1988, modified from FAO, 1985).

Potential	Degree of restriction in use		
	None	Slight to moderate	Severe
Salinity†			
TDS (ppm)	< 2,000	2,000–3,000	> 3,000
Specific toxicity sodium‡			
Drip irrigation (ppm)	< 100	100–350	> 350
Sprinkler irrigation (ppm)	< 70	> 70	
Chloride‡			
Drip irrigation (ppm)	< 180	180–500	> 500
Sprinkler irrigation (ppm)	< 110	>110	
Miscellaneous			
Nitrogen (ppm)§	< 5	5–30	> 30
Bicarbonate (ppm)¶	< 100	100–500	> 500

† Leaching fraction is 0.2.
‡ Most tree crops are sensitive to sodium and chloride; most annual crops are not sensitive.
§ As nitrate or ammonium.
¶ Applies only for overhead sprinkling.

Under normal irrigation practices and conditions, no problems are expected using water of the "no restriction" category. For water of the "slight to moderate restriction" category, careful crop selection, and special management practices are required. Such management should include the irrigation method, leaching or drainage practices, in addition to the use of soil and water amendments. It is worth mentioning that the concentration of Na is the restricting factor.

Sewage and Industrial Effluent

Valuable information was presented in six volumes on the use of industrial and sewage water (ASRT, 1990). The reports were presented at the National Conference on the Role of Technical Research and Water Use. The conference was held under the supervision of the Academy of Scientific Research and Technology (ASRT) in September 1990 (Tables 57 and 58).

Table 57. Acceptable limits of heavy metal content in sewage and industrial effluent to be used for irrigation.

Element	Symbol	ppm		
		Continuous irrigation	Use of 1 m/yr	Use of 3 m/yr
Aluminum	Al	5.00	20	8
Zirconium	Zr	0.10	2	8
Boron	B	0.75	1–10	2
Calcium	Ca	0.01	0.05	0.02
Chromium	Cr	0.10	1	0.4
Cobalt	Co	0.05	5	2
Copper	Cu	0.2	5	2
Flourine	F	1.00	15	6
Francium	Fr	5.00	20	8
Lead	Pb	5.00	10	4
Manganese	Mn	0.20	10	4
Molybdenum	Mo	0.01	0.05	0.8
Selenium	Se	0.02	0.02	0.02
Nickel	Ni	0.20	2.0	0.8
Zinc	Zn	2.00	10	4

Table 58. Water quality standard of sewage water to be used for irrigation (Law No. 93, year 1962).

Item	Sandy Soil	Clay Soil
pH	6–9	6–9
Sediment rate	1 cm/L/hour	1 cm/L/hour
Sulfide	5 ppm	0.1 ppm
Oil and grease	20 ppm	5.0 ppm
BOD		80 ppm
COD		50 ppm
Suspended materials		80 ppm

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