Drainage Research Institute

معهد بحوث الصرف

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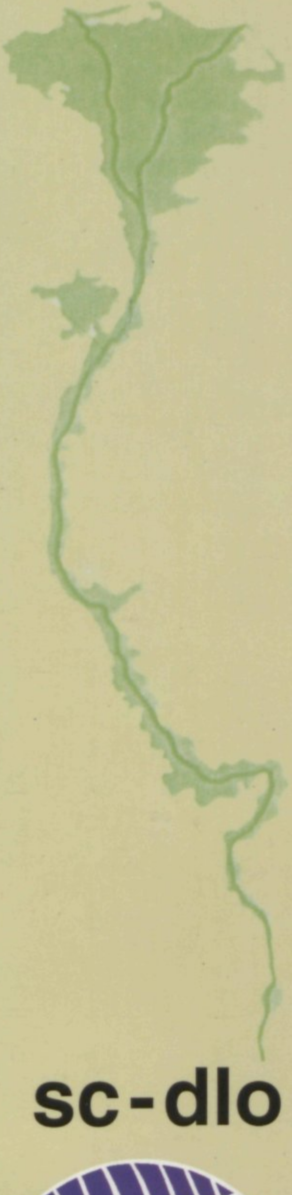
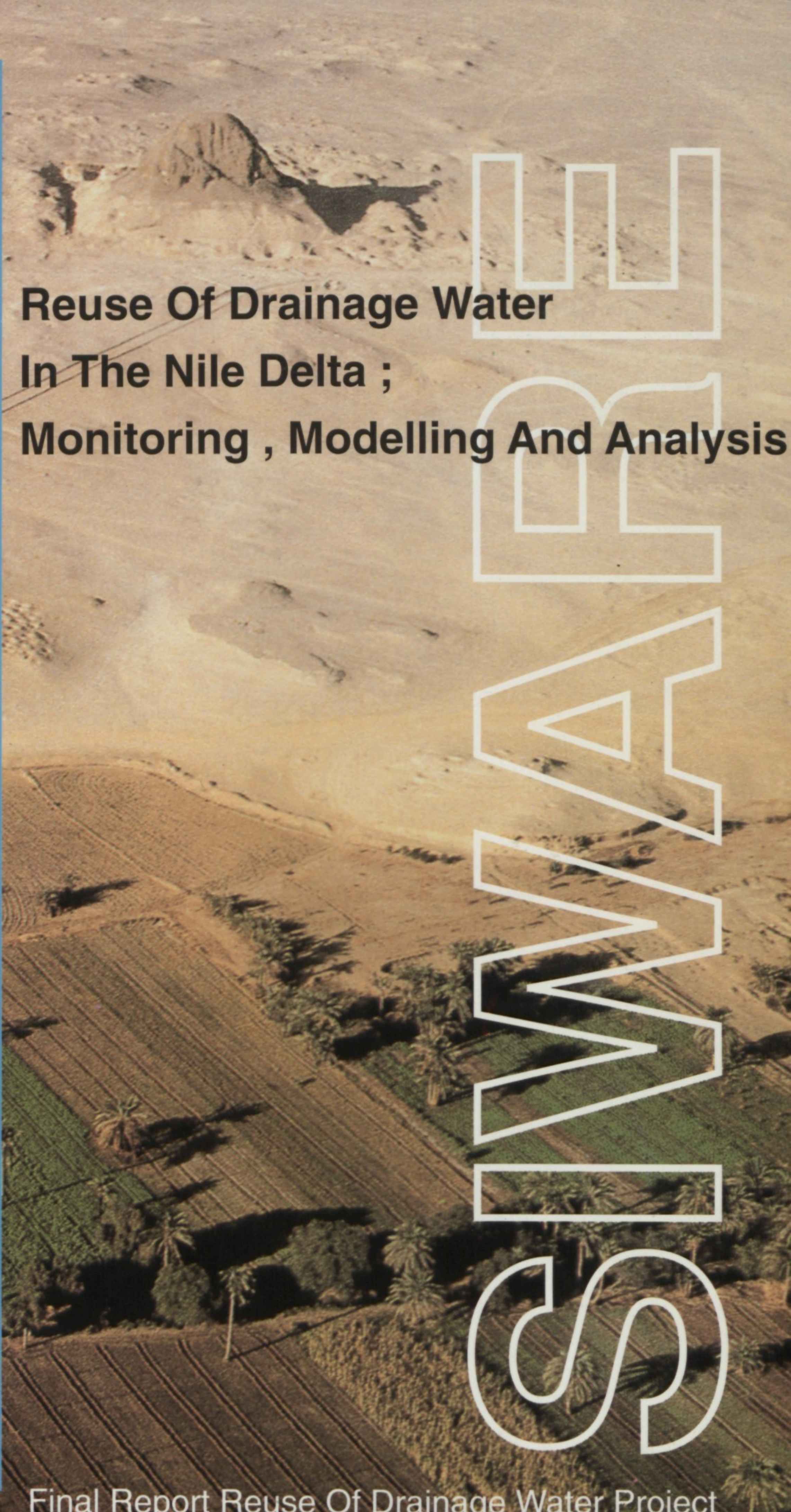


Reuse Of Drainage Water In The Nile Delta ; Monitoring , Modelling And Analysis



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Reuse Report 50, 1995

Final Report Reuse Of Drainage Water Project

Reuse of drainage water in the Nile Delta; Monitoring, modelling and analysis

Final Report Reuse of Drainage Water Project

Reuse Report 50, 1995

Drainage Research Institute, Kanater, Cairo (Egypt)
DLO Winand Staring Centre, Wageningen (The Netherlands)

CIP-DATA KONINKLIJKE BIBLIOTHEEK, DEN HAAG

Reuse

Reuse of drainage water in the Nile Delta; monitoring, modelling and analysis; final report Reuse of Drainage Water Project / Drainage Research Institute, DLO Winand Staring Centre. – Cairo: Drainage Research Institute; Wageningen: DLO Winand Staring Centre – Ill – (Reuse Report 50)
ISBN 90-327-0259-9
Subject headings: water distribution/water allocation/evapotranspiration

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Project 8576 [004 F]

Foreword

It is with great pleasure, after all these years of hard work, to present the final products and achievements of the Reuse of Drainage Water Project (RDWP). The Drainage Research Institute and the DLO Winand Staring Centre have finally reaped the fruits of more than ten years of cooperation by achieving the objectives of the RDWP. A well-established monitoring network is now functioning in the Nile Delta, providing valuable data on drainage water discharges and salinities. A summary of these data is regularly published in annual reports. The water management simulation model SIWARE is fully operational as well and we hope that it will prove to be a powerful tool for evaluating regional and national water policies in Egypt (and probably elsewhere) for a long time to come. For us, it has clearly demonstrated its capabilities and the prospects are good that it will be used in the Ministry of Public Work and Water Resources (MPWWR) of Egypt as well.

We would like to thank all those who participated directly and indirectly in making this achievement a reality. A special vote of thanks should be made towards the officials and engineers of the Irrigation and Planning Sectors and the National Research Center of the MPWWR. Without their assistance and guidance the achievement would not have been possible. We also appreciate the unlimited support of the Directorate-General for International Cooperation in the Netherlands and the Royal Netherlands Embassy in Cairo. Their understanding and appreciation were the real driving forces behind the whole project.

Finally, the Project Team deserves congratulations and thanks for patiently and consistently working on such a massive job which will remain as a landmark for technical cooperation between Egypt and the Netherlands.

Safwat Abdel Dayem	G.A. Oosterbaan
Director	Director
Drainage Research Institute	DLO Winand Staring Centre

March 31st, 1995

Abstract

DRI/SC-DLO. 1995. Reuse of drainage water in the Nile Delta; monitoring, modelling and analysis; final report Reuse of Drainage Water Project. 1995. Egypt, Kanater-Cairo, Drainage Research Institute; The Netherlands, Wageningen, DLO Winand Staring Centre. Reuse Report 50. 76 p.; 20 Figs.; 10 Tables; 2 Appendixes.

The growing population in Egypt in conjunction with its expanding agriculture and economical development require increasing amounts of water. The Nile water supply which is Egypt's most significant source of water, is not expected to increase in volume in the near future. Reuse of drainage water for irrigation has been adopted for many years now as an economically attractive means to increase the utilization rate of water, placing Egypt's irrigation system on the top of the world's list of efficient large-scale systems. In order to develop the necessary tools for safe and sustainable reuse of drainage water in irrigation, the Reuse of Drainage Water Project (RDWP) Phase I was executed from 1983-1988 and RDWP Phase II from 1991-1995.

The results of the two phases are an operational network for monitoring drainage water discharges and salinities on a routine basis at strategic locations along the major drains, a comprehensive database for monitored drainage water discharges and chemical composition, and a complete series of data yearbooks. For the evaluation of the potentials for reuse of drainage water in irrigation, the project has developed a mathematical model. This model provides the possibility to simulate Nile water allocation and distribution, including all system losses, the evolution of the horizontal and vertical distribution of soil salinity, the recharge and discharge of the groundwater system, the spatially distributed evapotranspiration of major crops, the unofficial reuse of drainage water for irrigation, the discharge rates and salinities at strategic locations along the drainage canals, and the available amounts of water in the drainage canals for reuse in irrigation. Input data, which are stored on files and in databases, cover irrigation and drainage canal system management, domestic and industrial water use, cultivated areas, drain depths and spacing, current and historical cropping patterns and crop growth development in the Nile Delta, soil types, soil characteristics and soil salinity.

The model is calibrated and validated for the Nile Delta and applied to evaluate a large number of different water management alternatives related to different water saving options and effects of land reclamation in the Eastern, Middle, and Western Nile Delta and adjacent desert regions. A version of the model, embedded in a graphical user interface, has been transferred to the Egyptian Ministry of Public Works and Water Resources for application in annual water allocation planning. The original version, embedded in an expert user interface, is the joint property of DRI and SC-DLO and is operational on DRI's integrated computer system for complex applications.

Key words: irrigation, drainage, reuse, database, model, water allocation, water distribution, water salinity, evapotranspiration, soil salinity, water management, planning, alternatives, water savings, land reclamation, user interface.

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Preface

The `Reuse of Drainage Water Project' is a cooperative venture of two technical agencies: the Drainage Research Institute (DRI) of the National Water Research Center, Kanater, Cairo, Egypt, and the DLO Winand Staring Centre (SC-DLO), Wageningen, The Netherlands.
The project is funded by the Ministry of Public Works and Water Resources of Egypt and by the Ministry of Foreign Affairs of the Netherlands in the framework of the joint programme of Technical Cooperation between Egypt and the Netherlands.

A Monitoring Committee has been appointed to review and evaluate the project activities. The members of this committee are:

Dr. B.B. Attia	*Ministry of Public Works and Water Resources, Egypt*
Eng. H.I. El-Atfy	*Drainage Research Institute, Egypt*
Dr. E.H. Imam	*Cairo University, Egypt*
Eng. M.Q. Nadar	*Ministry of Public Works and Water Resources, Egypt*
Ir. J.W. Wesseling	*Delft Hydraulics, The Netherlands*
Prof. Dr. J. Leentvaar	*Institute for Inland Water Management and Waste Water Treatment (RIZA), The Netherlands*

The Project Team during Phase II of the project consisted of the following members:

Drainage Research Institute (DRI)

Dr. Safwat Abdel Dayem	Director DRI, Project Director
Dr. Shaden Abdel Gawad	Deputy Director DRI, Project Coordinator

Reuse Modelling Team

Dr. Mohamed Abdel Khalek	Senior Staff Member
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Eng. Akram El Ganzouri	Staff Member
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Eng. Essam Khalifa	Staff Member (on leave since January 1994)
Eng. Amro El Shafie	Staff Member
Eng. Rasha El-Kholy	Staff Member

Reuse Monitoring Team

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Eng. Ashraf El-Sayed	Staff Member
Eng. Magdi Abdel Nabbi	Staff Member
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Eng. Mona Salah Mohamed	Staff Member
Eng. Madiha Ali	Staff Member

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Dr. P.E. Rijtema	Head of Environmental Protection Division (Project Director)
Ir. D. Boels	Head of Soil Conservation & Technology Department (Advisor Regional and National Water Management)
Ir. C.W.J. Roest	Head of Regional Environmental Impact Studies Department (Project Coordinator)
Ir. A.A.M.F.R. Smit	Resident Engineer, Egypt
Ir. T.N.M. Visser	Staff Member, Regional Environmental Impact Studies Department (Assistant Advisor Water Management)

The results of studies carried out in the Reuse of Drainage Water Project have been presented in preliminary reports and in this final report. The contents of the preliminary reports vary considerably, from a simple presentation of data to a discussion of research results with tentative conclusions.

All views, conclusions and recommendations expressed in the reports are those of the cooperating Institutes, and do not represent any official views of the Ministry of Public Works and Water Resources of Egypt, or the Ministry of Foreign Affairs of the Netherlands.

Summary

Background and objectives

To date Egypt has one of the world's most efficient large-scale irrigation systems, although there are opportunities for further improving its efficiency. In 1994, the cultivated area amounted to 7.4 million feddans and the Government of Egypt has adopted the horizontal expansion of cultivated lands as a major policy to increase crop production and create new job opportunities. It is planned to reclaim about 2.9 million additional feddans by the year 2000.

Developing industry, expanding agriculture and the growing population in Egypt require continuously increasing amounts of water. An annual Nile water supply of $55.5 \cdot 10^9$ m^3 is Egypt's almost exclusive source of fresh water. This supply is not expected to increase in the near future. The annual demand for water is estimated to reach $61.5 \cdot 10^9$ m^3 in year 2025, which can no longer be met by developing new water resources. Hence, increasing the efficiency of use presents itself as the only alternative to satisfy such requirements. Reuse of agricultural drainage water is an attractive solution from an economic point of view.

The Reuse of Drainage Water Project (RDWP) was established in 1983 to furnish the responsible authorities with information about the potentials for reuse of drainage water in irrigation and to quantify the effects of water management alternatives with different quantities of recycled drainage water. Although the primary aim of the project was to provide assistance to the Ministry of Public Works and Water Resources (MPWWR) in the planning and management of water resources, results of the project could also be used in Egypt by other Ministries and authorities.

The RDWP has been implemented in two phases. The first phase started in 1983 and terminated in 1988, the second phase started in 1991 and terminated in 1995. The project has been jointly executed by a cooperative venture of the Drainage Research Institute, Cairo, Egypt and the DLO Winand Staring Centre, Wageningen, the Netherlands.

In 1994, Egypt's cultivated area amounted to 7.4 million feddans

Achievements

The RDWP succeeded in establishing a comprehensive monitoring system along all major drains in the Nile Delta, including all facilities for collecting, processing, and reporting the gathered data. The project has also succeeded in developing and applying an integrated mathematical simulation model covering all major components of the water and salt cycle in delta areas under intensive agriculture. The model makes it possible to predict the short-term and long-term effects of various water management alternatives on such parameters as crop productivity, soil salinity, and drain discharges. Just as important as the availability of the physical outputs of the project is the development of human resources in the form of a well-trained project team capable of maintaining and upgrading the measurement network and providing necessary support for future model development and applications.

Monitoring programme

The drainage system in the Nile Delta is rather extensive serving 4.7 million feddans of the total 7.4 million feddans of agricultural land in Egypt. Drainage water from 22 drainage catchments flows by gravity to main open drains where it either discharges to the Northern Lakes and Mediterranean Sea, or is pumped by 21 reuse pump stations into irrigation canals, mixed with fresh Nile water and reused for irrigation. The total length of the main drains in the Nile Delta is about 1600 km.

In 1977 the Drainage Research Institute (DRI) started to collect on a monthly basis samples from about 47 sites located along the drains and drainage pump stations spread over the Delta. The open drainage system was surveyed in 1980 and a permanent network for routine monitoring was identified. Since the start of the RDWP in 1983, the network has been continuously maintained and upgraded to provide reliable measurements following standard methods and procedures. The current monitoring network consists of 80 measuring stations. Operation time counters, level gauges and EC (electrical conductivity) meters were installed at the pump stations. Level gauges, EC and velocity recorders were placed at open drain locations. Two important outfall drains were equipped with cable-way winches to continuously measure flow velocities at their outlets. The water quality parameters monitored in the measurement programme have been restricted to total salinity and to the major inorganic cations and anions related to water salinity.


The current monitoring network consists of 80 measuring stations ►

A computerized database system for storage, elaboration and retrieval of data was developed and has been continuously maintained and updated. A number of tailor-made programs for the elaboration, checking and presentation of data is included in the database system. The database includes two sub-databases. One is capable of storing and retrieving drain discharges and salinity, whereas the other one handles the chemical composition of drainage water and is linked with the laboratory database.

Data from the monitoring programme are published regularly in yearbooks. They include an introductory element which summarizes the annual quantity of drainage water flowing to the sea and the reused portion in each of the three Delta regions, East, Middle and West. They also present a classification of the drainage water flow to the sea according to its rates, salinity and adjusted SAR (Sodium Adsorption Ratio) over the Nile Delta.

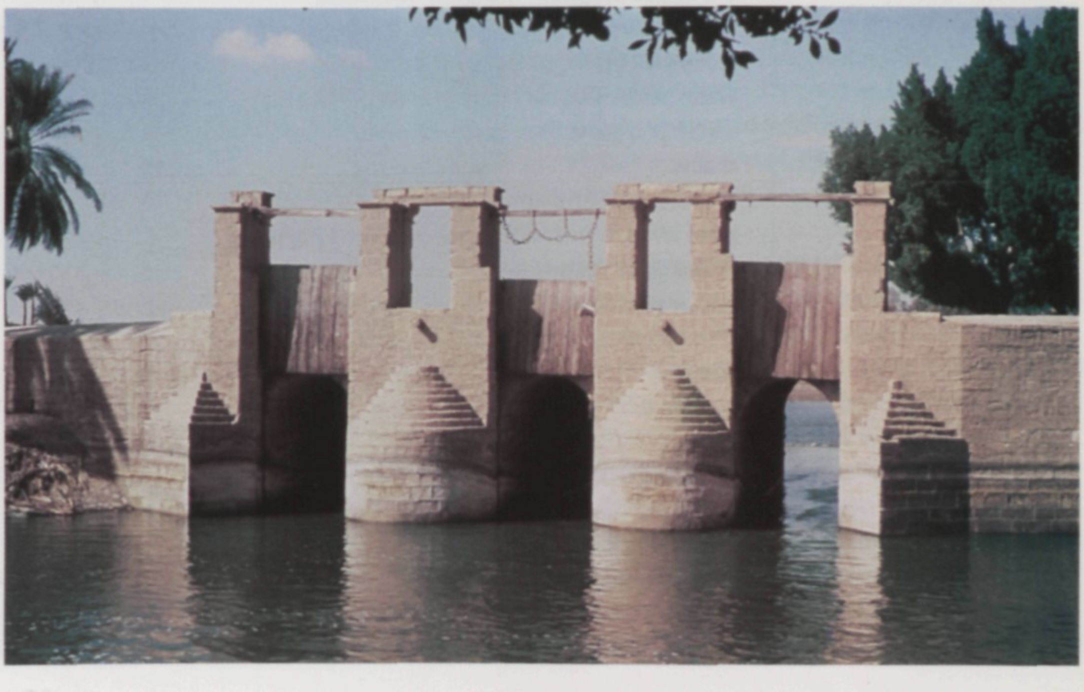
The drainage water monitoring programme clearly reveals that the drainage water quantity changes over time, depending on water use policies and the management of the main supply system, in particular the releases at the High Aswan Dam. The total drainage water discharged annually to the sea has varied from a maximum of $13.7 \cdot 10^9$ m^3 in 1984/1985 to a minimum of $11.5 \cdot 10^9$ m^3 in 1988/1989. The drainage water salinity is low in the southern part of the Delta, moderate in the middle part, and high in the coastal region.

The volume of drainage water officially reused for irrigation varied between a minimum of $2.7 \cdot 10^9$ m^3 in 1987/88 and a maximum of $4.2 \cdot 10^9$ m^3 in 1990/91. Since 1984/1985 the average salinity of the reused drainage water increased from 860 $g \cdot m^{-3}$ (0.135 $S \cdot m^{-1}$) to

1,200 g·m^{-3} (0.19 S·m^{-1}) in 1992/1993 . This trend is also seen in the salinity of the unused drainage water. The trend of increasing drainage water salinity has been reversed since the beginning of the 1990's but is still higher than the salinity levels at the beginning of the monitoring programme.

Simulation model

One of the fundamental limitations in the planning of future irrigation water management in Egypt is that changes in the quantity and salinity of reused drainage or irrigation water as a result of changes in water management, cropping patterns or other developments cannot be derived from historical data on drain discharge and salinity. Therefore, the simulation model SIWARE was developed by the RDWP as a tool for predicting drainage water quantity and salinity for any given water management or cropping pattern option. SIWARE is a physically based model and includes all relevant physical, hydrological, crop physiological, agronomical processes, as well as some other functional relationships. The program package is particularly instrumental for the simulation of regional and even national water management.
The application of the SIWARE model requires the subdivision (schematization) of the study area into a number of subareas, matching the boundaries of the Irrigation Directorates and Irrigation Districts. Further subdivision may be required to obtain uniform soil, hydrological and land use conditions within the subareas (calculation units). To this effect, the Nile Delta has been subdivided into 285 calculation units, of which 88 are located in the Eastern Delta, 116 in the Middle Delta and 81 in the Western Delta. The input data necessary for running the model normally comprise the irrigation and drainage system layout, soil characteristics, climate, agriculture (crops), domestic and industrial water use, and water management in the schematized area.
The SIWARE model includes a number of programs each with a specific function in the simulations. The DESIGN program deals with the allocation (distribution) of available Nile water among the intakes of main canals, which is based on the principle of proportionality between supply and demand. Groundwater abstraction, rainfall and anticipated reuse of drainage water are considered in the calculations. The agricultural demand is based on cropping pattern and the uniform crop water requirements in the Nile Delta. Finally, the required water depths at the control structures are calculated, assuming a distribution proportional to the demands in the area served by each main canal.



SIWARE calculates the required water depths at the control structures

The actual water requirements of each crop in each calculation unit are calculated by the WDUTY program which is based on the irrigation schedule and local soil and hydrological conditions. Also a reference evapotranspiration is calculated assuming abundant water supply and no adverse effect of soil salinity.

The actual water distribution among the subareas is calculated by the WATDIS program, based on a simplified approach of dynamic flow through canals. Adjustments of irrigation control structures are according to the procedures of the MPWWR and reflect the intended water distribution. The water abstraction for irrigation is based on the actual water requirements in a calculation unit. Also the return flows of drainage water by means of reuse pumps and water withdrawal for municipal and industrial use are taken into account.

The REUSE program, finally, calculates the salinity of water in irrigation canals, the distribution of abstracted canal water among field crops, the drainage water abstraction by farmers for supplementary irrigation (unofficial reuse) from local and regional drains, and the actual evapotranspiration as affected by soil moisture and salinity stress.

The drainage rates and drainage water salinity from the calculation units are also calculated by the REUSE program. The latter quantities, together with their salinities, are combined with spill losses from distributaries, disposed sewage water, and losses over the tail-ends of irrigation canals and are subsequently added to the regional drains.

This program furthermore calculates the discharge rates and salinities at strategic locations along the drainage canals and generates a warning when anticipated abstractions of drainage water through pump stations (official reuse) cannot be realized.

Management alternatives

The capabilities of the SIWARE model have been demonstrated through the analysis of six water management alternatives. The objectives and results of these alternatives are outlined below.

Water saving options by replacing rice with maize or reducing the rice water duty

A volume of $925 \cdot 10^6$ m^3 water, compared with the total irrigation water supply of 1987 was saved during 1988 by a reduction of 30% in the rice area in the Eastern Nile Delta. Model calculations, however, indicate that the same amount of water could have been saved by reducing the rice area by only 8% combined with a simultaneously reduction in the annual rice water requirement from the usual 8,800 m^3 per feddan to 7,400 m^3 per feddan. The drastic cut in the rice area resulted in a 2% reduction in the calculated total evapotranspiration, roughly equivalent to a 3% lower crop yield. This yield reduction could have been reduced by half by applying the proposed alternative.

An expansion of irrigated land in the Eastern Desert is feasible from the viewpoint of total crop production ►

Expansion of the agricultural area in the Eastern Desert

Model calculations show that an expansion of irrigated land in the Eastern Desert with a gross area of 350,000 feddans, while keeping the total Nile water supply to the Eastern Nile Delta constant, is feasible from the viewpoint of total crop production. The expansion, amounting to an approximately 17% raise in net cultivated area (reference 1988), resulted in a total increase in evapotranspiration of 11%, in both the short and the long term. This increase is more or less proportional to the expected increase in crop production. A study of this type, however, requires further economic analysis.

Improvement of local water management

Forbidding the use of diesel pumps and prohibiting unofficial reuse of drainage water by farmers resulted in a severe reduction in water supply to the crops, causing a loss of 4% in the calculated total evapotranspiration when compared to the reference situation of 1988 for the Eastern Nile Delta. The system losses decrease by about 2% and the official reuse of drainage water increases by about 8%. The salinity of irrigation water improves slightly. Banning diesel pumps for lifting water from irrigation canals, but allowing unofficial reuse, results in a reduction in system losses of about 11%, a reduction in official reuse of drainage water of 15%, and no reduction in total evapotranspiration.

Reduction in water to the old lands for meeting higher demands in other regions

Simulation results show that a reduction of the Nile water supply to the Middle Delta of up to 10% ($1,100 \cdot 10^6$ m^3 annually) is possible without serious adverse consequences for total agricultural production. Within certain limits, local adverse effects of reducing the supply to the area can be neutralized by an optional water distribution based on actual (spatial variable) crop water requirements instead of average values. The implementation of such an option may lead to a significant reduction in system losses and a reduction in the area where significant crop yield reductions would occur if the total supply were to be cut by the indicated percentage.

Two alternatives have been examined for the expansion of agricultural lands in the Western Nile Delta: 165,000 and 350,000 feddans

Changes in cropping pattern causing other water requirements than for the indicative pattern

Starting from an indicative cropping pattern in the Middle Nile Delta (1987), the area cultivated with crops that require a great deal of water has been enlarged by a maximum of 20%, with corresponding reductions in crops requiring less water. The reverse situation, where crops with low water consumption replace those with high demands has also been investigated. In either case the total Nile Water supply has also been kept constant based on the indicative cropping pattern. Growing a 20% larger area with high demand crops increases the calculated total crop water requirements by $2,700 \cdot 10^6$ m^3 per year. As a result, the irrigation system will be operated under stress conditions with a high efficiency of 80%, which also appears to be the ceiling. Although the calculated total crop water supply increases substantially, which can be partly attributed to larger volumes of unofficial reuse of drainage water, the much higher demands cannot be fully met. Consequently, the total evapotranspiration reduces by some 5%, indicating a yield loss of about 7%.

Growing a 20% larger area with low demand crops results in an annual $1,700 \cdot 10^6$ m^3 lower demand. The irrigation system losses increase dramatically by almost $1,400 \cdot 10^6$ m^3.yr^{-1} (+51%) and the irrigation system will be operated at a much lower level of efficiency (65%). The total crop water supply is more than sufficient, which is also demonstrated by an increase in total evapotranspiration of 3% when compared to the reference. The calculated yield gain is also 3%.

Expansion of the agricultural area while increasing the reuse of drainage water

Model results show that, starting from the reference situation of 1989, a further expansion of the irrigated lands in the Western Desert without additional reuse of drainage water will lead to a net total loss in evapotranspiration and hence in crop production for the whole Western Nile Delta. Such a situation is obviously not acceptable. Increasing the area by 165,000 feddans and implementing Phase I of the Umum reuse project results in an increase in total evapotranspiration of

1.7%. The implementation of Phase II of the Umum project results in a 3.7% increase in evapotranspiration. Extending the area by 350,000 feddan and implementing reuse Phase I results in an increase in evapotranspiration of only 1.5%, while realizing both phases leads to an increase by 3.3%. This clearly demonstrates that an expansion of the irrigated area beyond 165,000 feddans is not justified, as the additional evapotranspiration does not increase.

One of the side-effects of an expansion of irrigated land by 350,000 feddans and the implementation of Umum project Phase I and II is a 10% increase in the salinity of drinking water withdrawn from the Mahmoudeya Canal. The salinity of abstracted drinking water from the Nubareya Canal increases by about 40% up to 1,700 $g{\cdot}m^{-3}$ when both phases are implemented together. Moreover it is expected that the uptake rate will also be negatively affected when the irrigated area is increased by 350,000 feddans. Either moving the intakes of the drinking water plants to a location along the Nubareya Canal upstream of the mixing point with Umum drainage water, or finding another source, could resolve the expected adverse effects.

Future developments

The analysis of the complex Nile Delta water and salt system and the many applications considered so far have proven that the SIWARE package is a highly versatile tool for managers, planners, decision makers, and researchers. Possibilities for further model applications will remain whether related to applications on another scale, or to applications for completely different regions or even for other countries, Also the extension of the model package with water quality modules other than salinity should be contemplated by users and developers alike. As to meeting the immediate requirements in Egypt as well as in other countries, a SIWARE version coupled to a non-steady state groundwater model for saturated flows is currently under development.

1 Introduction

1.1 Background

The main and almost exclusive source of fresh water in Egypt is the River Nile. The average annual natural flow is estimated at Aswan as about $84 \cdot 10^9$ m^3. The Nile water agreement of 1959 with Sudan clearly defined a fixed share for Egypt. Egypt's present annual share downstream of Aswan is $55.5 \cdot 10^9$ m^3, while Sudan's share is $18.5 \cdot 10^9$ m^3. The remaining $10 \cdot 10^9$ m^3 are considered to be non-recoverable losses.

Egypt's share of the Nile water constitutes about 97% of its renewable water supply. The rest is in the form of scattered rainfall along the Northern Coast and small quantities of groundwater below the Western Desert and Sinai.

Egypt's share of the Nile water constitutes about 97% of its renewable water supply

This situation makes the country mostly dependent on imported surface water which is an indicator of the vulnerability of the population to water shortage.

Groundwater in the Nile Valley is considered as a reservoir recharged by the Nile or the irrigation system. A conservative estimate of the groundwater storage in the Nile Basin downstream Aswan is about $400 \cdot 10^9$ m^3. The present exploitation rate of groundwater in the Nile Valley and the Delta is estimated as $2.3 \cdot 10^9$ m^3. It is planned to increase the abstraction rate up to $4.9 \cdot 10^9$ m^3 annually.

The average annual rainfall in the coastal areas ranges between 150-280 mm per year. It diminishes to the south, amounting to about 30 mm per year in Cairo, and there is virtually no rainfall in Middle and Upper Egypt.

According to World Bank projections, Egypt's growing population, currently estimated at 58 million, is projected to reach between 86 and 100 million by the year 2025. Thus, the annual per capita availability of water, which is already within the stress limit, will become even further reduced. Hence, scarcity of water resources has dictated the need to use different types of low quality water.

Population growth has outstripped the expansion of cultivated land and has also caused a significant drop in cultivated land available per capita. The growth of agricultural production could not keep pace with the increasing need for food and fibres. As a result, food imports have gradually increased, endangering Egypt's balance of payments. Agricultural production currently contributes more than 60% of national income and further development of this sector is expected.

In 1994, the cultivated area amounted to 7.4 million feddans and the net water consumption was $37.5 \cdot 10^9$ m^3. The Government of Egypt has adopted the horizontal expansion of cultivated lands as a major policy to increase crop production and create new job opportunities. It is planned to reclaim about 2.9 million additional feddans by the year 2000. Further land reclamation using Nile water (directly or reused) is difficult to foresee without a technological revolution. Reclamation of some desert areas using fossil water is however possible. Under current irrigation practices and with current levels of efficiency in the irrigation system, the total irrigation water demands are about $51.5 \cdot 10^9$ m^3 per year. It is expected that irrigation demands will increase to $59.5 \cdot 10^9$ m^3 and $61.5 \cdot 10^9$ m^3 in years 2000 and 2025 respectively according to the expectation of Ministry of Public Works and Water Resources (MPWWR).

Water in Egypt is also required for various other purposes. The municipal water requirements amount annually to about $2.9 \cdot 10^9$ m^3 of which a significant portion is recovered. The remainder is returned to the drainage canal system. Industry requires about $5.9 \cdot 10^9$ m^3, of which a minor portion ($0.6 \cdot 10^9$ m^3) cannot be recovered. The water requirement for generating hydro-electric power is fully met by irrigation water releases except during the closure period when canals are maintained and very low release rates are necessary for navigation through the river. At that time, a total of $2.1 \cdot 10^9$ m^3 per year are released and cannot be recovered. Agriculture is, and will remain, the largest user of water. Evaporation from open water surfaces, which amounts to about $2 \cdot 10^9$ m^3, and evapotranspiration (consumptive use of crops) amounts to about $37.5 \cdot 10^9$ m^3, represent non-recoverable quantities.

Future municipal demands have been estimated on the basis of some scenarios related to population growth and the efficiency of the supply system. The most optimistic scenario assumes a minimal increase in population, rationalization of water use and an increase in efficiency. The average expectation is that the municipal water demands may increase up to $3.1 \cdot 10^9$ and $5.1 \cdot 10^9$ m^3 by the years 2000 and 2025 respectively. However, if any of these assumptions proves to be incorrect, demands will be correspondingly higher. According to the different scenarios of the Ministry of Industry for growth in industrial production, future annual demand for industrial water may reach $10 \cdot 10^9$ m^3 in year 2025. Current navigation demands will decrease after the completion of the Esna Barrage and Naga-Hammadi Ship lock from $2.1 \cdot 10^9$ to $0.4 \cdot 10^9$ m^3 per year.

A prolonged period of drought underlined the urgency to increase the reuse of drainage water

The River Nile will remain the only renewable water resource in Egypt. The limited winter rainfall on the north coast supplies only 1-2% of the annual volume provided by the Nile. Thus, it is essential to increase water use efficiency, recycle and reuse available water resources and develop unconventional water resources to meet future needs. Agricultural drainage water is considered one of the most economically feasible alternatives when it is reused for irrigation on an environmentally sound and sustainable basis.

Reuse of drainage water is not a new phenomenon in Egypt: the drainage water generated in the Nile Valley south of Cairo has returned to the Nile since ancient times. Only during the seventies was reuse of drainage water introduced in the Nile Delta, at first in the southern parts, where the drainage water salinity is generally low. In the eighties, a severe and prolonged period of drought in the catchment of the Nile underlined the urgency for additional plans to increase the reuse of drainage water. Drainage water became an accepted additional source of water, which had to be utilized to the maximum possible extent.

1.2 Scope of the project

The Reuse of Drainage Water Project (RDWP) was initiated to provide the MPWWR with information about the volumes of drainage water available in the Nile Delta for recycling in irrigation without adverse effects to soils and crop productivity. The objectives of the project were formulated as follows:

- to determine the quantity of the water currently available, its salinity and related chemical constituents, in the main drainage system of the Nile Delta;
- to predict the future water quality and quantity in the main drainage system of the Nile Delta as a result of changing water management practices in the future;
- to predict the long-term effects of reuse of drainage water in irrigation in the Nile Delta.

The RDWP has been implemented in two phases. The first phase started in 1983 and terminated in

1988, the second phase started in 1991 and terminated in 1995. In both phases the project was implemented by a cooperative venture of two technical agencies: DRI, Cairo, Egypt and SC-DLO, Wageningen, the Netherlands. To achieve the project objectives, the following activities were implemented by the RDWP:

- the installation and operation of a monitoring network covering the main drainage system in the Nile Delta to determine and report on an annual basis the discharges and water quality;
- the establishment of a database and regular publishing of collected and processed data;
- the upgrading of analytical laboratory facilities;
- the development and operation of a mathematical simulation model for the Nile Delta to predict future changes in drain discharge and salinity;
- the training of Egyptian counterpart staff in the implementation of the above facilities through special courses and 'on the job training'.

The physical scope of the project is defined by the three Nile Delta Regions: Eastern, Middle and Western Delta north of the Delta Barrages. The reclamation areas in the Eastern and Western Nile Delta Regions were not included. During the project implementation, however, it became clear that these reclamation areas could not be completely ignored.

The monitored water quality parameters in the measurement programme were restricted to salinity and the major inorganic cations and anions related to water salinity. Occasionally, on locations where environmental hazards were suspected, other parameters such as nutrients, organic compounds, heavy metals and pesticides were also measured. In the simulation model, the only water quality parameter included is salinity. For this purpose, the chloride anion was used as an indicator, because this element is not involved in adsorption to the soil, nor in precipitation reactions. Empirical relations were used to relate chloride concentrations to total salinity.

The simulation model developed by the RDWP covers the water flow through the irrigation system in the three Nile Delta Regions, on-farm water management, and the drainage water discharges through the main drainage system. The groundwater system itself has been excluded from the simulation model and is only represented as a (constant) boundary condition. Crop reaction in the model is limited to evapotranspiration. A reduction in this simulated parameter as a result of insufficient water supply or increased soil salinity levels is assumed to be an indicator of crop yield. No attempts have been made to include crop yield modelling in the simulation model. The simulation model is primarily intended to serve the needs of planners, technical water managers and decision makers of the MPWWR. No attempts have been made to include economic or social aspects or other consequences of water management in the simulation model. However, the model outputs could easily be made available for further analyses in these fields.

Although the primary aim of the project was to provide assistance to the MPWWR in the planning and management of water resources, results of the project could also be used in Egypt by other Ministries and Authorities such as:

- The Ministry of Public Health;
- The Ministry of Agriculture, Land Reclamation, Fisheries and Animal Husbandry;
- The Egyptian Environmental Affairs Agency;
- Research Centres and Universities;
- Regional and International Agencies involved in the development and conservation of water resources in Egypt.

The simulation model that has been developed can also be used in other parts of the world with similar conditions.

1.3 Focus of the project

Reuse of drainage water has been adopted as a policy instrument by the MPWWR to maximise the use efficiency of limited available water resources. Reuse of drainage water has certain advantages. Often large investments are not nesessary when drainage water can be lifted from drains to nearby irrigation canals. In such cases, extensive infrastructure does not need to be constructed and by proper operation of the receiving canal, the Nile water diversion to such canals can be reduced accordingly.

If agriculture is to be expanded in Egypt, water use efficiency in existing areas must be increased

Reuse of drainage water also has its drawbacks, however. The quantity of available drainage water depends on water management procedures and practices in the catchment area where this drainage water is generated. As such, the quantity of drainage water available for reuse in irrigation changes when water management systems or cropping patterns change. Another important aspect of drainage water reuse is that not only water is recycled by this practice, but also salts. Successful reuse of drainage water is therefore not only a question of supplying sufficient water to the complete command area, but also to prevent harmful effects due to recycling of leached salts. This can be achieved through careful water management both at the supply and farm level.

If agriculture is to be expanded in Egypt, water use efficiency in existing areas has to be increased. Two types of tools provide support in this matter: the monitoring network, which provides current and historical information on available quantities of drainage water for reuse and a model, which should be able to evaluate different options for saving water from the Nile Delta area. Savings can be achieved either by allocating less Nile water to the old lands and by increasing the use efficiency through reusing more drainage water locally, or by transporting drainage water from the Nile Delta to desert areas, where saline irrigation water is less harmful due to coarser textured soils. Efficient allocation for conjunctive use of Nile water, groundwater and drainage water, with minimum adverse effects on crop production, could be attained by using the model as a planning tool. For this type of evaluation of alternatives, the focus is on the long-term effects of various water management alternatives.

1.4 Reading guide

This report summarizes findings and conclusions previously made and described in detail in several related reports and studies.

Chapter 2 presents an overview of the RDWP's achievements.

In Chapter 3, a summary of the layout, the instrumentation and the calibration of the monitoring network is given. It provides a summary of drainage water quantities and salinity that were discharged to the sea or reused in irrigation. This chapter also gives a brief description of the model developed, the required input data and the calibration and validation of the model. The model capabilities for evaluating different water management options and the required expertise are presented at the end of this chapter.

In Chapter 4, a brief review is given of different water management options that have been analyzed within the framework of the Reuse of Drainage Water Project.

Finally, Chapter 5 deals with the potential of the simulation model SIWARE for other purposes and future developments.

2 Project implementation and achievements

2.1 Introduction

The Reuse of Drainage Water Project (RDWP) has accomplished a large number of tasks over a period of approximately eleven years. The majority of these tasks were aimed at providing the Government of Egypt with (i) - accurate data regarding drain discharges and salinity in the major drains in the Nile Delta, and (ii) - the means to carry out studies on different water management scenarios with a focus on the status of current and future possibilities of reuse of drainage water. To this effect the RDWP effectively delivered:

1 A comprehensive network of measurement locations at all major drains in the Nile Delta, including all the facilities needed to collect, process, and report the gathered data.
2 An integrated mathematical simulation model covering all major components of the water and salt cycle in delta areas under intensive agriculture.

Two project proposals, clearly defining aforementioned objectives, were submitted to the Netherlands Embassy and were subsequently granted and funded by the Netherlands Directorate General for International Cooperation. The RDWP has been implemented in two phases. The first phase started in June 1983 and terminated in June 1988. Its major achievements were the installation and operationalization of a delta-wide network of measurement locations along the main drains, usually referred to as the 'Routine Measurement Programme'; the establishment of a computerized database which includes drain discharges, drainage water salinity and chemical constituents; the publishing of data year books and the development of a computer model package named SIWARE (*SI*mulation of *Wa*ter management in the *A*rab *Re*public of *E*gypt). Upon completion of the formulation in 1988, the project team proceeded with the calibration and validation of the model for the Eastern Nile Delta followed by a number of scenario simulations. The availability of reliable data proved indispensable for these tasks. In 1991, the project published a comprehensive report containing all results obtained for the Eastern Nile Delta (Report 30).
The second phase of the project started in June 1991 under the title: 'Reuse of Drainage Water Project, Phase II (RDWP-II): Analysis of Water Management in the Middle and Western Nile Delta'. Similar modelling activities as implemented under Phase I for the Eastern Nile Delta were carried out for the Middle and Western Nile Delta. In addition, closer cooperation with the end-users of final project results in the Irrigation and Planning Sectors of the Ministry of Public Works and Water Resources (MPWWR) was sought. This cooperation entailed a mutual exchange of information and data, guidance to the project staff for addressing the priority issues defined by the Ministry, training courses, and transfer of the SIWARE package.
For the proper assessment of sound water budgeting in a system where reuse of drainage water in irrigation is included in water management, a monitoring programme has been implemented in the main drainage system. With the developed SIWARE model changes in drainage water quantity as a result of changing water management can also be predicted. Using special salinity modules, the SIWARE model also predicts changes in salinity in the (reused) drainage water, changes in soil salinity in receiving catchments, and effects on evapotranspiration.
The SIWARE model can be used as a tool at the MPWWR for annual water budgeting. Water is allocated to the main command canals in the Nile Delta according to the anticipated cropping pattern, municipal and industrial water requirements, groundwater abstraction, drainage water available for reuse and the amount of Nile water supplied from the Aswan High Dam. Based on an assumed available amount of drainage water at reuse pump stations, these quantities are subtracted from main canal intakes. The SIWARE model is used to verify the presence of drainage water in sufficient quantities, as assumed during allocation. If this proves not to be the case, the amount of drainage water is to be adjusted and the procedure is repeated with lesser quantities of drainage water.
As a by-product of the project's activities a tremendous amount of valuable data has been stored on files and in databases for the whole of

the Nile Delta. These data involve for instance (i) - the irrigation canal system (lay-out, dimensions, discharges, etc), (ii) - the drainage canal system (lay-out, discharges, official reuse, salinity, etc.), (iii) - crops (patterns, duties, irrigation frequencies, planting and sowing dates, succession, development, ratios between cultivated and gross areas, etc.), (iv) - climate (potential evapotranspiration, rainfall, etc.), (v) - soils (texture, hydraulic conductivity, diffusivity, moisture characteristics, swelling and shrinking characteristics, drain depths and spacings, etc.), (vi) - groundwater abstraction (agriculture, municipal and industrial use), (vii) - municipal and industrial withdrawal from irrigation canals, (viii) - hydrology (piezometric levels, salinity of groundwater, clay-cap thickness and permeability, etc.).

2.2 Activities during Phase I

In the DRI proposition to implement Phase I of the RDWP the following activities were mentioned:

1. Installation and operation of a monitoring network for drain discharges and salinity in the Nile Delta, which became known as the 'Routine Measurement Programme' (RMP);
2. Upgrading of laboratory practices and facilities;
3. Development of a physically based mathematical simulation model (SIWARE) for the prediction of drain discharges and salinity at the various locations where drainage water is reused (or envisaged to be reused) for irrigation purposes;
4. Calibration and validation of the SIWARE simulation model;
5. Application of the simulation model for a number of water management scenarios in the Nile Delta;
6. Transfer of knowledge to and training of DRI staff;
7. Reporting.

The first three activities were effectively accomplished during a time-span of approximately four years. The establishment of the monitoring network can be described as extremely successful with, since 1984, an uninterrupted flow of data and of publications of yearbooks presenting drain discharges and salinity at some 20 strategic locations and pumped rates and salinity of virtually all 70 drainage and reuse pump stations in the Nile Delta (Report 20). A steady increase in the accuracy was achieved through continuous calibrations. In addition, a database was developed for data storage and retrieval, including some modules for processing and presentation.

The DRI laboratory was steadily refurbished in order to cope with the increasing demand for chemical analyses of the water samples taken from the drains. The analyses include the major ions and such derived parameters as TDS (Total Dissolved Salts) and SAR. The laboratory currently functions satisfactorily, with their own automated data entry, providing reports which can be directly included in the yearbook publications.

Data on discharge of drainage water are obtained from monitoring the operation of the drainage pump stations and water depths at open drain locations using the regular calibration of drainage pumps and the established stage-discharge relations at the open drain locations. The drainage water salinity has been determined through recording of the electrical conductivity of the drainage water at the pump stations and at open drain locations. A number of tailor-made programs for the elaboration, checking and presentation of data is included in the database system. Facilities for retrieval and reporting of historical data are included in the database management system.

The development of the complete model package, on the other hand, appeared such a laborious task that it was decided by the end of the project in 1988 to restrict the application to the Eastern Nile Delta only. In close consultation with the Irrigation Sector, three different water management scenarios were selected for evaluating potential savings on the use of Nile water, namely: (i) - substituting rice by maize in the cropping pattern, (ii) - an expansion of the cultivated areas by reclaiming adjacent desert lands, and (iii) - re-introduction of 24 hour irrigation with low capacity lifting tools as previously used by farmers. Analyzed output parameters were (among others) the realized irrigation water savings, the total

reuse of drainage water, crop reaction, and soil salinity. All results were laid down in a comprehensive final report for Phase I (Report 30) and a number of papers presented at various conferences.
From the start of the project until the official end of Phase I in 1988, an extensive transfer of knowledge took place at different levels. The DRI staff was closely involved in the following activities:

- setup of the monitoring network;
- selecting measurement methods;
- data collection;
- data processing;
- data presentation;
- model formulation;
- model implementation.

Various on-the-job and tailor-made training courses were provided (both locally and abroad) for project staff members.

2.3 Activities during Phase II

In 1989, when it became clear that the SIWARE model package could be used in water resource planning and management to provide realistic answers to questions concerning the effects of various water management policies, DRI decided to submit a new project proposal to the Netherlands Directorate General for International Cooperation. This project proposal stipulated the following major activities, to be implemented over a period of three years:

1 The calibration and validation of the SIWARE package for the Middle and Western Nile Delta;
2 Satellite data study;
3 Knowledge transfer and training;
4 Reporting;
5 Additional activities.

With SIWARE a step-wise reduction of the water supply to the Middle Nile Delta has been evaluated

Modelling Middle and Western Nile Delta

A huge amount of input data was collected and processed for the Middle Delta. The model calibration on the basis of the data 1987 and the validation of the model simulations was successfully completed using input data for the year series 1985 through 1989. Results were largely within the accuracy limits set during Phase I (Report 44). Two water management scenarios, one addressing a step-wise reduction in the total water supply to the Middle Delta and another one dealing with the possible effects of large variations in the cropping pattern, were studied as well (Report 45).
Also for the Western Delta a large amount of data was collected. However, additional data had to be gathered after it appeared that no satisfactory results could be obtained for the selected calibration year 1987. After a thorough analysis of the available input data and consultation with the staff of the Irrigation Sector, switching to 1989 input data set improved considerably the results of calibration and validation of the model for the Western Nile Delta (Report 46). Finally, one scenario was simulated handling a two-step increase in the reuse of drainage water from the Umum drain concurrently with a two-step expansion in cultivated area by additional land reclamation in the Western desert fringes of the Delta (Report 47).
It should also be mentioned that the inauguration of a Task Force in November 1993, staffed by officials of the National Water Research Center (NWRC) and the MPWWR, substantially expedited the selection of the scenarios for the Middle and Western Delta. This committee also facilitated the acceptance of the modelling results at the

MPWWR and provided a suitable platform for future cooperation as well.

Satellite data study

The decision to process one or more satellite images was taken on the basis of a previous useful experience involving the Eastern Delta. Therefore, the project contracted a local agency, who processed two Landsat images (1987 and 1989) covering a major part of the old land in the Western Delta and the bordering reclamation zone in the Western Desert. Of both images the net agricultural area was determined. Furthermore, a crop classification was carried out discriminating between the areas cultivated with cotton, vegetables, and trees (1989 image only). Since the activity is considered to be recurrent, measures were taken to further strengthen DRI's capability to interpret pre-processed images. Most facilities (computer hardware and software) for this purpose were already in place by the end of the project.

Knowledge transfer and training

Training and the transfer of knowledge were largely achieved through specific courses, on-the-job training, and workshops. The courses addressed such items such as (i) - the structure and potential of the SIWARE model package, (ii) - the data requirements for SIWARE applications, (iii) - schematization procedures involved for SIWARE applications, (iv) - principles of remote-sensing and data processing techniques, (v) - introduction to Geographical Information System software (ARC/INFO).

On-the-job training was provided to project staff and engineers from the MPWWR through the various modelling stages carried out during the project. Major training elements were the calibration and validation of the model package for the Middle and Western Nile Delta, followed by the simulation of a number of water management scenarios. In addition, one project engineer was trained at SC-DLO and ILRI (International Institute for Land Reclamation and Improvement) in techniques for coupling the SIWARE package to a groundwater model. Such coupling is expected to be a necessary future development in the SIWARE package to account for the interaction between the surface and groundwater dynamics and changes with respect to time.

The project organized three workshops. The first one took place during the inception phase of the project with the objective informing MPWWR staff (Headquarters and regional offices) about the potential of the SIWARE package and its data requirements. The increased awareness and interest of the MPWWR staff definitely facilitated the data collection later on. A second workshop in April 1992, addressed the issue of the water management scenarios to be included in the model simulations and was also attended by officials of the MPWWR. Finally, the project convened a third workshop to present the final achievements and products to a broad forum. Various other round-the-table meetings were organized as well, mostly with MPWWR staff when urgent issues had to be resolved.

Reporting

A large number of reports were prepared dealing with practically all aspects covered by the project. A complete list of published reports, technical papers, and workshop proceedings is presented in Appendix 1.

Additional activities

During the execution of the project a number of additional activities were identified as essential for attaining the objectives stated in the project proposal. These activities were:

- Transfer of the SIWARE package to MPWWR;
- Development of two User Interfaces;
- Installation of a Local Area Network (LAN) in DRI;
- Purchase of GIS (Geographical Information System) software.

Transfer of SIWARE to Irrigation and Planning Sectors

In the project proposal the Irrigation Sector within the MPWWR was identified as the most likely end-user of the modelling results. At the onset of the

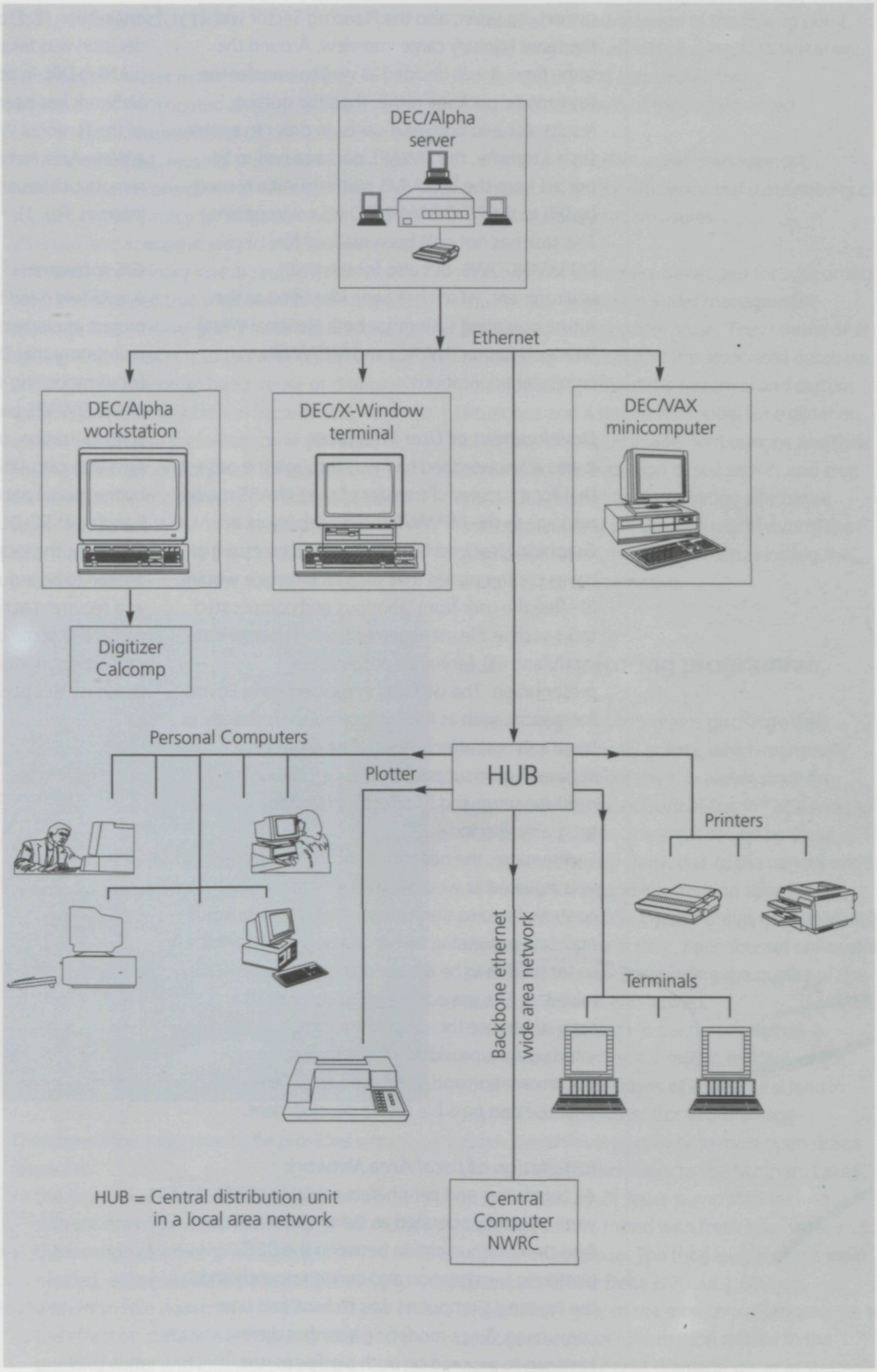


Fig. 1
DRI-computer and peripheral network configuration

project, however, also the Planning Sector within the same Ministry came into view. Around the same time, it was decided as well to transfer the total model package rather than the output results alone to both end-users. In order to enable such a transfer, the SIWARE package had to be ported from the VAX/VMS platform initially used by DRI to the PC-DOS/WINDOWS environment. This task has not only been realized for DOS/WINDOWS, but also for the UNIX environment, which has been identified as the future operating system for both National Water Research Center (NWRC) and MPWWR's computer applications.

Development of User Interfaces

It was acknowledged half way through the project that for a successful transfer of the SIWARE model package to the MPWWR the availability of a Graphical User Interface (GUI) would be essential. It was contemplated that such an interface would (i) - free the user from laborious and complicated tasks such as file management, (ii) - facilitate data input, and (iii) - enhance output data presentation. The GUI was implemented in Egypt for reasons such as having local support directly at hand and cost effectiveness. The project has secured future support for the GUI through a modular setup and by selecting familiar programming tools.

Furthermore, the need for a second User Interface was assessed as well. Such an interface was contemplated to significantly facilitate data input and data processing by expert users at DRI, which so far tended to be a laborious job prone to mistakes. The project therefore contracted a software house for its implementation. Both interfaces are provided with sufficient documentation and user manuals to facilitate their use and possible future development.

Installation of Local Area Network

All computers and peripherals available at DRI were originally operated as stand-alone devices. Also the communication between the DEC platforms (workstation and mini-computer) and the Personal Computers was tedious and time-consuming. Since modelling activities were foreseen to proceed on both platforms, the interaction had to be improved. Thereto the decision was taken to install a Local Area Network (LAN) in DRI. In addition, the DRI Local Area Network has been linked to the central computer of the National Water Research Center as a part of a Wide Area Network, thereby providing access to remote utilities and E-Mail facilities through Internet (Fig. 1).

GIS software

A two-fold need for GIS software arose during project implementation. First, it appeared mandatory that DRI should have all available tools for all modelling stages involved in the application of the SIWARE package. One of these stages is the schematization, or partitioning, of the selected area into calculation units which can be handled by the model package. This stage was previously handled at SC-DLO using the ARC/INFO package. Secondly, the local processing of satellite images proved to be arduous, while it was acknowledged as a recurrent activity. Since recent versions of ARC/INFO could be delivered with image processing modules, the decision was taken to purchase this package.

3 Tools developed for water management evaluation

3.1 Introduction

Since Egypt's water resources are limited, expansion of the irrigated area can only be realised by increasing water use efficiency. Among other alternatives, reuse of agricultural drainage water has been considered as an important supplementary source for irrigation water and an effective and economic way to increase water use efficiency. Preliminary investigations in the late seventies revealed that a substantial quantity of drainage water flowing to the sea has reasonable salinity which makes it suitable for reuse for irrigation. On the other hand, reuse of drainage water is prone to salinization hazards and associated adverse socio-economic effects. For the development of plans for reuse of drainage water, the Ministry of Public Work and Water Resources (MPWWR) needs accurate information concerning the current and future possibilities and impacts for such activities.

Sustainability of Egypt's agriculture is secured through a drainage canal network

Therefore information has to be provided with respect to:

- the location at which certain quantities of suitable drainage water are available for reuse;
- the location at which drainage water is needed, either separately or after blending with fresh Nile water;
- the effect on surface water quality when drinking water and industrial water are abstracted downstream of the mixing point;
- the long-term effects of using such water on soil salinity and crop productivity;
- the effectiveness of the implemented measures;
- the effect of other water management measures on the efficiency and sustainability of the implemented measures.

Two types of tools were developed for supporting the decision makers in water management involving drainage water reuse. They consist of a monitoring network and the associated database for information about the historical and current situations and a simulation model for evaluation of different water management options and their impacts on the evolution of soil salinity and crop yield. The possibility of evaluating alternative solutions or plans is especially useful during the plan preparation phase and when selecting the most attractive alternative.

3.2 Monitoring programme

Most of Upper Egypt's drains discharge their water into the Nile by gravity, which marginally affects the quality of the Nile water, since the salinity only increases from 250 g.m^{-3} at Aswan to 300 g.m^{-3} at Cairo. The areas served by these drains are relatively small, due to the narrow width of the Nile Valley and information about them is limited. All of Middle Egypt's drains discharge into the irrigation system (Nile, Bahr Youssef or Rosetta Branch). Information regarding the quality of the drainage water is also limited.
The drainage system in the Delta is rather extensive and serves 4.7 million feddans of the total 7.4 million feddans of agricultural land in Egypt. Drainage water from 22 drainage catchments flows by gravity to main open drains where it either discharges to the Northern Lakes or is pumped by 21 reuse pump stations into irrigation canals, mixed with fresh Nile water and reused for irrigation. The total length of the main drains in the Nile Delta is about 1,600 km.
The ultimate goal of the monitoring programme is to obtain accurate information related to the quantity and quality of drainage water at strategic

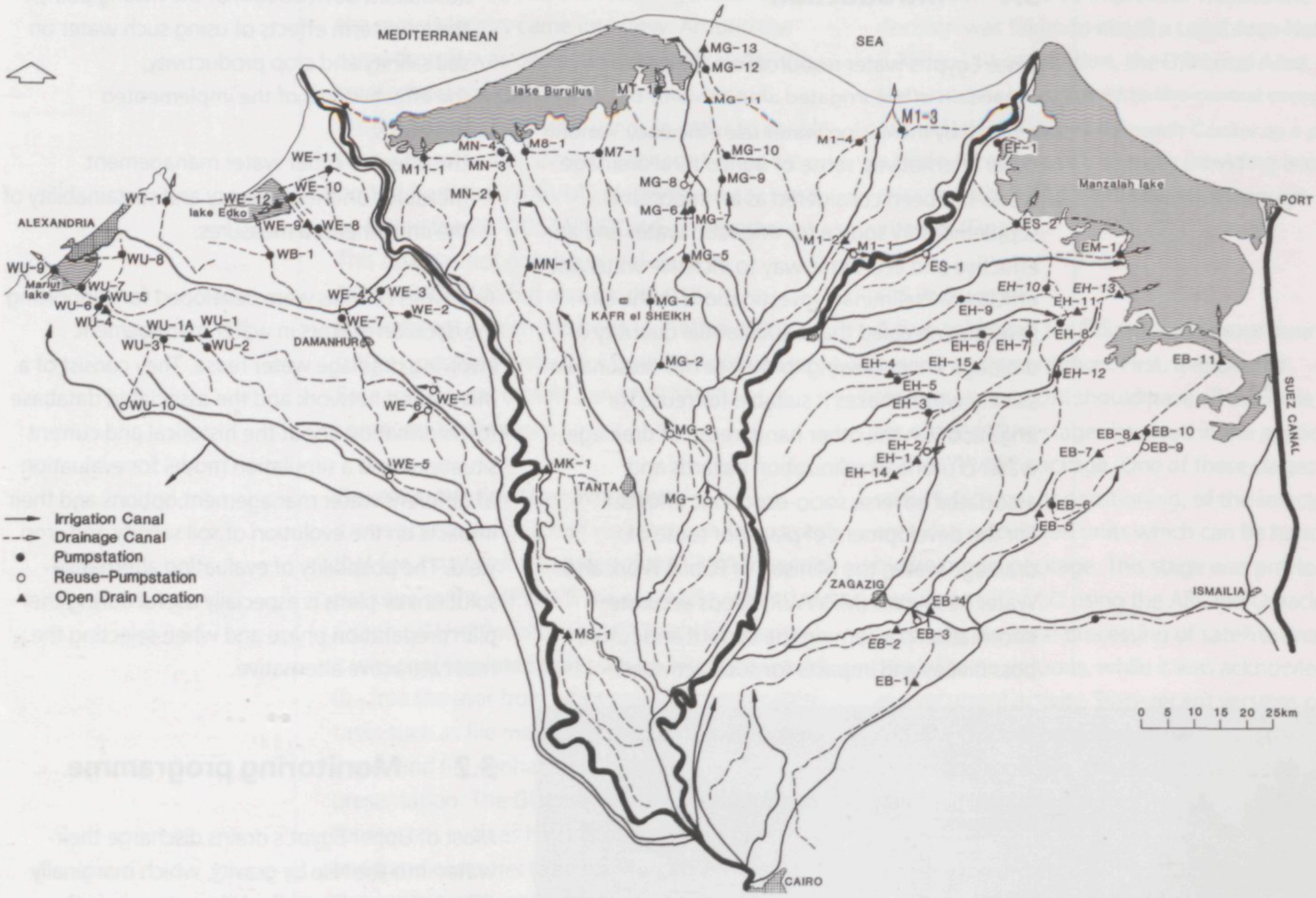


Fig. 2

General view of drainage water in the Nile Delta monitoring network 1992/1993)

locations along the main drains in the Nile Delta where significant changes take place due to the addition to or withdrawal from the drain.

3.2.1 Measurement network

In 1977 the Drainage Research Institute started to collect water samples from about 47 sites located along the drains and drainage pump stations spread over the Delta on a monthly basis. The open drainage system was surveyed in 1980 by field inspection and a permanent network for routine monitoring was established. The data on discharge and salinity have been collected since 1980 on a fortnightly basis, using very simple measuring methods. DRI with the involvement of Delft Hydraulics, started a calibration programme in 1981. The description of the activities and procedures used at the start of the Reuse of Drainage Water Project (RDWP) is presented in Report 1.

Since the start of the project in 1983, the network has been continuously maintained and upgraded to provide reliable measurements following standard methods and procedures. The monitoring network initially consisted of about 20 open locations and 70 pump stations, amongst them 21 for reuse of drainage water. A number of locations appeared not to be strategic and have since been abandoned. The current monitoring network consists of 80 measuring stations distributed as shown in Figure 2.

The measurement network of the RDWP covers most of the catchments in the Nile Delta. It contains major points of inflow, mainly drainage pump stations and important points of abstraction, mainly reuse pump stations. Check points are located at strategic locations along the main drains. A complete description of the monitoring network is given in Report 20.

In 1988, the responsibility for the monitoring network was completely transferred to DRI. A competent staff from DRI was trained in Egypt and the Netherlands to carry out the programme monitoring activities. Annually about six hundred man days are spent in the field for routine measurements, re-calibration of stage-discharge relations and maintenance of the field equipment. The DRI monitoring team also maintains and updates a comprehensive database of all relevant data produced by the measurements programme.

Instrumentation

The instrumentation of the network started in 1984 to enable a continuous and permanent monitoring of discharges and salinity. Operation time counters, level gauges and EC meters have been installed at the pump stations. Level gauges, EC and velocity recorders have been placed at open drain locations. A special velocity recorder (ENDECO) for the continuous recording of flow velocity and flow direction, temperature and salinity of water was installed at the Bahr Hadus outfall where back water effects were expected. The option for flow direction was needed to verify whether during certain periods intrusion would occur from the Lake Manzala into this drain. The completion of the instrumentation and the installation activities was reached at the end of 1987. Since then checkups have been carried out on a regular basis.

Two important outfall drains were equipped at the end of 1994 with cable-way winches to measure the flow velocities at their outlets. The first is Bahr Hadus Drain in the Eastern Nile Delta which is one of the main sources supplying El Salam Canal with drainage water (about 10^9 m^3 per year). The second is the Edko Drain in the Western Delta. Both sites are influenced by back water effects. The new instrumentation will increase the accuracy of the measurements.

A description of the equipment installed as well as the installation requirements at the measuring points, the procedures used for measurements and data elaboration are presented in Report 17.

Calibration

For each measurement location of the network a stage-discharge relationship has been established, giving the discharge quantity as a function of the easy to measure water level. In some cases back water effects occur. For those locations a discharge relation has been established as a function of the flow velocity at a fixed point and the corresponding cross-sectional area resulting in velocity-discharge relationships. A detailed description of the procedures to be followed during calibration at the measuring points and the elaboration of the field data to obtain rating curves are described in a manual (Report 17).

A first series of these calibration measurements was completed in 1986. The results have been presented in the Reports 6, 8, 9, 21 and 26 dealing with the three Delta regions. These reports give an extended description of the process and procedures followed for the determination of discharge relationships for both pump stations and open locations. The calibration of the rating curves has been repeated at regular time intervals. This has resulted in an accuracy of individual calibration measurements ranging from 2-4% at open drains to 6-7% at pump stations (Report 16). The discharge measurements can therefore be considered highly accurate.

Routine measurements

Measurements at pump stations are made twice a day or whenever substantial changes take place. They include the measurement of lifting head (difference in water levels at the suction and the delivery side of a pump station), and the electrical conductivity of the drainage water at the delivery side of the pump that is operating. The daily number of operation hours of each pump unit is also recorded.

The discharge at open locations is determined by different methods. The discharge of the drain is measured directly at its outfall or (for lower order drains) as the difference between the discharge measured in the higher order drain downstream and upstream of the location where the lower order drain disposes its water. Measurements at intermediate points in drains are used for checking purposes. Discharge measurements at the outfall of drains to the Coastal Lakes or to the Mediterranean Sea provide insight into the total drainage water releases to the sea.

3.2.2 Data analysis

Laboratory data

The DRI laboratory has an important task in the RDWP. The water samples regularly taken every three weeks during the routine measurement programme are analyzed in the laboratory. The laboratory analysis of each sample comprises the EC (Electrical Conductivity), TDS (Total Dissolved Salts), pH, SAR (Sodium Adsorption Ratio), adjusted SAR, RSC (Residual Sodium Carbonate), Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, SO_4^{2-} and Cl^{-}. Relationships have been derived between EC and TDS for each measurement location. These relationships are used for the translation of measured EC values in the drains into TDS values to decrease the workload at the laboratory. A full description of the procedures followed at the DRI laboratory is presented in a laboratory manual (Report 19).

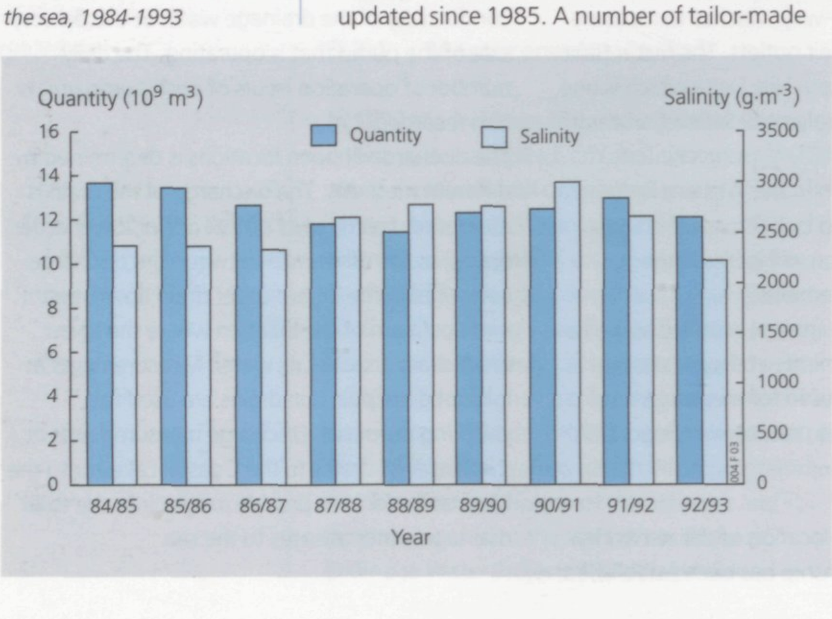
Database system

With the establishment of the measurement network which started in 1984, the routine monitoring of drainage water quantity and quality became a fact. This of course generated a considerable continuous flow of data to be stored and elaborated.

A computerized database system for storage, elaboration and retrieval of data collected in the routine measurement programme has been developed and continuously maintained and updated since 1985. A number of tailor-made programs for the elaboration, checking and presentation of data is included in the database system. The database includes two sub-databases. One stores drain discharges and salinity after field data have been processed by a special application program. The other one stores the chemical composition of drainage water and is linked with a database of the laboratory.

Information on historical discharge rates, its salinity and chemical composition at each measurement location can be retrieved from the database. The preparation of output for the yearbooks is started by a simple command procedure. A description of the database system and the corresponding computer programs is presented in Report 18.

Fig. 3
Quantity and salinity of drainage water discharge to the sea, 1984-1993



Yearbooks

Yearbooks, summarizing the results of the monitoring programme are published on a regular basis. For the period 1980-1983 the data concerning discharge and chemical composition were published separately for each of the Eastern, Western and Middle Delta. These data are given on a monthly basis in the Reports 4, 5, 10, and 11. Since 1984 results of the monitoring programme of the three delta parts are combined. The yearbooks consist of two parts, the first one deals with calculated monthly discharges and total salt loads per location in the Delta, while the second part gives the average monthly chemical composition per location. The aim of these yearbooks is to present the discharges and salinity of drainage water as the basis for further analyses of the results obtained through the monitoring programme (Reports 13, 14, 15, 31, 32, 33, 34, 35, 37, 38, 39).

The discharges of the pumping stations which are based on recent stage-discharge relations for each individual pump, have been compared with the discharges calculated by the Mechanical and Electrical Department of the MPWWR. When significant differences are noticed, the rating curve of the pump station is recalibrated.

The data yearbook includes an introductory part which summarizes the annual quantity of drainage water flowing to the sea and the reused portion in each of the three Delta regions, East, Middle and West. It also gives a classification of

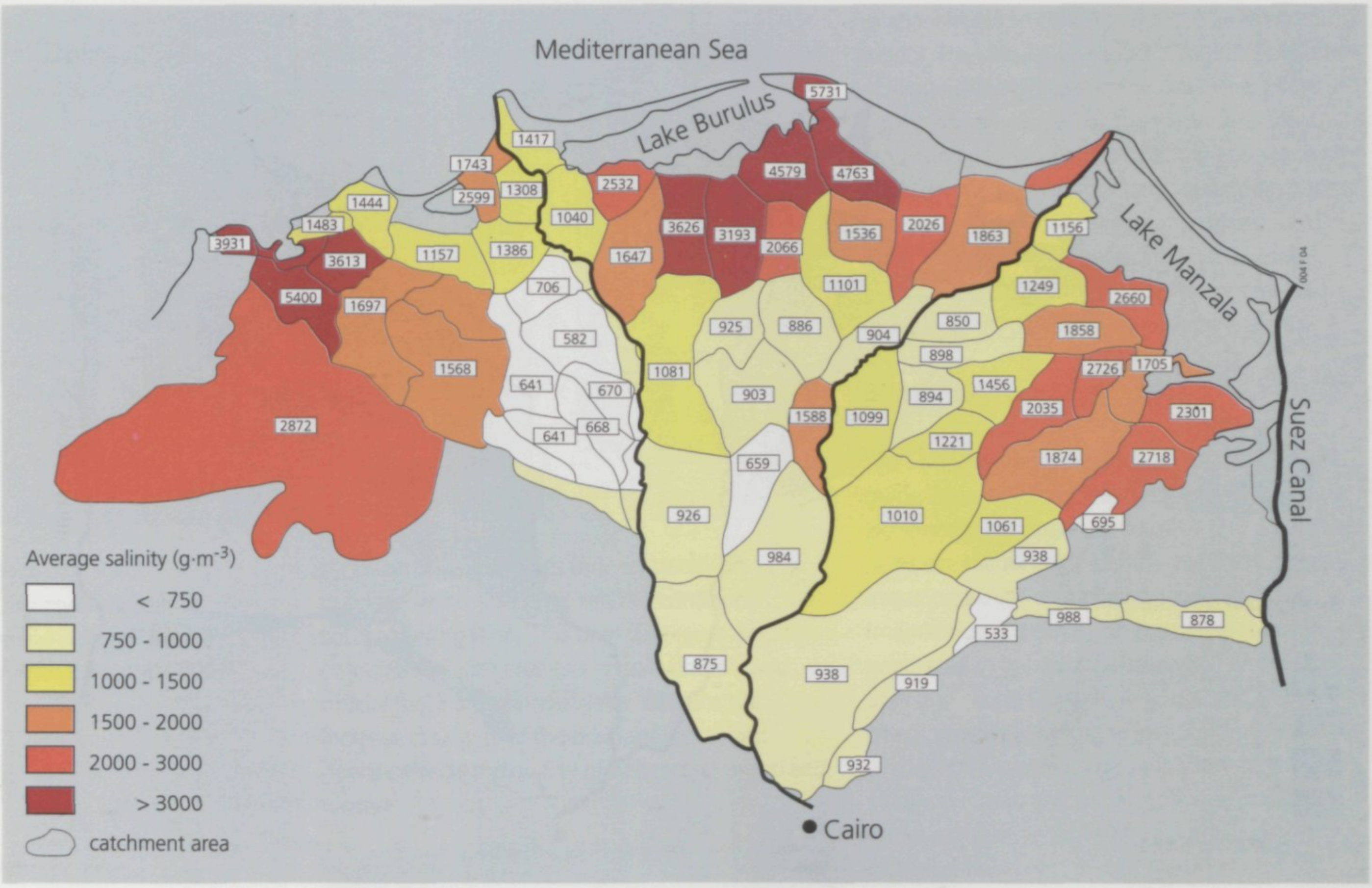


Fig. 4
Average salinity of drainage water in the Nile Delta, 1992/1993

the drainage water flow to the sea according to its salinity. It also presents delta maps showing the spatial distribution of the drainage rates, drainage water salinity and adjusted SAR over the Delta.

3.2.3 Overview of available drainage water

The drainage water monitoring programme clearly reveals that the drainage water quantity changes with time. The variations occur from month to month, season to season and year to year. The annual variations are primarily dependent on water use policies and the management of the main supply system, in particular the releases of the High Aswan Dam. The total drainage water discharged annually to the sea has varied from a maximum of $13.7 \cdot 10^9$ m^3 in 1984/1985 to a minimum of $11.5 \cdot 10^9$ m^3 in 1988/1989 as shown in Figure 3. The salt concentration in the drainage water depends on the quantity and salinity of irrigation water, soil salinity, groundwater salinity, distance from saline lakes or sea, climate and water management practices. Figure 4 illustrates the annual average drainage water salinity within each drainage catchment area in the Delta for the year 1992/1993. It shows that the drainage water salinity in the southern part of the Delta is low and ranges between 750 to 1000 $g.m^{-3}$ as it is only affected by irrigation water salinity. In the middle part of the Delta, where soil salinity is moderate, the drainage water salinity ranges from 1000 to 2000 $g.m^{-3}$. This rise is attributed to the salts originating from seepage of saline groundwater and from desalinization of soils through subsurface drainage. In the most northern part of the Delta parallel to the sea coast, drainage water salinity is high and reaches more than 3000 $g.m^{-3}$ in some locations. This is due to artesian upward seepage of saline groundwater, sea water intrusion and high soil salinity in this part of the Delta.
The average drainage rate during 1992/1993 per

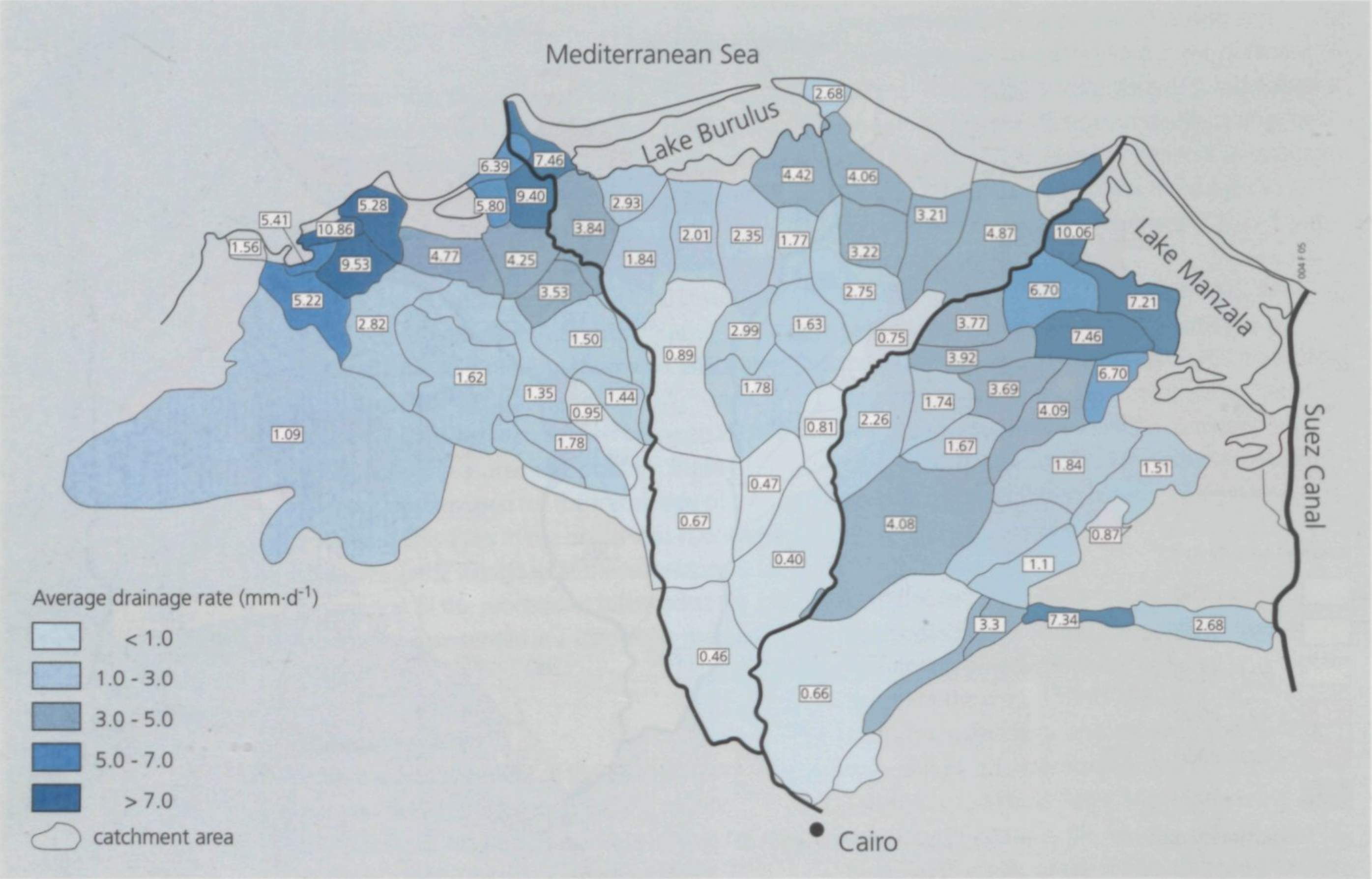


Fig. 5
Average drainage rate in the Nile Delta, 1992/1993)

drainage catchment area is shown as a typical example in Figure 5. The drainage rate is quite low in the south of the Delta where the water-table is low and natural drainage is high. The situation in the north is different. Extremely high rates were recorded in the catchments adjacent to the coast. There is no doubt that in these areas where the drainage rate exceeds the irrigation rate, a significant portion of the drainage water is not merely excess irrigation water. The northern parts of the Delta are subject to upward seepage of brackish groundwater. This seepage water is partly responsible of the high rates in the northern catchments. Another reason for the high rates in the north of the Delta is the high intensity of rice cultivation.

The low flows of the Nile water during the 1980s were associated with a reduction in the total official reuse of drainage water (Fig. 6). The volume of drainage water which was annually reused during the period 1984/1985 to 1992/1993 varied from $2.7 \cdot 10^9$ m^3 in 1987/88 to $4.2 \cdot 10^9$ m^3 in 1990/91. This water was pumped into irrigation canals and mixed with volumes of fresh water depending on the salinity of the drainage water used. The highest quantity of drainage water reused is currently in the Middle Nile Delta.

Both unused and reused drainage water has become steadily more saline since 1984. In 1984/1985 the reused portion had an average salinity of 860 g.m^{-3} (0.135 S.m^{-1}); by 1992/1993 it was 1200 g.m^{-3} (0.19 S.m^{-1}). This trend is also seen in the salinity of the unused drainage water as shown in Figure 7. The trend towards increased drainage water salinity has been reversed since the beginning of the 1990s but the salinity level is still higher than at the beginning of the monitoring programme.

Based on field observations, a conservative estimate of $2 \cdot 10^9$ m^3 was unofficially reused by farmers withdrawing directly from the drains. Lands along the main drains are located at the tail-ends of the supply irrigation canals where a

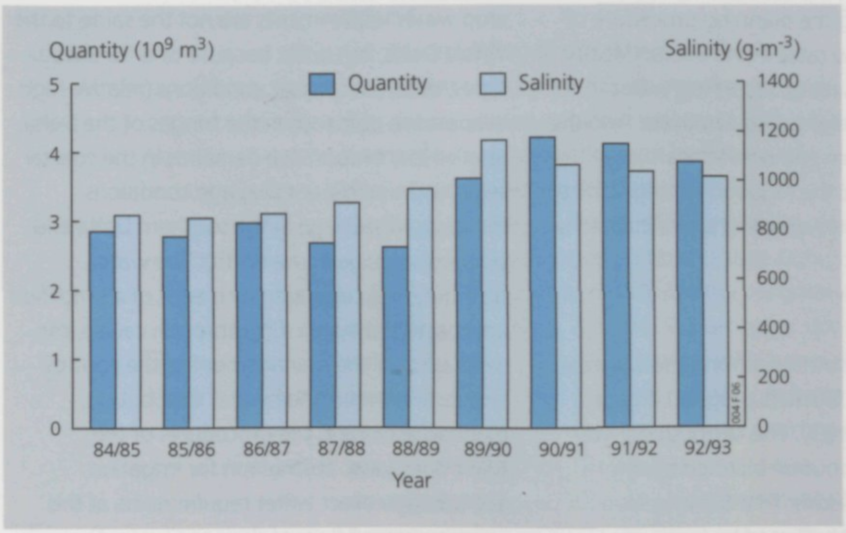


Fig. 6
Quantity and salinity of reused drainage water in the Nile Delta, 1984-1993

shortage of water forces farmers to rely on drainage water as a more reliable continuous source for irrigation. This unofficial reuse, in combination with changes in water supply and official reuse of drainage water, explains the increase in salinity of the drainage water and directly affects the quality of water discharged and reused.

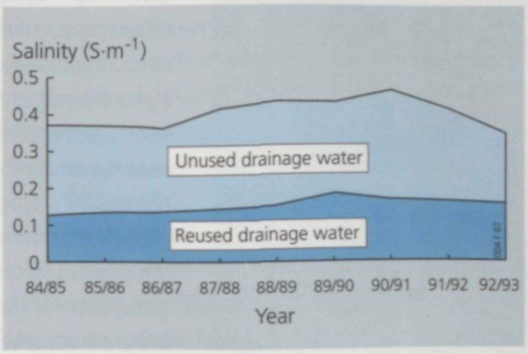


Fig. 7
Salinity of reused and unused drainage water in the Nile Delta, 1984-1993

3.3 The SIWARE model

One of the fundamental limitations in the planning of future irrigation water management in Egypt is that changes in the quantity and salinity of reused drainage or irrigation water as a result of changes in water management, cropping patterns or other developments cannot be derived from historical data on drain discharge and salinity. The proper procedure for predicting changes in such complex situations is to formulate all relevant physical, hydrological, agronomical and functional relationships and combine them in a simulation model. The simulation model SIWARE (*SI*mulation of *W*ater management in the *A*rab *R*epublic of *E*gypt) was developed by the RDWP as a tool for predicting drainage water quantity and salinity for any given water management or cropping pattern option. SIWARE is a package of programs and includes a number of physically based models, each having a specific function in the simulation of regional or national water management.

3.3.1 Description

The SIWARE program package (Report 40, User guide Report 27) requires the subdivision (schematization) of the study area into a number of subareas (calculation units). For each subarea irrigation water is supplied through only one (main) irrigation canal and the drainage water generated in the subarea is released to only one drainage canal. Soil type, land use and all other characteristics are more or less uniform within the borders of a subarea. The supply rate to the subareas is assumed to be continuous and irrigation rotation is therefore not included in the model. A flow chart of the SIWARE model, its programs, inputs and outputs is presented in Figure 8.

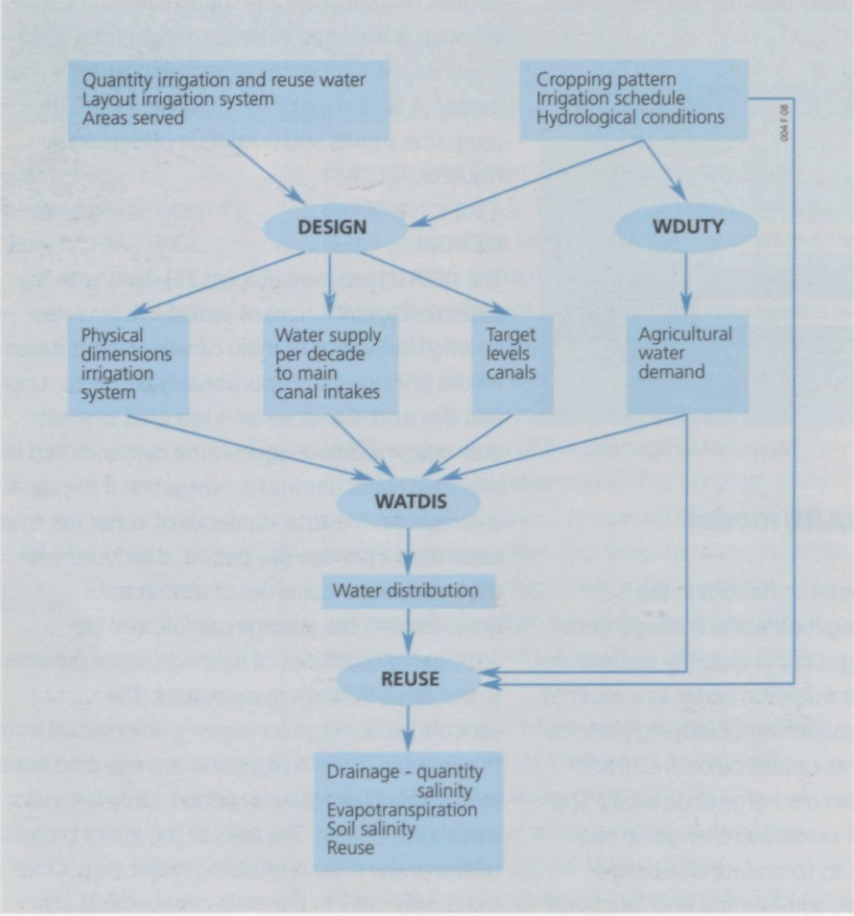
DESIGN

The DESIGN program (Report 25) deals with the allocation (distribution) of available Nile water among the intakes of main canals which is based on the principle of proportionality between supply and demand. Canal water is required to meet domestic, industrial, agricultural demands and to maintain water depths for navigation if the canal is navigable. The total demands of water per main canal intake per ten-day period, is reduced with the anticipated quantities of abstracted groundwater, the average rainfall, and the anticipated quantities of drainage water returned to the canal through reuse pumps. The agricultural demand for water is determined from the area of different crops and average crop water requirements per ten-day period. Only ten major crops are included. The area of the minor crops is added to the most resembling major crop. Once the supply rates to the main canal intakes are determined according the planning procedure of the MPWWR, the flow rates in the (hierarchical) canal system are calculated, assuming water distribution proportional to the demands. Also the water depths upstream and downstream of control structures and the required settings of the control structures (gates or weirs) are calculated as an option.

WATDIS

The actual water distribution among the subareas is calculated with the WATDIS program (Report 25, User guide Report 23). This distribution will deviate from the distribution planned by the MPWWR for three reasons. First the irrigation capacity of irrigation tools used by farmers is in reality higher than was assumed in the original design of the irrigation canal system (use of diesel pumps instead of sakkias). Secondly, farmers tend to over-irrigate their crops to a certain extent in order to cope with rough land levelling. Lastly the crop water requirements are not the same to the whole Delta, but differ because of different soil types, different climatic conditions (relative high evaporative demands in the fringes of the Delta, relative low evaporative demands in the coastal regions) and different seepage conditions (downward seepage in the southern Delta and upward seepage in the north). The water distribution is calculated by means of a simplified approach of dynamic flow through canals, the simulation of the management of the control structures conform the water distribution, planned according the procedures of the MPWWR, water abstraction for irrigation according to exact water requirements at this location, return flow of drainage water through reuse pumps and water withdrawal for municipal and industrial use.

Fig. 8
Flow chart of the SIWARE model, its programs, inputs and outputs



WDUTY

The water requirements of each crop in each calculation unit for each irrigation interval is calculated with the WDUTY program. The potential evapotranspiration is calculated from local meteorological stations and tabulated for different crop heights and soil cover. The actual evapotranspiration is bound to the potential evapotranspiration and is reduced when moisture stress, depending on crop physiology, is experienced between two successive irrigations. In the WDUTY program effects of soil salinity on evapotranspiration is ignored in order to calculate the maximum possible evapotranspiration. For the calculation of the actual evapotranspiration the program assumes abundant water supply. The total quantity, however, depends on the moisture deficit, on-farm conveyance losses and drainage losses during and after irrigation. Furthermore, seepage or leakage is accounted for. The total quantity of water passing the soil surface is limited by the maximum infiltration opportunity time of the different crops, expressing their susceptibility to prolonged oxygen deficiency. The average actual evapotranspiration is equal to or less than the potential evapotranspiration. The actual evapotranspiration calculated by the WDUTY program is referred to as the maximum or optimum evapotranspiration.

REUSE

For the simulation of drainage from the calculation units by the REUSE program (Report 22), the calculated irrigation water abstraction by farmers in each calculation unit is distributed proportionally among the field crops. Use of drainage water for supplementary irrigation within certain limits when water shortage occurs, is a farmer's decision and built into the program as a decision procedure. This use of drainage water is referred to as unofficial reuse and is withdrawn from either the regional drains or the local drains or from both. Nevertheless when water shortage remains, water is distributed according to the drought sensitivity of crops ('farmers preference'). It is virtually impossible to include all field plots of all the crops in the program calculations. One representative plot for each different major crop is considered in the program instead. A special algorithm is included in the program to determine the agricultural drain discharge and salinity, evapotranspiration, seepage and leakage, and soil salinity evolution for the whole calculation unit on the basis of corresponding calculated outputs of each representative plot. Furthermore the program calculates the salinity water in irrigation canals resulting from mixing with drainage water at the delivery side of reuse pumps and upward seepage of saline groundwater in seepage effected areas.

FAIDS

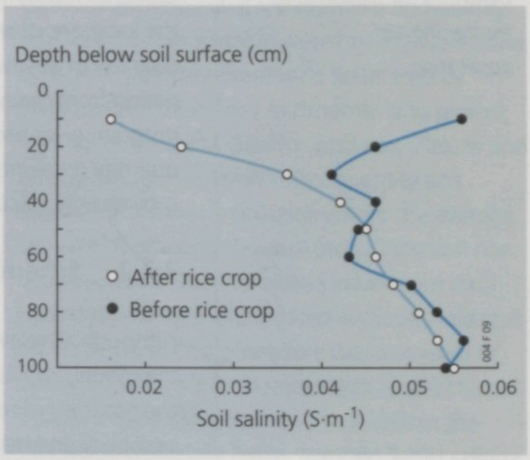
The application efficiency is determined by the FAIDS program (Report 29) through the simulation of the field irrigation. This program is built into both of the REUSE and the WDUTY programs.

The calculations include the determination of on-farm conveyance losses, the movement of a water front across a representative field plot during irrigation, the simultaneous infiltration and loss of water at locations in the plot where the total infiltration exceeds the water holding capacity of the soil or losses due to surface runoff. The total infiltration is restricted by either the supplied quantity of irrigation water or by the maximum infiltration opportunity time, which is determined by the sensitivity of crops to prolonged oxygen deficiency in the root zone. The program determines the leaching of salts from the soil during the irrigation and subsequent drainage. On shrinking and swelling soils the losses of water during irrigation through the cracks to the drainage system is considered ('rapid drainage'). As the swelling proceeds the rate of the losses diminish and become insignificant when swelling is complete.

Water losses to the atmosphere through evaporation from the soil surface and transpiration of crops, to the drainage system, and recharge (leakage) or discharge (seepage) of the groundwater system are calculated for each representative field plot during each period between two successive irrigations. The leaching rate of salts from the soil and the redistribution of salts in the soil profile (Fig. 9), including the effect of upward capillary flow to the root zone, are also calculated during this period.

Fig. 9

Example of soil salinity distribution before and after the rice growing season



The quantity and salinity of drainage water from all representative field plots are combined and transformed through a special algorithm in the REUSE program, considering resident time, to the drainage of the whole calculation unit. This quantity and its salinity is combined with spill losses from distributaries, disposal of sewage water and losses over the tail-ends of irrigation canals and added to the regional drains. The regional drains are considered as part of a hierarchical canal system where flow rates are not subject to dynamic changes. The flow rate changes when reuse pumps withdraw water from the drain, when drainage water from calculation

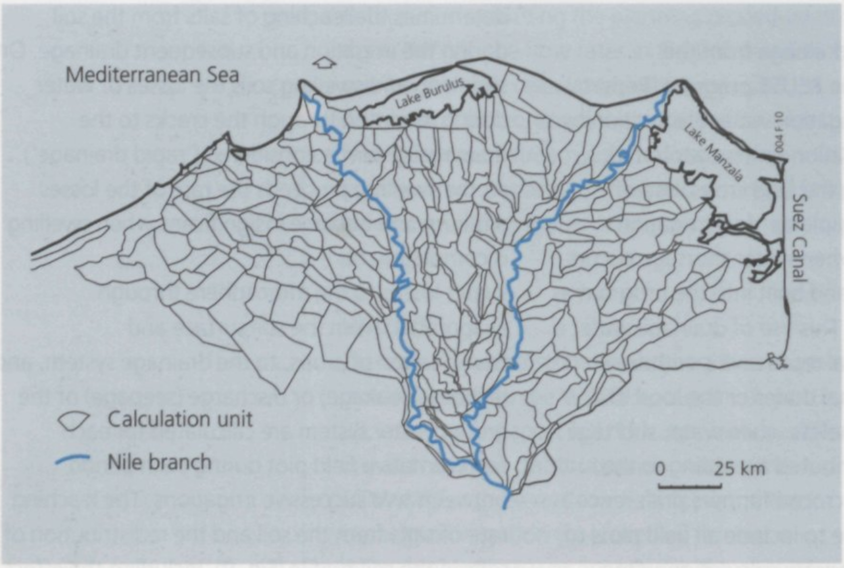


Fig. 10
Subdivision of the Nile Delta into calculation units for the SIWARE application

units is disposed or when canal seepage occurs. Both the salinity and flow rate in the regional drains increases in seepage affected regions. At the locations of reuse pump stations the actual quantity of abstracted drainage water per ten-day period from drainage canals is calculated. The program gives a warning when the anticipated quantity or salinity cannot be realized and provides the calculated quantity and salinity.

3.3.2 Schematization and input data

Although all relevant processes were simulated in the model, implicit simplified assumptions limit the accuracy of model output. Also spatial variability and heterogeneity cannot be considered to the extent of their real occurrence, so averaging and regional schematisation are necessities when applying the integrated regional water and salt management model SIWARE to all parts of the Nile Delta.

The Nile Delta has been schematized into a number of subareas according to the model requirements and are to a certain extent uniform with respect to soil hydrological, climatic and water supply conditions. The subdivision of the Delta by the MPWWR in administrative units, the so-called Irrigation Directorates for the management and operation of the water distribution system and the further subdivision of these Directorates into Irrigation Districts with a different number of distributary canals, has been reckoned by the model. Since the model calculation follows both the irrigation system hierarchy and the drainage system hierarchy, these districts have been split up into smaller units. The Nile Delta has been subdivided into 285 calculation units, of which 88 in the Eastern Delta, 116 in the Middle Delta and 81 in the Western Delta (Fig. 10).
The input data required for running the model are described below. They comprise five main groups.

System layout
This group of data includes the lay-out of the irrigation and drainage canal system, the position of control structures, reuse and drainage pump stations, major water intake points for drinking and industrial water (abstraction rates by minor intakes are combined per calculation unit) and the areas served downstream a number of strategic locations along the irrigation canals.

Soils and climate
This group of input data includes a soil map and a description of the physical characteristics of the different soil types, a map with thickness of the clay cap overlaying the aquifer system, together with a description of its physical characteristics. Information on rainfall and data for the determination of the potential evapotranspiration (net radiation, wind velocity, relative humidity, temperature, hours of sunshine) are required.

Agriculture
Data in this group comprise crop physiology: crop growth development, sensitivity to oxygen deficiency, moisture deficit and salt stresses, and furthermore data related to farm management: irrigation schedules of different crops, crop rotation and capacity of irrigation device (sakkia or pump).

Water management
This group of data relates to the total water demand: average crop water requirements, areas grown with different crops in different regions, water requirement for municipal and industrial water use, navigation requirement and conveyance losses. Also included are data regarding the available water resources

comprising quantity and salinity of Nile water, anticipated quantity and salinity of reused drainage water, groundwater abstraction for supplementary irrigation and its salinity, and drinking water supply and return flow of sewage water and salinity. Also data on drain depth and spacing are required. Finally information concerning the water allocation procedures, which in general have a legal and operational background, and the priority ranking of different water users goes with this group of data.

Domestic and industrial water use

Data in this group deal with the locations, source (surface or groundwater) and required abstraction rates of water for municipal and industrial water use. Also included is information on the location, rates and salinity of released sewage water to either irrigation canals or the open drains.

3.3.3 Calibration

The SIWARE model is usually applied to an area of several million feddan for which the amount of input data required is proportional to the size of the calculation units. In practice, there are three types of input data: (1) data which fully comply with the model requirements, (2) data obtained through interpolation, extrapolation or averaging, and (3) data on observed but not determined (i.e. not measured) parameters for which expert judgments were used. Model calibration includes the adjustment of uncertain parameters (input data of the second and third type) through matching the calculated drainage water discharge and salinity with the observed rates and salinity. The change in the calculated output when a certain parameter is changed, reflects the sensitivity of the model for that particular parameter. The model result, especially the drain discharge, is rather sensitive for the sowing or planting dates of crops, the irrigation schedule and rooting depth. The magnitude of the calculated drainage water salinity, is sensitive for the clay cap thickness in conjunction with the aquifer pressure and the salinity of the groundwater. Parameters belonging to the second data type were varied within ranges complying with the local variability. In general the ranges are limited and bound to the local minimum and maximum values of the parameter. Parameters of the third data type may be varied according to the logic of the parameter. These parameters concern the over-irrigation, the maximum unofficial reuse, farmers irrigation practice (operation of pumps, water distribution among crops) and the operation practice of level control structures.

Data on spatially distributed hydrological characteristics were limited and for model applications interpolation and extrapolations were necessary. These data belong to the second type. They include clay cap thickness, soil hydraulic conductivity, drainage resistance and piezometric head in the aquifer. The variability in these data is large in delta areas where soil heterogeneity is generally high. Special field and laboratory measurements were executed for those soil physical data that were not or insufficiently available from existing data and literature.

Data concerning initial soil moisture and salinity, and depth of water-table were not available (data type 3). These data have been generated by running the model for a sufficiently long period, with constant input data for land use, climate and distribution of irrigation water quantity and quality, to arrive at a situation where the average soil salinity remains constant (no salinization nor desalinization). The calculated initial input data have been verified with limited available field and literature data. This procedure was also used to obtain a steady state situation with respect to soil salinity in recently reclaimed saline soils in the Western and Middle Delta. The calculated salinity of drainage water from these areas deviated from the observed salinity because desalinization of these ares still occurs.

Model parameter estimation (calibration) and checking their accuracy (validation) have been performed at four levels for which measured data were available:

- at command canal level for water allocation (DESIGN);
- at irrigation canal level for water distribution within irrigation canal commands;
- at drainage catchment level for the integrated result of hydraulic and operational relations in the irrigation canal network, irrigation water supply, farmers irrigation practise, field water distribution, evapotranspiration, drainage and

salt accumulation relations, including official and unofficial reuse of drainage water (REUSE);
- at drainage catchment and composite catchment level, based on the measured data from the monitoring programme of DRI.

Calibration is virtually the adjustment of uncertain model parameters to obtain a good agreement between the calculated and observed results (drain discharge and salinity) of one single year. The calibration results have been evaluated by the average monthly deviation as a percentage of the calculated values of discharge and salinity from measured data. The adjustments should be continued until the accuracy, specified in this project is obtained (Table 1).

The criteria, presented in Table 1, are reasonably strict, since the error in the model output increases due to error propagation. The drainage discharge of a calculation unit is calculated from the water balance of this unit. All errors introduced by the calculation of the other simulated terms of the water balance are transferred to the calculated drainage discharge. When the other water balance terms are calculated with an average deviation of 10% and if the drainage quantity is 40% or 50% of the irrigation water supply to the unit, then the deviation in the calculated discharge is already more than 30% and 25%, respectively. When the error in the irrigation water intake by control structures equals 5%, then there will be a gradually increasing error in the calculated water supply to the most downstream calculation units which may reach as much as 50%.

The deviation in the salinity is determined by the deviations in the salt load of the different salt balance terms and by the deviation in the drainage water discharge. So all deviations introduced during the simulation are reflected in the monthly deviation of salinity. The criteria for model performance, on basis of discharge and salt concentration of drainage water, require a much smaller deviation in the other water and salt balance terms. Moreover it must be realized that the measured data of drainage water discharge and salt concentration have no specified accuracy and their inaccuracy (Report 16) contributes also to the mean monthly deviation.

Table 1. Pre-set model accuracy criterium for discharge and salinity: the average monthly deviation allowed

Area	Deviation allowed (%)	
	discharge	salinity
Single catchment	30	50
Composite catchment	20	30
Entire study area	10	20

The average monthly deviation of the calculated drainage water discharge and salinity in each single drainage catchment has been sorted in a descending order and plotted against the ratio of the accumulated area of the sorted catchments over the total study area (Fig. 11).

It appears from Figure 11 that the model performance in the Eastern Delta is satisfactory for both discharge and salinity for 99% of the area covered by single catchments (Report 30). All the calibration results of the Middle Nile Delta, whether in terms of discharges or chloride concentrations are in line with the quality criteria for model performance (Report 44). The average deviation of the calculated drain discharge in the Western Delta is less than 30% and 20%, respectively in about 90% and 65% of the area. The limited accuracy for this Delta part can mainly be attributed to large but unknown discharges of industrial and municipal sewage water from the city of Alexandria and unknown seawater intrusion at the suction side of the major drainage pump close to Alexandria (Report 46).

3.3.4 Validation

The model results should be sufficiently reliable for evaluating different water management alternatives. A model is reliable when the calculated drain discharges and salinity are in agreement with measured values for situations where the total Nile water supply significantly deviates from the supply in the calibration year. The reliability is determined by comparing model results with measured values for a number of

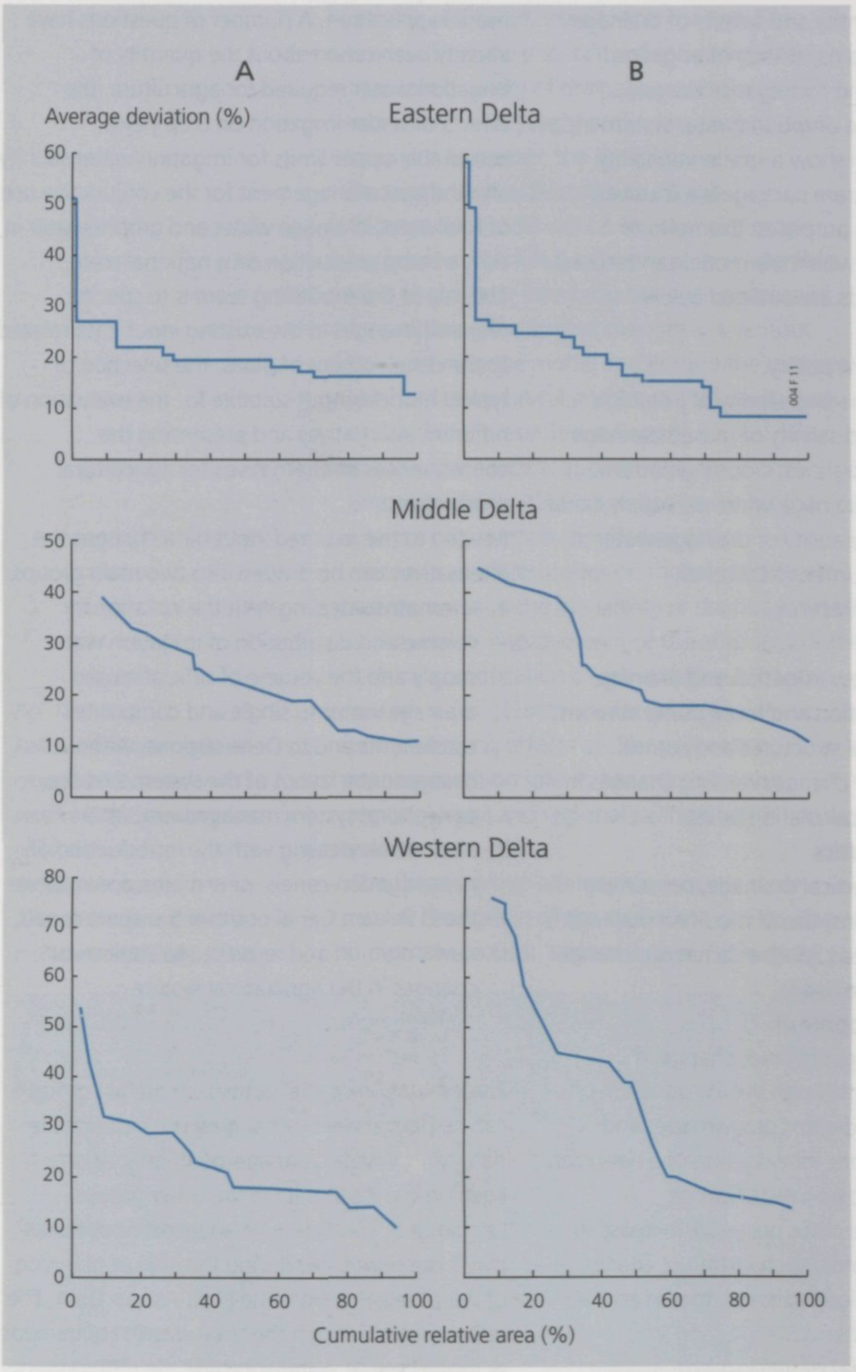


Fig. 11
Model deviation on single catchment scale for the Delta Regions East, Middle and West.
A: discharge;
B: chloride concentration

consecutive years. The calibrated parameters remain unchanged. The model is sufficient reliable when the variation in calculated output (drain discharge and salinity) is within limits similar to the variation in measured values. As yardstick for reliability the predictive value is introduced. This value is obtained in order to calculate the linear relationship (called 'trend') between measured and calculated drain discharge and also salinity. The average deviation of the calculated values from the 'trend' (~ 45^0-line), divided by the range (maximum minus minimum) of measured values is subtracted from 1 and the result, expressed as a percentage, is called the 'predictive value'. The criteria for validation used in this project are: the model is reasonably valid with predictive values of more than 50% and sufficiently valid with a value of 75%. However, when the range is small, the predictive values will be low, even when the calibration is highly successful. The predictive value is calculated for single drainage catchments. Model validation was performed for the Eastern Delta with field data of measured discharge and salinity over the period 1984 through 1988, for the Middle Delta over the period 1985 through 1990 and for the Western Delta for the period 1986 through 1990.

The drain discharge and salinity of the complete study area can be considered as sufficiently validated according to the above-mentioned criteria. For the Eastern Nile Delta, 10% of the area is not sufficiently validated for drain discharge and 20% for salinity (Report 30). In the Middle Nile Delta, the areas not sufficiently validated for drain discharge and salinity are 4% and 15%, respectively (Report 44). The validation for the Western Delta was less successful, which is mainly caused by the small variation in total Nile water supply (3% against 10-12% in the other Delta parts) and the ongoing land reclamation, for which no data were available (Report 46).

The results of the model calibration and validation show that the SIWARE model can be reliably used for the analysis and evaluation of different water management alternatives in the Nile Delta.

3.3.5 Capabilities

Once the model is calibrated and validated for a certain region, it can be applied for different purposes. All applications have in common that they deal with intended changes in water management for which no experience has been gained in the past and for which the medium-term and long-term effects have to be estimated with a certain degree of reliability. Effects are diverse and relate to crop production parameters, soil salinization, quantity and salinity of reused drainage water, quantity and salinity of drainage water in the main drains, salinity of irrigation water, operational and conveyance losses, recharge or discharge of groundwater system etc. In general effects will show a spatial variability. In this view, the program package is exclusively suitable for planning purposes. Examples of different aspects for which the model can be used to estimate the effects are outlined below.

Water management policy

Changes in volume and salinity of irrigation water, volume and salinity of reused drainage water, allocation policies, cropping pattern, effect of mixing drainage water on supply canal water quality, availability of drainage water at specific sites, and intensification of groundwater abstraction;

System layout

Introduction of new irrigation and drainage canals, new irrigation and reuse pump stations, changes in control structures and control system, any other changes causing changes in the layout of the calculation units;

Physical characteristics

Introduction of vertical drainage, subsurface drainage conditions, use of modified drainage systems in rice areas, land reclamation, change in aquifer pressure head;

Agricultural development

Change in net irrigated area, change in cropping pattern through the introduction of new crops with different growth rates and water requirements, introduction of a new crop rotation system, crop intensification (introducing three crops per year), increase in plot size due to farm mechanization, change in capacity of irrigation tools, changes in applied field irrigation system;

Urban and industrial development

Changes in municipal and industrial water use, changes in sewage flow rates from urban areas and industry.

The role of the responsible authorities during the development of different plans is primary the definition of alternatives they consider useful to be examined. Secondly the responsible authorities have to define questions to be answered through model application. A number of questions have already been raised about the quantity of irrigation water required for agriculture, the effects of under-irrigation on crop yields, acceptable upper limits for irrigation water salinity and the best management for the conjunctive use of Nile water, drainage water and groundwater in view of crop production on a national scale.
The role of the modelling team is to specify required changes in the existing input data related to the development of plans, the selection of typical model output suitable for the evaluation of different alternatives and presenting the consequences of alternatives for agricultural production.
Related to the required input data changes the alternatives can be divided into two main groups:

1. alternatives dealing with the variation in volume and distribution of irrigation water supply and the volume of official reused drainage water to single and composite catchments and to Delta regions, without changing the layout of the system and the agricultural system management;
2. alternatives dealing with the introduction of new irrigation canals, new drains, for instance the El Salaam Canal or other transport canals, new irrigation and reuse pump stations or changes in the agricultural system management.

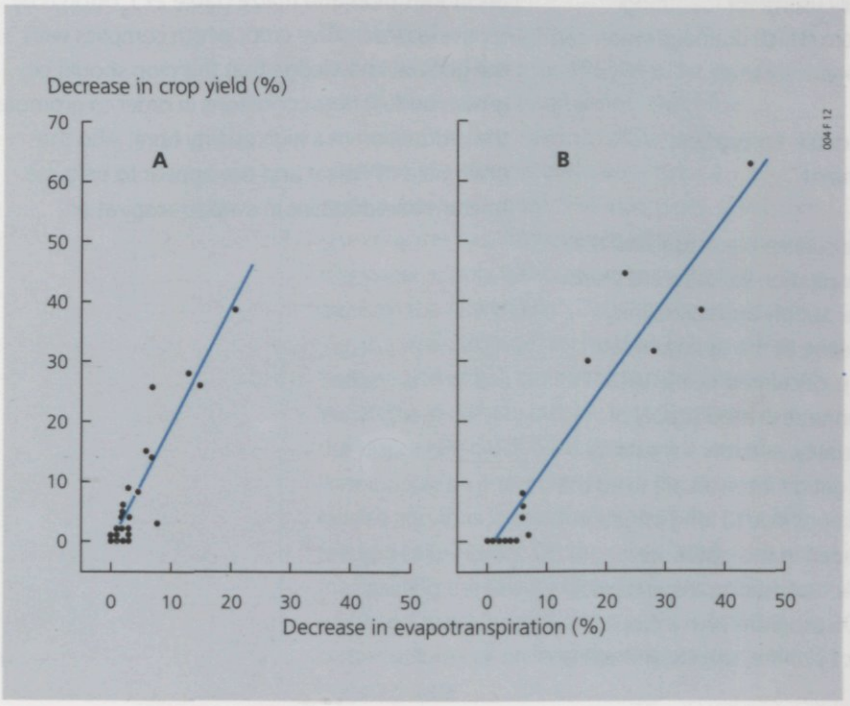
The evaluation of alternatives of the first group can be performed by changing the input of the data group 'water management' only, and keeping the input data in the other groups unchanged. This type of management options play a dominant role during the annual planning of water releases from the High Aswan Dam. The release should match the total water requirement or in the case of water shortage the requirements have to match the available quantity of water in which case the cropping pattern could be adapted by exchanging crops with a high water requirement by crops with moderate or low requirement. When the cropping pattern changes or the supplied quantity of water changes, the quantity of drainage water available for reuse changes too. Because reused drainage water is considered as a source for water, the High Dam releases will be adjusted to this change. The model offers the possibility of estimating the available quantity of drainage water for reuse when the water supply or the cropping pattern changes. Moreover, the model provides information on expected side effects.

Because the model will be used for planning purposes of this kind, a Graphical User Interface (GUI or end-user interface) has been developed for preparing the limited changes in the input data, running the model and getting the required output. The technical and functional description of this GUI is presented in Reports 42 and 43.

Besides these typical applications, the model embedded in the GUI is also applicable for the analysis of the effect of different water management alternatives on the irrigation water distribution and the availability of drainage water in the region, improvement of the efficiency of the system, identification of salt intrusion hazards, identification of locations for additional reuse pump stations, effects of changed water management on salinity hazards, local and regional reuse and regional saving of irrigation water.

The second group alternatives requires more radical changes in all the input data groups. The input data groups: 'system layout', 'soils and climate', and 'agriculture' have to be changed when large-scale changes take place in one or more calculation units.

Fig. 12
Relation between relative crop yield decrease and relative evapotranspiration reduction.
A: long berseem;
B: combination of all crops in Eastern Nile Delta, 1986



Changes in the almost-permanent input data, in particular when the system layout changes, requires highly qualified expertise to adapt all the input files correctly. An Expert User Interface (UI) has been developed, for experts present at DRI, to deal with the required input data operation. The technical and functional documentation of this interface for expert users of the SIWARE system is given in Report 41.

3.3.6 Output

The different programs of the SIWARE model package generate output for other programs in the package, as well as output which may be of the interest of the user.

The DESIGN program provides an overview of the main canal system and it provides for each canal a table with the area served, the industrial and municipal water use, the required intake rate during each ten-day period and the anticipated reuse.

The WDUTY program prepares for each crop in the area under consideration a table with the weighted average, the minimum and maximum calculated water requirement per irrigation interval.

The WATDIS program generates for the whole study area a table with the total monthly irrigation water supply, the (official) reused quantity of drainage water, the abstraction of irrigation water by farmers, and conveyance, spillway and tail-end losses.

The REUSE program generates output in a graphical form. This output (presented on a map) gives all input data (eg. soil type, depth of subsurface drainage, salinity of groundwater in the aquifer, cropping pattern etc.) and the output of the simulations which includes drainage rates, drainage water salinity, soil salinity (root zone), desalinization or salinization, seepage or leakage, evapotranspiration, irrigation water supply, unofficial reuse of drainage water and several system performance indicators. A table is generated with the different components of the water and salt balance per calculation unit on an

Table 2. Threshold value for evapotranspiration reduction above which the ratio of crop yield reduction and evapotranspiration reduction is valid

Crop	Evapotranspiration reduction threshold value (%)	Ratio of yield reduction and evapotranspiration reduction (-)
Wheat	2.0	1.11
Long berseem	1.3	1.98
Short berseem	1.5	1.81
Winter vegetables	2.9	1.57
Cotton	1.8	0.70
Maize	-1.5	2.55
Rice	0.2	0.87
Summer vegetables	2.2	0.95
Trees	12.9	10.55

annual basis. Also a table is generated containing a warning when the anticipated quantity of drainage water for reuse cannot be realized in certain periods, giving the expected quantity (and salinity) instead.

The average discharge rate and the salinity at certain locations along the drainage canals per ten-day periods can be inspected through graphs. This option is especially useful for identifing potential locations from which drainage water can be returned to the irrigation canals.

3.3.7 Crop response to water management

The SIWARE model calculates the actual and the 'optimum' evapotranspiration for different crops. Under optimum water supply and soil salinity conditions crops transpire at the optimum rate. The latter parameter is calculated by the WDUTY program, assuming an unrestricted supply of water quantity and quality, and low soil salinity conditions. As the irrigation intervals are fixed the effects of stress conditions due to long irrigation intervals may be included in this optimum evapotranspiration. Actual evapotranspiration is calculated in the FAIDS program with a crop-dependent function of climate, salinity and soil moisture stress.

The general shape of the crop yield response to soil salinity is a horizontal line until a certain threshold soil salinity value, and a linear decrease in crop yield with increasing soil salinity above this threshold value. For each crop a certain threshold value exists and a certain drop in yield per unit increase in soil salinity and both values depend on the crop's tolerance of salinity.

The major effect of soil salinity on crop response is caused by the increase in the soil water potential due to the osmotic pressure. This means that the major mechanism of the effect of soil salinity on evapotranspiration is similar to the effect of a lower moisture content in the crop root zone (physiological drought). In the model both relations were combined and a relation between relative evapotranspiration and crop yield is obtained and extensively discussed in Report 30. The correlation found following this procedure is rather good (Fig. 12). The reduction in evapotranspiration is therefore used as an indicator of crop yield depression due to soil salinity and/or water stress conditions. The relation found is based on a comparison of the SIWARE calculation results for 1986 with data from international literature.

The crops for which yields are most sensitive to reductions in evapotranspiration appear to be deciduous trees and maize (Table 2). Cotton is by far the least sensitive crop, which complies with the general knowledge that this crop should be grown under stress conditions in order to promote the production of a high quality fibre. Also the grain yield of wheat and rice appear to be quite tolerant to reductions in evapotranspiration.

4 Evaluation of water management alternatives

4.1 Introduction

The major and continuous concern related to water management in Egypt is to attain the utilisation rate of the limited water resources which gives the nation the most prosperity. Depending on the development in different economical sectors, the optimum allocation of water will shift with respect to time and place, requiring a continuous need for the development and planning of water resources. So far the highest priority has been attached to the drinking water supply and the development of agricultural production. Several plans have been developed and executed to extend the cultivated area and to increase the utilisation rate of water. The growing population and rapidly developing industrial sector, however, require increasing amounts of water and therefore the municipal and industrial sectors are expected to be strong competitors for the agricultural sector.

Since water resources are limited, the different plans related to water management focus on the increase in water use efficiency through which certain quantities of water will become available for additional economical activities. The reuse of drainage water has been adopted a long time ago as the most promising and economical attractive means of increasing the utilisation rate of water. The SIWARE model package is a tool for planners and decision makers to determine the maximum rate of reuse of drainage water under the condition that it remains social as well as economical attractive and guarantees a sustainable agriculture. The maximum utilization rate of water has, however, its limits because the Nile water supply, although fully controlled through the Aswan High Dam and Lake Nasser (Egypt's main storage reservoir on the Egyptian-Sudanese frontier), cannot always be guaranteed. Variations in climate outside Egypt, especially in the Upper Nile catchment and the Ethiopian Plateau play an important role in the amount of rainfall and thus in the discharge of the river Nile, feeding Lake Nasser. On the other hand, maintaining the salinity of the Egyptian soils within acceptable limits requires the release of certain volume of drainage water to outside the irrigated area.

Measures related to water management can be implemented at different levels. First, the Ministry of Public Works and Water Resources (MPWWR) has the option to interfere in the total amount of available irrigation water for the Delta. The Ministry might be able to reduce the allocation of Nile water, with adaptation of the cropping pattern, mainly by the reduction of the rice growing area, or with increasing the reused quantities of drainage water. At a lower level within the MPWWR, the internal distribution can be adapted in such a way that the supply follows the agricultural demand more closely in time and space, reducing the operational losses and thus improving system efficiency.

The SIWARE model package was applied for the analysis of six selected water management alternatives in the different regions of the Nile Delta to demonstrate its capabilities. These alternatives are:

In the Eastern Nile Delta:

1 Water saving by replacing rice in the cropping pattern by maize and/or reducing the rice water duty assuming acute water shortage in Nile water supply;
2 Expansion of the agricultural area in the Eastern Desert in annual increments of 44,000 feddans, starting with the situation in 1988 and re-allocation of water among main canal intakes according to the (changed) demands;
3 Improvement of the local water management situation by prohibiting the use of mobile irrigation pumps and/or prohibiting the unofficial reuse of drainage water by farmers;

In the Middle Nile Delta:

4 Stepwise reduction in the water supply and/or water distribution based on local instead of average crop water requirement;
5 Significant change in the cropping pattern;

In the Western Nile Delta:

6 Increase in reuse of drainage water and expansion of agricultural land in the Western Desert.

The detailed analysis of the different options for the water management alternatives 1, 2, and 3 is presented in Report 30, the analysis of the options for the water management alternatives 4 and 5 is given in Report 45 and the analysis of the water management alternative 6 is presented in Report 47.

4.2 Water saving options by replacing rice with maize or reducing the rice water duty

Background

In Egypt, the rate of irrigation water supply to the main canals is determined annually to meet the demand for water. This rate equals the total demand in the area served by the main canals, including operational and conveyance losses, but reduced with the quantity of abstracted groundwater and reused drainage water. Water requirements for agriculture are calculated from the area of different crops (cropping pattern) and water duties for each crop during each ten daily period. For annual planning, it is assumed that the crop water duties are uniform in certain regions (eg. Upper, Middle and Lower Egypt). Farmers in Egypt are in general free to choose the cropping pattern except for rice and cotton cultivation. For rice crop, the MPWWR distinguishes five zones of cultivation. For the Nile Delta in principle rice cultivation is forbidden in the south. In the north, where seepage conditions prevail and the soil is generally saline, rice is permitted on 50% of the area. An example for the distribution of the rice areas in the Eastern Delta is presented in Figure 13A.

To match the water demands with the available resources in periods of water shortage, crops with high water requirements may be replaced by crops with lower demands. In 1988 the available quantity of Nile water for the Eastern Delta was 15% lower than that in 1984. In this year the

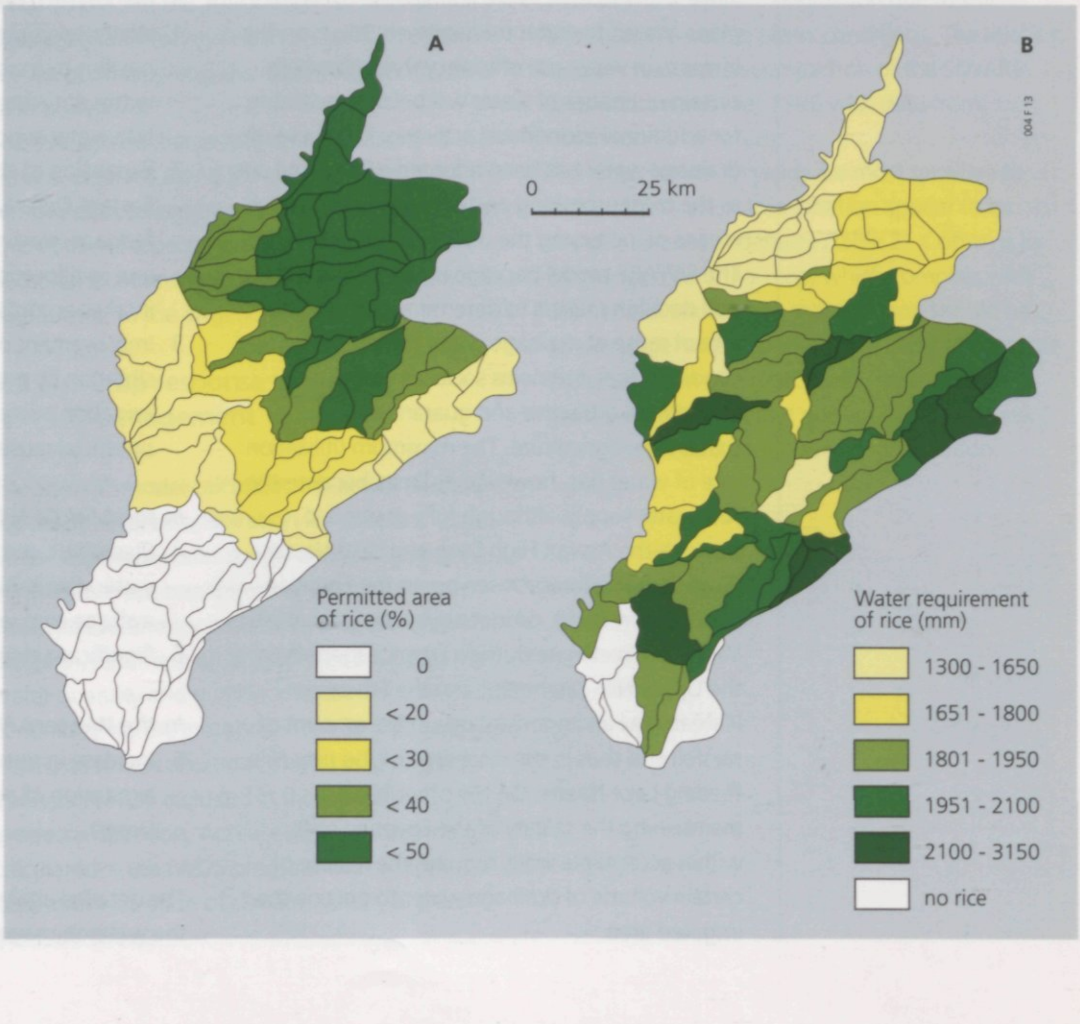


Fig. 13
The Eastern Nile Delta.
A: rice zones showing permitted percentages;
B: calculated water requirements of rice

*Table 3. Water supply, discharge and reuse (in 10^6 $m^3 \cdot yr^{-1}$) in the Eastern Nile Delta**

Year	Supply from Nile	Discharge to sea	Reuse
1984	12,243	4,633	0,801
1985	11,969 (-2.2)	4,355 (-6.0)	0,804 (+ 0.4)
1986	11,645 (-2.7)	4,281 (-1.7)	0,925 (+15.0)
1987	11,249 (-3.4)	3,948 (-7.8)	0,814 (-12.0)
1988	10,322 (-9.2)	3,652 (-7.5)	0,652 (-19.9)

** Figures in brackets indicate the percentage reduction from the preceding year*

Ministry reduced the rice area but noticed a significant reduction in the quantity of drainage water available for reuse (Table 3), which created considerable problems for the water distribution. The water requirement for rice used in the planning of water distribution is 2100 mm (8800 m^3 per feddan) for the whole growing season, but in practice the actual amount of water supplied to the rice by farmers varies appreciably. Values ranging from 1150 to 2200 mm (4800 - 9200 m^3 per feddan) are found in literature. The water requirement for rice, calculated with the WDUTY program of SIWARE also showed significant geographical variation (Fig. 13B). The calculated average water requirement was 1900 mm (8000 m^3 per feddan), which is about 10 % below the estimated water requirement used by the MPWWR.

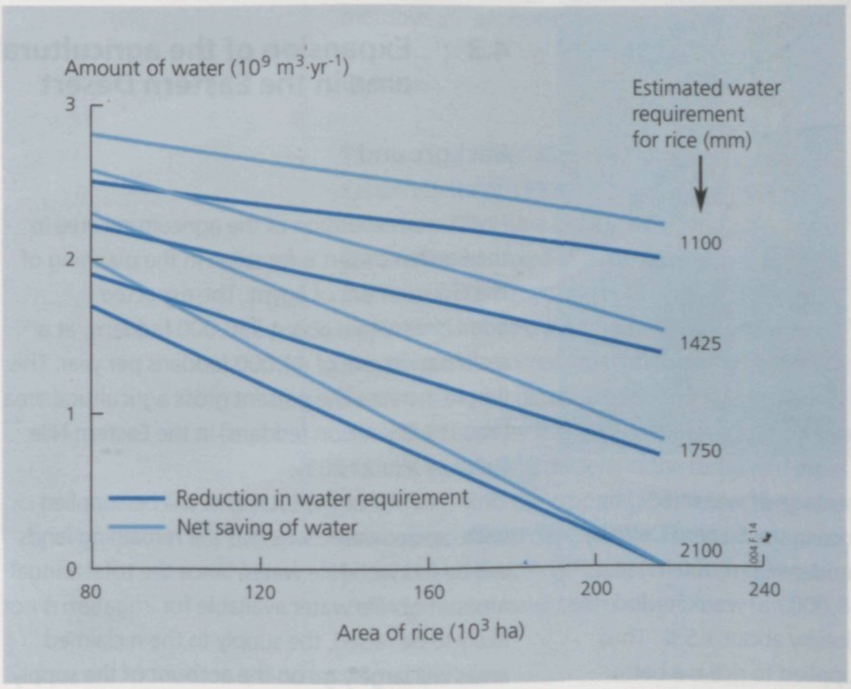


Fig. 14
Reduction in water requirement, and water net savings, in the Eastern Nile Delta for rice

Options

From the observed and calculated variation in water requirement of rice, it was concluded that water could not only be saved by reducing the area grown with rice, but also if these estimated water requirements were reduced. For this reason five rice areas were combined with four estimated water requirements of rice. Maize replaced rice in the cropping pattern in the options with rice area reductions. This resulted in twenty alternative water management options which were evaluated with the SIWARE model (Report 30).

Results

For all these options the relation between the gross water requirement and the amount of drainage water available for reuse was determined with the SIWARE model. The relation suggests that a lower water requirement also leads to a decline in the reuse of drainage water. Thus the net saving of water is less than the decrease in the water requirement. This net saving was calculated for every combination of rice area and estimated water requirement (Fig. 14).
If the area under rice is reduced, the water requirements are reduced with the requirements of rice and increased by the requirement of maize, replacing rice. The difference between both requirements are mainly attributed to the quantity of water required for the rice nurseries and the infiltration losses from the standing water layer in rice fields. Figure 14 shows the amount of water saved when the initial rice area of 214,000 ha is reduced. The difference between the rice water requirement and the maize water requirement is the net saved quantity of water. If, however, the water requirements for rice are reduced, less water is required. The effect of such a reduction is shown in Figure 15. Because rice is one of the main crops in Egypt a reduction in the rice area beyond a certain limit could lead to an increase in imports of foodstuffs which may not be socially and economically attractive.

Reducing the water supply and keeping the rice area unchanged can lead to a deficit of water available to crops during the growing season, resulting in reduced evapotranspiration and reduced crop yields. Evapotranspiration is strongly related to crop yield, thus it is used in SIWARE as an indicator for crop yield. Since the total seasonal evapotranspiration of rice is approximately equivalent to that of maize, total evapotranspiration in the whole study area for each of the twenty options can be used as an indication of the crop yield reduction. From the calculated results it appears that the same water savings can be achieved with less crop yield reductions when reducing the water duty for rice in stead of reducing the cultivated rice area. This can be seen from the relation between water saving and the reduction in evapotranspiration. Reducing the water duty for rice from the present 2100 mm to 1750 mm would result in a 6% water saving at the expense of a 0.25% evapotranspiration reduction (Fig. 15).

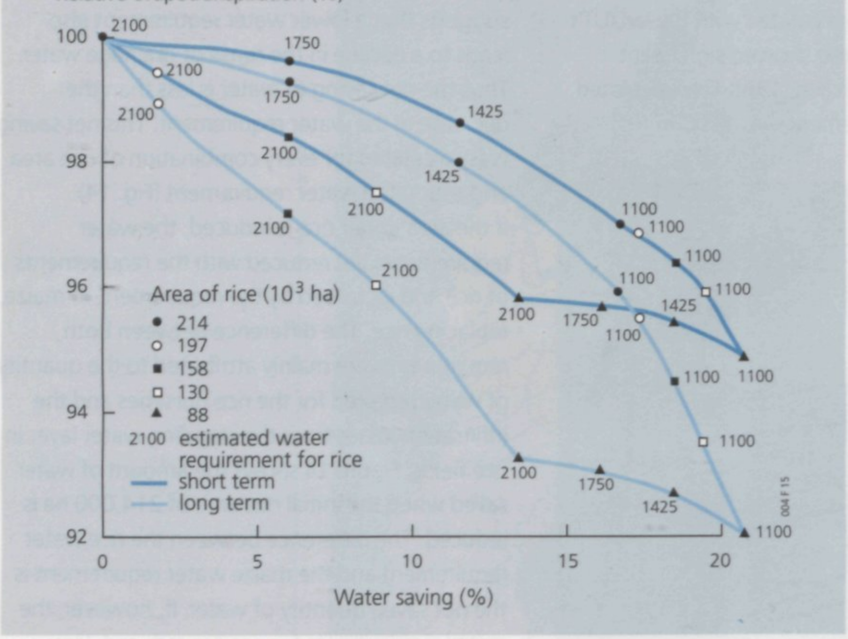


Fig. 15
Maximum and minimum evapotranspiration in the short term (1st year) and the long term (after 50 years)

Saving the same percentage of water (6%) by reducing the area of rice in the Eastern Delta by 25% from 510,385 feddans (214,000 ha) to 375,264 feddans (158,000 ha) would reduce the total evapotranspiration by about 1.5%. Thus reducing the water supplied to rice is a better policy than reducing the area of rice. If water is saved over a longer period there is a chance that the soil will become saline, causing evapotranspiration and crop production to decline further (Fig. 15). In the long term reducing the estimated water requirement for rice rather than reducing the area of rice also seems to be a better policy for combating soil salinity (Fig. 16).

Conclusions

Reducing the area of rice in the Eastern Nile Delta by 30% from 510,385 feddans to 375,264 feddans in 1988, the MPWWR was able to save $925 \cdot 10^6$ m³ water for this delta part compared with 1987. Model calculations, however, show that the same amount of water could have been saved by reducing the rice area by only 8%, i.e. to 468,356 feddans, and simultaneously reducing the water duty of rice from the usual 2100 mm to 1750 mm. The policy followed in 1988 resulted in a 2% reduction in evapotranspiration. This is roughly equivalent to a 3% lower crop yield. This reduction could have been reduced by half by applying the above alternative while total rice production would have been reduced by only 8% instead of the 30% reduction following the policy of 1988.

4.3 Expansion of the agricultural area in the Eastern Desert

Background

Horizontal expansion of the agricultural area in the Eastern Desert is foreseen in the planning of the Government of Egypt. The expected additional area is about 350,000 feddans, at a reclamation rate of 44,000 feddans per year. This would increase the present gross agricultural area (about 1.83 million feddans) in the Eastern Nile Delta by almost 20%.
Only 7 to 8% of the total area will be supplied with groundwater, whereas the remaining lands will be fed with Nile water. Since the total annual amount of Nile water available for irrigation is not likely to be raised, the supply to the reclaimed areas will largely go on the account of the supply

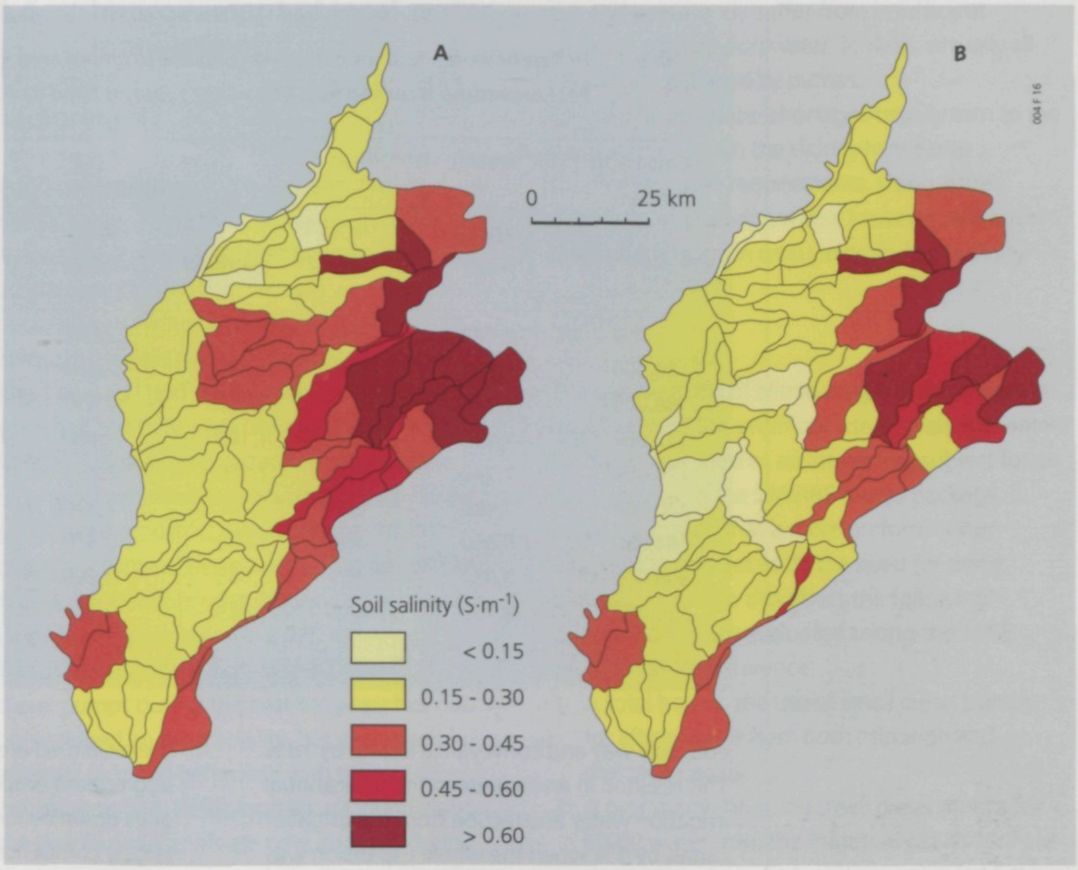


Fig. 16
Soil salinity in the Eastern Nile Delta in the long term, for two scenarios, both producing a water saving of 13.5%.
A: a 59% reduction in the area of rice (from 214,000 to 88,000 ha);
B: a 32% reduction in the estimated water requirement for rice (from 2100 to 1750 mm per growing season)

of the old lands. Reuse of drainage water, abstraction of groundwater, storage reservoirs, an improved water management and other irrigation methods are expected to offset water shortages.

Option

The existing water allocation situation in the Eastern Delta of 1988 has been taken as reference. The share of Nile water for the whole Eastern Delta is fixed at a quantity of $10,310 \cdot 10^6 m^3$ per year and allocated to the six main canal intakes, serving the Eastern Nile Delta including the new reclamation areas, proportional to the (changed) demands, following the procedure used by the MPWWR. It is assumed that the actual cropping pattern in the reclaimed areas will be similar to the cropping pattern in the existing reclaimed desert areas. Furthermore the possibilities for both official and unofficial reuse of drainage water have been fully utilized.

Results

The SIWARE model has been applied to evaluate the effects of the step-wise expansion of the cultivated area on the total evapotranspiration and system efficiency. Moreover the long-term effects (after 50 year) have been evaluated after the total expansion of 350,000 feddans was realized.

The calculations showed a decrease in the Nile water supply to the old lands between the Damietta Nile branch and the Suez Canal as a result of cultivating new areas. Until an expansion with 132,000 feddans the reduction in allocation for the canals serving the old lands follows the reduction for the total area more or less linearly. A further expansion causes a relative higher share of the total supply to be diverted to the old lands, due to a disproportional fall in the official reuse in this area.

The total quantity of official reused drainage water decreased by 28%, which was partly compensated by a decrease in system losses (tail-

Table 4. Different water balance components of the irrigated area in the Eastern Desert if a stepwise expansion is carried out. Nile water supply is fixed at 10,310·10^6 m^3 per year.

Expansion (feddan)	Quantity (10^6 $m^3 \cdot yr^{-1}$)					Total evapotranspiration (%)
	irrigation water	reuse official	reuse unofficial	system losses	total drainage	
0	7,780	622	1,130	2,690	4,260	100
44,000	7,830	600	1,110	2,630	4,130	101
88,000	7,870	575	1,100	2,550	4,030	103
132,000	7,910	550	1,100	2,480	3,940	105
176,000	7,940	525	1,100	2,430	3,850	106
220,000	7,980	500	1,100	2,370	3,750	107
264,000	8,000	480	1,090	2,330	3,650	109
308,000	8,050	465	1,085	2,260	3,600	110
350,000	8,100	448	1,085	2,220	3,540	111

end, spill way and conveyance losses) by 18%. This resulted in an increase in the total annual irrigation water abstraction from the irrigation canals by 4% when the whole expansion was implemented. The total unofficial reuse remained almost constant. As a consequence of the lower irrigation water losses and crop drainage, the calculated total discharge at the drainage outfalls is reduced considerably (17%) for the maximum expansion (Table 4).

Differences in evapotranspiration as calculated for the various crops are considered to be indicative for the changes in crop production. Generally, crop production will decline in the old lands as a direct result of the fixed Nile water allocation for the total area, leading to water and/or salinity stress conditions for the crops. Production in the reclaimed areas should compensate for these losses, and should yield a reasonably extra quantity which could be economically attractive. It appeared from the model calculations that an expansion of the arable land may indeed raise the country's crop production. The calculations showed an 11% higher aggregated (all crops) evapotranspiration after the last expansion has been brought into production. Comparing the 11% with the 17% expansion of the total net cropped area, the conclusion can be drawn that the reclaimed areas perform quite well. The aggregated evapotranspiration in the old land goes down by more than 5%, which can be largely compensated by an increase in evapotranspiration in the reclaimed desert areas. The long-term analysis also reveal that the aggregated evapotranspiration can be maintained during a period of 50 years in the total area, despite a small increase in average soil salinity, mainly concentrated in the old lands.

Conclusions

The expansion of irrigated land in the Eastern Desert with 350,000 feddans, keeping the total Nile water supply to the Eastern Nile Delta constant is feasible from a viewpoint of total crop production. An expansion corresponding to 17% of the net cultivated area in the old lands (reference 1988), would result in a total increase in the evapotranspiration by 11%, even on the long term. This increase in evapotranspiration is more or less justified by the expected increase in crop production. A study of this type requires further economic analysis.

4.4 Improvement of local water management

Background

In the past the irrigation water distribution in the Nile Delta appeared to be more equitable than nowadays. The traditional irrigation water practices were such that farmers were exclusively using sakkias (water wheels) for irrigating their fields. The supply pipes to the sumps from which these devices lifted their water had a limited diameter and they were under the control of the MPWWR. The limited capacity of the sakkias regularly compelled farmers to irrigate by night and tended to restrict over-irrigation, thereby creating a more uniform abstraction pattern and thus a more uniform distribution of the available amount of water over the area.

The gradual introduction of small capacity mobile diesel pumps during the past ten years has not only created an overcapacity, but also strongly affected farmers' behaviour with respect to irrigation timing. Fields located upstream along the distributary canals are now irrigated during the early morning using relatively large quantities of water during a relatively short period of time. As a consequence farmers with field plots downstream the canal would be confronted with water shortages. This situation sometimes aggravates to such an extent that plots at the very tail-end persistently suffer from insufficient amounts of irrigation water. To date, virtually all sakkias are replaced by pumps.

Farmers facing water shortages usually turn to the nearest drainage in the vicinity in order to supplement their requirements. Using large quantities of drainage water, however, will have profound effects on crop yields and soil salinity.

Options

The combination of eliminating the diesel pumps together with the unofficial use of drainage water has been indicated as an interesting subject for an evaluation with the SIWARE model package. It could be argued that a more uniform water distribution may set aside the need for using drainage water. To this effect the following options have been evaluated taking the 1988 situation as the reference:

1 A total ban on the use of small diesel pumps for lifting water from both irrigation and drainage canals;
2 A prohibition on using small diesel pumps for lifting water from the irrigation canals for field application, but not for lifting water from the drainage canals where reuse of drainage water is allowed.

The effects of the second option are expected to be small. The point being that for the reference

Table 5. Major water balance components of the irrigation and drainage systems for different abstraction options. Reference conditions in 1988; (1) - total ban on the use of mobile diesel pumps for irrigation and reuse of drainage water, and (2) - a ban on the use of diesel pumps for irrigation purposes only

Management option	Quantity (10^6 $m^3 \cdot yr^{-1}$)				
	total irrigation water supply	reuse official	unofficial	abstraction irrigation water	total system losses
Reference	10,310	692	1,311	7,788	2,658
1	10,310	683	0	7,810	2,595
2	10,310	537	1,028	7,888	2,366

case the maximum requirements was fully met by the defined number of sakkias. In addition, the total lifting capacity has been augmented here by adding some diesel pumps at the drain to cover emergency situations and to reduce the intensity of night irrigation. Therefore, this simulation run can only show how the situation was before the introduction of these diesel pumps.

Results

The results of the two simulation runs are summarized in Table 5 for the major irrigation and drainage water balance components. It is shown that changes in the farmers' abstraction from the irrigation canals is minimal when compared to the reference, i.e. a mere 1% higher value for the case in which diesel pumps are not allowed for lifting irrigation water (option 2). The reason behind this small increase can mainly be attributed to the more uniform abstraction pattern from the canals, causing lower losses and a more equitable distribution of the available water.

The official reuse logically shows the highest value for simulation option 1, where no water is lifted from the drainage canals for direct crop irrigation, thus leaving more water behind for official recycling. A drop of some 9%, from $1{,}131 \cdot 10^6\ m^3 \cdot yr^{-1}$ to $1{,}028 \cdot 10^6\ m^3 \cdot yr^{-1}$, is noticed for the option number 2 as a result of lower losses from the irrigation system to the drainage system (Table 5).

The irrigation system losses are made up of the following three components: (a) - spillway losses from the distributary and meskaa canals within a calculation unit, (b) - tail-ends losses from the command canals, and (c) - conveyance and evaporation losses from both the command and distributary canals. For reasons outlined before, both options indicate lower system losses. The higher quantities of officially recycled drainage water in the first option are due to the relatively higher losses when compared to the second option (Table 5). It has also been observed that in the absence of the diesel pumps, the losses tend to shift from the spillways within the calculation units to the tail-ends of the command canals.

The total amount of water given by farmers to their crops is composed of (1) - the water lifted from the distributary/meskaa canal system, (2) - the local groundwater abstraction, and (3) - the unofficial reuse of drainage water. Table 6 indicates a decrease in the total annual crop water supply from $9{,}298 \cdot 10^6\ m^3 \cdot yr^{-1}$ for the reference run to $8{,}189 \cdot 10^6\ m^3 \cdot yr^{-1}$ for the option without the use of diesel pumps for irrigation and unofficial reuse (option 1). This implies that the absence of unofficial reuse cannot be compensated by a higher canal water abstraction by the farmers, since the groundwater abstraction remains constant throughout the various simulations. For the last option, the lower availability of drainage water for unofficial reuse is almost fully compensated by a higher abstraction from the irrigation system, resulting in an almost equal supply as for the reference simulation.

The first option, however, appear to benefit from the less need to mix fresh irrigation water and the more saline unofficially reused drainage water. The average salinity of the crop water supply goes down from 445 $g.m^{-3}$ for the reference case to 365 $g.m^{-3}$ when the use of pumps is prohibited (option 1). For the second option, the outcome with 440 $g.m^{-3}$ salts appears much closer to the reference case.

Finally, Table 6 shows that in terms of evapotranspiration a loss in crop production could occur when the unofficial reuse of drainage water were prohibited. In addition, model simulations indicate that no substantial gains are likely to be made when banning the use of diesel pumps for irrigation purposes. Therefore, neither local water management option seems to offer a practical alternative to the present situation, and implementation appears to be unrealistic in any case.

Table 6. Total crop water supply and salinity, and total relative evapotranspiration for different management options

Management option	Total crop water supply ($10^6\ m^3 \cdot yr^{-1}$)	Average salinity crop water supply ($g \cdot m^{-3}$ total salts)	Total evapotranspiration (%)
Reference	9,298	445	100
1	8,189	365	96
2	9,295	440	100

4.5 Reduction of water supply to the Middle Delta

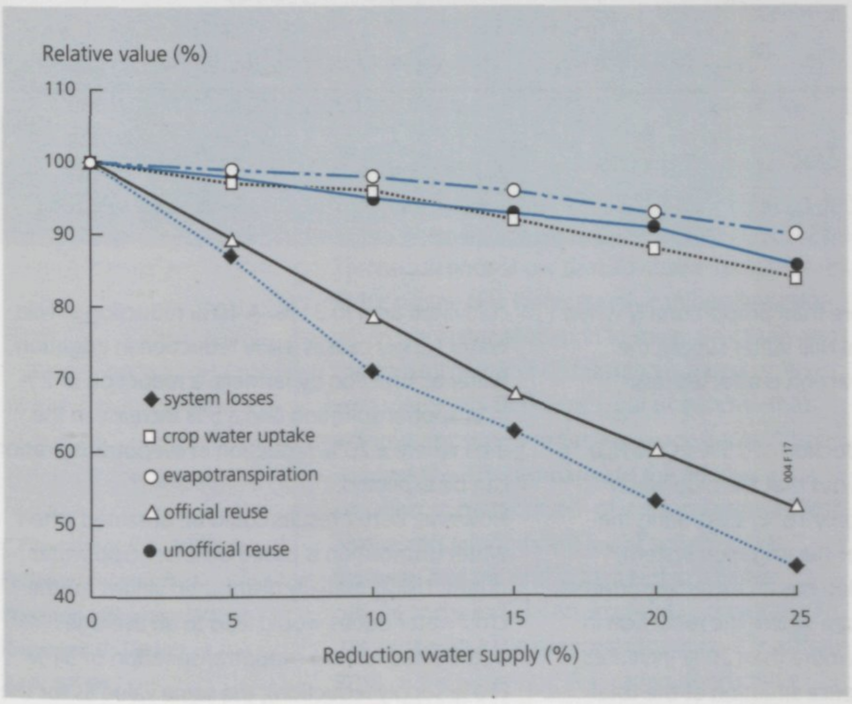
Background

It was shown in Section 4.3 that the expansions of the cultivated area in the Eastern Nile Delta on the account of the water budgets in the old lands have certain limits. For the same delta part it was also shown that a reduction in supply reduced the system losses, resulting in an increased water utilization rate. Assuming that no large-scale future land reclamations in the Middle Delta will be executed, the idea was raised to test the possibilities of reducing the supply to this delta part in order to gain additional quantities of Nile water to be diverted to reclamation projects in other delta parts. The objective of this water management option for water resource development is to reduce the supply as much as possible under the condition that adverse side effects are avoided.

Options

The Middle Delta includes about 1.5 million feddans of cultivated land. The reference supply rate of Nile water to this delta part amounts to $11 \cdot 10^9$ m^3 water. This quantity will be gradually reduced in five steps, each of 5% of the total supply, while the reuse of drainage water will be increased at the existing reuse stations. In conjunction with the supply reduction, water distribution based on exact crop water requirements has been tested for a better match of the water supply with the demand, resulting in less operational losses. The present water distribution is based on equal crop water requirements in the whole Nile Delta.

Fig. 17
Relative value of the components of the irrigation water balance as a function of various supply reductions using average crop water requirements



The effects of the supply reduction have been evaluated through the evapotranspiration and the soil salinity. An increasing soil salinity is considered to have major long-term effects on evapotranspiration, but will have no effect on crop water requirements. A second method for the evaluation of effects is the determination of the area where a reduction in the evapotranspiration, compared to the optimum evapotranspiration exceeds 20% and where the soil salinity exceeds 0.3 $S.m^{-1}$. Both values are seen as threshold values from where adverse effects on crop production may appear. This parameters indicate to which extent the total water supply can be safely curtailed without violating the sustainability of agriculture in general.

Results

Model calculations showed that a reduction of 5 to 10% in Nile water supply, while adhering to the present average crop water requirement,causes a loss of about 1-2% in the average relative evapotranspiration and a relative increase in the area with an insufficient evapotranspiration (i.e. reduction more than 20%) from 9% to some 12-15%. Curtailing the supply within these limits is apparently a rather safe practice in which shortages can be (partly) offset by some 14-26% lower system losses.

In Figure 17 the various components of the irrigation water balance are graphically presented, where the calculation results of the reference simulation have been set to 100 %. The irrigation water abstraction from the irrigation canals will be roughly the difference between the total supply, including official reuse, and the irrigation system losses. It appears from Figure 17 that although the

Table 7. ***Different components of the agricultural water supply system for the reference situation and four reduction simulations***

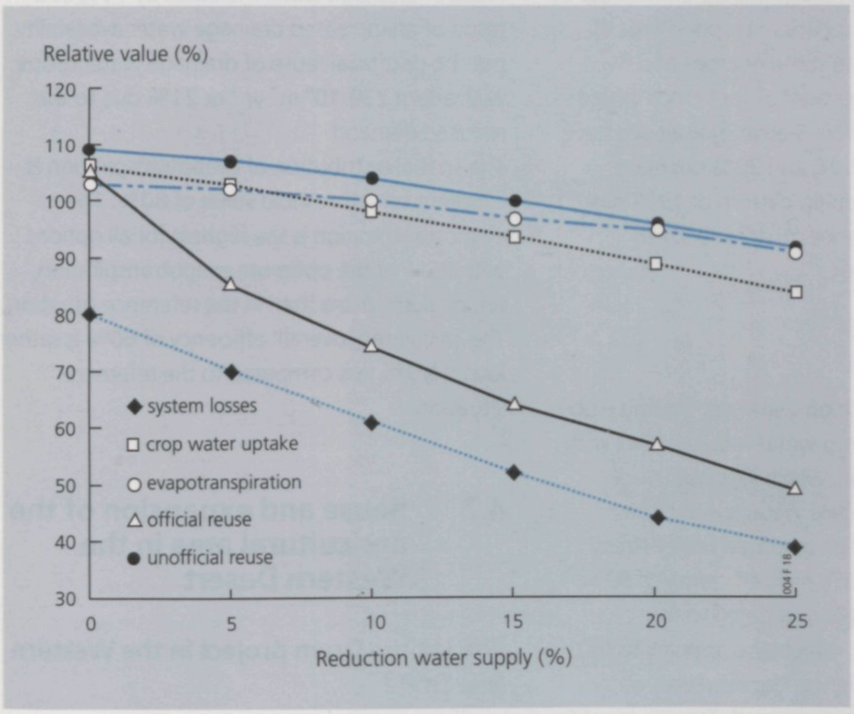
	Quantity (10^6 $m^3 \cdot yr^{-1}$)				
	ref.	-10%	-15%	-20%	-25%
Allocation based on average crop water requirements					
Nile water supply	11,113	10,002	9,447	8,892	8,337
Official reuse	582	460	397	349	306
Total supply	11,695	10,462	9,844	9,241	8,643
System losses	2,798	2,062	1,742	1,468	1,234
Irrigation uptake	9,195	8,701	8,404	8,092	7,713
Unofficial reuse	1,010	962	934	904	870
Groundwater use	424	424	424	424	424
Total crop supply	10,629	10,087	9,762	9,420	9,007
Allocation based on exact crop water requirements					
Nile water supply	11,113	10,002	9,447	8,892	8,337
Official reuse	582	430	375	329	288
Total supply	11,695	10,432	9,822	9,221	8,625
System losses	2,263	1,669	1,445	1,250	1,095
Irrigation uptake	9,724	9,034	8,649	8,239	7,808
Unofficial reuse	1,108	1,052	1,015	974	930
Groundwater use	424	424	424	424	424
Total crop supply	11,256	10,510	10,088	9,637	9,162

official reuse falls more than proportionally when compared to the total Nile water supply, the irrigation water abstraction is affected less severely (Table 7).

For the maximum reduction of 25% in the Nile water supply, it turns out that the crop water supply decreases by only 16%, illustrating the increased efficiency of the irrigation system. However, this reduction has an extremely adverse effect, because the area where the reduction in evapotranspiration is more than 20% increases from 9% in the reference situation of the total cultivated area to 31%. A 10% reduction in Nile water supply causes a 4% reduction in irrigation water abstraction by farmers, a reduction of 2% in evapotranspiration and a 5% increase in the area where a 20% reduction in evapotranspiration can be expected.

However, better results could be obtained when water distribution is based on exact crop water duties. Using spatially distributed values for the crop water duties would lead to an average aggregated relative evapotranspiration of 91% (10% supply reduction), the same value as for the reference simulation by a 0% reduction. Moreover, the spatial distribution of the relative evapotranspiration ameliorates surprisingly from 9% of the total area with a relative evapotranspiration of less than 80% for the present situation to a mere 6% for the 10% reduction in supply combined with water distribution based on exact water requirements. Prospects for the reuse of drainage water are less promising, but the major contribution to the high evapotranspiration values appears to come from an almost similar level of irrigation water abstraction by farmers (99% of the reference) due to some 40% lower irrigation system losses.

Fig. 18
Relative value of the components of the irrigation water balance as a function of various reduction simulations using exact crop water duties



The calculations show that adverse effects of reducing the Nile water supply can be alleviated when the water allocation to the main canals and the control of water distribution is based on exact crop water requirements. Figure 18 shows that without any supply reduction evapotranspiration increases by 3% compared to the reference situation. A better match of the local requirements also results in significant lower system losses (spillway and tail-end losses) and in a higher official and unofficial reuse of drainage water. On 2% of the area the evapotranspiration is less than 80% of the optimum, illustrating significantly improved water distribution. A supply reduction of 10% together with water distribution based on exact crop water requirements performs better than the reference situation: the evapotranspiration is almost similar to the reference situation, while on 6% (reference 9%) of the area the evapotranspiration is less than 80% of the optimum. Supply reductions of more than 20% to the Middle Delta score less than a similar reduction when the water distribution is based on average crop water duties.

Conclusions

The simulation results show that a reduction in Nile water supply to the Middle Delta of up to 10% ($1.1 \cdot 10^9$ m^3 annually) is possible without serious adverse consequences for total agricultural production. Within certain limits, the local adverse effects of reducing the Nile water supply to the Middle Delta can be neutralized by water distribution which is based on exact instead of average crop water requirements. This will lead to a significant reduction in system losses and a reduction of the area where significant crop yield reductions would occur when reduced supply had been implemented. When water distribution based on exact water requirements is implemented, the SIWARE package can be used to calculate the (spatially distributed) exact crop water requirements.

4.6 Changes in cropping pattern

Background

The overall irrigation efficiency in Egypt, according to the definition given by Thompson (1988)*, is classified as high. This is attributed to strict planning and operational procedures, including water distribution proportional to demand and partial control of the cropping pattern. Also the reuse of drainage water contributes to system efficiency. However, it has been disputed whether or not such strict planning procedures are strictly necessary to maintain system efficiency.

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* *Thompson, S.A. 1988. Patterns and trends in irrigation efficiency.* ***Water Resource Bulletin*** *24,1: 57-64.*

Approach

The SIWARE model has been applied to the Middle Delta to evaluate the effects of a deviating cropping pattern from an indicative cropping pattern on system efficiency. It was assumed that the Nile water supply to the Middle Delta matches the total demands including the requirements of an indicative cropping pattern. With respect to the internal irrigation water distribution, controlled by the various regulation structures, it was decided to adhere to the standard management followed by the MPWWR in combination with the cropping pattern of 1987.

The effects have been evaluated for an increase by approximately 10 and 20% in cropped area of high water consuming summer crops and two winter crops at the account of four crops with a low water consumption. Similar evaluations have been performed with 10 and 20% decrease, respectively. The cropping pattern of 1987 has been used as a reference situation with an indicative crop pattern.

Results

Growing 20% more high water consuming crops increased the total crop water requirements with $2{,}700 \cdot 10^6$ m^3 per year, which was not compensated by the Nile water supply. The irrigation system will be operated under stress conditions resulting in a high efficiency of 80%, with an increase by 4% compared to the reference conditions, which also appears to be the ceiling. As a consequence, the irrigation water abstraction by farmers increased. The marginal increase in official reuse by 3% and the sharply increased unofficial reuse with $171 \cdot 10^6$ m^3 per year (16% increase), added to the additional $441 \cdot 10^6$ m^3 per year irrigation water quantity abstraction by farmers could not fully compensate the increased demand. As a consequence the average evapotranspiration is 87% of the optimum evapotranspiration, a decrease by 5% compared to the reference situation. The spatial distribution of the evapotranspiration is rather poor. Evapotranspiration on 18% of the area is less than 80% of the optimum evapotranspiration and on 55% of the area less than 90%. The overall or 'project efficiency' is 59% (lowest) with a decrease by 4% compared to the reference situation.

Growing some 20% more crops with a low water consumption, resulted in a demand which was $1{,}700 \cdot 10^6$ m^3 per year less than necessary for the average crop pattern. This resulted in a very low efficiency of the irrigation system, amounting 65%, a decrease by 11% compared to the reference situation. The irrigation system losses increase dramatically with almost $1{,}400 \cdot 10^6$ m^3.yr^{-1} (51% increase), caused by a declined irrigation water abstraction by farmers with about $1{,}300 \cdot 10^6$ m^3.yr^{-1} or 15%. The official reuse of drainage water increases by 14% as a result of an increased drainage water availability, but the unofficial reuse of drainage water drops with about $220 \cdot 10^6$ m^3.yr^{-1} or 21% due to the reduced demand.

The spatial distribution of evapotranspiration is excellent for a threshold value of 80%. The evapotranspiration is the highest for all options with 95% of the optimum evapotranspiration, which is 3% more than in the reference situation. The calculated 'overall' efficiency of 60% is rather low. It is 3% less compared to the reference situation.

4.7 Reuse and expansion of the agricultural area in the Western Desert

The Umum Drain project in the Western Nile Delta

The MPWWR is developing plans for re-using drainage water from the Umum Drain to supplement the water supply through Nubareya Canal for new land reclamation in the Western Desert. In these plans a control structure will be built in the Umum Drain downstream of the confluence with the Truga pump station (see Fig. 19). By reversing the direction of drainage water flow in the Umum Drain as far as Shereshra pump station and pumping drainage water through Shereshra Drain and Sidi Eissa Drain to Nubareya Canal at Km 46. The drainage water from about 293,000 feddans (see Fig. 19) can be reused on

Fig. 19
The proposed layout of the Umum reuse project

the new land. In a previous study by DRI, it was estimated that this project could make about $1.1 \cdot 10^9$ m^3 of drainage water available for irrigation (Report 7). This figure of over one thousand million m^3 was based on average drainage flows during the period 1980 to 1984. To extend the area of agricultural land in the Western Delta several plans are being prepared. In the present study two alternatives for expansion of agricultural land are assumed. The first expansion is about 10% (165,000 feddans) and the second expansion 11.5% (185,000 feddans), bringing the total expansion to 21.5% (350,000 feddans) of the present total area. For all these scenarios the total Nile water supply has been kept constant resulting in a reduced water supply per unit area of 9% for the first expansion and 18% for the total expansion. In order to compensate for this reduction in water supply per unit area, reuse of drainage water from the Umum Drain has been considered in two phases. Implementing the first phase of the Umum reuse project results in an increase in water supply by about 4%. The second phase of the Umum reuse project results in an additional water availability of 4.5%, bringing the total gains of water to about 8.5%. The resulting relative total water supply per unit area is given in Table 8.

Table 8. Relative quantities of water available per feddan in the Western Nile Delta for three options

Expansion agricultural area (feddans)	Quantity (%) no additional reuse	Sheresha included (Umum phase I)	Truga included (Umum phase II)
0	100.0		
165,000	91.0	95.0	99.5
350,000	82.0	86.0	90.5

Scenarios

Based on the assumption that no additional Nile water supply will be allocated to the Western Delta for the two alternative plans to reclaim an additional 165,000 or 350,000 feddans, three water management options have been studied and analyzed using the SIWARE model package. The three options considered are: i) to reallocate the same quantities of Nile water, groundwater and drainage water presently used for the total area after expansion; ii) to reuse additional drainage water from the Umum Drain supplied by Shereshra pump station and Abu-Hommos area (Phase I); and iii) to reuse the total drainage water from the Umum Drain project which will also include Truga pump station drainage water (Phase II).

The water balance of the whole Western Delta (new and old land) on both a short-term and long-term basis is examined and the impact on evapotranspiration as a result of water availability to the crop and changes in soil salinity is determined.

Results

System performance

The model simulations indicate that the municipal water supply will be reduced as a result of reduced water supply in the options studied (Table 9). It should be borne in mind that the majority of drinking water pump stations are located near the tail-end of the Mahmudeya and Nubareya Canals. Such reductions in municipal water supply are, of course, not acceptable. In this respect the model simulations should be regarded as a warning that special measures safeguarding drinking water supply are warranted when water supply reduction options are considered for the Western Delta.

If additional land is reclaimed in the Western Desert, and no additional infrastructure is implemented to increase the available drainage water, official reuse of drainage water will decline (Table 9). Implementation of the Umum reuse project (Phase I and II) increases the official reuse of drainage water considerably. When both phases of the Umum project are in operation, the drain discharges diminish, and thereby also the available drainage water for unofficial reuse. When an additional 350,000 feddans is reclaimed, the actual amount of officially reused drainage water is 10% less than when 165,000 feddans is reclaimed (Table 9).

The SIWARE model simulations indicate that unofficial reuse of drainage water by farmers increases when the agricultural land in the Western Desert is increased, keeping the Nile water supply constant. This is mainly to compensate for the shortage of Nile water per unit area. This shortage causes a clear reduction in both the operational and spill losses. Upon implementation of the Umum reuse project Phase I and/or II, simulated unofficial reuse of drainage water decreases. Farmers located near tail-ends of irrigation canals and close to the Umum main drain apparently no longer have drainage water from the Umum Drain at their disposal. These farmers suffer not only from reduced irrigation water supply, but are also deprived of the drainage water source with which they were used to augment their irrigation water supply in times of shortages.

Table 9. Long-term water balance components for the alternatives of expansion of the agricultural area and reuse of drainage water in the Western Nile Delta

Water balance component	Quantity ($10^6\ m^3 \cdot yr^{-1}$)						
	no expansion	expansion = 165,000 feddan			expansion = 350,000 feddan		
	and add. reuse	no add. reuse	phase I	phase II	no add. reuse	phase I	phase II
Nile water supply	10,363	10,363	10,363	10,363	10,363	10,363	10,363
Official reuse	926	901	1,349	1,904	871	1,298	1,716
Operational losses[1]	1,072	1,026	1,047	1,089	1,064	1,076	1,090
Municipal water supply[2]	1,333	1,263	1,289	1,324	1,195	1,221	1,245
District water supply	8,884	8,975	9,376	9,854	8,975	9,364	9,744
Unofficial reuse	735	746	708	709	748	703	708
Spill losses	1,138	833	945	1,103	618	702	806
Crop water supply[3]	8,815	9,222	9,473	9,799	9,539	9,699	10,980
Evapotranspiration	5,712	5,724	5,811	5,922	5,698	5,797	5,903

[1] *including conveyance losses from the main irrigation system*

[2] *including groundwater abstraction for drinking water supply*

[3] *including 334 million $m^3 \cdot yr^{-1}$ of groundwater use*

Implementation of the Umum reuse project Phase I leads in the long term to an average increase in irrigation water salinity of 18% and when both phases are implemented, the total increase in irrigation water salinity amounts to 42%. The resulting long-term average irrigation water salinity of 475 $g.m^{-3}$ is expected to cause only limited crop yield reductions for maize and vegetable crops when grown on soils with limited internal drainage conditions. Although there is a higher level of irrigation water salinity in the Western Desert, where internal drainage conditions are good, no major problems are expected, as long as the water-table in these desert areas remains far below the land surface.
In all the options simulated a continuously increasing trend in soil salinity is noticed up to 50 years (Fig. 20). Since the reference situation also exhibits this trend, it can be concluded that the assumed equilibrium conditions for the reference situation were not reached.
Expansion of agricultural land causes soil salinity to increase faster, but after 50 years approximately similar average values for soil salinity are reached, except for the Umum reuse Phase II project. It can thus be concluded that reuse of drainage water in the desert area has only limited consequences for agriculture and drainage water salinity.
This conclusion has to be regarded carefully however. In the SIWARE model simulations, the water pressure and the salinity in the aquifer have been kept constant. In the long term, a rise in the water-table may also be expected in the desert area. This may in reality affect leakage losses and may lead to secondary salinization in these new areas in the future. Such a conclusion also depends on the correctness of assumptions regarding the assumed sprinkler irrigation efficiency of 75% and the presence of coarse textured soils in these new areas.

Project evaluation

Expansion of agricultural land in the Western Desert requires major investments in infrastructure including irrigation facilities. The Umum reuse projects Phase I and Phase II also require considerable investments in pump stations and remodelling of conveyance channels. The

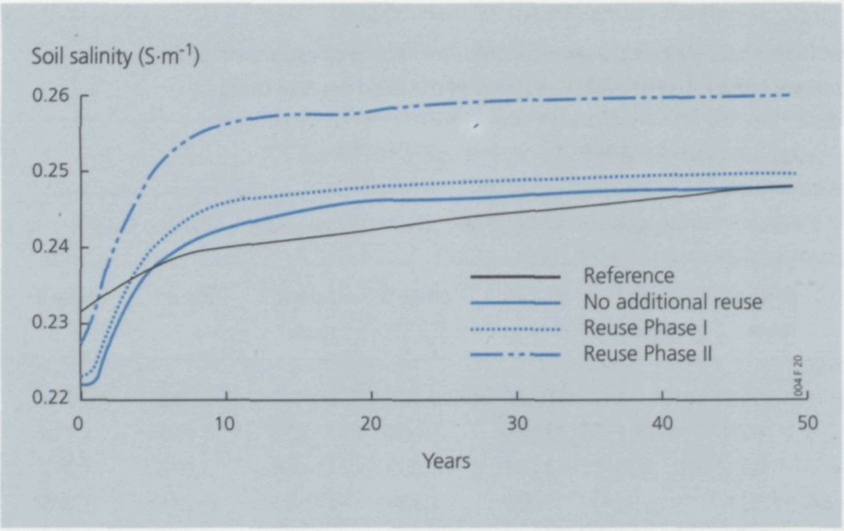

Fig. 20
Soil salinity evolution in the Western Nile Delta after land reclamation and implementation of the Umum reuse projects

operation and maintenance costs of the resulting irrigation system will increase significantly because of the need to pump water to higher elevations. At the same time, total crop production in the old lands will decrease due to diverting significant quantities of Nile and drainage water to the new lands. On the other hand, total financial output is expected to increase because of additional crop production on the new land and associated economical activities, creating additional job opportunities. In order to arrive at a reliable estimate of the optimum degree of expansion, among other factors, knowledge of changes in crop production level in both regions is indispensable. Basic data for this knowledge can be provided through the simulated evapotranspiration which relates to crop production, as shown in Section 3.6.

In the present study, gains in the desert area and losses in the delta area for the different options are evaluated in terms of evapotranspiration only. Evapotranspiration is used as an indicator for crop production. Gains in evapotranspiration can therefore be considered as benefits gained by the project and reductions in evapotranspiration as additional costs.

The SIWARE model simulations indicate that evaporative demand in the desert area is about 1.15 times as high as in the delta area. This means that 15% more water is required in the desert for growing the same crops as compared to the delta area (10,278 m^3 per feddan for the desert area and 9,014 m^3 per feddan for the delta area). Also, the productivity of the desert soils may be assumed to be less than the highly productive clay soils in the delta area. This leads to the conclusion that each unit of evapotranspiration (m^3) in the delta produces a higher economic return than each m^3 of evapotranspiration in the desert area.

Table 10 shows that extending the area without additional reuse of drainage water will lead to a net total reduction in evapotranspiration and hence a decrease in crop production. This option is therefore not attractive. Extending the area by 165,000 feddans and implementing Phase I of the Umum project results in an increase in total evapotranspiration of 1.7%. Implementing additional Phase II of the reuse project results in an

Table 10. Evapotranspiration in the old lands and new lands as a result of different expansions of land reclamation and reuse alternatives

Expansion (feddan)	Reuse alternative	Evapotranspiration (10^6 $m^3 \cdot yr^{-1}$)		
		Delta area	Desert area	Total
0	no add. reuse	4,174	1,537	5,712
165,000	no add. reuse	4,010	1,714	5,724
165,000	phase I	4,058	1,753	5,811
165,000	phase II	4,133	1,789	5,922
350,000	no add. reuse	3,835	1,863	5,698
350,000	phase I	3,877	1,920	5,797
350,000	phase II	3,942	1,961	5,903

increase in evapotranspiration of 3.7%. Extending the area by 350,000 feddans and implementing reuse Phase I results in an increase in evapotranspiration of 1.5% and with reuse Phase I and II together an increase of 3.3%. This clearly demonstrates that an expansion of the irrigated area by more than 165,000 feddans is not justified, as the additional evapotranspiration does not increase.

Municipal water quality

The Alexandria region depends on two sources for drinking water. The largest part of its municipal water requirements (about 80%) comes from Mahmudeya Canal. The SIWARE model simulations of the different horizontal expansion scenarios showed that the quality of water in the Mahmoudeya Canal will change. The salinity of drinking water supplied will increase by 10% when the total expansion of 350,000 feddans is implemented together with reuse Phase I and II of the Umum reuse project.

The drinking water supply pumping stations on the Nubareya Canal (Mariut pump station, located at Km 60 along the Nubareya Canal, and Borg El Arab pump station) both use water from the Mariut side branch at Km 96. These pump stations supply 15% of the drinking water for the Western Delta. The average salinity of these stations increases by about 40% up to 1,700 g.m^{-3} when both Phase I and Phase II of the Umum project are implemented. These problems could be solved by moving their intakes by 15 km and 50 km, respectively, to Km 45 at the Nubereya Canal, upstream of the mixing point with Umum drainage water. The model, however, did not adequately take into account the salinity in the downstream reach of the Nubereya Canal, which is attributed to a lack of information concerning the aquifer pressure and the salinity of the groundwater. Moreover the model concept and assumptions are not completely valid in the regions with rising water-tables that prevail on the fringes of the delta.

5 SIWARE's potential for other purposes and future developments

The SIWARE model has been specifically designed to meet the needs of decision makers in water management planning for the Nile Delta in Egypt. It provides information on the availability and suitability of the agricultural drainage water for irrigation. Several choices have been made implicitly or explicitly during model development to tailor SIWARE to the needs of the Ministry of Public Works and Water Resources (MPWWR) in Egypt and to the circumstances in the Nile Delta. The model, although a highly versatile tool for decision making in water management, has the potential for a number of improvements which can be accomplished by further development and refinement. These potential developments of the SIWARE model can be classified in three categories:

- software development, improving the ease of model application;
- model development, extending the applicability of the SIWARE model to other circumstances than those of the Nile Delta;
- linking SIWARE to water quality models to extend its applicability to water quality management and environmental impact assessment.

Software development

The Graphical User Interface facilitates the use of the model for short-term planning by the MPWWR. Further development of these interfaces is required in order to fully exploit the model's capabilities. At present for instance, lay-outs of irrigation and drainage canal systems have to be entered manually. Also establishing the simulation sequence for the distinguished subareas is a laborious and error-prone activity. Automatic determination of the simulation sequence and canal system definitions based on graphical input of the irrigation and drainage canals, location and type of control structures and links between subareas and irrigation and drainage canal systems would enhance and facilitate the application of SIWARE considerably.

Recent developments in commercially available database management systems offer interesting opportunities to shift from existing data input procedures for the SIWARE model to one general system for input and output handling. Implementation of such a database management system for the model would also further ease SIWARE model applications that require additional input and/or output data.

Presently irrigation rotation, taking place in the Nile Delta of Egypt mainly at distributary canal level, is assumed in SIWARE within the boundaries of the subareas. For application in other arid regions, or for studies at a regional level, irrigation rotation between canals or canal branches needs to be included in the SIWARE model.

Management of groundwater reservoirs

Under Nile Delta conditions, for which SIWARE has been developed, aquifer pressures are fairly constant. Groundwater use for irrigation and municipal water supply is of minor importance, compared to irrigation water supply. In the SIWARE model a constant aquifer pressure has consequently been chosen as the lower boundary of the simulated system.

In arid and semi-arid regions where groundwater is an important water resource, such as in the desert areas adjacent to the Nile Delta, the introduction of irrigated agriculture results in increased groundwater levels. Through horizontal groundwater flow this may significantly affect seepage conditions in other, nearby low lands, causing secondary soil salinization. The same holds true in the case of significant increases in local groundwater abstraction, changing seepage and leakage conditions in other areas.

For the simulation of irrigation water management under conditions where groundwater management plays an important role, the SIWARE model must be linked with a regional groundwater flow model.

Environmental impact analysis

The SIWARE model simulates the flow of water through irrigation canals, through the soil system, and through drainage canals. At an early stage of model development it was decided to limit water quality aspects to the simulation of the conservative chloride anion, which can be considered as a tracer for other water quality parameters. As such, the SIWARE model has proved to be capable of simulating water and salt balances correctly for the Nile Delta circumstances.

Several sources of pollution threaten water quality. World-wide agriculture is under pressure to increase production to feed the growing population. This is achieved by an increasing use of fertilizers and agro-chemicals. Waste-water discharges from industrial plants may include heavy metals and other toxic chemicals. Sewage discharge from municipalities includes organic compounds, bacteria and viruses.

For water-borne transport routes of chemical or biological substances the SIWARE model offers excellent opportunities. Through the inclusion of other water quality aspects in the SIWARE model, or by an external linkage to water quality modules, the model's potential for environmental impact assessment can be realized.

All transport routes of pollution, either through the application of agricultural chemicals applied to the soil surface, or through waste-water discharges to irrigation or drainage canals, are described in the SIWARE model. Extension of this model with the relevant processes provides a powerful tool for evaluating alternative measures combating water pollution.

In order to combat the deterioration of water quality, the development of sound water quality management policies and plans is essential. In addition to the installation of additional waste-water treatment facilities and the adaptation of the legal system, there is a need for water quality monitoring and information systems. The new project, Monitoring and Analysis of Drainage Water Quality, within the framework of the Netherlands-Egyptian Technical Cooperation will provide important data and information which can be used in the calibration and validation of the future water quality version of SIWARE.

Continued cooperation

Development and application of the SIWARE model package for the analysis of irrigation water management in the Nile Delta in Egypt has been a joint activity of the cooperating institutes, the Drainage Research Institute in Cairo and the DLO Winand Staring Centre in Wageningen. These activities were made possible by financial support from the Ministry of Public Works and Water Resources in Egypt and the Ministry of Foreign Affairs in the Netherlands.

Both cooperating institutes realize the importance of the SIWARE model as a decision support tool for water managers and planners both in Egypt as well as elsewhere in arid or semi-arid regions. They therefore decided to continue their cooperation to develop the SIWARE model package for universal applications.

The extension of SIWARE to other regions would consider in the first place its application to the whole Nile Delta as one region including the two Nile branches and the new reclamation areas. The application of SIWARE to Upper Egypt would be beneficial especially when a water quality module is included. At this stage, the SIWARE model cannot predict the effect of different types of pollutants in the drainage water on Nile water quality.

Actual evapotranspiration	**evapotranspiration** when **moisture** and **salinity stress** occur
Advance function	mathematical function describing the speed of a water front moving across the field during irrigation. Advance speed depends on irrigation capacity, surface roughness, open crack volume and infiltration rate
Allocation	planning procedure for determination of quantity of (Nile) water to be directed to intake of main canal during a certain time period
Allocation duty	quantity of water per feddan to irrigate a certain crop to be directed to a main canal intake during a certain time period. Includes **conveyance losses**. Used for water **allocation**
Alternative	one of the possible solutions for a problem
Application program	tailor-made computer program to be used in conjunction with a **database** to perform a certain data elaboration
Aquifer	term used in hydrology to indicate (thick) saturated soil layers where horizontal flow prevails
Aquifer pressure	pressure head observed in **aquifer**. In groundwater hydrology water column expressed in metres relative to a certain reference level. In **SIWARE** the reference level is either the soil surface or the depth of (subsurface) drains
Area/study area	defined area to which **SIWARE** is applied
Calculation unit	small part of **area** where relevant conditions are equal. Water supply originates from one (branch of a) **main canal**, agricultural drainage water released to only one main drain
Calibration	procedure to adjust certain **model** parameters to match model output with observations during a particular year
Capillary flow	water flow through unsaturated soil. In **SIWARE** used for upward flow from soil layers beneath the **root zone** into this zone
Case	term for a **SIWARE** run
Clay cap	relative thick layer of fine textured soil overlaying a coarse textured (thick) soil layer or **aquifer**
Conservative ion	ion found in soil solution which does not react with other ions and does not interact with soil particles. In **SIWARE** the chloride ion
Conveyance losses	quantity of water lost during transport through canals to a final destination. In **SIWARE**: evaporation from free water surface

Crack/crack formation	open space in soils caused by **shrinkage** of soil
Crop water requirement	quantity of water required for one feddan of a certain crop for one irrigation application or for the whole growing season of a crop. Approximately the quantity to recharge **moisture** deficit plus a certain quantity for soil leaching and **conveyance losses**
Database	a physical system to store and retrieve data concerning one or more subjects
DESIGN	a computer program in the **SIWARE** package for preparing inputs for the **WATDIS** program. Deals with canal dimensions, Nile water **allocation** and the determination of target levels to be maintained downstream of water depth control structures in irrigation canals (not intended for operational applications)
Digitizer	(electronic) table, connected to a computer for determination of (local) coordinates of lines on a drawing or map. Used to enter borders of **area** and **calculation units**
Discharge	1) hydraulics: certain flow rate through a cross-section of a canal; 2) hydrology: flow rate towards **aquifer** or flow rate through cross-section of aquifer
Distributary	irrigation canal, under rotation, from which farmers withdraw water for irrigation. In **SIWARE** assumed within the borders of a **calculation unit**
Distribution	operational procedure to divert planned quantities of water to specified locations at planned time moments. In the **WATDIS** program management procedures for maintaining target water depths upstream and downstream of control structures as calculated the **DESIGN** program
E-mail	Electronic mail. Procedure to send a message or file from a certain computer to another computer at a remote place. Use is made of telephone lines and communication satellites
EC	Electrical Conductivity. Physical-chemical parameter of (drainage) water to characterize its salinity. Parameter is related to **TDS**
Evapotranspiration	quantity of water lost to atmosphere per unit area per unit time period from (wet) soil surface and crop. Quantity depends on net solar radiation, air humidity, wind speed, duration of sunshine per day, but also on **moisture** and **salinity stress**
Expert judgment	in the absence of documented information the estimation of the magnitude of a certain phenomenon, quantity or procedure by an expert

Farmers' uptake	irrigation water abstraction from irrigation canal by farmers
File	here: set of data present on mass storage of computer under a *certain (file) name*
GUI	Graphical User Interface. Computer (shell) program for a user's friendly access to the complex **SIWARE** package. Its functions are transparent file management, easy data input, running of the **programs** and inspection (on screen) of program output in the form of graphs or maps
Heavy metal	toxic metals: Mercury, Cadmium, Lead, Copper, Zinc
HUB	central distribution unit in a **LAN** connecting **PCs**, terminals, plotters, and printers in the main circuit. A **HUB** causes data to 'jump' to a certain destination
Infiltration depth	quantity of water infiltrated per unit area into the soil
Infiltration opportunity time	time period that it takes a standing water layer found on the soil surface to infiltrate into the soil
Irrigation/drainage system	the totality of canals, water depth and flow rate control structures, (irrigation or drainage) pumps, intakes for municipal and industrial water use
LAN	Local Area Network. A physical network of wires for data exchange between (local) computers (see also **Server**)
Level control	operational procedure to control a predefined water depth upstream or downstream of a control structure. In Egypt the downstream water depth in a canal is related to a flow rate according to a **stage-discharge** relationship
Local water requirement	**crop water requirement** depending on local weather, soil, drainage and geo-hydrological conditions
Main canal	canal for conveying water to a vast area. No irrigation water uptake from this canal
Marwaa	*small irrigation channel under rotation, maintained by farmers, for water supply to farmers*
Model	1) representation of physical processes in the mathematical formulations and calculation procedures used in the **SIWARE** package; 2) schematic representation of real situation through data sets

Moisture deficit	difference between soil moisture holding capacity at field capacity and actual quantity of soil moisture
Moisture stress	soil moisture status preventing crops from realizing **potential evapotranspiration**
Network	1) see **Irrigation/drainage system** 2) see **LAN** 3) see **World Wide Web**
On-farm water management	1) irrigation practice at farm level 2) decisions of farmer related to water distribution among crops
Option	different solutions to a problem to attain almost similar results
PC	Personal Computer. Computer with mass storage facilities and own operating system. In general used as stand-alone computer, but can also be integrated in a **LAN**
Plot/field plot	piece of land treated in irrigation as a unit
Policy	predefined procedure in water management
Ponding period	time period with standing water layer on soil surface (see **Infiltration opportunity time**)
Potential evapotranspiration	**evapotranspiration** in absence of **moisture** and **salinity stress**
Program	coded mathematical formulations and procedures for execution by a computer. The **SIWARE** package is coded in standard Fortran 77
Rapid drainage	loss of water through **cracks** to field or subsurface drains during irrigation
Rating curve	relationship between water depth and **discharge** or between wet cross-section and discharge
Recharge	downward water flow to **aquifer**
Regional drainage	1) flow rate of water losses from **calculation unit** composed of agricultural drainage, spillway and tail-end losses, and disposed sewage water; 2) procedure in **REUSE** to translate field drainage into agricultural drainage from calculation unit
Representative plot	typical **plot** of certain crop in **calculation unit**
Resident time	elapsed time since drainage from **plot** occurred and this quantity appears in **regional drainage**

REUSE	program in **SIWARE** for calculation of drainage rates, **actual evapotranspiration** of all crops during successive irrigations, unofficial reuse by farmers, and irrigation water salinity
Root zone	depth below soil surface where 80% of root mass is found
Sakkia	animal or engine-driven waterwheel for lifting irrigation water from **sump**, operated by farmers. Present design based on thousands of years-old concept. Nowadays large number replaced by mobile diesel pumps
Salinity stress	osmotic potential in soil solution causing less than potential **evapotranspiration**. In general moisture and salinity stress act through similar mechanisms
Salinization	increasing soil salinity with respect to time. Cause: saline **seepage** and waterlogging or under-irrigation
SAR	Sodium Adsorption Ratio; parameter derived from chemical analysis of drainage water, to express sodicity of soils
Seepage/leakage	upward/downward flow from/to **aquifer**
Server	dedicated computer in **LAN** for organising data exchange between computers and mass storage or peripherals (printer, plotter, **digitizer**)
Shrinking	reduction of specific soil volume by diminishing the moisture content observed in soils with a significant content of clay minerals in the montmorillonite and smectite group
SIWARE	Simulation of Water management in the Arab Republic of Egypt. **Program** package described in this report
Stage-discharge	see **Rating curve**. Especially used in relation to flow control in irrigation canals and **discharge** measurements of drainage pump stations
Strategy	consecutive actions to implement a certain management **alternative**
Sump	well, connected through a specially designed tube with **marwaa** or **distributary**, from which water is lifted with **sakkia**. Owned by one or a small group of farmers
Swelling	increase in specific soil volume due to increasing moisture content. See **Shrinkage**

System losses	conveyance and operational water losses from irrigation canals. Tail-end losses at the end of a canal to drain, spillway losses from **distributary** to drain. See **Conveyance losses**
Terminal	screen with keyboard, connected to remote host computer. A terminal has no mass storage facilities nor can be used as stand-alone computer
TDS	Total Dissolved Salts per unit of volume of liquid
Validation	procedure to check the reliability of calibrated model for predictions
WATDIS	**program** for water distribution simulations
Water duty (local)	quantity of water required per feddan during one irrigation of a certain crop or during the whole growing season. Depends on local situation (climatical conditions, soil type, seepage or leakage conditions, irrigation capacity, **plot** size). Leaching requirements and conveyance losses included. Adverse effects of **salinity stress** ignored
Water management	total procedures and policies for water distribution in Egypt
WDUTY	**program** for the calculation of **water duty** for each crop during each irrigation in each **calculation unit**
Workstation	powerful computer for applications which require complex and heavy computer calculations (for example ARC-INFO. Could be connected to **LAN**.
World Wide Web	physical network of telephone lines and satellite communications between computers all over the world. Included are several computers at different nodes to relay messages and optimize the routing of messages. DRI has a main gateway to this web

[illegible]	program in SIWARE [illegible] of drainage rates, actual evapotranspiration of all crops during successive irrigations, unofficial reuse by farmers, and irrigation water salinity
[illegible]	depth below soil surface [illegible] % of root mass is found
Sakia	animal or engine-driven waterwheel for lifting irrigation water from sump, operated by farmers. Present design based on thousands of years-old concept. Nowadays large number replaced by mobile diesel pumps
Salinity stress	osmotic potential in soil solution causing less than potential evapotranspiration. In general moisture and salinity stress act through similar mechanisms
[illegible]	increasing soil salinity [illegible] time. Cause: saline seepage and waterlogging or underirrigation
[illegible]	Sodium Adsorption Ratio, parameter derived from chemical analysis of drainage water, indicates sodicity of soils
Seepage/leakage	upward or downward flow from the aquifer
Server	dedicated computer in LAN for managing data exchange between computers and shared storage or peripherals (printer, plotter, digitizer)
[illegible]	reduction of specific [illegible] decreasing the moisture content; observed in soils with a significant content of clay minerals of the montmorillonite and smectite group
[illegible]	Simulation of [illegible] in the Arab Republic of Egypt. Program package described in this report
[illegible]	see Rating curve. Especially used in relation to flow control in irrigation canals and discharge measurements of drainage pump stations
Strategy	consecutive actions to implement a certain management alternative
Sump	well, connected through a specially designed tube with marwa or distributary, from which water is lifted with sakias. Owned by one or a small group of farmers
Swelling	increase in specific soil volume due to increasing moisture content. See Shrinkage

Appendixes

1 List of Reuse Reports

No.	Year	Title
1.	1983	Manual on short-term routine measurement programme. 89 pp.
2.	1984	Complex, a computer model for solving chemical equilibria on the basis of activities. 31 pp.
3.	1985	Estimation of available water for El-Salam Canal Project. 14 pp.
4.	1985	Yearbook 1980-1983 Eastern Delta. Discharge and chemical composition of drainage water. 73 pp.
5.	1985	Drainage water discharges and salinities in the Nile Delta for 1980 - 1983. 24 pp.
6.	1985	Results of calibration measurements of pump stations and open drains, Eastern Delta 1981-1984. 25 pp.
7.	1985	Estimation of available drainage water for El-Umum Reuse Project. 31 pp.
8.	1985	Results of calibration measurements of pump stations and open drains, Western Delta 1981-1985. 33 pp.
9.	1986	Results of calibration measurements of pump stations and open drains, Middle Delta 1981-1985. 38 pp.
10.	1986	Yearbook 1980-1983 Western Delta. Discharge and chemical composition of drainage water. 84 pp.
11.	1986	Yearbook 1980-1983 Middle Delta. Discharge and chemical composition of drainage water. 60 pp.
12.	1986	Drainage water discharges and salinities in the Nile Delta for 1984. 60 pp.
13.	1986	Yearbook 1984. Drainage water in the Nile Delta. Discharges, salinities and chemical composition. 72 pp.
14.	1987	Yearbook 1985. Drainage water in the Nile Delta. Discharges, salinities and chemical composition. 101 pp.
15.	1988	Yearbook 1986. Drainage water in the Nile Delta. Discharges, salinities and chemical composition. 104 pp.
16.	1988	Accuracy analysis of routine measurement programme. 38 pp.
17.	1989	Manual on measurement programme for quality and quantity of drainage water in the Nile Delta. 118 pp.
18.	1987	Users manual of the data base system and computer programmes. 37 pp.
19.	1989	Manual DRI laboratory. 82 pp.
20.	1987	Description of the measurement network in the Nile Delta. 146 pp.

No.	Year	Title
21.	1987	Results of calibration measurements of pump stations and open drains in the Nile Delta; Update 1986. 39 pp.
22.	1989	Formulation of the 'REUSE' model. 52 pp.
23.	1994	Formulation of the water and salt distribution model 'WATDIS' for surface water systems. 95 pp.
24.	1993	Formulation of the on-farm water management model 'FAIDS'. 118 pp.
25.	1995	Users guide for the program 'WATDIS' (in press)
26.	1994	An update of calibration measurements of pump stations in the Western Delta, 1992 - 1993. 51 pp.
27.	1994	SIWARE Users manual V1.1. 117 pp.
28.	1991	Comparison between two approaches for irrigation water supply in the Eastern Nile Delta of Egypt. 45 pp.
29.	1995	Water quality results at selected reuse pump stations (in press)
30.	1991	Analysis of water management in the Eastern Nile Delta - Main Report. 245 pp.
31.	1988	Yearbook 1987. Drainage water in the Nile Delta. Discharges, salinities and chemical composition. 102 pp.
32.	1989	Yearbook 1988. Drainage water in the Nile Delta. Discharges, salinities and chemical composition. 119 pp.
33.	1991	Yearbook 1989. Drainage water in the Nile Delta. Discharges, salinities and chemical composition. 124 pp.
34.	1992	Yearbook 1990. Drainage water in the Nile Delta. Discharges, salinities and chemical composition. 124 pp.
35.	1993	Yearbook 1991. Drainage water in the Nile Delta. Discharges, salinities and chemical composition. 152 pp.
36.	1993	Training manual of SIWARE model. 106 pp.
37.	1993	Yearbook 1992. Drainage water in the Nile Delta. Discharges, salinities and chemical composition. 154 pp.
38.	1994	Yearbook 1992/1993. Drainage water in the Nile Delta. Discharges, salinities and chemical composition. 148 pp.
39.	1995	Yearbook 1993/1994. Drainage water quantities and qualities in the Nile Delta (in press)

No.	Year	Title
40.	1993	Description of the SIWARE Package Version 1.0. 20 pp.
41.	1994	Technical and functional documentation of an interface for expert users of the SIWARE system. 29 pp.
42.	1995	Maintenance manual Graphical Users Interface. 80 pp.
43.	1995	Graphical User Interface, Manual for end-user. 30 pp.
44.	1995	Calibration and validation of the SIWARE model: Middle Nile Delta. 45 pp.
45.	1994	Water management scenarios for the Middle Nile Delta: I. Reduction Nile water supply; II. Effects of deviating cropping pattern. 50 pp.
46.	1995	Calibration and validation of the SIWARE model: Western Nile Delta. 71 pp.
47.	1994	Water evaluation management scenarios Western Nile Delta; Umum Reuse Project and land reclamation in the Western Desert. 39 pp.
48.	1995	Re-calibration and validation Eastern Nile Delta (in press)
49.	1995	Water management scenarios Eastern Nile Delta. Evaluation implementation of El Salaam Canal project (in press)
50.	1995	Reuse of drainage water in the Nile Delta; monitoring, modelling and analysis; final report Reuse of Drainage Water Project.
-	1992	Proceedings of the Reuse Workshop on `Water Management in Irrigated Agriculture in Egypt', April 21-22, 1992. 207 pp.

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اليه فى هذه الظروف نتيجة زيادة المستخدم من مياه الصرف بصوره غير رسميه إلا أن ذلك أدى الى حدوث انخفاض فى معدلات البخر- نتح الفعليه بمقدار ٥٪ مما يؤدى الى نقص فى الانتاج المحصولى بمقدار ٧٪.

وعلى العكس من ذلك فإن زيادة زراعة المحاصيل الاقل استهلاكا للمياه بمقدار ٢٠٪ أدت الى انخفاض الاحتياجات المائيه السنويه بمقدار ١٧٠٠ مليون متر مكعب. الا ان الفواقد من شبكة الرى إزدادت بكميه كبيره لتصل الى حوالى ١٤٠٠مليون متر مكعب اى ما يعادل ٥١٪ زيادة عما كان متوقعا و هذا يؤدى الى انخفاض كفاءة تشغيل نظام الرى الى ٦٥٪ و صاحب ذلك زيادة معدلات البخر- نتح الفعليه بمقدار ٣٪ . ويعكس هذا زيادة فى الانتاج المحصولى بمقدار ٣٪ بسبب وفرة المياه وفى مثل هذه الاحوال يتحتم اتخاذ الاجراءات اللازمه لتقليل تصرفات الترع.

٦. التوسع فى استصلاح الاراضى بالاعتماد على إستخدام مياه الصرف الزراعى

اوضحت نتائج النموذج الرياضى فى اختبار سياسة التوسع فى استصلاح الاراضى فى منطقة غرب الدلتا عن طريق زيادة المساحه المزروعه بحوالى ١٦٥٠٠٠ فدان دون الزياده فى الحصه المائيه من النيل والاعتماد على تنفيذ المرحله الاولى من مشروع مصرف العموم التى تتضمن استخدام مياه محطة صرف الشريشره فقط واعادة توزيع الحصه المائيه الكليه التى تضم مياه النيل ومياه الصرف على إقليم غرب الدلتا شاملا الاراضى القديمه والمساحه الاضافيه المطلوب استصلاحها فأن ذلك أدى الى زيادة معدلات البخر - نتح الفعلى بمقدار ١,٧٪ بينما زادت هذه القيمه الي ٣,٧٪ بعد تنفيذ المرحله الثانيه التى تتيح استخدام كل مياه الصرف من محطتى الشريشره و تروجه على مصرف العموم.

كما اوضحت النتائج انه فى حالة زيادة المساحه المستصلحه الى ٣٥٠٠٠٠ فدان باستخدام مياه الصرف من المرحله الاولى لمشروع مصرف العموم يتسبب فى زيادة معدلات البخر- نتح بمقدار ١,٥ ٪ وادت المرحله الثانيه الى زيادة مقدارها ٣,٣٪ فى معدلات البخر - نتح الفعليه وبذلك فان زيادة المساحه المستصلحه الى اكثر من ١٦٥٠٠٠ فدان لا يضيف شيئا بالنسبه للانتاج المحصولى على مستوى الاقليم كله بينما تزداد مخاطر تملح الاراضى القديمه لعدم كفاية مياه الرى نتيجة انخفاض نصيب الفدان من كمية المياه المتاحه.

و من الاثار الجانبيه لزيادة الاراضى المستصلحه فى غرب الدلتا بمقدار ٣٥٠٠٠٠ فدان بالاعتماد على مشروع مصرف العموم حدوث زيادة مقدارها ١٠٪ فى درجة تركيز الاملاح فى مياه الشرب المأخوذه من ترعة المحموديه .. كما ان تركيز الاملاح فى مياه الشرب من ترعة النوباريه زاد بمقدار ٤٠٪ (أى ما يعادل ١٧٠٠ جزء فى المليون) الا انه يمكن تلافى ذلك الاثر عن طريق تغيير موقع سحب مياه الشرب للأمام بعيدا عن موقع الخلط او عن طريق إيجاد مصدرا اخر بديل لمياه الشرب.

الخطه المستقبليه لتطوير النموذج الرياضى

وضحت تماما امكانيات النموذج الرياضى خلال الفتره القصيره الماضيه التى انقضت منذ الانتهاء من اعداد النموذج من خلال نتائج التطبيقات التى استخدم فيها النموذج سواء فى شكل حساب عناصر الميزان المائي و الملحى باقاليم الدلتا الثلاثه وبصفه خاصه ما يصعب قياسه او حسابه بالطرق التقليديه مثل كمية مياه الصرف المستخدمه بشكل غير رسمى او فى محاكاة الظروف المختلفه للاداره المائيه مثل تلك التى ورد ذكرها فيما تقدم وهذا كله يؤهل النموذج ليكون أداة فعاله فى تخطيط و إدارة الموارد المائيه بدلتا نهر النيل بما يحقق افضل استخدام للموارد المائيه مع المحافظه على التربه من مخاطر التملح. ولذلك تم نقل النموذج الى قطاعى التخطيط والرى بوزارة الاشغال العامه والموارد المائيه لاستخدامه مستقبلا فى التطبيقات العمليه التى تقع فى نطاق اختصاصهما.

ومن ناحيه اخرى فان ذلك لا يمثل نهاية المطاف ولكن سيستمر معهد بحوث الصرف فى تحسين وتطوير النموذج ليكون اكثر دقه واكثر شمولا فى تناول متغيرات هيدرولوجيه مثل الحركه الديناميكيه للمياه الجوفيه نتيجة السحب والتخزين او متغيرات بيئيه تتعلق بنوعية مياه الصرف وتأثرها باعمال التسميد واستخدام المبيدات الحشريه كما ان المجال يتسع لاستخدام النموذج لمحاكاة ادارة المياه فى مناطق اخرى كصعيد مصر او الاراضى المرويه فى بلاد اخرى مثل الهند والباكستان التى تتشابه ظروف ادارة المياه فيها مع جمهورية مصر العربية.

ويستطيع النموذج التنبؤ بالتغيرات التى تحدث فى ملوحة التربه وانتاج المحاصيل على المدى القريب والبعيد نتيجة لاسلوب الاداره المائيه المتبعه ونوعية المياه المستخدمه وهو فى هذا المجال يحدد الانتاج المحصولى على اساس العلاقه بين كمية البخر - نتح الفعليه التى تتأثر بدورها بالنقص فى نسبة الرطوبه المتاحه فى منطقة جذور النبات ودرجة ملوحتها وبين الانتاج المحصولى.

وقد امكن استبيان قدرة النموذج الرياضى فى محاكاة عمليات الرى والصرف فى مناطق الدلتا من خلال تطبيقه فى دراسة حالات مختلفه لادارة وخدمة المياه والتركيب المحصولى و الفقره التاليه توضح هذه التطبيقات و اهدافها ونتائجها.

امثله لتطبيقات استخدام النموذج

١. توفير مياه الرى

وذلك عن طريق إحلال محصول الارز (وهو اكثر المحاصيل الحقليه إستهلاكا للمياه) بمحصول الذره (و هو محصول اقل استهلاكا للمياه) او عن طريق خفض المقننات المائيه لمحصول الارز عن المعدلات المعمول بها و تم تطبيق ذلك على اقليم شرق الدلتا حيث اشارت نتائج النموذج الرياضى الى انه يمكن توفير ما يعادل ٩٢٥ مليون متر مكعب من مياه الرى إذا ما انخفضت مساحات زراعة الارز بمقدار ٣٪ مقارنة بعام ١٩٨٨.

كما اوضحت النتائج انه من الممكن توفير نفس الكميه إذا ما تم خفض المساحات المسموح زراعتها بمقدار ٨٪ فقط و لكن مع خفض مقننات الارز او احتياجاته المائيه من ٨٨٠٠ م٣ / فدان الى ٧٤٠٠ م٣ / فدان. كما اوضحت النتائج تاثير ذلك الوفر فى المياه على الانتاج المحصولى وملوحة التربه على المدى القريب والبعيد.

٢. التوسع فى استصلاح الاراضى دون زيادة الحصه المائيه

أمكن تطبيق النموج الرياضى للتنبؤ بالتغيرات فى الانتاج المحصولى وملوحة التربه عند التوسع فى استصلاح الاراضى فى شرق الدلتا بمقدار ٣٥٠٠٠٠ فدان دون زيادة الحصه المائيه المتاحه لمنطقة شرق الدلتا وهذا التوسع يعادل حوالى ١٧٪ من المساحه الكليه الزراعيه (بالمقارنه بالمساحه الزراعيه فى عام ١٩٨٨) وقد وجد ان ذلك يؤدى الى زيادة فى معدلات البخر نتح الفعليه لكل منطقه شرق الدلتا بمقدار ١١٪ مما يشير الى عدم حدوث نقص كبير فى المحصول على مستوى المساحه الكليه الا ان مثل هذه الدراسات تتطلب إجراء مزيد من الدراسات الاقتصاديه التفصيليه.

٣. تنظيم الاداره والخدمه المائيه على المستوى الحقلى

تم استخدام النموذج الرياضى لدراسة امكانية تحسين إسلوب الاداره والخدمه المائيه فى منطقة شرق الدلتا عن طريق منع استخدام الطلمبات الديزل المتنقله فى عمليات الرى وكذا منع إعادة إستخدام مياه الصرف بصوره غير رسميه . وقد اظهرت النتائج ان ذلك يؤدى الى انخفاض معدلات البخر- نتح الفعليه (انخفاض الانتاجيه) بمقارنتها بنفس المعدلات عام ١٩٨٨.. وصاحب ذلك انخفاض فى الفواقد المختلفه من الري مع ضرورة زيادة معدلات إعادة استخدام مياه الصرف بصوره رسميه وحدوث تحسن فى درجة تركيز الاملاح فى مياه الرى المخلوطه ، اما فى حالة منع إستخدام الطلمبات فى الرى مع السماح بإعادة استخدام مياه الصرف بشكْل غير رسمى فقد حدث انخفاض فى فواقد شبكة الرى الى جانب إنخفاض معدلات استخدام مياه الصرف بصوره رسميه و عدم حدوث انخفاض فى معدلات البخر - نتح الفعليه للمحاصيل المختلفه لذلك فانه لا يتوقع حدوث اى تحسن فى انتاج المحاصيل فى كلا الحالتين.

٤. خفض كميات مياه الرى المستخدمه فى الاراضى القديمه

اشارت نتائج اختبار النموذج الرياضى على منطقة وسط الدلتا انه بخفض كميات مياه النيل فى هذا القطاع بمقدار ١٠٪ (اى ما يعادل حوالى ١,١ مليار متر مكعب) فانه لم تحدث اى تغيرات كبيره وموثره علي الانتاج المحصولى بصفه عامه - علما بانه عند استخدام هذا الاسلوب فى الاداره المائيه حدث انخفاضا محسوسا في فواقد شبكة الترع الرئيسيه.

٥. اختلاف الاحتياجات المائيه نتيجة اختلاف التركيب المحصولى الفعلى عن التركيب المحصولى التأشيرى

استخدم النموذج الرياضى لدراسة تأثير تغير التركيب المحصولى عما كان متوقعا فى منطقة وسط الدلتا حيث تم زيادة زراعة المحاصيل المستهلكه للماء بمقدار ٢٠٪ على حساب المحاصيل الاقل استهلاكا للمياه مع ثبات الحصه المائيه وقد اشارت النتائج الى ان تلك الزياده تؤدى الى زيادة المطلوب من المياه بمقدار ٢٧٠٠ مليون متر مكعب فى السنه.

زيادة المطلوب من المياه بمقدار ٢٧٠٠ مليون متر مكعب فى السنه ونتيجة لذلك فان كفاءة استخدام مياه الرى فى هذه الحاله ارتفعت الى حوالى ٨٠٪ وهو اقصى ما يمكن الوصول

(٢,٧) مليار متر مكعب عام ١٩٨٧/١٩٨٨ وبين (٤,٢) مليار متر مكعب عام ١٩٩٠/١٩٩١ .. كذلك اوضحت القياسات أن متوسط تركيز الاملاح فى مياه الصرف التى يعاد استخدامها تتراوح بين ٨٦٠ جزء فى المليون كحد ادنى و ١٢٠٠ جزء فى المليون كحد أقصى. كما لوحظ لجوء المزارعين المتزايد الى استخدام مياه الصرف الزراعى مباشرة فى الرى دون خلط بشكل غير رسمى يصعب رصده وتحديد كميته .

ب. النموذج الرياضى

إن أحد المستلزمات الاساسيه لتخطيط استخدام الموارد المائية التى تعتمد على اعادة استخدام مياه الصرف هو القدره على التنبؤ بالتغيرات المستقبلية فى كميات مياه الصرف ودرجة ملوحتها كنتيجة للتغيرات فى عناصر الاداره المائية و التركيب المحصولى .. لذلك فقد تم استنباط النموذج الرياضى SIWARE فى اطار مشروع إعادة إستخدام مياه الصرف و يعد هذا النموذج أداة لمحاكاة اسلوب الادارة والخدمة المائية على المستوى الاقليمى وعلى المستوى القومى.

ويقوم النموذج الرياضى على اساس تقسيم الاقاليم الى وحدات صغيرة (تسمى وحدات حسابيه) والتى تقع عادة ضمن نطاق وحدود ادارة الرى .. وقد يتطلب الامر أيضا تقسيم هذه الوحدات الى وحدات اصغر بحيث تكون المساحه الواقعه داخلها متجانسه من ناحية التربة والظروف الهيدرولوجية .. وعلى ضوء ذلك فقد قسمت دلتا نهر النيل الى ٢٨٥ وحدة حسابية منها ٨٨ وحدة فى شرق الدلتا و ١١٦ وحدة فى وسط الدلتا و ٨١ وحدة حسابية فى غرب الدلتا.

ويتطلب استخدام النموذج الرياضى معرفة بيانات عن الهيكل العام لنظام الرى والصرف بالمنطقة وكذا البيانات الضروريه عن خصائص التربه والخزان الجوفى وبيانات بالظروف المناخية والتركيب المحصولى .. هذا الى جانب كمية المياه المستخدمه للانشطة غير الزراعيه مثل الصناعة ومياه الشرب فضلا عن الاسلوب المستخدم فى ادارة وتوزيع المياه .

ويتكون النموذج الرياضى من مجموعه من النماذج الرياضية الفرعيه لكل منها دورا فى عملية المحاكاة .. فعلى سبيل المثال النموذج الرياضى DESIGN يختص بحساب كميات مياه الرى المطلويه عند مأخذ كل من الترع الرئيسية على اساس الموارد المتاحه والمطلوب منها للاستهلاك. وجدير بالذكر أن هذا النموذج ياخذ فى اعتباره المياه الجوفيه التى يمكن سحبها للاستخدام وكذا كميات مياه المطر (إن وجدت) وايضا المتاح من مياه الصرف لاعادة استخدامه وبالتالى يتم تحديد كمية مياه النيل العذبه المطلويه.

كذلك فان النموذج الرياضى الفرعى WDUTY يقوم بحساب الاحتياجات المائيه الفعليه لكل محصول ضمن الوحده الحسابيه آخذا فى الاعتبار نوع التربه والظروف الهيدرولوجيه وايضا اسلوب ونظام الرى.

اما النموذج الفرعى WATDIS فيقوم بالتوزيع الفعلى للمياه على كل الوحدات الحسابيه معتمدا على الخصائص الهيدروليكيه لشبكة الترع الموجوده فى كل نطاق من نطاقات الدلتا والظروف الهيدرولوجيه السائده فيها كذلك فان التمثيل الرياضى لنظام تشغيل البوابات والاعمال الصناعيه على شبكة الترع يطابق ذلك الذى يتم بمعرفة وزارة الاشغال العامه والموارد المائيه كما ان نظام محاكاة رفع المياه من الترع للاستخدام مبنى علي اساس الاحتياجات الفعليه لكل وحده حسابيه من مياه الرى وايضا الكميات اللازمه للاستخدام بواسطة الانشطه الاخرى (الصناعه و الشرب).

و النموذج الفرعى REUSE يقوم بحساب درجة تركيز الاملاح فى مياه الرى على إمتداد شبكة الترع نتيجة لاختلاطها بكميات مياه الصرف عند مواقع الخلط وكذا التغير نتيجة للعوامل الاخرى ثم يقوم بتوزيع كمية مياه الرى المأخوذه للوحده الحسابيه على المحاصيل الحقليه المختلفه وكذا يقوم بحساب كمية مياه الصرف المأخوذه بواسطة المزارعين بصوره غير رسيمه من شبكة المصارف لاغراض الرى. كذلك فان هذا النموذج يقوم بحساب معدلات البخر- نتح الفعليه أخذا فى الاعتبار الظروف السائده من حيث الرطوبه الموجوده فى التربه ودرجة تركيز الاملاح.

ثم يقوم هذا النموذج بحساب كميات مياه الصرف وكذا تركيز الاملاح بها الناتجه من كل محصول ضمن الوحده الحسابيه ثم يتم تجميع هذه الكميات المختلفه ويضاف اليها كميات مياه الرى المفقوده من نهاية ترع التوزيع وكميات مياه الرى المفقوده عند نهايات الترع الرئيسيه وكذا العائد من المياه المستخدمه فى الانشطه الغير زراعيه لتعبر عن كميات مياه الصرف الكليه فى المصرف العمومى بالمنطقه.

موجز عن مشروع إعادة إستخدام مياه الصرف فى دلتا نهر النيل

مقدمه

يعتبر نهر النيل هو المصدر الوحيد المتجدد للمياه العذبه فى مصر التى يبلغ نصيبها السنوى ٥٥,٥ مليار متر مكعب وفقا لاتفاقية عام ١٩٥٩مع السودان ولا ينتظر زيادة هذا الايراد فى المستقبل القريب.

ونظرا للزياده المطرده فى الطلب على المياه نتيجة الزياده السكانيه وزيادة انشطة الزراعه والصناعه فإن الاحتياجات الكليه قد تزداد الى حوالى ٦١,٥مليار متر مكعب فى السنه بحلول عام ٢٠٢٥ وهو ما لا يمكن الوفاء به دون اللجوء الى الوسائل غير التقليديه لتوفير المياه لذلك فان مياه الصرف تعد من المصادر التى قد تساهم فى سد الفجوه المائيه بين الموارد والاحتياجات.

ومنذ عام ١٩٨٣ تم البدأ فى تنفيذ مشروع إعادة إستخدام مياه الصرف كأحد ثمار التعاون الفنى بين الحكومه المصريه ممثله فى معهد بحوث الصرف التابع للمركز القومى لبحوث المياه بالقناطر الخيريه و بين الحكومه الهولنديه ممثله فى معهد إدارة المياه واستصلاح الاراضى - فاجننجين.

ويهدف المشروع الى انشاء شبكه رصد دائمه لقياس كمية ونوعية مياه الصرف وتوزيعها على امتداد شبكة الصرف وتغيرها من حيث الكم والنوع على مدار السنه كما يهدف الى اعداد نموذج رياضى للتنبؤ بكمية ونوعية مياه الصرف فى ظل حدوث اى متغيرات وتحديد تأثير اعادة استخدامها فى الرى على التربه والمحصول وقد تم تنفيذ المشروع على مرحلتين الاولى من ١٩٨٣ - ١٩٨٩ والثانيه من ١٩٩١ - ١٩٩٥.

إنجازات المشروع

أ. برنامج القياسات

يبلغ طول المصارف الرئيسيه فى دلتا نهر النيل حوالى ١٦٠٠ كيلو متر تخدم حوالى ٤,٧ مليون فدان من الاراضى الزراعيه موزعه على حوالى ٢٢ زمام صرف تصرف مياهها الى المصارف الرئيسيه والتى بدورها تلقى حملها الى البحيرات الشماليه او البحر الابيض المتوسط.

ومنذ عام ١٩٧٧ بدأ معهد بحوث الصرف بقياس تصرفات و تجميع عينات مياه المصارف من ما يقرب من ٤٧ موقع موزعه على مناطق الدلتا المختلفه .. عقب ذلك تم حصر شبكة المصارف عام ١٩٨٠ لاختيار المواقع الاستراتيجيه للقياسات الدوريه لمياه الصرف. ومنذ عام ١٩٨٣ بدأ مشروع إعادة استخدام مياه الصرف فى اقامة شبكة الرصد التى تضم حاليا حوالى ٨٠ موقع قياس وتزويد تلك الشبكه بالاجهزه والمعدات التى تضمن إجراء قياسات دوريه وفقا للطرق والمواصفات القياسيه المناسبه لتحديد التصرف وملوحة المياه عند كل موقع.

كما يشمل هذا البرنامج تحليل دورى لعينات من مياه الصرف بالمعمل لتحديد درجة تركيز الاملاح والكاتيونات والانيونات التى لها علاقه مباشره بصلاحية المياه للرى. هذا وقد تم انشاء قاعدة بيانات لتحليل واسترجاع البيانات المختلفه لمياه الصرف مزوده بحزمة من البرامج المساعده التى تقوم باختبار تلك البيانات وتنقيتها من اخطاء الحساب و السهو وتمثيلها بيانيا او جدوليا فى صورة تقارير خاصه

ومن أهم نتائج برنامج الرصد والقياس اصدار الكتاب السنوى والذى يتضمن كمية وملوحة مياه الصرف التى اعيد استخدامها فى أقاليم الدلتا الثلاثة (شرق - وسط - غرب) الى جانب تحديد كمية مياه الصرف المنطلقة الى البحر وملوحتها وكذا عناصر نوعيه المياه. ويتم توزيع الكتاب على عدد كبير من الهيئات والمؤسسات والشخصيات للاستفاده من هذه المعلومات فى خطط التنميه والتوسع.

وعلى ضوء برنامج القياس الدورى تم تحديد التغيرات التى تحدث فى كميات ونوعيه مياه الصرف مع الزمن وهو يرتبط بالتغيرات فى اسلوب وسياسة الادارة والخدمة المائية المتبعه وعلى الاخص مع كميات مياه النيل المنصرفة عند السد العالى ٠٠ وقد بلغت كمية مياه الصرف المنصرفة الى البحر أقصاها عام ١٩٨٤/١٩٨٥ (١٣,٧) مليار متر مكعب ٠٠ بينما بلغت أقلها فى عام ١٩٨٨/١٩٨٩ (١١,٥) مليار متر مكعب .. ٠٠ كذلك أوضحت القياسات ان نوعيه مياه الصرف جيده فى الجزء الجنوبى من الدلتا ومتوسطة فى الأجزاء الوسطى منها بينما بلغت درجة الاملاح اعلى مايمكن فى الجزء الشمالى من الدلتا.

و تراوحت كمية مياه الصرف التى يعاد استخدامها بصورة رسمية عن طريق الخلط بمياه ترع الرى مابين

التقرير النهائي

لمشروع إعادة إستخدام مياة الصرف

تقرير رقم ٥٠، سنة ١٩٩٥

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ISBN 90-327-0259 -9

PRINTED IN EGYPT

Reuse Of Drainage Water In The Nile Delta

Reuse Report 50. 1995