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THE DEVELOPMENT OF A SYSTEMATISED DECISION PROCESS FOR OPTIMISING WATER ALLOCATION PLANS IN EGYPT

by

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ABSTRACT

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Due to the arising awareness of the water scarcity threat, it was intended to support the decision practice regarding water allocation plans in Egypt by a systematised decision process that takes account of controversial issues within the agricultural system. To achieve this objective, the ensuing course of actions has been undertaken.

At first, the water situation in Egypt has been reviewed with a special focus on the challenge to satisfy increasing demands despite limited resources. Constraints impeding the development of water resources have been identified. The role of climatic fluctuations in the anticipated water scarcity has been highlighted. It has been concluded that the governmental efforts being undertaken to promote water availability should be coupled with optimising decisions on water allocation in order to generate sound disciplines of water use.

The Nile Basin Simulation Model (NBSM) has been introduced as a powerful tool for investigating physical impacts brought about by applying different water use alternatives. A detailed description of the model input and output has been provided. Weaknesses including confining New Lands within the closed irrigation system have been revealed. Proceedings for sorting out these shortcomings have been proposed.

Light has been thrown on Decision Support Systems (DSS). The role of computers in emphasising the usefulness of decision support has been explained. Composite programming has been introduced as a decision technique based on hierarchical tradeoff analysis. Implications of the introduced technique have been exemplified by applying the DSS procedure on a simple decision problem.

Based on the Composite Programming framework and NBSM output, a DSS has been developed to optimise water allocation schemes in Egypt. A questionnaire has been developed to reflect experts' views regarding the relative importance of DSS components. Schemes are prioritised according to their closeness to the top index 'Welfare of Egypt'. The whole process has been computerised and introduced in a user friendly package. Implausibilities affecting the acceptability of the developed model have been discussed.

Controversial issues of the Egyptian agriculture have been included in eighteen water use scenarios tested within the DSS. The variables used in outlining these scenarios are: i) projected reclamation areas, ii) cropping patterns, and iii) the distribution efficiency of the old irrigation system. The DSS run has resulted in favouring the scenarios undertaking a modest horizontal expansion, an improved canal efficiency and a change to less water consuming patterns and/or high value cash crops. A conducted sensitivity analysis has confirmed the attained results.

An endeavour has been carried out to remodel the NBSM in order to remedy the revealed weaknesses and to increase its potential for growing into an optimisation planning tool. Modifications have been made to split New Lands from the closed irrigation system and an optimisation routine has been added to the original model. Based on conducted runs of the modified model, it has been concluded that no Nile water should be diverted to New Lands.

Finally, a discussion has been performed about DSS results and the factors impeding a real-time application of the favoured scenarios. Also, the performance of DSS modules (NBSM + tradeoff hierarchy) has been brought under a general evaluation. Highlighting opportunities for further improving the developed decision process has been the closing recommendation for a growing programme of optimum water use.

CONTENTS

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LIST OF ACCOMPANYING MATERIAL

- A 3.5" computer diskette containing the setup files of the Decision Support System for Water Allocation Plans in Egypt (DSS). The following files are included:

CMDIALOG.VB_	SAMPLE.DS_	SPIN.VB_
DEFAULT. DS_	SETUP.EXE	THREED.VB_
DSS.EX_	SETUP.LST	VBRUN300.DL_
DSSSETUP.EX_	SETUPKIT.DL_	VER.DL_
GRID.VB_	MSAFINX.DL_	DSSSETUP.EXE

To install the DSS to a computer, insert the enclosed diskette into the floppy drive and load windows. From the File Manager, doubleclick DSSSETUP.EXE. The Setup installs the game files from A:\ to C:\DSS.

ACKNOWLEDGEMENTS

My particular thanks are due to Professor R.F. Stoner to whom I am deeply indebted for his exhaustive help and support throughout this research. Particular thanks are extended to Dr. A.C. Lock for his sincere guidance and constructive suggestions.

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NOMENCLATURE

a_i	weight attributed to criterion number i
a_{ij}	weight expressing the relative importance of indicators in group j
bn. m^3, milliard m^3	billion cubic meter(s)
DR	Drainage Reuse
DRI	Drainage Reuse Institute
DSS	Decision Support System
feddan(s), fed	0.42 hectare, 1.038 acre
GCM	General Circulation Model
GW	Groundwater
HAD	High Aswan Dam
km^2	squared kilometer(s)
L	metric distance
L_j	metric distance for group j of indicators
LE	Egyptian Pound(s)
max	maximum
m	meter(s)
m^3	cubic meter(s)
mm	millimeter(s)
MALR	Ministry of Agriculture and Land Reclamation
M. LE	Million Egyptian Pounds
M. m^3	Million cubic meters
M. tons	Million tons
MPWWR	Ministry of Public Works and Water Resources
M&I	Municipal and Industrial water use
n	number of criteria
n_j	number of indicators in group j
NBSM	Nile Basin Simulation Model
OM&R	Operation, Maintenance and Replacement
p	balancing factor
p_j	balancing factor among indicators for group j
ppm	parts per million
Reg	Region(s)
WDN	West Delta New lands
WDO	West Delta Old lands
MDN	Middle Delta New lands
MDO	Middle Delta Old lands
EDO	East Delta Old lands
EDN	East Delta New lands
SIN	Sinai
FAY	Fayoum
MEO	Middle Egypt Old lands
MEN	Middle Egypt New lands
UEO	Upper Egypt Old lands
UEN	Upper Egypt New lands

Rel . . . . Relative
Scenario B . . . . applying the base (default) cropping patterns
Scenario C . . . . applying a cotton intensification in the Delta
Scenario D . . . . . applying the base (default) old system's distribution efficiency
Scenario E . . . . applying an improved old system's distribution efficiency
Scenario F . . . . applying a full plan of horizontal expansion
Scenario I . . . . applying an intermediate plan of horizontal expansion
Scenario M . . . . applying a modest plan of horizontal expansion
Scenario S . . . . applying a sugar elimination in Upper and Middle Egypt
S/EWAM . . . . Spatial/Economic Water Allocation Model
S_i . . . . normalised value of criterion number i
S_{ij} . . . . normalised value of indicator i in group j of indicators
Tot . . . . Total
WUA . . . . Water User Association
Z_i . . . . value of criterion number i
Z_i^* . . . . ideal value of criterion number i
Z_i^{**} . . . . worst value of criterion number i
°C . . . . degree(s) Celsius

INTRODUCTION

Numerous arid and semi-arid countries occasionally encounter serious shortfalls in water availability. Consistently, Egypt is endangered despite the existence of the Nile, the High Aswan Dam and the world's most ancient and most extensive irrigation system. Straitened water conditions might have prevailed, due to Sahelian Drought (1980-1988), if only the 1988's flood had not taken place.

The possibility that Egypt will suffer still further cannot be discarded. Climatic fluctuations are expected to take part in determining the magnitude of the foreseen water crisis. The problem is aggravated by an anticipated increase in population and a low sustainability and/or high price of untraditional water abstractions. On the other hand, the Egyptian Government attempts to alleviate the food gap problem and mitigate the urban pressure on agricultural land by adopting a horizontal expansion policy. This implies a reclamation of desert areas outside the Nile Valley and Delta. The anticipated water scarcity puts decision makers in a dilemma as to whether to keep Nile water within old lands' boundaries or to divert it partially to less mature new lands.

In order to achieve an optimum water use programme, water allocation plans, currently based on officials' experiences and farmers' complaints, should be supported by a systematised decision technique that takes account of issues and controversies of the Egyptian agricultural system. The objective of the current study is to establish a prototype decision process, using modelling tools, to help Egyptian policy makers become more decisive about controversial water use disciplines. In this context, the current and prospective water situations in Egypt are reviewed. A planning model (NBSM) that simulates twenty years of Nile Basin operation is analysed. 'Composite Programming' is introduced as a promising decision making technique. Using the NBSM output and the Composite Programming framework, a Decision Support System (DSS) is structured and computerised in a user friendly environment. The DSS is used to analyse different water allocation strategies and propose the one(s) that best satisfies various interests regarding the welfare of Egypt. Finally, an endeavour is made to increase the NBSM reliability as a simulation planning tool and probe its potential for growing into an optimisation planning model.

CHAPTER I

THE WATER SITUATION IN EGYPT

1.1 BACKGROUND

Egypt is one of the oldest agricultural lands in history. Despite having no rainfall, Egyptians have been practising farming for more than 5,000 years, being the primary beneficiaries of the Nile water. This section presents some background on the Egyptian climate and physiography, population and agricultural system.

1.1.1 Climate and Physiography. Climatically, Egypt is generally classified as an extremely arid zone. Located between latitudes 22°N and 31°35'N, about 86 percent of Egypt's total area is considered as extremely arid and 14 percent as arid (Abu Zeid, 89). The total gross area is 1,001,450 km², of which only about 3.6 percent is agriculturally productive. This can be divided into three distinct agro-climatic zones (MMP, 88):

1) Lower Egypt (the Delta), extending from Cairo to the sea and characterised by some winter precipitation in the coastal belt. Average annual rainfall ranges from 65-190 mm and the mean monthly temperature ranges between 11.9°C and 26.6°C.
2) Middle Egypt, extending from Cairo (28 mm precipitation) south to the boundary of Minia/Assiut Governorates and characterised by minimal rainfall. Maximum temperatures and diurnal temperature variations are greater than in the Delta and winters are generally warmer.
3) Upper Egypt, extending southwards from the Minia/Assiut Governorate boundary to the Sudanese border and characterised by the almost complete absence of rainfall. While temperatures are very high from April to October, reaching 42°C in April and May, winters are generally mild. Upper Egypt is mostly subject to wide diurnal variations in temperatures.

Besides the Nile Valley and Delta, Egypt comprises:

- Western Desert, considered one of the most arid regions in the world. It occupies about two third of the area of the whole country.
- Eastern Desert, similar to Western Desert. It occupies more than one fifth of the total area of Egypt.
- Sinai Peninsula, characterised by a slightly greater rainfall than that in the other desert regions.

Fig. 1-1 shows a map showing the location of the River Nile. Ever flowing northwards to the Mediterranean sea, it induces human settlements to thrive in the lower reaches of the Nile River basin, in what is now Egypt.

1.1.2 Population. Estimates of Egypt's population indicate a growth from 26 million in 1960 to 55 million in 1990. Consequently, the per capita cultivated area that amounted to 0.19 feddans in 1960, is now 0.12 feddans. It is expected that, if this trend of growth were to continue, the population of Egypt will attain 117.4 million by the year 2050 (Biswas, 91a). It was found that, to keep the per capita share of the agricultural area from decreasing still further, it is necessary to add new areas at a rate of at least 150,000 feddans per year (Abu Zeid, 89). Table 1-1 shows the evolution of the annual increase rate of population over the period 1965-1988.

1.1.3 Agricultural System. Egypt's agricultural system may be typified by the following features:

- Rainfed agriculture, confined to the coastal belt and yielding an uncertain harvest of crops, such as barley and olives.
- Irrigated agriculture, elsewhere in the country (mainly in the Nile Valley and Delta), yielding the main agricultural products of Egypt namely: wheat, rice, sugar, pulses, cotton, meat, etc.

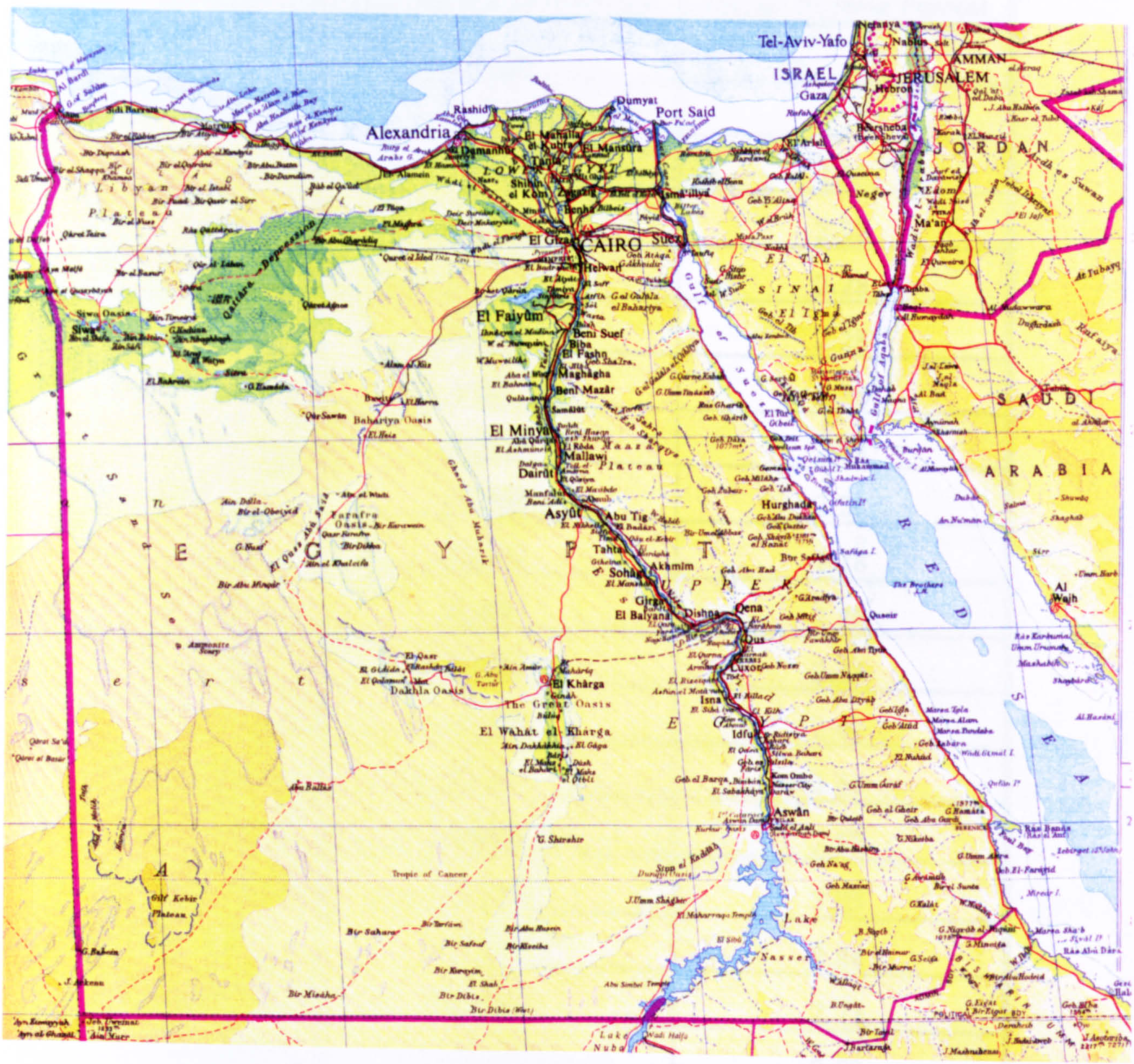

FIGURE 1-1. Map of Egypt

TABLE 1-1. Population of Egypt

Year	Population x 1,000 Persons	Annual Increase Percent
1965	29,389	-
1966	30,188	2.72
1967	30,892	2.33
1968	31,596	2.28
1969	32,316	2.28
1970	33,053	2.28
1971	33,807	2.28
1972	34,578	2.28
1973	35,366	2.28
1974	36,172	2.28
1975	36,997	2.28
1976	37,858	2.33
1977	38,794	2.47
1978	39,767	2.51
1979	40,889	2.82
1980	41,126	3.03
1981	43,322	2.84
1982	44,506	2.73
1983	45,721	2.73
1984	46,990	2.78
1985	48,349	2.89
1986	49,863	3.13
1987	51,297	2.88
1988	52,919	3.16

Source: Mid-year Estimation, Statistical Yearbook; Cited in: JICA, 91

The agricultural land base of Egypt totals to 7.5 million feddans. This area comprises some 7.3 million feddans lying within the Nile Basin and about 200,000 feddans elsewhere (rainfed and oases). Of the former area, some 5.5 million feddans located in the vicinity of the Nile are called 'old lands'. The remaining 1.8 million feddans are called 'new lands' for being recently reclaimed along the desert fringes of the Nile Basin. Table 1-2 shows the values of cultivable land, planted area and cropping intensity in Egypt over the period 1970-1989.

TABLE 1-2. Cultivable Land, Planted Area and Cropping Intensity in Egypt

Year	Cultivable Land x 1,000 feddans	Planted Area x 1,000 feddans	Cropping Intensity %
1970	5,665	10,747	189.7
1971	5,653	10,741	190.0
1972	5,682	10,832	190.6
1973	5,717	10,927	191.1
1974	5,736	11,028	192.3
1975	5,797	11,164	192.6
1976	5,799	11,199	193.1
1977	5,795	11,111	191.7
1978	5,804	11,142	192.0
1979	5,817	11,235	193.1
1980	5,865	11,130	189.8
1981	5,880	11,260	191.5
1982	5,834	11,167	191.4
1983	5,846	11,139	190.5
1984	5,830	11,027	189.1
1985	5,979	11,175	186.9
1986	6,004	11,137	185.5
1987	5,972	11,127	186.3
1988	6,102	11,234	182.6
1989	6,120	11,339	185.3

Source: Ministry of Agriculture; Cited in: JICA, 91

The contribution of the agricultural sector to the Egyptian economy declined significantly from 32 percent of total gross domestic product (GDP) in 1960 to about 20 percent in 1989. However, patterns for agricultural water demand currently account for nearly 84 percent of all water used (Biswas, 91b). Table 1-3 shows the evolution of the agriculture sector's contribution to Egyptian GDP, exports and employment during the last decade.

TABLE 1-3. Evolution of the Agriculture Sector's Contribution to Egyptian GDP, Exports and Employment

Year	1980	1985	1990
Share(%) of Agriculture in GDP (1987 prices)	25.4	19.3	19.9
Share(%) of Agriculture in Exports	22.5	17.7	20.3
Share(%) of Agriculture in Employment	36.7	35.8	N.A.

Source: WSP, 93a

1.2 PRESENT WATER RESOURCES AVAILABILITY

Egypt has been for long depending on continued 'cheap, easy and abundant' flow of the Nile River to sustain its ever increasing demands. Despite the construction of the High Aswan Dam (HAD), which not only provided Egypt with the complete regulation of annual Nile flows, but also gave sufficient over-year storage, Egypt seems unable to keep pace with the increasing water demands of its population growing at a rate approaching three percent annually. The exploration of additional water resources has become a top priority after experiencing the nine-year Sahelian drought that affected the quantity of water inflowing to Lake Nasser. This may be an introduction to a series of climatic changes that may influence the Nile Basin catchment, as will be shown in subsequent sections. Fig. 1-2 shows how the water upstream of the HAD reached a critical level and threatened the function of the turbines used in power generation. The Egyptian main water resources currently used are:

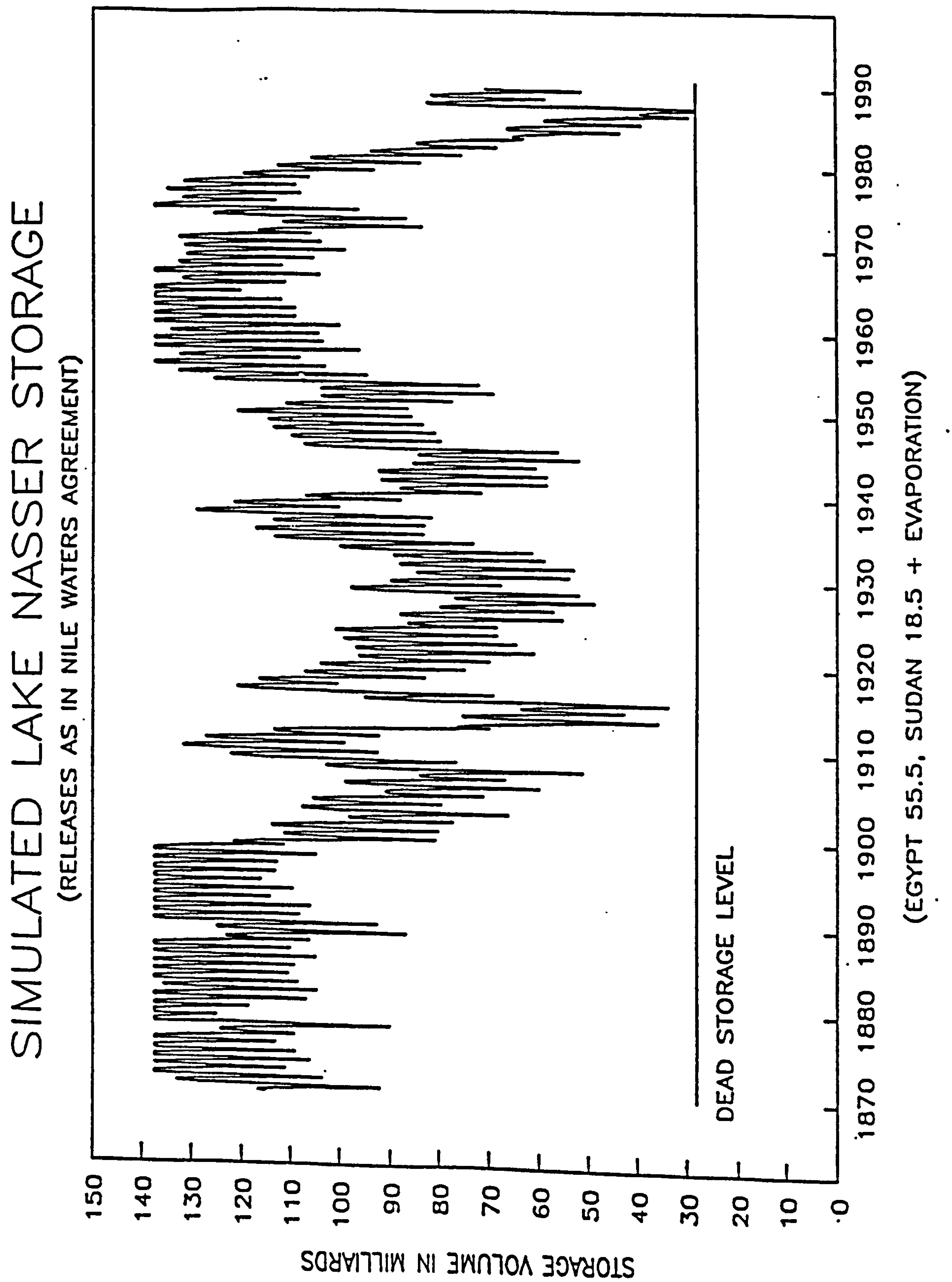

FIGURE 1-2. Simulated Lake Nasser Storage
Source: WSP, 93b

- The River Nile.
- Groundwater.
- Rainfall.
- Wastewater Reuse.

1.2.1 The River Nile. Between 1900 and 1959, the annual flow of the river at Aswan ranged from 65 to 130 bn. m^3 with an average of 84 bn. m^3 (El Kady, 79). These waters were allocated by the 1959 Agreement between Egypt and Sudan in the following amounts:

		Billion cubic meters
Egypt		55.5
Sudan		18.5
Evaporation & Seepage		10.0
	TOTAL	**84.0**

1.2.2 Groundwater. The Nile Valley and Delta constitute an aquifer system receiving water mostly as seepage from the River, canals and irrigated fields (MMP, 88). The lower boundary of this aquifer system is considered impervious. Its lateral boundaries along the sides of the Nile Valley allow a negligible horizontal flow. The Delta's western boundary comprises newly reclaimed lands, especially in West Behera, which, due to the groundwater build up, is now recharging the aquifer to the east of it by subsurface inflow. An exception exists in the Wadi Natrun area. This area, comprised within the Delta western boundary, is a discharge area because of its low altitude compared to surrounding areas. Eastern Delta is bounded from the south by Ismailia Canal that functions as a recharge boundary and from the north east by the Suez Canal. In the Nile Valley, flows across the southern and northern boundaries, at Aswan and Cairo respectively, are insignificant because of the decrease in aquifer thickness and the valley narrowing. The Delta's northern coast is characterised by the presence of a saline water zone that reduces gradually towards the south. This underlies the fresh water zone as shown in Fig. 1-3.

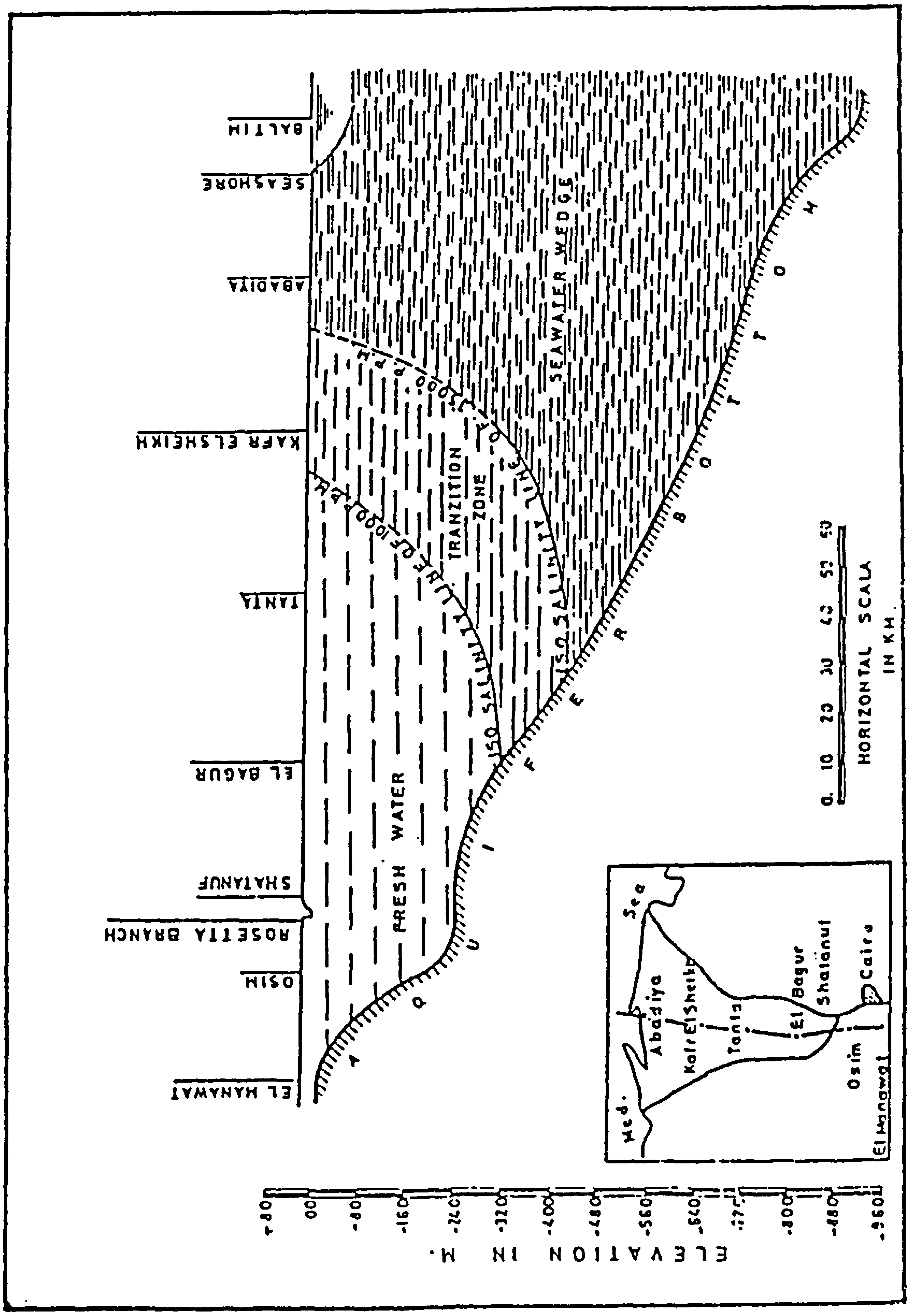

FIGURE 1-3. Sea Water Intrusion in the Nile Delta Aquifer
Source: WSP, 93c

Groundwater is also found in the Nubian sandstone aquifer underlying most of the Western Desert (Fig. 1-4) and is discharged naturally and artificially in the oases. Most recent studies have indicated that this is not a renewable resource. Further studies are carried out to investigate the groundwater potential within this regional aquifer. Groundwater aquifers of promising potential are also available in Sinai, but on a very limited scale (Abu Zeid, 92).

1.2.3 Rainfall. The total gross volume of precipitation over the Nile Valley and the Delta is about 1.5 bn. m^3 per year. The total net effective rainfall is equivalent to some 0.5 bn. m^3 per year (MMP, 88). Precipitation is only significant along the northern coast where it amounts to an annual average of 200 mm. A seasonal agricultural activity takes place along the coastal belt depending on this limited amount of rainfall.

1.2.4 Wastewater Reuse. An annual drainage to the sea and terminal lakes of about 13 bn. m^3 gives an indication of how important it is to consider reusing wastewater. This can do much to alleviate the dilemma of increasing water demands and limited water resources. However, the extent to which this process can be carried out depends on several factors. The latter include water quality considerations and the practical and economical feasibility of making drainage water readily available when and where it is needed for irrigation.

In Upper Egypt, all drains flow into the Nile (except in Fayoum Governorate where drainage water, of which an annual amount of 0.25 bn. m^3 is reused within the Governorate's boundaries, ends in Lake Qarun). The main projects for drainage water reuse are, therefore, concentrated in the Delta. The total quantity of official reuse in 1991 was estimated at 4.3 bn. m^3 (DRI, 93).

Reuse of drainage water in Egypt can take place on three different levels (DRI, 90):

1) The official reuse: This reuse of drainage water takes place by pump

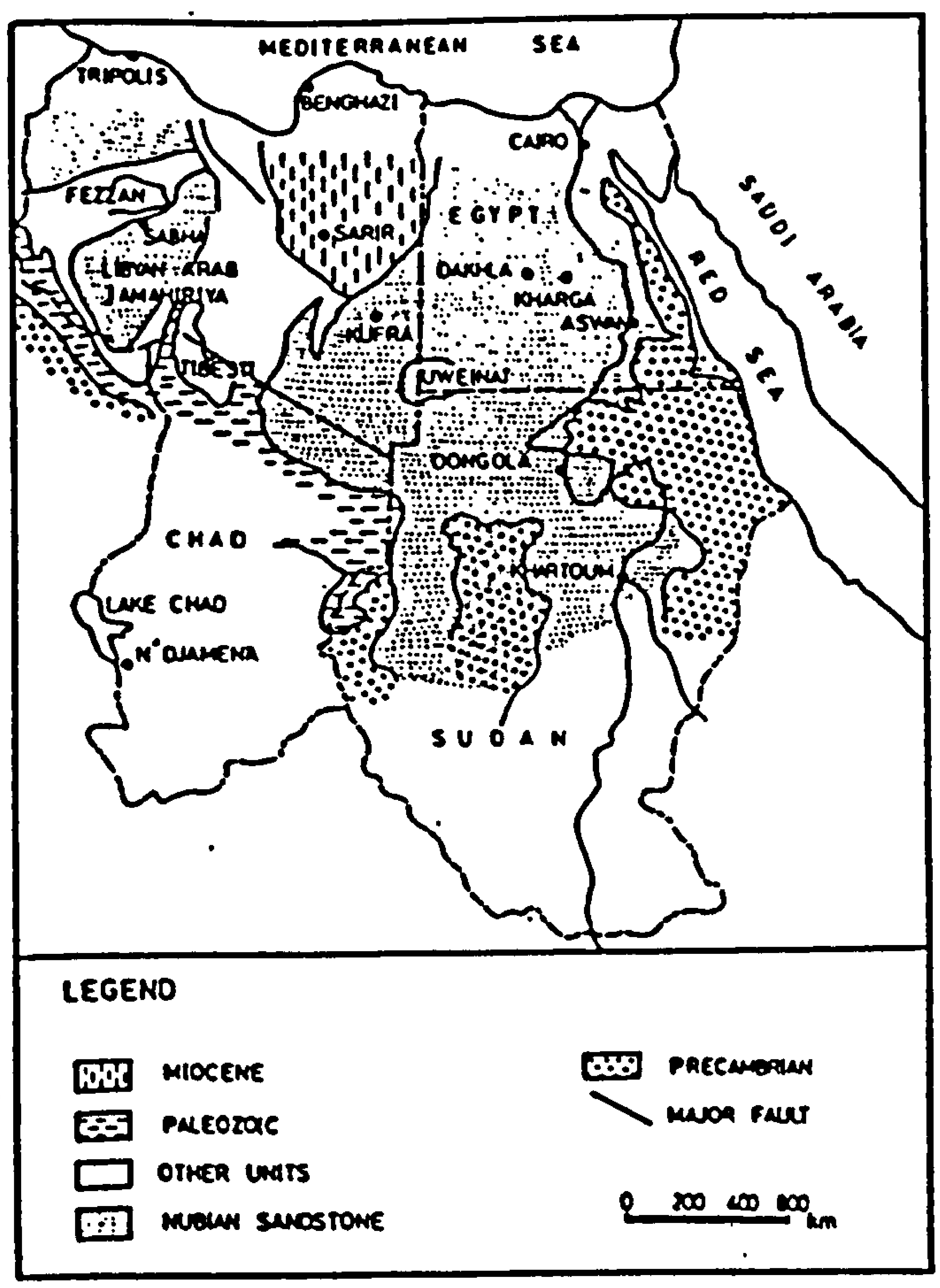

FIGURE 1-4. Regional Extent of the Nubian Sandstone Aquifer
Source: Hefny, et al, 92

stations. The quantity to be reused is part of the irrigation water allocation and distribution strategy of the Ministry of Public Works and Water Resources.

2) The unofficial external reuse: In case of water shortages, farmers may use drainage water generated in upstream areas and passing through or along their catchment for irrigation.
3) The unofficial internal reuse: If crop water demands are not satisfied despite unofficial external reuse, farmers start pumping drainage water from the smaller internal drains within their catchment.

1.3 EXPECTED EFFECTS OF CLIMATIC FLUCTUATIONS ON THE NILE BASIN

A tangible global climatic change is increasingly taking place. This change is mainly due to the growing atmospheric concentrations of greenhouse gases. The latter arise primarily from the burning of fossil fuels, the manufacture of cement, the changes in land use and other natural and anthropogenic activities disturbing the atmospheric balance. If measures are not taken to avoid the detrimental changes in human behaviour, climatic fluctuations will influence several parts of the world, including the Nile Basin region.

1.3.1 Effects on Temperatures. It is well established that atmospheric water vapour, carbon dioxide (CO_2), methane(CH_4), and other greenhouse gases trap a part of the Earth's radiant heat due to sunlight, thus causing warm temperatures that make life on earth possible. However, evidence exists that a global warming of 0.5°C manifested itself since 1860 with nearly half this rise occurring since 1965 (World Resources Institute, 90). An overall warming over the Nile Basin of about 0.5°C is also evident, but this warming mostly occurred in the early decades of this century (Hulme, 90). Using results from General Circulation Models (GCM), it is predicted that if CO_2 (or its equivalent in other greenhouse gas concentrations) reaches twice the preindustrial level (280 ppm in the year 1800), the average global temperatures would rise by 1.5 to 4.5°C, depending on the particular model used (National Research Council, 83). Similarly, the synthesised scenario that could result from a doubling of CO_2-equivalent (i.e., from 300 to 600 ppm) using the five GCM experiments performed at the Goddard Institute for Space Studies, the Geophysical Fluid Dynamics Laboratory, Oregon State University, the National Centre for Atmospheric Research, and the U.K. Meteorological Office, suggests mean seasonal temperature increases over the Nile Basin of between 2 and 4°C (Hulme, 90). Nevertheless, it is not expected that this doubled-CO_2 environment will take place before the year 2030 if current trends of greenhouse gas production continue (World Meteorological Organization, 86).

1.3.2 Effects on Precipitation. The fluctuations in global precipitation are influenced by a number of forcing factors of either a natural or anthropogenic origin. Historically, the natural factors were dominant. Currently, anthropogenic processes, such as human-induced land cover change, evaporation by the creation of artificial water bodies, and vegetation by the extraction of woodfuel (Ahlcrona, 88), are significantly affecting precipitation.

A possible future global rainfall scenario using the Goddard Institute of Space Studies Model spots the following changes (Jager, 88):

- Higher midlatitudes (45-60°N): rainfall increase of 5 percent in summer and 15 percent in winter.
- Lower midlatitudes (e.g., semi-arid Mediterranean climates): limited summer rainfall and 5-10 percent decrease in winter.
- Low latitudes (0-30°N): rainfall increase of 5-10 percent (large increase in equatorial regions, diminishing towards higher latitudes).

The precipitation climatology of the Nile Basin is not uniform. The contribution of the precipitation input to the overall Nile discharge may be divided between three selected regions of 5° latitude by 5° longitude dimensions each (Hulme, 90), as shown in Fig. 1-5. The three regions represent the Upper White

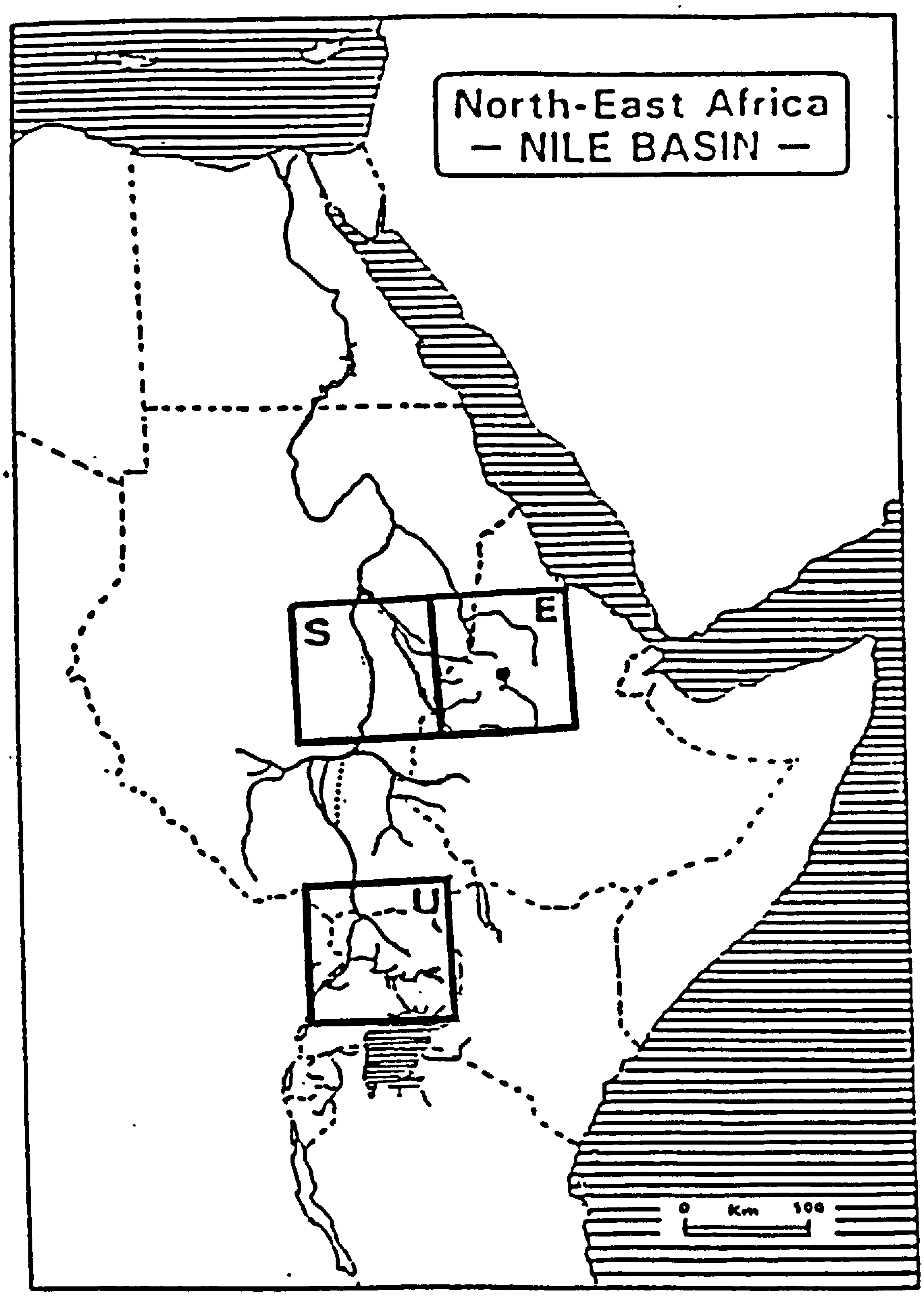

FIGURE 1-5. The Three Regions Contributing to the Precipitation Input to the Nile
(U = Uganda, E = Ethiopia, S = Central Sudan)
Source: Hulme, 90

Nile catchment (Uganda), the Upper Blue Nile catchment (Ethiopia) and the Middle Nile Basin (Central Sudan). Precipitation over the Blue Nile contributes 70 to 80 percent of the main Nile discharge. Rainfall over the White Nile accounts for 20 to 30 percent of the overall discharge. The contribution of precipitation over central Sudan in the Nile discharge is small.

Using a composite model scenario derived from a number of GCM experiments for estimating future precipitation changes over the Nile Basin suggests a high probability (between 0.8 and 0.9) for increased precipitation in both the summer and winter seasons over the White Nile catchment and an expected decrease in summer precipitation over the Blue Nile catchment. Thus, it is guessed, in the light of the anticipated high rates of evapotranspiration, that the flow of the Blue Nile will decrease while that of the White Nile will remain constant or slightly increase (Hulme, 90).

1.4 CONSTRAINTS IMPEDING THE FUTURE DEVELOPMENT OF WATER RESOURCES

The future development of Egyptian water resources is bound to certain constraints. The latter are related to the future availability of natural water from the Nile, potential groundwater abstractions, significance of rainfall contribution to the national water balance and feasibility of wastewater reuse development.

1.4.1 Future Availability of Natural Water from the Nile. The average Nile yield, upon which the water allocations (demonstrated in section 1.2.1) have been based, may be broadly questioned. This is due to the variability of mean Nile flows naturalised at Aswan and averaged over various sets of years (Fig. 1-6). Moreover, it has been explained that Blue Nile flows are likely to decrease, while White Nile flows are expected to remain constant or slightly increase. This would result in an overall reduction in Lake Nasser inflows. Based on the average Nile yield during the ten-year period 1978 to 1987, a new inflow equivalent to an average naturalised flow of 72 bn. m^3 was suggested to replace the current 84 bn.

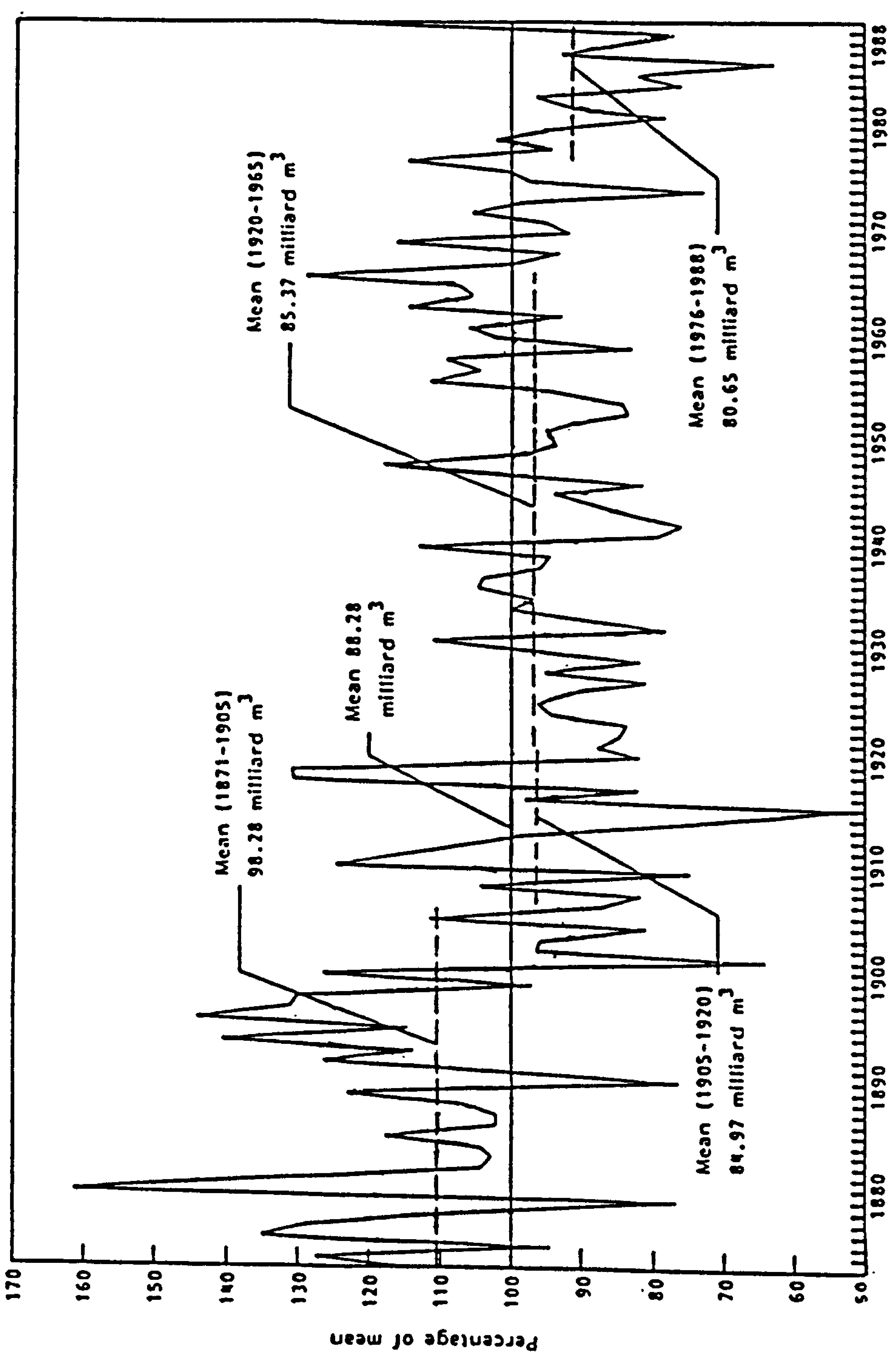

FIGURE 1-6. Annualised Nile Flow at Aswan

Source: Abu Zeid, et al, 91

m^3 (MMP, 88). This viewpoint may, however, be rather conservative because the 1978-1987 period was characterised by exceptionally low inflows (refer to Fig. 1-6). Further investigations are, therefore, needed to work out a naturalised average based on the latest inspections of the lake inflow and to identify proper measures to be taken if a prolonged drought creates an urgent water crisis.

Also, Sudan's annual abstraction from the Nile has not attained its national limit (18.5 bn. m^3). Sudan is expected to use its full water share in the future. This would result in further unavailability of Nile water to Egypt. On the other hand, an early resumption of Jonglei Project is doubtful because of the political instability in southern Sudan. The project was targeted to be the first phase of a greater plan for increasing the Nile yield. It was proposed to reduce evaporation losses by diverting the Nile flow through a canal bypassing the swamps in the Sudd region (Fig. 1-7). The expected benefit of this project was estimated at four bn. m^3 per year measured at Aswan, which would have been divided equally between Egypt and Sudan.

Being the source country of the Nile, Ethiopia, assisted by international organisations, is studying the feasibility of several irrigation projects to make use of the Blue Nile water (see Fig. 1-8). The Blue Nile yield may be curtailed by about six bn. m^3 if these projects are to take place (Said, 90). The equatorial plateau countries, namely: Rwanda, Burundi, Zaire, Kenya, Tanzania and Uganda (refer to Fig. 1-7), are less interested in Nile water. This is mainly due to their dependence on rainfed agriculture. Their total water requirements (municipal, agricultural and losses) up to the year 2010 are limited to 5.8 bn. m^3 annually (Gasser, 93). Mutual cooperation between the Nile riparian countries (the aforementioned nine countries in addition to the recently born Eritrea) is required to avoid possible problems of implementing a development project in one country resulting in a decrease of the water share of other nations.

1.4.2 Potential Groundwater Abstractions. Because groundwater of the closed aquifer identified in section 1.2.2 originates from the Nile, any abstraction

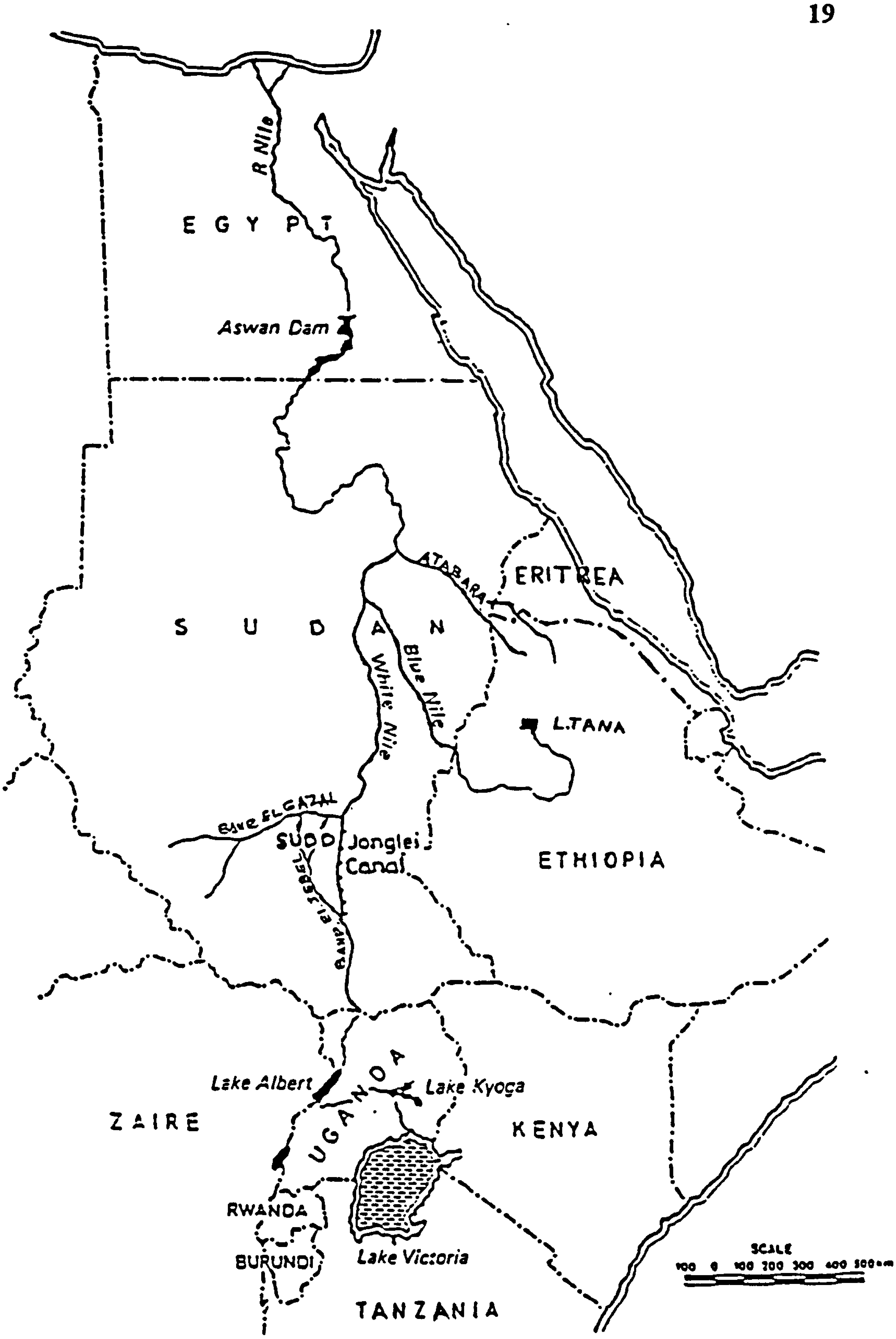

FIGURE 1-7. The Nile Basin Countries and the Location of Jonglei Canal

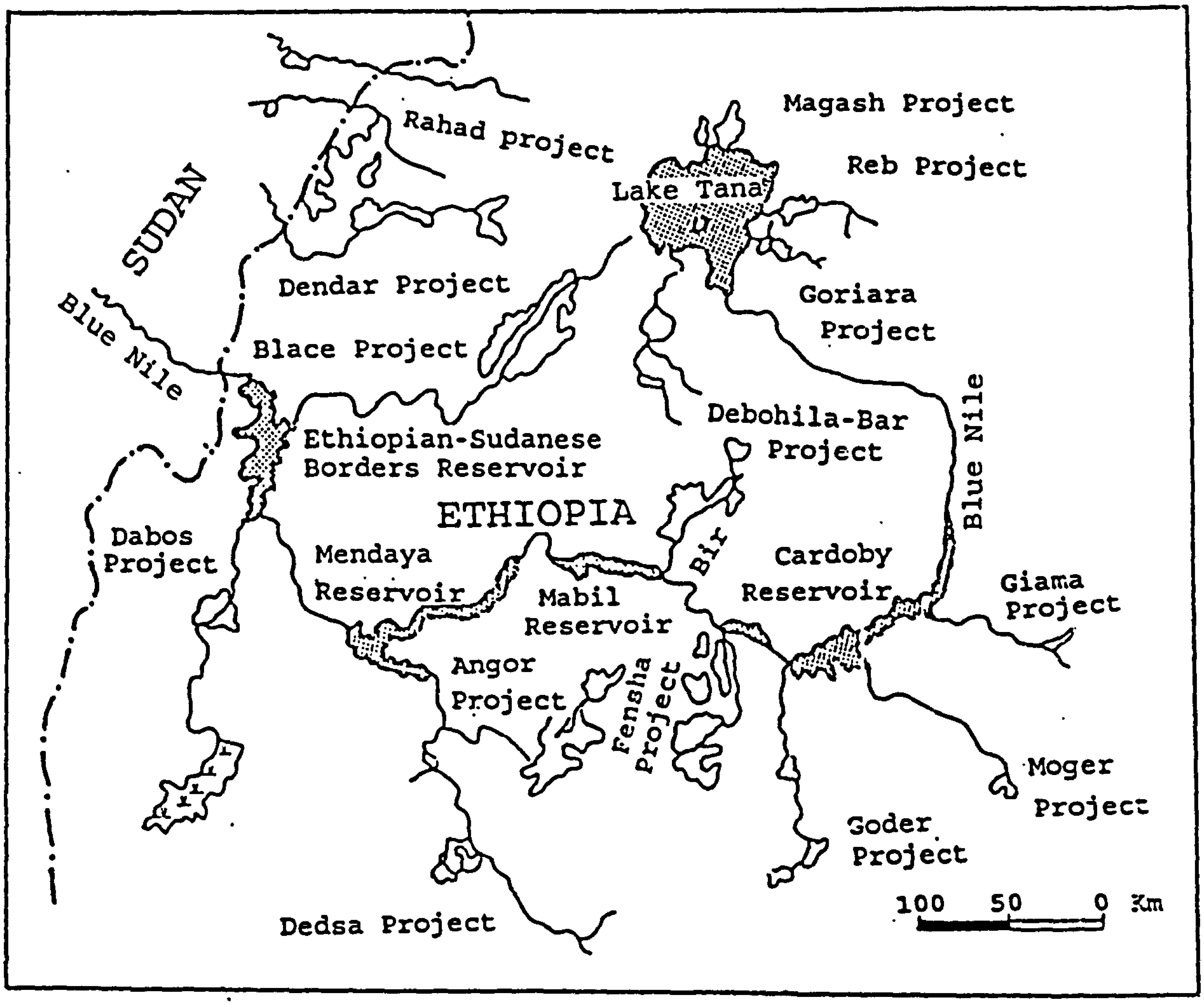

FIGURE 1-8. Suggested Projects on the Blue Nile
Source: Said, 90

from this aquifer will need to be replenished by surface water. Current abstractions from the Nile aquifer system amount to 4.4 bn. m^3/year. An estimated additional availability of 3.1 bn. m^3 may bring the total potential to some 7.5 bn. m^3. Indicative figures for current and future extraction rates in the flood plain and fringes of the Nile Valley and Delta are contained in table 1-4. Also, the annual rate of abstraction from desert wells is currently about 0.5 bn. m^3. Preliminary estimates point out that the total potential of groundwater abstraction from Egyptian deserts may attain 3.8 bn. m^3/year, as shown in table 1-5.

TABLE 1-4. Groundwater Present and Long-term Future Abstraction Rates (M. m^3/year)

Province	Locality	Present Abstractions	Future Abstractions	Total Potential
Nile Delta	Flood Plain	1,811.10	1,091.00	2,902.10
	West Desert Fringes	760.00	160.00	902.00
	East Desert Fringes	461.22	60.00	521.22
Total Delta and Fringes		3,032.32	1,311.00	4,343.32
Nile Valley	Flood Plain	1,155.83	1,203.93	2,359.76
	Desert Fringes	248.92	588.54	837.46
Total Valley Fringes		1,404.75	1,792.47	3,197.22
Total Flood Plain and Fringes		4,437.07	3,103.47	7,540.54

Source: WSP, 93d

TABLE 1-5. Groundwater Potential in Non-Riverine Aquifers (M. m^3/year)

Location	Present Extraction	Additional	Total Potential
West Desert	571	2,830	3,401
East Desert	5	200	205
Sinai	0	200	200
Total Deserts and Sinai	576	3,230	3,806

Source: WSP, 93d

Potentialities of the Nile aquifer system are dependent on the manner of operating the groundwater reservoir. Three major alternatives are identified for groundwater development (WSP, 93d):

- Annual regulation, whereby the area within the wellfield command is irrigated from groundwater only throughout the year. This implies pumping groundwater to withdraw the annual recharge to the aquifer.
- Intra-annual regulation, whereby net annual abstractions do not exceed the annual recharge from applied irrigation. Pumping groundwater is designed to withdraw the annual recharge to the aquifer during part of the annual cycle (the peak water requirement season). Replenishment would then take place during the non-pumping cycle (low water requirements).
- Inter-annual regulation, whereby net annual abstractions are in excess of the annual recharge, possibly over a number of years, to make up for shortages in surface water. In the long term, recovery of the aquifer should take place during periods of surface water surplus, so that an equilibrium between groundwater extraction and recharge is maintained.

1.4.3 Rainfall Future Significance. Rainfall contribution in water policy plans used to be neglected by Egyptian water policy makers. However, efforts are currently carried out to make maximum use of the winter rainfall along the northern coasts. The uncertainty about how regional patterns of rainfall will alter, in the light of the expected climatic fluctuations discussed in section 1.3.2, means that no useful prediction of this can, at present, be made (Parry, 92).

1.4.4 Feasibility of Wastewater Reuse Development. The main factors that hinder an effective drainage reuse development are water quality and salt balance considerations. The presence of heavily polluted effluents and other toxic substances limits the reuse of sanitary drainage because of harmful effects on plants and consequently on public health. Treatment of such heavily contaminated drainage water is considered costly.

The predominant influence of salinity on plants is growth suppression. Salts partly originate from river water, becoming concentrated on its course towards the North by repeated use and reuse. On the other hand, the aquifer contains highly saline water in the northern Delta (refer to Fig. 1-3). This adds intensely to the salinity in the area by upward seepage. To overcome salinity problems, drainage water is being used for irrigation purposes either directly or by mixing with fresh water to adjust the salinity to acceptable limits. In this context, the MPWWR has started a courageous endeavour to reclaim 365,000 feddans using drainage water (a total discharge of 2.6 bn. m^3/year of 1300 ppm average salinity) mixed at a ratio of 1:1 with irrigation water from the Damietta Branch. The mixture (salinity of 800 ppm) is thus carried by El Salam Canal to reclaim 165,000 feddans to the west of Suez Canal. El Salam Syphon will then carry the rest of the mixed waters across the Suez Canal to Sinai to reclaim an additional area of 200,000 feddans (Fig. 1-9).

An amount of 4.3 bn. m^3 of drainage water was officially reused in 1991, while the unofficial reuse was estimated at 1.5 to 2 bn. m^3 during the same period. Plans for drainage reuse are bounded by the extent of irrigation improvement projects. A more efficient distribution system would result in less drainage water. In addition, resulting drainage water would contain large quantities of salt added by upward seepage from the aquifer in the lower reaches of the basin, hence a high salt concentration. For these reasons, and in the light of the conservative criteria

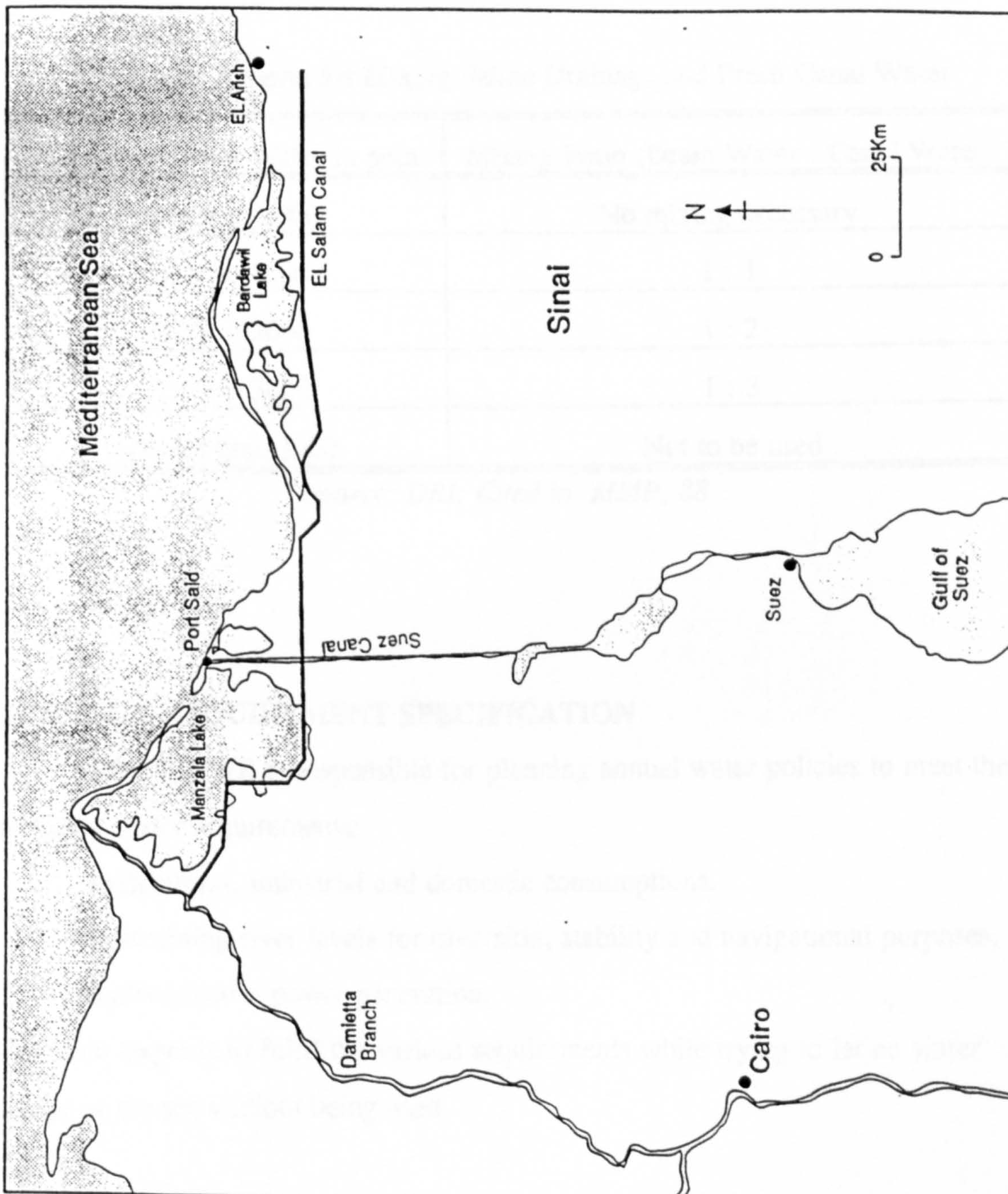

FIGURE 1-9. El Salam Canal Project Location Map

specified in table 1-6, the potential of drainage water reuse is considered limited (WSP, 93a).

TABLE 1-6. Criteria for Mixing Saline Drainage and Fresh Canal Water

Salinity of Drain Water in ppm	Mixing Ratio (Drain Water : Canal Water)
Less than 1000	No mixing necessary
1000 to 1500	1 : 1
1500 to 2000	1 : 2
2000 to 3000	1 : 3
Greater than 3000	Not to be used

Source: DRI; Cited in: MMP, 88

1.5 WATER REQUIREMENT SPECIFICATION

The MPWWR is responsible for planning annual water policies to meet the following water requirements:

- Agricultural, industrial and domestic consumptions.
- Maintaining river levels for diversion, stability and navigational purposes.
- Hydro-electric power generation.

The main target is to fulfil the various requirements while trying to let no water escape to the sea without being used.

1.5.1 Agricultural, Industrial and Domestic Requirements. Estimating Egyptian water requirements for agriculture necessitates determining the cropping areas and patterns and water duties. Monthly water requirements for each major canal are calculated and added to the municipal and industrial requirements obtained from the Municipal National Authority. The procedure is repeated within each directorate. The computation process at directorate level is illustrated in Fig. 1-10.

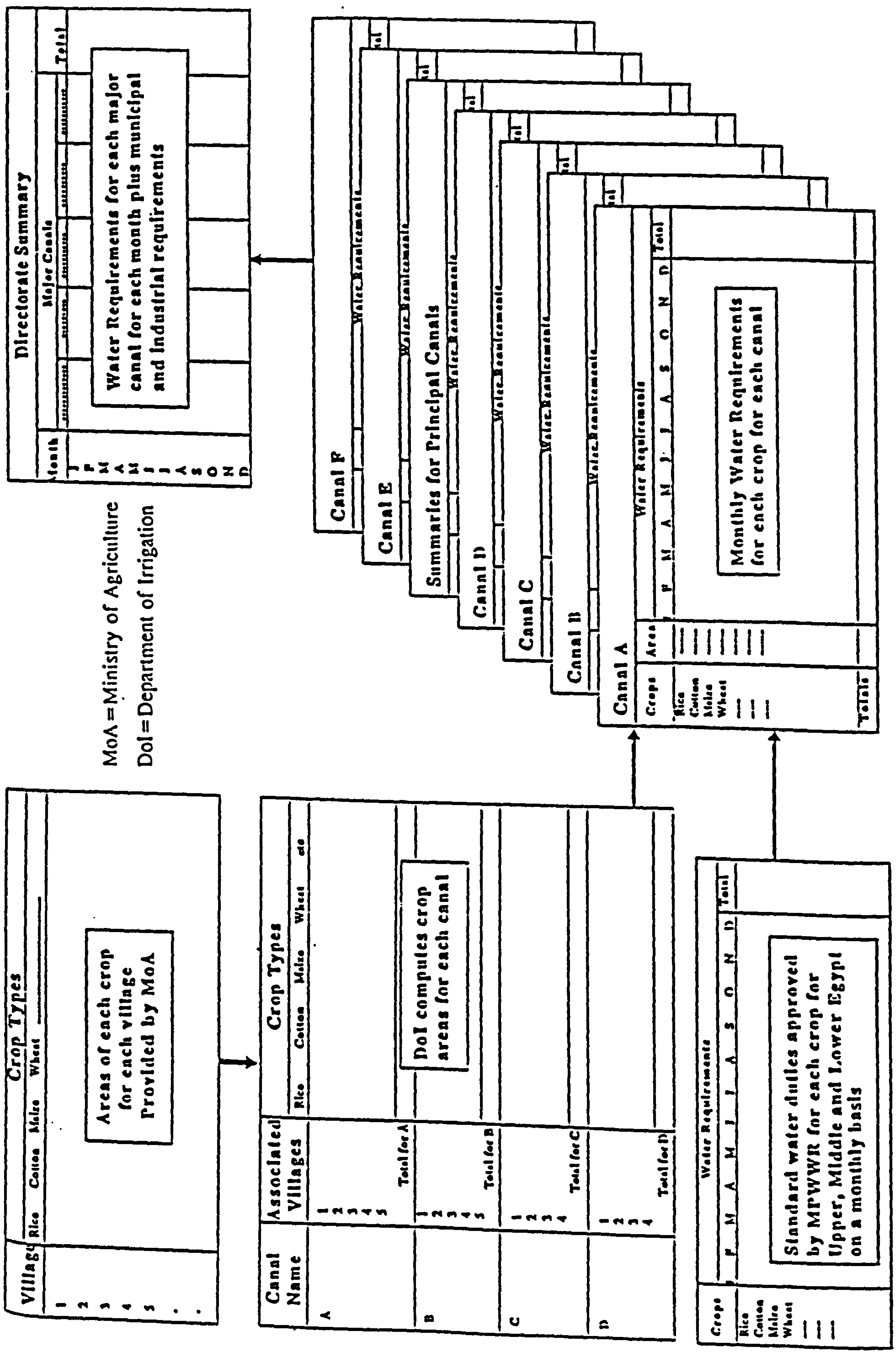

FIGURE 1-10. Computation of Water Requirements at Directorate Level
Source: MMP, 90

While agricultural water demands currently account for the largest amount of water usage in Egypt (about 84 percent), domestic and industrial activities use 3.1 and 4.6 bn. m^3 of water respectively. It is estimated that the present level of leakage from the municipal distribution system is 50 percent. However, it is assumed that domestic water use could be held at 3.1 bn. m^3 by the year 2000 by reducing this from 50 to 20 percent (Abu Zeid, 92).

1.5.2 Maintaining River Levels. Refilling headponds upstream of the main barrages means that certain water levels upstream of these barrages should be maintained to satisfy the levels of canal offtakes. On the other hand, differences between upstream and downstream water levels should not exceed predefined limits to protect against possible structural failures.

During the winter closure[1], additional discharges are released to satisfy navigational needs in the main river. The actual release of water from HAD for navigational purposes is about 1.8 bn. m^3. The recent completion of Naga-Hammadi Lock and New Esna Barrage will reduce water releases for navigation to 0.3 bn. m^3 by the year 2000. Most of these discharges are lost to the sea. However, various endeavours are carried out to minimise the water that goes to the sea during that period. These endeavours are considering the following options:

- Adjusting the starting date of the winter closure in order to stagger the closure period among different regions over a particular period of the year.
- Shortening the winter closure period.
- Minimising the water release, taking into consideration the restrictions with respect to navigation and offtakes.

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[1] During the winter closure (mostly in January), irrigation is suspended to allow for maintaining canals, drains and different components of the irrigation system. However, water is released to enable the continuity of cruising along the main river during the tourism high season.

- Remodelling irrigation structures along the Nile for reasons of structural stability.
- Storing closure period releases in coastal lakes, depressions and/or suitable areas for artificial groundwater recharge.
- Increasing winter irrigation in reclaimed desert areas with navigational water being entirely wasted.

1.5.3 Hydro-Electric Power Generation. The water requirement for hydropower generation is fully met by releases into the irrigation system. During the canal closure period, water released for various purposes (excluding irrigation) covers power requirements. During the winter of 1985/86, a decision was made by the MPWWR not to allow additional releases from HAD for power generation in order to face consequences of the drought taking place. No increased releases for power generation have been made from Aswan since.

1.6 DISCUSSION AND CONCLUSIONS

The foregoing review has clearly revealed the difficult situation Egypt is facing regarding water availability. Increasing demands for various purposes of the ever growing population are opposed by limited water resources. The total amount of Nile water available to Egypt is 55.5 bn. m^3. Within the Nile basin, pumping groundwater and reusing drainage water may be further developed. However, these waters constitute a part of the 55.5 bn. m^3 and cannot be regarded as additional. The problem is likely to become more serious and will continue well into the 21st century in the light of the expected global warming and drought.

The current strategy adopted by the MPWWR to meet projected requirements aims to augment water availability on internal and external bases. Promoting water availability inside Egypt is based on three principal courses of actions:

- Increasing the overall water use efficiency, i.e., reducing the quantity of water lost to the system by evaporation and/or flushed out to the sea. This can be achieved through specific interventions including: (i) reducing the cultivation of crops of a high water demand, (ii) saving water lost to the sea during the winter closure, and (iii) using more of the drainage water leaving the basin. In this approach, traditional efficiencies such as distribution and farm ones are rather insignificant because the Nile aquifer is considered a closed system. That is, distribution and application losses may be retrieved by means of groundwater abstraction and drainage reuse.

- Developing groundwater abstraction to the maximum safe yield within a well-defined strategy for aquifer operation. Investigations are also being undertaken to estimate the potential yield of non-riverine aquifers. These contain non-renewable groundwater subject to depletion. Such development is, in the long run, considered uneconomic.
- Expanding drainage water reuse, taking into consideration the anticipated low availability of drainage water due to the efforts aimed at economising on water use. The proposed expansion may take place by alleviating current water salinity limitations, which are thought rather conservative, especially when coupled with the cultivation of salt-tolerant crops on sandy soils under drip irrigation. It is to be noted that drainage reuse projects using 'mixing with fresh water' technique, e.g., El Salam Project, are constrained by the amount of fresh water available.

Water resources development outside Egypt is constrained by political limitations and climatic fluctuation hazards. Therefore, opportunities for such development are rather 'fuzzy' and may not be considered for strategic planning unless political stability disseminates among riparian countries and useful ideas and reliable data are exchanged on bi and/or multilateral bases.

In view of the above, the development of a comprehensive water use strategy has become a preeminent priority. Such a strategy should imply measures to meet water demands by optimising decisions on resource allocations in the light of the anticipated water availability and requirements in Egypt.

CHAPTER II

THE NILE BASIN SIMULATION MODEL

2.1 INTRODUCTION

The current version of the Nile Basin Simulation Model was developed under assignment of the Water Security Project. The latter endeavoured to present an overall water policy analysis for Egypt. In this context, the project was to develop realistic projections of water availability and demands over the next twenty years and to identify and schedule infrastructural development and/or measures with the aim to meet these demands.

The first version of the model was launched by Sir M.MacDonald & Partners Ltd in 1989 under the title: 'River Basin Modelling for Water Resource Management'. This model was initially envisaged as a training aid that would enable practicing engineers to appreciate and understand various aspects of the Nile basin management and the ways in which they interact.

The newly adapted and enhanced version appeared in 1993 under the name: 'Nile Basin Simulation Model'. The development of this new version enables the use of the model as a planning tool to compare and analyse alternative development options (WSP, 93b).

2.2 OUTLINE OF THE MODEL

The major purpose of the Nile Basin Simulation Model is to allow the user to investigate the effects of different synthesised scenarios of water use. Results of this investigation will be revealed to the user via the model's indicators, which will be influenced by changing the planning variables. The model mainly simulates twenty years of water management planning and operation for the Nile Basin.

Values of the planning variables are set by the planner and input into the program as targets to be met over a twenty-year period. These values are based on projected changes taken at five-year time steps representing four five-year plans between 1990 and 2010.

2.3 MODEL VARIABLES/INPUTS

The major variables used in the Nile Basin Simulation Model can be categorised in two groups of variables that are input into the model by the planner:

* Variables dealing with regional new and old lands in Upper, Middle and Lower Egypt.
* Variables dealing with Egypt as an overall unit.

2.3.1 Variables Dealing with Regional New and Old Lands in Upper, Middle and Lower Egypt. These variables influence the overall performance of the model and are, nevertheless, input at a regional level. The regions encompassed by the model and contributing to its overall performance are: West Delta New Lands, West Delta, Middle Delta, East Delta, East Delta New Lands, Sinai, Fayoum, Middle Egypt, Middle Egypt New Lands, Upper Egypt, and Upper Egypt New Lands.

1) **Regional new and old land areas:** Regional physical areas of old and new lands are entered into the model in squared kilometers. Considering new lands as separate regions from old lands is due to two major reasons:
   - To account for the projected increase in new lands over a twenty-year planning period. Projects of horizontal expansion are being targeted to offset the urban encroachment on old lands.
   - To allow the application of new land efficiencies that are different from those applied in old lands. The former are initially far less than the latter with an anticipated gradual increase as development proceeds.

   It is worth mentioning that the model assumes that the Nile River is the sole origin of irrigation water in both old and new lands. Therefore, the model does not take account of reclamation projects based on deep groundwater abstractions outside the Nile aquifer system.

2) **Irrigation efficiencies:** The irrigation efficiency is broken into two components within the model; farm efficiencies and distribution efficiencies.
   - Farm efficiencies: Farm efficiencies comprise field canal and application efficiencies and, thus, deal with the on-farm management and field application of water. Losses resulting from inefficient on-farm water management are manifested as:
     - Surface runoff from fields.
     - Excess deep percolation losses.
     - Incidental channel losses.

   - Distribution efficiencies: Distribution losses occur in canals and mesqas under the following forms:
     - Canal tail escape flows.
     - Mesqa escape flows.
     - Leakage to buried drainage system.
     - Canal seepage losses.
     - Incidental canal losses.

3) **Municipal and industrial requirements:** These requirements are obtained from the Municipal National Authority for each region. All potable and industrial demands take priority over irrigation demands. In 1990, the Egyptian water requirements for municipal and industrial purposes were estimated at 3 and 4.7 bn. m^3 respectively.

4) **Percentage of municipal and industrial water returned to the system:** Water consumed for municipal and industrial purposes in 1990 was 2.4 and 0.7 bn. m^3 respectively. The rest (0.6 bn. m^3 of municipal water + 4.0 bn. m^3 of industrial water) was returned to the system through drainage

channels. That is, some 20 and 85 percent of municipal and industrial water were actually returned to the system. A part of the returned water was reused within the system and the rest was flushed to the sea. Within the model, maximum percentages of 80 and 85 may be respectively imposed by the user on the amounts of municipal and industrial water returned to the system.

5) **Maximum groundwater drawdown depth:** Groundwater abstractions in the Nile Valley and Delta are limited by predefined development constraints. A maximum allowable regional drawdown of three meters is imposed to satisfy technical and economic considerations. This constraint also limits abstraction potential in areas where the hydraulic resistance of the semi-confining layer is high (MMP, 88). The reason for this limitation is that the average potential recharge (believed to be in excess of 2 mm per day on average) may be well below the abstraction rate.

6) **Maximum percentage of drainage water reused:** Factors that may limit the reuse of drainage water have been identified in section 1.4.4. Based on these factors, a maximum limit of 60 percent may be imposed by the user to constrain the amount of drainage water reused.

7) **Cropped areas:** The cropping pattern is determined by economic policies towards food production. Land and water resource availability is also an influencing factor in deciding on cropping patterns. Within the model, cropping patterns are set in terms of regional area percentages for each crop per season. In new land areas, an option is provided to specify whether sprinkler or surface methods are used in irrigation.

8) **Drainage reuse:** Drainage reuse entries are the maximum or target annual values of reuse to be fulfilled by the model if no constraint is imposed on drainage reuse abstraction (see 6 above). They are based on an assessment

of potential reuse of drainage water in bn. m^3 per month. However, the availability of drainage water and the maximum percentage that can be reused would restrict the actual amounts to less than the targeted values.

9) **Groundwater:** As with drainage reuse, groundwater entries are the maximum or target annual values of water pumping to be fulfilled by the model if no constraint is imposed on groundwater abstraction (see 5 above). They are based on an assessment of potential groundwater pumping in bn. m^3 per month. These are usually above what is reckoned to be the practical limit of groundwater exploitation.

Fig. 2-1, 2-2, 2-3 and 2-4 illustrate four templates comprising the nine variables previously identified. The template shown in Fig. 2-1 encompasses the variables from 1 to 6 for the Middle Egypt region. Fig. 2-2 shows the cropped area template for West Delta. Fig. 2-3 and 2-4 show the targeted values of drainage reuse and groundwater pumping in West and East Delta respectively.

2.3.2 Variables Dealing with Egypt as an Overall Unit. These variables influence the Egyptian irrigation system from a global perspective. They are input to the model as external parameters (excluded from the regional parameter templates) considering Egypt as an integrated study unit.

1) **Abstractions upstream of Aswan:** The annual abstractions are expressed in bn. m^3 as the equivalent abstractions at Lake Nasser after applying routing losses. After the effects of Sudanese and other upstream abstractions have been removed, the naturalised flow is converted within the model into a flow available to Egypt via Lake Nasser.

2) **Benefits from development upstream of Aswan:** Schemes are carried out within the Equatorial Nile Project to increase the Nile water yield. Three

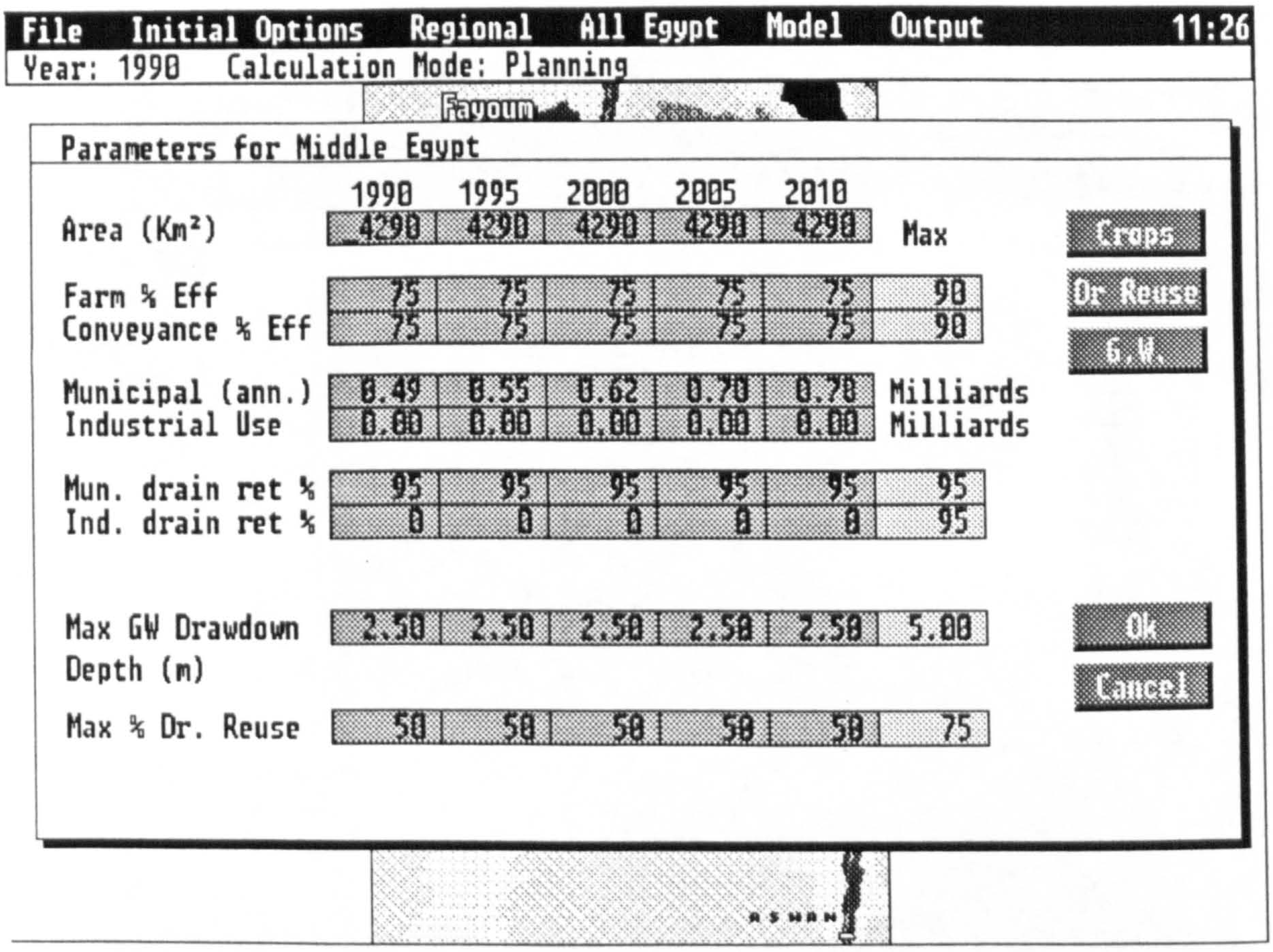

FIGURE 2-1. Template for Regional Model Parameters (Middle Egypt Region)

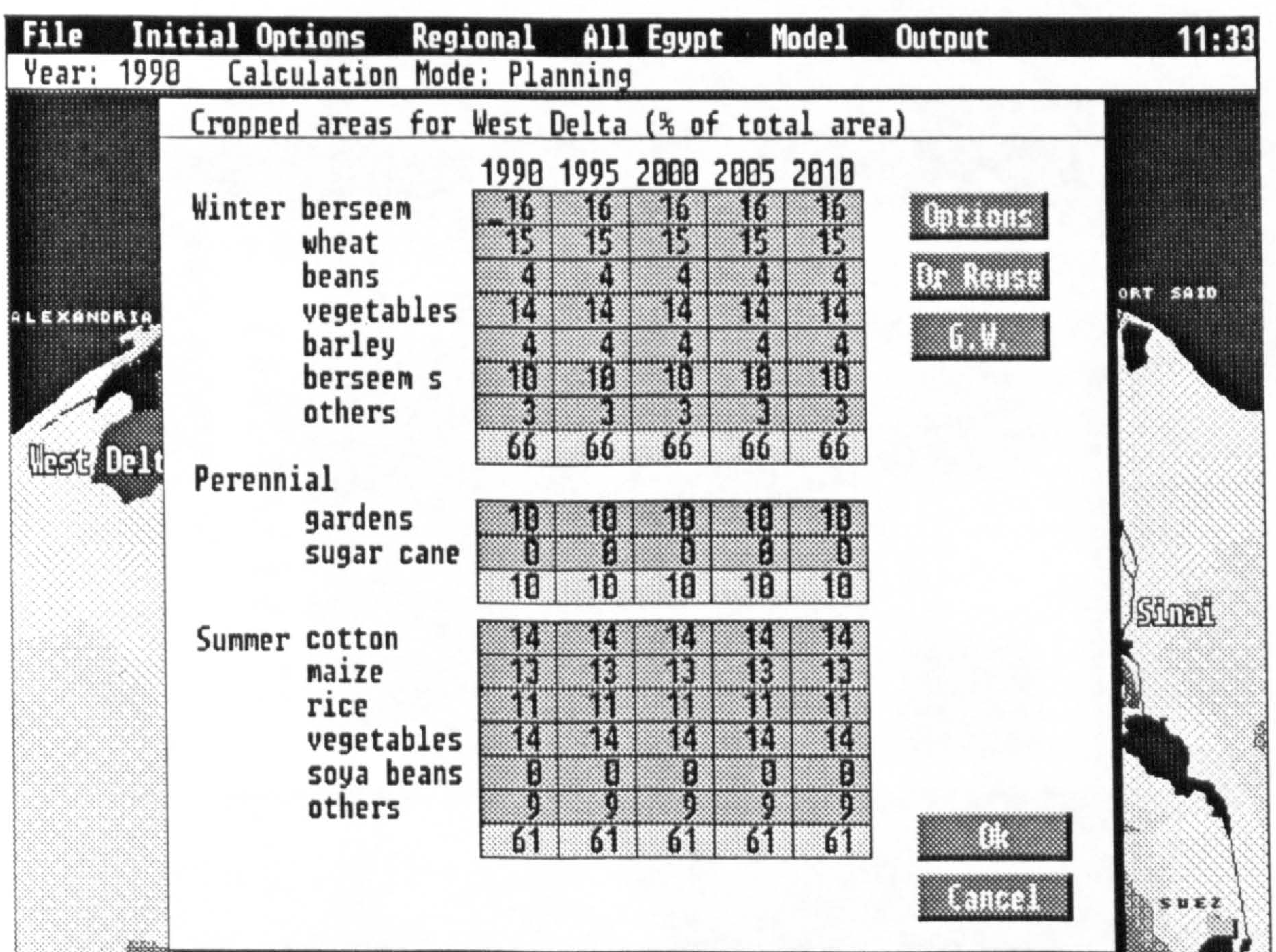

FIGURE 2-2. Template for Regional Cropping Patterns in West Delta

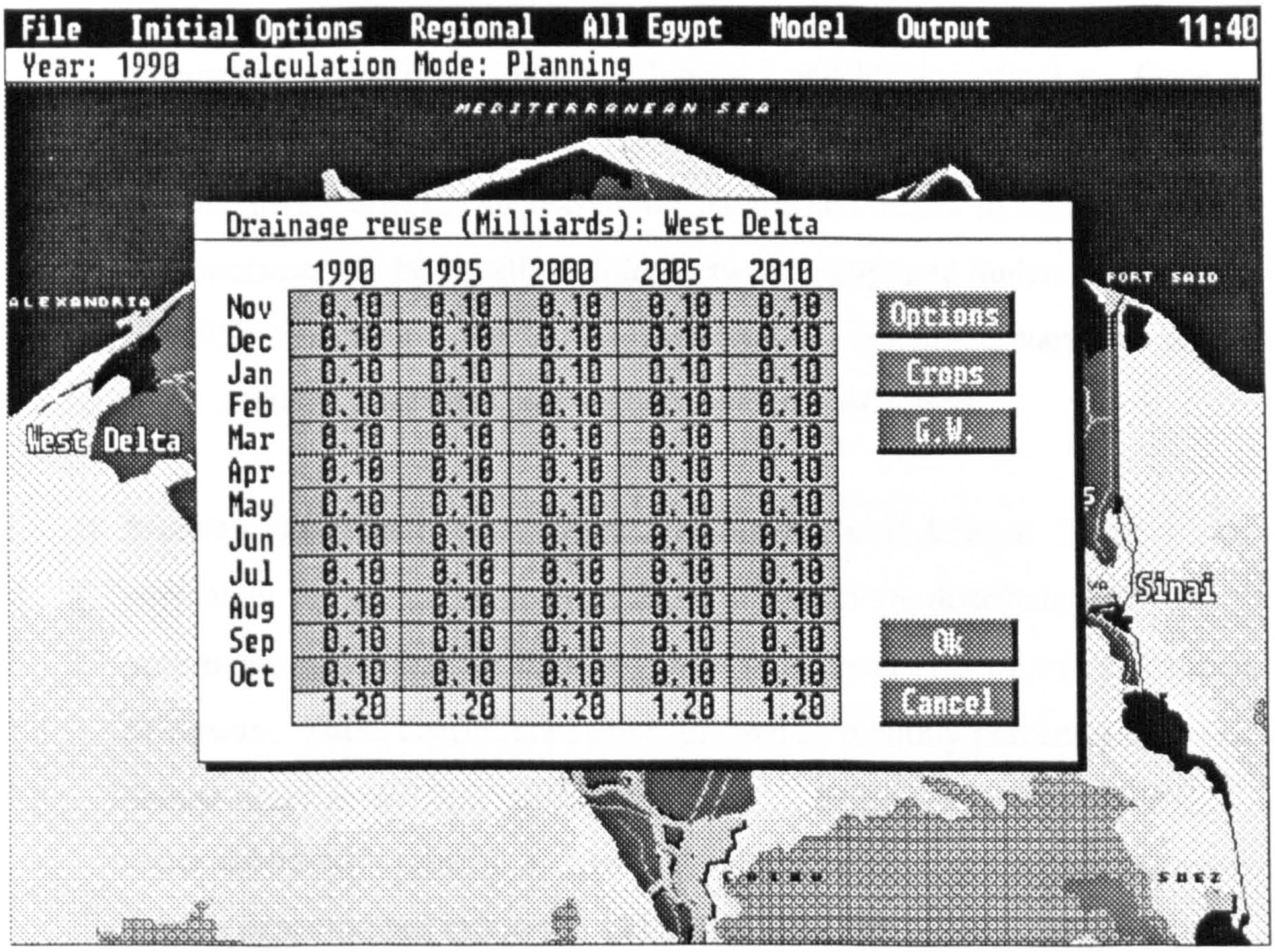

FIGURE 2-3. Template for Drainage Reuse in West Delta

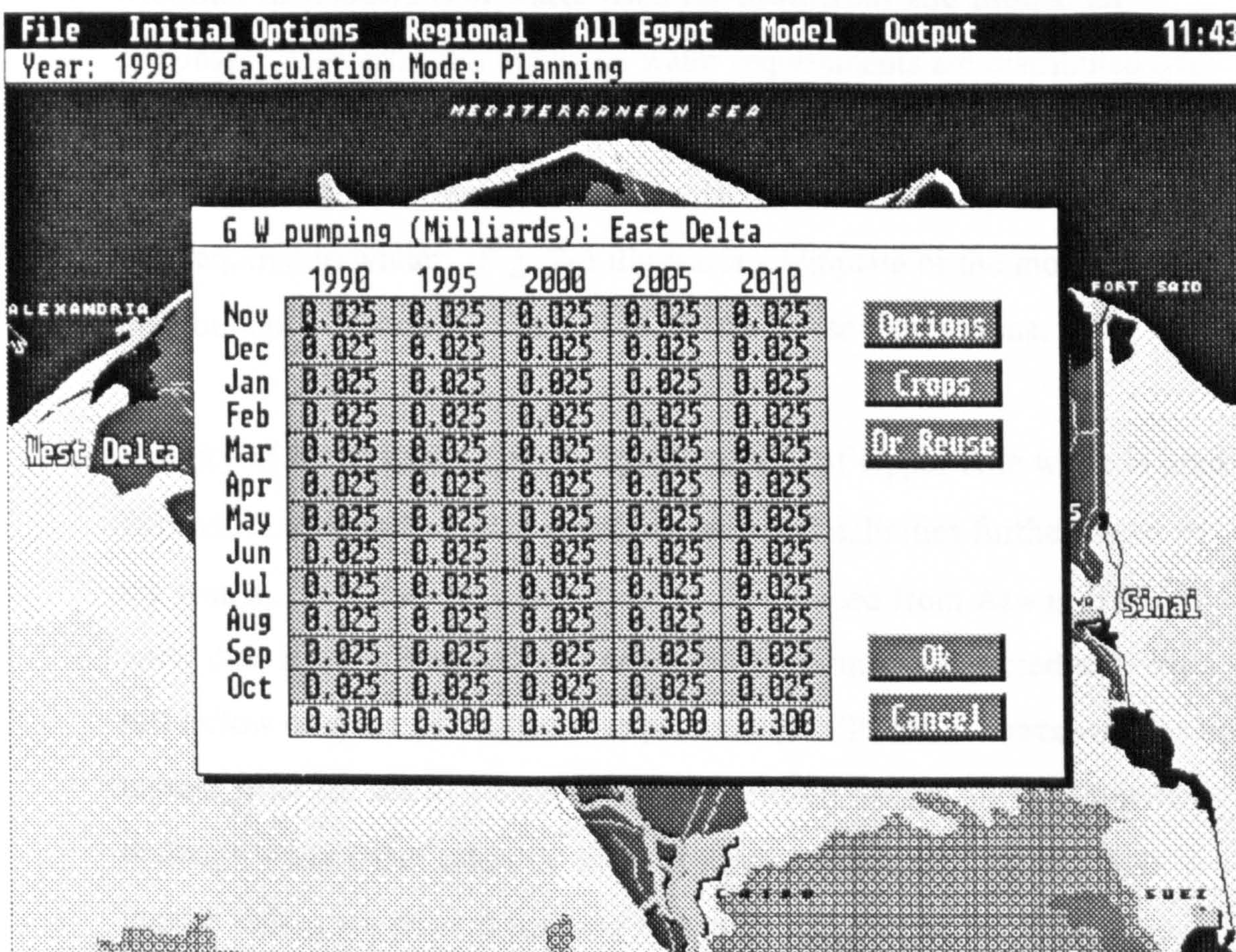

FIGURE 2-4. Template for Groundwater Pumping in East Delta

schemes are considered; Jonglei 1, Jonglei 2 and Machar Marshes. Once a project is terminated, its annual yield should be input to the model in bn. m^3 to simulate the effect of increasing the naturalised inflow to Lake Nasser. This increase will be equally divided between Egypt and Sudan according to the 1959 Agreement. Fig. 2-5 shows a template containing variables related to the annual abstractions and benefits upstream of Aswan.

3) **Monthly distributions of abstractions upstream of Aswan:** The equivalent annual Sudanese abstractions at Aswan are distributed in accordance to the planner's estimation of the monthly use of water upstream of Aswan. These distributions are expressed as monthly percentages of the annual water abstraction upstream of Aswan. Within the simulation run, water abstracted upstream of Aswan is subtracted from the inflow sequences to give denaturalised inflows to Lake Nasser.

4) **Monthly distributions of water used for municipal and industrial purposes:** Domestic and industrial water requirements are distributed over months as input percentages of the annual water used for these purposes. The amount of water required during summer will obviously be higher than that required in winter. Fig. 2-6 illustrates a template of the monthly distributions of municipal, industrial and Sudanese abstractions.

5) **Salinity of the system:** Specifying the salinity of Upper Nile water is used to produce estimates of river and drainage water salinities further down in the system. If the average salinity of water released from Aswan is 250 ppm, then Egypt's share of Nile water (55.5 bn. m^3) is expected to bring a salt inflow of some 14 million tons per year (MMP, 88). Moreover, the salt ingress from the sea to the northern coast also influences the salt content of drainage water either returned to the system or flushed to the sea. Salt ingress values are entered for each region in million tons per year. The salinity template is shown in Fig. 2-7.

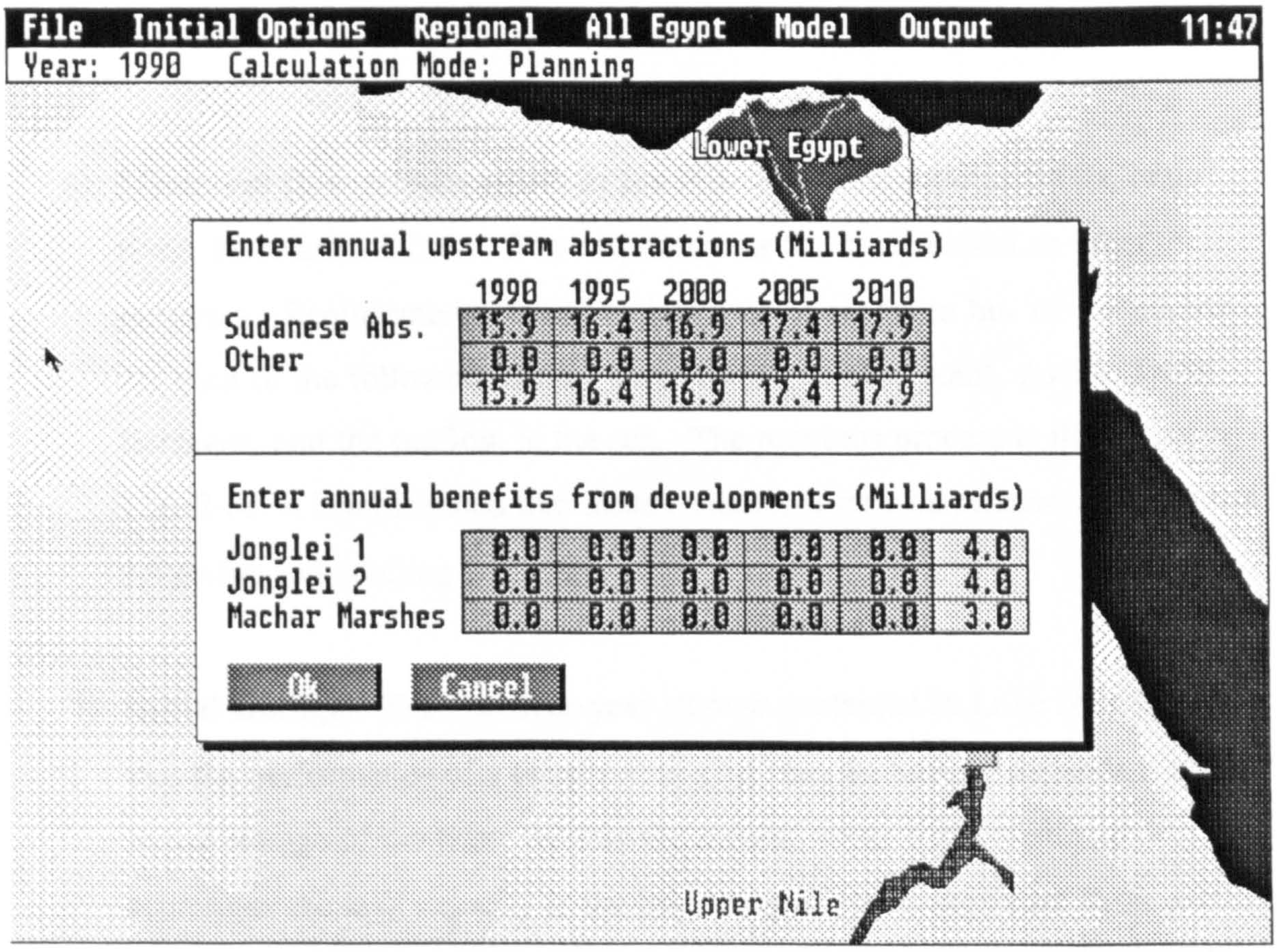

FIGURE 2-5. Template for Annual Abstractions and Development Benefits Upstream of Aswan

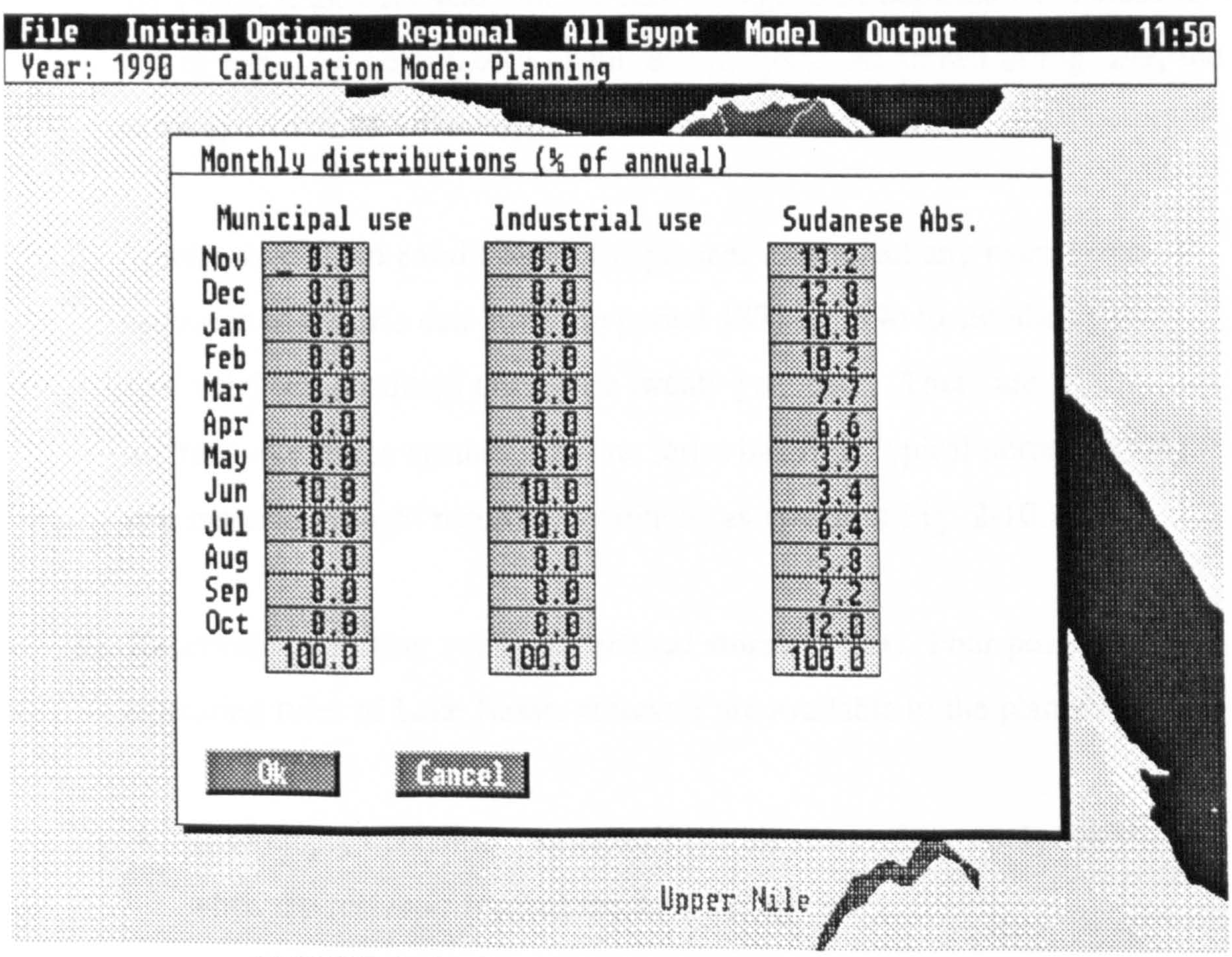

FIGURE 2-6. Template for Monthly Distributions

6) **Minimum flow requirements in the Nile:** At certain points in the main river, there are minimum flow requirements for navigational or other purposes. Requirements should be input to the model in bn. m^3 per month for each of the following points: Lake Nasser release point, Assiut, Delta Barrages, and the outflow to the sea. The previous process is illustrated in Fig. 2-8. It is anticipated that these constraints may be relaxed in the future following remodelling works at certain barrages.

7) **Initial storage:** The live over-year storage contained in Lake Nasser means that the performance of a twenty-year plan may be heavily dependent on the initial storage of the lake. Within the model, water initially stored represents the lake capacity at the beginning of November after three months of the annual flood start. While the lake-full capacity is 137.5 bn. m^3, the dead storage volume is 28.3 bn. m^3. During the extremely low inflows of the 1980s, it took six years for the lake storage to be depleted from close-to-full to some low point (about 38 bn. m^3) in 1988. As shown in Fig. 2-9, the starting volume of Lake Nasser is defaulted at 90 bn. m^3.

8) **Synthesised flood conditions:** The planner may select any twenty-year sequence of historic data from the period 1871 to 1990 to simulate the forecast flood condition during the twenty-year plan. There are, alternatively, three synthesised flow series based on typical normal, drought and extreme drought recorded conditions as shown in Fig. 2-10.

9) **Reservoir operating rules and critical storage limit:** Four possible operating rules of Lake Nasser reservoir are available to the planner:

- Lake empty operation: Releases from the reservoir are only reduced when the reservoir reaches the dead storage level.

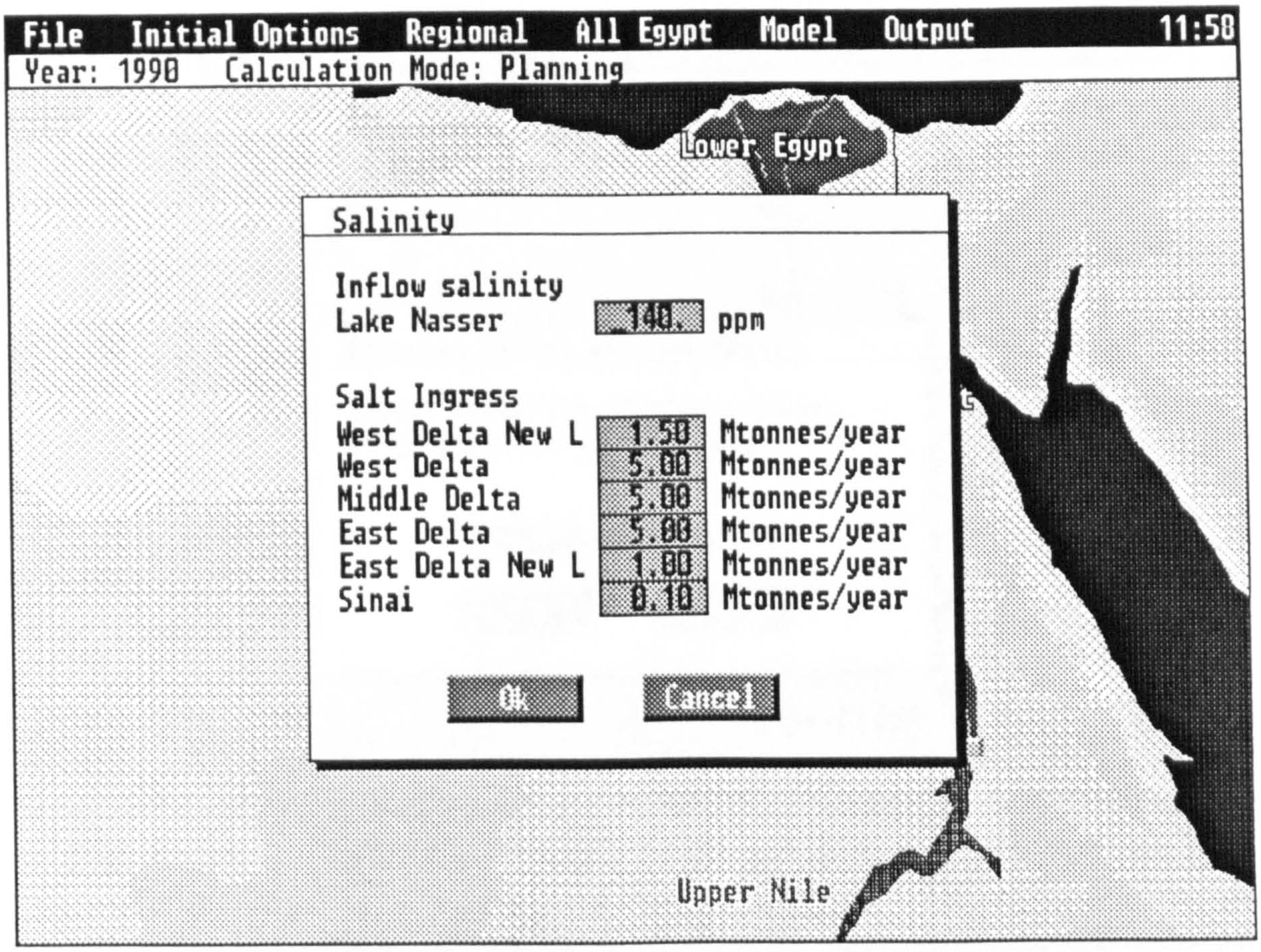

FIGURE 2-7. Template for Salinity and Salt Ingress

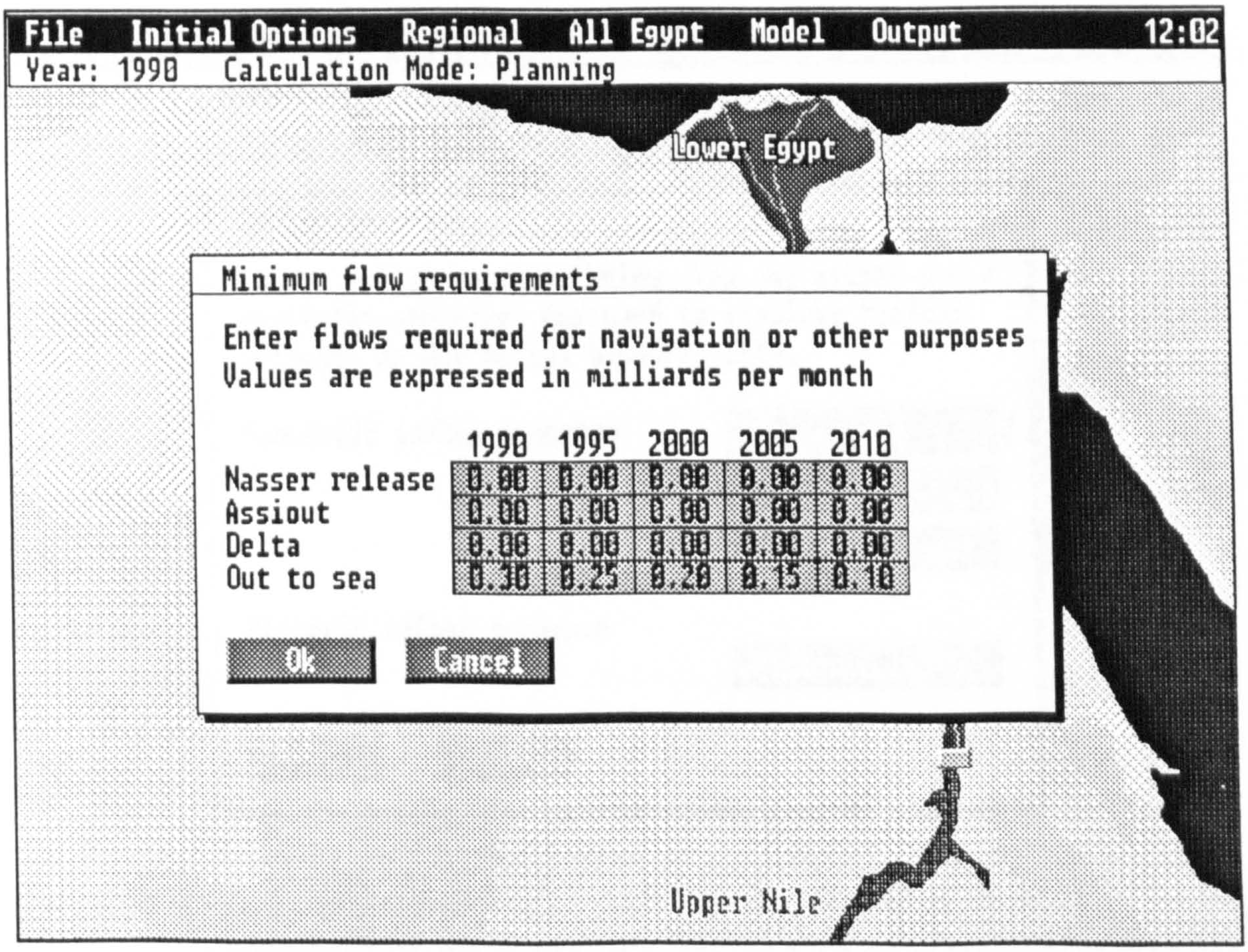

FIGURE 2-8. Template for Minimum Flow Requirements

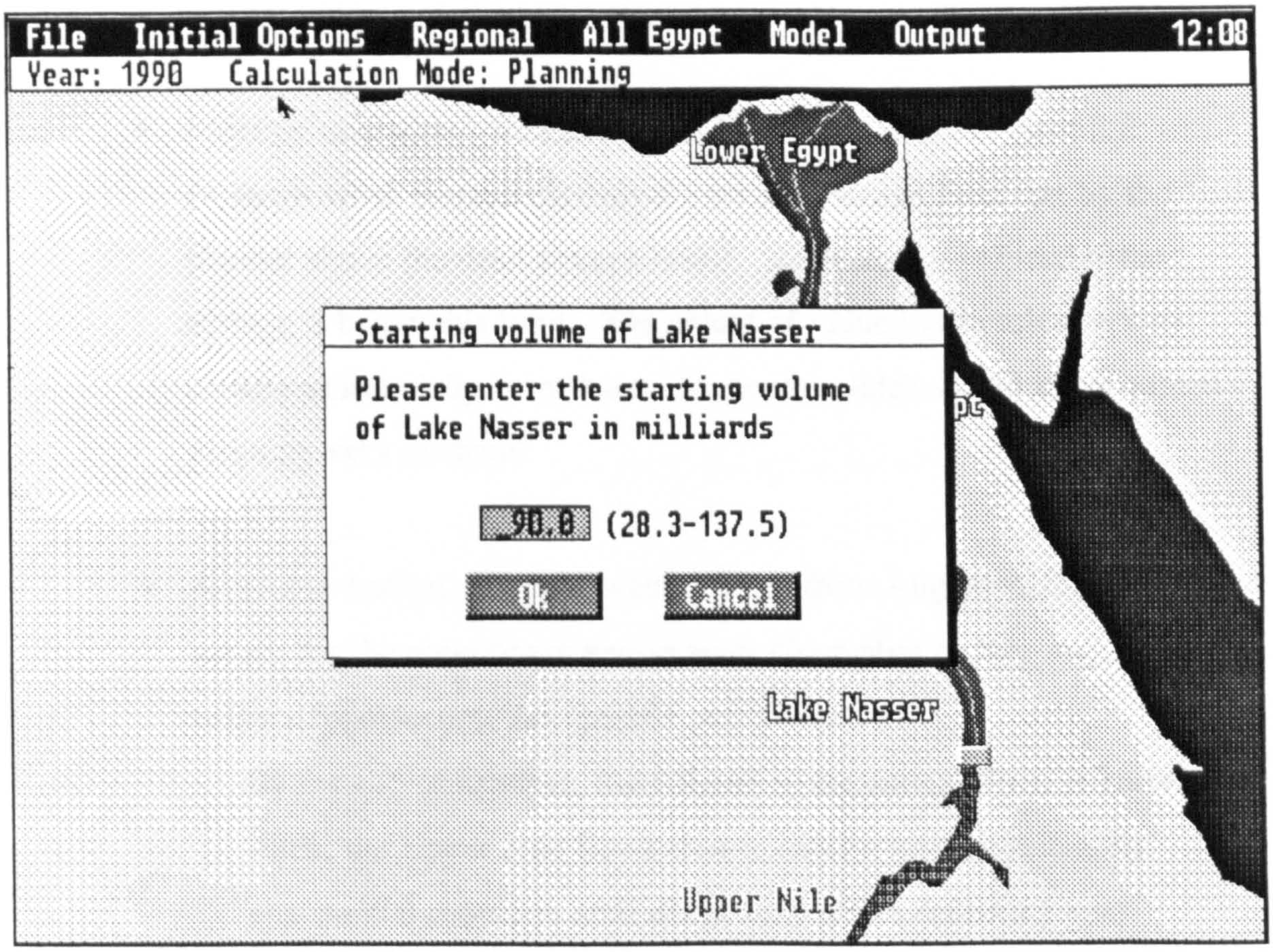

FIGURE 2-9. Template for Starting Volume of Lake Nasser

FIGURE 2-10. Template for Selecting Inflow Sequence

- Monthly operation: Releases for each month are set to meet full demands when storage exceeds the critical storage limit (set by the planner above the dead storage limit). Releases are reduced if the storage is below this limit. The extent of reduction in releases may change substantially from month to month, which would make annual planning very difficult.

- Annual operation: Egypt's water year is from August to July. Releases are set for the nine-month period from November to July inclusive. The reasons for selecting this specific period are:
  - By the end of October, the volume of the annual flood is known. Then, the Upper Nile flows tend to exhibit an approximately exponential recession until about June of the following year.
  - The high intensity of inflows in the period from August to October (about 70 percent of the annual inflows) is such that it is extremely unlikely that there could be any problem in meeting demands.

  If the forecast water availability above the critical storage limit is less than the demand for the same period (nine months), then releases for each month are reduced such that this reduction continues to the end of October. This is because annual planning at national, regional and farm level will have been based on releases being a reduced proportion of demand. The critical storage limit is preferably set slightly higher than the dead storage limit as insurance against actual inflows being below predictions.

- Inter-Annual operation: Release decisions are still made for a year at a time (as with the annual operating rule), but the decision on the need for reductions in releases is based on a longer term view of likely reservoir levels. To cover against successive dry years, the planner can specify a target reservoir limit for one year ahead. If the forecast level is lower than this limit, the releases during the coming year would be reduced. At the end of the year, the position would be reviewed and a new degree of reduction (if any) determined for the following year. This depends on water availability and demands similar to the annual operation, except that the calculations are based on the whole year to the end of October. The critical limit set by the operator needs to be considerably higher than for the annual operation because it relates to the level at the end of October rather than the end of July. Both annual and inter-annual operation have little or no risk of sudden and unpredictable release reductions in the middle of a cropping season. However, reductions are more frequent than in the case of monthly and lake empty operation.

The template of Lake Nasser operating rules is shown in Fig. 2-11 where an annual operation is assumed to take place.

2.4 MODEL INDICATORS/OUTPUTS

Model indicators are clustered into a number of templates identifying the output values of a specific run. These outputs reflect the physical impacts resulting from the application of a twenty-year plan of water management in Egypt.

2.4.1 Regional and All-Egypt Schematic Templates. The schematics are envisaged as illustrations of the different flow paths between the main source (Nile flow) and water final destinations (flow to sea, crop use or evaporation to the atmosphere). The different linkages connect four water systems between the main source (the Nile) and destinations; irrigation, drainage, groundwater, and domestic and industrial systems. Fig. 2-12 shows an example of the directions and quantities of different water components for the whole Delta and Sinai. The overall water balance shown by the schematic (i.e., water inflow to the system = water outflow from the system) indicates the capability of the model to account for land reclamation only within the Nile aquifer system where water used for irrigation

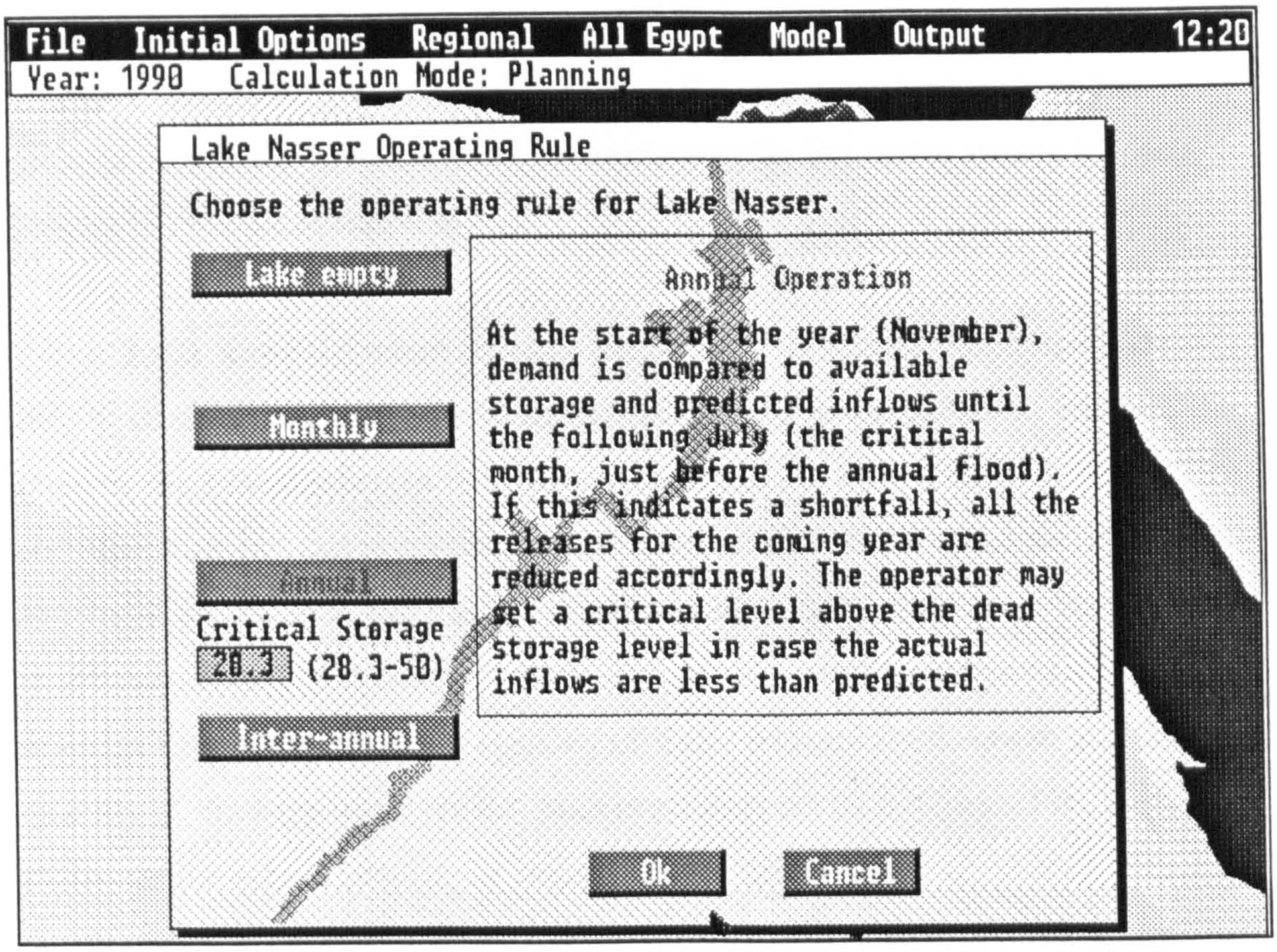

FIGURE 2-11. Template for the Choice of Lake Nasser Operating Rules

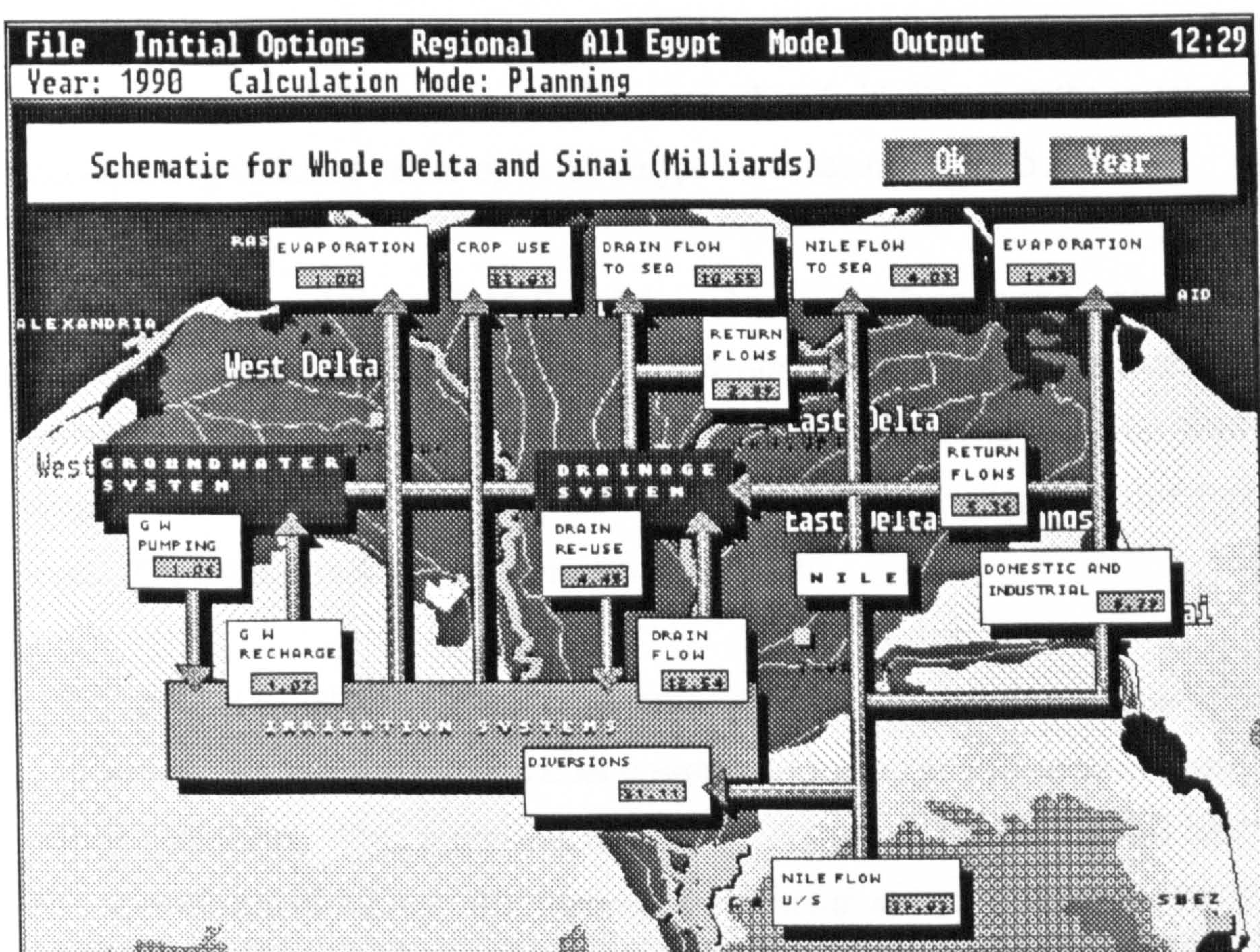

FIGURE 2-12. Schematic for Whole Delta and Sinai

returns to the closed groundwater reservoir. Water used in land reclamation projects outside the reservoir's boundaries is actually lost to the system by deep percolation into other aquifers.

2.4.2 Annual System Salinity Templates. A salinity output template shows, on an annual basis, the water flows from and to the system in various regions, the flow discharges in different reaches of the main river and the corresponding salt concentration for each case. Based on the broad assumption of an overall salt balance, the model estimates average salinity values at various points in the main river and drainage system. Salinity of water in the main river and drainage system depends on the quality of water released from Aswan and the quantity of drainage water reused, both previously set by the user. Fig. 2-13 illustrates the output template of system salinity for 1992.

2.4.3 Annual Water Balance Templates. An annual water balance template summarises the simulated water situation resulting from a twenty-year model run. Values of the water balance components for each selected year are displayed on either a regional or all-Egypt level. Fig. 2-14 illustrates the template encompassing indicator values of the all-Egypt water balance in 1995.

2.4.4 Annual Crop Yield Templates. Areas of different crops, expressed in squared kilometers, potential and actual crop yields, in tons per hectare, and the production of each crop, in million tons, are provided within the annual crop yield template for each individual year of the model run on either a regional or all-Egypt level. The latter case for 1998 is shown in Fig. 2-15.

2.4.5 Annual River Flow Templates. An annual river flow template summarises flow and abstraction values upstream of Aswan as well as Lake Nasser storage conditions. Also, it provides annual flow discharges at certain points on the Nile downstream of Aswan. All displayed values are in bn. m^3 as shown in Fig. 2-16, which illustrates the annual river flows in 2002.

System Salinity (ppm) & Salt Ingress (Mtonnes/year) 1992

	Div	conc	Ing	Ret	conc	Out	conc
West Delta New L	2.69	218	1.50	0.00		1.22	1716
West Delta	9.19	218	5.00	0.75	665	2.26	2875
Middle Delta	12.69	218	5.00	1.11	621	3.34	2110
East Delta	12.29	218	5.00	1.08	620	3.24	2162
East Delta New L	1.05	218	1.00	0.00		0.54	2271
Sinai	0.25	218	0.10	0.00		0.11	1369
Fayoum	3.26	191		0.00		1.36	456
Middle Egypt	9.97	191		4.56	418	0.00	
Middle Egypt New	0.33	191		0.18	352	0.00	
Upper Egypt	14.94	164		7.34	334	0.00	
Upper Egypt New	0.66	164		0.36	299	0.00	

	River	conc
Lake inflow	64.39	140
Lake release	55.83	164
At Assiut	47.93	191
At Delta Barrage	39.10	218
Nile flow to sea	3.87	533
Drainage to sea	10.72	2245

Print Year
Balance L Nasser Flows Crop Yield Cancel

FIGURE 2-13. Example of System Salinity Output in 1992

All Egypt Annual Water Balance (Milliards) 1995

Water Balance

Releases at Aswan		55.96
Surface Water Evaporation	2.05	
Crop Evapotranspiration	36.22	
Mun/Ind Consumptive Use	1.71	
Flow to Lake Qarun	1.36	
Flow to Sea	14.61	
Change in GW storage	0.00	
Change in SM storage	0.00	
Total		55.96

Municipal/Industrial

Diversion	8.53
Return flow	6.82
Net use	1.71

Irrigation System

Supply	59.30
Evaporation	2.05
Crop Evapotranspiration	36.22
Net Return Flows	21.03

Groundwater

Recharge to Groundwater	1.80
Pumping from Groundwater	1.80
Change in GW storage	0.00

Reliability to date

Number of rationed years	0
% of crop demand met	98

Year Region Graph Print
Cancel Flows L Nasser Salinity Crop Yield

FIGURE 2-14. Example of All-Egypt Annual Water Balance in 1995

Crop Yields (t/ha), Production (Mt) and Area (Km²)

All Egypt 1998

	Area	Pot Yield	Act Yield	%	Production
Winterberseem	6940.3	6.0	6.0	100.0	4.2
wheat	6987.2	4.0	4.0	100.0	2.8
beans	1629.3	2.0	2.0	98.5	0.3
vegetables	1933.3	20.0	19.8	99.0	3.8
barley	451.7	6.0	6.0	100.0	0.3
berseem s	3199.2	5.0	5.0	100.0	1.6
others	1477.7	5.0	4.9	98.4	0.7
	22626.7	6.9	6.8	99.6	13.7
Perennial					
gardens	2844.7	6.0	6.0	100.0	1.7
sugar cane	1359.5	101.0	101.0	100.0	13.7
	5620.2	30.7	30.7	100.0	16.6
Summercotton	4898.2	2.0	2.0	100.0	1.0
sorghum	1179.9	3.0	3.0	100.0	0.4
maize	8902.4	3.0	2.9	95.9	2.6
rice	3708.9	6.0	5.5	92.4	2.1
vegetables	2499.3	20.0	19.9	99.6	5.0
soya beans	0.0	0.0	0.0	0.0	0.0
others	1598.7	5.0	5.0	99.7	0.8
	22787.4	6.5	6.4	97.9	11.7

Year | Print | Region

Crop Stress | Balance | L Nasser | Flows | Salinity | Cancel

FIGURE 2-15. Example of All-Egypt Crop Yield Template in 1998

Annual River Flows (Milliards)

2002

Upper Nile

Upper Nile flow		73.65
Sudanese abstractions	17.10	
Other US abstractions	0.00	
Net inflow to L Nasser		56.55

Lake Nasser

Evaporation / seepage	10.34	
Change in storage	-10.51	
Release from L Nasser		56.72

Middle / Lower Nile

Flow at Assiout		48.81
Flow at Delta Barrages		39.80
Flow to sea		3.32

Year | Graph | Print | Cancel

Balance | L Nasser | Salinity | Crop Yield

FIGURE 2-16. Example of Annual Nile Flows in 2002

2.4.6 Lake Nasser Storage Template. After a twenty-year simulation run, water volumes in Lake Nasser may be displayed at the end of each year. The volume is calculated by adding the inflow to the initial storage for each individual year and subtracting the outflow and losses from the resulting sum. Simulated maximum and minimum Lake Nasser volumes during each planning year are also provided, as shown in Fig. 2-17.

Lake Nasser Volumes (Milliards)

	Inflow	Outflow	Losses	Max vol	Storage Min vol	End vol
1990	74.3	55.8	11.3	97.3	60.3	97.3
1991	58.1	55.8	11.3	97.9	74.9	88.2
1992	64.4	55.8	10.3	87.0	57.1	86.5
1993	82.7	55.9	11.0	102.3	63.0	102.3
1994	91.3	55.9	13.1	124.6	76.1	124.6
1995	70.7	56.0	14.7	127.1	105.3	124.7
1996	71.5	56.0	14.3	125.0	101.7	125.0
1997	70.8	56.2	14.5	126.8	103.7	125.1
1998	60.7	56.3	14.2	126.0	101.6	115.4
1999	63.0	56.4	13.1	114.9	89.2	108.9
2000	61.3	56.5	12.2	108.2	80.0	101.4
2001	56.1	56.6	11.3	101.4	72.1	89.6
2002	56.5	56.7	10.3	89.8	65.0	79.1
2003	49.2	56.9	9.2	80.0	59.6	62.2
2004	64.0	51.8	8.1	66.3	42.9	66.3
2005	55.6	57.3	7.6	65.9	38.5	56.9
2006	43.5	52.5	6.4	57.4	31.1	41.6
2007	83.7	26.7	8.5	90.1	33.1	90.1
2008	67.3	58.4	10.9	93.9	69.2	88.2
2009	57.4	58.0	10.0	89.3	50.3	77.6
Average	65.1	54.6	11.1	98.6	69.6	92.6

FIGURE 2-17. Example of Lake Nasser Volumes over a Twenty-Year Simulation

2.5 VALIDATION OF THE MODEL

Validation is essentially an exercise in building confidence that a model can first emulate the observed before it is used to extrapolate into the future. In this context, a comparison was made between the actual 1990/91 water balance and that generated by the Nile Basin Simulation Model (WSP, 93a). Except for Outflows from Fayoum, table 2-1 shows an acceptable range of errors of the model outputs when compared with the actual figures of water releases recorded by the MPWWR.

TABLE 2-1. Water Balance Validation of the Nile Basin Simulation Model (in bn. m^3)

Indicators		1990/91 Actual	Model Outputs	Error (%)
Inflow	Releases at Aswan	53.79	53.80	0.02
Outflow	Outflows at Edfina	1.60	1.34	16.25
	Drainage to the Sea	12.08	11.69	3.23
	Outflows from Fayoum	0.70	1.33	90.00
	Municipal & Industrial Use	1.54	1.54	0.00
	Evaporation from System	2.00	2.04	2.00
	Crop Consumptive Use	35.87	36.09	0.61
	Net GW Recharge	N.A.	-0.04	-
	Change in Soil Moisture Storage	N.A.	-0.19	-
Total Outflow and Use		53.79	53.80	0.02

Source: WSP, 93a

2.6 DISCUSSION AND CONCLUSIONS

The existence of a large number of variables within the Nile basin necessitated the development of a simulation model that looks at the effect of operating policies on the system from a strategic perspective. In this context, the Nile Basin Simulation Model was developed to simulate twenty years of system planning and operation.

The Nile Basin Simulation Model calculates the Nile water diversions, groundwater abstractions and drainage reuse quantities in the light of demands of the cropping patterns decided upon by the user. Outcomes are presented in terms of overall water use, reliability of supply and results on crop production. However, the model does not contain any criteria on which to base the allocation of water for social, economic or ecological satisfaction.

Through eighteen parameters to be input by the user, the model takes account of most expected variations in water abstractions upstream and downstream of Lake Nasser. However, the presence of so many variable entries constitutes a controversial issue. On one hand, it allows the user more freedom to analyse a wide range of water policies. On the other hand, it imposes a burden on the user to supply large sets of accurate data drawn from current and projected plans of governmental activities.

Because the allotment of lands for reclamation is approaching desert areas located outside the Nile aquifer system, the NBSM's role in investigating effects of the projected reclamation programme on the Egyptian irrigation system is endangered by a twofold problem. First, groundwater based reclamation projects outside the Nile aquifer system cannot be tested within the model. Second, the default assumption that Nile water used for irrigating new lands returns to the Nile system's closed aquifer indicates that the model can only simulate the water balance resulting from considering reclamation projects located within the groundwater reservoir's boundaries. The problem stems from the fact that water seeping outside the aforementioned boundaries is considered lost to the system by deep percolation into other aquifers.

Nevertheless, a preliminary validation of the model was carried out for the year 90/91. The water balance generated by the model using the 90/91 data gave computed discharges that are close to the actual releases inspected by the MPWWR. This may be due to, first, the minor subsurface discharge[2] and recharge[3] flows along

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2 because of the low altitude of some areas in the neighbourhood of the Nile aquifer system.

3 due to the frequent irrigation of new lands which may create GW mounds that recharge the Nile aquifer system.

the boundaries of the Nile aquifer system and, second, the diversion of Nile water to new reclamation projects along the coastal belt (where a major section of the reclamation activity outside the Nile aquifer system concentrates). It is, thus, reckoned that taking no account of the effects of these aspects in the Nile Basin Simulation Model is counterbalanced by including the relatively small area of new lands in the old lands' irrigation system, thus allowing the model to produce an acceptable replication of the system's behaviour.

In view of the above, it is concluded that further efforts are needed to increase the efficiency of the Nile Basin Simulation Model as a planning tool that is capable of assisting Egyptian policy makers become more decisive about water distribution strategies in the light of the anticipated water scarcity. These efforts include:

- set clear boundaries between groundwater based reclamation projects and those depending on the Nile as a main source of irrigation water,
- explicitly differentiate between reclamation projects confined within the Nile closed aquifer's boundaries and those underlain by other aquifers,
- include estimates of feasible deep groundwater abstractions and possible percolation losses in case of taking account of the reclamation projects located outside the Nile aquifer system, and
- develop an auxiliary model that uses the results of the Nile Basin Simulation Model to make decisions on various water use strategies. Alternatively, an optimisation module may be incorporated into the Nile Basin Simulation Model on which to base the allocation of water.

CHAPTER III

DECISION SUPPORT SYSTEMS

3.1 WHAT IS DECISION MAKING?

Decision making has been defined (Davis, 88) as a mechanism of going through certain steps each time a choice must be made between two or more competing alternatives. Most of the decisions we make in our daily life are done without any awareness that our mental process is actually going through the following 'give and take' procedure:

- Identify available alternatives to choose from.
- Examine the factors influencing each alternative.
- Evaluate each alternative in terms of some set of objectives, criteria or requirements.
- Compare and rank the possible outcomes.
- Select the alternative that provides the best, or most acceptable, course of actions.

3.2 WHEN/WHERE USE A DECISION SUPPORT SYSTEM?

A decision support system (DSS) is developed to help decision makers analyse the ramifications of a complex problem in order to optimise the choice of a feasible alternative solution. Decision support has become a valuable asset to virtually every management function at all levels of the decision process. The successful areas of decision support application have been surveyed and categorised into three groups of decision types: operational, tactical and strategic (Davis, 88).

3.2.1 Operational Decisions. The DSS has been used to support operational decisions in areas such as: material distribution, personnel or task assignments, production scheduling, and workload and personnel scheduling. Generally, operational decisions mainly deal with the administration of the day-to-day affairs.

3.2.2 Tactical Decisions. The DSS has been used to answer tactical questions in areas such as: determining staffing requirements and recruitment policies, projecting the expected workload and resource requirements, and performing financial planning and analysis. Generally, tactical decisions mainly deal with the best methods for satisfying the near term objectives.

3.2.3 Strategic Decisions. The DSS has been used to support strategic decisions in such areas as: establishing long range staffing requirements, selecting plant locations and layouts, evaluating long term capital expenditures, and evaluating strategic organisational issues. Generally, strategic decisions mainly deal with alternative strategies for satisfying long range goals. Issues that take a significant time to take effect or that require an extended time for implementation are also successful areas for strategic decisions.

3.3 COMPUTER ASSISTANCE IN DECISION SUPPORT DEVELOPMENT

The acquisition of the current generation of fast computers has enhanced the process of decision support because of their ability to handle structured (programmable) decision problems in short times. Computers can also solve ill-structured and complex problems using the 'Expert Systems' technique. This is a new and exciting field of development trying to turn computers into intelligent machines that can explain to the user 'Why' it requires a specific item of information or 'How' it has reached a certain conclusion (Stephenson et al, 91). Unfortunately, Expert Systems are not suited for all problems. Their use may lead to ignoring relevant variables to simplify the problem to human intellectual limitations. Therefore, it is evident that analytical methods are needed to help determine the worth of multicriteria alternatives according to the preferences set by the decision maker (Goicoechea et al, 82).

3.4 CLASSIFICATION OF MULTICRITERIA SOLUTION TECHNIQUES

An analytical method used in decision making problems is the multicriteria solution technique. Multicriteria solution methods have been classified on the basis of the information flow in the process as bottom-up and top-down flows (Cohon, 78).

3.4.1 Bottom-up Information Flow. If information flows from analyst to decision maker (bottom-up), this will contain results about a set of feasible alternatives (called the non-dominated set) without nominating a particular alternative to be prioritised. Techniques using such a methodology are called 'Generating Techniques'.

3.4.2 Top-down Information Flow. Information flowing from decision maker to analyst (top-down) occurs when decision makers explicitly articulate preferences so that a best-compromise solution may be identified. Methods using such a methodology are called 'Techniques that Incorporate Preferences'.

3.5 COMPROMISE PROGRAMMING

Compromise Programming is a decision technique incorporating preferences and that is based on geometrical definitions of best. It proceeds by first defining an ideal solution, i.e., a generally infeasible alternative that one would like to achieve if only one could. Computational procedures are then applied to find the feasible solution that is closest to the ideal solution on the basis of some distance measure (Cohon, 78), as will be shown subsequently. A composite form of Compromise Programming is applied to find a tradeoff among the conflicting objectives.

3.6 COMPOSITE PROGRAMMING

Composite Programming is an extension of Compromise Programming that employs a hierarchical, normalised type of methodology to organise a discrete problem into the following format (Stansbury et al, 91):

Step 1 Define alternatives or management options.

Step 2 Define basic indicators.

Step 3 Group basic indicators into progressively fewer, more general groups.

Step 4 Define weights, balancing factors, and worst and best values for the indicators.

Step 5 Evaluate and rank options.

Fig. 3-1 illustrates the procedure previously described.

3.6.1 Evaluation of Management Options Using Composite Programming.

The axiom of choice used in Compromise Programming is defined as follows (Zeleny, 76): "Alternatives that are closer to the ideal are preferred to those that are farther away. To be as close as possible to the perceived ideal is the rationale of human choice."

The measure of closeness used is,

$$L = \left(\sum_{i=1}^{n} a_i \left[Z_i^* - Z_i \right]^p \right)^{1/p} \qquad (p=1,2,\ldots,\infty) \qquad (3\text{-}1)$$

where

L = *metric distance*

p = *balancing factor*

n = *number of criteria*

a_i = *weight attributed to criterion number i*

Z_i^* = *ideal value of criterion number i*

Z_i = *value of criterion number i*

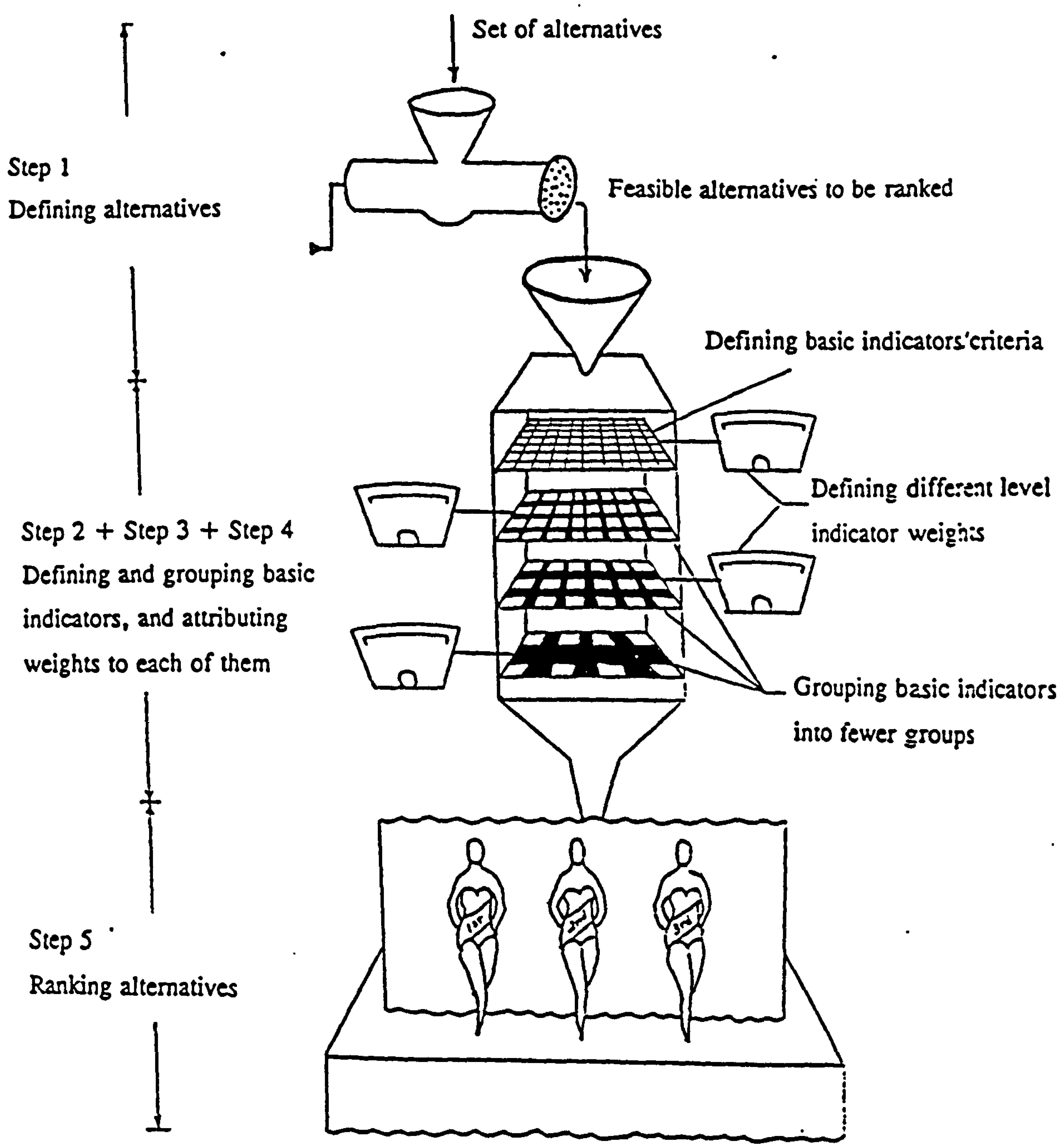

FIGURE 3-1. Composite Programming Procedure

It is to be noticed that for $a=1$, $p=2$ and $n=2$, equation (3-1) reduces to the usual notion of distance between two points (the Euclidean distance). That is,

$$L = ([Z_1^* - Z_1]^2 + [Z_2^* - Z_2]^2)^{1/2} \qquad (3\text{-}2)$$

Generally, the metric distance family defines a set of points being as close as possible to the ideal point. Their closeness to the ideal point ranges from the L ($p=1$) solution to the L ($p=\infty$) one. This set of points is called the 'compromise set'.

For each criterion, if the ideal function value is greater than the worst case function value, another form of equation (3-1) may be obtained by introducing a normalised scaling function defined as,

$$S_i = \frac{Z_i^* - Z_i}{Z_i^* - Z_i^{**}} \qquad (3\text{-}3)$$

where S_i = *normalised function of criterion number i*

Z_i = *value of criterion number i*

Z_i^* = *ideal value of criterion number i*

Z_i^{**} = *worst case value of criterion number i*

Similarly, if the ideal function value is less than the worst case function value, therefore,

$$S_i = \frac{Z_i - Z_i^*}{Z_i^{**} - Z_i^*} \qquad (3\text{-}4)$$

Fig. 3-2 and 3-3 illustrate the two cases previously mentioned.

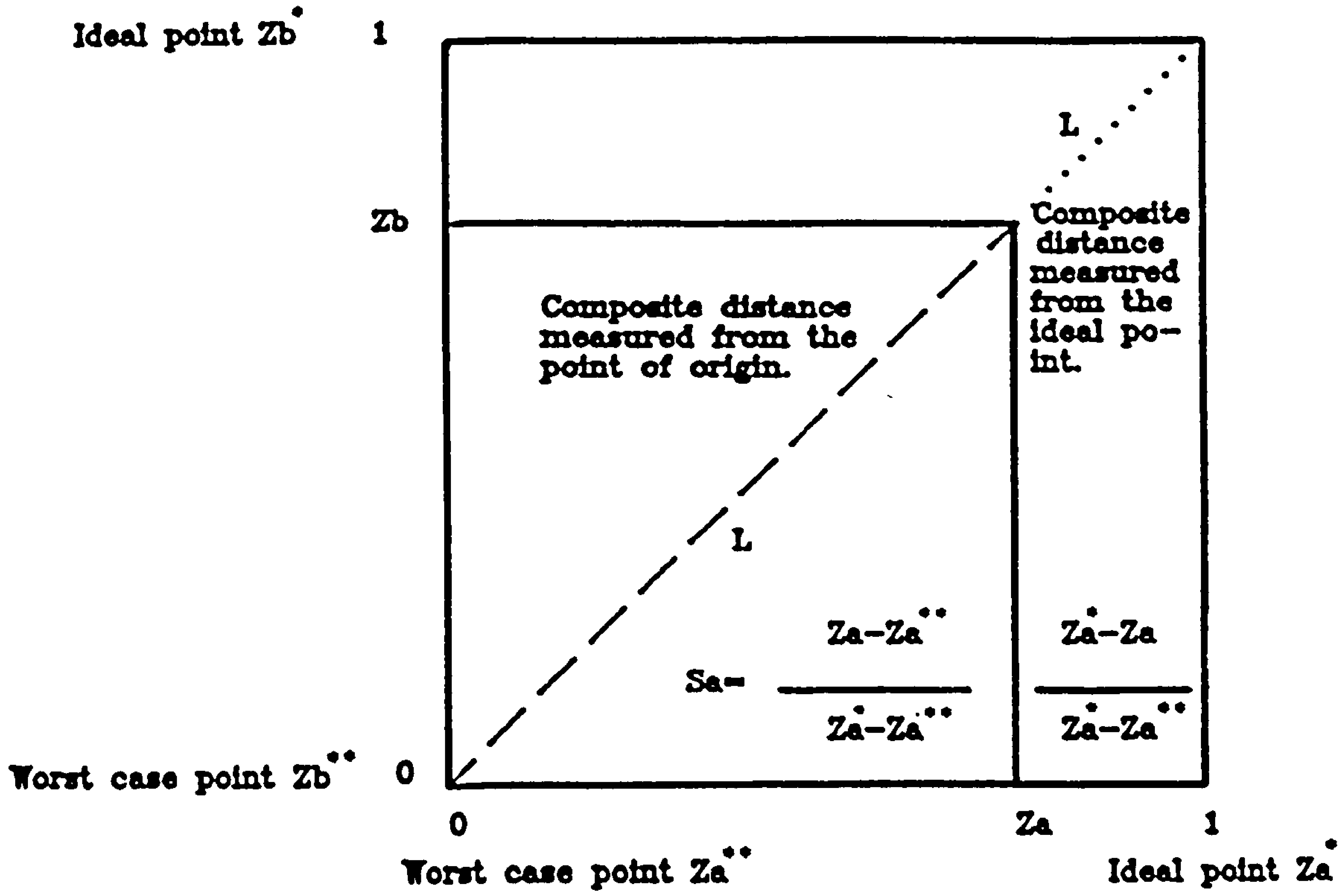

FIGURE 3-2. Composite Distance between Criteria a and b when the Ideal Value is Greater than the Worst Case Value (for criterion a)

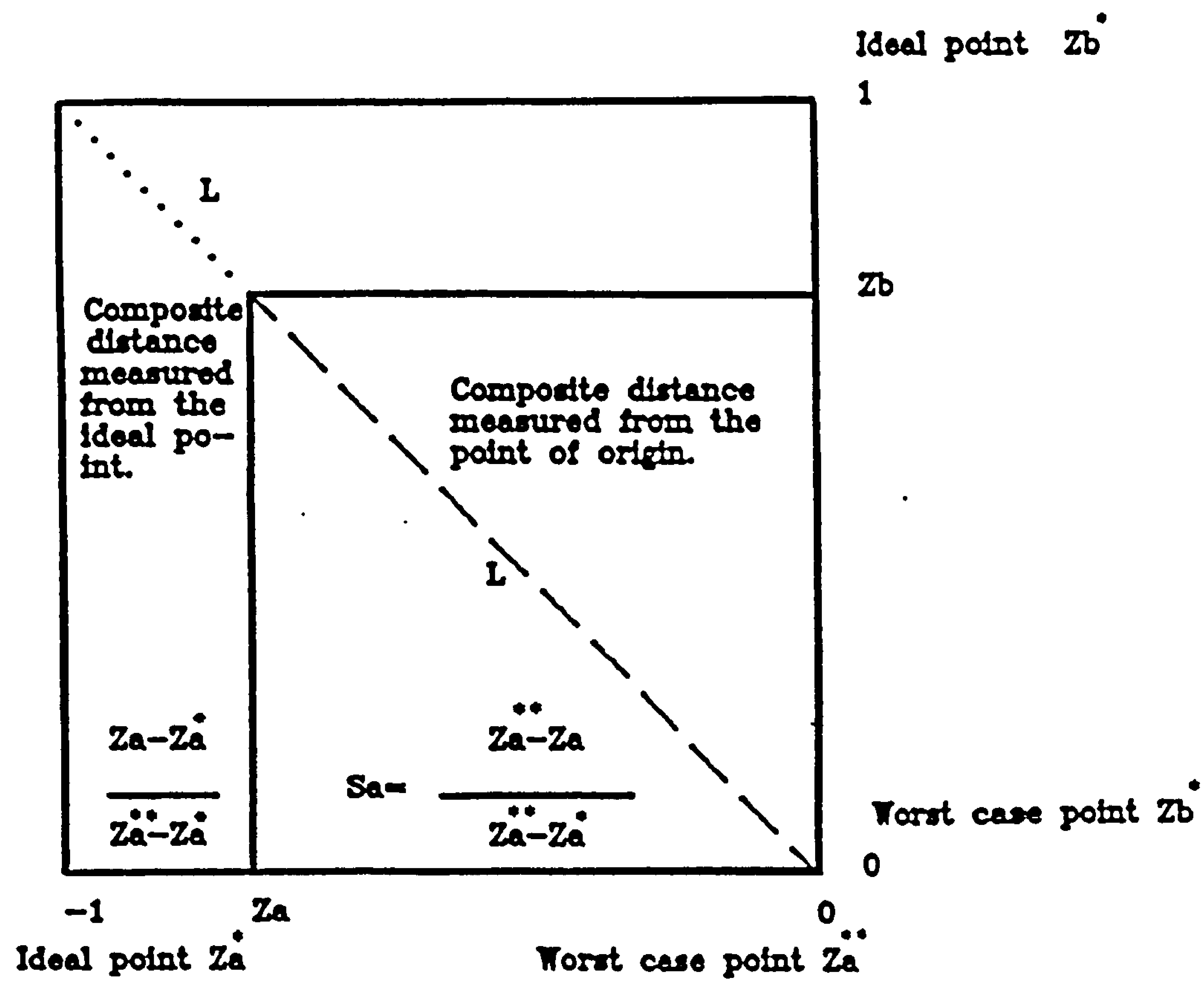

FIGURE 3-3. Composite Distance between Criteria a and b when the Ideal Value is Less than the Worst Case Value (for criterion a)

The composite distance is, thus, identified as follows:

$$L = \left(\sum_{i=1}^{n} a_i S_i^p \right)^{1/p} \qquad (p=1,2,\ldots,\infty) \qquad (3\text{-}5)$$

3.6.2 Hierarchical Composition. The basic law of hierarchical composition requires that the criteria of the bottom level of the hierarchy (basic indicators) be clustered in pairwise comparable groups according to their impact on the elements (indicators) in the next higher level. These are, in turn, grouped and compared according to elements in the next level and so on up to the focus of the hierarchy (Saaty, 88). Therefore, in order to get the composite distance between two criteria in one group of a specific hierarchical level according to their relative effect on another element of a directly higher level, the following modification of equation (3-5) may be used:

$$L_j = \left(\sum_{i=1}^{n_j} a_{ij} S_{ij}^{p_j} \right)^{1/p_j} \qquad (p_j=1,2,\ldots,\infty) \qquad (3\text{-}6)$$

where S_{ij} = *normalised value of indicator i in group j of indicators*

L_j = *composite distance for group j of indicators*

n_j = *number of indicators in group j*

a_{ij} = *weights expressing the relative importance of indicators in group j such that their sum equals one*

p_j = *balancing factor among indicators of group j*

3.6.3 Weight Incorporation. In order to express the relative importance of a set of criteria for a governing indicator in the level immediately above, priorities (weights) are introduced. These weights are first imposed on objectives or criteria to be compared with each other in the lowest level of the hierarchy. The origination of weights is done in terms of judgments of which criterion dominates another. Judgments may be obtained using a questionnaire. Experts are asked to judge the relative importance or dominance of one criterion over another. These judgments are subsequently converted into weights that reflect the dominance of an element over another in its effect on a more general index.

3.6.4 Balancing Factors. The introduction of balancing factors (p) constitutes a second set of weights applied on different groups of criteria through the composite distance calculation process. Operationally, only three points of the compromise set are usually calculated, that is, those corresponding to $p = 1$, 2 and ∞ (Goicoechea et al, 82). For $p = 1$, deviations from the ideal point $[Z_i^* - Z_i]$ are equally weighted. As p becomes larger than two, the fact that each deviation is weighted in proportion to its magnitude manifests itself. The larger the deviation, the larger is the weight imposed on that deviation. For $p = \infty$, the largest deviation receives the biggest weight and eventually,

$$L_j = \max S_{ij} \qquad (3\text{-}8)$$

At any solution, there will always be one function that will have the worst value or the farthest point from the ideal point. Sometimes, when the largest deviation is attributed to an unaffordable criterion (e.g., the probability that a dam be overtopped), avoiding such a solution becomes of major interest even if the other criteria of comparison classify this solution as the most favourable among other alternatives. In such a case, the use of $p = \infty$ becomes necessary as it confines the evaluation of the different alternatives to the criterion characterised by the largest deviation from the ideal point.

3.6.5 Relation between Indicators and Management Options. The structure of the relation between the alternatives or management options and the basic indicators or multicriteria, on which the different alternatives are evaluated, can be represented in a payoff matrix (Goicoechea et al, 82), as shown in table 3-1. The rating of the i^{th} criterion on the j^{th} alternative is represented by r_{ij} where i =

1,2,...,m and j = 1,2,...,n. According to the hierarchical composition law defined in section 3.6.2, the payoff matrix structure is successively repeated at each level of the hierarchy. This implies a series of consequent tradeoffs up the hierarchy's different levels between the effects of individual components of a group of criteria, in one level, on a governing element, in the next upper level, due to the application of various alternative solutions.

TABLE 3-1. Payoff Matrix

		Alternatives			
		1	2	...	n
Criteria	1	r_{11}	r_{12}	...	r_{1n}
	2	r_{21}	r_{22}	...	r_{2n}
	⋮				
	m	r_{m1}	r_{m2}	...	r_{mn}

Source: Goicoechea et al, 82

3.7 SUMMARY AND ILLUSTRATIVE EXAMPLE

The decision support process has been defined in this chapter. The role of computerised techniques in enhancing and speeding up the decision support operation has been highlighted. Dealing with complex decision problems that imply a tradeoff analysis (such as the operation of the Egyptian irrigation system) has called for the use of multicriteria solution techniques. In this context, the composite programming, an extension of the compromise programming, has been reviewed. This technique employs a hierarchically structured system that clusters the tradeoff criteria in pairwise comparable groups and resolves to measure their closeness to the ideal point. A set of weights is imposed arbitrarily on different criteria according to estimated relative impacts on a governing indicator in the upper level of the hierarchy. A payoff matrix is built to reflect the relation between indicators and management options at each level of the hierarchy. The process moves forward until composite distances to the ideal are calculated for the whole set of alternatives. The management option that is closest to the ideal point is prioritised.

The previous course of actions is illustrated by an example containing data from the central Tisza River in Hungary (Goicoechea et al, 82). The described example is concerned with the selection of a preferred water resource among five possibilities. Only two levels of criteria are assumed in the example (Fig. 3-4). Basic level's criteria are composited into more general terms constituting the second level of the hierarchy. A further tradeoff takes place to calculate the final composite distance to the ideal. The procedure of calculating composite distances is illustrated by the sequence shown in table 3-2.

Z-Table represents the payoff matrix (criteria versus alternatives). The selected criteria are denoted as: water quality (WQ), environment (ENV), social impact (SI) and total cost (TC). These are given the following numbers: i= 1, 2, 3 and 4 respectively. Criteria are to be composited by the tradeoff analysis into groups that are given numbers; j= 1 and 2. The alternatives are represented by five water resource options, for which optimisation is sought. The numbers contained in the table reflect values of the different criteria resulting from using each resource individually. Best and worst values are comprised in the last two columns of the table. The total cost is, for example, taken to be best for the socio-economy if it is as low as possible and vice versa. Best and worst values are denoted Z^* and Z^{**} successively.

In S_{ij}-table, the values given in Z-table are normalised by being given unitless values on a scale ranging from 0 to 1. This is carried out using the equations shown in the right column of the table. The normalisation process of the total cost value for option 1, can be demonstrated by the following calculation of S_{ij}:

$$S_{42} = \frac{101.8 - 99.6}{101.8 - 85.7} = 0.14$$

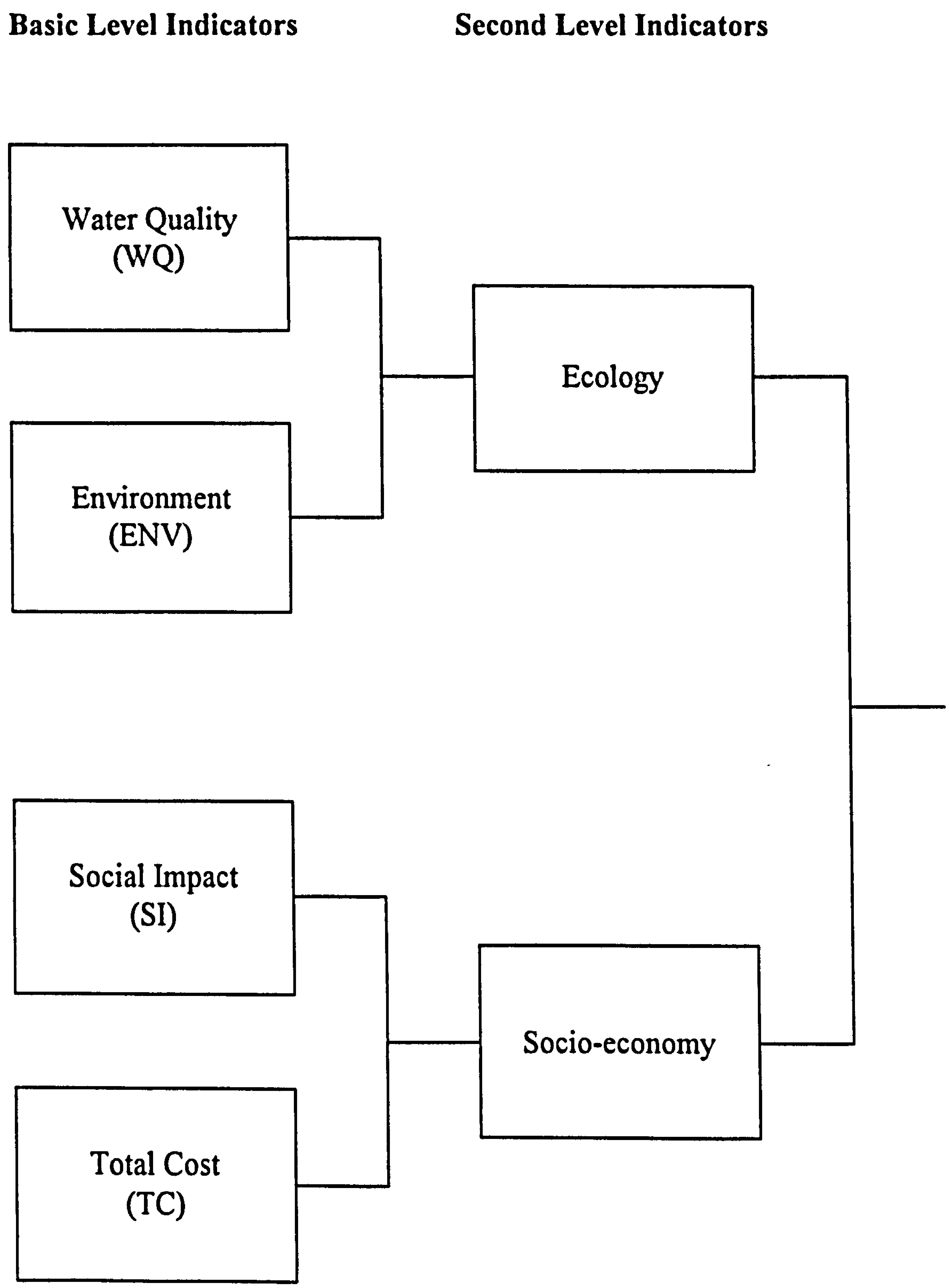

FIGURE 3-4. Criteria Clustered in a Two-Level Hierarchy

TABLE 3-2. Illustrative Example Applying the Composite Distance Technique (a_{ij} and a_{jk} = 0.5 for all i, j and k & $p_j = p_k = 1$)

ALTERNATIVES

Z-TABLE

j	i	IND.	1	2	3	4	5	Best Z^*	Worst Z^{**}
1	1	WQ	80.0	60.0	20.0	80.0	40.0	80.0	20.0
1	2	ENV	80.0	60.0	20.0	60.0	40.0	80.0	20.0
2	3	SI	80.0	80.0	60.0	20.0	40.0	80.0	20.0
2	4	TC	99.6	85.7	101.1	95.1	101.8	85.7	101.8

S_{ij}-TABLE

j	i	IND.	1	2	3	4	5	Equation Used
1	1	WQ	1.00	0.67	0.00	1.00	0.33	$S_{ij} = \frac{Z - Z^{**}}{Z^* - Z^{**}}$
1	2	ENV	1.00	0.67	0.00	0.67	0.33	$S_{ij} = \frac{Z - Z^{**}}{Z^* - Z^{**}}$
2	3	SI	1.00	1.00	0.67	0.00	0.33	$S_{ij} = \frac{Z - Z^{**}}{Z^* - Z^{**}}$
2	4	TC	0.14	1.00	0.04	0.42	0.00	$S_{ij} = \frac{Z^{**} - Z}{Z^{**} - Z^*}$

L_{jk}-TABLE

k	j	IND.	1	2	3	4	5	Equation Used
1	1	ECO-LOGY	1.00	0.67	0.00	0.83	0.33	$L_{jk} = (\sum_{i=1}^{2} a_{ij} S_{ij}^{p_j})^{1/p_j}$
1	2	SOCIO-ECONO	0.57	1.00	0.35	0.21	0.16	$L_{jk} = (\sum_{i=1}^{2} a_{ij} S_{ij}^{p_j})^{1/p_j}$

FINAL COMPOSITE DISTANCE L_k-TABLE

	k	IND.	1	2	3	4	5	Equation Used
	1	COMPOSITE DISTA	0.78	0.83	0.18	0.52	0.25	$L_k = (\sum_{j=1}^{2} a_{jk} L_{jk}^{p_k})^{1/p_k}$

WQ=Water Quality, ENV=Environment, SI=Social Impact, TC=Total Cost

In L_{jk}-table, the four criteria of S_{ij}-table are composited into fewer and more general criteria reflecting the fact that water quality and environment influence ecology. Similarly, influences of social impact and total cost on socio-economy are reflected. To fill the table, composite distances between the S_{ij}-table's factors are calculated using the equations in the right column of L_{jk}-table. For simplicity, weights for different indicators are selected to be equal (a_{ij}= 0.5) and balancing factors to equal one (p_j= 1). Thus, taking the example of calculating the composite distance (L_{jk}) between SI and TC for option 1, the following result is obtained:

$$L_{2\,1} = [0.5 * (1)^1 + 0.5 * (0.14)^1]^{1/1} = 0.57$$

Similarly, the two criteria of L_{jk}-table are composited using the equation shown in the right column of L_k-table. Weights are also selected to be equal (a_{jk}= 0.5) and balancing factors to equal one (p_k= 1), as shown in the following calculation of the composite distance L_k for option 1:

$$L_1 = [0.5 * (1)^1 + 0.5 * (0.57)^1]^{1/1} = 0.78$$

Using results from the final composite distance table, option 2 is preferred because it is the closest solution to the ideal point (in other words, the farthest solution from the point of origin) according to criteria and weights previously set.

CHAPTER IV

FRAMEWORK OF A DECISION SUPPORT SYSTEM FOR WATER ALLOCATION PLANS IN EGYPT

4.1 INTRODUCTION

The main objective of the Decision Support System being studied is to appraise the relative merits of prospective water use strategies in Egypt over a twenty-year period. In this context, two modules were selected to form a bi-component framework of the sought decision model. These modules are: (i) the Nile Basin Simulation Model (NBSM), and (ii) the tradeoff hierarchy.

The NBSM functions as an auxiliary tool that provides values used to identify the basic parameters of the tradeoff hierarchy. While the NBSM has been thoroughly analysed in Chapter II, the focus of this chapter will be on the analysis of the tradeoff hierarchy.

4.2 ANALYSIS OF THE TRADEOFF HIERARCHY

The tradeoff hierarchy is structured to reflect the aggregated impacts of the application of various water use scenarios on the welfare of Egypt. This is done through the NBSM parameters, which are used to make up values for the hierarchy's basic indicators. As shown in Fig. 4-1, the tradeoff hierarchy comprises three levels of indicators:

- Basic level indicators,
- Second level indicators, and
- Third level indicators.

All relationships between low level indicators and directly related ones of higher levels are assumed to be linear. Further investigations are needed to assess the validity of this assumption on a realistic basis.

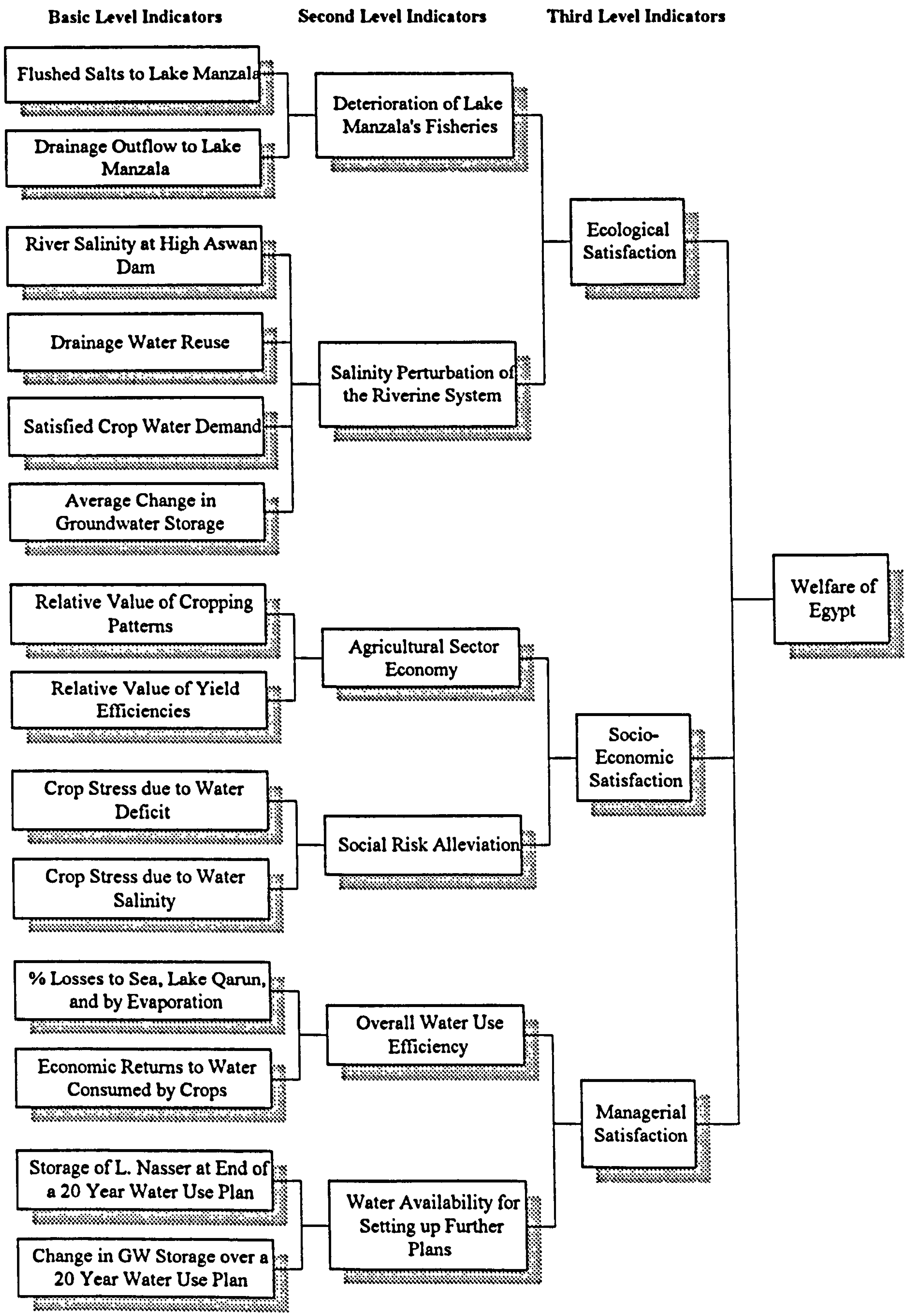

FIGURE 4-1. The Tradeoff Hierarchy

4.2.1 Basic Level Indicators. The basic level of the tradeoff hierarchy is composed of NBSM parameters representing the physical changes brought about by applying different scenarios of water use. The basic indicators used in this study are herein described.

1) **Flushed Salts to Lake Manzala.** Increasing the salt load of drainage water flowing to Lake Manzala (Fig. 4-2) is expected to augment the lake's water salinity. Consequently, the existence of fresh water species in the lake is negatively affected. This condition seems to favour the existence of marine species. However, it was found that without large infrastructural works to enlarge the lake-sea connection, it is expected that the lake's fish yield will decrease (WSP, 93e). The purpose of the infrastructural works is: (i) to dilute the pollutant contents carried within Cairo's sewage and drained to the lake via Bahr El Baqar Drain, and (ii) to allow the free entrance of marine fish to the lake. It is thus concluded that the salt load increase in the inflow to Lake Manzala contributes to the deterioration of the lake's fisheries.

2) **Drainage Outflow to Lake Manzala.** Due to the projected diversion of water to El Salam Canal, a reduction in drainage water flow to Lake Manzala is anticipated. This will result in a corresponding reduction in the discharge from the lake to the sea during low tide periods (WSP, 93e). Thus, the salt load carried off in the discharge from the lake to the sea will decrease, resulting in a salt concentration increase in the lake due to continuous evaporation. As previously explained, this is expected to affect the existence of fresh water fish species in the lake negatively. Therefore, the condition of Lake Manzala's fisheries will deteriorate with the decrease in drainage flow to the lake.

3) **River Salinity at High Aswan Dam.** The average salinity of Lake Nasser's water is about 200 ppm. The low salt concentration of the

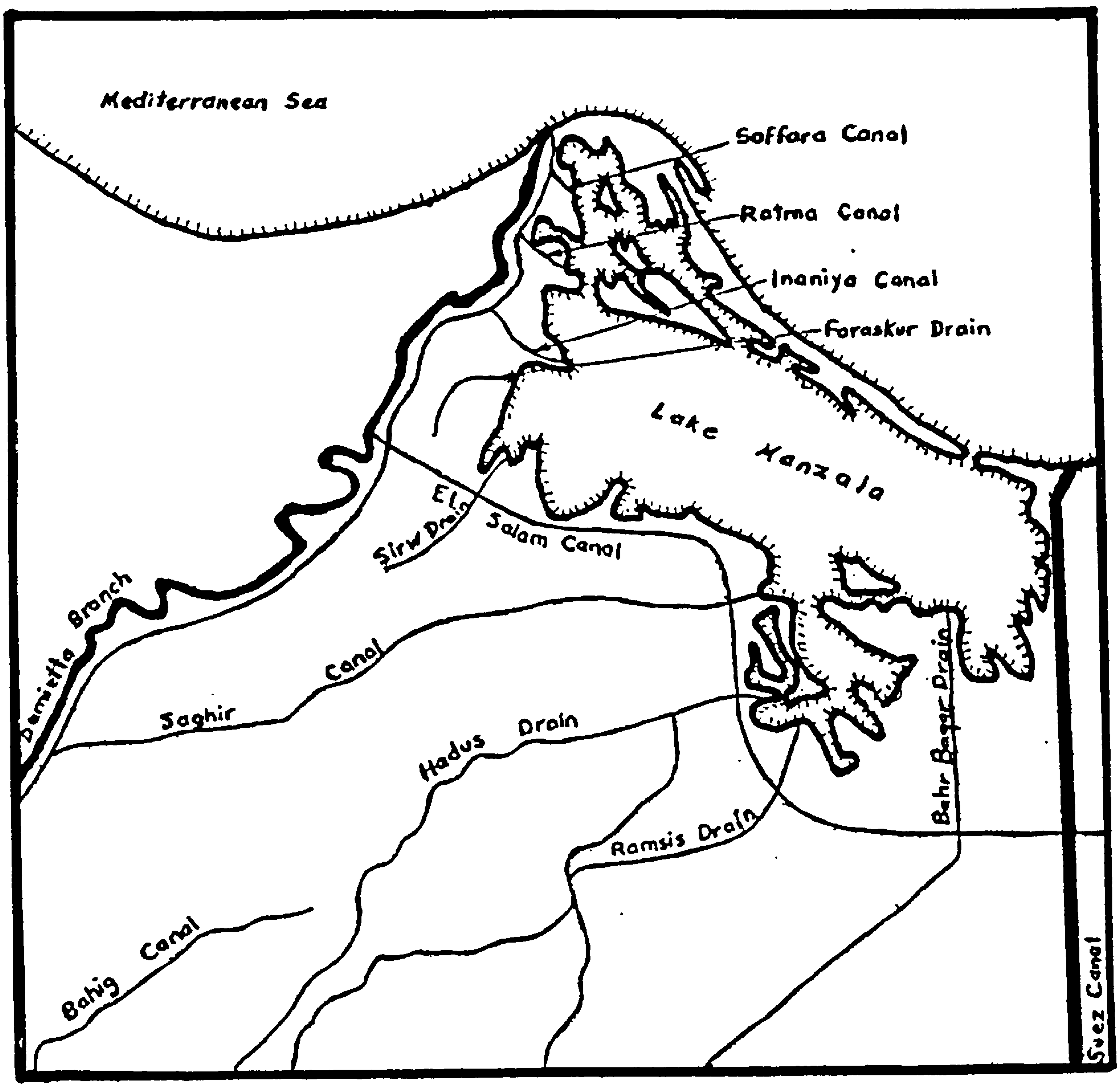

FIGURE 4-2. Location of Major Drains Flowing into Lake Manzala
Source: WSP, 93e

release is due to the absence of major anthropogenic interferences upstream of the dam. It is, however, likely that this salinity will be subject to an increase in the future. This is due to the prospective plans aimed at developing Lake Nasser's neighbouring areas. If the salinity of water released at HAD increases, the salinity of water used/reused in the downstream reaches will increase accordingly. Then, a growing salinity disturbance is expected to affect the Egyptian water system.

4) **Drainage Water Reuse.** As water travels along the course of the River Nile, an increment in water salinity takes place because of natural and anthropogenic factors. Natural factors include open water surface evaporation and transpiration of aquatic plants. This results in a presence of the same amount of dissolved salts in less water, hence a higher salt concentration than that of the original water. Also, sea water intrusion and upward seepage of saline groundwater cause water salinity to increase in the northern part of the Delta.
Anthropogenic factors contributing to the gradual increase of water salinity northwards are related to irrigation activities. Usually, soils contain large quantities of salts because of previous inundation followed by evaporation. As these soils are brought under irrigation, salts are carried off in the drainage water. Therefore, the presence of 88 agricultural drains discharging into the river from Aswan to Cairo, in addition to an official drainage water reuse amounting to 4.3 bn. m^3 in 1991 throughout the Nile Delta with an uncertain amount of unofficial reuse, play a crucial role in increasing the salt content of water towards the system's outlet. It is, thus, expected that the salinity perturbation in the riverine system will increase with larger amounts of reused drainage water.

5) **Satisfied Crop Water Demand.** The percentage of crop water demand met throughout the twenty-year plan of the NBSM is mainly controlled

by the amount of water released from Lake Nasser. It is used to show whether crops are fully or under irrigated. If the percentage value is less than 100, this means that fields are under irrigated due to water shortage. That is, if water demands for plant consumption cannot be satisfied, it is not expected that additional leaching requirements (if any) will, in turn, be fulfilled. This will result in a yield deterioration and a salinity build up in soil, hence a salinity perturbation of the system. The lower the percentage of crop water demand met, the more pronounced is the perturbation caused.

6) **Average Change in Groundwater Storage.** Because Egypt is located in a hot and arid region, water evaporation is extensive. Water evaporates from open wet surfaces and from shallow groundwaters. The storage of the closed groundwater aquifer may increase due to different reasons. These include over irrigation, a smaller rate of extraction than that of recharge and low canal and application efficiencies. The more saturated the aquifer, the closer is the water level to the ground and the more probable becomes evaporation from groundwater. Water evaporates leaving salts to accumulate in the soil and causing a build up in soil salinity. In the extreme case, groundwater reaches the ground surface. This results in waterlogging and a corresponding increase in salinity perturbation. It is expected that this indicator will soon be insignificant due to MPWWR's plans to establish system-wide tile drainage networks, thus allowing no hazardous rise of groundwater levels.

7) **Relative Value of Cropping Patterns.** The economic reforms currently taking place in Egypt grant farmers a complete freedom to select the cropping patterns that suit their own requirements and interests. This liberalisation is carried out in conjunction with the free market prices planned to prevail by the year 1995. Thus, from an

economic perspective, it would be beneficial if the cultivation of crops of high economic profitability expands to cover most of the cropped areas. A scale ranging from 0 to 10 has been developed to rank different crops according to their economic returns when maximum yields are attained. Cotton has been given a score of 10 as it has the highest economic value. The scale for major crops is shown in table 4-1. Multiplying the ratio of different crop areas with respect to the total cropped area by their scored economic returns per feddan (as demonstrated in equation 4-1) gives a sensible indication of the agriculture sector's economy. If the product increases, the sector's economy is promoted accordingly.

$$Rel.Value\ of\ Cropping\ Patterns = \sum_{i=1}^{i=18} \frac{Area\ of\ Crop\ (i)}{Tot.Cropped\ Area} * Score\ (i) \quad (4\text{-}1)$$

8) **Relative Value of Yield Efficiencies.** Augmenting the actual yield of high profitability crops is considered economically advantageous. Thus, multiplying the yield efficiency by the scored economic return per feddan (as demonstrated in equation 4-2) results in an indicator of the agriculture sector's economy. The economy is promoted as the product value increases.

$$Rel.Value\ of\ Yield\ Efficiencies = \sum_{i=1}^{i=18} \frac{A}{100} * \frac{B}{100} * Score\ of\ Crop(i) \quad (4\text{-}2)$$

where A = *% Yield Efficiency of Crop (i) due to Water Deficit Stress*

B = *% Yield Efficiency of Crop (i) due to Water Salinity Stress*

TABLE 4-1. Crop Economic Returns[4] at Maximum Yields and Corresponding Scores

Crops	Economic Returns at Max. Yields (used by the Water Security Project, 1993) (LE /feddan)	Scores (out of 10)
Cotton	3110.6	10.00
Long Berseem	434.1	1.16
Short Berseem	242.1	0.58
Sorghum	591.7	1.42
Maize	770.4	2.02
Gardens	1618.1	4.58
Wheat	1327.3	4.40
Beans	751.0	2.17
Rice	2262.0	7.12
Winter Vegetables	2351.7	6.92
Summer Vegetables	1260.5	3.33
Barley	826.1	2.49
Sugar Cane	1752.1	4.66
(Winter) Others	1392.7	3.78
(Summer) Others	940.3	2.40
Soya Beans	2080.4	6.69
Sprinkler	1618.1	4.58
Surface	2080.4	6.69

[4] Note that land costs are excluded from the economic returns used because controls on land use exist such that land has no alternative use but in agriculture. Also water costs are excluded for being not priced in Egypt. On the other hand, labour costs are included because the Egyptian farm labour has an opportunity value estimated at LE 6 per day.

9) **Crop Stress due to Water Deficit.** This indicator is used to reflect the extent of social satisfaction via the alleviation of social risk. It is expected that the farmers' feeling of risk will be alleviated by satisfying their demands for water to obtain maximum yields. It is thought that this feeling of risk will start to increase after the first incident of failure in maintaining the crop stress at zero percent due to a deficit in water supply. The higher the average percentage of crop stress due to deficits in water supply over the planning period, the more prolonged becomes the farmers' feeling of risk.

10) **Crop Stress due to Water Salinity.** The NBSM does not contain either an initial condition of soil salinity or a process for calculating the salinity build up due to frequent applications of saline irrigation water. Therefore, crop yield stresses due to salinity constraints will be solely controlled by the salt content of applied water. If water salinity results in a crop yield stress, it is thought that this will cause farmers to worry about a repetitive occurrence of such conditions. As the average crop yield stress due to water salinity increases, it is expected that the farmers' feeling of risk will extend accordingly.

11) **% Losses to Sea, Lake Qarun and by Evaporation (to the total water released).** The three major outlets for water lost to the Egyptian regional system are[5]:

- drainage to the sea and to Lake Qarun,
- non-consumptive use for inland navigation and regulations during the closure period, and
- evaporation.

The previous items can be grouped into two more general outputs: flow to the sea and evaporation. Reducing the ratio of water lost through

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5 Evapotranspiration and municipal and industrial consumptions are not considered lost to the system.

these outlets to the total amount of water released at Aswan increases the overall efficiency of water use throughout the planning period.

12) **Economic Returns to Water Consumed by crops.** Due to water scarcity compared to the increasing demands in Egypt, water is becoming a constraining factor in selecting cropping patterns. However, this is currently felt at the managerial level (officials and planners), but not at that of farmers. This is because the Egyptian water supply is not yet controlled by a pricing system. Therefore, the economic crop returns per unit of water consumed by crops may constitute an indicator of how well the overall water use efficiency would perform under various cropping strategies. Equation 4-3 calculates the indicator's value by, first, summing the product of each crop area by its economic return at a maximum yield (displayed in table 4-1) times the yield factors resulting from water deficit and salinity stress. Second, the result is divided by the quantity of water consumed by crops (evapotranspiration). The higher the economic crop returns to water, the better is the overall water use efficiency.

$$E = \frac{\sum_{i=1}^{i=18} \text{Area of crop } (i) * G * \frac{A}{100} * \frac{B}{100}}{ET * 10^6} \qquad (4\text{-}3)$$

where
- E = *Economic Returns to Water Consumed by Crops (M. LE / bn. m^3)*
- G = *Economic Return of Crop (i) at Maximum Yield (LE / feddan)*
- A = *% Yield Efficiency of Crop (i) due to Water Deficit Stress*
- B = *% Yield Efficiency of Crop (i) due to Water Salinity Stress*
- ET = *Evapotranspiration (bn. m^3)*

13) **Storage of Lake Nasser at the End of a Twenty-Year Water Use Plan.** The live storage capacity of the lake is 137.5 bn. m^3. It serves

to assure a long-term water availability for Egypt and, therefore, secure water storage for setting up a new water use plan. The dead storage capacity of the lake (28.3 bn. m^3) is the datum from which the availability of water is measured. Lake Nasser's level above this critical capacity at the end of a twenty-year planning period shows the availability of stored water for starting further plans. This availability is therefore expected to increase with respect to the storage build up in the lake at the end of the initial plan.

14) **Change in Groundwater Storage over a Twenty-Year Water Use Plan.** Because the old irrigation system is underlain by a closed aquifer, the abstraction of groundwater results in a subsequent replenishment of the aquifer. This is achieved by a recharge originating from irrigation losses (seepage from canals and losses from application). The main discharge components from the aquifer include: (i) groundwater return flows to the River, and (ii) groundwater extractions by wells.
Within the NBSM, the change in groundwater storage over a twenty-year planning period shows how much underground water is available for sustaining further water allocation plans. The larger the positive change in storage over the initial plan, the better is the water availability for starting further ones.

4.2.2 Second Level Indicators. Compared to the basic indicator level, the hierarchy's second level comprises indexes each of which is influenced by one or more basic indicators. These parameters are, in turn, expected to affect fewer and more general indexes comprised within the hierarchy's higher levels.

1) **Deterioration of Lake Manzala's Fisheries.** It is recognised that over 30 percent of Egypt's fish production comes from Lake Manzala. On the other hand, Lake Manzala is identified as an environmental black

spot. The lake is subject to different sorts of disturbances. The scope of this study will be on salt content changes.
Fish existence in the lake is considered an indicator of ecological satisfaction. This indicator is vulnerable to the increase in water salinity. Therefore, enhancing fish stocks in the lake constitutes an effort in the direction of promoting the lake habitat. Further studies are needed to assess the impact of other environmental disturbances (e.g., pollution) on the lake ecosystem.

2) **Salinity Perturbation of the Riverine System.** Because of a likely increase in water salinity within the riverine system, it is expected that the utility of water for fresh water uses will decrease. Irrigation water of high salinity may cause a plant yield reduction or even failure and salt build up especially in tight soils (old lands). Also safe drinking water should not, generally, exceed 500 ppm (PRIDE, 92). Moreover, an increase in water salinity adversely affects the river's existing fresh water fish species. These may eventually have to be replaced by marine species transplanted from the sea to the river. Avoiding such disturbances in the system is considered a positive contribution to the public ecological satisfaction.

3) **Agricultural Sector Economy.** The agriculture sector currently accounts for about 20 percent of both GDP and total exports, and about 36 percent of employment in Egypt. Promoting the agriculture sector's economy would, in the light of the free market prices being established, boost the socioeconomic satisfaction at both individual and national levels.

4) **Social Risk Alleviation.** Alleviating the social feeling of risk stemming from the frequent occurrence of crop yield stresses may constitute an effort in the direction of promoting socioeconomic satisfaction. The

considered crop yield stresses are due to either a shortfall in water supply or a deteriorated water quality.

5) **Overall Water Use Efficiency.** Planners and decision makers at the MPWWR need to assess the performance of proposed water use plans. Because the case dealt with is that of a closed basin, traditional farm and distribution efficiencies have no real significance. The selected overall water use efficiency can give a better indication of the managerial satisfaction. This indicator depends on: (i) the economic return per unit of water consumed by crops, and (ii) the percentage of water lost by evaporation and to the sea and to Lake Qarun to the total amount of water released from Aswan.

6) **Water Availability for Setting up Further Plans.** Another managerial concern is the availability of water after the application of a proposed twenty-year plan. If the remaining water is abundant, this will give the planner a greater confidence in setting up further water use plans.

4.2.3 Third Level Indicators. The ecological, socioeconomic and managerial satisfactions represent indicators of the public contentment bringing about the welfare of Egypt. Compositing the third level of indicators is followed by the emergence of the hierarchy's top index 'Welfare of Egypt'. The closer one scenario's top index to the ideal, the more prioritised becomes this scenario.

4.3 FUNCTION OF THE DSS TRADEOFF HIERARCHY

As previously explained, basic indicators are grouped into categories within which their effects on a more general factor, existing in the second level of the hierarchy, are traded off. Second level's factors are, in turn, grouped into new categories within which they are traded off to reflect their impacts on third level's indexes. The process continues until the top index, the promotion of which is sought, is generated. For this study, there are three levels of indicators, listed as shown in Fig. 4-1.

4.4 SELECTING WEIGHTS

Once the indicators' hierarchy is structured, a weight is selected for each indicator. For the sake of this selection, a questionnaire has been developed and addressed to experts to judge the relative importance of indicators at the hierarchy's different levels. Appendix A contains a copy of the questionnaire from which weights are deduced. A list of the experts contributing to the developed questionnaire is found in Appendix B.

The average judgments resulting from the developed questionnaire are shown in Fig. 4-3. Weight calculation then proceeds by normalising the aforementioned judgments. Deduced weights for the different indicators of the hierarchy are displayed in Fig. 4-4.

4.5 ASSIGNING BALANCING FACTORS

After the selection of a weight for each indicator, a balancing factor is assigned for each group of indicators. Balancing factors show the importance of the maximal deviations of indicators. Initially, the application of unity balancing factors takes place throughout the decision making process. Subsequently, different balancing factors should be applied to test the sensitivity of computed ranks regarding water use scenarios. High weights and balancing factors indicate that an indicator is relatively important (Stansbury, 89).

4.6 DEFINING BEST AND WORST VALUES

Defining best and worst values for a specific basic indicator implies indicating the values that result in best and worst conditions for the index located in the directly higher level of the hierarchy. The selected best and worst values are used to introduce the normalised scaling function for the basic indicators, as previously explained in section 3.6.1. These values are shown in table 4-2.

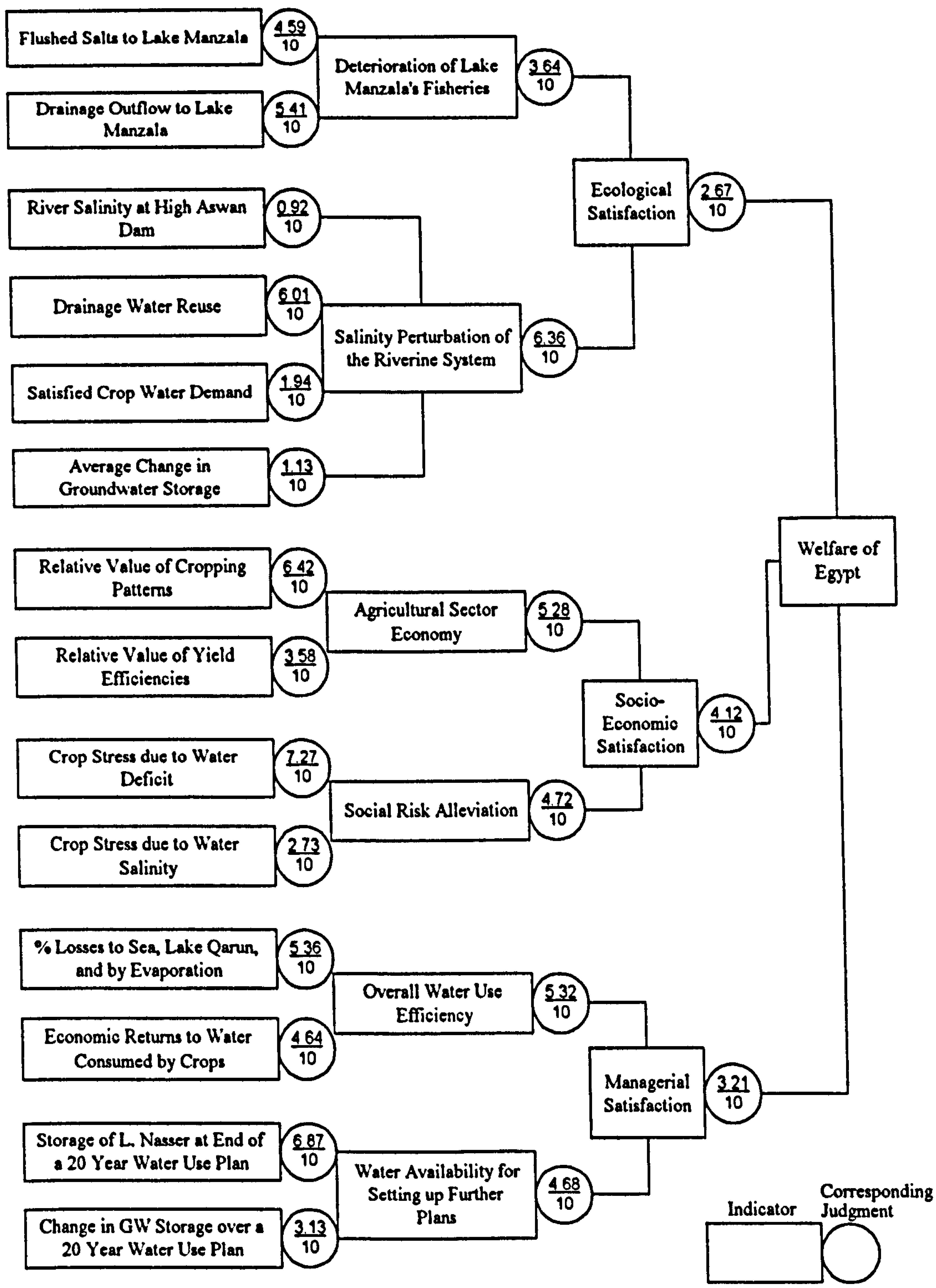

FIGURE 4-3. Average Judgments Resulting from the Circulated Questionnaire

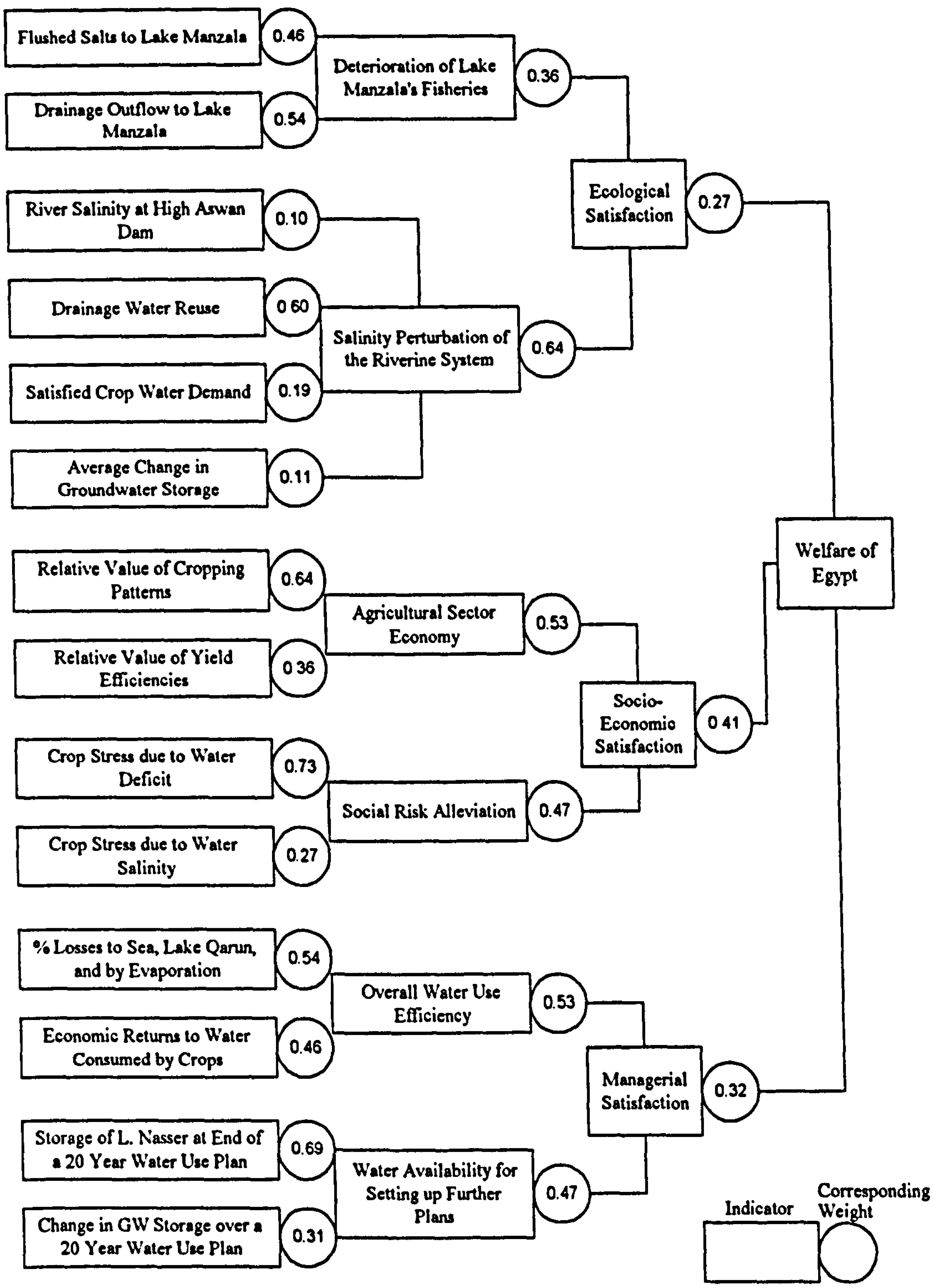

FIGURE 4-4. Deduced Weights for the Hierarchy's Components

TABLE 4-2. Defining Best and Worst Values for the Hierarchy's Basic Indicators

Basic Indicator	Best Values	Worst Values	Units	Notes
Flushed Salts to Lake Manzala	Minimum of all scenarios	Maximum of all scenarios	bn. m^3	
Drainage Outflow to Lake Manzala	Maximum of all scenarios	Minimum of all scenarios	M. tons	
River Salinity at High Aswan Dam	Minimum of all scenarios	Maximum of all scenarios	ppm	Values less than 100 ppm are disallowed
Drainage Water Reuse	Minimum of all scenarios	Maximum of all scenarios	bn. m^3	
Satisfied Crop Water Demand	Maximum of all scenarios	Minimum of all scenarios	percent	
Average Change in GW Storage	Minimum of all scenarios	Maximum of all scenarios	bn. m^3	Negative values are considered equal to zero
Relative Values of Cropping Patterns	Maximum of all scenarios	Minimum of all scenarios	scores	calculated using equation (4-1)
Relative Values of Field Efficiencies	Maximum of all scenarios	Minimum of all scenarios	scores	calculated using equation (4-2)
Crop Stress due to Water Deficit	Minimum of all scenarios	Maximum of all scenarios	percent	
Crop Stress due to Water Salinity	Minimum of all scenarios	Maximum of all scenarios	percent	
% Losses to Sea, L.Qarun & by Evaporation	Minimum of all scenarios	Maximum of all scenarios	percent	
Economic Returns to Water Consumed by Crops	Maximum of all scenarios	Minimum of all scenarios	M. LE / bn. m^3	calculated using equation (4-3)
Storage of L.Nasser at End of a 20-Year Plan	Maximum of all scenarios	Minimum of all scenarios	bn. m^3	Range between 28.3 and 137.5 bn. m^3
Change in GW Storage over a 20-Year Plan	Maximum of all scenarios	Minimum of all scenarios	bn. m^3	

4.7 THE DSS COMPUTER SOFTWARE

Based on the foregoing components of the envisaged DSS framework, a model is developed using Visual Basic for Windows to speed up the decision making process through a user friendly interface. The DSS model is designed to be used in conjunction with the Nile Basin Simulation Model (NBSM) which provides values used to identify the basic parameters of the tradeoff hierarchy. However, any prediction of these parameters by any other model, or by manual calculations, can also be evaluated by the produced software.

The program computes the composite distance of each conceived scenario to the 'ideal point' according to the criteria represented by the previously defined indicators and weights. It then ranks the different alternatives according to their closeness to the ideal. The shorter the composite distance measured from the ideal point (i.e., the longer the distance measured from the point of origin), the more advanced is the rank of the considered scenario with respect to other alternatives. A copy of the software is enclosed with the thesis. More information about using the DSS model can also be found in the USER MANUAL - Version 1.01 (Appendix C).

4.8 SUMMARY AND DISCUSSIONS

In this chapter, the framework of a Decision Support System is developed to analyse proposed policies of water allocation in Egypt over a twenty-year period and choose the one(s) that best satisfies various interests regarding the country's welfare. Several indicators are chosen to form the basic level of a multi-level hierarchy topped with the index 'Welfare of Egypt'. Impacts of the basic level indicators on fewer and more general indexes, existing within an intermediate level, are traded off. Intermediate level indexes are, in turn, used as indicators that reflect, by being traded off, impacts on the indexes of a subsequent level. Progressive tradeoffs are, thus, carried out until the top level index 'Welfare of Egypt' is eventually attained.

The hierarchy's basic indicators are selected from the output provided by the NBSM. Among various models surveyed at the Irrigation and Planning Sectors of the MPWWR, the NBSM is deemed a powerful planning tool that can simulate Egypt-wide water supply/demand performance from a strategic perspective. It can also provide the user with a wide variety of long range estimates under various national policies of water allocation.

The development of the hierarchy's intermediate levels, stemming from the basic indicators comprised in the bottom level, is based on the author's acquaintance with the Egyptian irrigation system and corresponding issues. There are further opportunities to add or eliminate indicators to the developed hierarchy as necessary. This would depend on the analyst's envisagement of the system controversies and on the model selected to simulate the operation and planning of the water storage and supply system.

In order to provide weights for the hierarchy's indicators, a questionnaire has been developed to survey expert views on the relative importance of the indicators to be traded off. It was previously stated that making decisions on Egyptian water issues is the responsibility of the MPWWR. However, Research Centres and Irrigation Departments at diverse Universities play an advisory role in the decision making process. Therefore, the developed questionnaire has not only been addressed to MPWWR's officials, but also to University staff members and researchers in the field of irrigation. There is a further opportunity to invite experts from other Ministries involved in water related aspects (ecologists, economists,. . .) to contribute to the questionnaire. This, however, depends on the enforcement of an organised mechanism allowing other Ministries to participate in the development of water policies in Egypt.

A DSS computerised model is generated to facilitate and speed up the calculation of the tradeoff process and display the results in a user friendly environment. During early stages of the DSS construction, a Fortran program (listed in Appendix D) was developed to compute the composite distances to the ideal and ranks of various alternatives. This was considered a preliminary attempt to originate a user friendly configuration of the DSS. However, no available Fortran version was, then, found capable of producing graphics or input boxes. Alternatively, the Visual Basic was used to overcome this difficulty, because it allows the utilisation of the graphical interface provided by the Windows system.

Confining the selection of basic indicators to those for which the NBSM can provide an outcome may result in questionable issues, including:

- Lake Manzala is not the sole black spot in the Egyptian ecosystem. Besides, the lake contribution is only 30 percent of Egypt's fish production. Further studies should, thus, consider various environmentally ill locations (e.g., Lake Mariut) and other habitat species (e.g., birds).
- Components of the public ecological satisfaction should include, beside halting the habitat deterioration and avoiding the disturbance of the system's salt balance, reducing the water pollution resulting from the return of industrial, domestic as well as agricultural drainage flows to the irrigation system. The role of the returned agricultural drainage flow in polluting water stems from the extensive application of fertilisers within the Egyptian system.
- The average change in groundwater storage, used as an indicator of the system salinity, will soon be insignificant. This is due to MPWWR's plans to disseminate tile drainage networks, thus alleviating waterlogging hazards.
- Within the model, market controlled crop prices are considered fixed parameters. Further modifications are, therefore, necessary in the DSS structure to allow a flexible entry of prices according to real-time estimations.

In addition to the above mentioned imponderables, some observed weaknesses in the DSS being studied are herein outlined. This model is exclusively developed to assist MPWWR policy makers with decisions on proposed water use strategies. The current version is only concerned with the Egyptian irrigation system. Its application elsewhere is inconceivable unless a proper model is used to simulate the operation of the chosen system. Changing parameters of the tradeoff hierarchy is then required to suit the considered system's conditions and prerequisites. On the other hand, the developed DSS is inflexible regarding probable changes in the present configuration. Because parameters and rules are embedded in the program's code, a programmer's intervention is deemed necessary for further modifications in the model. It would have been relatively straight forward to develop a DSS where the user could dynamically add indicators and weights, change groupings and save the resultant model, thus giving a flexible DSS program.

CHAPTER V

PRIORITISING WATER USE SCENARIOS WITHIN THE DSS

5.1 INTRODUCTION

There are several water use schemes that may be applied within the Egyptian system. The variability of these schemes stems from the wide range of factors that may be introduced and/or changed in the water demand function. For this study, water use alternatives are confined into few scenarios to be analysed and prioritised within the DSS. In this context, it is assumed that the only variables in the function of the Egyptian water demand are:

- horizontal expansion, carried out by adding new lands to the total cultivated area,
- change in cropping patterns, achieved by switching to crops of different characteristics, and
- change in the water distribution efficiency, carried out by improving the canal system.

Assumption: WD = f (HE, CP, DE)

where WD = Water Demand

HE = Horizontal Expansion

CP = Cropping Patterns

DE = Distribution Efficiency

5.2 CRITERIA FOR OUTLINING WATER USE SCENARIOS

The highlighted water use scenarios are structured so that the following parameters vary according to the adopted scheme:

- the projection of New Land reclamation,
- the land allotment for different cropping patterns, and
- the extent of improving the efficiency of the old system transferring water from the river to the fields.

Each parameter is delineated below.

5.2.1 Projected Horizontal Expansion. Land reclamation started on a national level in the early nineteenth century. The total cultivated area was then reported as two million feddans. These efforts were pursued until almost all heavy clay areas in the flood plain of the River Nile were under cultivation. Cultivated lands then totalled to an estimated 5.5 million feddans.

After 1952, efforts have increasingly focused on the reclamation of desert lands to offset the rapid population growth. In this context, some 1.5 million feddans were reclaimed up to the mid eighties. While these areas are called the old-new lands, areas recently reclaimed, amounting to about 0.5 million feddans, are termed the new-new lands.

The Land Master Plan study, carried out in 1986, identified land areas, totalling 2.8 million feddans, as potentially reclaimable. The prospective reclamation areas were ranked by land productivity into five categories as shown in table 5-1. While Category I was considered 'very good arable', Categories IV and V were regarded as 'limited arable'.

Based on the previous classification, three scenarios of horizontal expansion are derived, assuming a complete reclamation of class I lands by the year 1990. Within the 'modest' scenario (M), lands of class II and III are considered under development during the twenty-year plan 1990-2010 (a total of 502,600 feddans or 2110.9 km^2). All potential arable lands (including those of class IV and V) are expected to be reclaimed within the same plan period under the 'full' scenario (F). Averaging the full and modest scenarios yields an 'intermediate' one (I). It is to be noted that, for the three described scenarios, values of the other function variables shown in section 5.1, namely: cropping patterns and water distribution efficiencies, are maintained constant (i.e., their default values used by the Nile Basin Simulation Model remain unchanged).

TABLE 5-1. Land Master Plan Land Categories

Reg.	Land Category							
	I		II - III		IV - V		Total	
	x 1000 feddans	km^2	x 1000 feddans	km^2	x 1000 feddans	km^2	x 1000 feddans	km^2
UEN			160.7	674.9	670.9	2817.8	831.6	3492.7
MEN			26.5	111.3	197.4	829.1	223.9	940.4
WDN	41.5	174.3	220.3	925.3	423.1	1777.0	684.9	2876.6
MDN	59.0	247.8					59.0	247.8
EDN	268.5	1127.7	95.1	399.4	435.1	1827.4	798.7	3354.5
SIN	102.5	430.5			181.1	760.6	283.6	1191.1
Total	471.5	1980.3	502.6	2110.9	1907.6	8011.9	2881.7	12103.1

5.2.2 Projected Cropping Patterns. Due to the presence of governmental refineries (Fig. 5-1) and constraints on sugar imports, sugar cane production is considered partially subsidised by the Government. Although sugar cane is financially attractive to farmers, its production is strongly questioned due to high water consumption. Similarly, there is a necessity to take into account the value of the large water amounts used in growing rice. On another hand, cotton and wheat would make high economic contributions compared to their natural resource use (WSP, 93f).

Thus, looking at the possibility of inter-substitutability of crops is indispensable for achieving an optimal allocation of water. Table 5-2 summarises the shifts in cropping patterns envisaged by the Water Security Project (WSP, 93f). Column(1), representing Scenario (B), shows the base cropping patterns (applied by the MPWWR in 1990 and defaulted to the Nile Basin Simulation Model) for six major crops, namely: cotton, rice, maize, summer vegetables, wheat and sugar cane. Column(2), corresponding to Scenario (C), implies cropping pattern values resulting from increasing the cotton patterns in the Delta by six percent. This

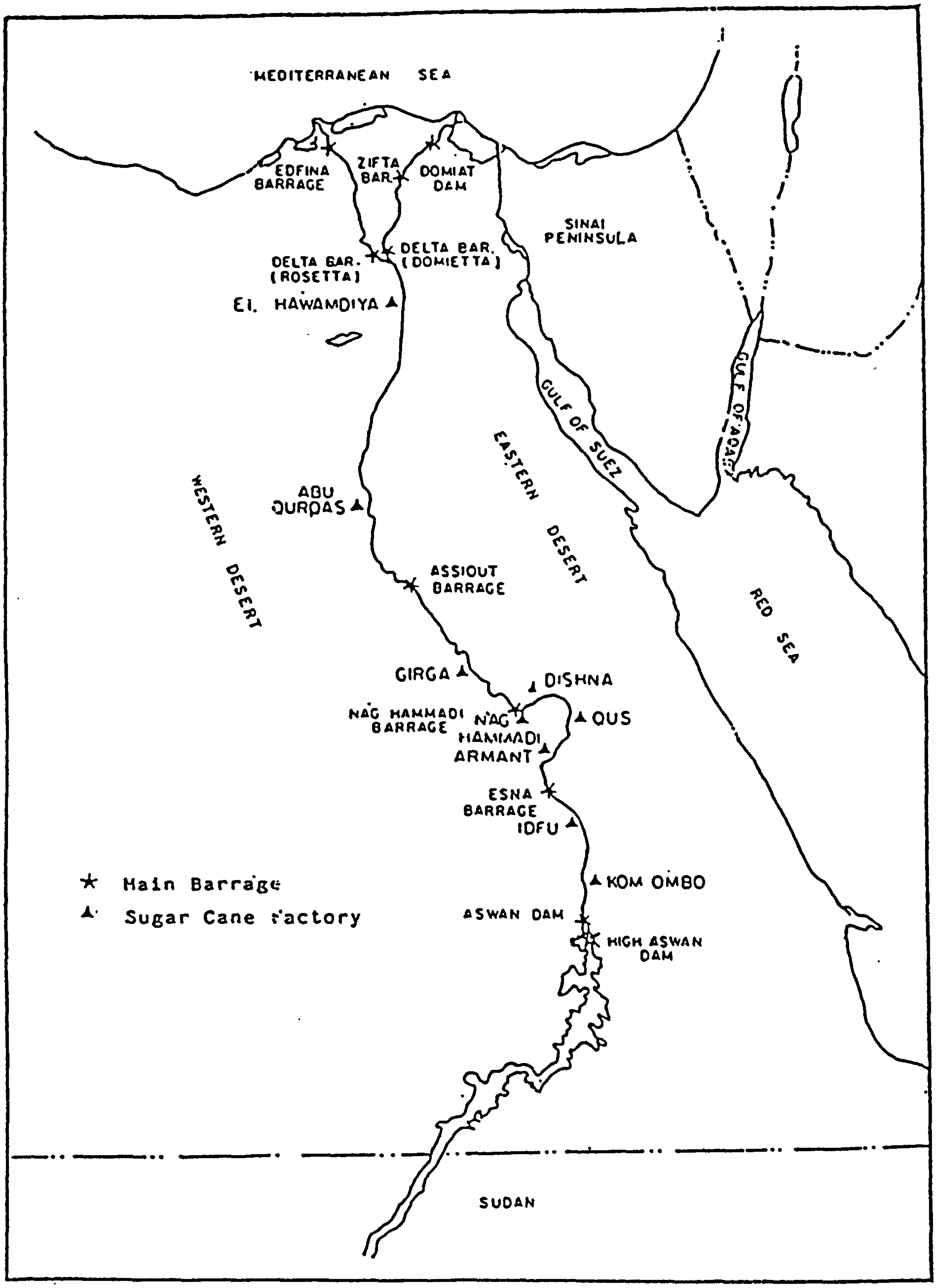

FIGURE 5-1. Sugar Factories in Egypt

increase is balanced by a two percent reduction in the patterns of rice, maize and summer vegetables. In Column(3), representing Scenario (S), it is assumed that sugar cane is cut in half in Upper Egypt, totally eliminated in Fayoum and Middle Egypt and replaced, in both cases, by wheat and cotton.

TABLE 5-2. Shifts in Cropping Patterns for All Egypt
(% of the total cultivated area)

	Column(1)	Column(2)	Column(3)
Crops	Scenario (B)	Scenario (C)	Scenario (S)
Cotton	15	18	17
Rice	11	10	11
Maize	28	26	28
Summer Veg.	7	6	7
Wheat	22	22	24
Sugar Cane	4	4	1

5.2.3 Projected Distribution Efficiencies. Changing projected areas of the New Land reclamation programme has yielded three schemes of development: the 'full' (F), 'intermediate' (I), and 'modest' (M) scenarios. Similarly, changing cropping patterns has produced another three schemes; the 'base patterns' (B), 'cotton intensified' (C) and 'sugar cane reduced' (S) scenarios. Amalgamating these scenarios yields a matrix of nine plans as follows:

MB	IB	FB
MC	IC	FC
MS	IS	FS

Adding the base distribution efficiency (D), believed to be about 75-80 percent for old land canals, to the components of the foregoing matrix yields:

MBD	IBD	FBD
MCD	ICD	FCD
MSD	ISD	FSD

Increasing the efficiency of the system transferring water from the Nile to the fields to 85 percent in Old Lands would generate another matrix comprising nine additional scenarios, thus yielding a total of eighteen scenarios to be tested within the DSS.

(1) MBD Scenario	(2) IBD Scenario	(3) FBD Scenario	(4) MBE Scenario	(5) IBE Scenario	(6) FBE Scenario
(7) MCD Scenario	(8) ICD Scenario	(9) FCD Scenario	(10) MCE Scenario	(11) ICE Scenario	(12) FCE Scenario
(13) MSD Scenario	(14) ISD Scenario	(15) FSD Scenario	(16) MSE Scenario	(17) ISE Scenario	(18) FSE Scenario

5.3 LOADING WATER USE SCENARIOS INTO THE DSS

The NBSM is initially fed with the eighteen scenarios summerised in section 5.2.3. Running the model over a twenty-year period is then carried out for each scenario. Results are saved as output files, from which values of the DSS indicators are subsequently quoted. For each scenario, the DSS can import data sets from the corresponding NBSM output files. Data to be retrieved are mostly contained in three NBSM output templates averaged over the period 1990-2010, namely:

- Annual Water Balance for All Egypt[6],
- Crop Yield, Production and Area (Crop Stress)[7], and
- System Salinity and Salt Ingress[8].

By importing the above mentioned data sets into the DSS, values of most basic indicators are automatically input into the model except the ones listed below:

Basic Indicator	Corresponding NBSM Template
- River Salinity at High Aswan Dam (averaged over 1990-2010)	System Salinity and Salt Ingress (output file)
- Drainage Water Reuse (averaged over 1990-2010)	Schematic for All Egypt
- Satisfied Crop Water Demand (averaged over 1990-2010)	Annual Water Balance for All Egypt (output file)
- Storage of Lake Nasser at the End of the Twenty Year Plan	Lake Nasser Volumes (output file)

N.B. Values of the tabulated indicators are quoted by the user from the corresponding NBSM templates and manually input into the DSS.

Weights and balancing factors are then applied to indicators. As previously explained in section 4.4, applied weights are those resulting from the questionnaire circulated among various officials. It was also stated in section 4.5 that unity

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6 Contained data are imported by following the DSS menu sequence Edit| Water Balance, and clicking the '*Import Data File*' button.

7 Contained data are imported by following the DSS menu sequence Edit| Crop Data, and clicking the '*Import Data File*' button.

8 Contained data are imported by following the DSS menu sequence Indicators| Ecological| Fisheries Deterioration, and clicking the '*Import Data File*' button.

balancing factors are preliminarily chosen for all indicators. The impact of using other balancing factors is subsequently tested through a sensitivity analysis.

5.4 RESULTS OF THE DSS PRELIMINARY RUN

Having been loaded with the eighteen scenarios being tested, the DSS model becomes ready to rank the reviewed scenarios. Ranks depend on the scenarios' potential for bringing about the welfare of Egypt. Results of the run may be displayed by the model through graphical and/or tabulated interfaces, as shown in Fig. 5-2 and table 5-3.

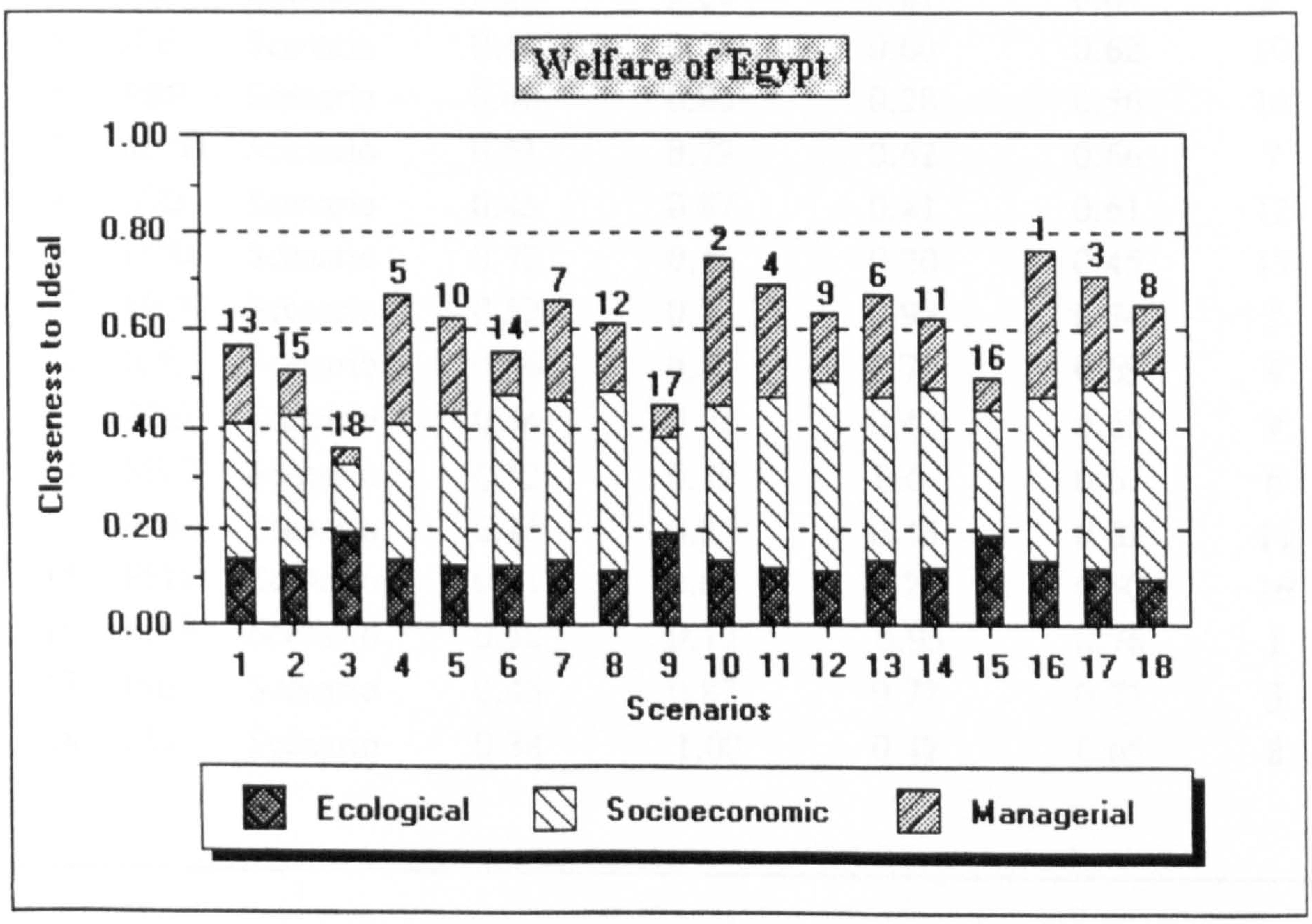

FIGURE 5-2. Run Results Showing Ranks of the Tested Scenarios in Compliance with their Closeness to the Ideal Point

TABLE 5-3. Scenario Ranks according to their Closeness to the Welfare of Egypt Based on the Amalgamation of Ecological, Socioeconomic, and Managerial Satisfactions

No.	Scenario Name		Ecological Satisfaction	Socio-Economic Satisfaction	Managerial Satisfaction	Welfare of Egypt	Rank
1	MBD	Scenario	0.52	0.66	0.49	0.57	13
2	IBD	Scenario	0.46	0.74	0.29	0.52	15
3	FBD	Scenario	0.72	0.33	0.10	0.36	18
4	MBE	Scenario	0.52	0.66	0.81	0.67	5
5	IBE	Scenario	0.47	0.74	0.60	0.62	10
6	FBE	Scenario	0.48	0.83	0.28	0.56	14
7	MCD	Scenario	0.51	0.79	0.62	0.66	7
8	ICD	Scenario	0.45	0.87	0.41	0.61	12
9	FCD	Scenario	0.72	0.46	0.20	0.45	17
10	MCE	Scenario	0.52	0.75	0.93	0.74	2
11	ICE	Scenario	0.46	0.83	0.72	0.69	4
12	FCE	Scenario	0.44	0.92	0.42	0.63	9
13	MSD	Scenario	0.52	0.79	0.64	0.67	6
14	ISD	Scenario	0.46	0.87	0.43	0.62	11
15	FSD	Scenario	0.71	0.60	0.20	0.50	16
16	MSE	Scenario	0.52	0.79	0.93	0.76	1
17	ISE	Scenario	0.45	0.87	0.72	0.71	3
18	FSE	Scenario	0.38	1.00	0.42	0.65	8

5.5 SENSITIVITY ANALYSIS

Due to diversity of interests, and since weights and balancing factors are chosen according to individual judgments of relative importance, a sensitivity analysis is found necessary. In this context, different weighting schemes are applied and resulting impacts studied. For each weighting scheme, weights and balancing factors are systematically changed. This is best achieved by providing the DSS program with a subroutine that can take account of investigated changes in weights and balancing factors. The added routine should promptly display sensitivity results to allow for comparison with the preliminary outcome.

The sensitivity analysis is achieved through changing the sensitivity parameters (weighting steps and exponents). As previously explained in section 3.6.4, significant balancing factors are equal to 1, 2 and ∞. Effects of unity balancing factors could be investigated using results of the preliminary run. The sensitivity parameters allows the user to further study the impact of applying other balancing factors (i.e., 2 and ∞). In addition, weights may be changed progressively according to the weight step chosen by the user.

For example, using a weight step of 0.10 for each of the satisfaction indicators (ecological, socioeconomic and managerial), associated with exponent values of 1.0, 2.0 and ∞ respectively, yields 99 weighting schemes. Appendix E contains results of the exemplified sensitivity analysis showing the closeness to the ideal and corresponding ranks of water use scenarios under various weighting schemes. Fig. 5-3 shows a graph illustrating the scenario classification resulting from averaging the outcome of the aforementioned weighting schemes.

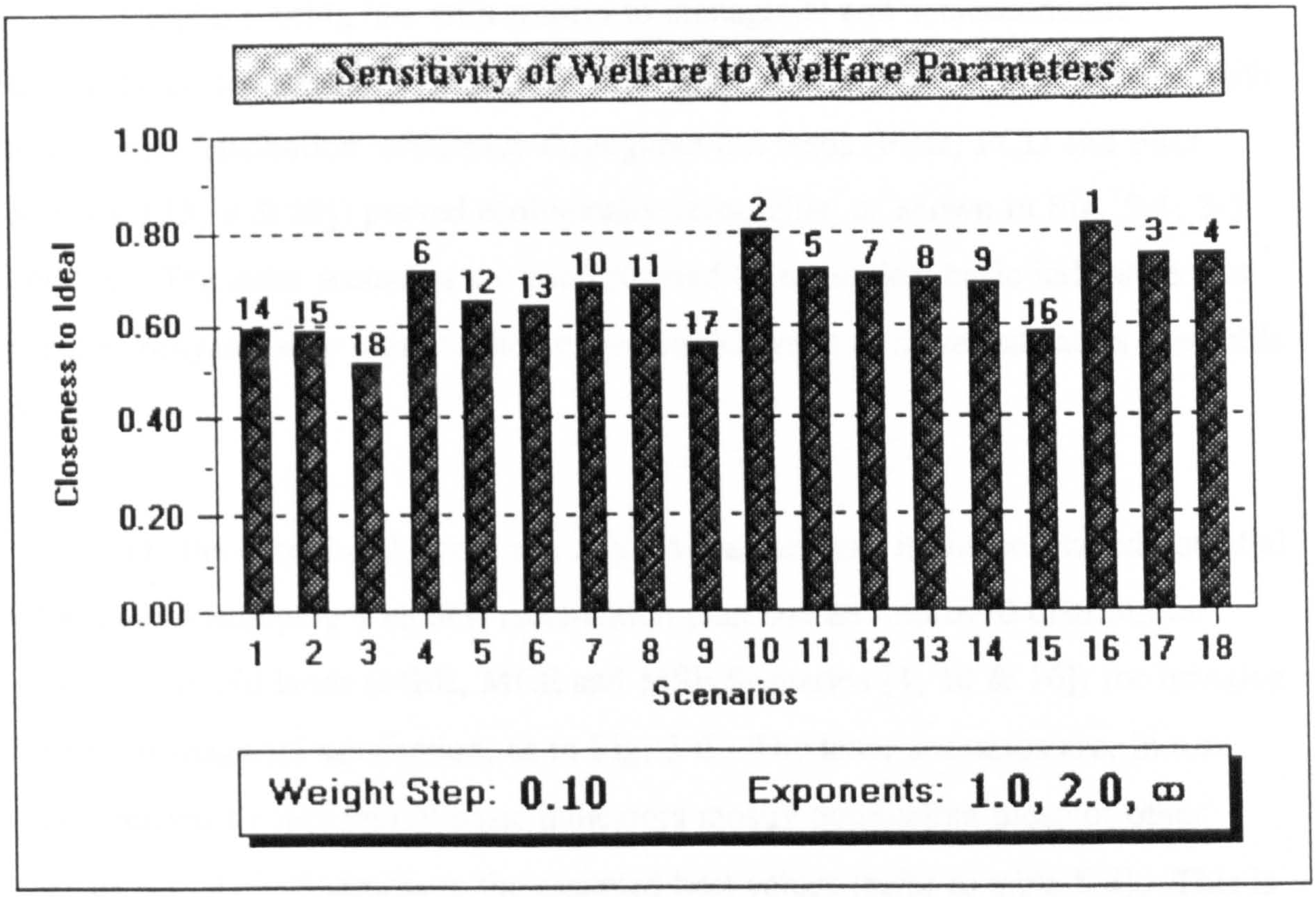

FIGURE 5-3. Scenario Ranks and Closeness to Ideal Resulting from a Sensitivity Analysis Applying a 0.1 Weight Step Associated with Balancing Factors of 1, 2 and ∞ respectively

5.6 CONCLUSIONS

Results of the DSS preliminary run, displayed in section 5.4, demonstrate a prioritisation of MSE Scenario [16] followed by MCE Scenario [10]. These scenarios imply a modest reclamation plan associated with an improvement in the distribution system's efficiency in Old Lands. While in MCE Scenario [10] a six percent increase in cotton patterns replaces equivalent patterns of rice, maize and summer vegetables in the Delta, MSE Scenario [16] eliminates sugar cane production partially in Upper Egypt and totally in Middle Egypt and Fayoum.

A sensitivity analysis is conducted to confirm the above mentioned results. MSE and MCE Scenarios [16 &10] are, again, favoured. The solution is, thus, a robust one.

Despite scoring low with respect to managerial and socioeconomic satisfactions, the scenarios projecting a full horizontal expansion plan coupled with a restricted distribution efficiency throughout old lands (FBD, FCD and FSD Scenarios [3, 9 & 15]) proved ecologically favourable, as shown in Fig. 5-4, 5-5 and 5-6. The latter scenarios are characterised by ecological basic indicators that are generally equal or close to the best values assigned to these indicators (see table 5-4).

On the other hand, there is a noticed preeminence in the envisaged potential of scenarios implying a modest reclamation plan and an improved distribution efficiency in old lands (MBE, MCE and MSE Scenarios [4, 10 & 16]) for bringing about a managerial satisfaction, as in Fig. 5-6. The latter scenarios are, in turn, characterised by managerial basic indicators mostly dominating those of other scenarios in their closeness to the assigned best values (refer to table 5-4). This is the reason why MBE, MCE and MSE Scenarios [4, 10 & 16] score highly with respect to managerial satisfaction.

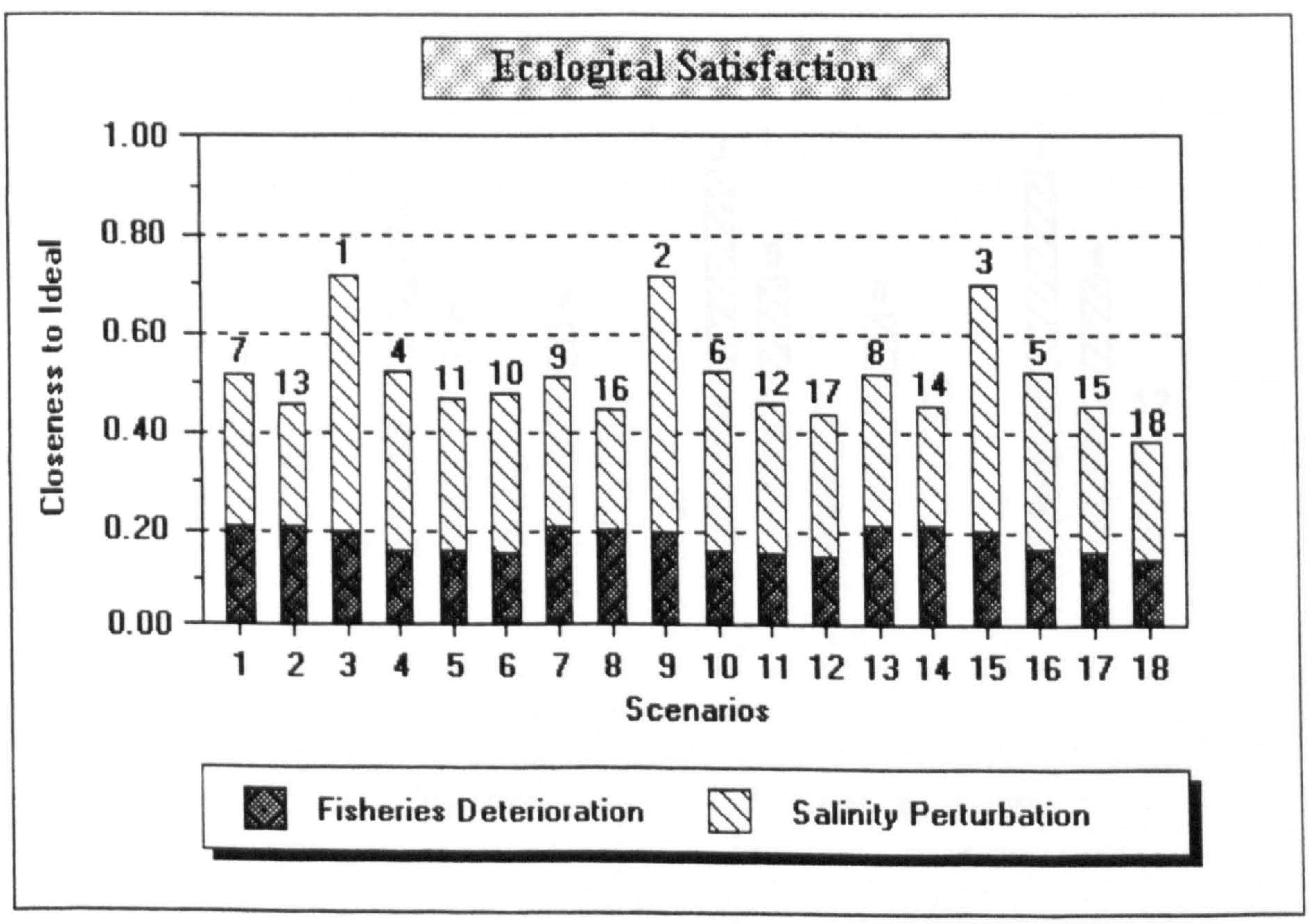

FIGURE 5-4. Closeness of the Tested Scenarios to Ecological Satisfaction

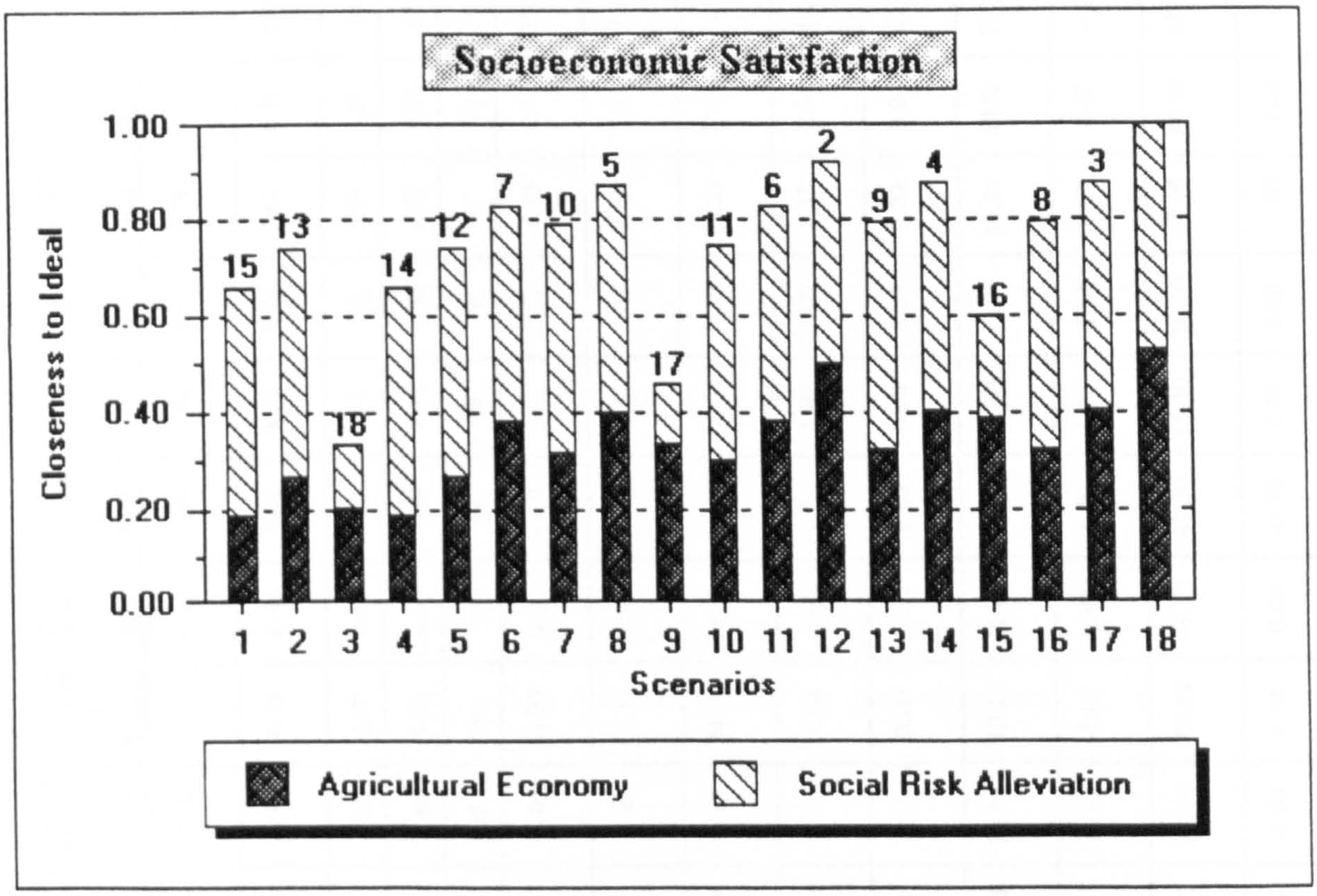

FIGURE 5-5. Closeness of the Tested Scenarios to Socioeconomic Satisfaction

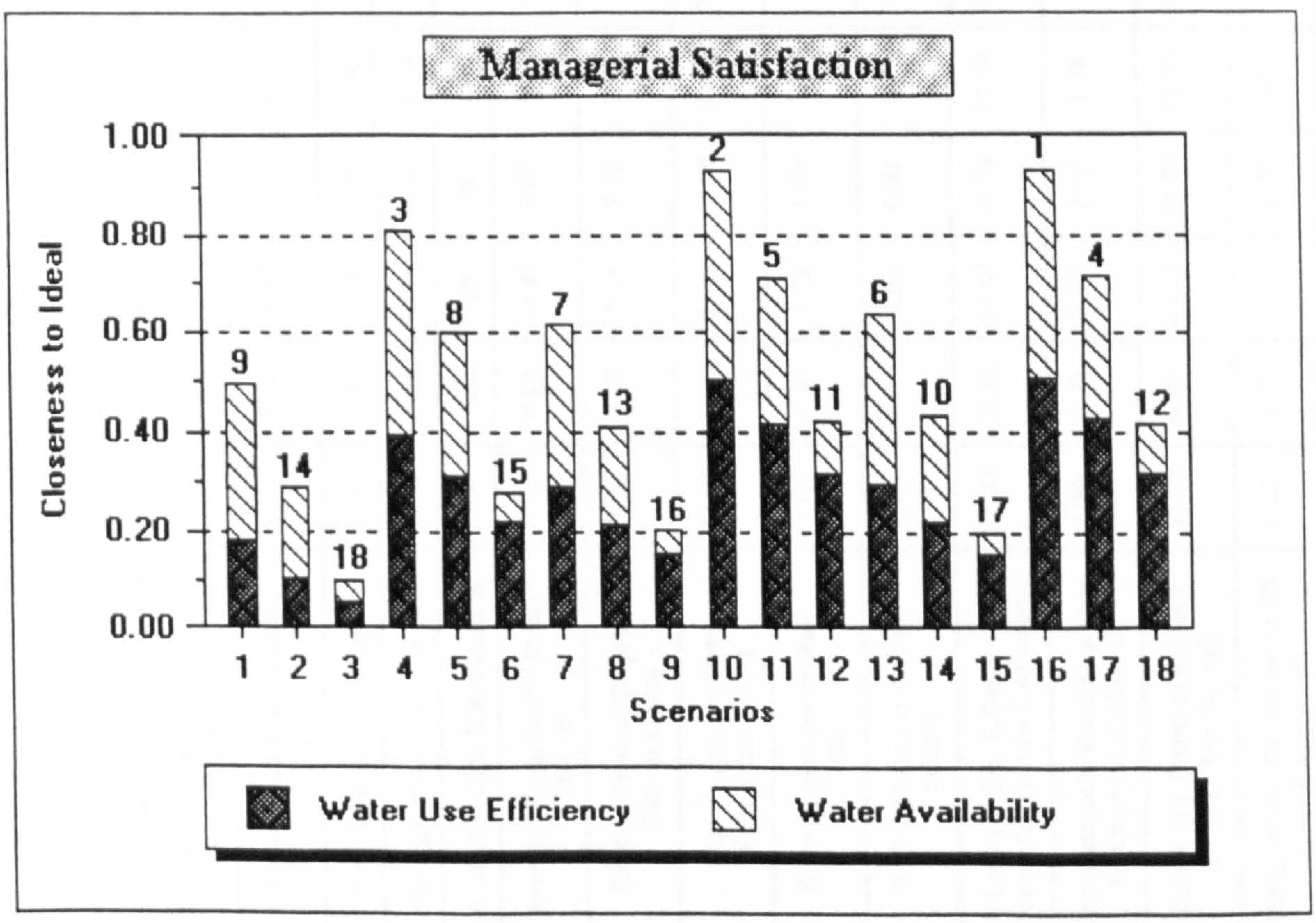

FIGURE 5-6. Closeness of the Tested Scenarios to Managerial Satisfaction

TABLE 5-4. Values of the Basic Indicators Evolved from NBSM Results regarding the Eighteen Tested Scenarios

	Basic Indicators \ Scenarios	1 MBD	2 IBD	3 FBD	4 MBE	5 IBE	6 FBE	7 MCD	8 ICD	9 FCD	10 MCE	11 ICE	12 FCE	13 MSD	14 ISD	15 FSD	16 MSE	17 ISE	18 FSE
ECOLOGICAL	Drainage Outflow to L.Manzala (bn. m^3)	4.08	4.47	*4.77*	3.72	4.11	4.49	4.07	4.46	*4.76*	3.71	4.10	4.49	4.08	4.47	*4.79*	3.72	4.11	4.52
	Flushed Salts to L.Manzala (M. tons)	8.35	8.49	*8.61*	8.32	8.46	8.60	8.35	8.49	*8.61*	8.32	8.46	8.61	8.34	8.48	*8.61*	8.31	8.46	8.63
	River Salinity at HAD (ppm)	164	161	*158*	167	164	160	165	162	*158*	167	164	160	165	162	*159*	168	165	161
	Drainage Water Reuse (bn. m^3)	4.59	4.66	*4.40*	4.59	4.65	4.66	4.59	4.66	*4.40*	4.59	4.66	4.69	4.59	4.66	*4.41*	4.59	4.66	4.73
	% Satisfied Crop Water Demand	98	98	*97*	98	98	98	98	98	*97*	98	98	98	98	98	*97*	98	98	98
	Average Change in GW Storage (bn. m^3)	0.01	0.01	*-0.05*	0.00	0.00	-0.03	0.01	0.01	*-0.05*	0.00	0.00	-0.01	0.01	0.01	*-0.05*	-0.01	-0.01	-0.01
SOCIOECONOMIC	Relative Value of Cropping Patterns (score)	7.17	7.28	7.45	7.17	7.28	7.45	7.34	7.45	7.62	7.34	7.45	7.62	7.35	7.46	7.63	7.35	7.46	7.63
	Relative Value of Yield Efficiencies (score)	74.05	74.05	73.42	74.05	74.05	74.01	74.05	74.05	73.42	74.01	74.01	73.98	74.05	74.05	73.58	74.05	74.05	74.05
	% Crop Stress due to Water Deficit	1.00	1.00	1.71	1.00	1.00	1.06	1.00	1.00	1.71	1.06	1.06	1.12	1.00	1.00	1.53	1.00	1.00	1.00
	% Crop Stress due to Water Salinity	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MANAGERIAL	% Losses to Sea, L.Qarun and by Evaporation (to total HADrelease)	32.62	32.88	33.03	*30.74*	31.04	31.32	32.63	32.88	33.09	*30.75*	31.05	31.35	32.83	33.06	33.33	*30.92*	31.23	31.58
	Econ.Returns to Water Consumed by Crops (M. LE/bn. m^3)	1.80	1.78	1.77	*1.80*	1.78	1.75	1.85	1.83	1.181	*1.85*	1.83	1.80	1.86	1.84	1.83	*1.87*	1.84	1.81
	Storage of L.Nasser at End of a 20-Year Plan (bn. m^3)	62.10	46.60	47.40	*77.50*	61.70	43.40	63.60	48.10	47.70	*78.90*	63.10	43.20	65.50	50.00	47.50	*80.90*	65.10	42.20
	Change in GW Storage over a 20-Year Plan (bn. m^3)	0.20	0.20	-1.00	*0.00*	0.00	-0.60	0.20	0.20	-1.00	*0.00*	0.00	-0.20	0.20	0.20	-1.00	*-0.20*	-0.20	-0.20

It is noticed that substituting large patterns of sugar cane with high value cash crops is prioritised by the DSS. Also, involving cotton intensification within a specific scenario results in promoting the denoted alternative. This is due to the increased economic returns and significant water savings, resulting in improved socioeconomic and managerial satisfaction. Thus, superior ranks are assigned to the scenarios implying sugar cane elimination or cotton intensification.

The final result shows a prioritisation of the plans undertaking a modest horizontal expansion and an improved canal efficiency down to the mesqa level when coupled with a change in cropping patterns to less water consuming yields and/or high value cash crops. This result is based on the amalgamation of ecological, socioeconomic and managerial satisfactions. Assuming that each of the three satisfaction series (shown in table 5-3) follows a normal distribution, the confidence limits for a zero cross correlation test between each satisfaction level and the other can be calculated as;

$$C.L. = \pm \frac{U_{1-\alpha/2}}{\sqrt{N}}$$

where $C.L.$ = confidence limits,

$U_{1-\alpha/2}$ = a standardised normally distributed quantile at significance level α,

and

N = the sample size (18 scenarios).

It is found that $U_{1-\alpha/2}$ equals 1.96 at $\alpha = 0.05$ (from normal distribution tables). This results in ± 0.46 confidence limits. Thus, the cross correlation coefficient between any two levels of satisfaction will be considered significant only if it is larger than 0.46 or less than -0.46, and insignificant otherwise.

Table 5-5 shows the correlation coefficients between different satisfaction levels. A strong negative correlation is noticed between the ecological and socioeconomic satisfactions. That is, the promotion of socioeconomic satisfaction is expected to be at the expense of ecological satisfaction and vice versa. The other correlations between satisfaction levels (ecological-managerial and socioeconomic-managerial) are considered insignificant and their values are thought to stem only from the variability of data.

TABLE 5-5. Correlation Coefficients between Different Satisfaction Levels

Satisfaction	Ecological	Socioeconomic	Managerial
Ecological	1		
Socioeconomic	-0.91245	1	
Managerial	-0.43167	0.397406	1

Results are, however, distorted by fixing crop prices and permanently considering cotton the cash crop of the highest value. In a liberalised environment, prices are subject to endless fluctuations due to market forces. Also, the DSS results are affected by unconstraining releases from Lake Nasser. This is resorted to in order to avoid the option appended to the NBSM to 'manualise' annual releases. The aforementioned option is incorrect because it implies retaining a constant outflow from the lake even if the total demand is less than this constant outflow. The manually set release should represent the upper limit of the outflow rather than a fixed water release from the lake. The other case, implying unconstrained releases, would result in assigning inaccurate values to basic indicators pertaining to scenarios where annual lake outflows exceed 55.5 bn. m^3.

It is well established that the calculated composite distances and ranks of the scenarios previously entered into the DSS are relative to each other. Therefore, results may be influenced by defining best and worst values as the maximum or minimum values of the basic indicators provided by the NBSM (refer to table 4-2). The implication is a variable denominator ($[Z^{*}-Z^{**}]$ or $[Z^{**}-Z^{*}]$) used in the calculation of the normalised value (S) for each indicator (as previously demonstrated by the example shown in table 3-2). In order to avoid this imperfection, it is recommended that best and worst values are fixed on a real-time basis. That is, a survey, based on historical and projected data, should be undertaken to select the best and worst values for all indicators.

In this context, the DSS is provided, within a new version (1.02) of the model, with a supplementary option[9] that allows the user to input the basic indicators' best and worst values manually. Attention should, however, be paid because a random estimation of best and worst values for indicators may result in over or underestimating the basic indicators' closeness to the ideal. Inaccuracies in calculating composite distances may, then, be aggregated all the way to Welfare of Egypt and, eventually, affect the final ranking of the tested scenarios.

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[9] Accessed via the DSS menu sequence Edit|Ranges.

CHAPTER VI

REMODELLING THE NILE BASIN SIMULATION MODEL

6.1 INTRODUCTION

The Nile Basin Simulation Model (NBSM) has been used to provide the Decision Support System (DSS) with indicators for ranking water use scenarios according to their potential for bringing about the welfare of Egypt. Because of the difficulty of acquiring reliable information about projected governmental plans, these scenarios have been based on available data included in the default database of the NBSM, either in their raw or modified form.

However, shortcomings have been noticed regarding the NBSM configuration and its default data. This chapter reveals these weaknesses and endeavours to remodel the original program according to actual conditions and economic needs. Moreover, a study is undertaken, using the remodelled program, to weigh the economic implications of bringing new reclamation projects under surface irrigation against those of the more realistic scenario where the reclamation of New Lands is based on deep groundwater abstractions.

6.2 SUBDIVISIONS OF THE AGRICULTURAL LAND BASE OF EGYPT

The Water Security Project (WSP, 93a) divided newly reclaimed lands into old new and new new lands. This division was based on the history of reclamation. That is, lands reclaimed from no more than ten years were called new new lands while those reclaimed since 1952 were termed old new lands. It is believed, however, that reclaimed lands can reach the ultimate production after about ten years of development (WSP, 93g). Moreover, while irrigation in most new new areas is completely dependent on groundwater, irrigation in the old new reclamation schemes is either totally or mainly with surface water (WSP, 93d). Old new and old (traditionally cultivated) lands may, thus, be grouped into one category called Old Lands confined within the same land use boundaries (i.e., having the same irrigation source).

Because the closed aquifer's boundaries (Geological Maps - Appendix F) almost coincide with the boundaries of using surface water in irrigation (Land Use Maps - Appendix G), Old Lands are assumed to be totally underlain by the Nile aquifer system and irrigated with Nile originated water. That is, Old Lands are considered confined within the boundaries of the Nile aquifer system and totally dependent on Nile originated water. On the other hand, new new lands (termed New Lands) are excluded from being either underlain by the closed aquifer or irrigated with Nile originated water. Irrigation outside the Nile aquifer system is based on pumping groundwater from various aquifer systems (Fig. 6-1) underlying newly developed regions.

6.3 NBSM'S LAND CONFIGURATION AND DEFAULT AREAS

Within the NBSM, the default cropped areas, categorised into Old and New Lands, total about 7.5 million feddans (31,640 km^2), which is equal to the actual area of the agricultural land base of Egypt. Of this area, about 0.4 million feddans (1,770 km^2) are considered, within the model, to be New Lands. It has been noticed, however, that the model considers the whole area (Old and New Lands) located within the Nile aquifer system's boundaries and fully irrigated with Nile originated water. Differences between New and Old Lands are confined to two main aspects:

- the type of soil and the corresponding wilting point and field capacity, and
- the number of potential crops and corresponding yields.

According to the NBSM default configuration, inputs and outputs to the Old and New systems are illustrated by the schematic shown in Fig. 6-2. Subsurface losses from the irrigation system are considered seeping into the groundwater closed aquifer and the drainage system.

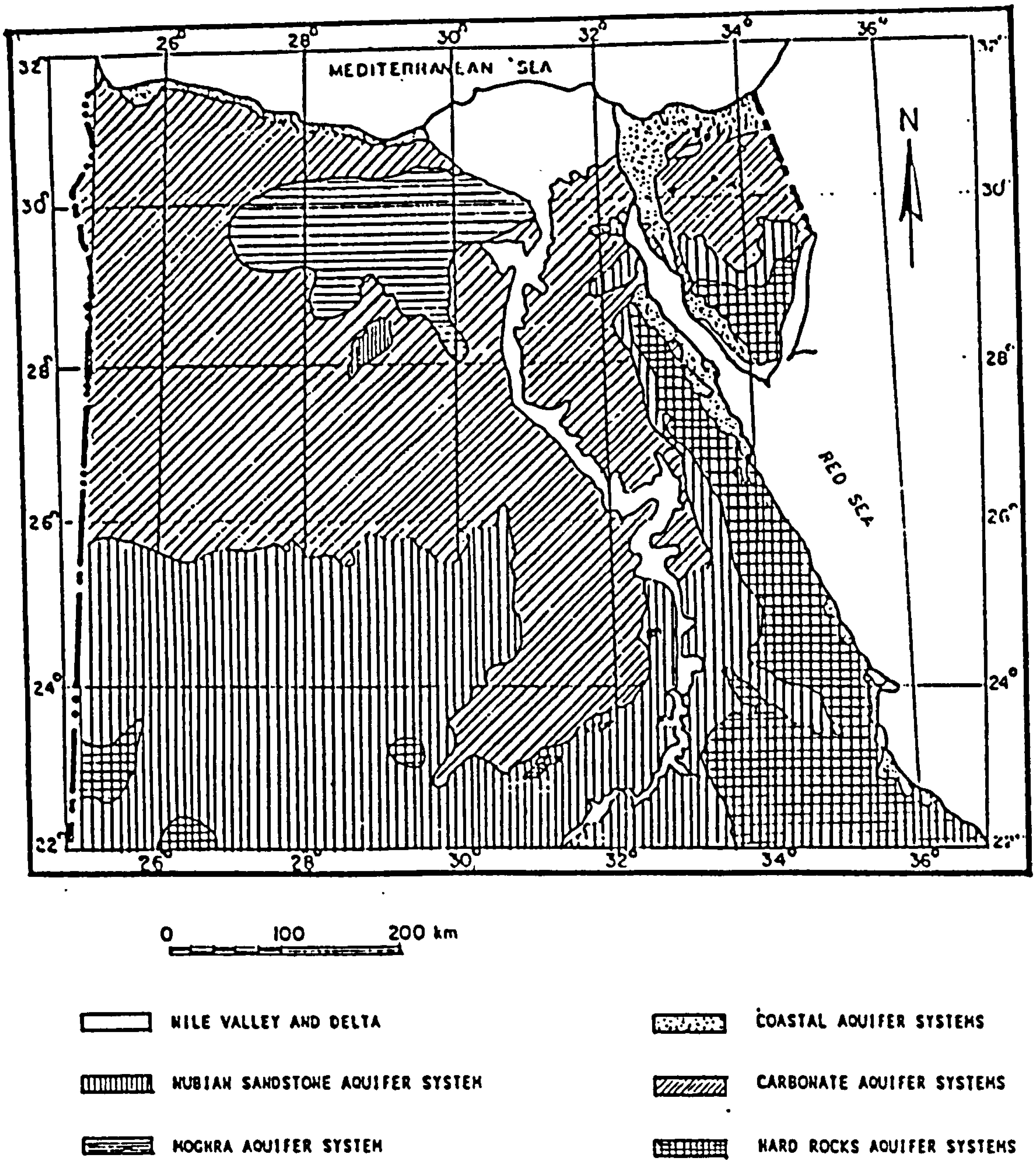

FIGURE 6-1. Geographical Distribution of Aquifer Systems in Egypt
Source: WSP, 93d

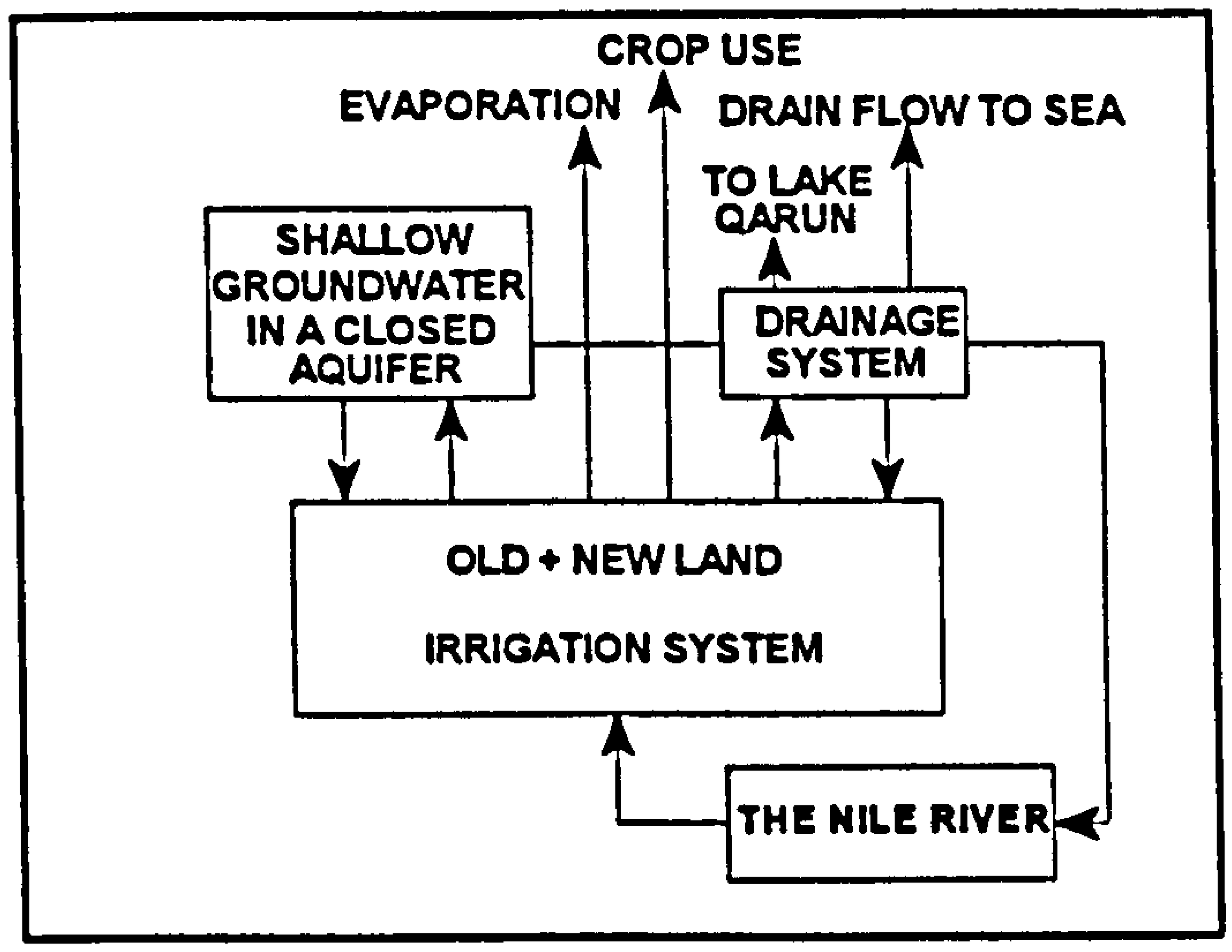

FIGURE 6-2 Schematic of the NBSM Default Configuration regarding Old and New Land Irrigation Systems

6.4 ADJUSTING THE NBSM LAND CONFIGURATION

An attempt is made to adjust the default land configuration by splitting the subregions comprising New Lands from the Old irrigation system embedded in the Nile Basin Simulation Model. This may be carried out either by setting the area of New Lands at zero km^2 or by conducting a set of modifications in the NBSM embedded rules.

Setting the area of New Lands at zero km^2 results in confining the allocation of Nile water only to Old Lands. Despite being a realistic approach, it does not allow the NBSM to simulate the effects of projected horizontal expansion plans unless a separate model that accounts for the New Land irrigation system is coupled to it.

Alternatively, the following courses of action constitute a reasonable approach to simulating the effect of splitting the New Lands from the Old Land irrigation system:

- The flow from New Lands to groundwater and drainage systems is set to nil to simulate the fact that excess irrigation water is lost to the system by deep percolation.

- Drainage reuse is disallowed in the New Lands.
- New Lands are supplied solely with groundwater abstracted from independent aquifers[10].
- The interflow between the Nile and the groundwater aquifers underlying New Lands is disallowed.

Fig. 6-3 displays a schematic of the adjusted configuration regarding Old and New Lands.

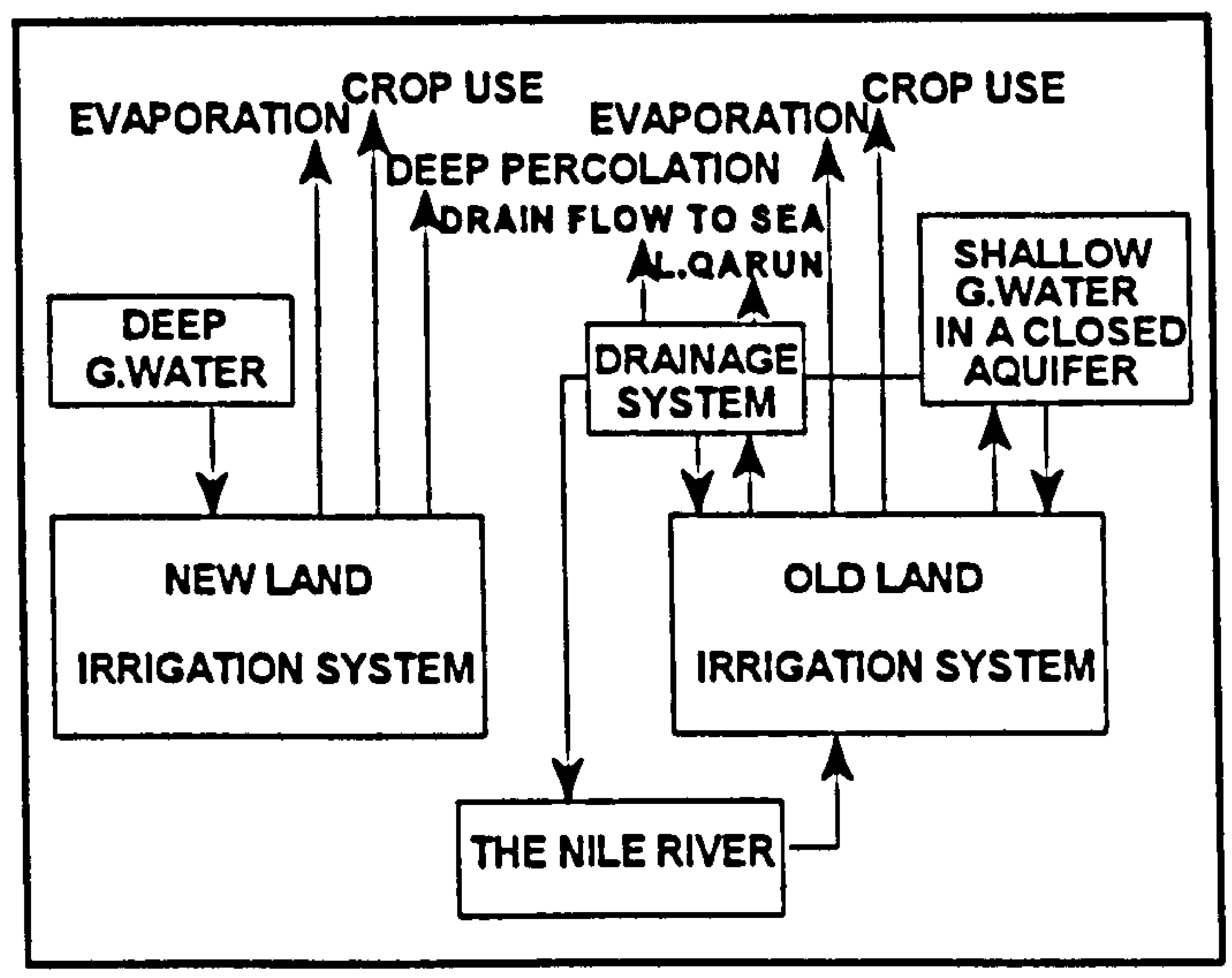

FIGURE 6-3 Schematic of the Adjusted Configuration regarding Old and New Land Irrigation Systems

6.5 PROBLEMS RELATED TO THE GROUNDWATER BASED IRRIGATION IN NEW LANDS

The complete dependence on non-renewable water originating from the same underground source (aquifer) for the reclamation of New Lands may eventually result in:

- A significant drop in groundwater levels, implying more energy consumption for pumping water from greater depths. Such a development is regarded as uneconomic because groundwater is eventually mined.
- A build up in salt concentration, due to the evaporation of a portion of

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[10] Exceptions to this configuration are found in the coastal belt's reclamation projects. These are supplied with Nile water whereas groundwater pumping is strictly banned for fear of sea water intrusion.

pumped water. Salts are left in the soil and leached by subsequent irrigations. Several reclamation projects (e.g., the private reclamation projects near Cairo-Alexandria road) are currently suffering from such problems. Land owners are calling upon urgent Nile water supplies to restore the water table and salinity levels.

Further in this chapter, substituting Nile diversions for deep groundwater abstractions in New Lands is economically weighed against scenarios where irrigation in New Lands is entirely groundwater oriented.

6.6 INCORPORATING AN ECONOMIC COMPONENT INTO THE NBSM

In order to remedy the absence of a NBSM economic content on which to base allocation schemes, the Spatial/Economic Water Allocation Model (S/EWAM) is developed with the aim of optimising the annual economic returns resulting from allocating irrigation water to different subregions in Egypt. The S/EWAM is an adaptation of the NBSM, which contains an extra routine for optimising a function subject to fixed upper and lower bounds of the independent variables. The optimisation procedure is based on changing the values of abstracted groundwater (GW) and reused drainage water (DR) (the independent variables) in each of the eleven Egyptian subregions to achieve maximum returns at minimum costs. In other words, the objective is to maximise the following equation:

$$Revenues = \sum_{subregion = 1}^{11} (Economic\ Returns - Water\ Costs)$$

where:

$$Economic\ Returns = \sum_{Crop = 1}^{18} (Crop\ Production * Crop\ Price)$$

and

$$\begin{aligned} Water\ Costs = \; & Quantity\ of\ Diverted\ Nile\ Water * Nile\ Water\ Costs + \\ & Quantity\ of\ Abstracted\ Groundwater * GW\ Costs + \\ & Quantity\ of\ Reused\ Drainage\ Water * DR\ Costs \end{aligned}$$

The delineation of different aspects influencing the performance of the previous equation is shown below.

6.6.1 Simulated Nile Water Diversions versus GW and DR Abstractions in Old Lands. The regional scope of the model implies a discrepancy between the actual and simulated farming practices. Farmers irrigate old lands generally using surface water diverted from the Nile until it becomes unavailable. Then, they start pumping from the shallow water aquifer and/or from drains. Conversely, the model initially tends to achieve the targeted GW and DR subregional abstractions (based on estimations of the actual GW and DR abstractions). The remaining crop water requirements are subsequently fulfilled with Nile water diversions.

Based on the foregoing explanation, it is expected that the simulated diversions from the Nile would make up for any decrease in GW and/or DR abstractions. However, the increase in Nile diversions may be greater than the saved GW and/or DR because of conveyance losses all along the water's route from the Nile to its ultimate destination. If the course of water is confined within old lands, evaporation will be the sole phenomenon to account for conveyance losses. This is due to the presence of the closed aquifer underlying old lands. Surface water seeping into the aquifer is not considered lost to the system because it will be used as groundwater in an upstream subregion.

Because of the closed aquifer, the GW level in Old Lands is supposed to drop due to substantial abstractions. This is subsequently offset by a replenishment with an equivalent amount of Nile originated waters. On the other hand, the MPWWR is imposing a maximum depth for GW drawdowns in Old Lands (believed to be 3 m). GW target values cannot be achieved if the abstraction hits this critical depth before requirements are fulfilled. That is, more water diversions from the Nile to Old Lands will be desired to compensate for the shortfalls resulting from banning GW abstractions beyond the predefined limit.

Similarly, DR abstractions depend on the availability of drainage water. This, in turn, depends on the sufficiency of other waters to meet crop requirements. Therefore, a need to increase diversions from the Nile may arise to satisfy DR target abstractions.

6.6.2 Costs of Surface Originated Water. For centuries, Egyptian farmers have considered free water to be their inherited right. The introduction of a pricing system to water supply, particularly to the traditionally cultivated old lands, is viewed as a major challenge for the Egyptian Government due to its social and political implications. However, the major reforms, to which the Egyptian economy is being subjected, necessitate a recognition of the water's value to allow water saving techniques to disseminate and to let farm commodity prices move towards international free market levels. The rate to charge for surface water diverted for irrigation purposes might be considered from three viewpoints:

- recurrent operation and maintenance costs of the irrigation and drainage system as well as capital expenditures for replacements (OM&R),
- water opportunity costs resulting from its limited availability (the economic price), and
- investments in the existing irrigation and drainage infrastructure (considered sunk costs).

First, attempts were made to determine the OM&R costs needed for providing adequate irrigation and drainage services. One approach was to calculate system-wide OM&R costs for all water use sectors and allocate the costs among the various sectors to isolate the specific portion due to the irrigation sector (ISPAN, 93). A value of LE 0.03 /m^3 was selected as an approximate figure of OM&R averaged over the different approaches to calculate the system costs (WSP, 93f). The selected value of OM&R costs is viewed as the price of Nile water diversions that ought to be imposed on farmers to recuperate the actual expenditures of the MPWWR.

Second, the opportunity costs of water are the expected returns from water in its best alternative use. Considering the alternative use of irrigation water within other economical activities has repeatedly been rejected by the Egyptian Government's policy makers. Therefore, the principle of opportunity costs is applied only on water in excess of the requirements of traditionally cultivated old lands. The Water Security Project (WSP, 93f) estimated the opportunity costs of water at LE 0.07 /m^3. The water delivery to newly reclaimed lands is, thus, totally priced at LE 0.10 /m^3.

6.6.3 Costs of Underground Originated Water. Reclamation projects outside the Nile aquifer system are mainly irrigated with underground water, which requires the use of mechanical pumps powered by motors to pump water from wells. Because New Lands are generally remote from developed areas in the Nile Valley and Delta, the continuity of fuel and electricity supply is not guaranteed. Therefore, one renewable energy source only is considered, specifically: solar generators. The Groundwater Resource Evaluation of East Owienat Area (Salem, 92) defined an irrigation system powered by solar energy and generalised its application to reclamation projects outside the Nile Basin. Calculating the system cost for an assumed twenty-year lifetime is carried out in terms of water discharges and pumping heads as shown in Fig. 6-4 and 6-5. The ratio "cost (averaged over twenty years)/discharge" for each unit system may be plotted against the total costs (averaged over twenty years) of supplying each subregion with water pumped at different heads (Fig. 6-6). Total costs are acquired by multiplying the subregional water supply, calculated by the S/EWAM on an annual basis, by the aforementioned ratio. In Fig. 6-7, the same ratio is plotted against the discharge of each unit system.

Fig. 6-6 and 6-7 are developed to determine the unit system discharge that corresponds to the total costs of water supplies to each subregion. The process may be used in computing the pumping head at which diverting Nile water would be less expensive than further GW pumping. Accordingly, it is found, using the curves displayed in Fig. 6-4, 6-6 and 6-7, that pumping GW at an average static head of 40 m is almost economically equivalent to diverting Nile water to New Lands.

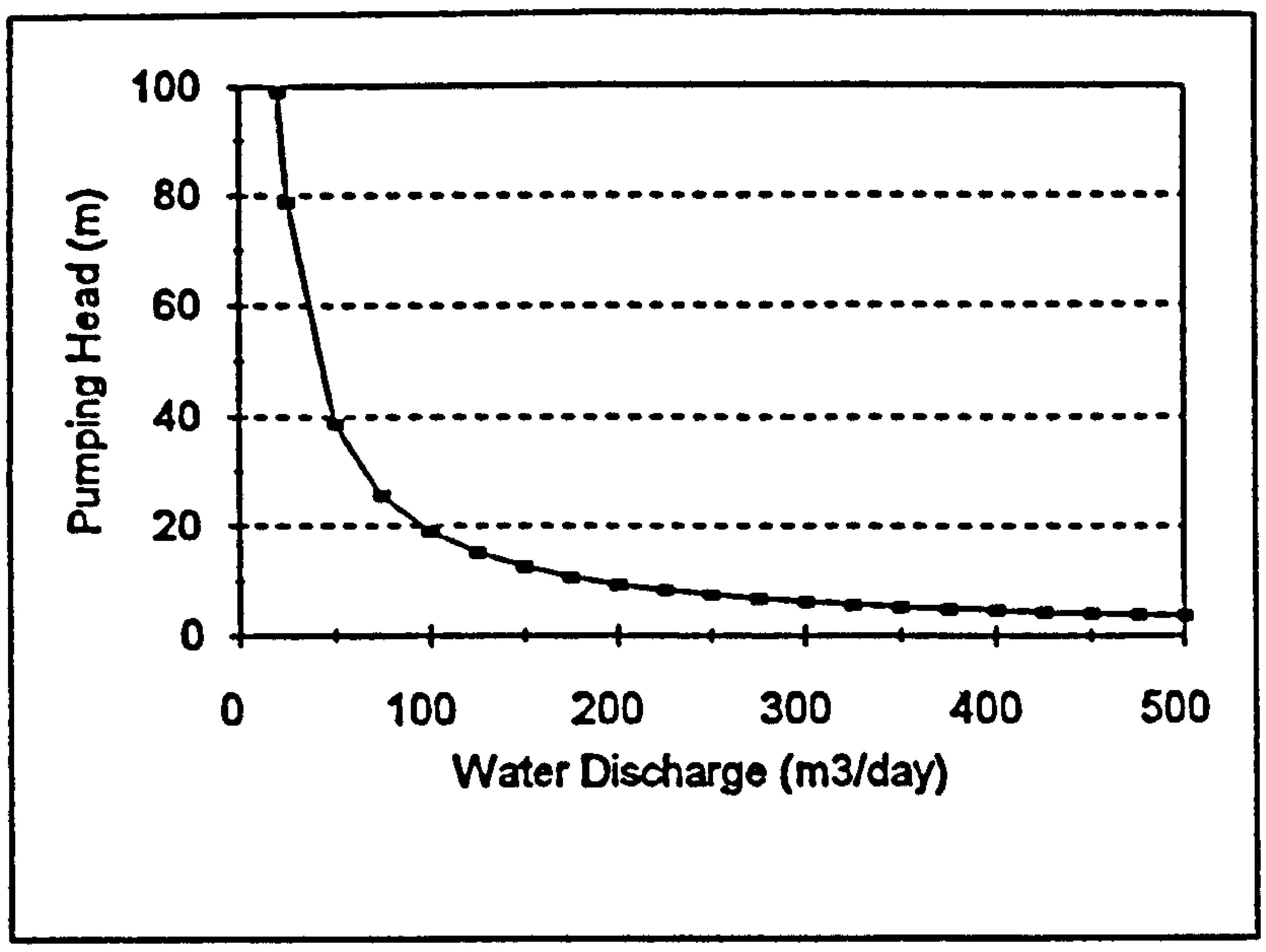

FIGURE 6-4. Water Discharge vs Pumping Head
Source: Salem, 92

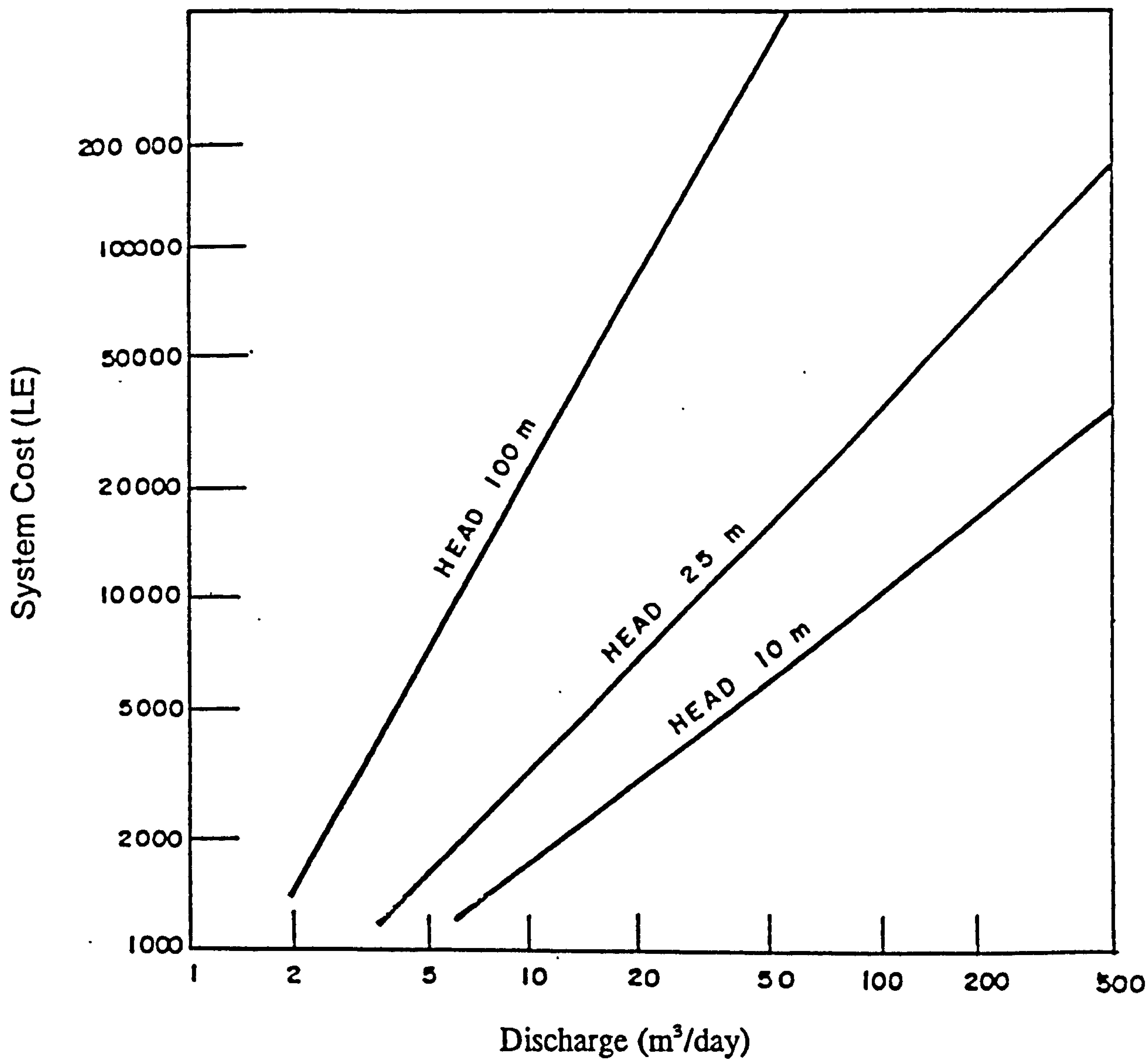

FIGURE 6-5. Cost of Solar Irrigation System as a Function of Water Head and Discharge
Source: Salem, 92

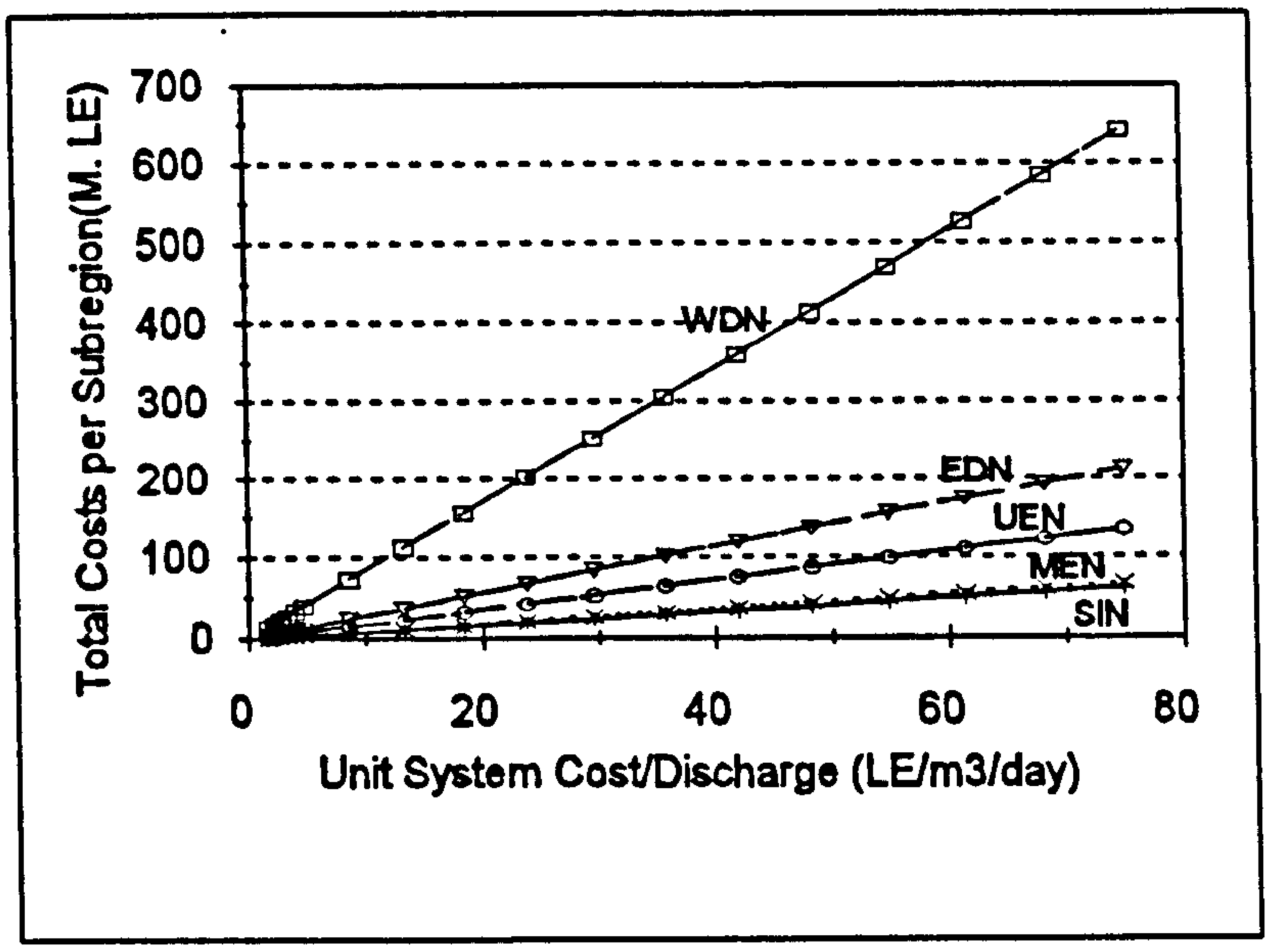

FIGURE 6-6. Unit System Cost/Discharge vs Total Costs for each Subregion
(All Costs are averaged over a twenty-year lifetime)

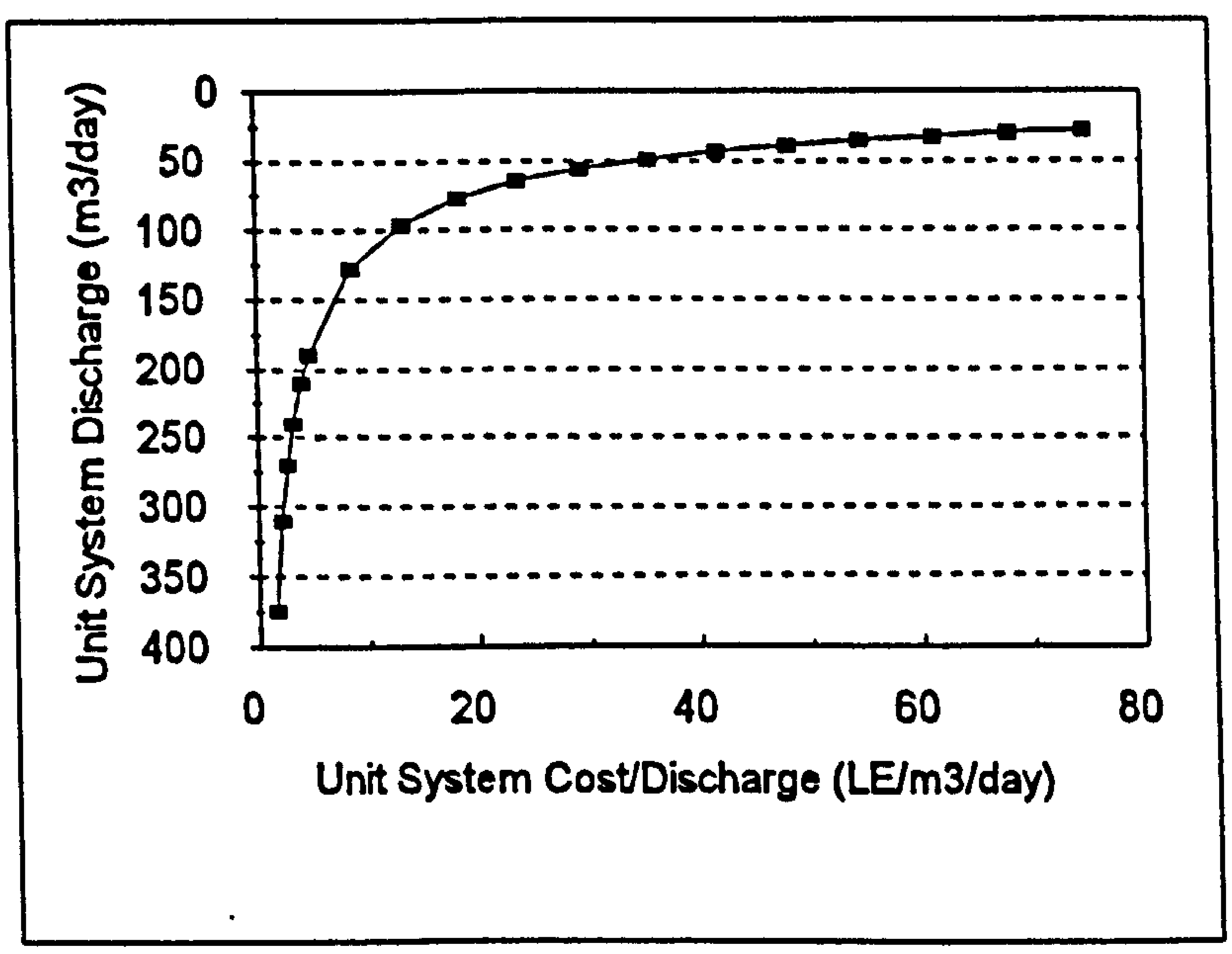

FIGURE 6-7. Unit System Cost/Discharge vs Unit System Discharge
(All costs are averaged over a twenty-year lifetime)

6.6.4 Economic Returns. In the S/EWAM, as in the NBSM, shortfalls in crop yields are due to water deficits and salinity stresses. Results of the NBSM default run reveal the predominance of crop stresses due to water deficits over those due to salinity hazards. The foregoing discussion has also shown that diversions from the Nile can make up for decreasing GW and/or DR abstractions. In order to reach an optimum economic return with yields close to potential, the optimisation model ensures a low-cost water allocation strategy resulting in a maximum production of economically profitable crops, such as cotton, rice and wheat. These are generally found in old subregions. If requirements of more profitable crops are already fulfilled (i.e., the actual production equals the potential one), the model tends to improve the production of less profitable crops. Cutbacks in water supply from the Nile (if any) are meant to be confined to subregions where crops of low profitability and/or high tolerance to water shortage prevail. Also, the optimisation of water allocation within the S/EWAM takes into account the need not to perturb the acceptable rates of water salinity, thus avoiding salinity stresses in crop productions.

6.7 S/EWAM RUNS FOR 1990/91

The S/EWAM is used to appraise the implications of bringing New Lands, originally irrigated with groundwater, under surface irrigation. In this context, three model runs for the year 1990/91 are considered. Two runs consider New Lands entirely irrigated with water of a non-riverine origin, assuming average static pumping heads of 60 and 20 m. The third run assumes that New Lands are brought under irrigation with surface water diverted from the Nile. Results of these runs are displayed in tables 6-1, 6-2 and 6-3. A list of the S/EWAM main program is found in appendix H.

TABLE 6-1. S/EWAM's Results of Simulating and Optimising a Scenario where Irrigation in New Lands is Dependent on Pumping Groundwater at an Average Static Head of 60 m

Reg	GW (bn. m³)		DR (bn. m³)		Nile Diversions (bn. m³)		Water Costs (LE)		Revenues*** (LE)	
	Sim*	Opt**	Sim	Opt	Sim	Opt	Sim	Opt	Sim	Opt
WDN	3.133915	2.180566					526,948,894	366,649,017	-411,275,935	-250,976,058
WDO	0.300000	0.604000	1.166081	1.200000	6.803485	6.396699	248,086,955	246,020,955	2,274,344,807	2,276,410,807
MDO	0.300000	0.604000	1.200000	1.200000	10.339934	9.956727	355,198,003	352,821,815	2,550,811,879	2,556,075,608
EDO	0.296947	0.604000	1.200000	1.200000	9.941025	9.553524	343,139,173	340,725,726	2,758,872,896	2,764,449,224
EDN	1.042975	0.476395					175,369,993	80,102,897	-135,329,352	-40,160,219
SIN	0.298471	0.298471					50,186,082	50,186,082	-39,063,682	-39,063,682
FAY	0.000000	0.024495	0.120000	0.119885	4.555301	4.491746	140,259,014	139,083,760	343,365,292	344,486,930
MEO	0.321849	0.450000	0.000000	0.004598	9.544318	9.366447	295,984,995	294,631,345	1,142,001,736	1,143,416,152
MEN	0.330806	0.169778					55,622,972	28,547,197	-45,302,972	-18,227,197
UEO	0.396000	0.450000	0.000000	0.00362	14.569326	14.493883	448,959,766	448,425,086	1,367,202,875	1,367,739,032
UEN	0.659632	0.498365					109,130,501	83,797,135	-91,586,501	-66,253,135
Tot			3.686081	3.794076	55.753388	54.259027	2,750,668,897	2,430,991,015	9,712,258,495	10,037,897,458
Release from Lake Nasser (bn. m³) =					50.872873	49.893285				

* Sim = Simulated

** Opt = Optimised

*** Revenues = Economic Returns - Water Costs

TABLE 6-2. S/EWAM's Results of Simulating and Optimising a Scenario where Irrigation in New Lands is Dependent on Pumping Groundwater at an Average Static Head of 20 m

Reg	GW (bn. m^3)		DR (bn. m^3)		Nile Diversions (bn. m^3)		Water Costs (LE)		Revenues*** (LE)	
	Sim*	Opt**	Sim	Opt	Sim	Opt	Sim	Opt	Sim	Opt
WDN	3.133915	2.180987					113,319,033	78,862,147	2,353,926	36,810,812
WDO	0.300000	0.322536	1.166081	1.195893	6.803485	6.739446	248,086,955	247,736,259	2,274,344,807	2,274,695,503
MDO	0.300000	0.370588	1.200000	1.200000	10.339934	10.250961	355,198,003	354,646,450	2,550,811,879	2,552,026,324
EDO	0.296947	0.371535	1.200000	1.200000	9.941025	9.846895	343,139,173	342,552,907	2,758,872,896	2,760,227,173
EDN	1.042975	0.494817					37,712,876	17,892,055	2,327,765	18,719,785
SIN	0.298471	0.298471					10,792,391	10,792,391	330,009	330,009
FAY	0.000000	0.002037	0.120000	0.119885	4.555301	4.550297	140,259,014	140,166,590	343,365,292	343,453,218
MEO	0.321849	0.368063	0.000000	0.000543	9.544318	9.481964	295,984,995	295,517,106	1,142,001,736	1,142,491,025
MEN	0.330806	0.169781					11,961,580	6,139,117	-1,641,580	3,684,136
UEO	0.396000	0.435322	0.000000	0.000112	14.569326	14.517751	448,959,766	448,595,552	1,367,202,875	1,367,568,100
UEN	0.659632	0.498365					23,851,572	18,020,363	-6,307,572	-476,363
Tot			3.686081	3.727532	55.753388	55.387315	2,029,265,358	1,960,920,937	10,433,662,034	10,499,529,722
Release from Lake Nasser (bn. m^3) =					50.872873	50.884755				

* Sim = Simulated

** Opt = Optimised

*** Revenues = Economic Returns - Water Costs

TABLE 6-3. S/EWAM's Results of Simulating and Optimising a Scenario where New Lands are Brought under Irrigation with Surface Water

Reg	GW (bn. m^3)		DR (bn. m^3)		Nile Diversions (bn. m^3)		Water Costs (LE)		Revenues*** (LE)	
	Sim*	Opt**	Sim	Opt	Sim	Opt	Sim	Opt	Sim	Opt
WDN					3.133915	2.180993	313,391,555	218,099,305	-197,718,596	-102,426,346
WDO	0.300000	0.331944	1.166081	1.200000	6.803485	6.723133	248,086,955	247,652,306	2,274,344,807	2,274,779,456
MDO	0.300000	0.398399	1.200000	1.200000	10.339934	10.215906	355,198,003	354,429,137	2,550,811,879	2,552,504,861
EDO	0.296947	0.400866	1.200000	1.200000	9.941025	9.809880	343,139,173	342,322,371	2,758,872,896	2,760,759,766
EDN					1.042975	0.511290	104,297,543	51,129,008	-64,256,902	-13,889,199
SIN					0.298471	0.298471	29,847,096	29,847,096	-18,724,696	-18,724,696
FAY	0.000000	0.002853	0.120000	0.120000	4.555301	4.547862	140,259,014	140,121,452	343,365,292	343,496,613
MEO	0.321849	0.384360	0.000000	0.000642	9.544318	9.459960	295,984,995	295,348,827	1,142,001,736	1,142,666,809
MEN					0.330806	0.169780	33,080,570	16,978,044	-22,760,570	-7,140,787
UEO	0.396000	0.450000	0.000000	0.000217	14.569326	14.498417	448,959,766	448,459,018	1,367,202,875	1,367,705,012
UEN					0.659632	0.501129	65,963,158	50,112,887	-48,419,158	-32,568,887
Tot	1.630796	2.089758	3.686081	3.725747	61.219187	58.916821	2,378,207,827	2,194,499,449	10,084,719,565	10,267,162,605
Release from Lake Nasser (bn. m^3) =					56.338672	54.426797				

* Sim = Simulated

** Opt = Optimised

*** Revenues = Economic Returns - Water Costs

6.8 SUMMARY AND CONCLUSIONS

An endeavour is made to remodel the NBSM to avoid its major weaknesses that lie in:

- treating Old and New Lands as one unit brought under irrigation with Nile water and underlain by the same closed groundwater aquifer, and
- the absence of an economic content on which to base the allocation of water.

In this context, New Lands are split from the closed irrigation system by undertaking the following modifications to the New Lands simulated within the NBSM:

- setting their flow to groundwater and drains to nil,
- disallowing their reuse of drainage water,
- supplying them solely with groundwater abstracted from independent aquifers, and
- disallowing the interflow between the Nile and the groundwater aquifers underlying New Lands.

Also, a routine that optimises the spatial allocation of water is coupled with the modified model.

Since the optimisation process is directed by the economic returns and costs of water, it is found necessary to determine a price for water in its various allocations despite being provided to farmers free of charge. Within the current study, the OM&R cost of the existing irrigation system is approximately estimated at LE 0.03 /m^3 of water. An extra opportunity cost of LE 0.07 /m^3 is imposed on water delivery to New Lands. Water pumped from New Lands' local aquifers is priced according to the head and rate of pumping. However, the determination of pumping costs with respect to heads and discharges is based on a static assumption where the time factor is not considered. That is, this research takes no account of either the lowering of the water table with respect to time or the increase in the cost of energy required for pumping water at dropping levels.

Cost estimates being included in the remodelled program (S/EWAM), the latter is used to analyse the implications of diverting Nile water to irrigate New Lands. These diversions are actually proposed to remedy the problems resulting from the frequent use of non-renewable and deep groundwater in the reclamation of New Lands. It is found that diverting Nile water to irrigate New Lands would be more expensive than abstracting groundwater from local aquifers only if pumping groundwater takes place at an average static head of 40 m or less.

Referring to the simulated results displayed in tables 6-1, 6-2 and 6-3, it is noticed that providing New Lands with irrigation water, either diverted from the Nile or abstracted from groundwater aquifers at pumping depths exceeding 20 m, would mostly result in negative revenues (economic returns less water costs). It is, also, noticed that the cost of pumping groundwater at 60 m depth is 68.14 percent more expensive than that of diverting Nile water to irrigate New Lands. That is, the cost of pumping water increases by an average of 3.4 percent per one meter increase in head for an average groundwater depth between 40 and 60 m. However, substituting groundwater extraction at 60 m depth for Nile water diversion to New Lands would bring about some five bn. m^3 savings in the quantity of water released from Lake Nasser. Conserving water would, thus, be at an expense of about[11] LE 0.07 /m^3. This value is expected to increase with pumping water from greater depths. It is to be noted, however, that the release from Lake Nasser is not allowed to exceed 55.5 bn. m^3 due to political obligations. This constraint is ignored within the S/EWAM because the 'set releases' control contained in the NBSM fixes the release at the predefined limit even if the demand for water is less than 55.5 bn. m^3.

Due to the relatively high value of water diverted to New Lands and the considerable increase in water costs with respect to deepening pumping heads, it is

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$$\frac{2,750,668,897 - 2,378,207,827}{(56.338672 - 50.872873) * 10^9}$$

expected that optimising water allocation to New Lands would result in a substantial improvement in revenues. This anticipation conforms with the results displayed in tables 6-1, 6-2 and 6-3. It is shown that the quantities of water pumped and diverted to most New Lands are significantly curtailed to achieve larger revenues. The changes in revenues and water quantities are less tangible in Old Lands where water abstractions are priced at relatively lower rates.

The objective of optimising the allocation of water is to yield maximum revenues. Total revenues of the three studied cases (pumping groundwater at 60 and 20 m and diverting Nile water to New Lands) are simulated at some ten bn. LE. As a result of the optimisation process, the simulated revenues increase by 3.35, 0.63 and 1.81 percent respectively for the aforementioned cases. The results of the optimisation exercise imply that pumping groundwater at 60 m would, if substituted for diverting Nile water to New Lands, save releases from Lake Nasser at[12] LE 0.05 /m^3, which is LE 0.02 /m^3 less expensive than the 'without optimisation' case.

In view of the above and referring to the conventional efforts currently made at the MPWWR to conserve water released at HAD[13] for satisfying the requirements of the horizontal expansion plans proposed by the MALR, it is concluded that the optimisation of water allocation on a subregional level would constitute a promising discipline for conserving releases subject to a recognition of the true value of water and the real capacity of groundwater aquifers. The current optimisation exercise also shows the importance of selecting land to be reclaimed. Because the

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$$\frac{2,430,991,015 - 2,194,499,449}{(54.426797 - 49.893285) * 10^9}$$

13 including: reducing the area of sugar and rice, shortening the canal closure period and efficiently using the M&I wastewater and agricultural drainage water.

exploitation of the Nile water resource is approaching the total amount that is available to Egypt (55.5 bn. m^3), a decision should be made to give priority to allocating water to those lands with the highest potential economic revenue. Due to the high fertility of Old Lands, a wide selection of crops (including economically profitable crops) may be cultivated. Also, the cost of diverting Nile water to New Lands is estimated at a higher rate than that of exploiting it within Old Lands' boundaries. No Nile water should, thus, be diverted from Old Lands to meet the needs of less mature lands in the new subregions. Alternatively, deep groundwater may be useful in the case of reclamation projects outside the Nile Valley and Delta. The non-renewable nature of this water should, however, be taken into account when considering the sustainability of such projects. It is, also, recommended to divert quantities saved from the M&I wastewater and agricultural drainage water to the New Lands to avoid any contamination or salinisation of the Nile aquifer system. Including these environmental effects in the optimisation process should be investigated in further studies.

CHAPTER VII

GENERAL DISCUSSIONS ABOUT THE STUDY RESULTS AND CONCLUSIONS

7.1 INTRODUCTION

The purpose of the current study is to establish a systematised decision process aimed at helping MPWWR policy makers become more decisive about controversial water use disciplines. To achieve this objective, a number of tasks were carried out, including: i) develop a prototype decision support framework for pointing out the water policy that is likely to realise the welfare of Egypt and, ii) demonstrate the capabilities of the auxiliary tool that feeds the decision system, reveal its weaknesses, and probe its potential for allowing planners to grope towards optimum diversion patterns.

The development of the decision support system (DSS) necessitated structuring alternative scenarios to be tested within a comparative environment. In this context, water use scenarios were structured in order to allow controversial issues to contest on bringing about the welfare of Egypt. The resulting closeness to the ideal showed a prioritisation of the scenarios implying a modest plan of horizontal expansion, a change in cropping patterns to less water consuming and higher profitability crops, and an improvement in the distribution efficiency of the old irrigation system.

The DSS results are controlled by the physical impacts evolving from the application of different water use disciplines within the NBSM. It was, therefore, conceived that remodelling the NBSM's original program in order to increase its usefulness as a sensible planning tool would constitute a worthwhile exercise. This endeavour was concluded by a call to halt the diversion of Nile water from the alluvial land to meet the needs of less mature plots overlying non-renewable aquifers in the new subregions.

7.2 IMPLICATIONS OF THE DSS RESULTS

The results shown by the DSS imply that, even if it is managed to secure an annual release that exceeds the 55.5 bn. m^3 limit, a smart twenty-year strategy for allocating Nile water should consider the notions delineated below.

7.2.1 Halting Strategies Implying Desert Land Reclamation Using Nile Water. Despite the foreseen difficulties in water resource development, most MPWWR decision makers consider the go-ahead with an ambitious national policy for horizontal expansion unavoidable. Such a strategy is considered vital for overcoming the food gap problem, counterbalancing the urban encroachment on the productive agricultural land, and, thus, bringing about the country's welfare. However, the MPWWR officials' viewpoint on horizontal expansion conflicts with the DSS results. The latter show that the welfare of Egypt may be realised by applying a limited plan of horizontal expansion rather than a sizeable one. The reason for this discrepancy is that the DSS is designed to favour the increase in yields and returns of agricultural lands brought about under minimum water abstractions. Applying a vertical expansion policy and creating urban communities outside the Nile Valley and Delta may be a worthwhile alternative to the reclamation of desert land, which would ultimately be at the expense of water supply to Old Lands.

7.2.2 Changing Cropping Patterns to Less Water Consuming and Higher Profitability Crops. The DSS results indicate that switching to smaller patterns of sugar cane and rice would yield more valuable water use alternatives. However, a real-time application of these results is deemed problematic. Reducing the area of sugar cane because of its high water consumption is encountered by a probable shutdown of sugar factories spread over Upper and Middle Egypt. The decision of eliminating sugar cane patterns will, therefore, necessitate a political thrust. On the other hand, the extensive irrigation of rice patterns in Northern Delta plays an important role in safeguarding the fresh water aquifer against sea water intrusion. Therefore, plans for reducing rice patterns should take into account the technical considerations that underlie the choice to grow rice in the lower Delta regions.

Also, specifying high value cash crops to prevail over a twenty-year period is impractical. Crop profitabilities are determined according to market forces that control prices through the level of demand. Fixing crop prices for a long term planning is, therefore, inaccurate. Shifting cropping pattern plans to high value cash crops is valid on a tactical level where crop prices may be more precisely predicted.

7.2.3 Improving the Efficiency of the Distribution System in Old Lands. Despite doubts about the need and benefits of reducing retrievable losses seeping into the closed aquifer underlying old lands, the DSS results show that scenarios implying an improvement of the old system's distribution efficiency score highly compared to other alternatives. This is due to water savings caused by: i) lessened wet surfaces along channel courses, resulting in reduced evaporation rates and, ii) decreased losses directly flowing to the terminal lakes in Northern Delta. The increase in Lake Nasser storage resulting from the aforementioned savings is expected to safeguard the agricultural system against hazardous crop stresses due to water supply deficits. Investments needed for undertaking the system improvement are not, however, accounted for in the DSS. These are expected to determine, to a great extent, the feasibility of such a project.

7.3 PERFORMANCE OF THE MODULES USED IN DSS DEVELOPMENT

The DSS structure is based on two main modules:

- the Nile Basin Simulation Model (NBSM), and
- the tradeoff hierarchy.

7.3.1 The Nile Basin Simulation Model. The NBSM, being a powerful simulation planning tool, constitutes an important module in the DSS framework.

Its role is to provide the decision support process with data about the physical impacts brought about by different water use disciplines symbolising, inter alia, the inclusion of desert lands in the agricultural land base of Egypt. It is, therefore, worthwhile widening the outlook of the model to include desert lands outside the Nile Valley and Delta as a detached unit from the old agricultural sector confined within the boundaries of the Nile basin. Incorporating an optimisation routine into the NBSM is also deemed necessary for allowing planners to value one course of action against another. This necessitates a cost estimation of water actually delivered to farmers free of charge.

An endeavour was conducted to remodel the NBSM so that it can take account of the aforementioned hints. Estimating Nile water prices was based on OM&R costs of the irrigation system with an extra opportunity cost imposed on water diverted to new lands. On the other hand, deep groundwater was priced according to the head and rate of pumping. The conclusions attained by the remodelled program implied confining Nile water diversions to agricultural projects that require minimum diversion costs and result in maximum economic returns. In this context, it was recommended to halt the Nile water based horizontal expansion. Deep groundwater abstractions may, alternatively, be used. However, groundwater based reclamation projects are constrained by the non-renewability of this water source. An additional supply from M&I wastewater and agricultural drains may help with sustaining reclamation projects outside the Nile Valley and Delta.

7.3.2 The Tradeoff Hierarchy. The use of the tradeoff analysis is advantageous because it allows a wide spectrum of disciplines to be studied compared to the more traditional approach of primarily studying economic impacts. However, the actual structure of the tradeoff hierarchy may be questioned because the selection of the hierarchy's indicators and their amalgamation is based on an individual perspective. Nevertheless, various viewpoints on the relative importance of indicators are included via a questionnaire form circulated among officials and researchers of the MPWWR and Cairo University. In the same context, the reliability of results is supported by a sensitivity analysis conducted using weighting schemes that are systematically changed.

The developed DSS software allows planners to procure comparable sets of results in a user friendly environment. Within the current study, an analysis of the outcomes of eighteen water use disciplines covering major controversial issues was carried out on ecological, socioeconomic and managerial bases. The negative correlation revealed between ecological and socioeconomic satisfactions seemed in harmony with the trend of criticising irrigation projects for development on ecological bases (e.g., the increasing environmental concern about Jonglei Canal Project).

Due to the liberal reforms the agricultural sector is brought under, it is expected that an integration of socioeconomic and managerial satisfactions will take place shortly. This is because the Water User Associations (WUA), being established, are expected to bridge the gap between the farmers and authorities' perceptions of irrigation issues. For instance, the first application of a totally liberalised cropping season, during 1994/95, resulted in a considerable increase in rice patterns. Despite its high water consumption, rice attracted farmers by its high economic profitability. The absence of a WUA's role obliged the MPWWR to enforce fines on unauthorised patterns of rice. This might, alternatively, be substituted with a pricing system imposed on different rates of water consumption.

7.4 OPPORTUNITIES FOR FURTHER IMPROVING THE PRESENT WORK

The undertaken study endeavoured to develop a prototype decision routine for selecting the water strategy that is suitable for Egyptian conditions. Suggestions are herein introduced to improve the reliability of the developed process as a real-time tool for supporting decisions on water allocation strategies. These recommendations are envisaged to promote the likelihood of achieving an optimum water use programme.

- Work out a definite value of the irrigation service fee in Egypt. Attempts are being made to achieve a consensus on the establishment of cost recovery and cost sharing to ensure the sustainability and efficiency of water resource management.
- Allow more flexibility in the DSS structure to permit the user to modify crop prices and hierarchy components as necessary. It may be required to account for aspects that were not included in the DSS (e.g., pollution in different black spots) or to delete others that are no longer valid (e.g., the effect of groundwater level on the system salinity).
- Conduct a survey based on historical and projected data to select appropriate maximum and minimum values for the basic indicators. This is aimed at avoiding the over or underestimation of composite distances resulting from a random consideration of best and worst indicator values, which may result in aggregated errors eventually affecting the DSS output.
- Endeavour to coordinate computerised management information systems in the MPWWR (e.g., the telemetry system) to provide the DSS user with up-to-date input, thus avoiding redundant and inaccurate data.
- Consider the costs of projected plans in the process of deciding on development alternatives (e.g., the improvement of the old irrigation system).
- Include modifications made to the NBSM Fortran program (regarding the New Land configuration and the insertion of an optimisation routine) in the originally developed user friendly package. The incorporation of deep groundwater in the simulation process necessitates a capacity determination of non-riverine aquifers to allow the user to test the sustainability of groundwater based reclamation projects outside the Nile Valley and Delta.
- Account for the M&I and other water concerns in the DSS. In practice, Ministries and Authorities that have some activity related to water resources should be involved in the decision mechanism regarding the establishment of strategic water policies.
- Incorporate the constraint limiting HAD releases to 55.5 bn. m^3 into the NBSM so that the annual release is fixed only if the total water demand exceeds 55.5 bn. m^3.
- Embody a more detailed salinity model in the NBSM instead of the rather simple approach assuming an overall salt balance.

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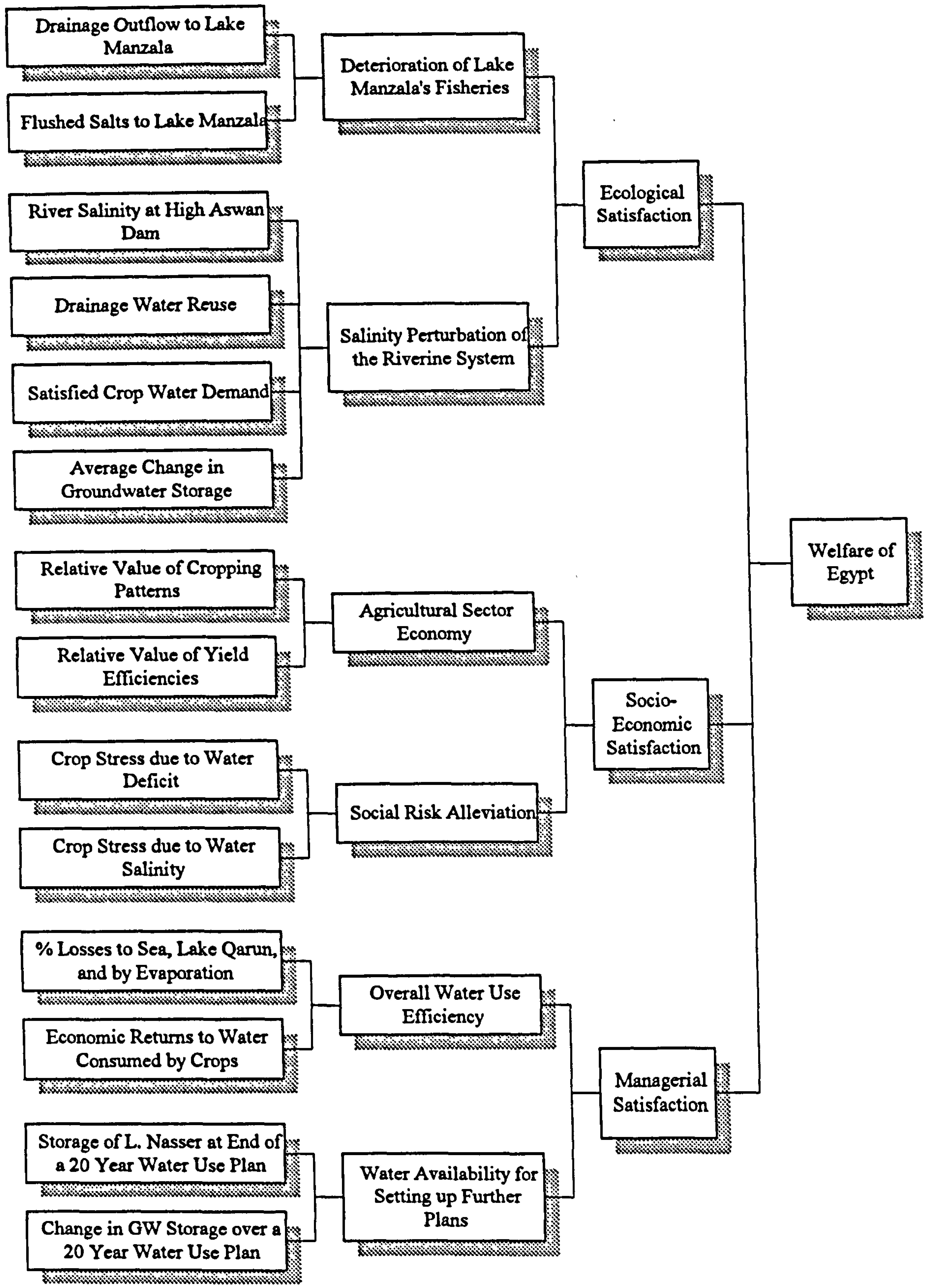
APPENDIX A

QUESTIONNAIRE

(10 questions)

Name : --

Position: --


Drainage Outflow to Lake Manzala
Flushed Salts to Lake Manzala
Deterioration of Lake Manzala's Fisheries
River Salinity at High Aswan Dam
Drainage Water Reuse
Satisfied Crop Water Demand
Average Change in Groundwater Storage
Salinity Perturbation of the Riverine System
Ecological Satisfaction
Relative Value of Cropping Patterns
Relative Value of Yield Efficiencies
Agricultural Sector Economy
Crop Stress due to Water Deficit
Crop Stress due to Water Salinity
Social Risk Alleviation
Socio-Economic Satisfaction
Welfare of Egypt
% Losses to Sea, Lake Qarun, and by Evaporation
Economic Returns to Water Consumed by Crops
Overall Water Use Efficiency
Storage of L. Nasser at End of a 20 Year Water Use Plan
Change in GW Storage over a 20 Year Water Use Plan
Water Availability for Setting up Further Plans
Managerial Satisfaction

OBJECTIVE:

The tradeoff hierarchy is structured to reflect the aggregated impacts of the application of various water use scenarios on the welfare of Egypt. This questionnaire is developed for experts to judge weights, or relative importance, of the indicators at different levels of the hierarchy.

THUS, IN THE LIGHT OF THE ABOVE ILLUSTRATED HIERARCHY AND FROM YOUR OWN POINT OF VIEW, GIVE A SCORE OUT OF TEN (so that a+b+...=10 for each question) TO REFLECT:

ECOLOGICAL

1) THE IMPACT OF

Drainage Outflow to Lake Manzala[1] a=... / 10

Flushed Salts to Lake Manzala[2] b=... / 10

ON

Deterioration of Lake Manzala's Fisheries

---

1 The diversion of drainage water, originally flowing to Lake Manzala, to the desert will result in a salt concentration increase in the Lake, adversely affecting the existence of fresh water species in the Lake.

2 The increase in the salt load of the drainage water flow to Lake Manzala is expected to endanger the fresh water species in the Lake.

2) THE IMPACT OF

River Salinity at High Aswan Dam[3] a=... / 10

Drainage Water Reuse[4] b=... / 10

Satisfied Crop Water Demand[5] c=... / 10

Average Change in Groundwater Storage[6] d=... / 10

ON

Salinity Perturbation of the Riverine System

---

3 The higher the salinity of the water inflow from HAD (e.g. due to development of areas in the neighbourhood of Lake Nasser), the more disturbed becomes the riverine system in the downstream reaches.

4 The larger the scale of drainage water reuse, the more tangible is the salinity perturbation of the riverine system.

5 This is used to indicate whether crops are fully or under irrigated. Under irrigation results in a yield deterioration as well as a salinity build up in soil, hence a salinity perturbation of the system.

6 The more saturated the Nile closed aquifer, the closer is the water level to the ground and the more probable becomes evaporation from GW, leaving salts to accumulate in soil.

3) THE IMPACT OF

Relative Value of Cropping Patterns[7] a=... / 10

Relative Value of Yield Efficiencies[8] b=... / 10

ON

Agricultural Sector Economy

---

7 The economic value of proposed cropping patterns with respect to cotton (of the highest economic return) may constitute an indicator of how well the performance of the agricultural sector economy will be.

8 Augmenting yield efficiencies of high profitability crops with respect to cotton is considered economically advantageous.

4) THE IMPACT OF

Crop Stress due to Water Deficit[9] a=... / 10

Crop Stress due to Water Salinity b=... / 10

ON

Social Risk Alleviation

9 It is thought that avoiding crop stresses resulting from a shortage in water supply and/or a high water salinity will help with alleviating the farmers' feeling of risk.

5) THE IMPACT OF

% Losses to Sea, Lake Qarun and by Evaporation (to the total water released)[10] a=... / 10

Economic Returns to Water Consumed by Crops b=... / 10

ON

Overall Water Use Efficiency

10 Reducing the percentage of water lost to the system to the total amount of water released at Aswan and increasing the economic returns to water consumed by crops are expected to promote the overall water use efficiency.

6) THE IMPACT OF

Storage of Lake Nasser at the End of a Twenty-Year Water Use Plan[11] a=... / 10

Change in Groundwater Storage over a Twenty-Year Water Use Plan b=... / 10

ON

Water Availability for Setting Up Further Plans

---

11 The sustainability, or the water availability for setting up future plans, is indicated by the end water storage in Lake Nasser and the change in groundwater storage as a result of an initial twenty-year water use plan.

ECOLOGICAL

7) THE IMPACT OF

Deterioration of Lake Manzala's Fisheries[12]

a=... / 10

Salinity Perturbation of the Riverine System[13]

b=... / 10

ON

Ecological Satisfaction

12
Thirty percent of Egypt's fish production comes from Lake Manzala. Enhancing fish stocks in the Lake is expected to promote the Egyptian ecosystem.

13
An increase in water salinity adversely affects the river's existing fresh water fish species, hence disturbing the ecological satisfaction.

8) THE IMPACT OF

Agricultural Sector Economy[14] a=... / 10

Social Risk Alleviation[15] b=... / 10

ON

Socioeconomic Satisfaction

---

14 The agricultural sector accounts for 20% of both GDP and total exports and 36% of employment in Egypt. Promoting the sector's economy would boost the socioeconomic satisfaction.

15 Alleviating the social feeling of risk stemming from the frequent occurrence of crop yield stresses would constitute an effort in the direction of promoting socioeconomic satisfaction.

9) THE IMPACT OF

Overall Water Use Efficiency[16] a=... / 10

Water Availability for Setting up Further Plans[17]

b=... / 10

ON

Managerial Satisfaction

16

The overall water use efficiency may indicate how well the performance of a water use plan is. The higher the efficiency, the better is the performance of the plan and the more promoted becomes the managerial satisfaction.

17

The water availability for setting up further plans presents the sustainability of a proposed water use plan and, consequently, the capability of realising managerial satisfaction.

GENERAL

10) THE IMPACT OF

Ecological Satisfaction	a=... / 10
Socioeconomic Satisfaction	b=... / 10
Managerial Satisfaction	c=... / 10

ON

Welfare of Egypt

NOTE:

Please brief any weakness in the present questionnaire form and state missing indicators that may, from your perspective, affect the decision making process by being incorporated into the developed hierarchy.

APPENDIX B

LIST OF CONTRIBUTORS TO THE DEVELOPED QUESTIONNAIRE

Name	Previous Job(s)	Present Job(s)
Eng. Gamil Mahmoud	- Deputy Minister for Ministry Affairs, MPWWR. - Head of the Planning Sector, MPWWR.	- General Coordinator of the Supplementary Irrigation Project, UN. - Senior Expert at the MPWWR.
Eng. Sarwat Fahmy	- Head of the Planning Sector, MPWWR. - Chairman of the Egyptian Drainage Authority, MPWWR.	- Senior Expert at the MPWWR. - Head of the Monitoring Office of the IMS Project, USAID.
Dr. Mona El Kady		- Deputy Chairman of the National Water Research Center (NWRC). - Director of the Strategic Research Program, NWRC.
Dr. Hussam Fahmy		Assistant Unit Manager of the Nile Water Strategic Research Unit, NWRC.
Dr. Mohamed Ahmed Abdel Khalik		Head of Open Drainage Division, Drainage Research Institute, NWRC.
Dr. Maha Tawfik		Researcher, NWRC.
Eng. Waguih Aly Mostafa		Assistant Researcher, NWRC.
Dr. Kamal Milad Soliman		Assistant Professor, Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University.
Dr. Mohamed Sherif El Manadily		Assistant Professor, Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University.
Dr. Magdy Abdel Waheed		Lecturer, Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University.
Dr. Aly Soliman		Lecturer, Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University.
Eng. Mohamed Ezzat El Shamy		Civil Engineer, Planning Sector, MPWWR.

APPENDIX C

Decision Support System
for
Water Allocation Plans in Egypt

USER MANUAL - Version 1.01

by: Tarek A. Ahmed

(December, 1995)

1. INTRODUCTION

The Decision Support System (DSS) is a simple decision support tool that was developed using Visual Basic for WINDOWS. The system utilises the tradeoff hierarchy approach to appraise the relative merits of suggested plans for Egyptian water use over a short or long study period. The DSS has no restrictions on the study period provided that you supply the average values for the basic parameters during this study period. The DSS will simply climb the hierarchy (Figure 1) up to the 'Welfare of Egypt' for each scenario and then rank the scenarios according to the relative value of this final indicator.

The DSS was designed to be used in conjunction with the Nile Basin Simulation Model (NBSM) which provides values used to identify the basic parameters of the trade-off hierarchy. However, any prediction of these parameters by any other model, or by hand calculations, can be evaluated by the program.

The NBSM is a simple large scale simulation model for the Egyptian water use system which allows the user to set a wide range of parameters covering cropping patterns and areas, efficiencies, demands, infrastructural development, reservoir operating rules, etc..., and to run the model for a range of Lake Nasser inflow scenarios. The model is mainly a strategic planning tool that calculates the required diversions and releases and presents the results in terms of overall water use and reliability of supply, and contains results on crop production. For detailed information about the NBSM, please refer to MOTT MACDONALD INTERNATIONAL LIMITED, Demeter House, Station Road, Cambridge CB1 2RS, The United Kingdom.

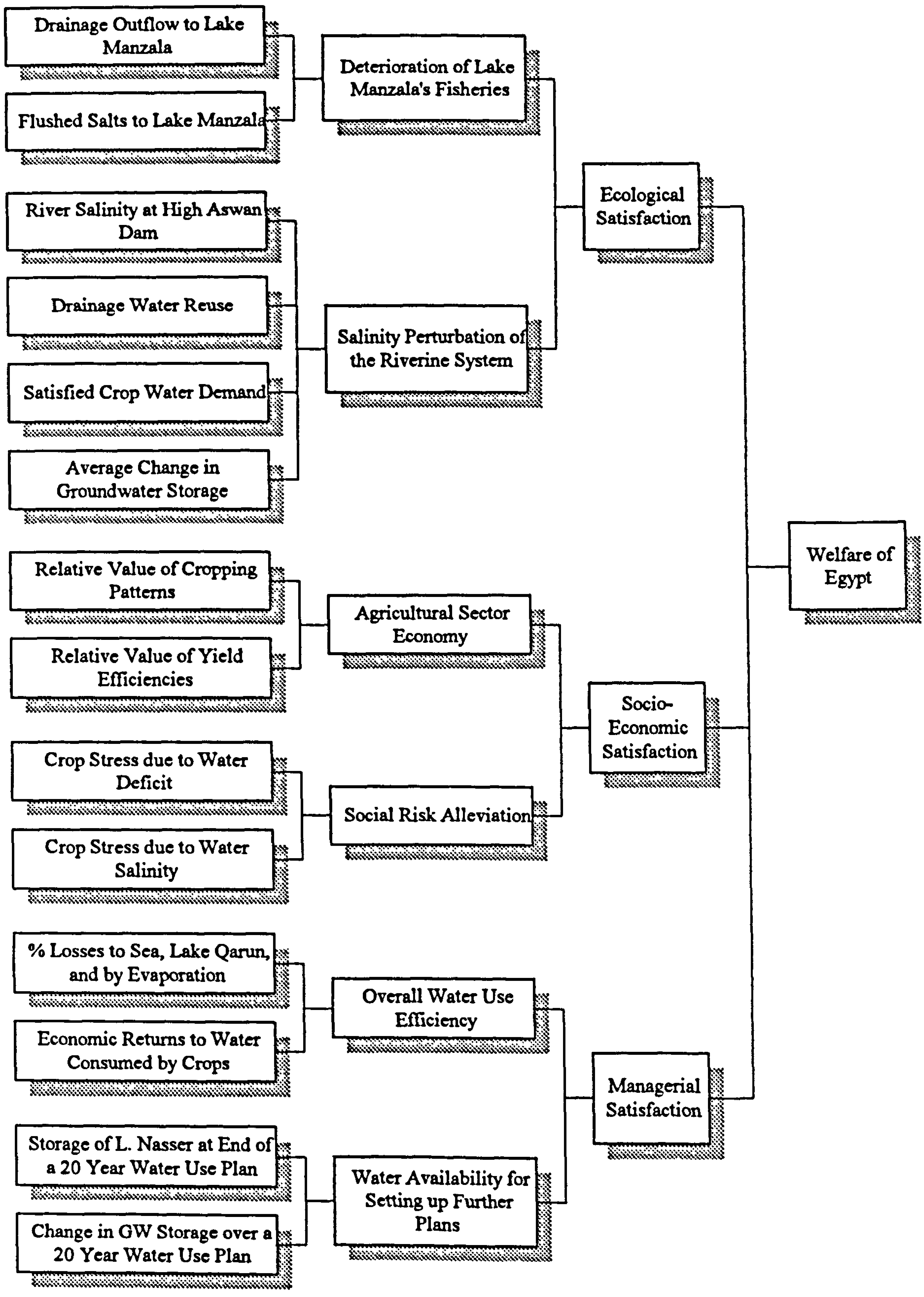


Figure 1 The Tradeoff Hierarchy of Indicators

2. PROGRAM REQUIREMENTS

Before you can start playing, you should have a working copy of the game. You obtain a working copy by installing the game from the distribution disk to your computer's hard disk. Before you start the installation, make sure you have the following hardware and software:

- IBM compatible machine with 80286 processor or higher.
- 750 KB of hard disk space.
- VGA display and adaptor.
- 2 MB of memory or more.
- A mouse is recommended.
- Microsoft DOS 5.0 or higher.
- Microsoft Windows 3.1 or higher.

3. INSTALLATION

3.1 Files on the Distribution Disk

Make sure that you have the following **14** files on your distribution disk:

CMDIALOG.VB_	SAMPLE.DS_	SPIN.VB_
DEFAULT. DS_	SETUP.EXE	THREED.VB_
DSS.EX_	SETUP.LST	VBRUN300.DL_
DSSSETUP.EX_	SETUPKIT.DL_	VER.DL_
GRID.VB_	MSAFINX.DL_	

3.2 How to Install DSS

1. Load Windows (at the DOS prompt (C:>) type WIN).
2. Insert the Distribution Disk into drive A: (or B:)
3. From the File menu of the Program Manager or the File Manager, choose Run.
4. Type A:SETUP
5. The Setup automatically installs the game files to C:\DSS. You can change this directory when the setup asks for the Program Directory (Figure 2).

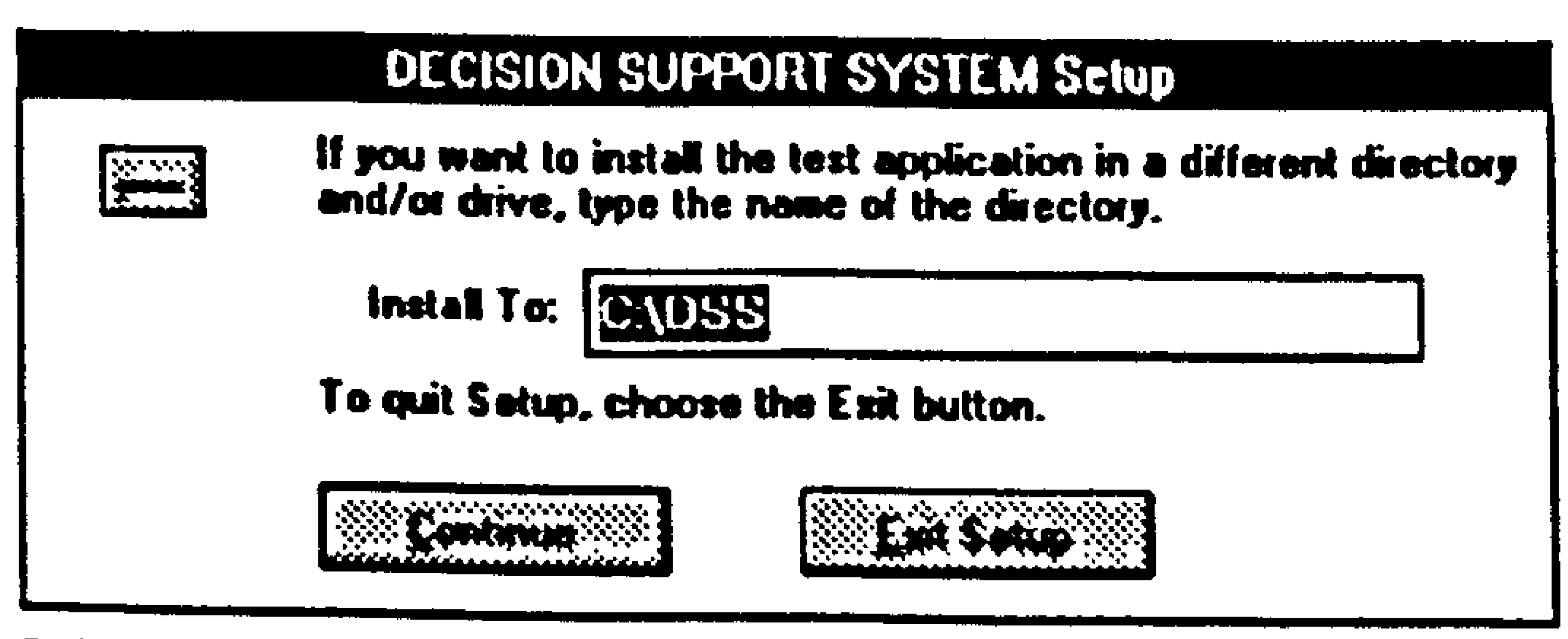


Figure 2 Program Directory Dialog Box of the DSS Setup Utility

Important: You cannot simply copy files from the Distribution Disk and run DSS. You must use the Setup program which decompresses and installs the files in the appropriate directories.

6. **DSS** is now installed. A program group will appear in WINDOWS Program Manager containing the icon of the **DSS** (Figure 3).

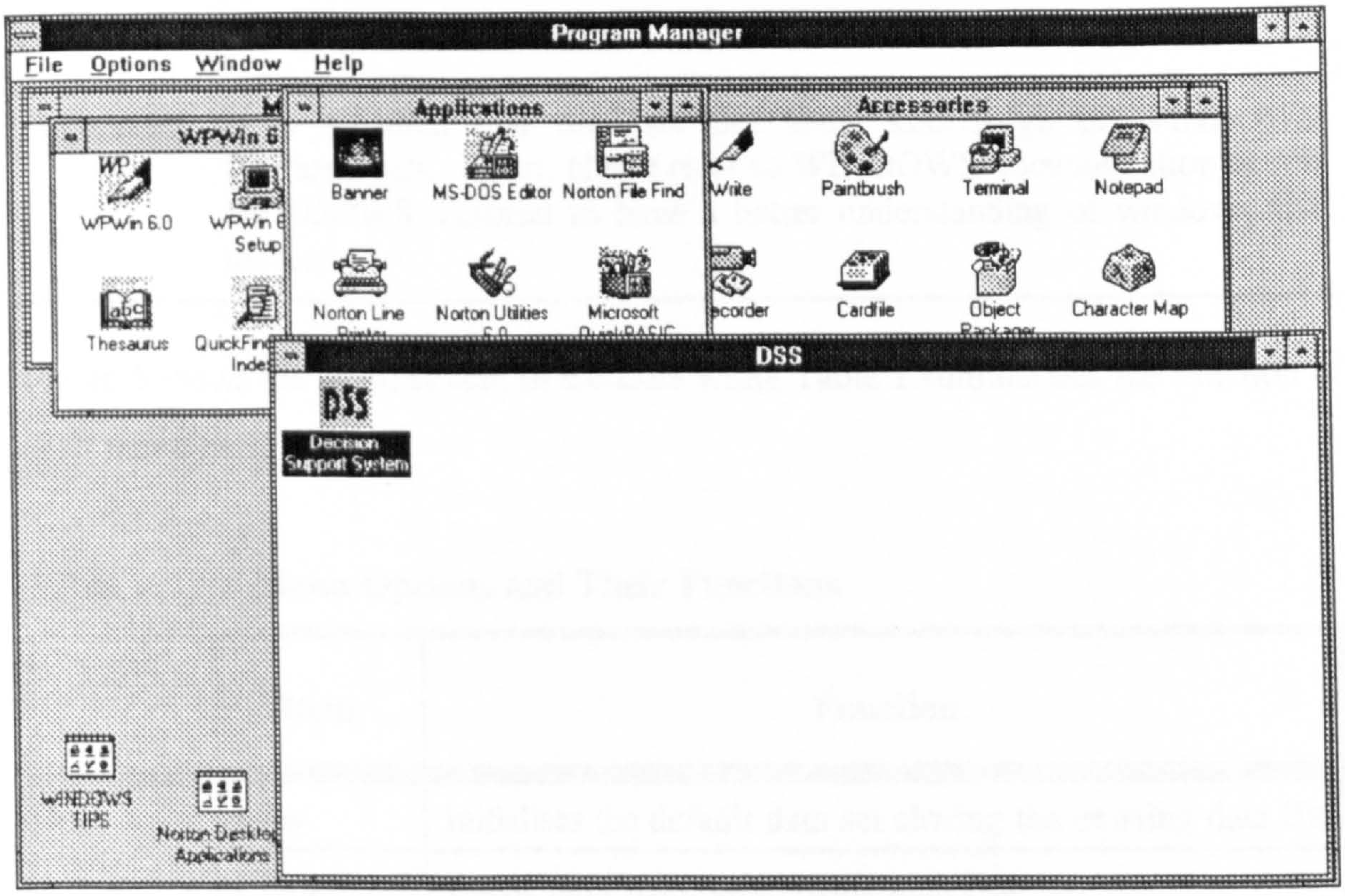


Figure 3 The Decision Support System Program Group in the Program Manager

4. RUNNING THE DSS

4.1 Getting Started

To start the DSS, open the program window (the program group called **DSS** in the Windows Program Manager) then press ***ENTER*** or double-click the DSS icon. The DSS starts with the display of the Introductory Screen (Figure 4) which

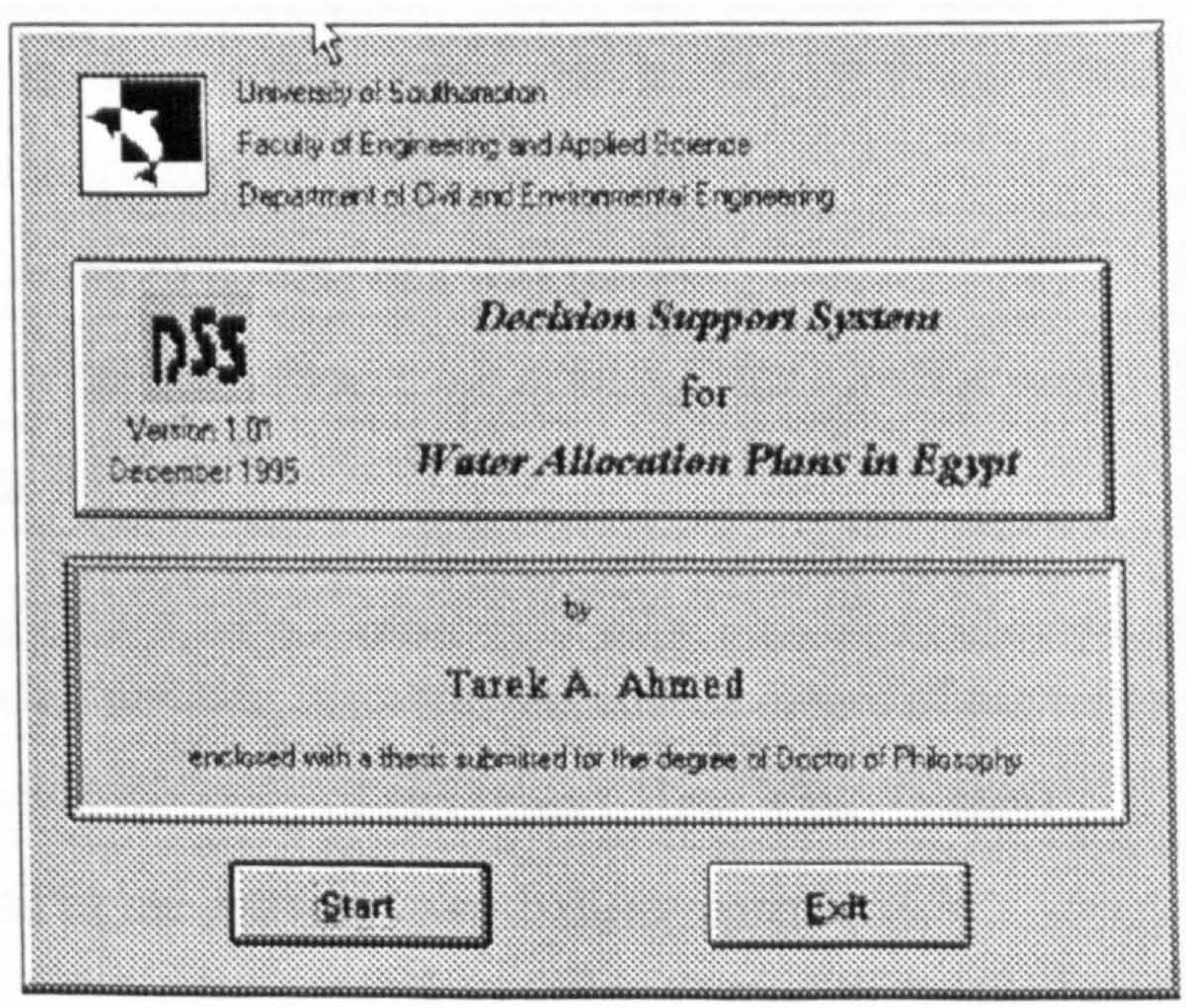


Figure 4 The Opening Screen of the DSS

carries the program name and logo. Click the *'Start'* button to begin the program or the *'Exit'* button to end.

4.2 Exploring DSS Menu System

When the DSS starts, its window should fill the whole screen, but it can be sized as needed. The DSS window is blank except for the menu bar as the program is a menu-driven application that utilises the standard features of WINDOWS menus.

Important: It is assumed that the user has some knowledge of WINDOWS fundamentals. If not, please refer to WINDOWS documentation or run WINDOWS Tutorial to have a better understanding of windows and menus.

Figure 5 shows the menu system of the DSS while Table 1 summarises the function of each menu item.

Table 1. DSS Menu Options and Their Functions

Main Menu	Item	Function
File	New	Initialises the default data set closing the existing data file
	Open	Reads data from an existing data file
	Save	Saves the current data to a file
	Save As	Saves the current data to a file with different name/directory
	Write Data	Write the basic data to a text file
	Print Data	Prints the basic data to the default WINDOWS printer
	Exit	Ends the DSS
	About	Displays development information about the DSS
Edit	Scenarios	Enables addition, removal, and editing names of scenarios
	Crop Data	Enables the entry of crop data (Area, Yield factors)
	Water Balance	Enables the entry of water balance components

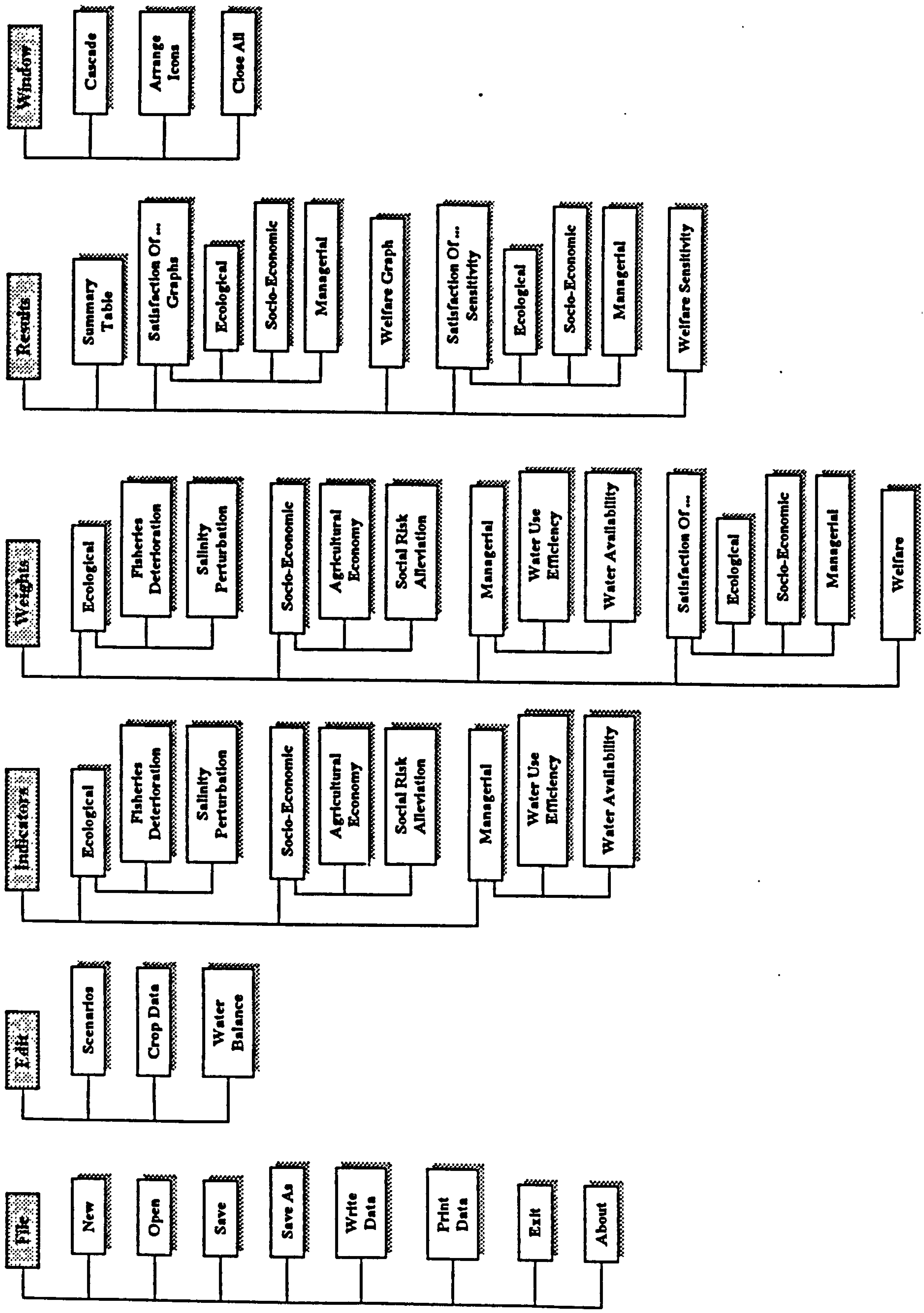

Window
Cascade
Arrange Icons
Close All
Results
Summary Table
Satisfaction Of ... Graphs
Ecological
Socio-Economic
Managerial
Welfare Graph
Satisfaction Of ... Sensitivity
Ecological
Socio-Economic
Managerial
Welfare Sensitivity
Weights
Ecological
Fisheries Deterioration
Salinity Perturbation
Socio-Economic
Agricultural Economy
Social Risk Alleviation
Managerial
Water Use Efficiency
Water Availability
Satisfaction Of ...
Ecological
Socio-Economic
Managerial
Welfare
Indicators
Ecological
Fisheries Deterioration
Salinity Perturbation
Socio-Economic
Agricultural Economy
Social Risk Alleviation
Managerial
Water Use Efficiency
Water Availability
Edit
Scenarios
Crop Data
Water Balance
File
New
Open
Save
Save As
Write Data
Print Data
Exit
About

Table 1. DSS Menu Options and Their Functions (Continued)

Main Menu	Item	Function
Indicators	Ecological	Enables the entry/display of the basic indicators affecting the Ecology - divided into Fisheries Deterioration and Salinity Perturbation
	Socio-Economic	Enables the entry/display of the basic indicators affecting Social and Economic aspects of water use - divided into Agricultural Economy and Social Risk Alleviation
	Managerial	Enables the entry/display of the basic indicators affecting Managerial aspects of water use - divided into Water Use Efficiency and Water Availability
Weights	Ecological	Enables the entry of weights and exponent for the basic indicators affecting Ecology - divided into Fisheries Deterioration and Salinity Perturbation
	Socio-Economic	Enables the entry of weights and exponent for the basic indicators affecting Social and Economic aspects of water use - divided into Agricultural Economy and Social Risk Alleviation
	Managerial	Enables the entry of weights and exponent for the basic indicators affecting Managerial aspects of water use - divided into Water Use Efficiency and Water Availability
	Satisfaction of	Enables the entry of weights and exponent for second level indicators affecting each of Ecological, Socio-Economic, and Managerial aspects of water use.
	Welfare	Enables the entry of weights and exponent for the final level of indicators directly affecting the welfare of Egypt
Results	Summary Table	Displays the values of final level indicators and welfare of Egypt in a tabular form

Table 1. DSS Menu Options and Their Functions (Continued)

Main Menu	Item	Function
	Satisfaction of Graphs	Displays graphs for the final level indicators and their components for each of the Ecological, Socio-Economic, and Managerial aspects of water use
Results	Welfare Graph	Displays a graph of the welfare of Egypt and its components
	Satisfaction of Sensitivity	Performs a sensitivity analysis using the given parameters for the selected secondary indicator and displays the resulting welfare graph
	Welfare ... Sensitivity	Performs a sensitivity analysis using the given parameters for the welfare and displays the resulting welfare graph
Window	Cascade	Arrange open windows behind each other in such a way that you can see the titles of all open windows
	Arrange Icons	Arranges icons of minimised windows
	Close All	Closes all open results windows

5. USING THE DSS

5.1 Data Entry

In order to use the DSS to evaluate the relative merits of different scenarios of water use in Egypt, some basic data are required for each scenario. These different data items are entered through three menus: the 'Edit' menu, the 'Indicators' menu, and the 'Weights' menu. General data, including scenario names, cropping patterns, and water balance components, are entered from the 'Edit' menu for each scenario. Values of the basic indicators, which are not calculated from the general data, are entered from the 'Indicators' menu. The calculated basic indicators can also be displayed through this menu. Finally, weighting factors for the different trade-off hierarchy components, which are applied to all scenarios, are entered from the 'Weights' menu. The following sections will tell you how to enter these data items and how to get them for the NBSM.

5.1.1 Scenarios

First, you need to assign names to the different scenarios you want to inter-compare. The DSS deals with scenarios by names so that it can help you remember which values and results relate to a specific scenario. The DSS handles the numbering of scenarios internally. However, you will see the numbers of scenarios on different graphs and tables.

To edit a scenario name, add a new scenario, or remove an existing scenario, you need to use the menu sequence Edit| Scenarios to open the 'Scenario' dialog box (Figure 6). The dialog box contains a drop-down list that contains the names of all existing scenarios. To edit a scenario name, select it from the list and then edit it in the 'Edit Scenario Name' box. You can have scenario names as long as 25 characters. By default, the program assigns the name "Basic Scenario" to the first scenario, and continues sequentially with the rest of scenarios as "Scenario #2", "Scenario #3", etc.

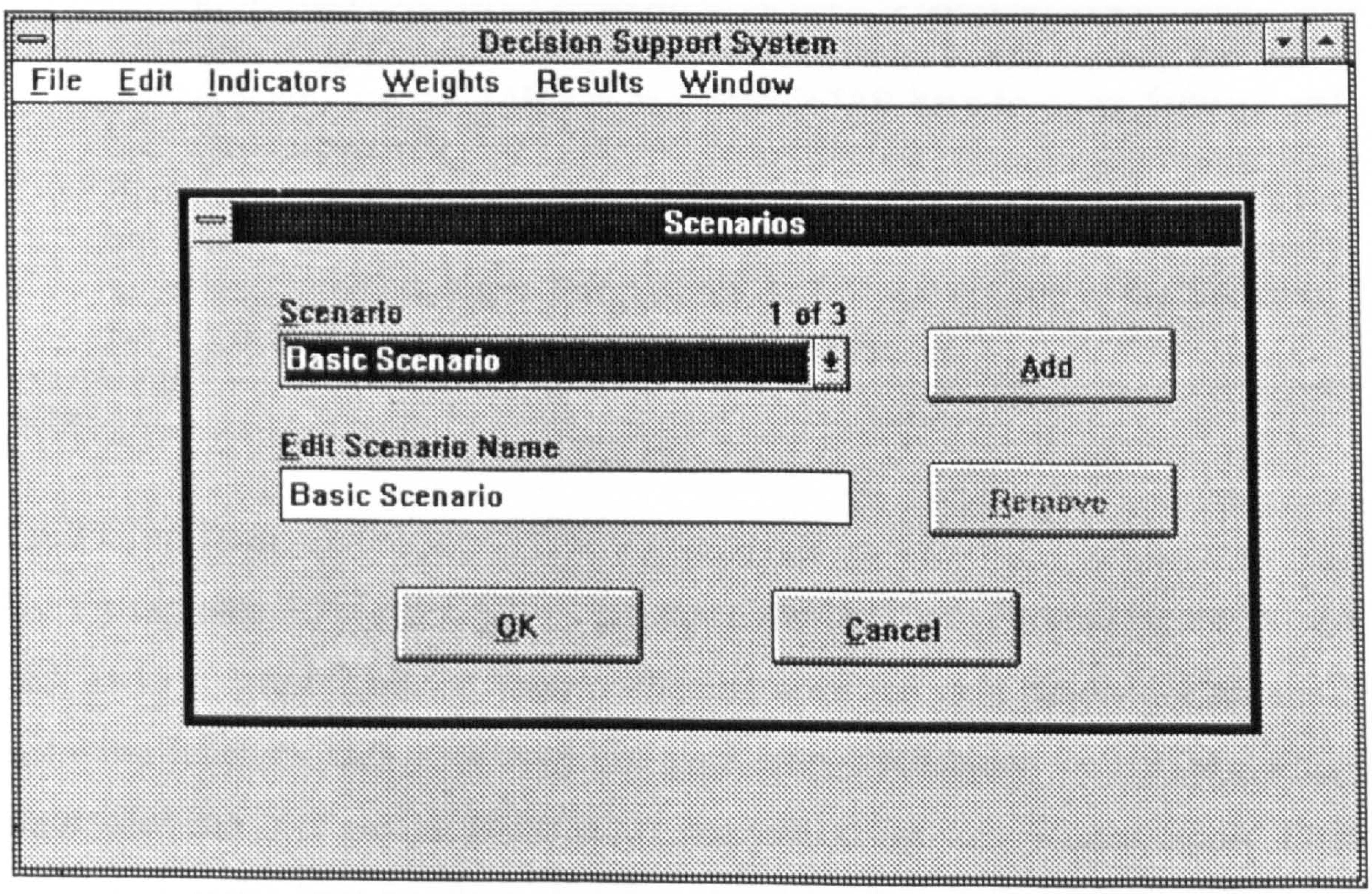


Figure 6 The Scenarios Dialog Box in the DSS

To add a new scenario, click the *'Add'* button, a new scenario will be added and assigned the name "Scenario #n", where 'n' is the number of the first free scenario. For example, if there are three scenarios and you add a fourth one, it will be named "Scenario #4". The program will also copy all the data of the first scenario to the new scenario to be used as a template for entering the real values. To remove an existing scenario, select it from the scenarios drop-down list and then click *'Remove'*, the scenario will be removed with all of its data.

Tip: If you make a mistake and remove the wrong scenario, do not worry of losing your data, simply click *'Cancel'* and all the changes you have made will be discarded. Even if you click *'OK'*, you can reload the file telling the program not to save the changes.
The *'Cancel'* and *'OK'* buttons work the same way in all forms.

The minimum number of scenarios is set at 3, representing the least reasonable number of scenarios allowed for comparison. Therefore, if you have only three scenarios, the *'Remove'* button will be disabled (grayed) automatically. However, there is no maximum number of scenarios, i.e., you can add as many scenarios as your computer's memory can hold, but more than 30 scenarios will result in ugly graphs.

Tip: In all data entry forms, to navigate between different boxes, buttons, etc. using the keyboard, use the TAB key and SHIFT+TAB keys to move forward and backward respectively.
Another easy method is to use the 'Access Keys' which appear underlined in the box label or the button caption. By pressing ALT+Access Key, you move directly to the box/button you want. For example, ALT+S will get you to the 'Scenarios' list box in all the scenario-dependent dialog boxes.

5.1.2 Crop Data

Use the sequence Edit|Crop Data to open the 'Crop Data' entry form (Figure 7). For each scenario, you will need to enter/modify crop areas and yield factors due to salinity and water deficit for each of 18 crops (the same crops available in the NBSM). Crops are divided into three groups; winter crops, perennial crops, and summer crops. First, select the scenario from the 'Scenarios' drop-down list, then enter the crop data for this scenario. Access keys are provided for each crop, season, and data item to enable fast

Tip: Units used in the DSS are the same units used by the NBSM in order to help a direct transfer of data from the model to the DSS.

navigation.

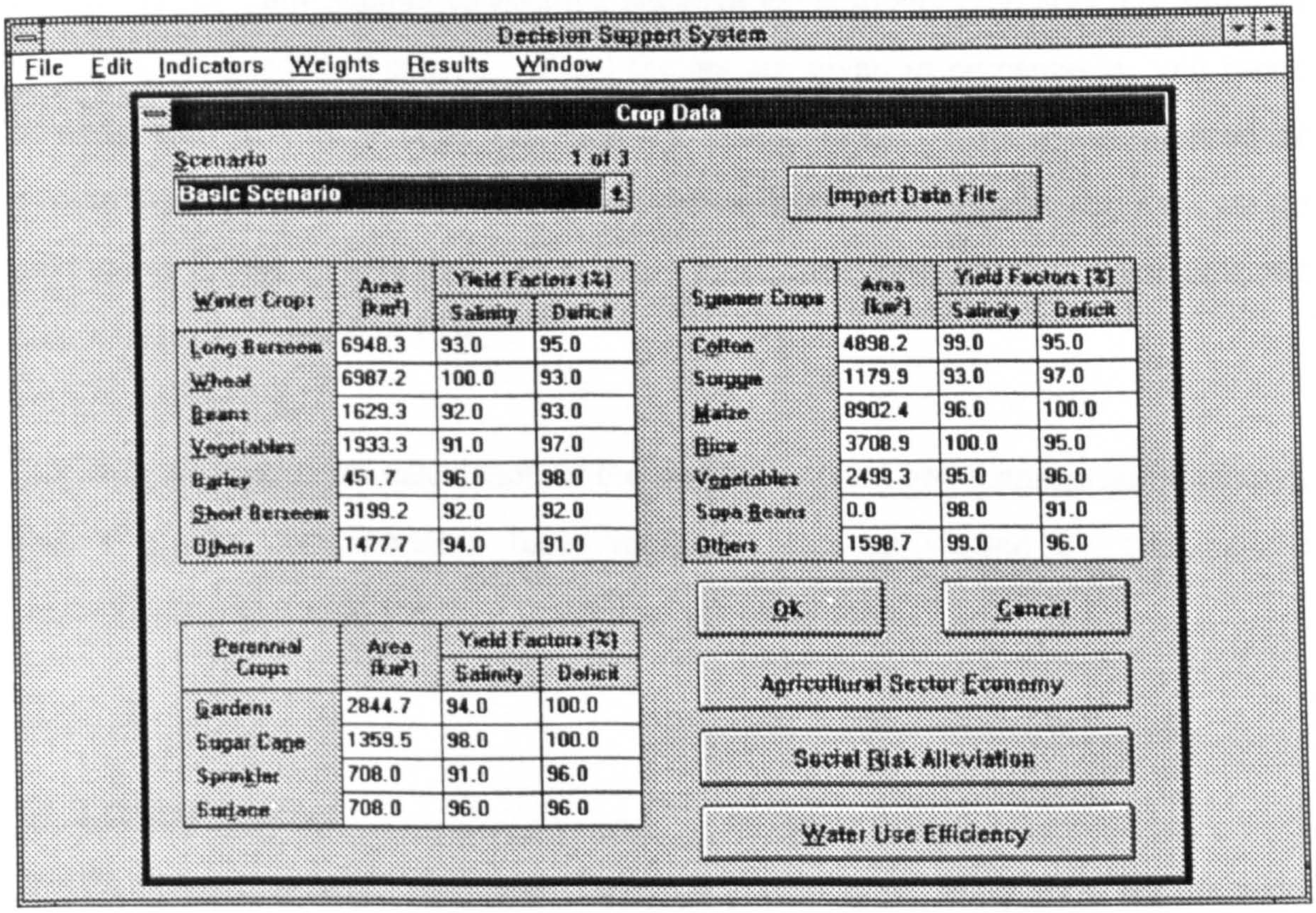


Figure 7 Crop Data Entry Form

The crop data values can be obtained from the NBSM results screen named 'Crop Stress', accessed from the 'Crop Yield' screen, for all Egypt and for the average year. Moreover, the NBSM results can be imported directly into the DSS. To do so, first print the results screen 'Crop Stress' for the average year to a text file (refer to NBSM documentation to see how to print to a file), then in the 'Crop Data' entry form of the DSS, click *'Import Data File'*, provide the name of the file in the 'Import Crop Data' dialog box and click 'OK' to import the target data.

Important: The data will be imported for the currently selected scenario (which appears in the 'Scenarios' list). Thus, make sure you are importing the right data file for the right scenario.

When you enter the data, by either way, the program checks its validity and assigns the lower or upper limit, whichever nearer, if necessary. For example, areas should not be negative, i.e., any attempt to assign a negative value to any crop area will result in zero area assigned to this crop. Yield factors are given in percentages, and range between zero to 100 percent. If you try to import data from a disorganised or incomplete file, the program will try to read as much as it can and will then assign valid values for the missing data items. Care must, therefore, be taken when entering data, especially, imported files.

Crop data are used in the calculation of the socio-economic and managerial indicators. Values of the corresponding basic indicators can be viewed by clicking the corresponding button at the bottom right of the entry form.

5.1.3 Water Balance

Use the menu sequence Edit|Water Balance to display the entry form for the water balance components (Figure 8). In this screen, you are asked to enter the different components of the Egyptian water balance for an average year of the study period. The components are divided into three categories:

1) Water consumption, comprising crop evapotranspiration and municipal and industrial net water consumption.
2) Water losses, comprising evaporation from surface water, drainage to lake Qarun, and the major component which is the water drained to the sea (the sum of fresh and drainage water flushed to the sea).
3) Change in soil moisture and groundwater storages.

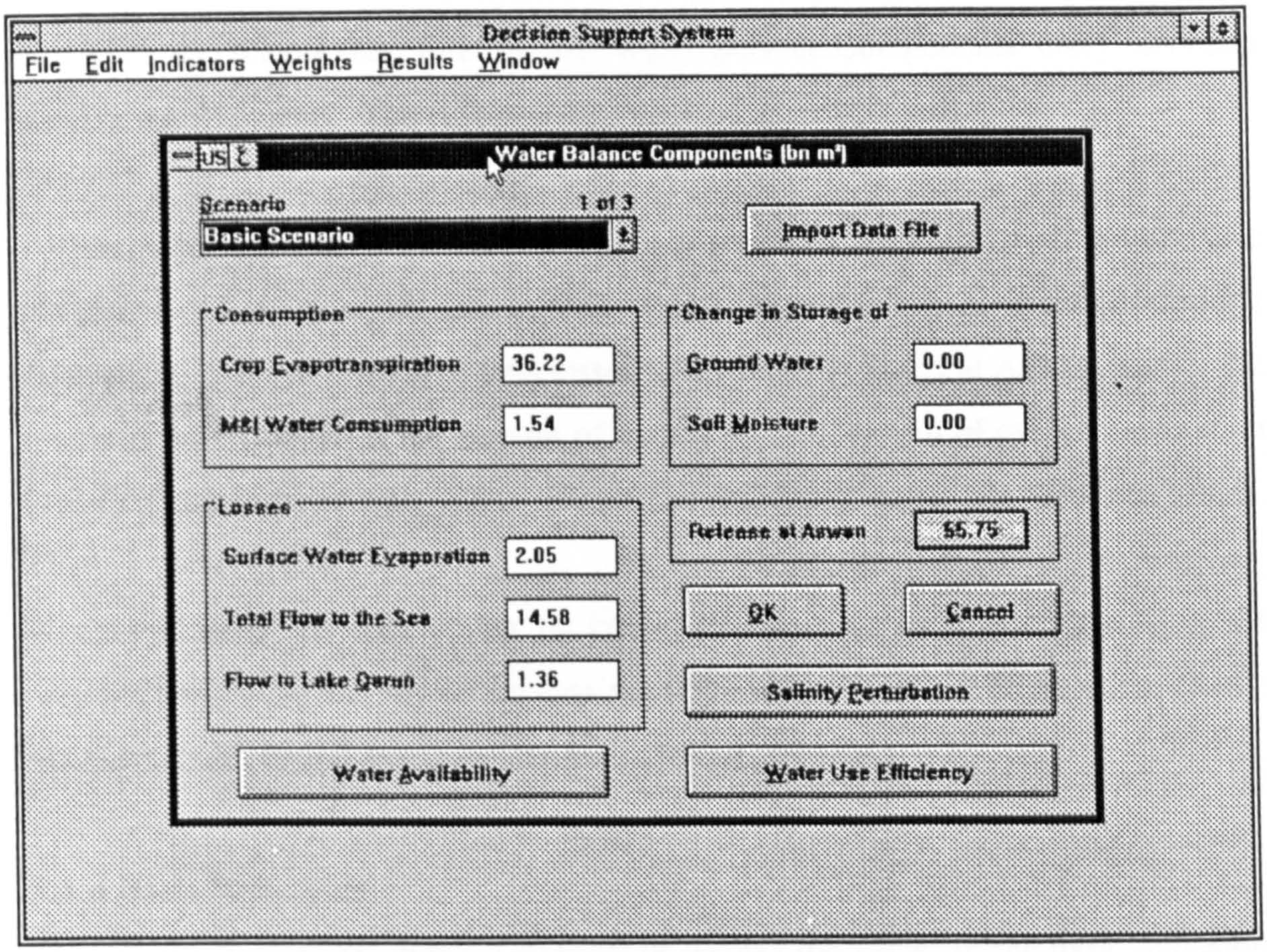


Figure 8 Water Balance Entry Form

The program calculates the water released at Aswan as the closing component of the water balance equation.

Tip: Color coding in data entry screens:

- Values in blue boxes are final values calculated by the program to be used directly in the DSS evaluation and cannot be edited directly.
- Values in yellow boxes are intermediate values calculated by the program.
- Values in white boxes are data items that need to be entered/modified either manually or by importing data from the NBSM.

The water balance data can be obtained from the first results screen of the NBSM, named 'Annual Water Balance for all Egypt' for the average year of the study period. You can import the water balance components directly into the DSS in exactly the same way ofimporting crop data. That is, print the 'Water Balance' results screen, within the NBSM, to a text file. Then, in the DSS, select the scenario you want to import the data for, click *'Import Data File'* on the 'Water Balance Components' entry form and provide the file name. The data will be imported and displayed.

Different components of the water balance are used to evaluate different basic indicators. For example, the overall water use efficiency is assessed through calculating: 1) the percentage of total losses to the water released at Aswan, and 2) the return to water, which is the amount of money gained per unit of evapotranspiration (water consumed by crops). Click '*Water Use Efficiency*' to see the resulting values.

When you enter the data (either by typing in values or by importing a file), the program checks the validity of the data as all the values must not be negative, except for the changes in soil moisture and groundwater storages.

5.1.4 Basic Indicators

Through the 'Indicators' menu, you enter or display the values of the basic indicators affecting the welfare of Egypt. The menu follows the hierarchical system of indicators shown in Figure 1. Indicators displayed in blue boxes cannot be edited because they are calculated from the general data (accessed through the 'Edit' menu), i.e., they can be changed by editing the general data values. Other editable indicators are displayed in white boxes.

Use the menu sequence Indicators|Ecological|Fisheries Deterioration to display an entry form (Figure 9) where you enter the average quantity and the salinity of water drained to Lake Manzala from each of 'East Delta' and 'East Delta New Lands' regions. These values can be obtained from the NBSM 'System Salinity and Salt Ingress' results screen for the average year of the study period. You can also import the data directly from the NBSM into the DSS using the same procedure explained earlier. The program adds both discharges to get the 'Drainage Outflow to Lake Manzala', calculates the salt load for each region (displayed in yellow boxes), and displays the sum as the 'Flushed Salts to Lake Manzala'. The values entered or imported are used for the current scenario as displayed in the 'Scenarios' list box. All values should not be negative The minimum salinity value is set equal to the salinity of the river at HAD entered in the 'Salinity Perturbation' screen as described below.

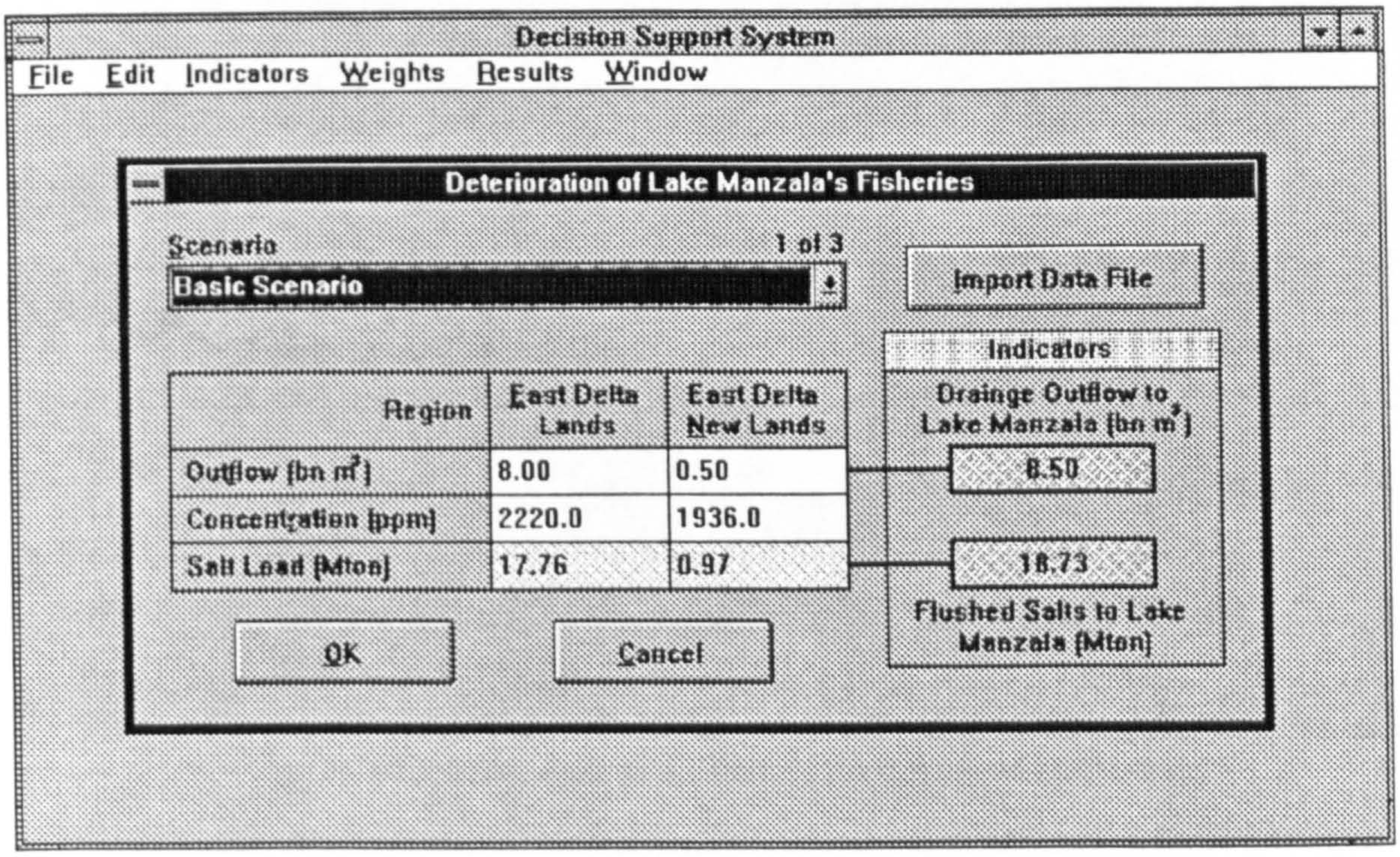


Figure 9 Dialog Box of Fisheries Deterioration Indicators

Similarly, the menu sequence Indicators|Ecological|Salinity Perturbation will open a dialog box (Figure 10) for entering basic indicators disturbing the salt balance of the river Nile system. This screen contains four data items that are collected from different results screens of the NBSM. The following list determines which results screens you need to look at to extract these values:

Indicator	NBSM results screen
River Salinity at HAD	System Salinity and Salt Ingress
Drainage Water Reuse	Schematic Diagram for Water Balance (under All Egypt menu)
Satisfied Crop Water Demand	Annual Water Balance
Average Change in Groundwater Storage	Annual Water Balance

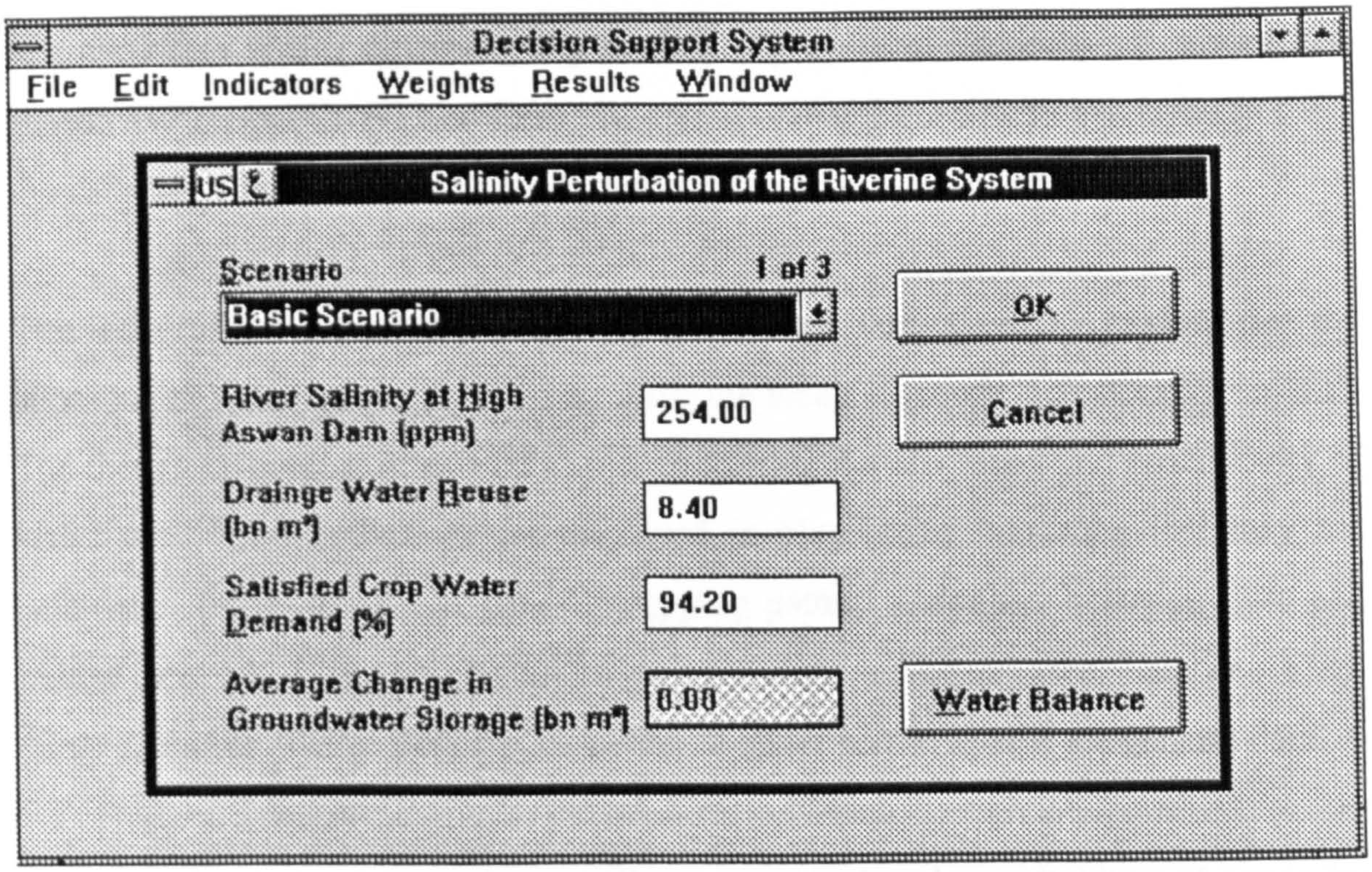


Figure 10 Dialog Box of Salinity Perturbation Indicators

As usual, the program will check the entered values against the valid range of each indicator. The following table lists the valid range for the 'Salinity Perturbation' data items.

Table 2 Valid Ranges for 'Salinity Perturbation' indicators

Indicator	Minimum	Maximum
River Salinity at High Aswan Dam (ppm)	100	_*
Drainage Water Reuse (bn m^3)	0	_
Satisfied Crop Water Demand (percent)	0	100
Average Change in Groundwater Storage (bn m^3)	_	_

* All values accepted

From the menu sequence Indicators|Socio-Economic, you can access the two submenus; Agricultural Economy and Social Risk Alleviation. Each of these submenus displays a dialog box containing two basic indicators in blue boxes. The values of these indicators are calculated from the crop data previously entered. To alter any of these values, click *'Crop Data'*, the display switches to the 'Crop Data' entry form where you can make further changes. If you click *'Agricultural Economy'* or *'Social Risk Alleviation'* on the 'Crop Data' form, the corresponding form will be displayed to show the calculated indicators (but you cannot edit the crop data at that time).

The last group of indicators, which represents the extent of success in managing the allocation of water, can be accessed by using the menu sequence Indicators|Managerial. The first group consists of two indicators measuring the efficiency and productivity of water use. Both indicators are displayed in blue boxes indicating that they are calculated from the general data of cropping pattern and water balance. You can change their values by changing the cropping pattern and/or the water balance. Click *'Crop Data'* or *'Water Balance'* to switch to either screen to edit the general data.

The second group consists of two indicators measuring the availability of water for subsequent plans. You can obtain the first indicator, 'Storage of Lake Nasser at End of a 20 Year Water Use Plan', from the NBSM 'Lake Nasser' results screen displaying the storage volume at the end of the last year of the planning period. It can only be within the allowable live storage of the lake, i.e., between 28.3 bn m^3 (dead Storage) and 137.5 bn m^3 (Lake Nasser's maximum capacity). The program automatically checks the entered value and assigns the maximum or minimum limit, whichever closer, if the value entered is out of this range. The second indicator, 'Change in Groundwater Storage over a 20 Year Water Use Plan', is calculated from the general data of water balance. This value, displayed in a blue box, can be either positive or negative.

5.2 Weighting Factors

Now you have entered all the values of the basic indicators, either directly or by entering some general data to calculate them. You can directly go to the 'results' screen and the program will calculate the next levels of indicators up to the 'Welfare of Egypt' (according to the hierarchical system illustrated in Figure 1). In this way, the program will assume equal weights for all indicators in their logical groups and a unit exponent for all groups in all levels of the hierarchy. If you want to assign a different weight to some indicator, you need to use the 'Weights' menu.

Under the 'Weights' menu, the whole hierarchy of indicators can be assigned different weighting factors and each group can have an exponent. The exponent is a different way of assigning more importance to one indicator over the other(s). The general equation used to calculate the next level's indicator from its basic components is:

$$LK = \left(\sum_{i=1}^{i=n} W_i \times LJ_i^{Exp} \right)^{1/Exp}$$

where,

i	=	numeration of indicators in this group of indicators at the current level
n	=	number of indicators in this group
LK	=	index existing at the next level
LJ_i	=	value of indicator number i in this group of the current level
W_i	=	weight of indicator number i in this group
Exp	=	Assigned exponent to this group of indicators

Thus, the exponent gives preference to the indicator having higher contribution to the next level's indicator over other components, i.e., if some component contributes 90% to the next level's indicator, the higher the value of the exponent, the more dominant becomes this component, even if it is assigned a low weight. Exponent values can be either 1 (the default), 2, or ∞. The extreme case of infinity will make the dominant indicator the sole contributing factor.

Tip: Weights and exponents are scenario-independent, i.e., the same values are applied to all scenarios. This is necessary to enable the comparison of scenarios.

To change the weights/exponent of, for example, 'Fisheries Deterioration' basic indicators, use the menu sequence Weights|Ecological|Fisheries Deterioration. Once the dialog box is opened (Figure 11), you can change weights by clicking the up and down arrows beside the 'Weight' box. Note that the weight of the other indicator changes accordingly so that the sum of weights equals one. You can directly type in a weight value. In the latter case, you need to press enter (or move to the other box) to see the change of the other indicator's weight. The program automatically checks

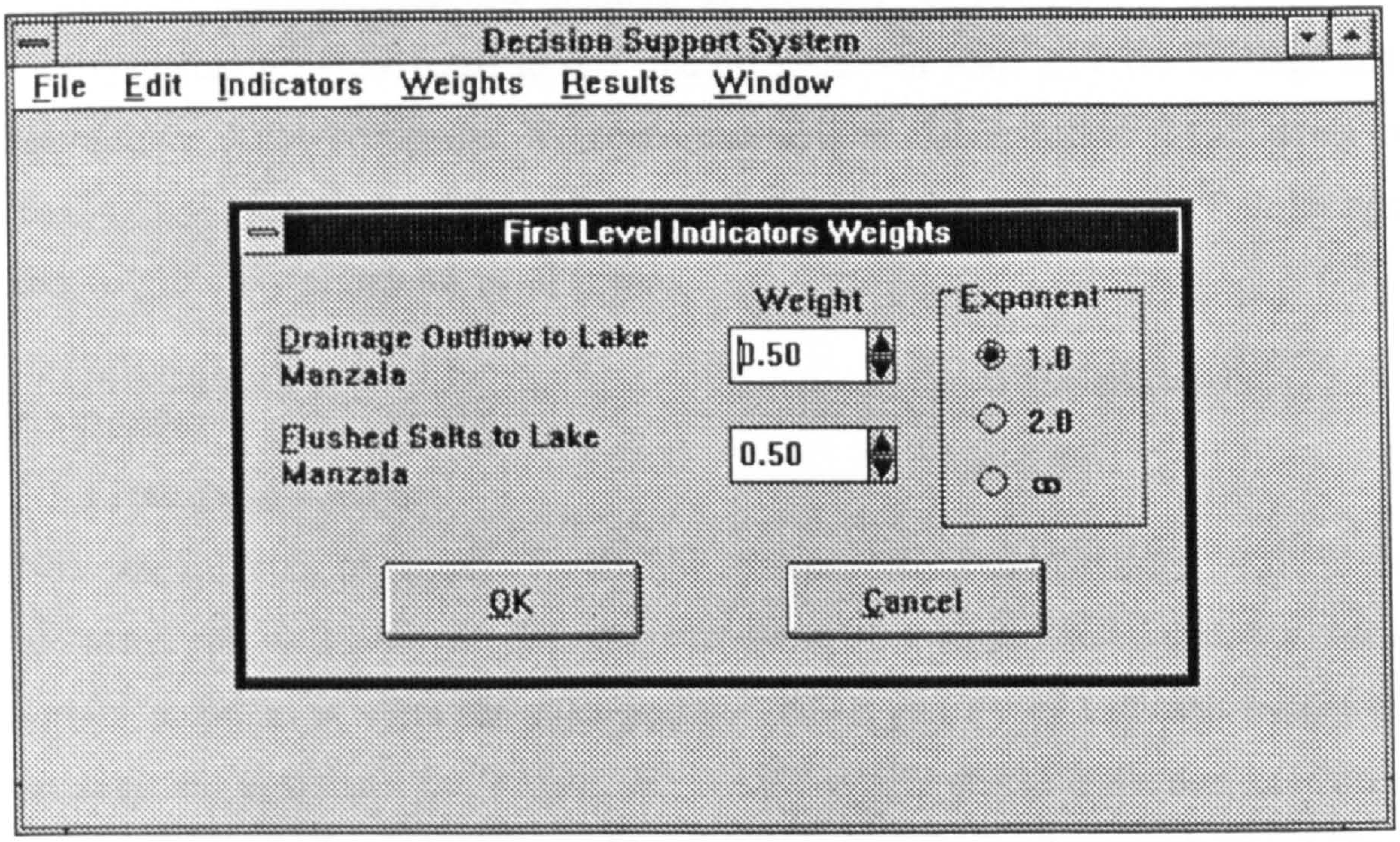


Figure 11 Dialog Box for Weights/Exponent Entry

any invalid weights (negative values or values exceeding unity, and assigns 0 or 1, whichever closer, instead. The exponent can be selected from the list of options to the side.

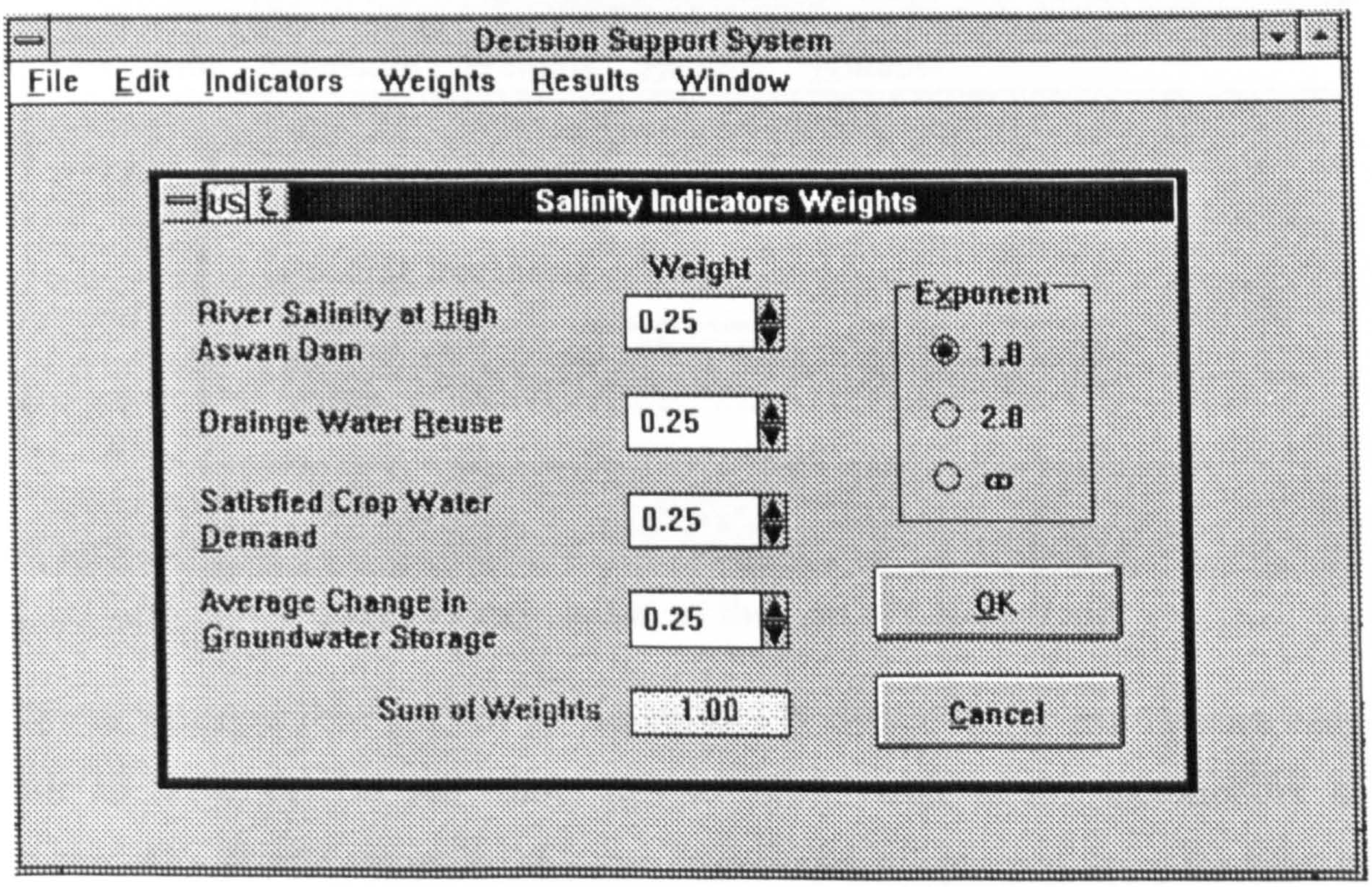


Figure 12 Entry Form for Salinity Indicators Weights/Exponent

If there are more than two components, e.g., Salinity Perturbation indicators (Figure 12), a blue box showing the sum of weights is displayed at the bottom of the dialog box to guide you assign valid combinations of weights. If you click *'OK'* while the displayed sum does not equal to one, the program will issue an error message and return to the dialog box again. You can enter weights and exponents for all levels in the same way. By default, the program equally weighs all components in their groups and assigns unity exponents to all groups.

5.3 Results

5.3.1 Results of Analysis

Now you are ready to perform the analysis, see the results and compare the different scenarios you have entered. You do not need to click a specific button or access a certain menu to perform the calculations. When you try to view the results by accessing any item under the 'Results' menu, the program checks if the data have been changed since the last calculation. If so, it directly performs the calculations before viewing the required results screen. A progress bar will be displayed to show that the program is calculating the different levels of indicators until the 'Welfare' level and ranking the different scenarios accordingly (Figure 13).

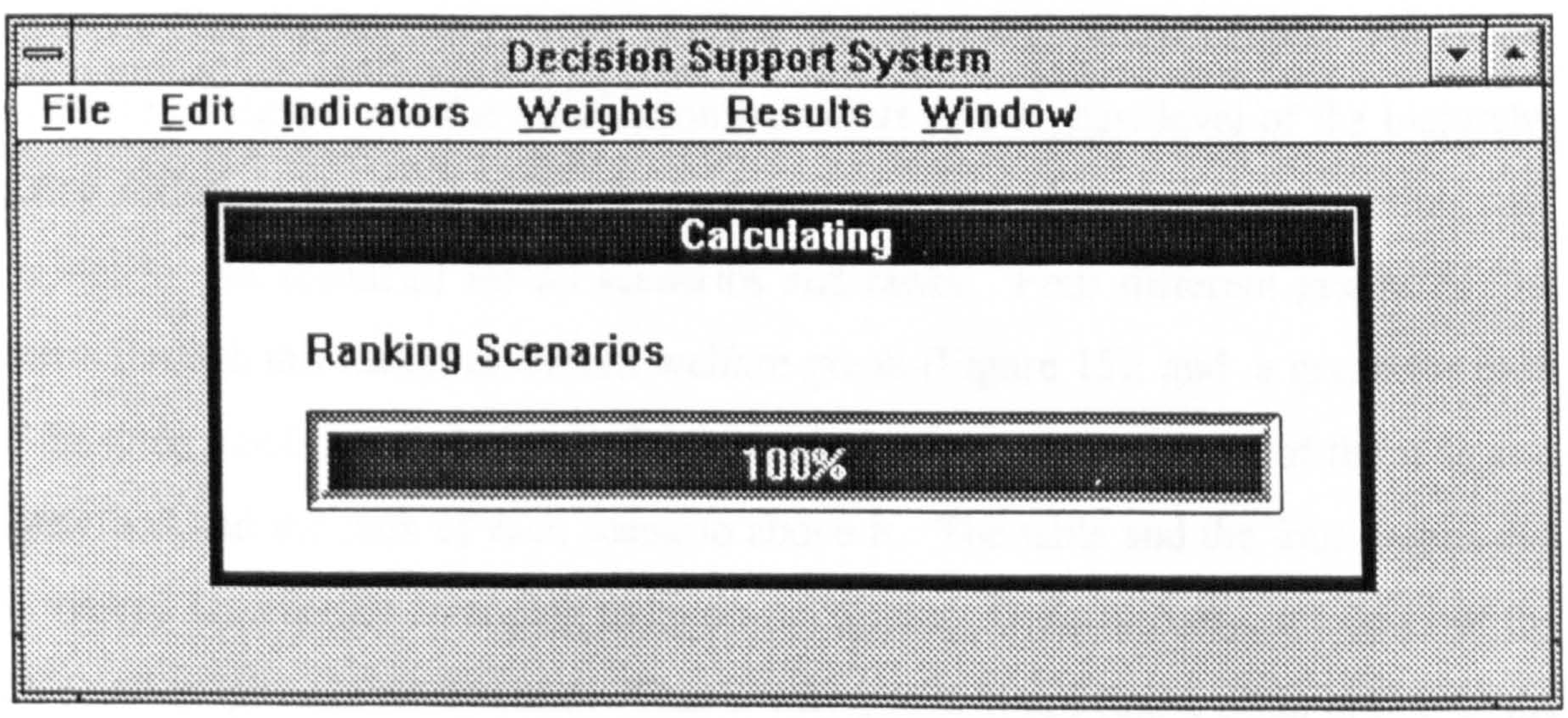
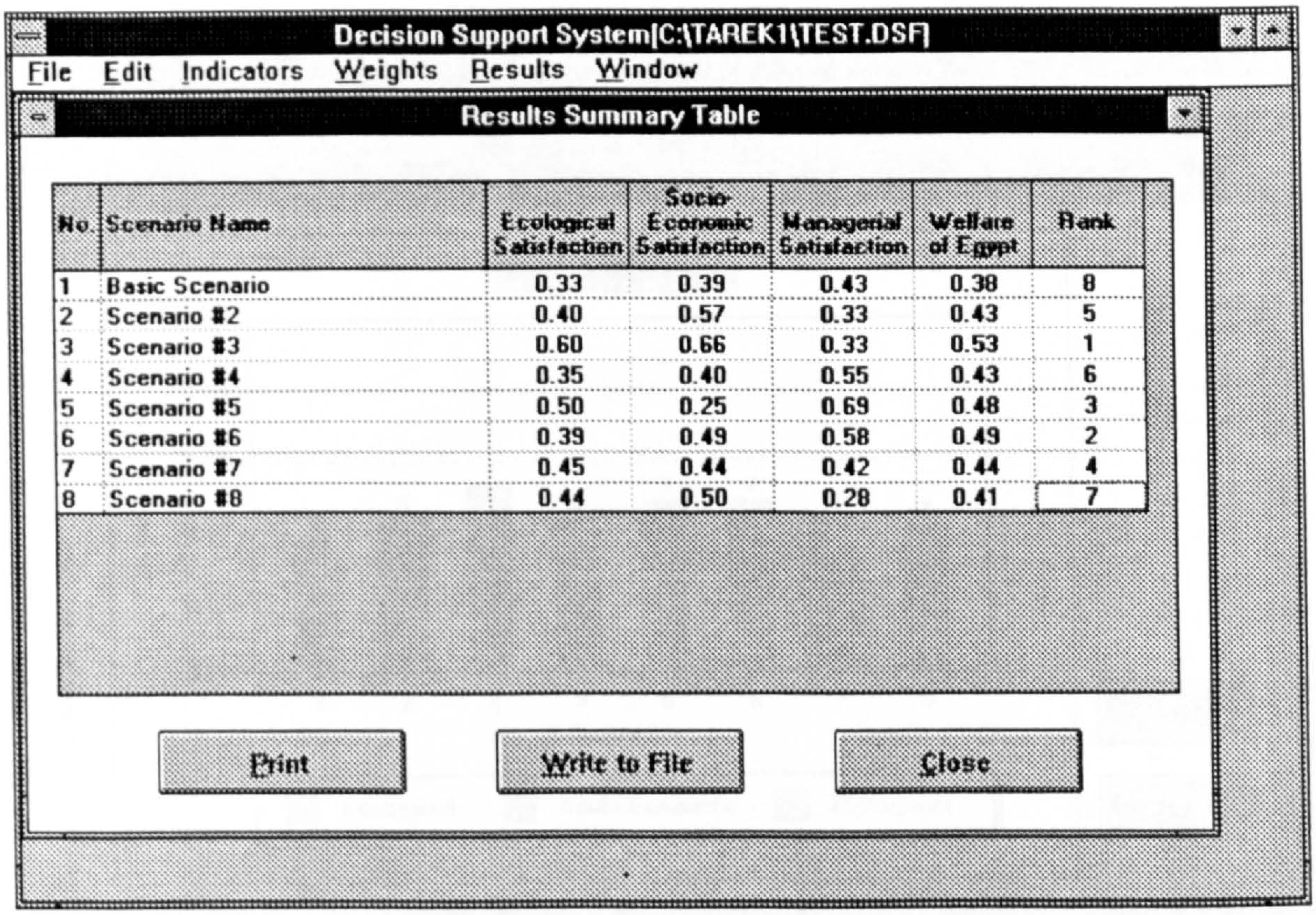


Figure 13 Progress Bar at the End of Calculations

During the calculations you may get this message "Indicator '......' has the same value for all scenarios. Do you really want to fix the value of this indicator for all scenarios?". If your answer is *'YES'*, the calculations will proceed fixing the value of this indicator. If you have clicked *'YES'* by mistake, click *'NO'* so that the program cancels the calculations and issues another message advising you to change the value of this indicator for one or more scenarios as required.



No	Scenario Name	Ecological Satisfaction	Socio-Economic Satisfaction	Managerial Satisfaction	Welfare of Egypt	Rank
1	Basic Scenario	0.33	0.39	0.43	0.38	8
2	Scenario #2	0.40	0.57	0.33	0.43	5
3	Scenario #3	0.60	0.66	0.33	0.53	1
4	Scenario #4	0.35	0.40	0.55	0.43	6
5	Scenario #5	0.50	0.25	0.69	0.48	3
6	Scenario #6	0.39	0.49	0.58	0.49	2
7	Scenario #7	0.45	0.44	0.42	0.44	4
8	Scenario #8	0.44	0.50	0.28	0.41	7

Figure 14 The Summary Table of the DSS Results

The results can either be viewed in a tabular or graphical form. Use the menu sequence Results|Summary Table to view the tabulated values (Figure 14) of the 'Welfare of Egypt' and the satisfaction indicators (the highest level of the hierarchy which measures the Ecological, Socio-Economic, and Managerial Satisfaction with respect to this scenario) for all scenarios and ranks. Four different graphs can be shown through this menu; an overall welfare graph (Figure 15); and a graph for each of the three satisfaction indicators. Each graph shows the components of the indicator concerned and the rank of each scenario above it. The table and the four graphs can be viewed together by arranging them on the screen. Unfortunately, windows of the table and graphs cannot be sized. This is why you will not find a tiling option in the 'Windows' menu.

On each of the results windows you will find two buttons, a *'Close'* button to close the window, and a *'Print'* button which sends a copy of the graph/table to your currently selected printer in WINDOWS. On the 'Summary Table' window you will find a third button called *'Write to File'* which sends the summary table to a text file where you can reformat it as desired.

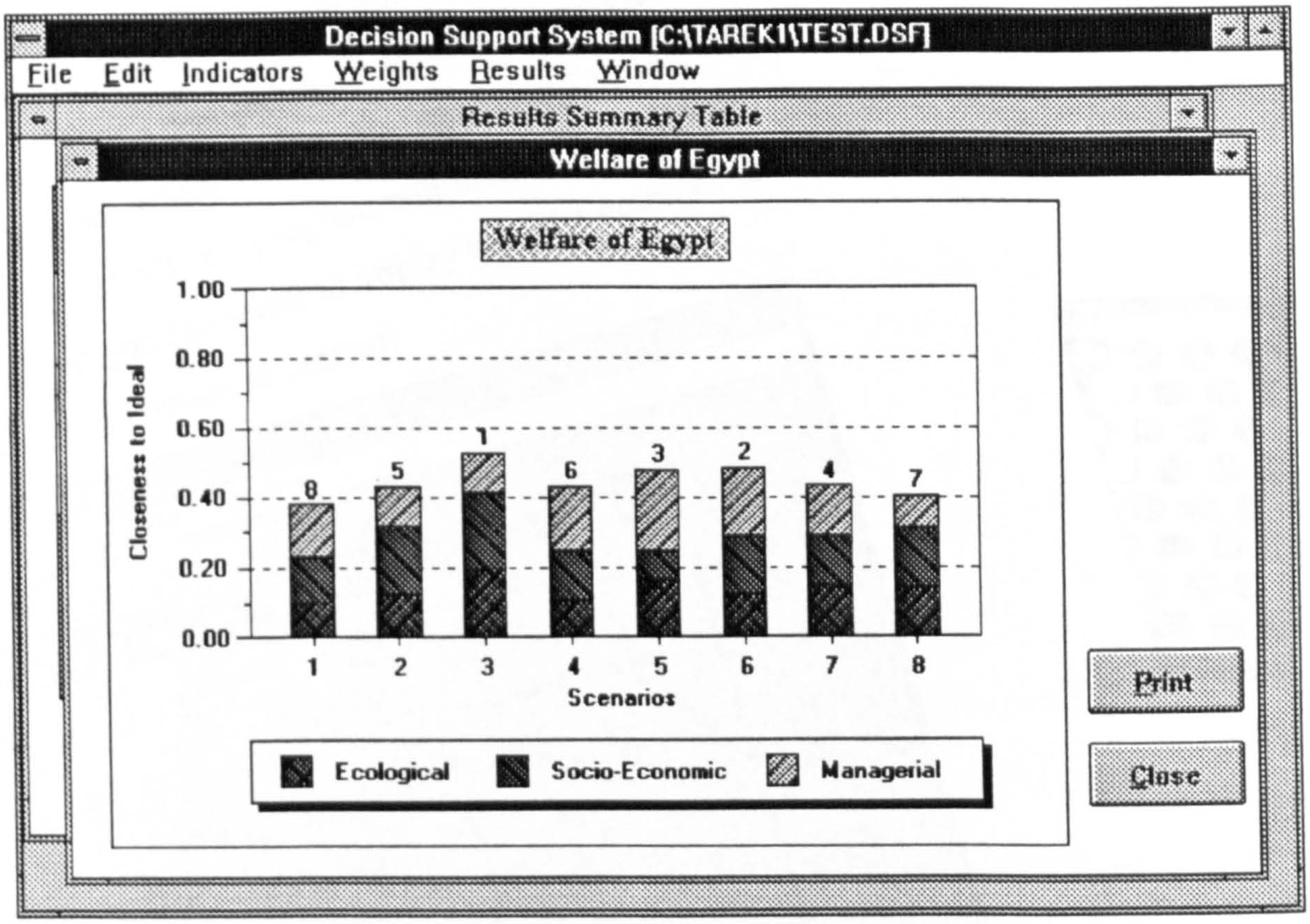


Figure 15 Graph of Welfare Results

5.3.2 Sensitivity Analysis

There are two more options in the 'Results' menu which were disabled before performing the calculations. You can use these two items to analyze the sensitivity of the scenario ranks to changes in weighting factors and exponents of the upper two levels of indicators, namely; the satisfaction indicators and the welfare. It is thought that going below this level in showing results and performing sensitivity is not necessary.

When you use the menu sequence Results|Satisfaction of ... Sensitivity, or Results| Welfare Sensitivity, you get a dialog box asking about the sensitivity parameters (Figure 16). The first parameter is the step of the change in weight. For this parameter, you have four options; either to preserve the values of weights as previously entered by choosing 'No Change' or to select one of three values; 0.1, 0.2, or 0.25. The smaller the step value, the more detailed is the performed sensitivity and the longer time it takes. This step is used to change the weight of each component of the chosen indicator through the full range of weight (0-1). The second parameter is the exponents used in the analysis. The original exponent value will always be chosen and

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n add one or both of the other two values. If you select 'No Change' tep, only the exponent will be changed in the sensitivity analysis. To ee another group of options which controls the displayed form of the sensitivity analysis. By default, the program will display the results in and graphical formats but you can select to display only the graph or the cking the appropriate option button as desired.

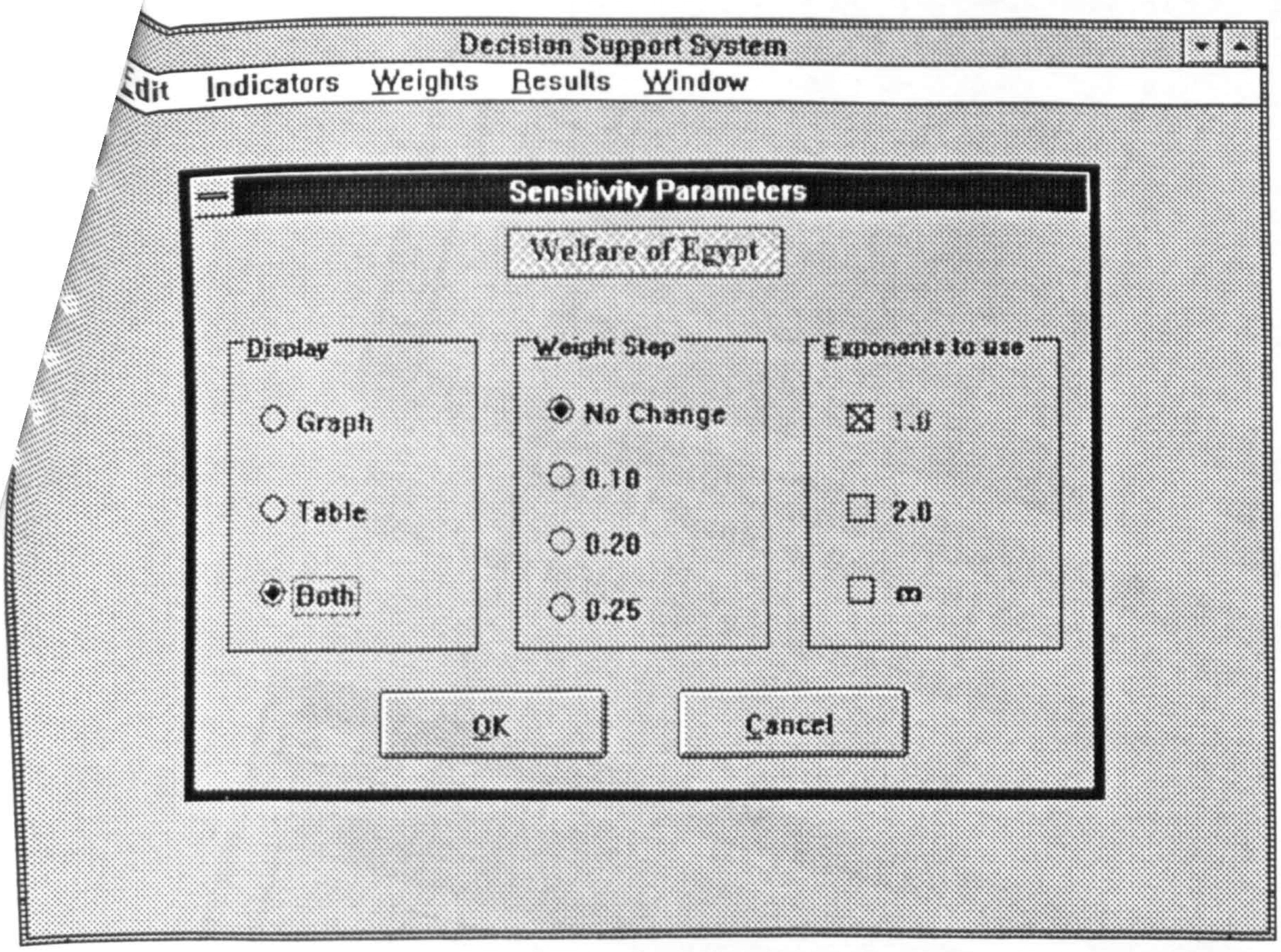
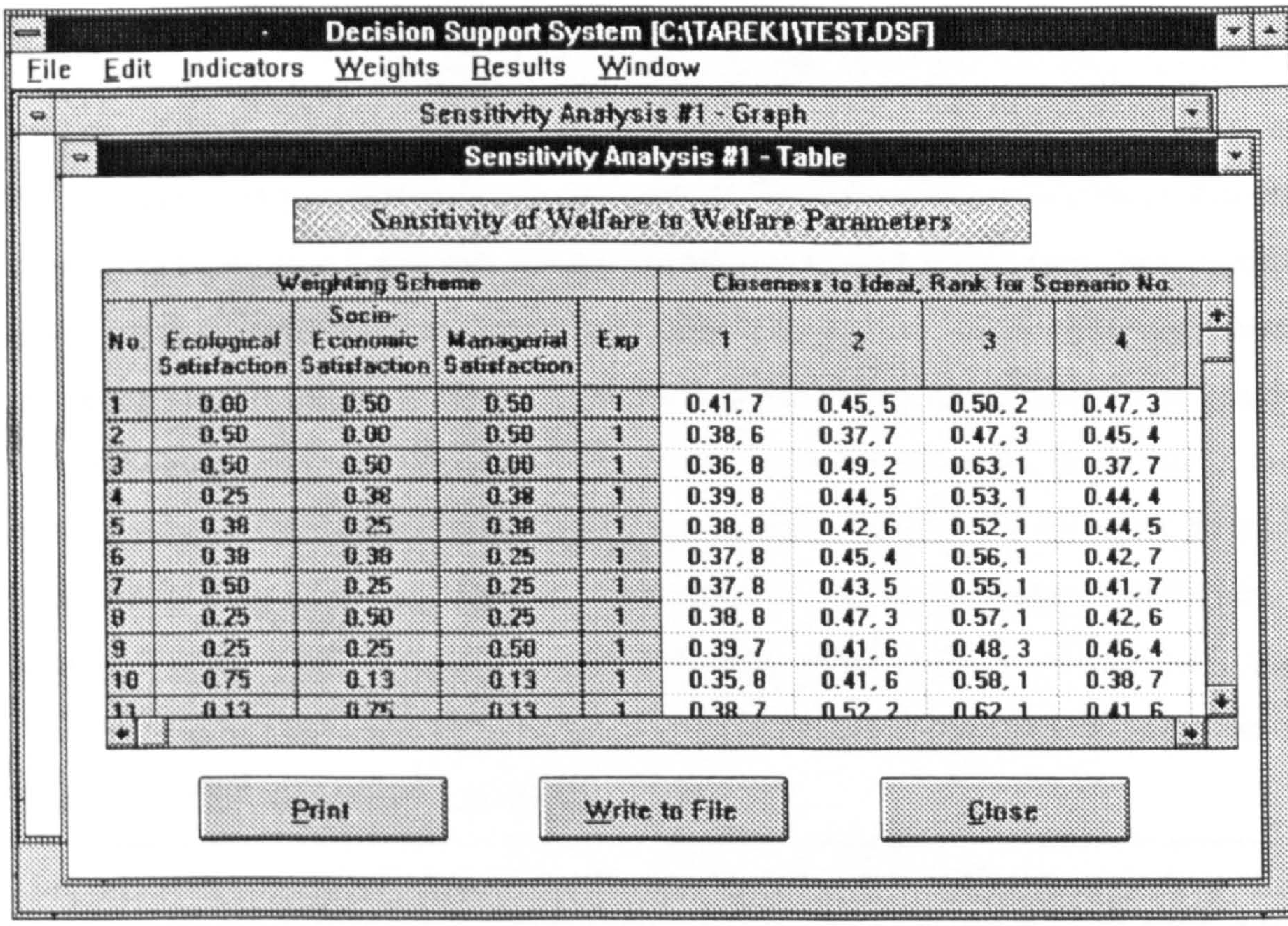


Figure 16 Sensitivity Parameters Entry Form

After you have entered the parameters you want and selected the desired form of output, click *'OK'* and the program starts the calculations and displays the progress bar. When calculations are finished, the selected output is displayed. The table displayed in Figure 17 shows the closeness to the ideal of each scenario and its rank for the different weighting schemes selected through the weight step and exponents. The graph of Figure 18 illustrates the closeness of each scenario to the ideal and its rank averaged over the various weighting schemes. In fact, the sensitivity graph is very similar to the results graphs except that the components of the selected indicator are not shown because their contribution will vary for each weighting scheme. The used sensitivity parameters are shown instead. The buttons on the graph and table



Weighting Scheme					Closeness to Ideal, Rank for Scenario No.			
No.	Ecological Satisfaction	Socio-Economic Satisfaction	Managerial Satisfaction	Exp	1	2	3	4
1	0.00	0.50	0.50	1	0.41, 7	0.45, 5	0.50, 2	0.47, 3
2	0.50	0.00	0.50	1	0.38, 6	0.37, 7	0.47, 3	0.45, 4
3	0.50	0.50	0.00	1	0.36, 8	0.49, 2	0.63, 1	0.37, 7
4	0.25	0.38	0.38	1	0.39, 8	0.44, 5	0.53, 1	0.44, 4
5	0.38	0.25	0.38	1	0.38, 8	0.42, 6	0.52, 1	0.44, 5
6	0.38	0.38	0.25	1	0.37, 8	0.45, 4	0.56, 1	0.42, 7
7	0.50	0.25	0.25	1	0.37, 8	0.43, 5	0.55, 1	0.41, 7
8	0.25	0.50	0.25	1	0.38, 8	0.47, 3	0.57, 1	0.42, 6
9	0.25	0.25	0.50	1	0.39, 7	0.41, 6	0.48, 3	0.46, 4
10	0.75	0.13	0.13	1	0.35, 8	0.41, 6	0.58, 1	0.38, 7
11	0.13	0.75	0.13	1	0.38, 7	0.52, 2	0.62, 1	0.41, 6

Figure 17 Results of Sensitivity Analysis in Tabular Format

windows work in the same way as for other results windows.

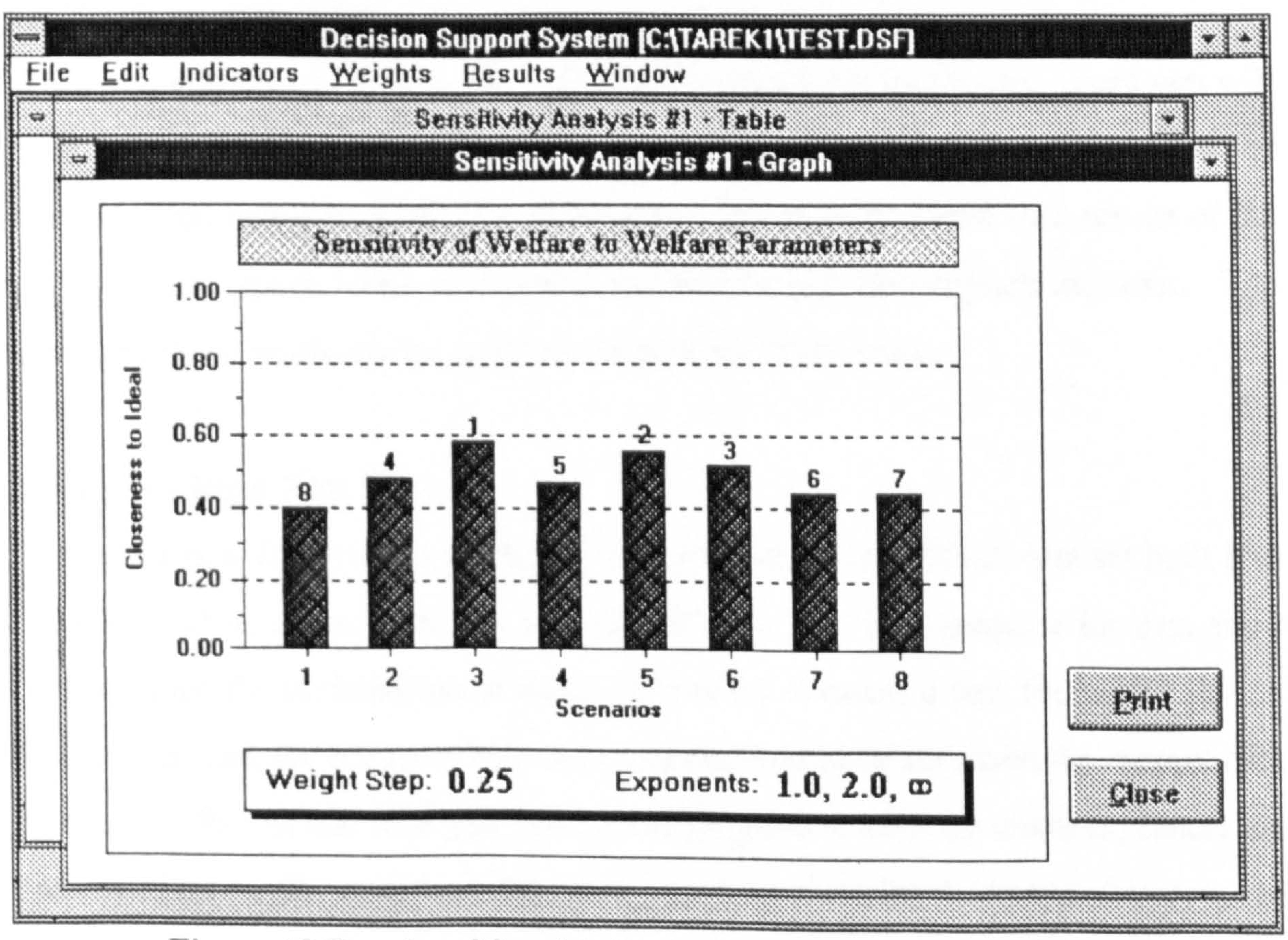


Figure 18 Results of Sensitivity Analysis in Graphical Format

You can perform as many sensitivity analyses as you want (you are only limited by your computer's memory) and view them all while viewing other results windows at the same time. This may facilitate the comparison between different schemes, but the screen may become crowded with so many windows. In such a case, you can minimise some windows, move others apart to be able to compare. The 'Window' menu provides an active list of all the open windows (even if they are minimised) to enable fast switching between open windows. It also provides 'Arrange Icons' for a fast arrangement of the minimised windows, and a fast closure of all windows through 'Close All' item. Choose 'Cascade' to arrange all the open windows behind each others. If you try to access any of the data menus, namely 'Edit', 'Indicators', and 'Weights', all the open results windows will be closed as the program expects you to change the data to perform a different analysis.

Important: If you close a 'Sensitivity Analysis' window, you will need to perform the analysis again with the same parameters. It is therefore recommended to minimise this window instead of closing it. On the other hand, in the case of results windows, results will still be saved in computer's memory even if you close their windows.

5.4 Working with Files

When you enter a set of data, you will need to save it for future use. Then you will need to load it some time later for entry completion/modification or to perform the analysis. You may also need to print the input data to be enclosed with results of the analysis in a report. You will definitely need to end the program and exit. The aforementioned needs can be satisfied through the 'File' menu.

5.4.1 Creating a New File

To create a new file, use the menu sequence File|New. The default data set built into the DSS will be copied to a new untitled file to be used as a template for data entry (this is called the initialisation of data). If you try to create a new file before saving the existing one, the program will warn you that you have not saved the current data set (Figure 19). At that time you can tell the program to save the changes, cancel the opening of a new file, or discard the changes and continue the initialization process of the new file. The same message is displayed when you try to Exit the program without saving the current data set.

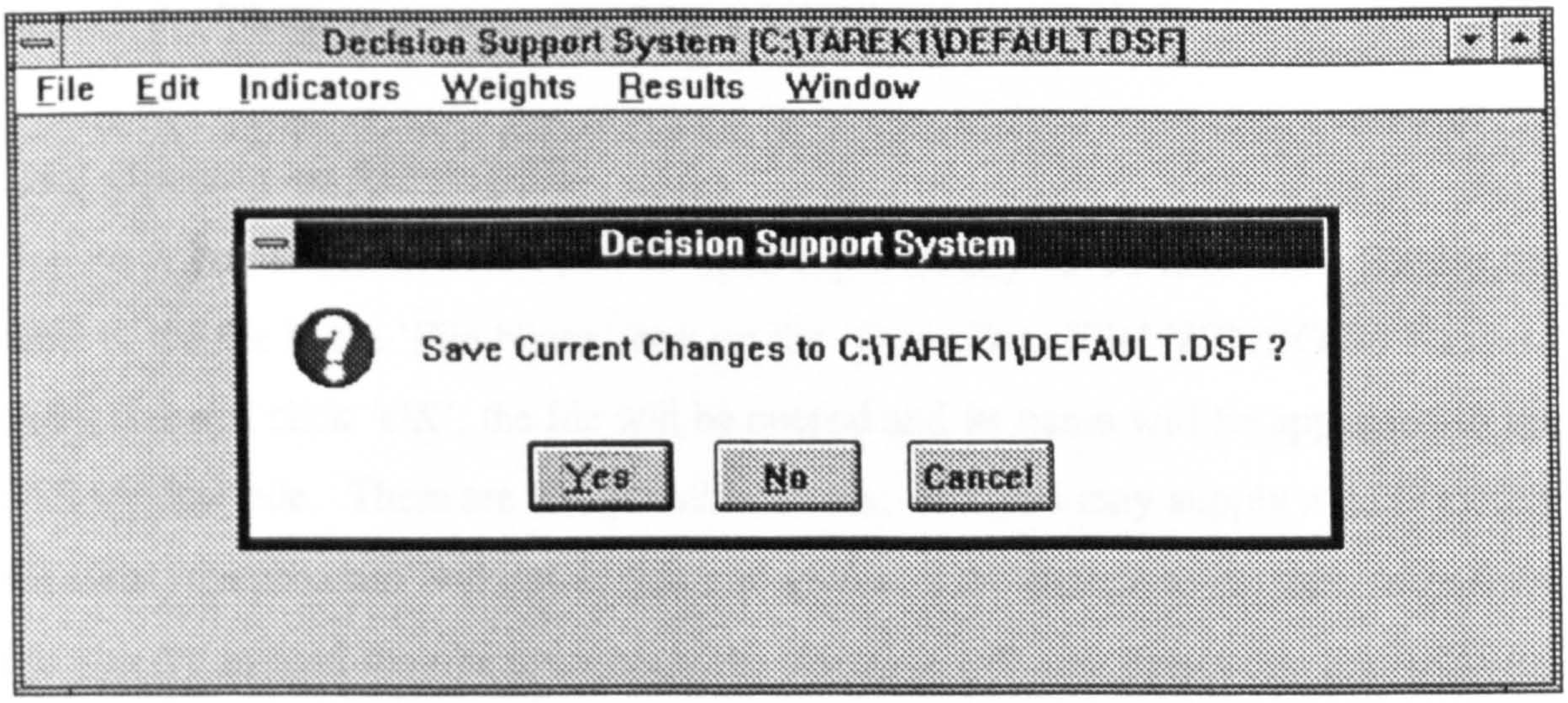


Figure 19 Warning Dialog Box for not Saving the Changes

5.4.2 Saving Data to a File

To save the changes you have made to a file, use the menu sequence File|Save or the short cut ***Ctrl-S***. If you have not saved the file previously, a WINDOWS standard 'Save As' dialog box will be displayed (Figure 20) to allow the user to provide the file name and choose its location. If you choose an existing name, the program will ask for a confirmation to/to not overwrite. The path and name of the saved file will be appended to the title of the menu. If you make some changes and save the file again,

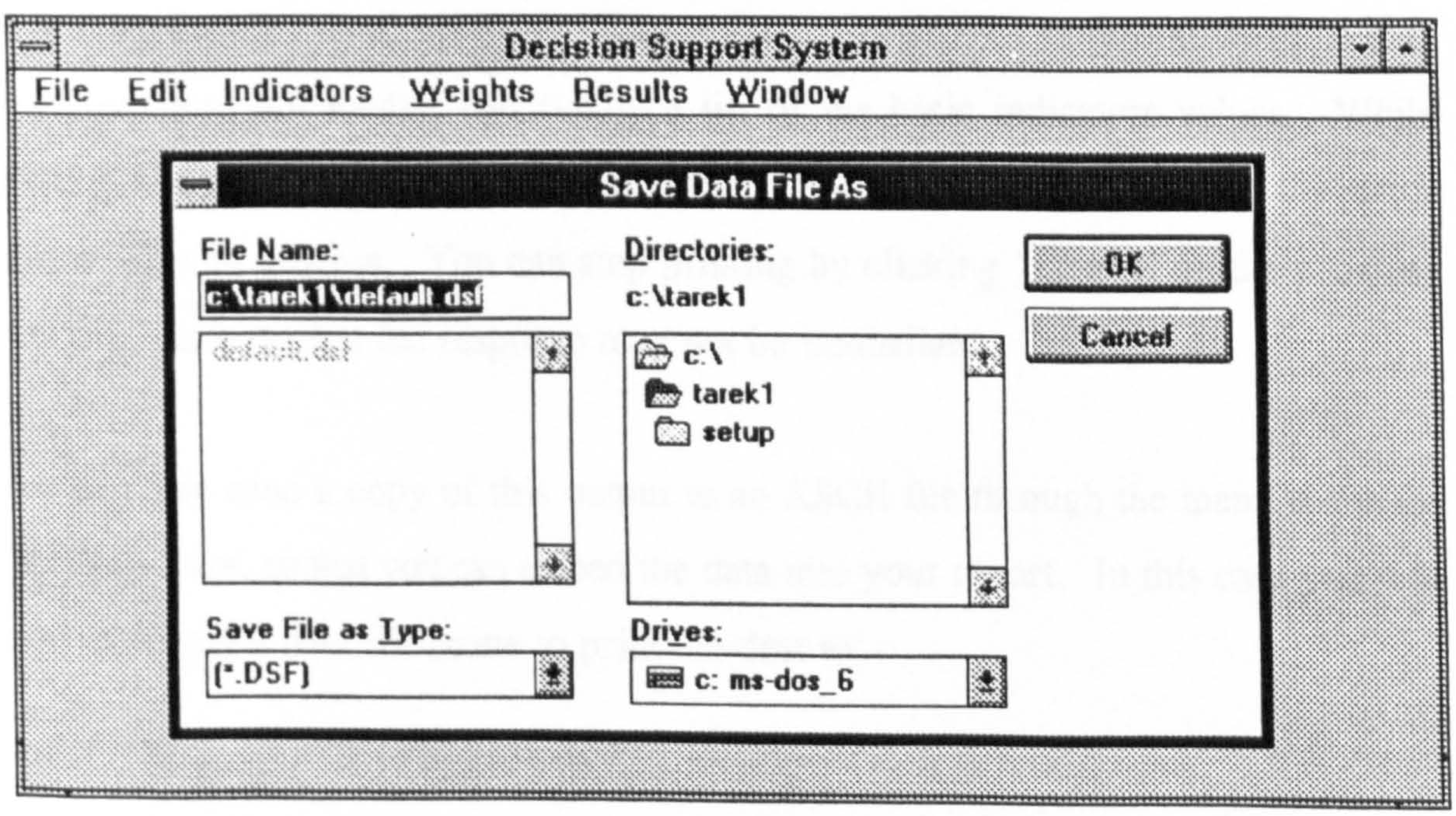


Figure 20 The Standard WINDOWS Save-As Dialog Box

it will be saved directly with the same name and the old data will be overwritten. To keep the old data, you need to save the file with a different name which can be done through the File|Save As menu sequence (or the short cut ***Ctrl-A***).

5.4.3 Opening an Existing File

Use the menu sequence File|Open to open a previously saved data file. Supply the name of the file in the 'File Name' box on the 'Open Data File' WINDOWS standard dialog box and click *'OK'*, the file will be opened and its name will be appended to the DSS window title. There are two possible errors; first you may supply a non existing file name, the program will detect that and give you the chance to correct, second the file you try to load may be corrupted, the program will also detect that and will stop loading it. The program uses 'DSF' (Decision Support File) as a default extension for saved and loaded files. However, you can save and load files with different extensions as long as the file format is correct.

Important: DSFs are saved in a binary format and the program checks the file format while loading it. Any trial to edit the file using any editor will result in corrupting the file. DSS can only read files saved within its environment.

5.4.4 Printing Data

Through the menu sequence File|Print Data, you can get a formatted hardcopy of your data. To print a scenario's whole data, two pages are needed. The program is capable of printing the crop data, the water balance data, the fisheries deterioration basic data (outflows and salt loads), and finally a list of the basic indicators values. While printing, the program will display a progress bar in a small window showing the status of the printing process. You can stop printing by clicking '*Cancel*' on the progress window, but note that the response may not be immediate.

You can also send a copy of this output to an ASCII file through the menu sequence File| Write Data, so that you can embed the data into your report. In this case you will need to supply a data file name to print the data to.

5.4.5 Exiting the DSS

After you have finished your data entry and/or analysis, you may want to end the program. Use the menu sequence File|Exit (or the short cut *Ctrl-X*), to end the execution of the DSS. If your file has changed since the last time you saved it, the program will give you a chance to save it before exiting.

Now, we have gone together through the different tasks that DSS can do. What remains now is that you prepare your scenarios and take off performing the analysis.

APPENDIX D

```
************************************************************************
*    This program computes the composite distances of different options
*     of water use and prioritises their use by ranking them from best
*    to worst according to pre-defined criteria.
************************************************************************
      DIMENSION Z(19,3)
      DIMENSION MAX(19)
      DIMENSION MIN(19)
      DIMENSION BESVAL(19)
      DIMENSION WORVAL(19)
      DIMENSION S(19,3)
      DIMENSION LJ(3,9,3)
      DIMENSION LJF(9,3)
      DIMENSION LK(3,3,3)
      DIMENSION LKF(3,3)
      DIMENSION LL(3,3)
      DIMENSION LLF(3)
      DIMENSION ORDER(3)
*
      INTEGER I,J,K,L,T,P,CHP,ORDER,COUNT,COUN,C,R
      REAL Z,S,MAX,MIN,BESVAL,WORVAL,A1,A2,A3,LJ,LJF,LK,LKF,LL,LLF,PCH
*
      CHARACTER*40 INFO (19)
      CHARACTER*40 INFO1 (9)
      CHARACTER*40 INFO2 (3)
      CHARACTER*40 INFO3
*
      OPEN (UNIT=7,FILE='C:\PROFOR\DATAFILE\INFO3.DAT',STATUS='OLD')
      OPEN (UNIT=8,FILE='C:\PROFOR\DATAFILE\INFO2.DAT',STATUS='OLD')
      OPEN (UNIT=9,FILE='C:\PROFOR\DATAFILE\INFO1.DAT',STATUS='OLD')
      OPEN (UNIT=10,FILE='C:\PROFOR\DATAFILE\BASLEVDA.DAT',STATUS='OLD')
      OPEN (UNIT=11,FILE='C:\PROFOR\DATAFILE\INFO.DAT',STATUS='OLD')
      OPEN (UNIT=20,FILE='C:\PROFOR\DATAFILE\ZTAB.DAT',STATUS='UNKNOWN')
      OPEN (UNIT=21,FILE='C:\PROFOR\DATAFILE\STAB.DAT',STATUS='UNKNOWN')
      OPEN (UNIT=22,FILE='C:\PROFOR\DATAFILE\Lj.DAT',STATUS='UNKNOWN')
      OPEN (UNIT=23,FILE='C:\PROFOR\DATAFILE\Lk.DAT',STATUS='UNKNOWN')
      OPEN (UNIT=24,FILE='C:\PROFOR\DATAFILE\Ll.DAT',STATUS='UNKNOWN')
      OPEN (UNIT=26,FILE='C:\PROFOR\DATAFILE\RANK.DAT',STATUS='UNKNOWN')
*
      READ (10,*) ((Z(I,T),T=1,3),I=1,19)
      READ (11,'(A)') (INFO(I),I=1,19)
      READ (9,'(A)') (INFO1(J),J=1,9)
      READ (8,'(A)') (INFO2(K),K=1,3)
      READ (7,'(A)') INFO3
*
      PRINT 1
      WRITE (20,1)
    1 FORMAT (1X,'The table below shows the basic indicator values(Z) fo
     +r the three options')
      PRINT 2
      WRITE (20,2)
    2 FORMAT ('______________________________________________________________
     +___________')
      PRINT 5
      WRITE (20,5)
    5 FORMAT (1X,'Basic Indicators                    1
     +2          3')
```

```
      PRINT 7
      WRITE (20,7)
 7    FORMAT ('________________________________________________________________
     +___________')
      DO 20 I=1,19
          IF (INFO(I).EQ.' ') THEN
            PRINT*, ' '
            WRITE(20,*) ' '
            GOTO 20
          ENDIF
          PRINT 10, (Z(I,T),T=1,3)
          WRITE (20,10) (Z(I,T),T=1,3)
 10   FORMAT (41X,F8.3,2X,F8.3,2X,F8.3)
          PRINT 15, INFO(I)
          WRITE (20,15) INFO(I)
 15   FORMAT ('+',A)
 20   CONTINUE
      PRINT 22
      WRITE (20,22)
 22   FORMAT ('________________________________________________________________
     +___________')
      PRINT*, 'Press any key to continue'
      READ*
*
*
*
      J=1
      K=1
      DO 50 I=1,19
          IF (INFO(I).EQ.' ') THEN
            J=J+1
            IF (INFO1(J).EQ.' ') J=J+1
            GOTO 50
          ENDIF
          T=1
          MAX(I)=Z(I,T)
          MIN(I)=Z(I,T)
*
          CALL OPTIMZ(MAX,MIN,Z,I,T)
*
       PRINT 23, INFO(I)
 23   FORMAT ('0','The values of the basic indicator ', A,'     for the
     + different options are :')
          PRINT 25, (Z(I,T),T=1,3)
 25   FORMAT ('0',40X,F8.3,2X,F8.3,2X,F8.3)
 30   PRINT 35, MAX(I),MIN(I)
 35   FORMAT ('0','MAX. VALUE (Zmax) =',2X,F8.3,5X,'MIN. VALUE (Zmin)
     +=',F8.3)
          PRINT 40, INFO(I), INFO1(J)
 40   FORMAT ('0','What extreme value of the indicator ',A,'    is bes
     +t for ',A,' ?  (Enter Value) ')
          READ*, BESVAL(I)
 43   PRINT 44, INFO(I), INFO1(J)
 44   FORMAT ('0','What extreme value of the indicator ',A,'    is wor
     +st for ',A,'?  (Enter Value) ')
       READ*, WORVAL(I)
       DO 45 T=1,3
```

```
        IF (BESVAL(I).GE.MAX(I)) THEN
          S(I,T)=(Z(I,T)-WORVAL(I))/(BESVAL(I)-WORVAL(I))
        ELSEIF (BESVAL(I).LE.MIN(I)) THEN
          S(I,T)=(WORVAL(I)-Z(I,T))/(WORVAL(I)-BESVAL(I))
        ELSE
          PRINT*, 'ERROR ! PLEASE RETYPE BEST AND WORST VALUES '
          GOTO 43
        ENDIF
 45   CONTINUE
        PRINT*,'                    ____________________'
        PRINT*,' '
 50   CONTINUE
      PRINT 52
 52   FORMAT ('0',' ')
      PRINT 53
 53   FORMAT ('0',' ')
*
 55   CALL SARRAY(S,I,T,INFO)
*
*
*
      J=1
      I=1
 60   IF (I.EQ.20) THEN
        GOTO 250
*
*
      ELSEIF (INFO(I).EQ.' ') THEN
        J=J+1
        I=I+1
        IF (INFO1(J).EQ.' ') J=J+1
        GOTO 60
*
*
      ELSEIF (I.EQ.8.OR.I.EQ.19) THEN
        DO 70 T=1,3
          LJF(J,T)=S(I,T)
 70     CONTINUE
        I=I+1
        GOTO 60
*
*
      ELSEIF (I.EQ.5.OR.I.EQ.10.OR.I.EQ.13.OR.I.EQ.16) THEN
 75     PRINT 80
 80     FORMAT ('0','Enter the weights of the following basic indicators
     +  that are traded off ;')
        PRINT 81, INFO(I)
 81     FORMAT (1X,A)
        PRINT 82, INFO(I+1)
 82     FORMAT (1X,A)
        PRINT*, 'such that their sum equals one ! '
 85     PRINT 90, INFO(I)
 90     FORMAT ('0','Weight (a1) of the basic indicator ',A,'     is  ')
        READ*, A1
        A2=1-A1
        PRINT 95, INFO(I+1),A2
 95     FORMAT (' ','Consequently weight (a2) of ',A,'          will b
```

```
  +c  ',F4.2)
       PRINT*,' '
       PRINT*,'Press any key to continue'
       READ*
       PRINT 97
97  FORMAT ('0','The table below contains Lj values for trading-off;')
       PRINT*, INFO(I)
       PRINT*, INFO(I+1)
   PRINT*,'when P = 1, 2 & 3 and their ranks for different scenarios'
       PRINT*, '_______________________________________________________
  +_____________'
       PRINT 99
99  FORMAT (1X,'First Level Impacts                    1
  +2        3')
       PRINT*, '_______________________________________________________
  +_____________'
       P=1
100   DO 105 T=1,3
         LJ(P,J,T)=(A1*(S(I,T))**P+A2*(S((I+1),T))**P)**(1.0/REAL(P))
105   CONTINUE
106   PRINT 107, (LJ(P,J,T),T=1,3)
107   FORMAT ('0',40X,F8.3,2X,F8.3,2X,F8.3)
        PRINT 108, INFO1(J)
108   FORMAT ('+',A)
*
110   CALL LJCLASS(COUNT,COUN,ORDER,T,P,J,LJ,INFO1)
*
        P=P+1
        IF (P.EQ.2) THEN
          GOTO 100
        ELSEIF (P.EQ.3) THEN
          DO 115 T=1,3
            IF (S(I,T).GE.S((I+1),T)) THEN
              LJ(P,J,T)=S(I,T)
            ELSE
              LJ(P,J,T)=S((I+1),T)
            ENDIF
 115    CONTINUE
          GOTO 106
        ELSE
        ENDIF
        I=I+2
        GOTO 227
*
*
    ELSEIF (I.EQ.1) THEN
        PRINT 116
 116   FORMAT ('0','Enter the weights of the following basic indicators
    + that are traded off;')
        PRINT 117, INFO(I)
 117   FORMAT (1X,A)
        PRINT 118, INFO(I+1)
 118   FORMAT (1X,A)
        PRINT 119, INFO(I+2)
 119   FORMAT (1X,A)
        PRINT*,'such that their sum equals one ! '
        PRINT 120, INFO(I)
```

```
120   FORMAT ('0','Weight (a1) of the basic indicator ',A,'    is  ')
       READ*, A1
       PRINT 125, INFO(I+1)
125   FORMAT ('0','Weight (a2) of the basic indicator ',A,'    is  ')
       READ*, A2
       A3=1-A1-A2
       PRINT 130, INFO(I+2),A3
130   FORMAT (' ','Consequently weight (a3) of ',A,'          will b
   +e  ',F4.2)
       PRINT*,' '
       PRINT*,'Press any key to continue'
       READ*
       PRINT 132
132  FORMAT ('0','The table below contains Lj values for trading-off;')
       PRINT*, INFO(I)
       PRINT*, INFO(I+1)
       PRINT*, INFO(I+2)
   PRINT*,'when P = 1, 2 & 3 and their ranks for different scenarios'
       PRINT*, '_____________________________________________________
   +_____________'
       PRINT 133
133  FORMAT (1X,'First Level Impacts                    1
   +2          3')
       PRINT*, '_____________________________________________________
   +_____________'
       P=1
135   DO 140 T=1,3
          LJ(P,J,T)=(A1*(S(I,T))**P+A2*(S((I+1),T))**P+A3*(S((I+2),T))**
   +P)**(1.0/REAL(P))
140   CONTINUE
142   PRINT 143, (LJ(P,J,T),T=1,3)
143   FORMAT ('0',40X,F8.3,2X,F8.3,2X,F8.3)
       PRINT 144, INFO1(J)
144   FORMAT ('+',A)
*
145   CALL LJCLASS(COUNT,COUN,ORDER,T,P,J,LJ,INFO1)
*
       P=P+1
       IF (P.EQ.2) THEN
         GOTO 135
       ELSEIF (P.EQ.3) THEN
         DO 160 T=1,3
           DO 155 C=I,(I+2)
             DO 150 R=I,(I+2)
                 IF (S(C,T).LT.S(R,T)) GOTO 155
150          CONTINUE
             LJ(P,J,T)=S(C,T)
155        CONTINUE
160      CONTINUE
         GOTO 142
       ELSE
       ENDIF
       I=I+3
       GOTO 227
*
*
*
```

```
   ELSE
   ENDIF
*
*
227     PRINT*,'                              ________________'
          PRINT*,' '
230     PRINT*, 'Choose a value for P (1, 2, 3) '
          READ*, PCH
         IF(PCH.NE.1.AND.PCH.NE.2.AND.PCH.NE.3) THEN
            PRINT*, 'ERROR ! PLEASE RETYPE 1, 2 OR 3'
            GOTO 230
          ENDIF
          CHP=PCH
        PRINT*, '__________________________________________
   +___________'
235   DO 240 T=1,3
          LJF(J,T)=LJ(CHP,J,T)
240   CONTINUE
*
   GOTO 60
*
250  CALL LJARRAY(LJF,J,T,INFO1)
*
*
   K=1
   J=1
260  IF(J.EQ.10) THEN
        GOTO 550
*
*
   ELSEIF(INFO1(J).EQ.' ') THEN
        K=K+1
        J=J+1
        IF(INFO2(K).EQ.' ') K=K+1
        GOTO 260
*
*
   ELSEIF(J.EQ.1.OR.J.EQ.4) THEN
        PRINT 261
261    FORMAT ('0','Enter the weights of the following basic indicators
   + that are traded off;')
        PRINT 262, INFO1(J)
262    FORMAT (1X,A)
        PRINT 263, INFO1(J+1)
263    FORMAT (1X,A)
        PRINT*, 'such that their sum equals one ! '
        PRINT 270, INFO1(J)
270    FORMAT ('0','Weight (a1) of the basic indicator ',A,'     is  ')
        READ*, A1
        A2=1-A1
        PRINT 275, INFO1(J+1),A2
275    FORMAT (' ','Consequently weight (a2) of ',A,'          will b
   +e  ',F8.3)
        PRINT*,' '
        PRINT*,'Print any key to continue'
        READ*
        PRINT 280
```

```
280 FORMAT ('0','The table below contains Lk values for trading-off;')
       PRINT*, INFO1(J)
       PRINT*, INFO1(J+1)
    PRINT*,'when P = 1, 2 & 3 and their ranks for different scenarios'
       PRINT*, '_______________________________________________________
   +_____________'
       PRINT 285
285 FORMAT (1X,'Second Level Impacts                    1
   +2         3')
       PRINT*, '_______________________________________________________
   +_____________'
       P=1
287   DO 290 T=1,3
         LK(P,K,T)=(A1*(LJF(J,T))**P+A2*(LJF((J+1),T))**P)**(1.0/REAL(P
   +))
290   CONTINUE
295   PRINT 300, (LK(P,K,T),T=1,3)
300   FORMAT ('0',40X,F8.3,2X,F8.3,2X,F8.3)
       PRINT 308, INFO2(K)
308   FORMAT ('+',A)
*
310   CALL LKCLASS(COUNT,COUN,ORDER,T,P,K,LK,INFO2)
*
       P=P+1
       IF (P.EQ.2) THEN
         GOTO 287
       ELSEIF (P.EQ.3) THEN
         DO 315 T=1,3
           IF (LJF(J,T).GE.LJF((J+1),T)) THEN
             LK(P,K,T)=LJF(J,T)
           ELSE
             LK(P,K,T)=LJF((J+1),T)
           ENDIF
315     CONTINUE
         GOTO 295
       ELSE
       ENDIF
       J=J+2
       GOTO 520
*
*
    ELSEIF(J.EQ.7) THEN
       PRINT 361
361   FORMAT ('0','Enter the weights of the following basic indicators
   + that are traded off;')
       PRINT 362, INFO1(J)
362   FORMAT (1X,A)
       PRINT 363, INFO1(J+1)
363   FORMAT (1X,A)
       PRINT 364, INFO1(J+2)
364   FORMAT (1X,A)
       PRINT*,'such that their sum equals one ! '
       PRINT 370, INFO1(J)
370   FORMAT ('0','Weight (a1) of the 1st level indicator ',A,' is  ')
       READ*, A1
       PRINT 375, INFO1(J+1)
375   FORMAT ('0','Weight (a2) of the 1st level indicator ',A,' is  ')
```

```
      READ*, A2
      A3=1-A1-A2
      PRINT 380, INFO1(J+2),A3
380   FORMAT (' ','Consequently weight (a3) of ',A,'          will b
   +e  ',F4.2)
      PRINT*,' '
      PRINT*,'Press any key to continue'
      READ*
      PRINT 385
385  FORMAT ('0','The table below contains Lk values for trading-off;')
      PRINT*, INFO1(J)
      PRINT*, INFO1(J+1)
      PRINT*, INFO1(J+2)
   PRINT*,'when P = 1, 2 & 3 and their ranks for different scenarios'
        PRINT*, '_______________________________________________
   +______________'
      PRINT 390
390  FORMAT (1X,'Second Level Impacts                    1
   +2         3')
      PRINT*, '_______________________________________________
   +______________'
      P=1
395   DO 400 T=1,3
        LK(P,K,T)=(A1*(LJF(J,T))**P+A2*(LJF((J+1),T))**P+A3*(LJF((J+2)
   +,T))**P)**(1.0/REAL(P))
400   CONTINUE
405   PRINT 410, (LK(P,K,T),T=1,3)
410   FORMAT ('0',40X,F8.3,2X,F8.3,2X,F8.3)
      PRINT 420, INFO2(K)
420   FORMAT ('+',A)
*
425   CALL LKCLASS(COUNT,COUN,ORDER,T,P,K,LK,INFO2)
*
      P=P+1
      IF (P.EQ.2) THEN
        GOTO 395
      ELSEIF (P.EQ.3) THEN
        DO 440 T=1,3
          DO 435 C=J,(J+2)
            DO 430 R=J,(J+2)
              IF (LJF(C,T).LT.LJF(R,T)) GOTO 435
430         CONTINUE
            LK(P,K,T)=LJF(C,T)
435       CONTINUE
440     CONTINUE
        GOTO 405
      ELSE
      ENDIF
      J=J+3
      GOTO 520
*
*
*
    ELSE
    ENDIF
*
*
```

```
520     PRINT*,'                              ______________________'
          PRINT*,' '
525     PRINT*, 'Choose a value for P (1, 2, 3)  '
          READ*, PCH
          IF(PCH.NE.1.AND.PCH.NE.2.AND.PCH.NE.3) THEN
            PRINT*, 'ERROR ! PLEASE RETYPE 1, 2 OR 3'
            GOTO 525
          ENDIF
          CHP=PCH
        PRINT*, '_____________________________________________
   +___________'
530   DO 535 T=1,3
          LKF(K,T)=LK(CHP,K,T)
535   CONTINUE
*
   GOTO 260
*
 550 CALL LKARRAY(LKF,K,T,INFO2)
*
*
   L=1
   K=1
 560 IF(K.EQ.4) THEN
        GOTO 780
*
*
*
    ELSE
         PRINT 561
 561   FORMAT ('0','Enter the weights of the following basic indicators
    + that are traded off;')
         PRINT 562, INFO2(K)
 562   FORMAT (1X,A)
         PRINT 563, INFO2(K+1)
 563   FORMAT (1X,A)
         PRINT 564, INFO2(K+2)
 564   FORMAT (1X,A)
         PRINT*,'such that their sum equals one ! '
         PRINT 590, INFO2(K)
 590   FORMAT ('0','Weight (a1) of the 2nd level indicator ',A,' is  ')
         READ*, A1
         PRINT 592, INFO2(K+1)
 592   FORMAT ('0','Weight (a2) of the 2nd level indicator ',A,' is  ')
         READ*, A2
         A3=1.0-A1-A2
         PRINT 595, INFO2(K+2),A3
 595   FORMAT (' ','Consequently weight (a3) of ',A,'          will b
    +e  ',F4.2)
         PRINT*,' '
         PRINT*,'Press any key to continue'
         READ*
         PRINT 600
 600  FORMAT ('0','The table below contains LI values for trading-off;')
         PRINT*, INFO2(K)
         PRINT*, INFO2(K+1)
         PRINT*, INFO2(K+2)
     PRINT*,'when P = 1, 2 & 3 and their ranks for different scenarios'
```

```
      PRINT*, '_____________________________________________________
     +_____________'
      PRINT 610
610 FORMAT (1X,'Final Level Impacts                    1
     +2          3')
      PRINT*, '_____________________________________________________
     +_____________'
      P=1
615  DO 620 T=1,3
        LL(P,T)=(A1*(LKF(K,T))**P+A2*(LKF((K+1),T))**P+A3*(LKF((K+2),T
     +))**P)**(1.0/REAL(P))
620  CONTINUE
625  PRINT 630, (LL(P,T),T=1,3)
630  FORMAT ('0',40X,F8.3,2X,F8.3,2X,F8.3)
      PRINT 640, INFO3
640  FORMAT ('+',A)
*
645  CALL LLCLASS(COUNT,COUN,ORDER,T,P,LL,INFO3)
*
      P=P+1
      IF (P.EQ.2) THEN
        GOTO 615
      ELSEIF (P.EQ.3) THEN
        DO 660 T=1,3
          DO 655 C=J,(J+2)
            DO 650 R=J,(J+2)
                IF (LKF(C,T).LT.LKF(R,T)) GOTO 655
650        CONTINUE
            LL(P,T)=LKF(C,T)
655      CONTINUE
660    CONTINUE
        GOTO 625
      ELSE
      ENDIF
      K=K+3
      GOTO 745
*
   ENDIF
*
*
745    PRINT*,'                    _________________'
        PRINT*,' '
750    PRINT*, 'Choose a value for P (1, 2, 3)  '
        READ*, PCH
        IF(PCH.NE.1.AND.PCH.NE.2.AND.PCH.NE.3) THEN
          PRINT*, 'ERROR ! PLEASE RETYPE 1, 2 OR 3'
          GOTO 750
        ENDIF
        CHP=PCH
       PRINT*, '_____________________________________________________
     +_____________'
755  DO 760 T=1,3
        LLF(T)=LL(CHP,T)
760  CONTINUE
*
   GOTO 560
*
```

```
780 CALL LLARRAY(LLF,T,INFO3)
*
800 CALL LLFRANK(COUNT,COUN,ORDER,T,LLF,INFO3)
*
   END
*-----------------------------------------------------------*
*
   SUBROUTINE OPTIMZ(MAX,MIN,Z,I,T)
*
   DIMENSION Z(19,3)
   DIMENSION MAX(19)
   DIMENSION MIN(19)
   INTEGER I,T,COUNT
   REAL MAX,MIN,Z
   DO 1000 T=2,3
       IF (Z(I,T).GT.MAX(I)) THEN
         MAX(I)=Z(I,T)
       ELSEIF (Z(I,T).LT.MIN(I)) THEN
         MIN(I)=Z(I,T)
       ELSE
       ENDIF
1000 CONTINUE
   RETURN
   END
*-----------------------------------------------------------*
*
   SUBROUTINE SARRAY(S,I,T,INFO)
*
   DIMENSION S(19,3)
   INTEGER I,T
   REAL S
   CHARACTER*40 INFO(19)
   PRINT 1010
   WRITE (21,1010)
1010 FORMAT ('0','The table below contains the calculated (S) values')
   PRINT 1015
   WRITE (21,1015)
1015 FORMAT ('______________________________________________________
   +___________')
   PRINT 1020
   WRITE (21,1020)
1020 FORMAT (1X,'Basic Indicators                    1
   +2        3')
   PRINT 1022
   WRITE (21,1022)
1022 FORMAT ('______________________________________________________
   +___________')
   DO 1050 I=1,19
       IF (INFO(I).EQ.' ') THEN
         PRINT*, ' '
         WRITE (21,*) ' '
         GOTO 1050
       ENDIF
       PRINT 1030, (S(I,T),T=1,3)
       WRITE (21,1030) (S(I,T),T=1,3)
1030   FORMAT (41X,F8.3,2X,F8.3,2X,F8.3)
       PRINT 1040, INFO(I)
```

```
      WRITE (21,1040) INFO(I)
1040  FORMAT ('+',A)
1050 CONTINUE
    PRINT 1052
    WRITE (21,1052)
1052 FORMAT ('________________________________________________
   +__________')
    PRINT*,'Press any key to continue'
    READ*
    RETURN
    END
*--------------------------------------------*
*
    SUBROUTINE LJCLASS(COUNT,COUN,ORDER,T,P,J,LJ,INFO1)
*
    DIMENSION LJ(3,9,3)
    DIMENSION ORDER(3)
    INTEGER COUNT,COUN,ORDER,T,P,J
    REAL LJ
    CHARACTER*40 INFO1 (9)
*
1070   DO 1100 COUNT=1,3
          ORDER(COUNT)=1
          DO 1080 T=1,3
            IF (COUNT.EQ.T) GOTO 1080
            IF (LJ(P,J,COUNT).LT.LJ(P,J,T)) ORDER(COUNT)=ORDER(COUNT)+1
1080     CONTINUE
          IF (COUNT.GE.2) THEN
            DO 1090 COUN=1,(COUNT-1)
          IF (LJ(P,J,COUN).EQ.LJ(P,J,COUNT)) ORDER(COUNT)=ORDER(COUNT)+1
1090      CONTINUE
          ENDIF
1100   CONTINUE
        PRINT 1130, P,(ORDER(COUNT),COUNT=1,3)
1130   FORMAT (1X,'Rank of options when P=',I1,19X,'Rk.',I2,5X,'Rk.',I2
    +,5X,'Rk.',I2)
    RETURN
    END
*--------------------------------------------*
*
    SUBROUTINE LJARRAY(LJF,J,T,INFO1)
*
    DIMENSION LJF(9,3)
    INTEGER J,T
    REAL LJF
    CHARACTER*40 INFO1 (9)
*
    PRINT 1135
    WRITE (22,1135)
1135 FORMAT ('0','The table below contains the calculated (Lj) values')
    PRINT 1137
    WRITE (22,1137)
1137 FORMAT ('________________________________________________
   +__________')
    PRINT 1140
    WRITE (22,1140)
1140 FORMAT (1X,'First Level Impacts                   1
```

```
   +2        3')
   PRINT 1142
   WRITE (22,1142)
1142 FORMAT ('______________________________________________
   +__________')
   DO 1160 J=1,9
       IF (INFO1(J).EQ.' ') THEN
         PRINT*, ' '
         WRITE (22,*) ' '
         GOTO 1160
       ENDIF
       PRINT 1145, (LJF(J,T),T=1,3)
       WRITE (22,1145) (LJF(J,T),T=1,3)
1145   FORMAT (41X,F8.3,2X,F8.3,2X,F8.3)
       PRINT 1150, INFO1(J)
       WRITE (22,1150) INFO1(J)
1150   FORMAT ('+',A)
1160 CONTINUE
   PRINT 1162
   WRITE (22,1162)
1162 FORMAT ('______________________________________________
   +__________')
   RETURN
   END
*----------------------------------------------------------*
*
   SUBROUTINE LKCLASS(COUNT,COUN,ORDER,T,P,K,LK,INFO2)
*
   DIMENSION LK(3,3,3)
   DIMENSION ORDER(10)
   INTEGER COUNT,COUN,ORDER,T,P,K
   REAL LK
   CHARACTER*40 INFO2 (3)
*
1170   DO 1200 COUNT=1,3
         ORDER(COUNT)=1
         DO 1180 T=1,3
          IF (COUNT.EQ.T) GOTO 1180
          IF (LK(P,K,COUNT).LT.LK(P,K,T)) ORDER(COUNT)=ORDER(COUNT)+1
1180     CONTINUE
         IF (COUNT.GE.2) THEN
          DO 1190 COUN=1,(COUNT-1)
         IF (LK(P,K,COUN).EQ.LK(P,K,COUNT)) ORDER(COUNT)=ORDER(COUNT)+1
1190     CONTINUE
         ENDIF
1200   CONTINUE
        PRINT 1230, P,(ORDER(COUNT),COUNT=1,3)
1230   FORMAT (1X,'Rank of options when P=',I1,19X,'Rk.',I2,5X,'Rk.',I2
   +,5X,'Rk.',I2)
   RETURN
   END
*----------------------------------------------------------*
*
   SUBROUTINE LKARRAY(LKF,K,T,INFO2)
*
   DIMENSION LKF(3,3)
   INTEGER K,T
```

```
      REAL LKF
      CHARACTER*40 INFO2 (3)
*
      PRINT 1235
      WRITE (23,1235)
1235  FORMAT ('0','The table below contains the calculated (Lk) values')
      PRINT 1237
      WRITE (23,1237)
1237  FORMAT ('______________________________________________
     +__________')
      PRINT 1240
      WRITE (23,1240)
1240  FORMAT (1X,'Second Level Impacts                    1
     +2          3')
      PRINT 1242
      WRITE (23,1242)
1242  FORMAT ('______________________________________________
     +__________')
      DO 1260 K=1,3
          PRINT 1245, (LKF(K,T),T=1,3)
          WRITE (23,1245) (LKF(K,T),T=1,3)
1245    FORMAT (41X,F8.3,2X,F8.3,2X,F8.3)
          PRINT 1250, INFO2(K)
          WRITE (23,1250) INFO2(K)
1250    FORMAT ('+',A)
1260  CONTINUE
      PRINT 1262
      WRITE (23,1262)
1262  FORMAT ('______________________________________________
     +__________')
      RETURN
      END
*----------------------------------------------------------*
*
      SUBROUTINE LLCLASS(COUNT,COUN,ORDER,T,P,LL,INFO3)
*
      DIMENSION LL(3,3)
      DIMENSION ORDER(3)
      INTEGER COUNT,COUN,ORDER,T,P
      REAL LL
      CHARACTER*40 INFO3
*
1270    DO 1300 COUNT=1,3
          ORDER(COUNT)=1
          DO 1280 T=1,3
            IF (COUNT.EQ.T) GOTO 1280
            IF (LL(P,COUNT).LT.LL(P,T)) ORDER(COUNT)=ORDER(COUNT)+1
1280      CONTINUE
          IF (COUNT.GE.2) THEN
            DO 1290 COUN=1,(COUNT-1)
          IF (LL(P,COUN).EQ.LL(P,COUNT)) ORDER(COUNT)=ORDER(COUNT)+1
1290        CONTINUE
          ENDIF
1300    CONTINUE
         PRINT 1330, P,(ORDER(COUNT),COUNT=1,3)
1330    FORMAT (1X,'Rank of options when P=',I1,19X,'Rk.',I2,5X,'Rk.',I2
     +,5X,'Rk.',I2)
```

```
      RETURN
      END
*----------------------------------------------------*
*
      SUBROUTINE LLARRAY(LLF,T,INFO3)
*
      DIMENSION LLF(3)
      INTEGER T
      REAL LLF
      CHARACTER*10 INFO3
*
      PRINT 1335
      WRITE (24,1335)
1335  FORMAT ('0','The table below contains the calculated (LI) values')
      PRINT 1337
      WRITE (24,1337)
1337  FORMAT ('____________________________________________________
     +___________')
      PRINT 1340
      WRITE (24,1340)
1340  FORMAT (1X,'Third Level Impacts                    1
     +2        3')
      PRINT 1342
      WRITE (24,1342)
1342  FORMAT ('____________________________________________________
     +___________')
          PRINT 1345, (LLF(T),T=1,3)
          WRITE (24,1345) (LLF(T),T=1,3)
1345   FORMAT (41X,F8.3,2X,F8.3,2X,F8.3)
          PRINT 1350, INFO3
          WRITE (24,1350) INFO3
1350   FORMAT ('+',A)
C1360  CONTINUE
      PRINT 1362
      WRITE (24,1362)
1362  FORMAT ('____________________________________________________
     +___________')
      RETURN
      END
*----------------------------------------------------*
*
      SUBROUTINE LLFRANK(COUNT,COUN,ORDER,T,LLF,INFO3)
*
      DIMENSION LLF(3)
      DIMENSION ORDER(3)
      INTEGER COUNT,COUN,ORDER,T
      REAL LLF
      CHARACTER*40 INFO3
*
1470    DO 1500 COUNT=1,3
          ORDER(COUNT)=1
          DO 1480 T=1,3
            IF (COUNT.EQ.T) GOTO 1480
            IF (LLF(COUNT).LT.LLF(T)) ORDER(COUNT)=ORDER(COUNT)+1
1480      CONTINUE
          IF (COUNT.GE.2) THEN
            DO 1490 COUN=1,(COUNT-1)
```

```
      IF (LLF(COUN).EQ.LLF(COUNT)) ORDER(COUNT)=ORDER(COUNT)+1
1490  CONTINUE
      ENDIF
1500 CONTINUE
   WRITE (26,1505)
1505 FORMAT ('____________________________________________
   +__________')
   WRITE (26,1510)
1510 FORMAT (1X,'Final Level Impacts                1
   +2       3')
   WRITE (26,1515)
1515 FORMAT ('____________________________________________
   +__________')
      PRINT 1530, (ORDER(COUNT),COUNT=1,3)
      WRITE (26,1530) (ORDER(COUNT),COUNT=1,3)
1530  FORMAT (1X,'Final Rank of options for Egyptian Welfare',1X,'Rk.'
   +,I2,5X,'Rk.',I2,5X,'Rk.',I2)
      PRINT*, '____________________________________________
   +____________'
   RETURN
   END
```

APPENDIX E

Sensitivity of Welfare to Welfare Parameters

	Weighting Scheme				Closeness to Ideal, Rank for Scenario No.						
No.	Ecological Satisfaction	Socio-Economic Satisfaction	Managerial Satisfaction	Exp	1	2	3	4	5	6	7
1	0.00	0.50	0.50	1	0.58, 13	0.52, 15	0.22, 18	0.74, 5	0.67, 9	0.55, 14	0.70, 8
2	0.50	0.00	0.50	1	0.51, 9	0.37, 18	0.41, 15	0.67, 3	0.53, 8	0.38, 17	0.56, 7
3	0.50	0.50	0.00	1	0.59, 16	0.60, 14	0.53, 18	0.59, 15	0.61, 13	0.65, 8	0.65, 10
4	0.10	0.45	0.45	1	0.57, 13	0.51, 15	0.27, 18	0.71, 5	0.65, 9	0.55, 14	0.68, 7
5	0.45	0.10	0.45	1	0.52, 9	0.41, 17	0.40, 18	0.67, 3	0.56, 8	0.43, 16	0.59, 7
6	0.45	0.45	0.10	1	0.58, 15	0.57, 16	0.48, 18	0.61, 12	0.61, 14	0.62, 11	0.65, 8
7	0.20	0.40	0.40	1	0.57, 13	0.51, 15	0.32, 18	0.69, 5	0.63, 9	0.54, 14	0.66, 7
8	0.40	0.20	0.40	1	0.54, 9	0.45, 17	0.40, 18	0.67, 3	0.58, 8	0.47, 15	0.61, 7
9	0.40	0.40	0.20	1	0.57, 14	0.54, 16	0.44, 18	0.64, 8	0.61, 12	0.58, 13	0.64, 6
10	0.30	0.35	0.35	1	0.56, 13	0.50, 15	0.37, 18	0.67, 5	0.61, 8	0.53, 14	0.65, 7
11	0.35	0.30	0.35	1	0.55, 13	0.48, 16	0.39, 18	0.67, 4	0.60, 8	0.51, 14	0.63, 7
12	0.35	0.35	0.30	1	0.56, 13	0.51, 16	0.40, 18	0.66, 5	0.60, 9	0.54, 14	0.64, 7
13	0.40	0.30	0.30	1	0.56, 13	0.49, 16	0.42, 18	0.65, 4	0.59, 8	0.52, 14	0.63, 7
14	0.30	0.40	0.30	1	0.57, 13	0.52, 15	0.38, 18	0.66, 6	0.62, 10	0.56, 14	0.65, 7
15	0.30	0.30	0.40	1	0.55, 13	0.48, 15	0.36, 18	0.68, 4	0.60, 8	0.50, 14	0.64, 7
16	0.50	0.25	0.25	1	0.55, 12	0.49, 17	0.47, 18	0.63, 3	0.57, 8	0.52, 16	0.61, 7
17	0.25	0.50	0.25	1	0.58, 14	0.56, 15	0.37, 18	0.66, 9	0.64, 12	0.60, 13	0.68, 7
18	0.25	0.25	0.50	1	0.54, 12	0.45, 15	0.32, 18	0.70, 3	0.60, 8	0.47, 14	0.63, 7
19	0.60	0.20	0.20	1	0.54, 11	0.48, 18	0.52, 15	0.61, 3	0.55, 10	0.51, 17	0.59, 6
20	0.20	0.60	0.20	1	0.60, 14	0.60, 15	0.37, 18	0.66, 11	0.66, 12	0.65, 13	0.70, 9
21	0.20	0.20	0.60	1	0.53, 9	0.42, 15	0.27, 18	0.72, 3	0.60, 8	0.43, 14	0.63, 7
22	0.70	0.15	0.15	1	0.54, 11	0.48, 18	0.57, 8	0.59, 5	0.53, 12	0.50, 16	0.57, 7
23	0.15	0.70	0.15	1	0.62, 15	0.63, 14	0.36, 18	0.66, 13	0.68, 12	0.69, 11	0.72, 10
24	0.15	0.15	0.70	1	0.52, 9	0.38, 15	0.23, 18	0.74, 3	0.60, 8	0.39, 14	0.63, 7
25	0.80	0.10	0.10	1	0.53, 9	0.47, 17	0.62, 3	0.57, 6	0.51, 12	0.50, 14	0.55, 8
26	0.10	0.80	0.10	1	0.63, 15	0.67, 13	0.35, 18	0.66, 14	0.70, 12	0.74, 11	0.74, 9
27	0.10	0.10	0.80	1	0.51, 9	0.35, 15	0.19, 18	0.77, 3	0.60, 8	0.36, 14	0.62, 7
28	0.90	0.05	0.05	1	0.53, 9	0.46, 17	0.67, 3	0.54, 6	0.49, 10	0.49, 12	0.53, 8
29	0.05	0.90	0.05	1	0.65, 15	0.71, 13	0.34, 18	0.66, 14	0.72, 12	0.78, 8	0.76, 10
30	0.05	0.05	0.90	1	0.50, 9	0.32, 14	0.15, 18	0.79, 3	0.60, 8	0.32, 15	0.62, 7
31	1.00	0.00	0.00	1	0.52, 7	0.46, 13	0.72, 1	0.52, 4	0.47, 11	0.48, 10	0.51, 9
32	0.00	1.00	0.00	1	0.66, 14	0.74, 12	0.33, 18	0.66, 15	0.74, 13	0.83, 7	0.79, 10
33	0.00	0.00	1.00	1	0.49, 9	0.29, 14	0.10, 18	0.81, 3	0.60, 8	0.28, 15	0.62, 7
34	0.00	0.50	0.50	2	0.58, 14	0.56, 15	0.25, 18	0.74, 6	0.67, 12	0.62, 13	0.71, 9
35	0.50	0.00	0.50	2	0.51, 12	0.38, 18	0.51, 11	0.68, 3	0.54, 8	0.39, 17	0.57, 7
36	0.50	0.50	0.00	2	0.60, 17	0.62, 14	0.56, 18	0.60, 16	0.62, 13	0.68, 6	0.66, 10
37	0.10	0.45	0.45	2	0.58, 14	0.55, 15	0.33, 18	0.72, 6	0.66, 12	0.61, 13	0.69, 9
38	0.45	0.10	0.45	2	0.53, 10	0.43, 18	0.50, 14	0.68, 3	0.56, 8	0.46, 17	0.59, 7
39	0.45	0.45	0.10	2	0.59, 16	0.59, 15	0.53, 18	0.62, 13	0.62, 14	0.65, 11	0.66, 10
40	0.20	0.40	0.40	2	0.57, 14	0.54, 15	0.39, 18	0.70, 6	0.64, 12	0.59, 13	0.67, 8
41	0.40	0.20	0.40	2	0.54, 13	0.48, 18	0.48, 17	0.68, 3	0.59, 8	0.51, 16	0.62, 7
42	0.40	0.40	0.20	2	0.58, 15	0.57, 16	0.50, 18	0.64, 11	0.62, 13	0.62, 12	0.65, 8
43	0.30	0.35	0.35	2	0.57, 14	0.53, 16	0.45, 18	0.68, 5	0.62, 11	0.58, 13	0.65, 8
44	0.35	0.30	0.35	2	0.56, 14	0.52, 16	0.47, 18	0.68, 5	0.61, 10	0.56, 13	0.64, 8
45	0.35	0.35	0.30	2	0.57, 14	0.54, 16	0.47, 18	0.67, 6	0.61, 12	0.59, 13	0.65, 8
46	0.40	0.30	0.30	2	0.56, 15	0.52, 17	0.49, 18	0.66, 5	0.60, 11	0.57, 13	0.64, 8
47	0.30	0.40	0.30	2	0.57, 14	0.56, 15	0.45, 18	0.67, 7	0.63, 12	0.61, 13	0.66, 9
48	0.30	0.30	0.40	2	0.56, 13	0.51, 16	0.44, 18	0.69, 4	0.61, 10	0.55, 14	0.65, 7
49	0.50	0.25	0.25	2	0.55, 15	0.51, 18	0.54, 17	0.64, 4	0.58, 12	0.55, 16	0.62, 7
50	0.25	0.50	0.25	2	0.59, 15	0.59, 14	0.43, 18	0.67, 11	0.65, 12	0.65, 13	0.69, 9

Sensitivity of Welfare to Welfare Parameters

	Weighting Scheme				Closeness to Ideal, Rank for Scenario No.						
No.	Ecological Satisfaction	Socio-Economic Satisfaction	Managerial Satisfaction	Exp	1	2	3	4	5	6	7
51	0.25	0.25	0.50	2	0.55, 13	0.48, 16	0.40, 18	0.71, 3	0.61, 9	0.52, 14	0.64, 7
52	0.60	0.20	0.20	2	0.55, 16	0.50, 18	0.58, 10	0.62, 3	0.56, 14	0.54, 17	0.60, 9
53	0.20	0.60	0.20	2	0.60, 15	0.62, 14	0.42, 18	0.67, 12	0.67, 13	0.69, 11	0.71, 10
54	0.20	0.20	0.60	2	0.54, 13	0.45, 15	0.36, 18	0.73, 3	0.61, 8	0.48, 14	0.64, 7
55	0.70	0.15	0.15	2	0.54, 11	0.49, 18	0.62, 5	0.60, 6	0.54, 12	0.53, 17	0.58, 9
56	0.15	0.70	0.15	2	0.62, 15	0.66, 14	0.40, 18	0.67, 13	0.69, 12	0.72, 11	0.73, 10
57	0.15	0.15	0.70	2	0.53, 12	0.42, 15	0.32, 18	0.75, 3	0.61, 8	0.44, 14	0.63, 7
58	0.80	0.10	0.10	2	0.53, 11	0.48, 18	0.65, 3	0.57, 6	0.52, 12	0.51, 14	0.56, 8
59	0.10	0.80	0.10	2	0.63, 15	0.69, 13	0.38, 18	0.67, 14	0.71, 12	0.76, 8	0.75, 10
60	0.10	0.10	0.80	2	0.52, 9	0.38, 15	0.27, 18	0.77, 3	0.60, 8	0.39, 14	0.63, 7
61	0.90	0.05	0.05	2	0.53, 9	0.47, 17	0.69, 2	0.55, 6	0.49, 13	0.50, 12	0.54, 8
62	0.05	0.90	0.05	2	0.65, 15	0.71, 13	0.36, 18	0.66, 14	0.72, 12	0.79, 7	0.77, 10
63	0.05	0.05	0.90	2	0.51, 9	0.34, 15	0.20, 18	0.79, 3	0.60, 8	0.34, 14	0.62, 7
64	1.00	0.00	0.00	2	0.52, 7	0.46, 13	0.72, 1	0.52, 4	0.47, 11	0.48, 10	0.51, 9
65	0.00	1.00	0.00	2	0.66, 14	0.74, 13	0.33, 18	0.66, 15	0.74, 12	0.83, 7	0.79, 10
66	0.00	0.00	1.00	2	0.49, 9	0.29, 14	0.10, 18	0.81, 3	0.60, 8	0.28, 15	0.62, 7
67	0.00	0.50	0.50	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
68	0.50	0.00	0.50	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
69	0.50	0.50	0.00	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
70	0.10	0.45	0.45	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
71	0.45	0.10	0.45	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
72	0.45	0.45	0.10	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
73	0.20	0.40	0.40	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
74	0.40	0.20	0.40	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
75	0.40	0.40	0.20	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
76	0.30	0.35	0.35	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
77	0.35	0.30	0.35	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
78	0.35	0.35	0.30	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
79	0.40	0.30	0.30	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
80	0.30	0.40	0.30	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
81	0.30	0.30	0.40	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
82	0.50	0.25	0.25	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
83	0.25	0.50	0.25	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
84	0.25	0.25	0.50	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
85	0.60	0.20	0.20	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
86	0.20	0.60	0.20	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
87	0.20	0.20	0.60	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
88	0.70	0.15	0.15	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
89	0.15	0.70	0.15	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
90	0.15	0.15	0.70	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
91	0.80	0.10	0.10	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
92	0.10	0.80	0.10	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
93	0.10	0.10	0.80	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
94	0.90	0.05	0.05	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
95	0.05	0.90	0.05	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
96	0.05	0.05	0.90	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
97	1.00	0.00	0.00	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
98	0.00	1.00	0.00	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
99	0.00	0.00	1.00	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12

Sensitivity of Welfare to Welfare Parameters

	Weighting Scheme				Closeness to Ideal, Rank for Scenario No.						
No.	Ecological Satisfaction	Socio-Economic Satisfaction	Managerial Satisfaction	Exp	8	9	10	11	12	13	14
1	0.00	0.50	0.50	1	0.58, 13	0.52, 15	0.22, 18	0.74, 5	0.67, 9	0.55, 14	0.70, 8
2	0.50	0.00	0.50	1	0.51, 9	0.37, 18	0.41, 15	0.67, 3	0.53, 8	0.38, 17	0.56, 7
3	0.50	0.50	0.00	1	0.59, 16	0.60, 14	0.53, 18	0.59, 15	0.61, 13	0.65, 8	0.65, 10
4	0.10	0.45	0.45	1	0.57, 13	0.51, 15	0.27, 18	0.71, 5	0.65, 9	0.55, 14	0.68, 7
5	0.45	0.10	0.45	1	0.52, 9	0.41, 17	0.40, 18	0.67, 3	0.56, 8	0.43, 16	0.59, 7
6	0.45	0.45	0.10	1	0.58, 15	0.57, 16	0.48, 18	0.61, 12	0.61, 14	0.62, 11	0.65, 8
7	0.20	0.40	0.40	1	0.57, 13	0.51, 15	0.32, 18	0.69, 5	0.63, 9	0.54, 14	0.66, 7
8	0.40	0.20	0.40	1	0.54, 9	0.45, 17	0.40, 18	0.67, 3	0.58, 8	0.47, 15	0.61, 7
9	0.40	0.40	0.20	1	0.57, 14	0.54, 16	0.44, 18	0.64, 8	0.61, 12	0.58, 13	0.64, 6
10	0.30	0.35	0.35	1	0.56, 13	0.50, 15	0.37, 18	0.67, 5	0.61, 8	0.53, 14	0.65, 7
11	0.35	0.30	0.35	1	0.55, 13	0.48, 16	0.39, 18	0.67, 4	0.60, 8	0.51, 14	0.63, 7
12	0.35	0.35	0.30	1	0.56, 13	0.51, 16	0.40, 18	0.66, 5	0.60, 9	0.54, 14	0.64, 7
13	0.40	0.30	0.30	1	0.56, 13	0.49, 16	0.42, 18	0.65, 4	0.59, 8	0.52, 14	0.63, 7
14	0.30	0.40	0.30	1	0.57, 13	0.52, 15	0.38, 18	0.66, 6	0.62, 10	0.56, 14	0.65, 7
15	0.30	0.30	0.40	1	0.55, 13	0.48, 15	0.36, 18	0.68, 4	0.60, 8	0.50, 14	0.64, 7
16	0.50	0.25	0.25	1	0.55, 12	0.49, 17	0.47, 18	0.63, 3	0.57, 8	0.52, 16	0.61, 7
17	0.25	0.50	0.25	1	0.58, 14	0.56, 15	0.37, 18	0.66, 9	0.64, 12	0.60, 13	0.68, 7
18	0.25	0.25	0.50	1	0.54, 12	0.45, 15	0.32, 18	0.70, 3	0.60, 8	0.47, 14	0.63, 7
19	0.60	0.20	0.20	1	0.54, 11	0.48, 18	0.52, 15	0.61, 3	0.55, 10	0.51, 17	0.59, 6
20	0.20	0.60	0.20	1	0.60, 14	0.60, 15	0.37, 18	0.66, 11	0.66, 12	0.65, 13	0.70, 9
21	0.20	0.20	0.60	1	0.53, 9	0.42, 15	0.27, 18	0.72, 3	0.60, 8	0.43, 14	0.63, 7
22	0.70	0.15	0.15	1	0.54, 11	0.48, 18	0.57, 8	0.59, 5	0.53, 12	0.50, 16	0.57, 7
23	0.15	0.70	0.15	1	0.62, 15	0.63, 14	0.36, 18	0.66, 13	0.68, 12	0.69, 11	0.72, 10
24	0.15	0.15	0.70	1	0.52, 9	0.38, 15	0.23, 18	0.74, 3	0.60, 8	0.39, 14	0.63, 7
25	0.80	0.10	0.10	1	0.53, 9	0.47, 17	0.62, 3	0.57, 6	0.51, 12	0.50, 14	0.55, 8
26	0.10	0.80	0.10	1	0.63, 15	0.67, 13	0.35, 18	0.66, 14	0.70, 12	0.74, 11	0.74, 9
27	0.10	0.10	0.80	1	0.51, 9	0.35, 15	0.19, 18	0.77, 3	0.60, 8	0.36, 14	0.62, 7
28	0.90	0.05	0.05	1	0.53, 9	0.46, 17	0.67, 3	0.54, 6	0.49, 10	0.49, 12	0.53, 8
29	0.05	0.90	0.05	1	0.65, 15	0.71, 13	0.34, 18	0.66, 14	0.72, 12	0.78, 8	0.76, 10
30	0.05	0.05	0.90	1	0.50, 9	0.32, 14	0.15, 18	0.79, 3	0.60, 8	0.32, 15	0.62, 7
31	1.00	0.00	0.00	1	0.52, 7	0.46, 13	0.72, 1	0.52, 4	0.47, 11	0.48, 10	0.51, 9
32	0.00	1.00	0.00	1	0.66, 14	0.74, 12	0.33, 18	0.66, 15	0.74, 13	0.83, 7	0.79, 10
33	0.00	0.00	1.00	1	0.49, 9	0.29, 14	0.10, 18	0.81, 3	0.60, 8	0.28, 15	0.62, 7
34	0.00	0.50	0.50	2	0.58, 14	0.56, 15	0.25, 18	0.74, 6	0.67, 12	0.62, 13	0.71, 9
35	0.50	0.00	0.50	2	0.51, 12	0.38, 18	0.51, 11	0.68, 3	0.54, 8	0.39, 17	0.57, 7
36	0.50	0.50	0.00	2	0.60, 17	0.62, 14	0.56, 18	0.60, 16	0.62, 13	0.68, 6	0.66, 10
37	0.10	0.45	0.45	2	0.58, 14	0.55, 15	0.33, 18	0.72, 6	0.66, 12	0.61, 13	0.69, 9
38	0.45	0.10	0.45	2	0.53, 10	0.43, 18	0.50, 14	0.68, 3	0.56, 8	0.46, 17	0.59, 7
39	0.45	0.45	0.10	2	0.59, 16	0.59, 15	0.53, 18	0.62, 13	0.62, 14	0.65, 11	0.66, 10
40	0.20	0.40	0.40	2	0.57, 14	0.54, 15	0.39, 18	0.70, 6	0.64, 12	0.59, 13	0.67, 8
41	0.40	0.20	0.40	2	0.54, 13	0.48, 18	0.48, 17	0.68, 3	0.59, 8	0.51, 16	0.62, 7
42	0.40	0.40	0.20	2	0.58, 15	0.57, 16	0.50, 18	0.64, 11	0.62, 13	0.62, 12	0.65, 8
43	0.30	0.35	0.35	2	0.57, 14	0.53, 16	0.45, 18	0.68, 5	0.62, 11	0.58, 13	0.65, 8
44	0.35	0.30	0.35	2	0.56, 14	0.52, 16	0.47, 18	0.68, 5	0.61, 10	0.56, 13	0.64, 8
45	0.35	0.35	0.30	2	0.57, 14	0.54, 16	0.47, 18	0.67, 6	0.61, 12	0.59, 13	0.65, 8
46	0.40	0.30	0.30	2	0.56, 15	0.52, 17	0.49, 18	0.66, 5	0.60, 11	0.57, 13	0.64, 8
47	0.30	0.40	0.30	2	0.57, 14	0.56, 15	0.45, 18	0.67, 7	0.63, 12	0.61, 13	0.66, 9
48	0.30	0.30	0.40	2	0.56, 13	0.51, 16	0.44, 18	0.69, 4	0.61, 10	0.55, 14	0.65, 7
49	0.50	0.25	0.25	2	0.55, 15	0.51, 18	0.54, 17	0.64, 4	0.58, 12	0.55, 16	0.62, 7
50	0.25	0.50	0.25	2	0.59, 15	0.59, 14	0.43, 18	0.67, 11	0.65, 12	0.65, 13	0.69, 9

Sensitivity of Welfare to Welfare Parameters

No.	Weighting Scheme: Ecological Satisfaction	Weighting Scheme: Socio-Economic Satisfaction	Weighting Scheme: Managerial Satisfaction	Exp	Closeness to Ideal, Rank for Scenario No. 8	9	10	11	12	13	14
51	0.25	0.25	0.50	2	0.55, 13	0.48, 16	0.40, 18	0.71, 3	0.61, 9	0.52, 14	0.64, 7
52	0.60	0.20	0.20	2	0.55, 16	0.50, 18	0.58, 10	0.62, 3	0.56, 14	0.54, 17	0.60, 9
53	0.20	0.60	0.20	2	0.60, 15	0.62, 14	0.42, 18	0.67, 12	0.67, 13	0.69, 11	0.71, 10
54	0.20	0.20	0.60	2	0.54, 13	0.45, 15	0.36, 18	0.73, 3	0.61, 8	0.48, 14	0.64, 7
55	0.70	0.15	0.15	2	0.54, 11	0.49, 18	0.62, 5	0.60, 6	0.54, 12	0.53, 17	0.58, 9
56	0.15	0.70	0.15	2	0.62, 15	0.66, 14	0.40, 18	0.67, 13	0.69, 12	0.72, 11	0.73, 10
57	0.15	0.15	0.70	2	0.53, 12	0.42, 15	0.32, 18	0.75, 3	0.61, 8	0.44, 14	0.63, 7
58	0.80	0.10	0.10	2	0.53, 11	0.48, 18	0.65, 3	0.57, 6	0.52, 12	0.51, 14	0.56, 8
59	0.10	0.80	0.10	2	0.63, 15	0.69, 13	0.38, 18	0.67, 14	0.71, 12	0.76, 8	0.75, 10
60	0.10	0.10	0.80	2	0.52, 9	0.38, 15	0.27, 18	0.77, 3	0.60, 8	0.39, 14	0.63, 7
61	0.90	0.05	0.05	2	0.53, 9	0.47, 17	0.69, 2	0.55, 6	0.49, 13	0.50, 12	0.54, 8
62	0.05	0.90	0.05	2	0.65, 15	0.71, 13	0.36, 18	0.66, 14	0.72, 12	0.79, 7	0.77, 10
63	0.05	0.05	0.90	2	0.51, 9	0.34, 15	0.20, 18	0.79, 3	0.60, 8	0.34, 14	0.62, 7
64	1.00	0.00	0.00	2	0.52, 7	0.46, 13	0.72, 1	0.52, 4	0.47, 11	0.48, 10	0.51, 9
65	0.00	1.00	0.00	2	0.66, 14	0.74, 13	0.33, 18	0.66, 15	0.74, 12	0.83, 7	0.79, 10
66	0.00	0.00	1.00	2	0.49, 9	0.29, 14	0.10, 18	0.81, 3	0.60, 8	0.28, 15	0.62, 7
67	0.00	0.50	0.50	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
68	0.50	0.00	0.50	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
69	0.50	0.50	0.00	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
70	0.10	0.45	0.45	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
71	0.45	0.10	0.45	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
72	0.45	0.45	0.10	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
73	0.20	0.40	0.40	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
74	0.40	0.20	0.40	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
75	0.40	0.40	0.20	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
76	0.30	0.35	0.35	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
77	0.35	0.30	0.35	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
78	0.35	0.35	0.30	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
79	0.40	0.30	0.30	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
80	0.30	0.40	0.30	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
81	0.30	0.30	0.40	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
82	0.50	0.25	0.25	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
83	0.25	0.50	0.25	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
84	0.25	0.25	0.50	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
85	0.60	0.20	0.20	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
86	0.20	0.60	0.20	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
87	0.20	0.20	0.60	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
88	0.70	0.15	0.15	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
89	0.15	0.70	0.15	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
90	0.15	0.15	0.70	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
91	0.80	0.10	0.10	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
92	0.10	0.80	0.10	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
93	0.10	0.10	0.80	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
94	0.90	0.05	0.05	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
95	0.05	0.90	0.05	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
96	0.05	0.05	0.90	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
97	1.00	0.00	0.00	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
98	0.00	1.00	0.00	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12
99	0.00	0.00	1.00	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10	0.74, 13	0.83, 9	0.79, 12

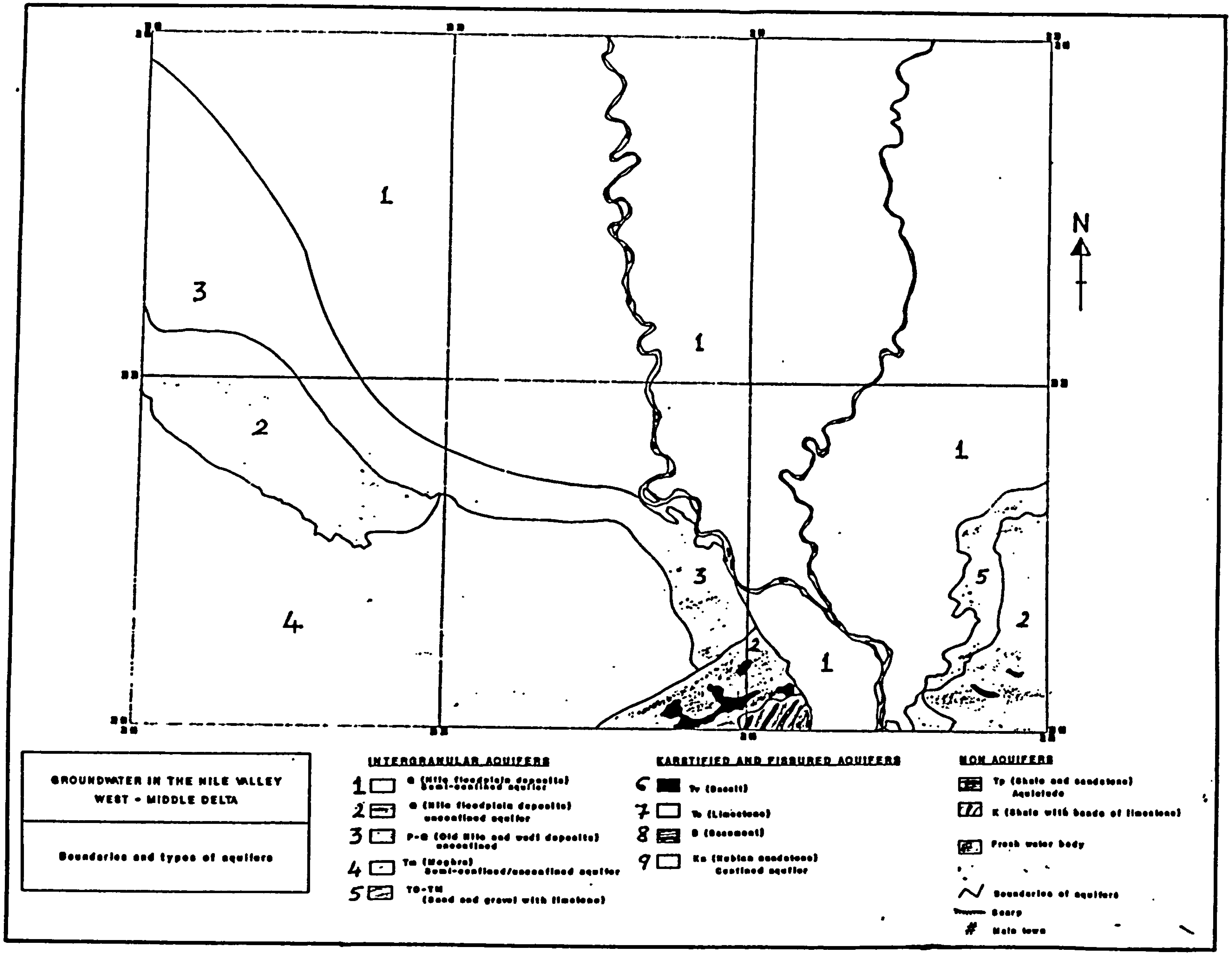
Sensitivity of Welfare to Welfare Parameters

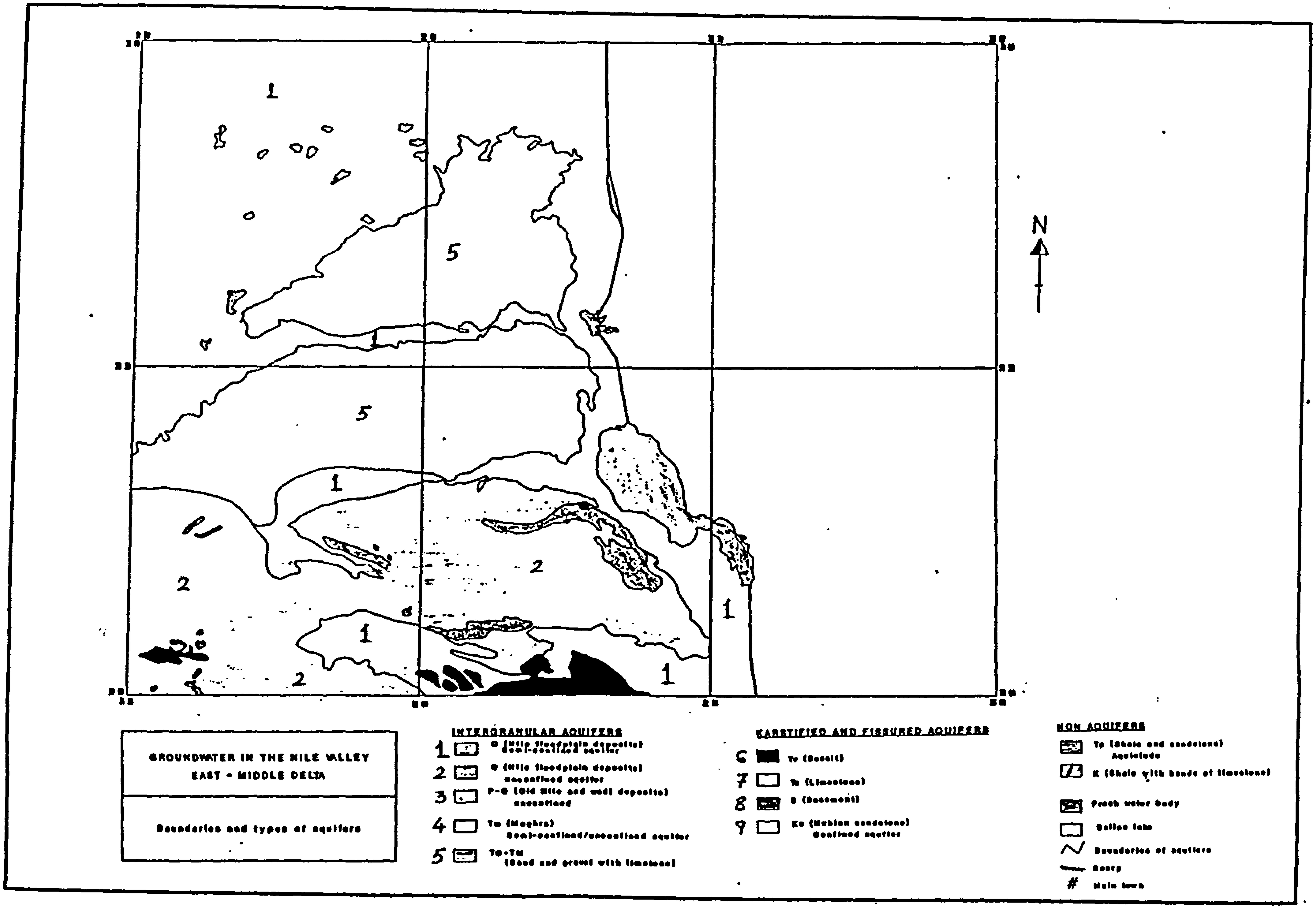
	Weighting Scheme				Closeness to Ideal, Rank for Scenario No.			
No.	Ecological Satisfaction	Socio-Economic Satisfaction	Managerial Satisfaction	Exp	15	16	17	18
1	0.00	0.50	0.50	1	0.58, 13	0.52, 15	0.22, 18	0.74, 5
2	0.50	0.00	0.50	1	0.51, 9	0.37, 18	0.41, 15	0.67, 3
3	0.50	0.50	0.00	1	0.59, 16	0.60, 14	0.53, 18	0.59, 15
4	0.10	0.45	0.45	1	0.57, 13	0.51, 15	0.27, 18	0.71, 5
5	0.45	0.10	0.45	1	0.52, 9	0.41, 17	0.40, 18	0.67, 3
6	0.45	0.45	0.10	1	0.58, 15	0.57, 16	0.48, 18	0.61, 12
7	0.20	0.40	0.40	1	0.57, 13	0.51, 15	0.32, 18	0.69, 5
8	0.40	0.20	0.40	1	0.54, 9	0.45, 17	0.40, 18	0.67, 3
9	0.40	0.40	0.20	1	0.57, 14	0.54, 16	0.44, 18	0.64, 8
10	0.30	0.35	0.35	1	0.56, 13	0.50, 15	0.37, 18	0.67, 5
11	0.35	0.30	0.35	1	0.55, 13	0.48, 16	0.39, 18	0.67, 4
12	0.35	0.35	0.30	1	0.56, 13	0.51, 16	0.40, 18	0.66, 5
13	0.40	0.30	0.30	1	0.56, 13	0.49, 16	0.42, 18	0.65, 4
14	0.30	0.40	0.30	1	0.57, 13	0.52, 15	0.38, 18	0.66, 6
15	0.30	0.30	0.40	1	0.55, 13	0.48, 15	0.36, 18	0.68, 4
16	0.50	0.25	0.25	1	0.55, 12	0.49, 17	0.47, 18	0.63, 3
17	0.25	0.50	0.25	1	0.58, 14	0.56, 15	0.37, 18	0.66, 9
18	0.25	0.25	0.50	1	0.54, 12	0.45, 15	0.32, 18	0.70, 3
19	0.60	0.20	0.20	1	0.54, 11	0.48, 18	0.52, 15	0.61, 3
20	0.20	0.60	0.20	1	0.60, 14	0.60, 15	0.37, 18	0.66, 11
21	0.20	0.20	0.60	1	0.53, 9	0.42, 15	0.27, 18	0.72, 3
22	0.70	0.15	0.15	1	0.54, 11	0.48, 18	0.57, 8	0.59, 5
23	0.15	0.70	0.15	1	0.62, 15	0.63, 14	0.36, 18	0.66, 13
24	0.15	0.15	0.70	1	0.52, 9	0.38, 15	0.23, 18	0.74, 3
25	0.80	0.10	0.10	1	0.53, 9	0.47, 17	0.62, 3	0.57, 6
26	0.10	0.80	0.10	1	0.63, 15	0.67, 13	0.35, 18	0.66, 14
27	0.10	0.10	0.80	1	0.51, 9	0.35, 15	0.19, 18	0.77, 3
28	0.90	0.05	0.05	1	0.53, 9	0.46, 17	0.67, 3	0.54, 6
29	0.05	0.90	0.05	1	0.65, 15	0.71, 13	0.34, 18	0.66, 14
30	0.05	0.05	0.90	1	0.50, 9	0.32, 14	0.15, 18	0.79, 3
31	1.00	0.00	0.00	1	0.52, 7	0.46, 13	0.72, 1	0.52, 4
32	0.00	1.00	0.00	1	0.66, 14	0.74, 12	0.33, 18	0.66, 15
33	0.00	0.00	1.00	1	0.49, 9	0.29, 14	0.10, 18	0.81, 3
34	0.00	0.50	0.50	2	0.58, 14	0.56, 15	0.25, 18	0.74, 6
35	0.50	0.00	0.50	2	0.51, 12	0.38, 18	0.51, 11	0.68, 3
36	0.50	0.50	0.00	2	0.60, 17	0.62, 14	0.56, 18	0.60, 16
37	0.10	0.45	0.45	2	0.58, 14	0.55, 15	0.33, 18	0.72, 6
38	0.45	0.10	0.45	2	0.53, 10	0.43, 18	0.50, 14	0.68, 3
39	0.45	0.45	0.10	2	0.59, 16	0.59, 15	0.53, 18	0.62, 13
40	0.20	0.40	0.40	2	0.57, 14	0.54, 15	0.39, 18	0.70, 6
41	0.40	0.20	0.40	2	0.54, 13	0.48, 18	0.48, 17	0.68, 3
42	0.40	0.40	0.20	2	0.58, 15	0.57, 16	0.50, 18	0.64, 11
43	0.30	0.35	0.35	2	0.57, 14	0.53, 16	0.45, 18	0.68, 5
44	0.35	0.30	0.35	2	0.56, 14	0.52, 16	0.47, 18	0.68, 5
45	0.35	0.35	0.30	2	0.57, 14	0.54, 16	0.47, 18	0.67, 6
46	0.40	0.30	0.30	2	0.56, 15	0.52, 17	0.49, 18	0.66, 5
47	0.30	0.40	0.30	2	0.57, 14	0.56, 15	0.45, 18	0.67, 7
48	0.30	0.30	0.40	2	0.56, 13	0.51, 16	0.44, 18	0.69, 4
49	0.50	0.25	0.25	2	0.55, 15	0.51, 18	0.54, 17	0.64, 4
50	0.25	0.50	0.25	2	0.59, 15	0.59, 14	0.43, 18	0.67, 11

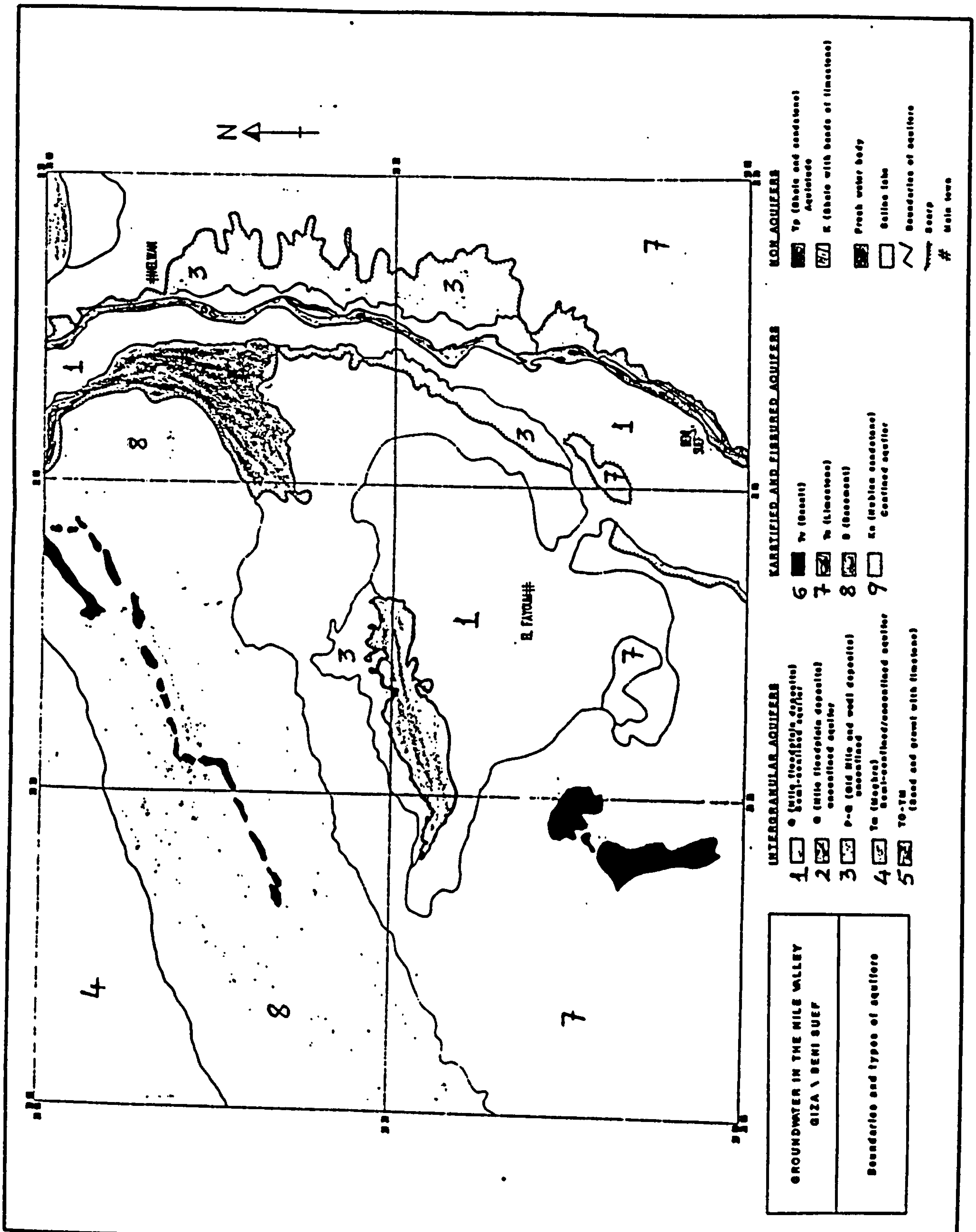
Sensitivity of Welfare to Welfare Parameters

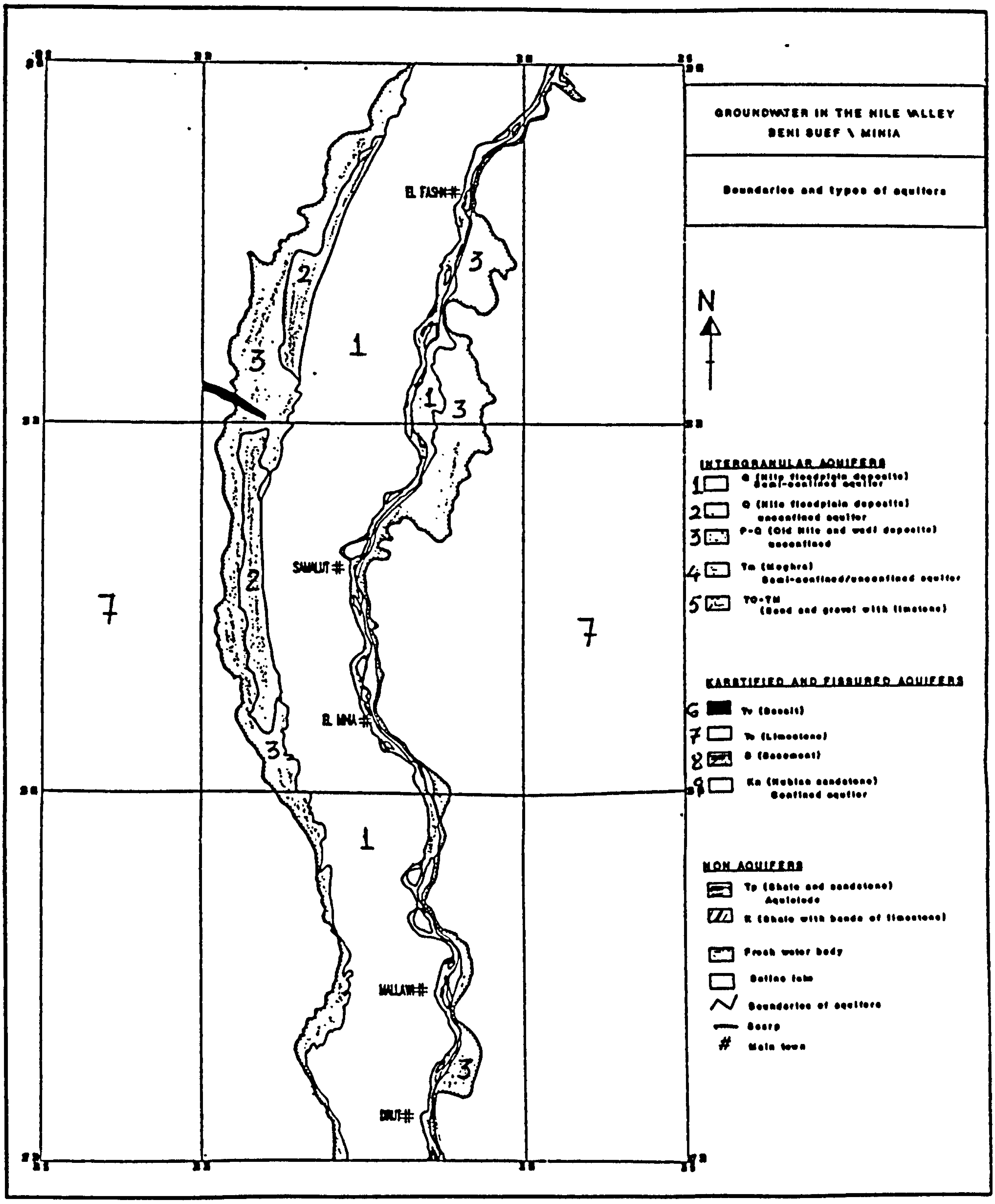
No.	Weighting Scheme: Ecological Satisfaction	Socio-Economic Satisfaction	Managerial Satisfaction	Exp	Closeness to Ideal, Rank for Scenario No.: 15	16	17	18
51	0.25	0.25	0.50	2	0.55, 13	0.48, 16	0.40, 18	0.71, 3
52	0.60	0.20	0.20	2	0.55, 16	0.50, 18	0.58, 10	0.62, 3
53	0.20	0.60	0.20	2	0.60, 15	0.62, 14	0.42, 18	0.67, 12
54	0.20	0.20	0.60	2	0.54, 13	0.45, 15	0.36, 18	0.73, 3
55	0.70	0.15	0.15	2	0.54, 11	0.49, 18	0.62, 5	0.60, 6
56	0.15	0.70	0.15	2	0.62, 15	0.66, 14	0.40, 18	0.67, 13
57	0.15	0.15	0.70	2	0.53, 12	0.42, 15	0.32, 18	0.75, 3
58	0.80	0.10	0.10	2	0.53, 11	0.48, 18	0.65, 3	0.57, 6
59	0.10	0.80	0.10	2	0.63, 15	0.69, 13	0.38, 18	0.67, 14
60	0.10	0.10	0.80	2	0.52, 9	0.38, 15	0.27, 18	0.77, 3
61	0.90	0.05	0.05	2	0.53, 9	0.47, 17	0.69, 2	0.55, 6
62	0.05	0.90	0.05	2	0.65, 15	0.71, 13	0.36, 18	0.66, 14
63	0.05	0.05	0.90	2	0.51, 9	0.34, 15	0.20, 18	0.79, 3
64	1.00	0.00	0.00	2	0.52, 7	0.46, 13	0.72, 1	0.52, 4
65	0.00	1.00	0.00	2	0.66, 14	0.74, 13	0.33, 18	0.66, 15
66	0.00	0.00	1.00	2	0.49, 9	0.29, 14	0.10, 18	0.81, 3
67	0.00	0.50	0.50	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
68	0.50	0.00	0.50	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
69	0.50	0.50	0.00	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
70	0.10	0.45	0.45	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
71	0.45	0.10	0.45	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
72	0.45	0.45	0.10	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
73	0.20	0.40	0.40	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
74	0.40	0.20	0.40	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
75	0.40	0.40	0.20	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
76	0.30	0.35	0.35	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
77	0.35	0.30	0.35	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
78	0.35	0.35	0.30	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
79	0.40	0.30	0.30	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
80	0.30	0.40	0.30	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
81	0.30	0.30	0.40	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
82	0.50	0.25	0.25	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
83	0.25	0.50	0.25	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
84	0.25	0.25	0.50	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
85	0.60	0.20	0.20	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
86	0.20	0.60	0.20	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
87	0.20	0.20	0.60	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
88	0.70	0.15	0.15	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
89	0.15	0.70	0.15	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
90	0.15	0.15	0.70	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
91	0.80	0.10	0.10	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
92	0.10	0.80	0.10	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
93	0.10	0.10	0.80	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
94	0.90	0.05	0.05	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
95	0.05	0.90	0.05	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
96	0.05	0.05	0.90	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
97	1.00	0.00	0.00	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
98	0.00	1.00	0.00	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10
99	0.00	0.00	1.00	3	0.66, 18	0.74, 14	0.72, 15	0.81, 10

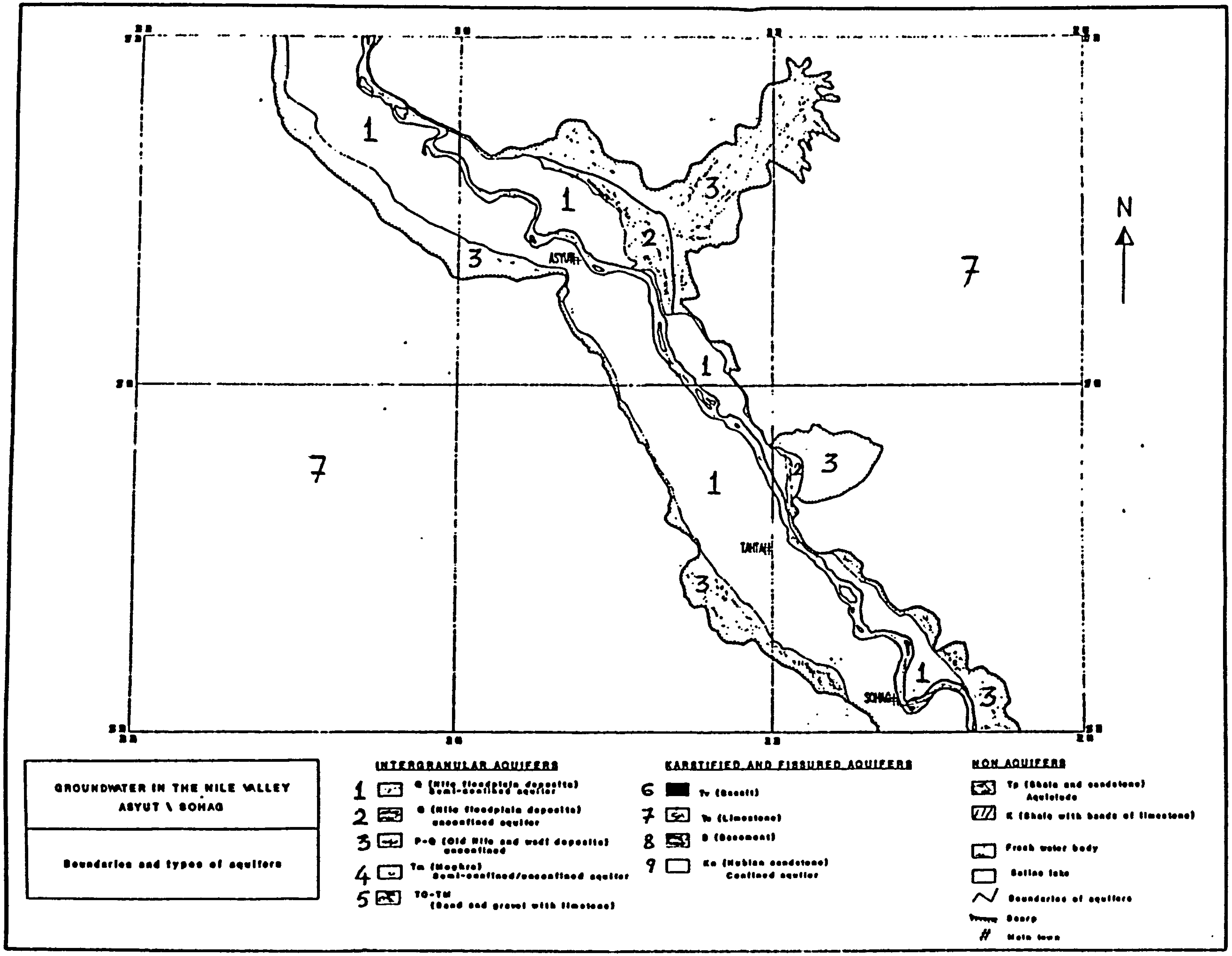
APPENDIX F

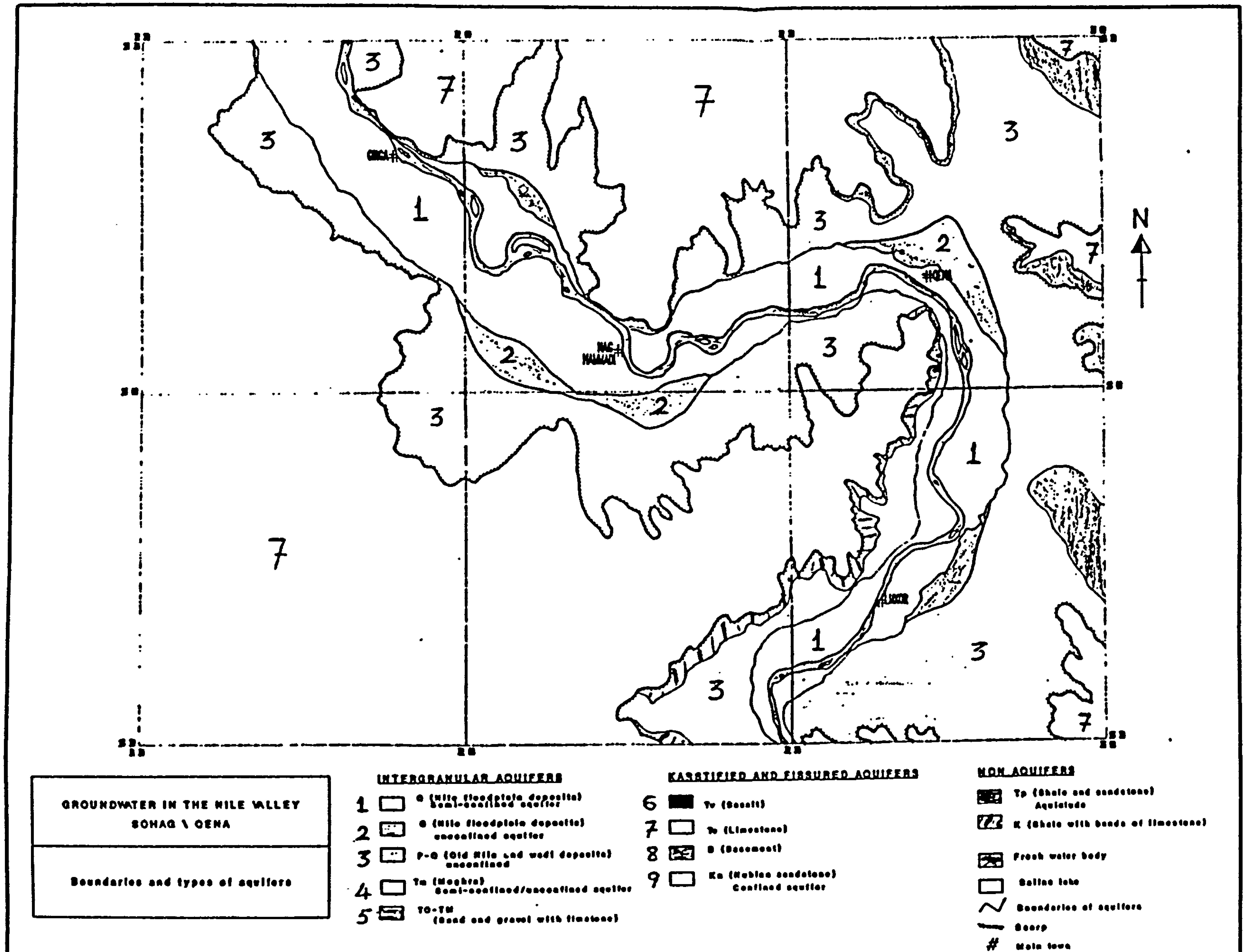

GROUNDWATER IN THE NILE VALLEY
WEST - MIDDLE DELTA
Boundaries and types of aquifers
N
INTERGRANULAR AQUIFERS
1 Q (Nile floodplain deposits) Semi-confined aquifer
2 Q (Nile floodplain deposits) unconfined aquifer
3 P-Q (Old Nile and wadi deposits) unconfined
4 Tm (Moghra) Semi-confined/unconfined aquifer
5 TQ-TM (Sand and gravel with limestone)
KARSTIFIED AND FISSURED AQUIFERS
6 Tv (Basalt)
7 Te (Limestone)
8 B (Basement)
9 Ku (Nubian sandstone) Confined aquifer
NON AQUIFERS
Tp (Shale and sandstone) Aquiclude
K (Shale with bands of limestone)
Fresh water body
Boundaries of aquifers
Scarp
Main town

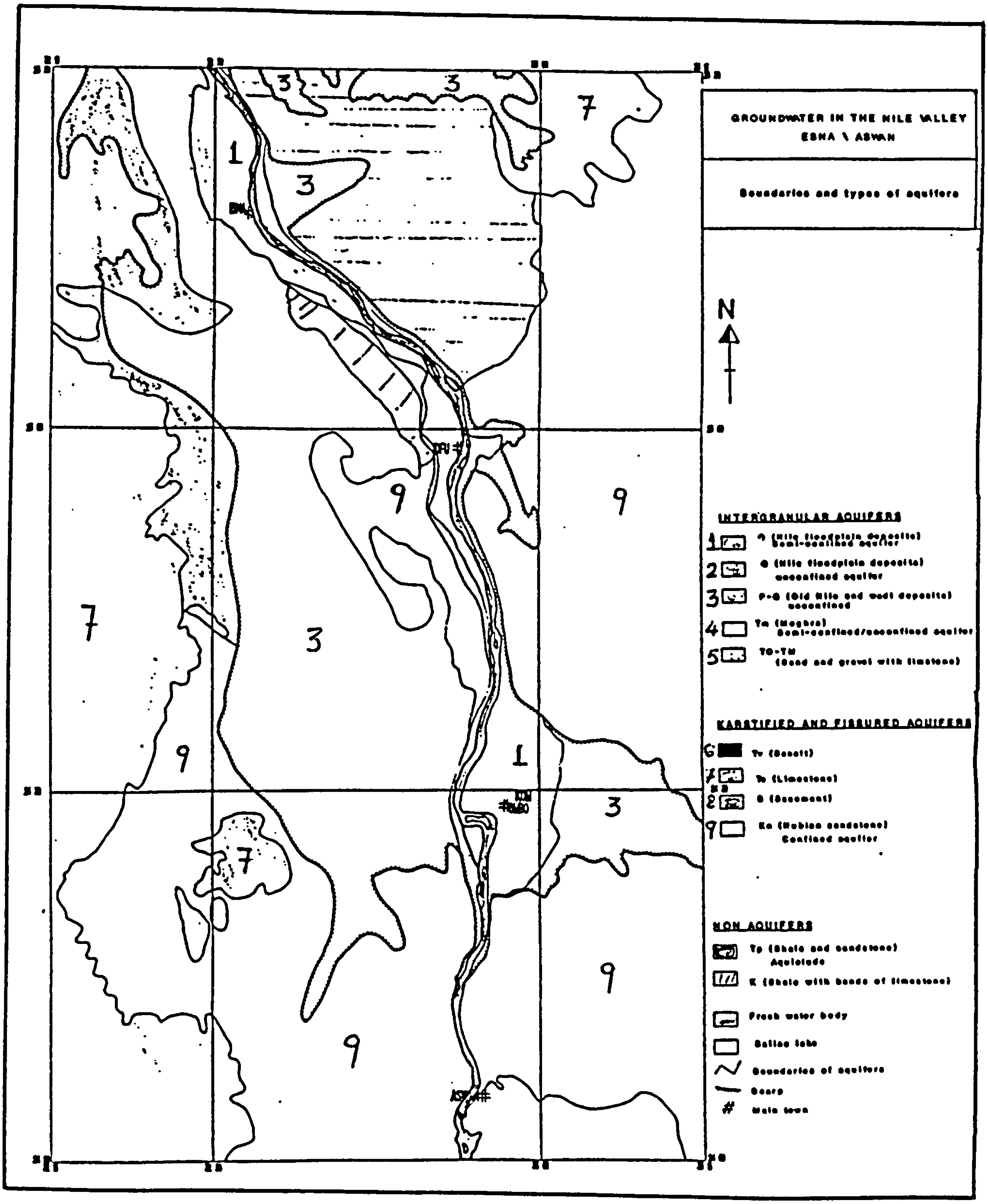

N
GROUNDWATER IN THE NILE VALLEY
EAST - MIDDLE DELTA
Boundaries and types of aquifers
INTERGRANULAR AQUIFERS
2 Q (Nile floodplain deposits) unconfined aquifer
3 P-Q (Old Nile and wadi deposits) unconfined
4 Tm (Moghra) Semi-confined/unconfined aquifer
5 TQ-TM (Sand and gravel with limestone)
KARSTIFIED AND FISSURED AQUIFERS
6 Tv (Basalt)
7 Tm (Limestone)
8 B (Basement)
9 Ke (Nubian sandstone) Confined aquifer
NON AQUIFERS
Tp (Shale and sandstone) Aquiclude
K (Shale with bands of limestone)
Fresh water body
Saline lake
Boundaries of aquifers
Scarp
Main town


N
HELWAN
EL FAYOUM
BENI SUEF
GROUNDWATER IN THE NILE VALLEY
GIZA \ BENI SUEF
Boundaries and types of aquifers
INTERGRANULAR AQUIFERS
1 Q (Nile floodplain deposits) Semi-confined aquifer
2 Q (Nile floodplain deposits) unconfined aquifer
3 P-Q (Old Nile and wadi deposits) unconfined
4 Tm (Moghra) Semi-confined/unconfined aquifer
5 TO-TM (Sand and gravel with limestone)
KARSTIFIED AND FISSURED AQUIFERS
6 Tv (Basalt)
7 Te (Limestone)
8 B (Basement)
9 Kn (Nubian sandstone) Confined aquifer
NON AQUIFERS
Tp (Shale and sandstone) Aquiclude
K (Shale with bands of limestone)
Fresh water body
Saline lake
Boundaries of aquifers
Scarp
Main town

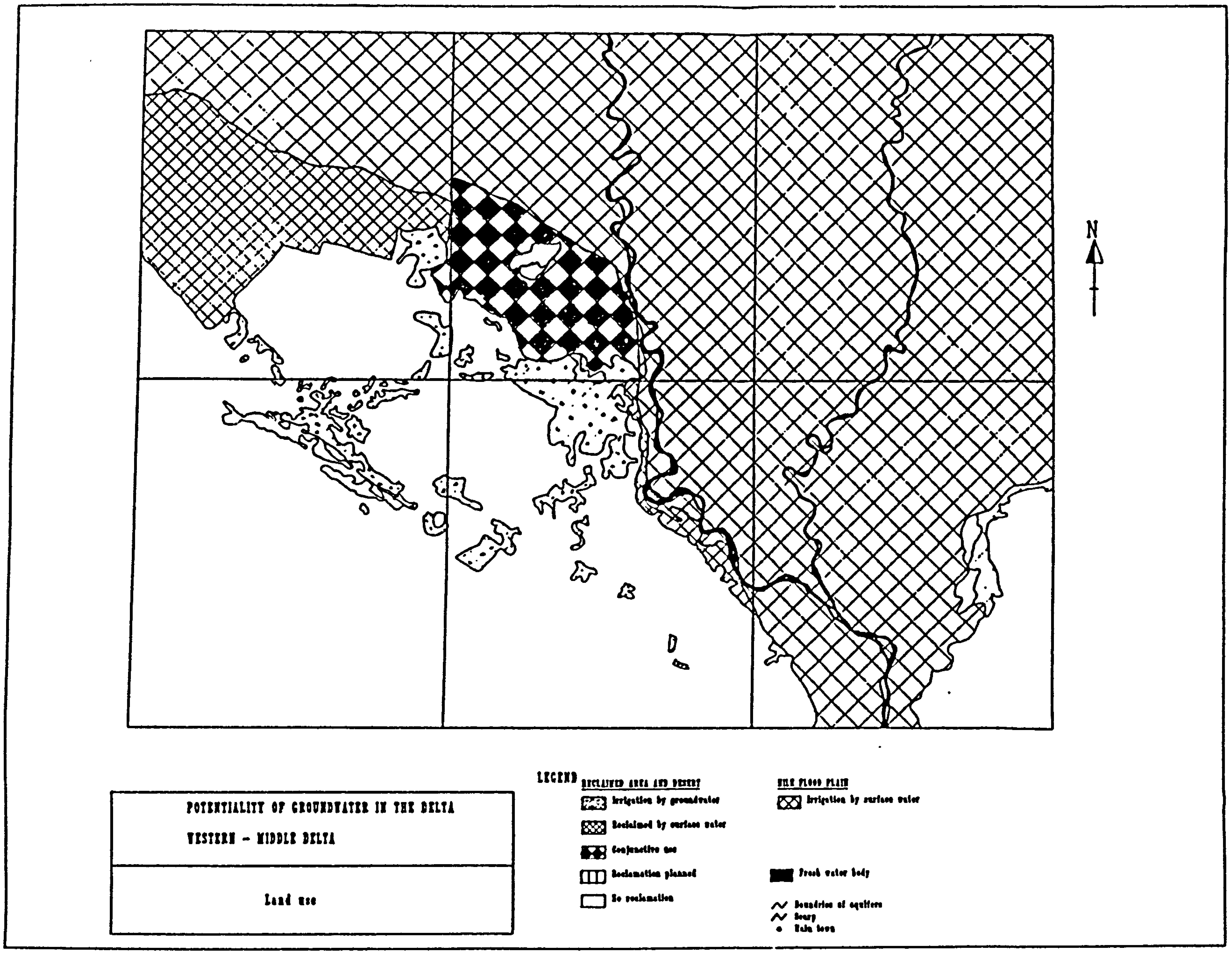

GROUNDWATER IN THE NILE VALLEY
BENI SUEF \ MINIA
Boundaries and types of aquifers
N
EL FASHN
SAMALUT
EL MINIA
MALLAWI
DIRUT
1
2
3
7
INTERGRANULAR AQUIFERS
Q (Nile floodplain deposits) Semi-confined aquifer
Q (Nile floodplain deposits) unconfined aquifer
P-Q (Old Nile and wadi deposits) unconfined
Tm (Moghra) Semi-confined/unconfined aquifer
TO-TM (Sand and gravel with limestone)
KARSTIFIED AND FISSURED AQUIFERS
Tv (Basalt)
Te (Limestone)
B (Basement)
Kn (Nubian sandstone) Confined aquifer
NON AQUIFERS
Tp (Shale and sandstone) Aquiclude
K (Shale with bands of limestone)
Fresh water body
Saline lake
Boundaries of aquifers
Scarp
Main town

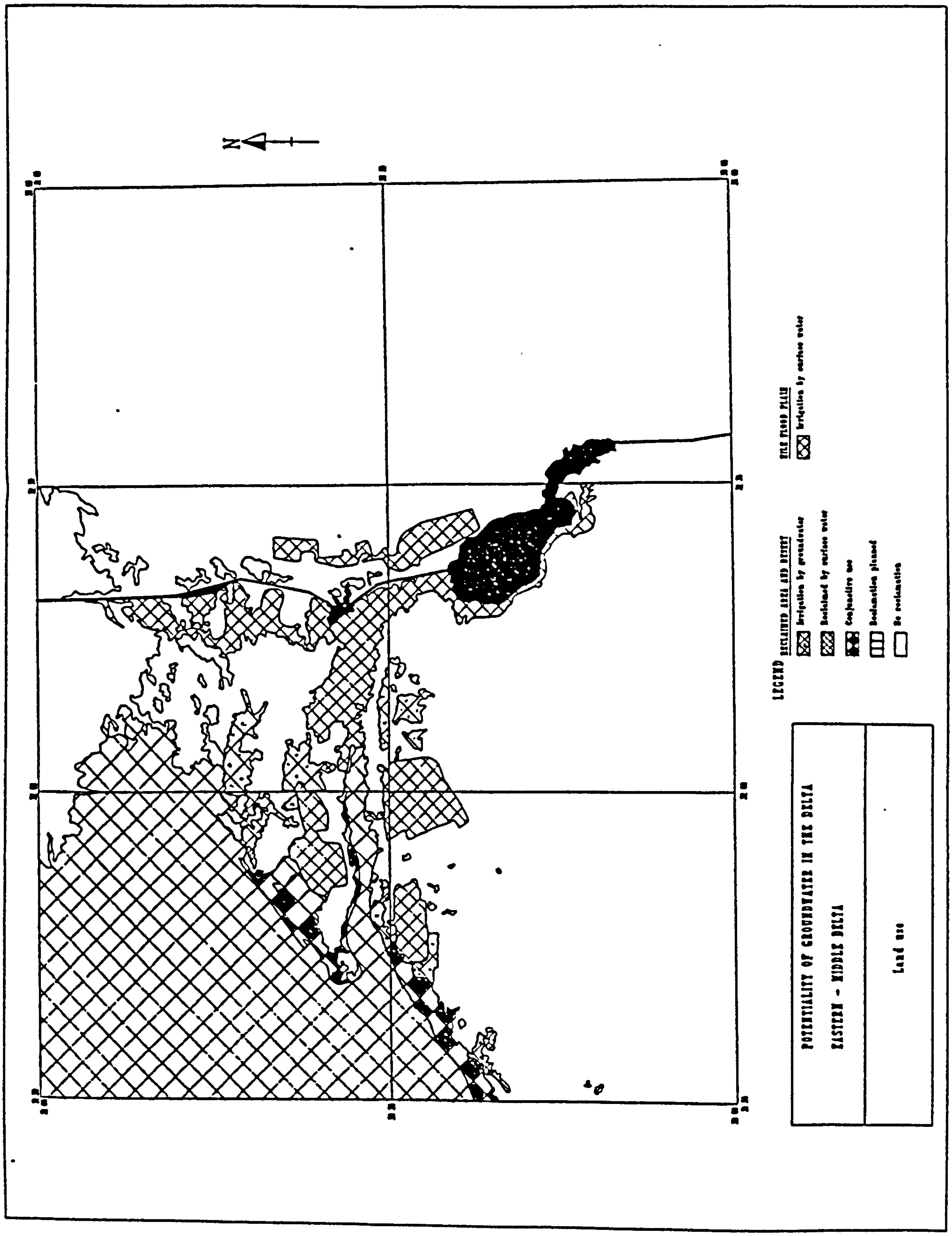

N
ASYUT
TAHTA
SOHAG
GROUNDWATER IN THE NILE VALLEY
ASYUT \ SOHAG
Boundaries and types of aquifers
INTERGRANULAR AQUIFERS
1 Q (Nile floodplain deposits) Semi-confined aquifer
2 Q (Nile floodplain deposits) unconfined aquifer
3 P-Q (Old Nile and wadi deposits) unconfined
4 Tm (Moghra) Semi-confined/unconfined aquifer
5 TO-TM (Sand and gravel with limestone)
KARSTIFIED AND FISSURED AQUIFERS
6 Tv (Basalt)
7 Te (Limestone)
8 B (Basement)
9 Kn (Nubian sandstone) Confined aquifer
NON AQUIFERS
Tp (Shale and sandstone) Aquiclude
K (Shale with bands of limestone)
Fresh water body
Saline lake
Boundaries of aquifers
Scarp
Main town

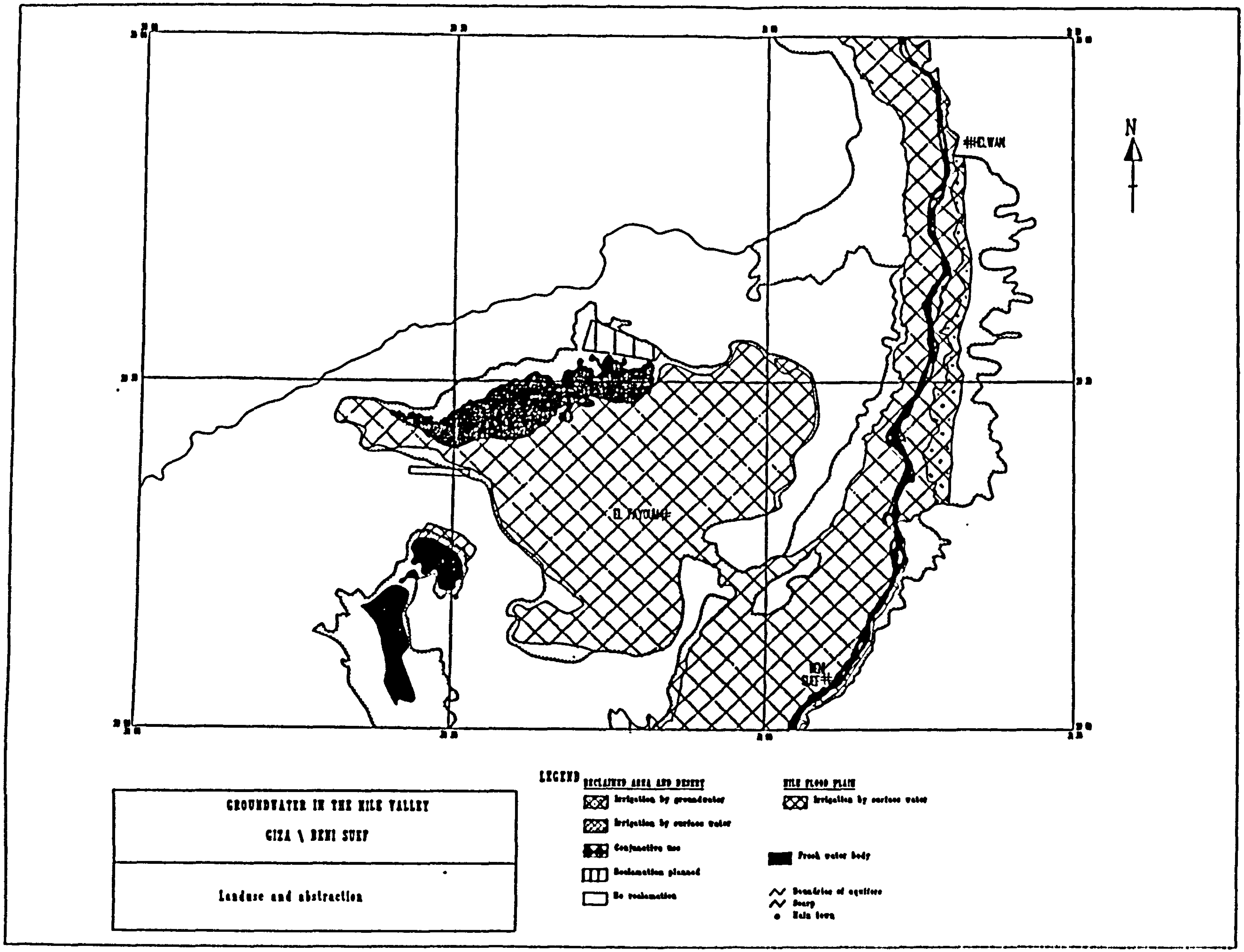

N
GIRGA
NAG HAMMADI
QENA
LUXOR
GROUNDWATER IN THE NILE VALLEY
SOHAG \ QENA
Boundaries and types of aquifers
INTERGRANULAR AQUIFERS
1 Q (Nile floodplain deposits) Semi-confined aquifer
2 Q (Nile floodplain deposits) unconfined aquifer
3 P-Q (Old Nile and wadi deposits) unconfined
4 Tm (Moghra) Semi-confined/unconfined aquifer
5 TO-TM (Sand and gravel with limestone)
KARSTIFIED AND FISSURED AQUIFERS
6 Tv (Basalt)
7 Te (Limestone)
8 B (Basement)
9 Ku (Nubian sandstone) Confined aquifer
NON AQUIFERS
Tp (Shale and sandstone) Aquiclude
K (Shale with bands of limestone)
Fresh water body
Saline lake
Boundaries of aquifers
Scarp
Main town

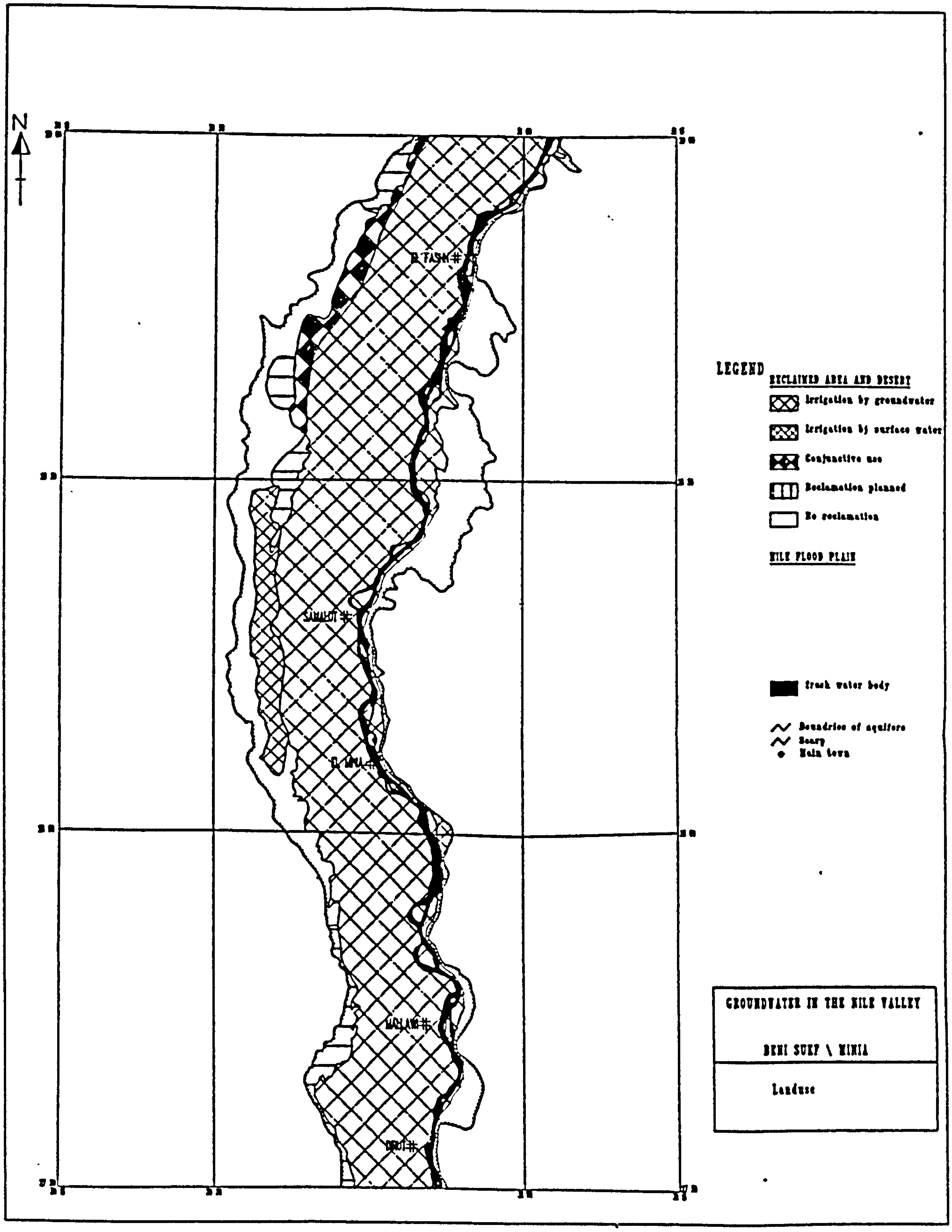

GROUNDWATER IN THE NILE VALLEY
ESNA \ ASWAN
Boundaries and types of aquifers
N
INTERGRANULAR AQUIFERS
(Nile floodplain deposits) unconfined aquifer
(Old Nile and wadi deposits) unconfined
Tm (Moghra) Semi-confined/unconfined aquifer
(Sand and gravel with limestone)
KARSTIFIED AND FISSURED AQUIFERS
Tv (Basalt)
Te (Limestone)
B (Basement)
Ku (Nubian sandstone) Confined aquifer
NON AQUIFERS
Tp (Shale and sandstone) Aquiclude
K (Shale with bands of limestone)
Fresh water body
Saline lake
Boundaries of aquifers
Scarp
Main town
1
3
7
9

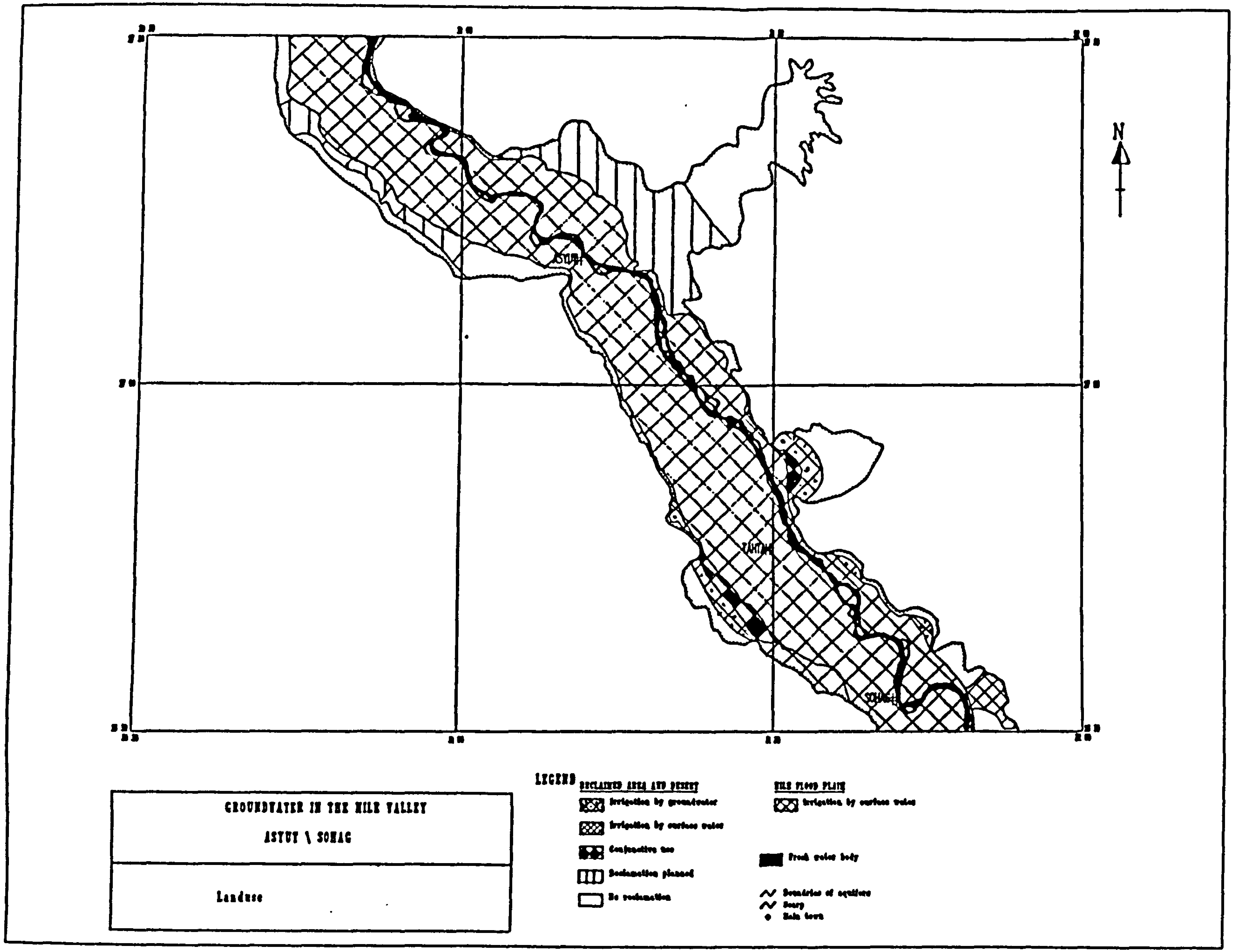
APPENDIX G

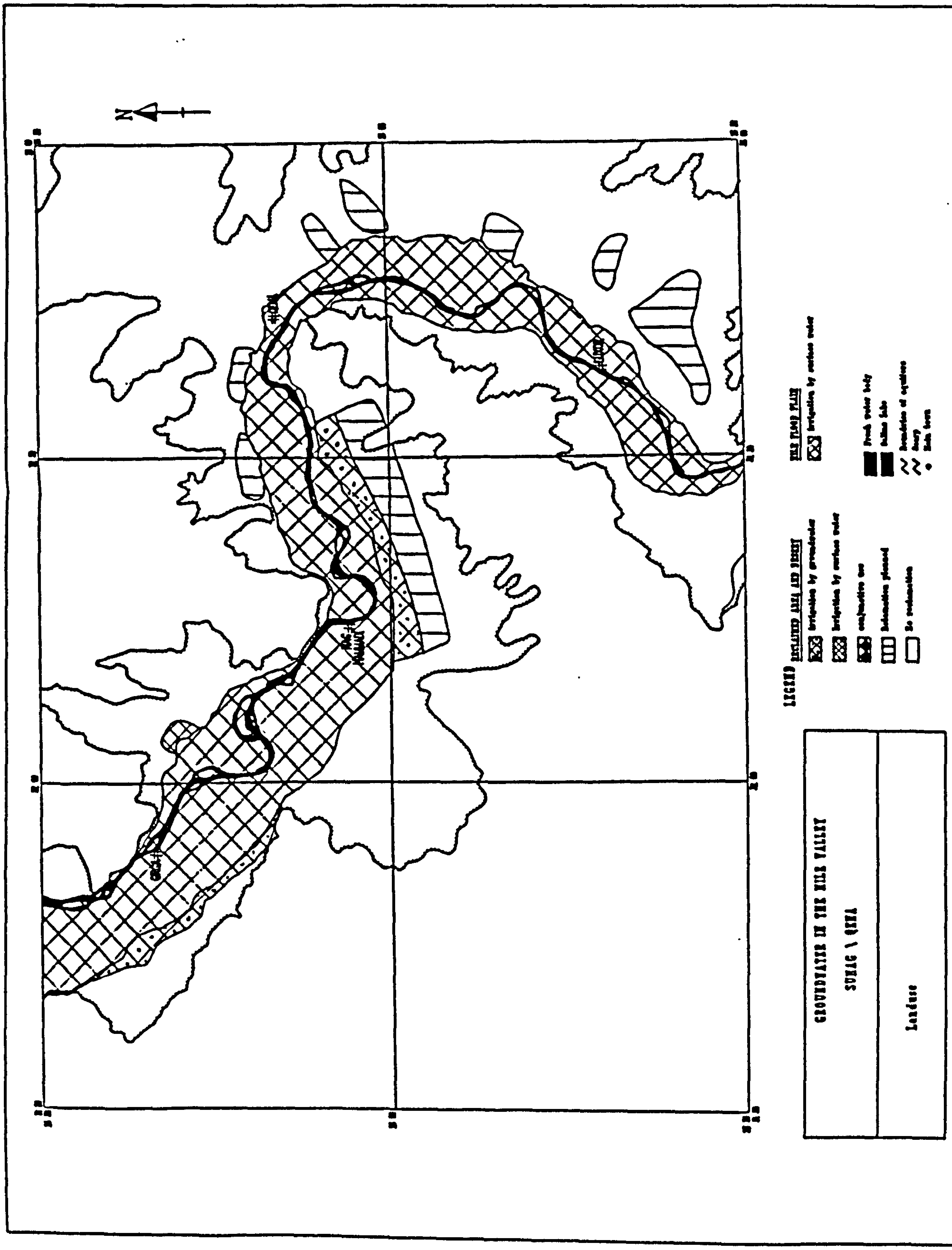

N
POTENTIALITY OF GROUNDWATER IN THE DELTA
WESTERN - MIDDLE DELTA
Land use
LEGEND
RECLAIMED AREA AND DESERT
Irrigation by groundwater
Reclaimed by surface water
Conjunctive use
Reclamation planned
No reclamation
NILE FLOOD PLAIN
Irrigation by surface water
Fresh water body
Boundries of aquifers
Scarp
Main town

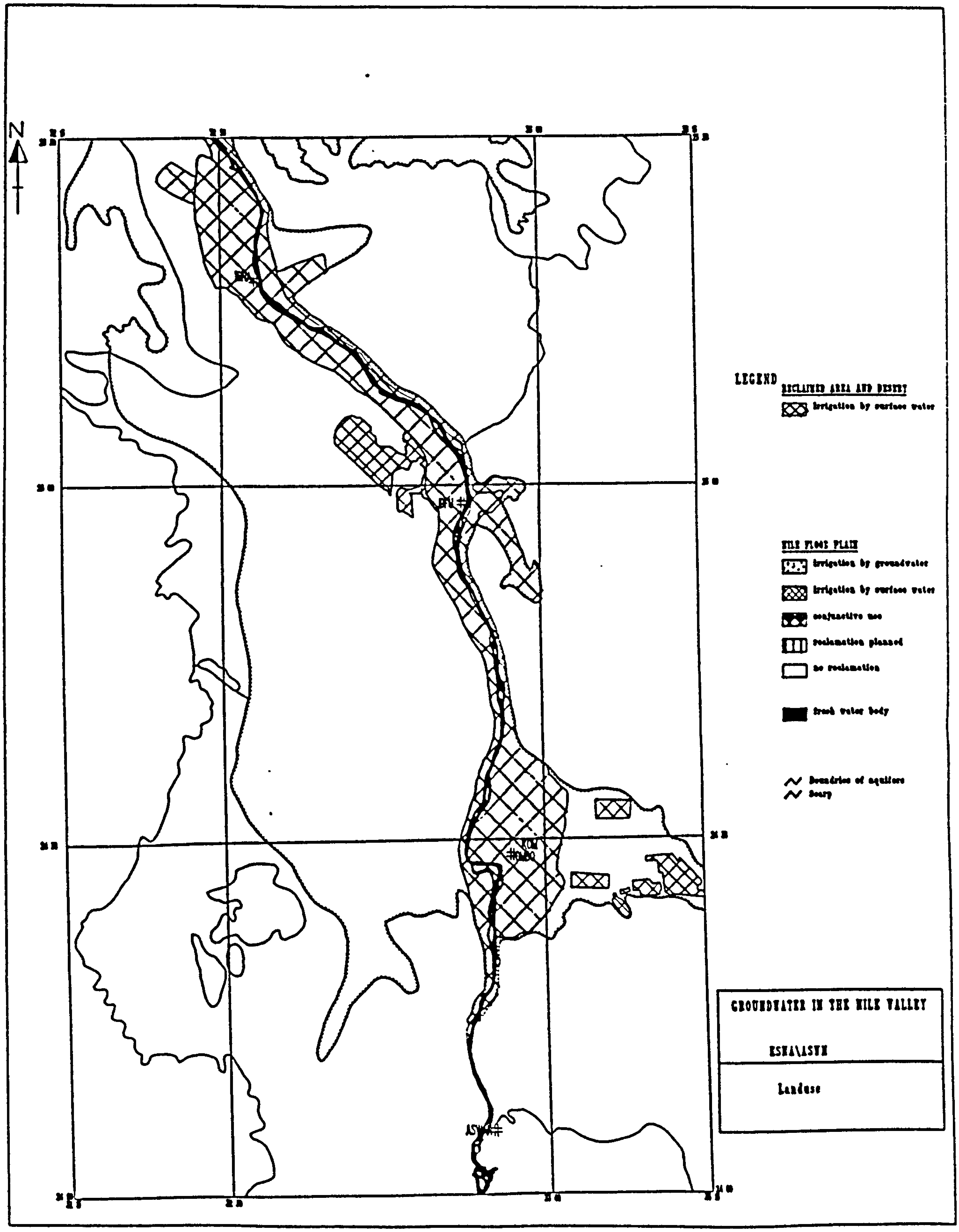

POTENTIALITY OF GROUNDWATER IN THE DELTA
EASTERN - MIDDLE DELTA
Land use
LEGEND


N
#HELWAN
EL FAYOUM#
BENI SUEF#
GROUNDWATER IN THE NILE VALLEY
GIZA \ BENI SUEF
Landuse and abstraction
LEGEND
Conjunctive use
Reclamation planned
No reclamation
Fresh water body


N
LEGEND
RECLAIMED AREA AND DESERT
Irrigation by groundwater
Irrigation by surface water
Conjunctive use
Reclamation planned
No reclamation
NILE FLOOD PLAIN
fresh water body
Boundries of aquifers
Scarp
Main town
GROUNDWATER IN THE NILE VALLEY
BENI SUEF \ MINIA
Landuse


N
ASYUT
TAHTA
SOHAG
GROUNDWATER IN THE NILE VALLEY
ASYUT \ SOHAG
Landuse
LEGEND
RECLAIMED AREA AND DESERT
Irrigation by groundwater
Irrigation by surface water
Conjunctive use
Reclamation planned
No reclamation
NILE FLOOD PLAIN
Irrigation by surface water
Fresh water body
Boundaries of aquifers
Main town


GROUNDWATER IN THE NILE VALLEY
SOHAG \ QENA
Landuse
LEGEND
Irrigation by groundwater
Irrigation by surface water
conjunctive use
Reclamation planned
No reclamation
NILE FLOOD PLAIN
Irrigation by surface water
Fresh water body
Saline lake
Boundary of aquifers


N
LEGEND
RECLAIMED AREA AND DESERT
Irrigation by surface water
NILE FLOOD PLAIN
Irrigation by groundwater
Irrigation by surface water
conjunctive use
reclamation planned
no reclamation
fresh water body
Boundries of aquifers
Scarp
GROUNDWATER IN THE NILE VALLEY
ESNA\ASWN
Landuse

APPENDIX H

```
C    *****************************************************************
C
      PROGRAM nile_water_security
C
C    *****************************************************************
C
      IMPLICIT REAL*8 (A-H,O-Z)
      INCLUDE'param.inc'
      include'5yearopt.inc'
      INCLUDE 'keys.for'
      INCLUDE 'regions.inc'
      INCLUDE'com_int.for'
      INCLUDE'com_nas.for'
      INCLUDE'com_up.for'
      INCLUDE'status.inc'
      INCLUDE'results.inc'
      INCLUDE'glob_var.inc'
      LOGICAL pulldown_load
      INTEGER pulldown_multi,click_type
      LOGICAL click
      INTEGER*2 workin(0:10),workout(0:56)
      CHARACTER*32 loadmsg,savemsg,fname*64,fread*3,fname2*64
      CHARACTER*5 YN
      LOGICAL named,changed,there
      LOGICAL edit_canal
      INTEGER alert,mem
      DOUBLE PRECISION copy(120)
      DOUBLE PRECISION schem_num(16)
      LOGICAL lcopy
      equivalence (lcopy,table_pool)
      integer i,k,iiiflag
      PARAMETER(STRESS=1,YIELD=2)
C
      INTEGER         N,LIW,LW
      PARAMETER         (N=22,LIW=N+2,LW=N*(N-1)/2+2+12*N)
      INTEGER         Nout
      PARAMETER         (Nout=6)

      DOUBLE PRECISION  F
      INTEGER         IBOUND, IFAIL, J

      DOUBLE PRECISION  BL(N), BU(N), W(LW), X(N)
      INTEGER         IW(LIW)

      EXTERNAL        E04JAF
C
      DATA workin/10*1,2/
      DATA loadmsg/'Loading:'/
      DATA savemsg/'Saving:'/
C
      iregion=1
      isubregion=0
      ilevel=0
      model_mode=1
      model_year=1
      iiiflag=1
C
```

```
 63 icount=1
    IF(iiiflag .NE. 1) CALL NEXT_YEAR

    OPEN(28,FILE='results.$$$',FORM='UNFORMATTED')
    open(19,file='status.dat',iostat=ier)
    write(19,*,iostat=ier) 'Memory free =',mem()
C
C    Load in fixed data.
C
    IF(MODEL_YEAR .EQ. 1) THEN
           CALL fixdat
           invol=39.0
    ENDIF
C
C    Load in default settings.
C
    ncrop(0)=19
    DO 32 i=1,ncrop(0)
         icrop(0,i)=i
 32 CONTINUE
C
C    Calculate actual cropped areas from percentages.
C
    tarea(0)=0.0D0
    DO 20 i=1,11
         tarea(0)=tarea(0)+tarea(i)
         CALL calc_crop(i)
 20 CONTINUE

    CALL total_crops
C
    OPEN(1,FILE='DATA\DEFAULT.NWS')
    DO 40 i=1,nregions
         CALL read_region(1,i)
 40 CONTINUE
    CALL read_global(1)
    CLOSE(1)
C
    iseq=1
    CALL inflow
C
    OPEN(30,FILE='GW_&_SM.dat')
C
    calculated=.FALSE.
    CALL calc_whole
    CALL write_output
C
C    Start of main event loop.
C
    CALL load_all
 45 print*,'Allow surface irrigation in New Lands ? (Y/N)'
    read(*,'(A)') conjuse
    if(conjuse.ne.'Y'.and.conjuse.ne.'y'.and.conjuse.ne.'N'.and.conjus
   +e.ne.'n') then
           print*,'ERROR ! Please type Y or N'
           goto 45
    endif
```

```
******************************************************************
*    Example Program Test
******************************************************************

C     WRITE (NOUT, FMT=99999)

*     AdjustedReleases=.TRUE.
*     AdjustedRelVal=55500000000.0D0

      close(28)
      OPEN(29,FILE='results.$$$',FORM='UNFORMATTED')

      PRINT 145, model_year
 145  format('1','You are now optimising year no.',i2,'     Press any ke
     +y to continue ..')
      read*

*     GW : from 1 to 11 and DR : from 12 to 22
      DO 150 isubreg=1,11
            CALL read_output(isubreg,model_year,schem_num,nryear,per_met,
     +      us_flow,ds_flow,qfayoum)
            X(isubreg)=schem_num(8)
            X(isubreg+11)=schem_num(9)
 150  CONTINUE
*     PRINT*,' '
*     PRINT*,'GW for regions 1 to 11 succeeded by DR for same regions'
*     print*,X

      close(29)

      IBOUND=0
*     GW : from 1 to 11 and DR : from 12 to 22
      BL(1)=0.0D0
      BU(1)=0.76D0
      BL(2)=0.0D0
      BU(2)=0.604D0
      BL(3)=0.0D0
      BU(3)=0.604D0
      BL(4)=0.0D0
      BU(4)=0.604D0
      BL(5)=0.0D0
      BU(5)=0.461D0
      BL(6)=0.0D0
      BU(6)=0.012D0
      BL(7)=0.0D0
      BU(7)=0.256D0
      BL(8)=0.0D0
      BU(8)=0.45D0
      BL(9)=0.0D0
      BU(9)=0.125D0
      BL(10)=0.0D0
      BU(10)=0.45D0
      BL(11)=0.0D0
      BU(11)=0.125D0
      BL(12)=0.0D0
      BU(12)=1.2D0
      BL(13)=0.0D0
```

```
      BU(13)=1.2D0
      BL(14)=0.0D0
      BU(14)=1.2D0
      BL(15)=0.0D0
      BU(15)=1.2D0
      BL(16)=0.0D0
      BU(16)=0.1D0
      BL(17)=0.0D0
      BU(17)=1.2D0
      BL(18)=0.0D0
      BU(18)=0.12D0
      BL(19)=0.0D0
      BU(19)=0.1D0
      BL(20)=0.0D0
      BU(20)=0.1D0
      BL(21)=0.0D0
      BU(21)=0.1D0
      BL(22)=0.0D0
      BU(22)=0.1D0
      IFAIL=1
      CALL E04JAF(N, IBOUND, BL, BU, X, F, IW, LIW, W, LW,IFAIL)
      PRINT*,'AFTER E04JAF'

      IF (model_year .LT. 20) THEN
 253      PRINT*,'Do you need to optimise year no.',model_year+1,' ? (
     +Y/N)  '
          READ(*,'(A)') YN
          IF (YN .EQ. 'Y' .OR. YN .EQ. 'y') THEN
                iiiflag=iiiflag+1
                GOTO 63
          ELSE IF (YN .EQ. 'N' .OR. YN .EQ. 'n') THEN
                GOTO 263
          ELSE
                PRINT*,'Typing Error ! Please Try Again'
                GOTO 253
          ENDIF
      ENDIF

 263  WRITE (NOUT, FMT=99998) IFAIL
      IF (IFAIL.NE.1) THEN
          WRITE (NOUT, FMT=99997) F
          WRITE (NOUT, FMT=99996) (X(J), J=1, N)
      ENDIF
      STOP

99999 FORMAT ('E04JAF Example Program Results',/1x)
99998 FORMAT (///'Error Exit Type', I3,'-See Routine Document')
99997 FORMAT (///'Function Value on Exit is', E16.4)
99996 FORMAT (' At the Point ', 4F9.4)
      END
************************************************************
      SUBROUTINE FUNCT1 (N,XC,FC)

      include 'param.inc'
      include '5yearopt.inc'
      include 'results.inc'
      include 'status.inc'
```

```
      INTEGER i,k,l,m,ireg,it,icrop,isubreg
      REAL INPCOSTS(21),BYPROVAL(21),PERCRPR(21),GWC(11),DRC(11),FWC(11)
      DOUBLE PRECISION     YPRICE,COUNT,COUNT1,WCOSTS
      real*8          Yprreg
      DOUBLE PRECISION     schem_num(16),us_flow,ds_flow
      DOUBLE PRECISION     supply,Nsupply,TOTSUPP,NTOTSUPP
      REAL*8       OLDGW,OLDDR,OLDTOTS,OLDYPR,OLDWCO
      REAL*8       gwdiff,drdiff,totsdiff,yprdiff,wcodiff
      real*8      fay

      CHARACTER*10 cropname(21)
      CHARACTER*3 regname(11)
      CHARACTER*7 comp

      DOUBLE PRECISION     FC
      INTEGER          N

      DOUBLE PRECISION     XC(N)

      DOUBLE PRECISION     X1(11), X2(11), OLDX1(11), OLDX2(11)
*      parameter (stress=1,yield=2)
      integer iflag
      data iflag/1/

      if (iflag.eq.1) then
      iflag=0

      OPEN (UNIT=9,FILE='C:\NWT\DATA\INPCOSTS.DAT',STATUS='OLD')
      OPEN (UNIT=10,FILE='C:\NWT\DATA\BYPROVAL.DAT',STATUS='OLD')
      OPEN (UNIT=11,FILE='C:\NWT\DATA\PERCRPR.DAT',STATUS='OLD')
      OPEN (UNIT=12,FILE='C:\NWT\DATA\GWC.DAT',STATUS='OLD')
      OPEN (UNIT=13,FILE='C:\NWT\DATA\DRC.DAT',STATUS='OLD')
      OPEN (UNIT=14,FILE='C:\NWT\DATA\FWC.DAT',STATUS='OLD')
      OPEN (UNIT=15,FILE='C:\NWT\DATA\CROPNAME.DAT',STATUS='OLD')
      OPEN (UNIT=16,FILE='C:\NWT\DATA\REGNAME.DAT',STATUS='OLD')

      READ(9,*) (INPCOSTS(icrop),icrop=1,21)
      READ(10,*) (BYPROVAL(icrop),icrop=1,21)
      READ(11,*) (PERCRPR(icrop),icrop=1,21)
      READ(12,*) (GWC(ireg),ireg=1,11)
      READ(13,*) (DRC(ireg),ireg=1,11)
      READ(14,*) (FWC(ireg),ireg=1,11)
      READ(15,*) (CROPNAME(icrop),icrop=1,21)
      READ(16,*) (REGNAME(isubreg),isubreg=1,11)

      OLDGW     = 0.0D0
      OLDDR     = 0.0D0
      OLDTOTS    = 0.0D0
      OLDYPR    = 0.0D0
      OLDWCO     = 0.0D0

      endif

*      if(icount.EQ.3) GOTO 3000

*     X1 is GW and X2 is DR
```

```
*     print 4
* 4   FORMAT('1','  X1 Values (GW)',5x,'  X2 Values (DR)')

      X1(1)=  XC(1)
      X1(2)=  XC(2)
      X1(3)=  XC(3)
      X1(4)=  XC(4)
      X1(5)=  XC(5)
      X1(6)=  XC(6)
      X1(7)=  XC(7)
      X1(8)=  XC(8)
      X1(9)=  XC(9)
      X1(10)=  XC(10)
      X1(11)=  XC(11)
      X2(1)=  XC(12)
      X2(2)=  XC(13)
      X2(3)=  XC(14)
      X2(4)=  XC(15)
      X2(5)=  XC(16)
      X2(6)=  XC(17)
      X2(7)=  XC(18)
      X2(8)=  XC(19)
      X2(9)=  XC(20)
      X2(10)=  XC(21)
      X2(11)=  XC(22)

*     DO 250 i=1,11
*          print*, X1(i),X2(i)
* 250 CONTINUE

 200  OLDX1(1)   =   X1(1)
      OLDX1(2)   =   X1(2)
      OLDX1(3)   =   X1(3)
      OLDX1(4)   =   X1(4)
      OLDX1(5)   =   X1(5)
      OLDX1(6)   =   X1(6)
      OLDX1(7)   =   X1(7)
      OLDX1(8)   =   X1(8)
      OLDX1(9)   =   X1(9)
      OLDX1(10)  =   X1(10)
      OLDX1(11)  =   X1(11)

      OLDX2(1)   =   X2(1)
      OLDX2(2)   =   X2(2)
      OLDX2(3)   =   X2(3)
      OLDX2(4)   =   X2(4)
      OLDX2(5)   =   X2(5)
      OLDX2(6)   =   X2(6)
      OLDX2(7)   =   X2(7)
      OLDX2(8)   =   X2(8)
      OLDX2(9)   =   X2(9)
      OLDX2(10)  =   X2(10)
      OLDX2(11)  =   X2(11)

      DO 500 ireg=1,11
           DO 400 it=1,12
                DO 300 m=1,5
```

```
            ground_water(m,it,ireg)=  X1(ireg)*1000000000.0D0/12.0D0
            drainage_reuse(m,it,ireg)=X2(ireg)*1000000000.0D0/12.0D0
300       CONTINUE
400     CONTINUE
500 CONTINUE
    DO 700 ireg=1,11
        DO 600 m=1,5
            gw_pump_cap(m,ireg)=     X1(ireg)*1000000000.0D0
            dr_reuse_cap(m,ireg)=    X2(ireg)*1000000000.0D0
600     CONTINUE
700 CONTINUE

    DO 800 m=1,5
        gw_pump_dep(m,1)= 0.0D0
        dr_max_per(m,1) = 0.0D0
        gw_pump_dep(m,2)= 5.0D0
        dr_max_per(m,2) = 0.75D0
        gw_pump_dep(m,3)= 5.0D0
        dr_max_per(m,3) = 0.75D0
        gw_pump_dep(m,4)= 5.0D0
        dr_max_per(m,4) = 0.75D0
        gw_pump_dep(m,5)= 0.0D0
        dr_max_per(m,5) = 0.0D0
        gw_pump_dep(m,6)= 0.0D0
        dr_max_per(m,6) = 0.0D0
        gw_pump_dep(m,7)= 5.0D0
        dr_max_per(m,7) = 0.75D0
        gw_pump_dep(m,8)= 5.0D0
        dr_max_per(m,8) = 0.75D0
        gw_pump_dep(m,9)= 0.0D0
        dr_max_per(m,9) = 0.0D0
        gw_pump_dep(m,10)= 5.0D0
        dr_max_per(m,10) = 0.75D0
        gw_pump_dep(m,11)= 0.0D0
        dr_max_per(m,11) = 0.0D0
800 CONTINUE

    OPEN(28,FILE='results.$$$',FORM='UNFORMATTED')
    CALL calc_whole
    CALL write_output
    CLOSE(28)
    OPEN(29,FILE='results.$$$',FORM='UNFORMATTED')

    CALL out_yield(max_year,0,model_year,2)
    DO 1000 icrop=1,21
        if(CROPNAME(icrop).EQ.' ') goto 1000
        if(table_pool(4,icrop) .EQ. 0.0D0 .AND. table_pool(5,icrop)
   +    .EQ. 0.0D0) GOTO 1000

1000 CONTINUE

    TOTSUPP=0.0D0
    NTOTSUPP=0.0D0

    print*,'______________________________________________________________
   +__________'
    print*,'Reg   GW abstraction      DR abstraction      FW dive
```

```
     +rsion'
      print*,'______________________________________________________
     +____________'

      DO 2000 isubreg=1,11
            CALL read_output(isubreg,model_year,schem_num,nryear,per_met
     +,us_flow,ds_flow,qfayoum)
            if (isubreg .eq. 7) fay=schem_num(12)-schem_num(9)
            if (isubreg .eq. 1 .or. isubreg .eq. 5 .or. isubreg .eq. 6 .
     +or. isubreg .eq. 9 .or. isubreg .eq. 11) then
                  Nsupply= schem_num(1)+schem_num(2)+schem_num(12)-schem
     +_num(9)+schem_num(11)-schem_num(8)
                  print*, regname(isubreg), Nsupply
                  NTOTSUPP=NTOTSUPP+Nsupply
            else
                  supply= schem_num(1)+schem_num(2)+schem_num(12)-schem_
     +num(9)+schem_num(11)-schem_num(8)
                  print*, regname(isubreg), schem_num(8), schem_num(9),
     +supply
                  TOTSUPP=TOTSUPP+supply
            endif

 2000 CONTINUE
      print*,'______________________________________________________
     +____________'

      CALL read_output(0,model_year,schem_num,nryear,per_met,us_flow,ds_
     +flow,qfayoum)

      print*,'Total ',schem_num(8),schem_num(9),TOTSUPP
      print*,'      ',NTOTSUPP
      print*,'______________________________________________________
     +____________'

 2050 print*,'Rel. at Aswan=',us_flow-NTOTSUPP
      print*,'surface water evap.=',schem_num(1)-fay
      print*,'crop evapotranspir.=',schem_num(2)
      print*,'mun/ind consump.use=',schem_num(5)
      print*,'flow to lake qarun =',fay
      print*,'flow to sea        =',ds_flow+schem_num(3)
      print*,'GW recharge        =',schem_num(11)
      print*,'GW pumping         =',schem_num(8)
      print*,'change GW storage  =',schem_num(11)-schem_num(8)
      print*,'change SM storage  =',us_flow -
     +                  (schem_num(1)-fay + schem_num(2) +
     +                   schem_num(5) +
     +                   ds_flow+schem_num(3) +
     +                   schem_num(11) - schem_num(8))-
     +                  fay

      print*,'______________________________________________________
     +____________'
      print*,'Reg     Economic Return per Region      Water Costs per R
     +egion'
      print*,'______________________________________________________
     +____________'
```

```
      YPRICE=0.0D0
      WCOSTS=0.0D0
      DO 2200 isubreg=1,11

            CALL out_yield(max_year,isubreg,model_year,2)
            Yprreg=0.0D0

            DO 2100 icrop=1,21
                  COUNT=(((PERCRPR(icrop) + BYPROVAL(icrop))
     +             * table_pool(4,icrop)/100.0D0)
     +             - INPCOSTS(icrop))
     +            * table_pool(5,icrop) * 1000000.0D0
                  Yprreg = Yprreg + count
2100        CONTINUE
2150        YPRICE = YPRICE + Yprreg

            CALL read_output(isubreg,model_year,schem_mum,nryear,per_met
     +,us_flow,ds_flow,qfayoum)
            if (isubreg .eq. 1 .or. isubreg .eq. 5 .or. isubreg .eq. 6 .
     +or. isubreg .eq. 9 .or. isubreg .eq. 11) then
                  Nsupply  =   schem_mum(1)+schem_mum(2)+schem_mum(12)-sc
     +hem_mum(9)+schem_mum(11)-schem_mum(8)
                  piezhead = (32.7/ 1813.77) ** (-1.0194)
                  aaa=312.6+piezhead
                  bbb=0.36926*(piezhead**0.3152)
                  if(conjuse .eq. 'N' .or. conjuse .eq. 'n') then
                        COUNT1= (Nsupply*1000000000.0D0/365)*aaa*(32.7**
     +bbb)/32.7
                  elseif(conjuse .eq. 'Y' .or. conjuse .eq. 'y') then
                        COUNT1=aaa*(((schem_mum(8))*
     +                  1000000000.0D0/365)**bbb)
     +                  +(schem_mum(1)+schem_mum(2)-schem_mum(8))
     +                  * 0.10 * 1000000000.0D0
                  endif
            else


                  COUNT1=( schem_mum(8) * GWC(isubreg) +
     +              schem_mum(9) * DRC(isubreg) +
     +              (schem_mum(1) + schem_mum(2) + schem_mum(12)-
     +               schem_mum(9) + schem_mum(11) - schem_mum(8)
     +              ) * FWC(isubreg)
     +            ) * 1000000000.0D0
            endif
2170        WCOSTS = WCOSTS + COUNT1

            print*,regname(isubreg),'      ',Yprreg,'        ',COUNT1

2200 CONTINUE

      print*,'____________________________________________________
     +__________'
      print*,'Total    ',YPRICE,'       ',WCOSTS
      print*,'____________________________________________________
     +__________'
```

```
2600 FC= 1/(YPRICE - WCOSTS)
     PRINT*,'Func.val. for year',model_year,' =',FC,' at iter.',icount
     print*,'____________________________________________________
    +__________________'
     print*,'          _________________________________________'
     print*,'                ______________________'
     icount=icount+1

     OLDGW=schem_num(8)
     OLDDR=schem_num(9)
     OLDTOTS=TOTSUPP
     OLDYPR=YPRICE
     OLDWCO=WCOSTS

     CLOSE(29)

     RETURN

 3000 END
C
C     ****************************************************************
C
      SUBROUTINE set_reals_to_zero(array,num)
C
C     ****************************************************************
C
      REAL array(*)
C
      DO 10 i=1,num
         array(i)=0.0
   10 CONTINUE
C
      RETURN
      END
C     ****************************************************************
C
      SUBROUTINE comp_wait(handle)
C
C     ****************************************************************
C
      RETURN
      END
C
C     ****************************************************************
C
      SUBROUTINE add_extension(fname,ext)
C
C     ****************************************************************
C
      CHARACTER*(*) fname,ext
C
      len=length(fname)
      IF(INDEX(fname,'.').EQ.0) THEN
         IF(len.GT.0) THEN
           fname=fname(:len)//'.'//ext
         ELSE
           fname='.'//ext
```

```
        END IF
      END IF
      RETURN
      END
C
C     *****************************************************************
C
      BLOCK DATA region_positions
C
C     *****************************************************************
C
      INCLUDE 'param.inc'
      INCLUDE 'regions.inc'
      INCLUDE 'monnames.inc'
      INCLUDE 'monthoff.inc'
      INCLUDE 'glob_var.inc'
      INCLUDE'5yearopt.inc'
C
      DATA nregs/4/
      DATA regx/393,428,430,382/
      DATA regy/68,200,355,454/
      DATA nsregs/6,5,0,0/
      DATA fsreg/1,7,12,12/
      DATA sregx/90,148,293,437,475,595,247,328,328,329,329/
      DATA sregy/220,170,139,198,247,295,49,111,156,344,389/
      DATA region_e,subregion_e/
     + 'Lower Egypt','Upper/Middle Egypt','Lake Nasser','Upper Nile',
     + 'All Egypt',
     + 'West Delta New Lands','West Delta','Middle Delta',
     + 'East Delta','East Delta New Lands','Sinai',
     + 'Fayoum','Middle Egypt','Middle Egypt New Lands',
     + 'Upper Egypt','Upper Egypt New Lands'/
      DATA month_names/'Nov','Dec',
     + 'Jan','Feb','Mar','Apr','May','Jun','Jul','Aug','Sep','Oct'/
      DATA ystring/'1990','1991','1992','1993','1994','1995','1996',
     +            '1997','1998','1999','2000','2001','2002','2003',
     +            '2004','2005','2006','2007','2008','2009','2010'/
      DATA moff/11,12,1,2,3,4,5,6,7,8,9,10/
C
      DATA mun_dist,ind_dist,sud_dist/
     + 8,8,8,8,8,10,10,8,8,8,8,8,100,
     + 8,8,8,8,8,10,10,8,8,8,8,8,100,
     + 8,8,8,8,8,10,10,8,8,8,8,8,100/
      DATA gw_pump_dep/55*2.5/
      DATA dr_max_per/55*0.4/
      DATA rule_opt,inf_opt,start_year/1,1,1900/
      END

C *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***
      subroutine  please_wait(handle)
C
C   Displayed message Reading data please wait on the screen
C
C   RJS  Original routine                        22/2/93
C *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***
      return
      end
```