Aus dem Institut für Agrarökonomie
der Christian-Albrechts-Universität zu Kiel

MATHEMATICAL PROGRAMMING MODELS FOR OPTIMISING IRRIGATION WATER MANAGEMENT IN EGYPT

Dissertation

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ABSTRACT

The availability of reliable water supplies from Lake Nasser is governed by an existing water sharing agreement, under which 55.5 billion cubic meters of water are allocated to Egypt. Due to the increasing demand for water caused by rapidly growing population and fixed water supplies, greater emphasis is now being placed on the need to improve the efficiency in use of the available water resources for crop production.

Linear Programming (LP) was used to make decisions about irrigation water management options in conjunction with optimal cropping patterns to ensure optimal use of water. The suggested optimal model was then used to measure the impact of different water policies. The solution of the LP model was obtained using GAMS modelling programme. The LP model was essentially static, allocating irrigation water in a single year among different crops in the first stage of the mathematical analysis at governorates level and in the second stage at the global level. The crop allocation model, which maximised gross margins for a growing season, was constrained by land, water, and organisation constraints (a minimum and maximum area under each crop of the last 5 years). The calculations were based on statistical data from the official statistical institutions in Egypt, where the technical coefficients were determined as the average of real values for the three years (1999-2001).

The results showed that there is a potential to increase net income from crop production through efficient allocation of irrigation water. The optimal cropping patterns would result in an increase in income by 3.01 % and 3.82 % over the actual farm income at the governorates and global levels, respectively. They can also help increase food self-sufficiency ratios. The results also showed the future impact of different water policies resulting from the use of comparative-static planning models. The results of the various scenarios, which can be implemented in Egypt, are as follows: Under increasing water supply conditions through improving water distribution efficiency, the total gross margins increased by 1.71 % and 1.50 % more than the optimal base values at the governorates and global levels, respectively. Under drought conditions, farm income decreased by 5.30 % and 5.05 % indicating losses below the basic solution at the governorates and global levels, respectively. Under water charging scenario (Partial Cost Recovery), farm income decreased representing increased production costs. There was no impact on resources use under this scenario.

Keywords: Resource Economics, Water Management, Linear Programming, Optimal Cropping Pattern, Water Use Efficiency, Water Drought Scenario, and Water Charging.

ZUSAMENFASSUNG

Das Wasserangebot Ägyptens ist im Wesentlichen auf den Nilabfluss des Aswan Staudamms begrenzt. Auf der Grundlage eines zwischenstaatlichen Übereinkommens mit dem Sudan stehen Ägypten jährlich 55,5 Mrd. m^3 Nilwasser zur Verfügung. Durch den Bevölkerungsanstieg steigt auch die Nachfrage nach Wasser, jedoch bleibt das Angebot an Wasser fix. Da also das Wasserangebot nicht erhöht werden kann, wurde in der Dissertation untersucht, wie sich eine optimierte Wassernutzung auf Produktion und Einkommen der Landwirtschaft auswirken. Zunächst wurden in Hinblick auf die Wassernutzung die optimalen Anbaustrukturen im Untersuchungsgebiet bestimmt. Dann wurden die Auswirkungen der zukünftigen Strategien auf der betrieblichen Ebene mit Hilfe eines komparativ statischen Modells analysiert. Datengrundlage bildeten aktuelle staatliche Daten aus den Jahren 1999-2001, aus denen jeweils der Mittelwert in das Modell, ein statisches LP-Modell für die optimale Anbaustruktur, einfloss. Als mathematische Software wurde GAMS eingesetzt. Es wurde der DB aus der pflanzlichen Produktion maximiert. Die Nebenbedingungen entsprechen den gegenwärtigen Verhältnissen in den einzelnen Regionen: Die gesamte regionale Ackerfläche, das Wasserangebot und für jede Frucht die minimale und maximale Anbaufläche der letzten 5 Jahre als Anbaubeschränkung.

Zuerst wurden die optimalen Anbaustrukturen bei den aktuellen politischen Rahmenbedingungen ermittelt. Aus der Modellrechnung ergab sich ein Anstieg des Gesamtdeckungsbeitrages von 3,01 % (auf Ebene der Provinzen) und 3,82 % (für Gesamtägypten) gegenüber der Ist-Organisation sowie eine Erhöhung des Selbstversorgungsgrades. Im nächsten Schritt wurden die Auswirkungen bei unterschiedlicher Wasserpolitik geschätzt und ergaben folgende Ergebnisse: Die politische Maßnahme einer Erhöhung der Wassermenge durch Steigerung der Wasserverteilungseffizienz führt zu höheren Einkommen. Ein Vergleich der neuen Lösung mit den Ergebnissen des Basismodells zeigte, dass hierbei insgesamt der Deckungsbeitrag um ca. 1,71 % (auf Ebene der Provinzen) und 1,50 % (für Gesamtägypten) anstieg. Würde im Gegensatz dazu die Wassermenge reduziert (für eine Neulanderschließung), würde das Einkommen in den bisher bewirtschafteten Regionen sinken. Der Vergleich der Lösung mit den Ergebnissen des Basismodells lässt erkennen, dass insgesamt der Deckungsbeitrag um ca. 5,30 % (auf Ebene der Provinzen) und 5,05 % (für Gesamtägypten sinken würde. Die Erhebung eines Wasserpreises zur Deckung der laufenden Kosten wirkt sich nicht auf die Wassernachfrage aus, und das Einkommen sinkt entsprechende der erhöhten Produktionskosten.

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Abbreviations

CAPMAS	Central Agency for Public Mobilization and Statistics (Cairo)
CCA	Common Country Assessment
EHDR	Egyptian Human Development Report
FAO	Food and Agriculture Organization of the United Nations (Rome)
GDP	Gross Domestic Product
ISPAN	Irrigation Support Project for Asia and the Near East, 1993
MALR	Ministry of Agriculture and Land Reclamation
MWRI	Ministry of Water Resources and Irrigation
MP	Ministry of Planning, Economic and Social Development Plan, 2001
NWRC	National Water Research Centre
UN	United Nations
WMRI	Water Management Research Institute

Measures

BCM	Billion Cubic Meter
Feddan	0.42 hectare
ha	hectare
kg	kilogram
km	kilometre
km^2	square kilometre
m^3	cubic meter
MCM	Million Cubic Meter
%	percent
^{O}C	degree Celsius

Exchange Rates

LE	Egyptian Pound
	(3.65 LE equal about 1 US $ in 2000)
USD	United State Dollar

CHAPTER 1

INTRODUCTION

1.1 Problem Description

The main and almost exclusive resource of fresh water for Egypt is the Nile River. Egypt relies on the availability of its annual share of Nile water, which is stored in Lake Nasser. This is approximately 55.5 billion cubic meters annually following agreement between Egypt and Sudan in 1959. Agriculture is the major consumer of water, consuming about 83 % of Egypt's quota of water. Demand for water is increasing due to a rapidly growing population, urbanisation and higher standards of living. Furthermore, the country's agricultural policy emphasises augmenting crop production where cultivated land should be increased by about 1.4 million hectares until 2017 in order to feed the growing population and to accomplish higher standards of living.

Enlargement of agricultural land simultaneously under Egyptian conditions means demand for water will increase. This increase in demand for the limited water resources puts pressure on the decision-makers to formulate policies and programs to improve the allocation of the scarce water resources. Various water users, especially in the agricultural sector, which is considered a thrust area for achieving maximum conservation of water, must reconsider their water requirements in order to overcome the problem of water scarcity and keep the national balance of water in equilibrium. A critical situation arises from not only a sharp increase in water demand, but also from increased competition for limited water resources among the different users. Therefore greater emphasis is now being placed on the need to improve the efficiency in use of available water resources for crop production. Consequently, efficient water use has become Egypt's long goal term under 2017 Water Policy.

For the agricultural sector, optimising irrigation management becomes a vital and crucial issue, due to the limited freshwater and land resources. The scarcity of water makes it difficult to expand the cultivated area decreasing per capita land. This is reflected in the increasing food gap, and agriculture will be faced by big challenges in the years to come. Considering that the two main limitations facing increased agricultural production are the availability of additional cultivable land and adequate irrigation water, it is necessary to introduce new scientific techniques in agriculture and in irrigation management as well. The use of mathematical programming models to design future plans for water development can be a powerful tool to ensure efficient use of these resources. There are many factors that need to be considered in irrigation management in order to improve the efficiency in the use of water. One of the key decisions is how much water should be allocated to a particular crop relative to other crops. An efficient allocation of water must strike a balance between the competing demands. This needs an economic modelling approach, which can determine the optimal allocation of water for various uses.

Against this background, the main objective of this study was to determine the optimal cropping patterns to ensure optimal use of water under different policies. This study presented a management tool using mathematical models for determining optimal use of water in conjunction with optimal cropping patterns. Results of the modelling showed how optimal cropping patterns and the potential to reallocate water resources in an optimal way can be achieved. This study also examined these models with the aim of identifying future potential improvement in irrigation management. This will be valuable for policy information, which may serve as a guideline in pre-season indicative planning for cropping patterns and irrigation water use in the Egyptian agriculture.

The problem statement can be captured in number of questions that this study addressed:

(1) What are the major challenges that face Egypt's agriculture and irrigation sectors?

(2) What are the relevant economic criteria and instruments that could be used in irrigation water planning and management?

(3) What is the optimal irrigation water demand and how should water be allocated to crops?

- What is the actual irrigation water demand?
- What amount of land and water resources should be devoted to each crop in a homogenous irrigation area and what are the potential gains that can be made by employing an optimal cropping pattern?

(4) What degree can farmers respond to future water management strategies?

- What is the impact of water management practices of increasing and/or decreasing water availability on crop production?
- What is the impact of charging water policy on crop production?

1.2 Objectives and Hypotheses

This study attempted to examine how irrigation water can be optimally allocated to crops under different policies, and how these polices influence the farmer's economic situation. The main aim of this study is to develop mathematical model based on an economic efficiency criteria for improving water use in Egyptian agriculture. It is for this reason that the following specific objectives are outlined:

(1) To review the relevant economic criteria and instruments that could be used as a tool in planning and irrigation water management.

(2) To develop an optimisation model to:

- Choose the optimal cropping pattern, among different alternatives, which satisfies the existing land and water availability constraints, as well as agronomic and economic conditions of crop production for each agricultural region of Egypt.
- Generate optimising criteria that describe the role of scarcity value (opportunity costs) in determining the allocation of the Nile water.
- Examine the future economic impact of different irrigation policies on crop production, resources uses and farm income.

These application models can be designed to serve as a decision–making tool for planners of agricultural production on both the regional and the national level. They have three main goals:

- To provide regional planners with a decision support tool for planning irrigation water in crop production under various conditions.
- To provide the national planner with a decision support tool aimed at planning irrigation water supply side according to irrigation water demand side.
- To provide decision makers with a tool suitable for "what-if" questions of water charging policies.

In line with the objectives of the study, the following general hypotheses are to be tested:

- Water resources play an important role in crop production.
- Decisions of cropping pattern and irrigation water use are not optimal.
- A policy that addresses the directly economic instrument is more effective in motivating farmers to choose the economically water management strategy than indirect policies, suggesting alternative cropping patterns.
- Water charging could have a positive impact on the efficiency of irrigation water use.

1.3 Methodology

This study was conducted in three steps: First step related to the theoretical section, collection of the relevant publications and literature addressing the issue of irrigation efficiency, modelling irrigation water use and charging policies. The second step was the data collection that was carried out in July 2003 in Egypt for the empirical section, after the permission from the Central Agency for Public Mobilisation and Statistics in Egypt. The empirical study utilised these secondary data obtained from the following official statistical institutions; the Ministry of Agriculture and Land Reclamation (MALR), the Ministry of Water Resources and Irrigation (MWRI), and the Central Agency for Public Mobilisation and Statistics (CAPMAS), Egypt.

On the last stage, the obtained data was analysed in the empirical section. The methods of data analysis used were positive analysis, which dealt with the calculation of irrigation water requirements and patterns of allocation, gross margins and economic value of water in chapter 4. And the normative analysis was mainly used in the empirical study. Mathematical programming models that determine optimal use of water used the methodology for optimisation. The linear programming (LP) was applied to make decisions about irrigation water management options in conjunction with optimal cropping pattern to ensure optimal utilisation of available land and water resources taking into consideration the specified constraints. Then the impact of irrigation policies on farm income, resources use and cropping pattern were determined. The solution of the LP model was obtained using GAMS (Brooke *et al.*, 1998) modelling language.

Research Approach

The research approach consists of 5 parts, as shown in Figure1.1. The approach began with the description of Egypt's agricultural sector and water situation. It is necessary, therefore, to understand the climate conditions, the agricultural production system, Egypt's water resources situation, and irrigation system. This is then followed by economic instruments for improved irrigation water management to elaborate and present the theoretical and methodological foundation for modelling economic management and policy issues of irrigation water use according to the Egyptian conditions.

It is followed by a preliminary assessment of irrigation water use for Egypt, as a basis for comprehensive understanding of irrigation water use patterns and description of technical coefficients for modelling purpose. Then, based on the availability of statistical data the planning models were calculated as a base for scenarios to examine the future impacts of different water policies, which focused on the basis of future potential improvements in irrigation water management in Egyptian agriculture.

Impact analyses measure the future economic impact of any change by comparing the development with and without policy change. The static modelling of future scenarios was applied in a comparative static analysis in which the optimal actual system was compared to the optimal system in the future when implementing irrigation management strategies.

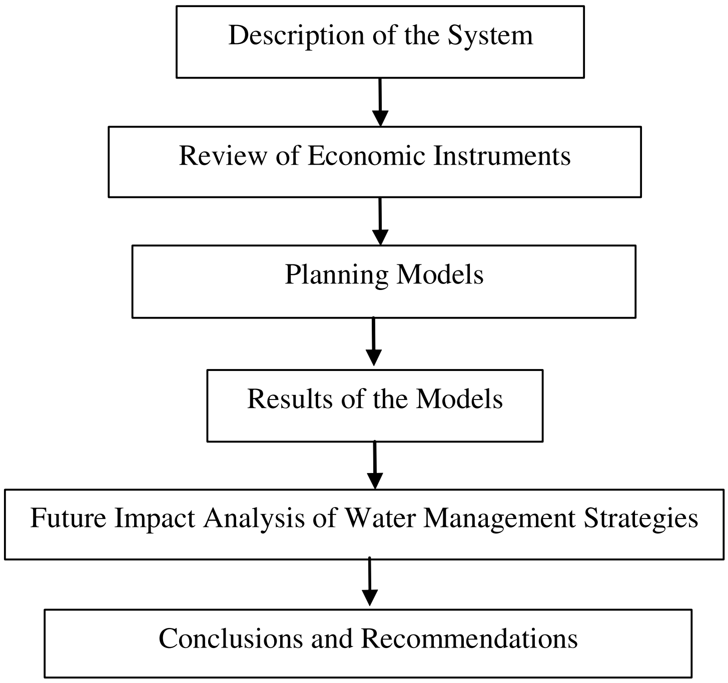


Figure1.1 Research Approach of the Study

As Hazell and Norton (1986) report, linear programming (LP) is well suited for such a study because of the following reasons: many activities and constraints can be considered at the same time, secondary explicit and efficient optimum seeking procedure is provided, results from changing variables can easily be calculated once formulated. The policy instruments can also easily be incorporated by means of additional or modified activities in the models.

The mathematical model was used to obtain the optimal use of irrigation water. It was designed to maximise total gross margins, subject to technical constraints including the production function and land-water resources available, and management constraints. Thereafter, the suggested optimal model was used to measure the impact of future irrigation policies such as the impact of improvements of irrigation efficiency, water drought, and implementing water charging policy.

1.4 Organisation of the Study

This study is organised in six chapters. Following this introductory chapter, an overview on the Egypt's agricultural sector and water resources is given in chapter two. Chapter three deals with the theoretical approach of economic instruments for improved irrigation water planning and management with emphasis on mathematical analysis of irrigation water use. This chapter describes how systems theory can be applied to irrigation management with emphasis on the application of mathematical modelling to crop production under the Egyptian conditions and problems of the irrigation system.

Chapter four is concerned with the preliminary assessment of irrigation water use. This chapter describes the data used to generate the technical coefficient that are the variables on which all the calculations of the models are based. Chapter five deals with optimisation models of irrigation water use in Egypt. In chapter six, the future economic impact analysis, the impact of irrigation management practices and water charging policy, is analysed. The simulation conditions are valid to examine the effects of changing water availability and charging policy. Finally, summary, conclusions, and recommendations are drawn.

CHAPTER 2

EGYPT'S AGRICULTURE AND WATER RESOURCES

2.1 Introduction

Egypt's agricultural sector is the backbone of the economy and the sustainability of this sector is vital for the overall development of the country. It is almost entirely dependent on irrigation and characterised by the limitations of the cultivable land that is determined by the Nile River. This chapter is organised as follows: Section 2.2 provides the background on the Egyptian physiography and climate. Section 2.3 gives an overview on Egyptian agricultural sector. Section 2.4 deals with water resources situation assessment in Egypt. Finally, conclusions to the chapter are presented in section 2.5.

2.2 Physiography and Climate

Egypt is located in an arid climatic zone except for its northern parts that lie in the warm moderate area, which is similar to that of the Mediterranean region, characterised by hot dry summers, moderate winters with little rainfall increasing along the coastal area. Evapotranspiration exceeds the rains and water resources are limited. Egypt occupies slightly more than one million km^2 of which only about 5.5 % are populated while most of it is desert lands. It can be divided into four major physiographic regions: Nile Valley and Delta, Western Desert, Eastern Desert, and Sinai Peninsula (Year Book, 2002). Nile Valley and Delta region has an area of about 4 % of the total area of the country. Egypt can be divided into three main agro–climatic zones:

I. Lower Egypt (Nile Delta), extending from the north of Cairo to the Mediterranean Sea and characterised by some winter precipitation.
II. Middle Egypt, extending from Cairo south to the boundary of Minia/Assuit governorates and characterised by minimal rainfall.
III. Upper Egypt, extending southwards from the Minia/Assuit governorates boundary to the Sudanese border and characterised by the almost complete absence of rainfall.

The prevailing climatic conditions at three main locations, in north Egypt (Alexandria), in middle Egypt (Giza), and in south Egypt (Aswan) are as shown in Table 2.1.

Table 2.1 Mean Monthly Climatologically Data in Egypt

Location	Temperature				Rainfall (mmday-1)	Relative humidity (%)	Evaporation (mm day-1)
	January		August				
	Max., (°C)	Min., (°C)	Max., (°C)	Min., (°C)			
Alexandria	18.5	9.3	30.6	22.8	191.8	65-72	1.6-7.5
Giza	19.5	6.4	34.4	20.4	20.2	53-73	1.5-7.7
Aswan	24.2	9.5	42.0	26.4	1.4	18-41	2.8-8.5

Source: Kotb *et al.,* 2000.

The rainy period is limited mostly during the period October to March where most of its volume fall from November to February. Annual precipitation in various with location, the highest annual precipitation totals, reaching 191.8 mm, is recorded around Alexandria. Inland, there is a very sharp precipitation gradient with only 20.2 mm falling in the middle of Egypt (Giza). Further inland, it continues to decline until at Aswan a value of 1.4 mm is recorded. In southern Egypt several years may elapse without any rain at all. Throughout Egypt rainfall reveals considerable variability over time and space. This means agriculture is depending on irrigation. Daily evaporation ranges from 1.5 to 8.5 mm with a main daily reference evapotranspiration from ca. 2.0 to 10.0 mm. This also means crop production requires intensive irrigation.

2.3 Overview on Egypt's Agricultural Sector

2.3.1 The Role of Agriculture in the National Economy

Egypt, with a per capita income of USD 1,390 a year (World Bank, 2004), is a large developing country. According to the most recent World Bank Classification of economies, it is classified among the lower-middle-income economies. Agriculture is central to the Egyptian economy. To get a picture of the role of agriculture in the national economy, the following indicators are important.

2.3.1.1 Agriculture's Contribution to Gross Domestic Product

Table 2.2 presents the total agricultural GDP and its percentage of the Gross Domestic products. The Agricultural GDP was estimated to be about LE 21,680 million in 1991/92 and increased to about LE 24,470 million in 1995/96 at 1991/92 prices. In the same period its share of GDP decreased from 16.54 % to 15.95 %. Using 1996/97 prices, the Agricultural GDP increased from LE 42,325 million in 1996/97 to about LE 49,894 million in 2001/2002. In the same time its share of GDP decreased from 17.67 % to 16.29 %, as show in Table 2.2.

Table 2.2 Agricultural GDP Share in GDP and its Growth Rate

Year	GDP (million LE)	Agr. GDP (million LE)	Agr. GDP (% of total)	Agr. GDP growth rate
1991/92	131,057	21,680	16.54	2.00
1992/93	134,335	22,220	16.54	2.50
1993/94	139,622	23,072	16.52	3.80
1994/95	146,149	23,741	16.24	2.90
1995/96	153,369	24,470	15.95	3.10
1996/97	239,500	42,325	17.67	3.40
1997/98	253,090	43,905	17.35	3.70
1998/99	268,730	45,620	16.98	3.90
1999/2000	282,201	47,083	16.70	3.40
2000/2001	295,957	48,740	16.50	3.50
2001/2002	306,303	49,894	16.29	3.60

Source: National Bank of Egypt.

The period 1991/92-1995/96 at 1991/92 prices.

The period 1996/97-2001/2002 at 1996/97 prices.

This result indicates that the sectoral share in national economy was taking a decreasing share in GDP at which other sectors take the advantage to share more than agriculture. The relative decline in the role of agriculture partly reflects the strong growth in other sectors. Meanwhile, the agricultural GDP growth rate increased from 2.00 to 3.60 within the same period.

2.3.1.2 Employment in the Agricultural Sector

According to Table 2.3, the percentage of agricultural labour as a proportion of national labour was decreased from 33.36 % in 1991/1992 to 28.10 % in 2000/2001. In terms of numbers employed, this represented a slight increase since 1991/92, with a 4,585 thousand person compared to 2000/2001, with 5,079 thousand persons employed in agriculture. Such an increase cannot be compared to the great increase in the national labour force.

Table 2.3 Agricultural Labour Shares in the National Employment

Year	Employment (thousand)	Agr. Labour (thousand)	%
1991/92	13,742	4,585	33.36
1992/93	13,991	4,620	33.02
1993/94	14,463	4,682	32.37
1994/95	14,893	4,744	31.85
1995/96	15,385	4,812	31.28
1996/97	15,825	4,747	30.00
1997/98	16,344	4,820	29.49
1998/99	16,829	4,899	29.11
1999/2000	17,434	4,985	28.60
2000/2001	18,019	5,079	28.10

Source: National Bank of Egypt.

The proportion of agricultural labour has been decreasing due to modern technologies that have increased production efficiency. This means that there is less dependence on labour.

2.3.1.3 Agricultural Investment

Investment is an indicator reflecting the importance of agriculture sector. Table 2.4 shows that the agricultural, irrigation and drainage investments have tended to increase year after year due to the launch of new land projects.

Table 2.4 Agricultural Investments Shares in the National Investments

Year	Investments (thousand LE)	Agr. Investments (thousand LE)	%
1995/96	44,106.00	3,742.00	8.48
1996/97	55,280.00	4,811.00	8.70
1997/98	62,010.00	6,837.00	11.03
1998/99	68,587.00	8,226.00	12.00
1999/2000	73,106.00	9,893.00	13.53
2000/2001	80,500.00	11,610.30	14.42

Source: National Bank of Egypt.

The agricultural investments out the farm were governmental, which represented about 36 % in 1999/2000 (MP, 2001). While the private agricultural investments were about 64 % that included all in farm investment. It can be noted that the increasing role of the private sector in agricultural investments. Most of governmental investments were in Research, Institutional Support and Agricultural Extension under the Agricultural Liberalisation Policies.

2.3.1.4 Agriculture Share in Exports and Imports

According to Table 2.5, the share of agricultural exports as a proportion of total exports declined from 15.62 % in 1990 to 7.97 % in 1997. On the import side, there was a decrease from 20.44 % in 1990 to 14.98 % in 1997. This indicates how much liberalisation of agricultural trade affects agricultural foreign trade in both exports and imports.

Table 2.5 Agriculture Shares in National Exports and Imports

Year	Total Export (million LE)	Agr. Export (million LE)	%	Total Imports (million LE)	Agr. Import (million LE)	%
1990	6,953.8	1,086.0	15.62	24,823.2	5,074.7	20.44
1991	11,764.7	843.5	7.17	25,216.3	4,357.0	17.28
1992	10,171.2	954.4	9.38	27,656.1	5,611.2	20.29
1993	10,464.5	850.2	8.12	27,550.4	4,691.2	17.03
1994	11,757.5	1,341.1	11.41	32,460.6	6,549.3	20.18
1995	11,703.8	1,355.1	11.58	39,890.9	7,729.7	19.38
1996	12,004.1	1,056.1	8.80	44,217.9	8,424.8	19.05
1997	12,825.9	1,022.6	7.97	44,768.8	6,705.9	14.98

Source: National Bank of Egypt.

2.3.2 Features of the Egyptian Agriculture

Egyptian agriculture is characterised by the scarcity of land and water resources. Beyond the limitations of two important factors land and water, it possesses also some features as follows.

2.3.2.1 Components of the Agricultural Production

The agricultural GDP contains three main sub-sectors: plant production, livestock production, and fisheries production. The plant production sub-sector basically carries the agricultural sector contributing 61.19 % of the agricultural GDP. The rest of the sub-sectors contribute as follows: livestock 30.87 % and fisheries 7.93 %, as shown in Table 2.6. The implication of the agricultural output value and its components is the remarkable decrease in the importance of animal production due to the absence of natural pastures and the high cost of land use for meat and dairy production.

2.3.2.2 Cropping Pattern

An analysis for cropping pattern of Egyptian agriculture in selected years 1990, 1995, and 2000 indicates that it based on basic groups: cereals, fibres (cotton mainly), green fodder, sugar crops, legumes, vegetables, and fruits. Table 2.7 shows that the strategic crops retained their relative position, mainly cereals and green fodder crops in all selected years.

Table 2.6 Value of Agricultural Production by Commodity Groups in 2000

Components	Value (In million LE)	% Of each group	% Of the total
Cereals	12,648.10	28.84	17.65
Legume	708.50	1.62	0.99
Fibbers	1,370.50	3.13	1.91
Oil Seeds	530.46	1.21	0.74
Sugar	1,702.56	3.88	2.38
Vegetables	8,001.94	18.25	11.17
Fruit	9,362.22	21.35	13.06
Green Fodder	6,912.00	15.76	9.65
Other Crops	2,615.72	5.96	3.65
Plant Production	**43,852.00**	**100.00**	**61.19**
Animal Production	**22,126.00**	**100.00**	**30.87**
Fishery	**5,686.00**	**100.00**	**7.93**
Total	**71,664.00**		**100.00**

Source: MALR, Economic Affairs Sector, General Administration for Statistics, Agricultural Statistics Bulletin, 2002.

In 2000, it illustrated in Tables 2.6 and 2.7 affects the components and value of the agricultural production. Wheat and clover are the major crops in winter season while cotton, rice; maize, and vegetables are the main crops in summer season. The increasing importance of the area of green fodders reflects the increasing importance of animal production in the overall agricultural output. Similarly, increasing importance of the area of cereals reflects increasing importance of cereals production value and the relative importance of other crop groups is also reflected.

Table 2.7 Major Crops Areas (thousand Feddan) within Each Group in Selected Years

Crops	1990		1995		2000	
	Area	%	Area	%	Area	%
Cereals	5,479	44.98	6,869	49.72	6,657	47.81
Wheat	1,955	16.05	2,512	18.18	2,463	17.69
Maize	1,976	16.22	2,080	15.06	1,929	13.85
Rice	1,038	8.52	1,401	10.14	1,570	11.27
Others	511	4.20	877	6.35	696	5.00
Cotton	993	8.15	710	5.14	518	3.72
Green Fodder	2,457	20.17	2,412	17.46	2,389	17.16
Sugar Crops	297	2.44	357	2.58	455	3.27
Legumes	394	3.23	378	2.74	388	2.79
Oilseed Crops	170	1.40	240	1.74	255	1.83
Vegetables	1,176	9.65	1,421	10.29	1,723	12.37
Fruits	867	7.12	1,015	7.35	1,088	7.81
Other Crops	347	2.85	411	2.98	451	3.24
Total Cropped Area	12,181	100.00	13,815	100.00	13,925	100.00
Total Cultivated Area	6,918		7,813		7,813	
Cropping Intensity (%)	176		177		178	

Source: MALR, Economic Affairs Sector, General Administration for Statistics, Agricultural Statistics Bulletin, Different Issues.

In 2000, the total cropped area was 13.92 million Feddan. The total cultivated area was estimated to about 7.8 million Feddan, so the cropping intensity was 178 %. From Table 2.7, about half the area was used for cereals with wheat representing about 18 %, maize 14 %, and rice 11 %. Clover constituted about 17 %. Together, the cereals and clover occupied two-thirds of the cropped area. Cotton area was 518 thousand Feddan representing only 4 % of the total cropped area in 2000. Fruits and vegetables together accounted for about 20 % of the total cropped area. Other crops including sugar, legumes, oilseeds, and others represented about 11 % of the total cropped area.

2.3.2.3 Crop Intensification System

Egyptian agriculture is one of the most intensive agriculture in the world from the point of view of the use for surface unit, which is cultivated two or three times a year, on the bases for limited land and permanent irrigation. There are various rotations, but all use winter and summer crops with some Nili crops. Winter crops cover the season from November to May, the major crops being Egyptian clover, wheat, broad beans, and winter vegetables. Summer crops include cotton, rice, maize, and summer vegetables, and the grown between April and October. Nili crops (July-October) are of much less importance. These crop rotations are found in old lands. While, in the new lands, major crops are primarily fruits, oil trees, and vegetables planted in larger fields. Table 2.7 shows that the crop intensification coefficient has increased from 176 % in 1990 to 180 % in 2000, i.e., almost two crops are cultivated annually per unit of area (Feddan). The high crop intensification in 2000 is attributed to the considerable increase in the area under vegetables that last for a shorter time and to decrease in the area under cotton, which lasts for a longer period.

2.3.2.4 Intensive Use of Chemical Inputs

Dependence of Egyptian agriculture on irrigation, the relative stability cropping pattern and crop intensification system have produced a growing demand for chemical fertilisers and pesticide. There are three major plant nutrients; nitrogen, phosphorus, and potassium. Nitrogen is the most important of all fertilizer elements utilised by the Egyptian farmers accounting for more than 70 % of the total nutrient consumption. Almost all of the rest of the fertilisers used are phosphorus based. Since soils in Egypt generally contain adequate amounts of potassium, the use of this element is limited. Fertiliser's consumption during the period 1986/87-1996/97 is shown in Table 2.8.

Table 2.8 Fertiliser Consumption (in thousand tons) by Type in Egypt

Year	Nitrogen	Phosphorus	Potassium	Total	Index (1986/87) =100
1986/87	655.30	181.20	30.10	866.60	100.00
1987/88	677.10	185.90	35.00	898.00	103.62
1988/89	799.10	203.70	30.70	1,033.50	119.26
1989/90	754.10	164.90	46.10	965.10	111.37
1990/91	745.10	184.20	35.50	964.80	111.33
1991/92	720.00	150.00	38.40	908.40	104.82
1992/93	769.80	191.00	41.30	1,002.10	115.64
1993/94	2,493.70	739.90	60.00	3,293.60	380.06
1994/95	2,404.40	903.20	80.00	3,387.60	390.91
1995/96	2,582.90	1,106.40	38.00	3,727.30	430.11
1996/97	2,752.70	1,206.00	54.80	4,013.50	463.13

Source: MALR, Economic Affairs Sector, General Department of Agricultural Statistics, Agricultural Statistics Summery, 1997.

Agricultural intensification aggravates pest problems through the creation of large monocultures, the introduction of genetically uniform plant varieties, the reduction of intervals between cropping intercropping and the use of agrochemicals. The quantity of pesticides consumed in the Egyptian agriculture decreased from 31.44 thousand tons in 1986 to only 8.37 thousand tons in 1998, as shown in Table 2.9. Irrational intensive use of chemical inputs, result in pollution of irrigation water, and high ground water table, hence deterioration of agricultural environment determining water resources development.

Table 2.9 Treated Areas (thousand Feddan) and Quantity of Pesticides (thousand tons)

Year	Treated Areas	Quantity of Pesticides	Treated Areas Against Cotton Wasp	Treated Areas Against Pink
1986	560	31.44	136	4,402
1987	651	17.65	348	4,526
1988	674	17.01	289	4,484
1989	924	17.07	419	4,282
1990	527	12.65	316	2,881
1991	345	8.01	163	2,974
1992	322	5.83	196	3,234
1993	174	4.62	22	3,049
1994	135	2.43	231	1,827
1995	607	12.73	821	2,214
1996	1,022	2.64	677	2,759
1997	990	9.29	623	2,213
1998	565	8.37	687	2,024

Source: MALR; http://www.agri.gov.eg/database/mobed.htm.

2.3.3 Self-Sufficiency Level of Major Food Commodities

Water resources development is challeng to improved food self-sufficiency where Egypt still depends on importing large amounts of food to feed its population. Achieving self sufficiency means the stat's ability to provide the basic food needs to the population and to ensure the availability of the minimum of these needs to a great extent. This goal can be achieved through the national production of food or the availability of enough foreign currencies to finance importing the food requirements.

Table 2.10 Percentage of Self-Sufficiency of Major Food Stuffs

Item	95/96	96/97	97/98	98/99	99/00
Wheat	41.00	40.80	47.90	54.20	65.80
Maize	103.30	101.60	105.10	112.10	56.60
Rice	110.40	106.80	111.60	118.20	116.60
Beans	80.50	91.70	96.60	96.40	84.10
Potatoes	116.40	106.30	115.00	110.00	111.80
Meat	79.40	79.20	85.80	80.40	60.60
Poultry	100.00	100.00	100.00	100.00	100.00
Fish	71.30	74.30	73.10	72.40	75.70
Eggs	99.90	112.20	100.00	100.00	100.00
Oils and Fats	72.70	35.50	36.00	34.80	57.60
Sugar	72.00	50.90	51.00	56.50	71.20

Source: CAPMAS, Statistical Year Book-June 2002.

The ratio can be estimated through measuring the percentage of production to the percentage available for consumption. Table 2.10 shows the self-sufficiency ratios of food stuffs in Egypt between 1995/96 to 1999/2000. The increase in the self-sufficiency ratio of wheat is the most apparent achievments of the policy reform in Egypt. It increased to more than 65.80 % in 99/2000. Naturally, rice, potaotes, and also other vegetables crops have a self-sufficiency ratio exceed 100 %. For the other crops and products meat, fish, oil, sugar, and fat products, self-sufficiency ratios were less than 100 % and ranged from 57.60 % for oils and fats, 71.20 % for sugar and to more than 60 % and 75 % for meat and fish, respectively, in 1999/2000.

2.3.4 Agricultural Land Resources

Agricultural land base of Egypt totalling is about 7.8 million Feddans, representing around 3.5 % of the total land area, covering three different production regions. The first is the old irrigated lands refer to lands along the Nile Valley and in the Delta with an area of 5.4 million Feddans that are irrigated from the Nile. This region represents the most fertile soils, which is alluvial silt and clay loams, with generally sustainable crop rotations.

The second production region is the newly reclaimed land, which is viewed as an opportunity for increasing the cultivated land by about 1.9 million Feddans. This includes desert areas outside the Nile Valley, water must be conveyed over some distance from the Nile, or supply from deep wells. Soils here are generally sandy, calcareous, and poor in organic matter. The reclaimed lands are considerably less productive than the old lands. The third region is the rain fed land, about half a million Feddans, located along the Northwest Coast and in North Sinai and yielding an uncertain harvest of crops, such as barley and olives.

2.3.4.1 Agricultural Land Use, Farm Structure, Tenure, and Water Rights

The land tenure system in Egypt changed with the 1952 Agrarian Reform which reduced the holdings of the largest landowners and set ceilings on holdings by families (100 Feddan) and individuals (50 Feddan). The Land Reform positively affected a number of beneficiaries, most of whom had been share croppers: they received their land and became official tenants, with fixed rents amounting to 7 times the annual land tax, which was fixed according to the quality of the land. In 1991, regulations were changed to fix the rent at 22 times the land tax, and now the rent changes every 2 or 3 years. In 1993, the Government issued a Privatisation Law, which includes provision for the return of lands to the owners from the pre-Agrarian Reform period. It gives them the right to rent their land freely or to cultivate it themselves.

Access to irrigation water from the Nile is regulated by the State. The Directorate of Irrigation is responsible for management of the irrigation system up to the tertiary canal system, the 'mesqas'. These minors as well as the field level watercourses are the responsibility of the farmers, with respect to maintenance and repairs. Water from the Nile is a nationally owned and managed asset. In the newly reclaimed lands, where water comes from wells and boreholes, control is exercised by the landowner that has invested in the drilling and equipment of the well.

Table 1, in the Appendix, shows the number of land holding and area according to the tenure state. It is indicated that land tenure is almost under owned. For legality of holders, persons are in most cases holding (90.7 %) as indicated in Table 2 in the Appendix. As shown in Table 3 and 4 in the Appendix, for land under different irrigation water sources, Nile water is the most source of irrigation of about 86 % of the land holed. On the other hand, about 30 % and 40 % of the land holed are served by open drain with lateral and tail drains, respectively.

2.3.4.2 Distribution System of Land Ownership

The distribution system of land ownership determines development of water resources. One of the prominent characteristics of Egyptian agriculture is the prevalence of small-scale, household agricultural systems, especially in the old lands due to limited growth rat of new lands with high growth rat of population. According to the 1996 Agricultural Census, the total land holdings were estimated at 2.9 million holdings. It was estimated that nearly 96 % of the holdings are less than 5 Feddan and have only 57 % of the total area. At the same time, the total land area of holdings of 10 Feddans and above roughly doubled, less than 2 % of the number of holdings contained about 33 % of the total area (CAPMAS, 2001). Moreover, one and the same holding is divided into a number of plots, separated either by another holder's land, irrigation or a drainage canal. Fragmentation and dispersal of the agricultural land holding have always negative impacts on water resources development, farm income and agricultural growth rate. This is evidenced by:

- The difficulty in implementing modern irrigation and agricultural techniques.
- The loss in land resources due to the fact that a part of it is used for building, digging irrigation, and drainage canals, and roads, and water losses during irrigation process.
- The high cost of machine and equipments, irrigation and agronomic practices, the low efficiency of agricultural labour, land and the use of water resources.
- The waste of time and effort caused by moving the machinery from one area to another on the farm.

2.3.5 Review of Agricultural Economic Policies

During the sixties and seventies the agricultural policy was biased in favour of consumers and other sectors of the national economy at the expense of the agricultural sector itself. That period was characterised by heavy government interventions in land tenure system, area restriction for crop production and administered pricing, as well as regulated agricultural imports and exports, with the aim of mobilising surpluses into other sectors of the national economy. These interventions had a negative effect on agricultural development and food security.

In the 1980s, the Government of Egypt shifted from centralised state planning and control towards free market economy. In 1986/87, the Ministry of Agriculture and Land Reclamation took active measures in the reforming the agriculture sector by liberalising production, marketing, prices, foreign trade, and investment of agriculture. In 1993, the complete liberalisation of the agricultural sector resulted in the following (MALR):

- Removing gradually government controls on farm output prices, cropping pattern, and procurement quotas with regard to all crops.
- Increasing farm gate prices to cope with international prices.
- Phasing out farm input subsidies.
- Removal of government control on private sector in importing, exporting and distribution of farm inputs to compete with the government's Principal Bank for Development and Agricultural Credit (PBDAC).
- Diverting the role of the PBDAC to financing agricultural development projects
- Imposing limitation on governmental ownership of land and sale of new land to private sector.
- Confining the role of the Ministry of Agriculture (MOA) to Agricultural Research, Extension and Economic Policies.
- Liberalising the land tenure system.
- Adjusting the interest rate to reflect the commercial rate.
- Adjusting the foreign exchange rate to reflect the real value of local currency.

The Ministry of Agriculture developed a strategy for agricultural development in Egypt up to 2017, aimed at increasing the annual growth rate of agricultural production to 4.1 % through the optimum utilisation of agricultural resources, achieving food security through better utilisation of comparative advantages, creating new opportunities for gainful employment in rural areas, and improving incomes and living standards of rural population.

2.4 Water Resources Situation Assessment

Water scarcity will be the critical challenge for the future of Egypt. Securing water demand on continuous base is a vital element for sustained development. Water is the most valuable of all the natural resources, it governs every development process. The Nile supplies 96 % of Egypt's fresh water, however, ground water resources are seen as having great potential for development of water resources in future. The largest percentage of water consumption is in the agriculture. This section deals with the Egypt's present and potential water resources and their current and future multi-use applications. It also presents irrigation and drainage systems, and the Water Policy.

2.4.1 Egypt's Water Resources

Water resources in Egypt are limited to the following resources: Nile River, it's main and almost exclusive resource of fresh water, Egypt exploits ground water aquifer in the desert and underlying agricultural lands in Nile Valley and Delta. Rainfall is concentrated in the northern coastal areas. The reuse of drainage water has been practiced. These issues can be divided into conventional and non-conventional water resources as follows.

2.4.1.1 Conventional Water Resources

1- Nile Water

Egypt relies on the availability of its annual share of Nile water that is stored in Lake Nasser. That is approximately 55.5 billion cubic meters annually by agreement between Egypt and Sudan in 1959. The 1959 Agreement was based on the average flow of the Nile during the period 1900-1959, which was 84 billion m^3/year at Aswan. Average annual evaporation and other losses from the High Dam Lake were estimated to be 10 billion m^3/year, leaving a net usable annual flow of 74 billion m^3/year. It was agreed that 18.5 billion m^3/year is allocated to Sudan and 55.5 billion m^3/year to Egypt (International Water Law, Documents). Other sources of water are not dependable, so that the Nile is the main source, originating outside of the country borders. Nile has no tributaries in Egypt and it penetrates the Sudanese-Egyptian borders as single main canal. This is considered to be a challenge for decision makers in water management.

<u>Description of the Nile Basin</u>

River Nile is one of the world longest rivers; the length of the River Nile from its remote sources to its mouth on the Mediterranean Sea is about 6,800 kilometres. The Nile River has a catchment's area about 3.11 million km^2, which represents 10.3 % of the area of the continent, and spreads over ten countries: namely Burundi, Tanzania, Kenya, Democratic Republic of Congo, Eritrea, Rwanda, Ethiopia, Uganda, the Sudan and Egypt, as shown in Figure 2.1. The river is fed by two main systems; the White Nile and the Blue Nile systems.

The White Nile system

White Nile system rises from Lake Victoria, then flows north and westwards through Lake Kyoga and Lake Albert; it flows north to Nimule where it enters Sudan. It then flows over rapids entering the Sudan plain, through the vast swamps of the Sudd, and via Lake No before meeting with the Blue Nile at Khartoum in Sudan and forming the Nile.

Lake Victoria, which is the second largest fresh water sea in the world, is a depression with a surface of about 69,000 km^2, at a level sea of 1,134 metres. The lake catchment's is divided between five countries: Burundi, Kenya, Rwanda, Tanzania and Uganda. Three sources contribute to the net supply of Lake Victoria: the outflow of River Kagera, the direct precipitation on the lake surface and the direct runoff of the land portion of the catchment's (Karyabwite, 2000, p. 15). The average discharge on the outlet of the lake is 23.5 billion m^3/year, as shown in Figure 2.3. The Nile flows out of Lake Albert at the extreme north corner of the lake, flows through northern Uganda, and at the Sudan border under the name of Bahr El Jebel. The total annual discharge amounts about 26.5 billion m^3/year, as shown in Figure 2.3. Then it flows into southern Sudan, where the flow is dramatically slowed down by a massive natural swamp system called the Sudd region in southern Sudan. The swamp is characterised by floating of marsh vegetation, broken off from their moorings, and in various states of decomposition. Less than 50 % of the total water entering the Sudd region flows out of it into the White Nile; the remainder, which is about 17 billion m^3/year, is disappeared through evaporation and evapotranspiration.

In southern Sudan at Lake No the Bahr El-Ghazal joins the Bahr El-Jebel and the combined stream turns abruptly to the east, the river becomes the White Nile. This river has an extremely flat slope. In the upper 120 km from Lake No to the mouth of the Sobat River, there are several swamps, khors and lagoons. In the remaining 800 km, from Malakal to just upstream Khartoum, the channel of the White Nile is almost free of swamps (Karyabwite, 2000, p. 19).

Source: www.nilediscourse.org.

Figure 2.1 Nile Basin Boundaries and Feeding Sources.

The Blue Nile system

The Blue Nile tributaries, the Sobat, the Blue Nile and the Atbara, emanate from the Ethiopian Highlands and they are highly seasonal rivers. The Sobat River basin includes most of the plain east of the Bahr El-Jebel and Bahr El-Zaraf and parts of Abyssinian Mountains and Lakes Plateau. The river outfall into the White Nile with annual discharge at sub-basin exits about 13.50 billion m^3/year (Figure 2.3).

The Main Nile

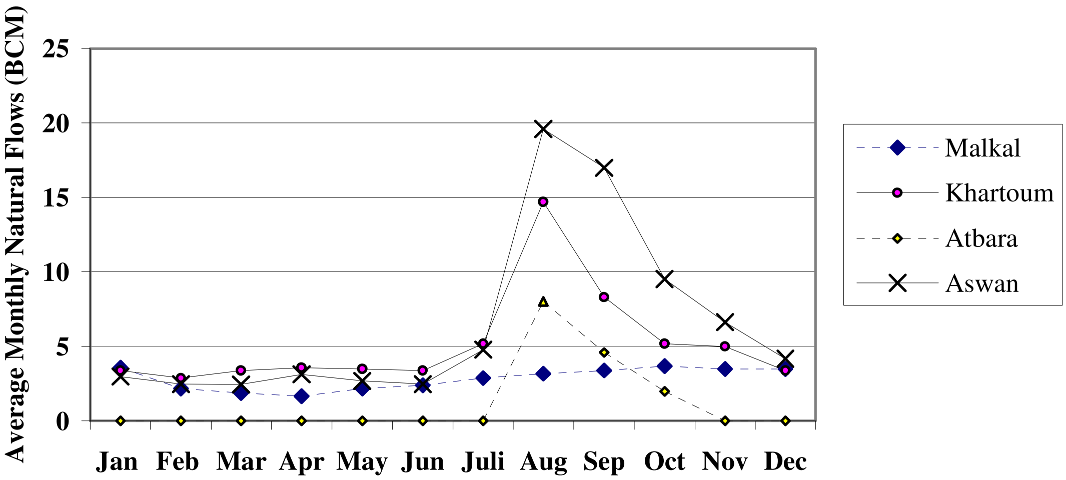
At Khartoum the White Nile meets up with the Blue Nile to form the Nile, which then makes the long journey northward to the Mediterranean Sea. The last tributary to this final course is the Atbara River, which rises in the Ethiopian highlands, and joins the Nile about 322 km north of Khartoum. The Atbara is more strongly seasonal in its flow. The average annual discharge of River Atbera amounts about 12 billion m^3/year, as shown in Figure 2.3. North of the Atbara, no substantial tributary feeds the Nile as it crosses hundreds of kilometres of harsh desert. The river flows north through Lake Nasser reservoir, and the Aswan Dam before splitting into two branches, the Rosetta Branch to the west and the Damietta to the east just north of Cairo.

Table 2.11 River Nile Sources

Source	Average annual flow (Billion m^3)	Average Contribution (%)
White Nile	24	29
Blue Nile	48	57
Atbara River	12	14
Total at Aswan Dam	84	100

Source: Belyazid *et al.*, 2000, p. 4.

The available average flow of the Nile entering Egypt at Aswan is about 84 billion m^3/year. The main portion of the Nile's 84 billion m^3/year at Aswan comes from the Blue Nile during its flood season, with the remainder from the White Nile and Atbara. The White Nile's flow is especially important because it arrives during the months when the Blue Nile is very low. The river has lost a large proportion of its original water by evaporation and evapotranpiration. Losses of water occurring in Aswan Dam are estimated to be 10 billion m^3 of the stored water annually. The Aswan High Dam is the major regulatory facility on the Nile. It provides protection against floods and drought and is the most important source of electric power. The Nile water is diverted from the lake Nasser into network of Nile canals through different control structure. These canals provide water mainly for irrigation. Figure 2.2 shows average monthly flows at the different tributaries and Aswan.



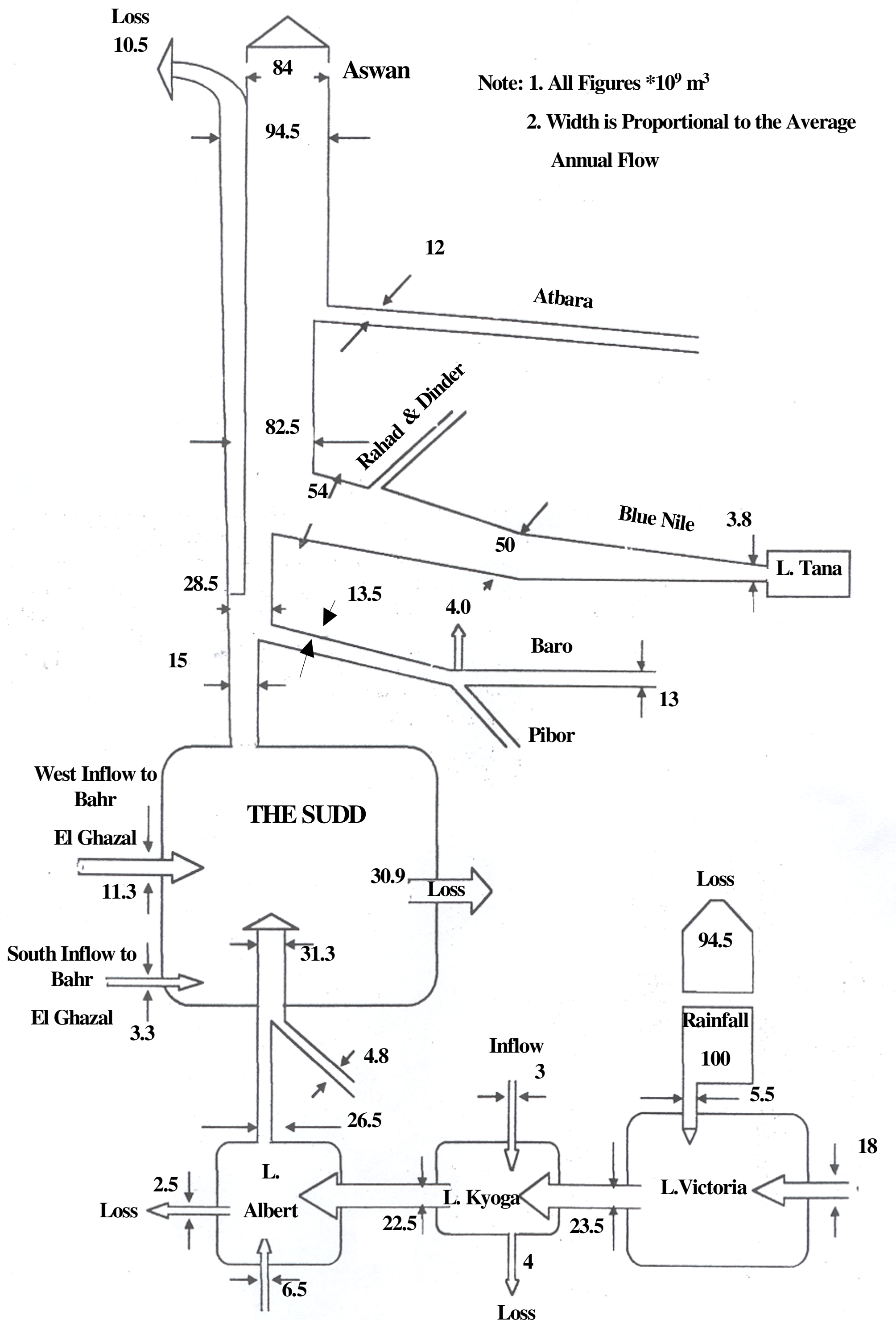
Source: CAPMAS, Irrigation and Water Resources Bulletin, 2000.

Figure 2.2 Average Monthly Flows at the Main Nile Tributaries, and at Aswan

From Figure 2.2, the natural flow of the Nile can be divided into two seasons: The short season from July to September that is high flow season and long season from October to June. The Nile flow at Aswan in the short season is mainly affected by Khartoum flow including the Blue Nile. On the other hand, the long season is affected by Malkal flow including the White Nile.

Future Potential Development of Surface Water Resource

According to the above description of the Nile River systems, studies show that a huge portion of Nile water is lost before it reaches Aswan through seepage, evapotranspiration and over-bank flows to the swampy lands that fringe the basin in many parts and especially in the equatorial Plateau. Large quantities of water are lost in Bahr El-Jabal and Bahr El-Zaraf, Bahr El-Ghazal and the Sobat basins. It is estimated that the water supply to Lake Nasser could therefore be increased by as much as 18 billion m^3/year to be shared by Egypt and Sudan by implementing the four phases of the upper Nile projects namely: Jonglei I, Jonglei II, Machar Marshes and Bahr El-Ghazal. The joint Egyptian-Sudanese Committee has outlined development programs, the first of which is the construction of the Jonglei Canal (MWRI, 2000):



Source: Nile Water Sector, MWRI.

Figure 2.3 Schematic of Upper Nile Average Annual Flows.

- Limiting Losses in Swamps Northern Bahr El-Jabal and Bahr El-Zaraf: The project aims to minimise the losses occurring in the sub basins of Bahr El-Jabal and Bahr El-Zaraf of the Equatorial Plateau, which is about 14 billion m^3/year (50 % of the water entering this region, Figure 2.3). Implementing the Jonglei Canal Project, which will be shared equally between Egypt and Sudan, could save about 7.00 billion m^3/year of this quantity. Aswan will obtain about 4.00 billion m^3/year of the saved water in the first phase, which is still in the planning stages, and 3.00 billion m^3/year in the second phase. Egypt's share after the project implementation will increase to 59.00 billion m^3/year.
- Limiting Losses in Bahr El-Ghazal Swamp Basins: Discharges of Bahr El-Ghazal basin into the streams are usually about 14.0 billion m^3/year. As shown in Figure 2.3, a large portion of this quantity is lost in the swamp and only 0.6 billion m^3 reaches the White Nile at lake No. It is possible to save about 7 billion m^3/year at Aswan by the proposed schemes aimed at saving water losses in Bahr El-Ghazal. The gains will be divided equally between Egypt and Sudan; Egypt's share will increase to 62.50 billion m^3/year.
- Limiting Losses in EL-Sobat and the Machar swamps: The conservation schemes aim at conserving water losses in the Sobat and Machar swamps. The total losses in the Sobat and Machar swamps are about 15 billion m^3/year. The proposed project could save 4 billion m^3/year at Aswan. An equal sharing of this gain will take place thus increasing Egypt's share in the Nile water to 64.50 billion m^3/year.
- The development of more water resources in Egypt's annual share of Nile water is estimated at about 9 billion m^3/year as a result of the implementation of Upper Nile conservation schemes. However, it still depends on agreements between the Nile basin countries and availability of financial resources, which is very expensive. Furthermore, its implementation will take a long time. Therefore, it can not provide a solution to the scarcity problem in short term.

2- Groundwater Resources

The ground water can be an important source contribution to the future agricultural expansion plans. Groundwater exists in the non-renewable deep aquifers within the Western Desert, most notably the Nubia Sandstone Aquifer, which extends below the vast area of the New Valley governorate. Preliminary estimates indicated that the total groundwater storage in this area is in the order of 40,000 billion m^3, but their exploitation raises two problems; the costs of pumping and exploitation would be too high and the duration of the resource too short. The safe yields of about one billion m^3 of groundwater can be used annually at an economical rate (Abu-Zeid, 1995, p. 35).

In addition, groundwater is available in the Sinai in numerous aquifers of varying capacities and qualities, the shallow aquifer in northern Sinai, the Valley aquifers, and the deep aquifers. The salinity increases from 2,000 PPM to 9,000 PPM near the coast. In the northern and central parts of Sinai, groundwater aquifers are recharged from rainfall especially from the heavy rainstorms falling and collected in the valleys (Abu-Zeid, 1995, p. 35). Use of this fossil water depends on the cost of pumping, depletion of storage, and potential economic return over the long run. The total groundwater abstraction was estimated about 0.60 billion m^3/year (MWRI, 2000). Generally, the development of more water supplies through the groundwater aquifer is non-renewable and associated with high costs for the country.

3- Rain Water Resources

Rainfall on the Mediterranean coastal strip decreases from 200 mm/year at Alexandria to 75 mm/year at Port Said. It also decreases inland to about 25mm/year near Cairo. The average total amount of rainfall is about 1.00 billion m^3/year (MWRI, 2000). This meagre rainfall occurs in winter, in the form of scattered showers, and storms and therefore cannot be considered a reliable source of water. Nevertheless, insignificant seasonal rain-fed agriculture is practiced on Egypt's north coast and in the Sinai.

2.4.1.2 Non-conventional Water Resources

Non-conventional water resources aim at supplying enough water to meat part of the water demand, and the horizontal expansion and the agricultural development. These sources can not be considered as independent resources. Non-conventional sources need to be managed with care to avoid water and land deterioration. A brief description of these resources is presented below.

1- The Renewable Groundwater Aquifer in the Nile Valley and Delta

The groundwater aquifer underlying the agricultural lands of the Nile Valley and the Delta is entirely recharged and is dependent on deep percolation of irrigation water and seepage for the irrigation system. It cannot, therefore, be considered a source in itself. And it cannot be added to the country water resources but rather be considered as a reservoir in the Nile River system. As the main source of recharge is the seepage from River Nile, the recharge rate is more than 3.5 billion m^3/year. Total storage capacity of the Nile Valley aquifer is about 200 billion m^3, with an average salinity of 800 PPM. The salinity increases from 1,000 PPM near Cairo to 5,000 PPM 50 km from the Mediterranean Coast. Another 300 billion m^3 is the storage capacity in the Delta aquifer (Abu-Zeid, 1995, p. 35). Although the total aquifer 500 billion m^3, the safe yield was estimated at 7.5 billion m^3/year (MWRI, 2000), but the current total rate of abstracting the groundwater in the Valley and Delta for domestic, industrial and irrigation was about 4.80 billion m^3 (MWRI, 2000). This is still below the potential safe of this aquifer.

2- Re-use of Agricultural Drainage Water

The permitted total amount of the recycled water in the Nile Delta is about 5 billion m^3 (MWRI, 2000). However, according to public law, the use of drainage water for irrigation purposes is prohibited except after permission from the Ministry of Irrigation and according to the conditions of water and land. Abu-Zeid (1988, p. 24) indicates that the general criteria used by the MWRI for the use of drainage water in irrigation are as follows:

- Drainage water with salt concentration < 700 PPM can be used directly.
- Drainage water with salt concentration 700 to 1500 PPM can be mixed with fresh water in proportions of 1:1.
- Drainage water with salt concentration 1500 to 3000 PPM can be mixed with fresh water in proportions of 1:2.
- Drainage water with salt concentration > 3000 PPM can not be used without chemical treatment.

Water transfer from the Nile through Al Salam/Sheikh Gaber Canal to North Sinai Development Project has been designed on basis of mixing the fresh water from Demiatta Nile branch with drainage water from Srew and Bahr Hadous drains. This project will allow reclamation of 400,000 Feddans in north Sinai region. In additional, recycling agricultural drainage water (non-official): The Egyptian farmers also re-use water themselves from branch drain canals whenever a shortage occurs in tertiary canal. However, the total amount of the recycled water without permition was about 2.8 billion m^3 (MWRI, 2000).

3- Re-use of Sanitation Drainage Water

Sanitary drainage water is used in agriculture and tree planting after treating it to meet the specifications. Some amount of the treated water was about 0.70 billion m^3/year used in irrigation in specific locations outside the greater Cairo regions (MWRI, 2000). Treated water could become an important irrigation source in the future, due to the increasing demand.

4- Desalination

Desalination is a strategic water reserve for some locations along the Mediterrean and the Red Sea coasts as well in Sinai Peninsula to meet municipal and industrial demands in some remote areas, where the cost of constructing pipelines to transfer Nile water is relatively high. And the economic value of water is high enough to cover desalination cost, especially to supply tourism villages. However, the total desalinted water is much less than 1.00 billion m^3/year. The source is infeasible to irrigation use due to its high cost, which ranges between 3 to 7 LE/m^3 (MWRI, 2000) compared to other sources.

2.4.2 Egypt's Water Demands

Egypt's water demands increase with time against fixed water supply due to increase the cultivated areas, in order to feed the growing population and to accomplish higher standards of living needs as well as the agricultural policy to reclaim new lands. The signing of the 1959 Agreement is a long term binding agreement. Current water use is estimated at 67.60 billion m^3, comprising of agriculture, Industrial and municipal demand of 55.20, 7.60, and 4.50 billion m^3, respectively, as shown in Table 2.12. Demand is expected to reach 87.90 billion m^3/year by the year 2017, as a maximum area of 3.4 million Feddans will be added to the cultivated land. As noted the added 12.10 billion m^3/year water use over the released water from Aswan High Dam comes from re-used agricultural drainage water, municipal recycled water, ground water and some rainfall. More worrying is that longer time trend by 2017 water consumption is expected to increase up to 87.90 billion m^3/year due to new agricultural development projects. This suggests a supply gap of approximately 20 billion m^3/year.

Due to the intensive use of land in the Nile Valley and Delta and expected increases in water demand for all users, it is clear that unless action is taken, future demand for water will far out-weight the resource supply. It is expected that the water saving practices and non-conventional water resources could close the supply gap but this leaves no room for higher consumption, as shown in Table 2.12.

Table 2.12 Current and Projected Water Resources and Requirements
(billion m^3/year)

Sources	2000	2017	Needs	2000	2017
Nile water	55.50	57.50*	Irrigation	55.20	70.70
Deep subterranean water	0.60	3.50	Industrial	7.60	10.60
Subterranean water (Valley and Delta)	4.80	7.50	Muncipal	4.50	6.60
Recycling agricultural drainage water	5.00	8.40	Navigation	0.30	0.00
Recycling drainage water	0.70	2.50			
Rainfall	1.00	1.50			
Improving irrigation system		7.00			

Source: MWRI, Unpublished Data.

*Including the 2 billion m^3/year possibly yield from Jonglei project, the project has not been completed.

From the previous analysis, it is clear that serious freshwater deficits could occur in Egypt in the next decades. The potential impacts on economic and social development could catastrophic. The amounted of Nile water is not expected to increase in the near future as it will need a great political effort and agreement with the Nile Basin countries sharing the Nile. Therefore, the use of all available water resources should be optimised.

2.4.4. Irrigation System

The Nile system below Aswan can be considered a closed system with a single input from Aswan High Dam and five outlets, which are: Evapotranspiration, evaporation, non-reused municipal and industrial consumption, drainage water, and navigation water released to the sea. Therefore, Valley and Delta groundwater and reused drainage water can be considered as internal mechanisms to increase the global efficiency of irrigation system and not added resources. Irrigation system extends over 1,200 km south of Aswan to the Mediterranean Sea. It consists of the main dam and a network of diversion structures to distribute the water to where it is needed. Such system includes canals, pumping stations, and barrages, in order to render perennial irrigation possible. The old Aswan Dam was also constructed in 1902 as first storing project with storage capacity 1 billion m^3, which enlarged twice to 5.3 billion m^3 in 1933. Moreover, other barrages were constructed on the Nile as Esna, Nagea Hammady, Assiut, Zifta, and Edfina. The largest water project is the Aswan High dam (AHD), which was established during the period 1964 to 1970 has a storage capacity of 162 billion m^3. The AHD presently ensures Egypt's annual quota of 55.5 billion m^3 of water for irrigation and other purposes. Table 2.13 shows the benefits of AHD construction.

Table 2.13 Shares between Egypt and Sudan before and after the High Dam Construction (billion m^3/year)

Item	Before High Dam	Benefit of High Dam	After High Dam
Mean annual discharge	84		84.0
Losses	32		10.0
Egypt's share	48	7.5	55.5
Sudan's share	4	14.5	18.5

Source: Unpublished Data from Nile Water Sector, MWRI.

Lake Nasser was created behind the Aswan High Dam and is 500 km long with an average lake width 10 kilometers, (MWRI). From Lake Nasser above the High Dam, the river courses 800 km before splitting near Cairo into the Damietta and Rosetta branches. The Nile River supplies water to the main canals, which include approximately 34,000 km in length of the main canals (rayah), which feed branch canals that in turn feed secondary canals: There are 19,900 km length of public drains and 80,000 km of private canals (mesqas), which refer to secondary canals and farm drains. Throughout this system, water is distributed annually, not only for cultivated land, but also for municipal and industrial use, for generation of hydro-electricity and for the navigation (Abu-Zeid, 1995, pp. 40). Operation and maintenance of the system is the Government's responsibility. Ownership of the water system and enforcement of the law and legislation are also the Government responsibilities. The irrigation system in the old lands of the Nile Valley is a combination of gravity and water lifting system. At the third level (mesqas), distributors receive water according to a rotation schedule. Water is pumped from these distributors to irrigate the fields (about 0.5-1 m of lift). The farmers use private traditional lifting mechanical driven devices (diesel pumps) to raise water from the tertiary level system to the fields.

The irrigation system in the new lands is based on the cascade of pumping stations from the main canal to the fields. In the new reclaimed areas, farmers have to use sprinkler or drip irrigation. Surface irrigation techniques are prohibited by law. The main reason for this ban is that these areas are more subject to water shortages and most of the new reclaimed land is sandy soil. The canal system is designed, operated, and maintained by the Ministry of Irrigation, which administers the system through 22 administrative offices, which tend to coincide with governorate boundaries, 48 supervision offices and 167 districts.

The drainage system includes open drains, subsurface drains and pumping stations. Drainage water from irrigated lands on both sides of the Nile Valley is returned to the Nile River in Upper Egypt and in the Southern Delta. Drainage water in the Delta is either pumped back into irrigation canals for re-use in irrigation or pumped into the Northern lakes or the Mediterranean.

The techniques of distributing irrigation water on the field can be classified as follows: First, Surface Irrigation Techniques are the prevailing irrigation systems in Egypt covering about 82 % of the irrigated land, the Nile Valley and Delta, and their efficiency of 60 % is considered to be low. Basin irrigation is the predominant technique used in surface irrigation and most of irrigated wheat, clover, and rice are irrigated by this method. Cotton and vegetables are irrigated by furrows. The second method is Sprinkler irrigation technology, which takes up about 8 % of the irrigated land in Egypt, in the new lands. With sprinkling techniques a high degree of efficiency of 75 % is achieved with the lowest possible operating pressure and small volume of water. And the use of drip irrigation technologies covering about 12 % of the irrigated land in Egypt in the new lands and their efficiency of 90 % is considered to be high. There should, therefore, be no doubts as to the practicability and economic efficiency of these methods.

There are some restrictions in the use of modern irrigation technologies in Egypt's agriculture such as: high capital costs for drip and sprinkler irrigation, while surface is zero, limited areas of crops and fragmentation, it is difficult for the farmer to adopt modern techniques due to low level of knowledge and skill of the farmers. Also, the modern techniques can not be applied in the northern region in order to prevent the interference of Sea water. Moreover, most field crops such as cotton, rice, maize, wheat and clover should be irrigated only by the surface system.

2.4.4 Water Management in Egypt

In Egypt, just as in other countries, the irrigation system management is operated by the state. The Ministry of Water Resources and Irrigation is the only one that authorises water use and is mandated to control and manage all fresh water resources in Egypt including the surface and subsurface water. In addition to construction, supervision, operation, and maintenance of all the irrigation structures and drainage networks, the Ministry is also responsible for providing all other sectors with their needs of good quality fresh water. It is represented at the governorate level through general irrigation directorates, which are then subdivided into inspectorates and districts, ensuring proper co-ordination among agencies involved in water resources (Ministries of Agriculture and Land Reclamation, Tourism, Power, Transportation, Industry, and Housing and Reconstruction). At the farm level, farmers bear the responsibility for the construction, operation and maintenance of the system.

Egypt's Water Policy is still supply management side oriented, and a new approach towards a policy of demand management becomes evidence as integrated water management approach. The Ministry formulates the National Water Policy to face the problem of water scarcity. The overall policy's objective is to utilise the available conventional and non-conventional water resources to meet the socio-economic and environmental needs of the country. The main elements of future water policy till the year 2017 are: 1) Optimal use of available water resources; 2) Water quality protection and pollution abatement; and 3) Development of new water resources in cooperation with the Nile Basin riparian countries.

2.4.3 Determinate Factors for Water Resources Development in Egypt

Annual per capita fresh water availability in Egypt dropped from 1,893 m^3 in 1959 to 900-950 m^3 in 2000 and is likely to 670 m^3 by 2017 and 536 m^3 by 2025 (UN, CCA, 2001). The main reason behind this rapid fall is fixed water resources and rising population. There are other more important factors escalating the water problem. In this section, the main factors in determining the development of water resources are discussed.

2.4.3.1 Social Factors

Population Growth

The rate of population growth determines the development of water resources. Population has tripled in the last 50 years from over 18 million in 1947 to about 62 million in 1996, according to the preliminary results of the 1996 Population Census, to about 67 million in 2000 excluding Egyptians living abroad with growth rate 2 % (Year Book, 2001) and it is expected to rise to about 95 million by the year 2025 (UN, CCA, 2001). On the other hand, resources do not increase at the same rate, especially those of agriculture and food. Hence, a gap is created between population growth and resources. Therefore, the future water policy should consider this population growth and a growing demand for food.

The unbalance between population and land resources is notably translated by a relative reduction in the agricultural land in spite of the efforts to colonize, by cultivation and reclamation of new land in the desert. Concretely, urban expansion has led to a decrease in agricultural areas in the Nile valley and Delta. The cultivated land/capita fell from 0.22 to 0.11 Feddans/capita. The reclamation of new land projects, which nevertheless need large quantities of water is imperative, on the one hand, in order to face the increasing demand for food and, on the other, to compensate for the loss of agricultural land due to the strong urban expansion around the cities of the Nile Valley and Delta.

Quality of Life

The accelerated socio-economic growth during the last decades is reflected in a better quality of life. The human development indicators have improved remarkably over the last 30 years. According to EHDR (2003) there is an increase in the proportion of the population with access to piped water to 91.3 % in 2001 compared to 70.9 % in 1976. Almost 100 % of the urban households have access to sanitation facilities against 78.2 % in rural areas. Access to sanitation has been a subject of development during the last 20 years according to UN CCA (2001). Advancements in living standards together with population growth have been reflected in expansion of water consumption levels for domestic use. Domestic water use grew from 1.99 billion m^3 in 1980 to 4.27 billion m^3 in 2001 (MWRI). Further augmentation of the life quality and the population growth will push up demand for water.

Poverty

Although there has been an observed change in life quality, poverty is still a problem in Egypt. According to the estimates of Human Development Report (EHDR, 2003) 21.4 % of the total rural population of Egypt are poor. The incidence of poverty in rural areas of the country points to the concentration of poverty in rural areas. Often low-income levels and poverty in rural areas result in an increase of irrigation water use through shifting the cropping patterns towards the high water consuming crops (rice, sugarcane). The liberalisation policies resulted in some changes in cropping patterns occurring favouring production of high value added crops, which are rice and sugarcane with highest water needs among other field crops. For example annual production of rice increased from 2.24 million tons in 1980/1981 to 6.00 million tons in 1999/2000 and area under rice crop expanded almost by 67 % (from 0.95 million Feddan in 1980/1981 to 1.59 million Feddan in 1999/2000 (MALR)). The cropping patterns that sometimes result in water stress serve the welfare interests of rural households. According to the UN CCA (2001), a total of 57 % of the population lives in rural areas and are engaged in agricultural activities. As the dependency on irrigation, agriculture becomes the largest user of water. It is still a key source of income for a majority of the rural population.

Although the area under rice is restricted by the Government, it some times gets out of control and there are observed violations of the quotas set by the Government. The 1998 national survey shows that the main reason of crop choice decision is the crop profitability. The profit seems more relevant in this case accounting the poverty levels in rural areas. Rice is a high value crop and is likely become an important contributor in raising the income (Poverty Reduction in Egypt, 2002). So the area under rice and sugarcane tend to expand satisfying the welfare needs of farmers.

Farmer's Behaviour

The farmer behaviour results from the level of education, accessibility, and availability of information and cultural patterns, which determine the patterns and practices of water use. In general, farmers are less educated and have poor access to production facilities with low earning capacity. However, the farmers are really poor and have little knowledge about crop water requirement. Moreover, they prefer old methods they are used to and resist innovations. In Egypt, the short duration variety of rice finds difficulties to expand in spite of its lower water needs. This is due to its taste, which Egyptian farmers do not like and refuse to cultivate it because of its taste. Moreover, uncertainty in water availability pushes some farmers to over-irrigate, as they are not sure of the continuity in water delivery.

2.4.3.2 Physical Factors

Water Resources

Fresh water sources from Nile are limited for Egypt by an international agreement between Sudan and Egypt in 1959. The agreement entitled Egypt to 55.5 billion cubic meters of Nile water per year. The share of water per capita is currently about 833 m^3/year, which places it below the water poverty level (1000 m^3) recommended by the World Bank. Further, the water demands are in excess of the available water supplies. The gap is filled by recycling the water. Therefore, Egypt is faced with a potential water scarcity due to increasing water demand against fixed water supply that could limit the economic development plans.

Land Resources

The total area of Egypt is 1,001,450 km^2, most of which is desert lands. Per capita cultivated land declined from about 0.23 Feddans in 1960 to about 0.13 Feddans in 1996. The sharp decline in per capita of both cultivated and cropped area resulted in a decrease in per capita crop production on one hand, and competition for water between agriculture and other sectors on the other hand. This affects directly food security. The food and habits requirements and increasing demand for jobs have pushed the Government to expand land plans. The plans promise to add 3.4 million Feddans of desert land to the cultivated area. Therefore, a considerable increase in demand for water is expected to occur.

2.4.3.3 Economic Factors

As water supply fails to match the growing demand, competition for water will intensify from all water use sectors. The agricultural sector may lose some of its existing supply of water as the largest water user. Annual freshwater withdrawals for agriculture sector in 2001 amounted to about 83 %. In spite of its high water consumption levels its contribution to GDP accounts only for 16.5 % compared to industrial and service sectors with 33.3 % and 50.2 % share of GDP, respectively. As a result, agriculture is likely to be affected by increasing water scarcity due to the growing demands from other sectors. It will have to compete with high marginal values from non agricultural uses in the long run. The result will be a transfer of water from agriculture to the other sectors that have higher marginal value for water. The last 10 years have seen an increase in water consumption by industry from 7.8 % in 1990 to 10 % in 2001, which was mainly compensated by reducing the share of other users. Therefore, the impacts of intensifying competition between sectors are already becoming evident. It is important to emphasize the fact that economic reasons behind the water reallocation can most likely lead to the emergence of water scarcity conditions in the agricultural sector as it is a low value water user.

2.4.3.4 Political Factors

The free water provision condition contributes to increase in demand against limited water supply; therefore they are considered to be one of the major driving forces of water scarcity. On the contrary, irrigation is heavily subsidised by the Government. Irrigation subsidy policy in Egypt serves social objectives of providing services for a wider group of the population avoiding the exclusion of the marginal group who cannot afford system service. It reduces the food cost and supports development in rural areas. From the perspective of food security, subsidies on irrigation hold absolute explicit importance since food production is completely dependant on irrigation. Other positive social effects from subsidies have influence on the generation of employment and increasing farm income. Through affordability of irrigation, agriculture absorbs around 50 % of labour force in rural Egypt. The subsidies on irrigation avert increase in poverty, unemployment, crime, and social instability that can lead to political instability.

2.5 Conclusions

The foregoing review has clearly revealed the difficult situation of limited water and land resources. The Egyptian economy depends to a great extent on agriculture, a condition that will continue for many years to come. Egypt's agriculture is an important economic sector that contributed about 17 % to the GDP. It is, however, almost entirely dependent on irrigation since the mean annual rainfall is only 20.2 mm, ranging from 1.4 mm in south Egypt to about 191.8 mm in the northern coastal region. The Nile River is the sole source of assured water supply for approximately 7.8 million Feddans of fertile agricultural land, which is intensively cultivated to crops including cotton, rice, sugarcane, and vegetables in summer and wheat, clover, and vegetables in winter season.

Egypt's most remarkable feature is the concentration of its entire population and nearly all its agricultural lands on only 3.50 % of the total land areas. In Egypt, the most critical factors affecting its development are the availability of water and land, resulting in tensions between agriculture and urban development. Nearly all cultivated lands are irrigated as the country basically consists of a single irrigation system formed by the river Nile where all the runoff and drainage from irrigation is reused downstream. Annual population trend is such (annual growth rate of 2 %) that the country depends on other countries for food. Cropping intensity in Egypt is unusually high (178 %) as more than one crop and sometimes as many as three are planted each year. The old lands of the Nile Valley radically differ from new lands of the reclaimed desert areas. In the old lands, irrigation water is transferred continuously from the main canal system into secondary canals by combined gravity and water lifting systems. The fields are irrigated by surface methods in rotation using water pumped from side branches. In the new lands, water is pumped under pressure from the main canal to the fields. In these areas, the more efficient sprinkler or drip irrigation systems are mandatory by law. In Egypt, land ownership patterns directly shape the farm size distribution. The large number of very smallholdings adds up to a very large proportion of the total irrigated lands. However, a few large agri-business holdings on the New Lands occupy a significant proportion of the irrigated land.

Water resources in Egypt are becoming scarce and the surface water resources from the Nile River are now fully exploited by agriculture, industries and for drinking water. Furthermore, Egypt's water demands increase with time against fixed water supply due to increase the cultivated and cropped areas in order to feed the growing population and to accomplish higher standards of living since the agreement was signed in 1959 and will continue to do so in the future. The Government of Egypt intends to meet the challenge of water scarcity by 1) making the best use of available water resources, 2) protecting water resources from pollution, and 3) enhancing co-operation with other Nile Basin countries.

Development of more water supplies is not expected to increase in the near future as it will require a great efforts and agreement with the Nile basin countries. Therefore, the use of all available water resources should be optimised. This should lead to achieving the maximum net return per unit of water. Water should be allocated among sectors and sub-sectors in a way that is consistent with its economic value when used for different purposes. The marginal value from water use is not the same in all sectors. It is highest for drinking water and decreases sequentially for domestic, industrial to agriculture uses. Therefore, agriculture is the sector most likely to be confronted with decreasing supplies if economic criterias are to be used to allocate water supply. The agricultural sector will face the challenge to increase the water productivity. As about 83 % of the Nile water is utilised for agriculture. Consequently the largest gains would be achieved by optimising irrigation water use.

It is useful to present a practical approach to manage and optimise the irrigation water use in Egypt, under geographic and socio-economic constraints. This will be demonstrated, based on the cases study in Egypt (governorates level). These cases show that water scarcity value can be incorporated in irrigation management by proper choice of cropping pattern for each agricultural governorate. This can be useful for irrigation and agricultural planners.

CHAPTER 3

ECONOMIC INSTRUMENTS FOR IMPROVED WATER MANAGEMENT

3.1 Introduction

Water is becoming an increasingly scarce resource and constraining agricultural development in Egypt. There is an increasing demand for water by the users in agriculture as well as by other sectors, and increasing the concern about improving water use efficiency. Therefore, this chapter targets policy makers involved in water management decisions, promoting better understanding and making paradigm shift towards improving water management. The objective is to elaborate and present the theoretical and methodological foundation for modelling economic management and policy issues of irrigation water under Egyptian conditions.

The second section of this chapter is based on a literature survey reviewing recent publications about irrigation efficiency, to define terms of water productivity and efficiency measurement. The methodology of optimisation is applied in the third section to demonstrate how these economic criteria can be determined by applying appropriate mathematical models. This can be used to calculate optimal allocation of scarce water resources to competing water consuming activities and regions in Egypt. Recent publications about water charges are used as a basis for discussions in section four. Finally, section five is based on literature survey about irrigation water management and mathematical models that can be used for planning irrigation water use and charging policies.

3.2 Conceptual Framework of Irrigation Water Productivity and Efficiency[1]

Achieving a high irrigation water efficiency and productivity is the ultimate goal in water planning and management in Egypt. The Government of Egypt expects that water management will have significant impact on water savings in order to free up water resources

[1] *Ibid. Bader and Hanf (2003).*

that help to meet the needs of new land reclamation projects. In this section, the most important concepts of water management regarding to potential development of water productivity and frequently used measures of irrigation efficiency will be discussed.

3.2.1 Potential Development of Water Productivity in Egypt

There are three paths generally applicable for increasing agricultural production from irrigation water resources: i) to develop more water supplies by increasing storage and diversion facilities, ii) to exploit more of the developed primary water supply for productive purposes through water saving practices, and iii) to produce more output per unit of water deployed, i.e. to increase water productivity (Molden *et al.*, 2000). The first path refers to supply side response, while paths 2 and 3 are related to responses to demand side management. These options will be discussed with respect to Egypt in some more detail.

- To develop more supplies by increasing storage and diversion facilities is rather restricted. Surface water resources are limited to Egypt's share of the flow of the River Nile, in accordance with terms of the Nile water agreement between Egypt and Sudan. The 1959 Agreement is based on the average flow of the Nile during the period 1900-1959, which was 84 billion m^3/year in average at Aswan. Average annual evaporation and other losses from the High Dam Lake were estimated to be 10 billion m^3/year, leaving a net usable annual flow of 74 billion m^3/year. It was agreed that 18.5 billion m^3/year is allocated to Sudan and 55.5 billion m^3/year to Egypt (International Water Law, Documents). Other sources of water cannot be considered a dependable water sources, so that this path cannot be used in Egypt.
- Water savings practice can be realised by making use of a process of recycling previously used fresh water. By re-introducing drainage water into the irrigation network, an equivalent quantity of fresh water is released for new irrigation projects. The drainage water of Upper Egypt returns directly to Nile River where it is mixed automatically with Nile water to be used for purposes downstream. The official amount of recycled agricultural drainage water was about 4.5 billion m^3 during 1999/2000 (Year Book, 2000). The amount of drainage water reuse will be increased in future to meet the increasing demand. The main drainage reuse expansion is the El-salam canal project for reclaiming 92 thousand hectares in west Suez and 168 thousand hectares in Sinai. Nile water is mixed with drainage water in a 1:1 ratio so that salinity does not exceed 1000 part per million in additions for cultivating the suitable crop patterns (MWRI).

In addition, about 50% of the water diverted and delivered for municipal uses is actually consumed in its initial application. The remainder returns to the stream in form of wastewater and can be reused in agriculture after treating. The amount of treated water was about 0.7 billion m^3 during 1999/2000 (Year Book, 2000). The increasing demand for domestic water due to population growth and improved living standards and the growing use of water in the industrial sector due to expansion of Egyptian industry will increase the total amount of sanitary drainage water available for reuse. Treated water could become an important irrigation source in the future. Moreover, fresh water savings can be obtained by improving the efficiency of both the irrigation network and irrigation technique. Reducing water losses is a promising way to make more water available for agriculture. The water lost by seepage from channels during conveyance and distribution forms a significant proportion of loss of potential use. A considerable amount of fresh water is consumed for transporting as water losses, particularly when water is transported long distances. The total losses occurring are calculated about 16.5 billion m^3/year in average from Aswan to the fields' level during the period (1996-2000) before applied to crops (CAPMAS, 2000). In consequence, the amount of water losses during transporting substantially differs among regions and among months. Other reasons for differences in field losses are the design of the irrigation system, the distance between field and the source of water, weeds in irrigation networks canals, accurateness of land preparation, and agronomic practices. Most of these factors are strongly dependent from the level of knowledge and skill of the farmer.

- The third path to ameliorate the irrigation water situation is to produce more output per unit of water deployed, to increase water productivity. Water productivity can be increased by obtaining more production with the same amount of water or by reallocating water from lower to higher valued crops. Indeed, the greatest increases in the productivity of water in irrigation have not been from better irrigation water management practices, but rather from increased crop yields due to better plant varieties and agronomic practices (Molden and de Fraiture 2000). For this reason, water efficiency and productivity terms should be used in conjunction to assess water management strategies and practices to produce more production with less water (Guerra *et al.*, 1998).

3.2.2 Frequently Used Measures of Irrigation Efficiency

Generally speaking, the term "efficiency" expresses the relation between the actual input or output of a production process and the input or output that could be expected under ideal process conditions. Hence, efficiency is either defined as $E = I_i / I_a$ or as $E = O_a / O_i$ with E = measure of efficiency, I_a input actually used in the process, I_i the input necessary under ideal conditions, O_a output actually resulting from the process, O_i output expected under ideal conditions.

The definition of efficiency differs among engineering, agronomic and economic perspective. The used measures of efficiency depend on the area of interest. From engineering perspective irrigation efficiency defines the relation between the amount of water that is effectively utilised on field and the amount of water from the main water source. The agronomic perspective of irrigation efficiency relates to the production from one unit of water and measures the production value actually produced divided by the theoretically possible produce. The economic perspective describes the really produced net value of this production and relates it to the maximum net value being possible to generate. All these perspectives are important in determining optimal water use, particularly in Egypt where water is scarce. However, the potential for improving water management differ from each perspective. The approaches that are used to assess irrigation and its impact on water resources efficiency as follows:

Irrigation (Hydraulic) Efficiency

Classical irrigation efficiency (E_C) is defined as the volume of water used beneficially divided by the volume of water diverted (Keller *et al.,* 1996). Irrigation efficiency is affected by all levels of distribution and associated losses, from the main supply source to main canals (conveyance efficiency), secondary canals (distribution efficiency), tertiary canals (tertiary efficiency) to the farm (farm efficiency) and being applied to crops (field efficiency). Although the classical irrigation efficiency concept is normally appropriate for irrigation system design and management, it could lead to erroneous conclusions and serious mismanagement of scarce water resources if it is applied for water accounting systems at regional or state wide scale. This is because the classical approach ignores the potential reuses of irrigation return flows.

To overcome the limitations of the classical irrigation efficiency concept, a new concept has been proposed, called effective efficiency (E_E). (E_E) is defined as the beneficially used water divided by the amount of freshwater consumed for the process including the losses during conveying and applying the water. The volume of water that becomes usable surface runoff or deep percolation is subtracted from the total volume delivered in the new model (Keller *et al.,* 1996). This concept is necessary to correctly evaluate the net water losses within the Nile river basin or groundwater system in Egypt.

In Egypt, the classical irrigation efficiency (E_C) was 65-70 % over all irrigation system during the period from (1991-1999), while the effective efficiency (E_E) was 75-80 % because of reusing of agricultural drainage water (MWRI). The (E_E) on Egypt's irrigated agriculture differs from region to region. The agricultural drainage water in upper and middle Egypt returns to the river or recharges aquifers and can be directly reused without any problem. In contrast, in northern part drainage water have a high salinity level. Further, the Damietta and Rosetta branches are contaminated by industrial drainage into the Mediterranean Sea. Where drainage water with high salinity level and fresh water with low quality is used for irrigation, the soil tend to degrade and thus excess irrigation water has to be applied for leaching requirement to maintain a favourable soil salinity level for crop production. Therefore, it becomes a problem in the concept of effective efficiency (E_E) tend to overestimate the available water resources where the use of recycling water exhibit negative externalities (i.e., salinity in northern part). For this reason, it would be better to define the production per unit of water and its value from an economic point of view of water management when comparing the water use efficiency. Considering the salinity problem there is not much real water saving to be made through irrigation efficiency at the macro system, but the only option available in the short run is the economic criterion in Egypt's water management. However, irrigation efficiency can be not ignored because it clearly points up the water losses within the system. Therefore, farmers must be more educated about irrigation and to avoid losses and to enhance applied irrigation technology.

Agronomic (Technical) Efficiency

Agronomic efficiency focuses on water productivity by the crop. Water productivity (WP) can be expressed as the yield (in kilograms) produced per cubic meter of water consumed by crops. More generally, it can be expressed as the economic value of production per unit of water consumed (Molden, 1999). Crop production depends on a number of inputs other than water input; therefore, partial water productivity (WP) is most commonly measured as crop output per cubic meter of water.

This measure is helpful in describing aggregate production trends and comparing production statistics from irrigated regions and countries. Those indicators relate output from irrigated agriculture to unit land and water. Where water is a constraining resource, output per unit water may be more important, whereas if land is a constraint relative to water, output per unit land may be more important (Molden, 1999). The agronomic efficiency involves economic components including output per unit of water but it does not capture differences in the value of water in alternative uses or the costs of other inputs. A more appropriate measure to the decision maker could be the economic return per unit water used, which represents the net return attained from the production per unit of water used.

Net Value per Unit of Water

A rather simple measure of efficiency V is sometimes used that take care of the total water losses W_L from water source to point of application. V is determined as

$$V = Y(P - C) - Y(P - C)W_L$$

$$V = Y(P - C)(1 - W_L)$$

where, (V) value per unit of water, (Y) yield per unit of water, (P) market price per unit of yield, (C) production costs, (W_L) inefficiency of water use factor considering the share of water losses from the source of water to the field per m^3.

The value of water losses must be taken into consideration in calculation profitability in crop production. Allocation and management policy should primarily pay attention to water losses value. This means that it is essential to develop information on withdrawals, losses and returns. This concept may be advantageously used under conditions of water movement in Egypt. The relative water losses measured in monetary terms should determine the agricultural water distribution. The most productive activities will thus compete for the lowest water losses. This concept presupposes a set of basic assumptions which reflects Egyptian agricultural conditions:

- Isolation: There is only one source of irrigation water (Lake Nasser) and all agricultural regions should satisfy their water requirement from it through canal.
- Land characteristics: The Nile extends about 1,532 km. from the southern Egyptian borders to the Mediterranean Sea in the north.
- Transportation: It is assumed that there is no transport infrastructures such as pipes and that water are transported to farmers using open canals.
- Transportation requirements: Water can be made available in dependence of the irrigation requirements of the crops with respect to time and region.

Virtual Water

Virtual water is a very new concept. Virtual water represents the amount of water needed to raise a certain quantity of food. In other words, one tonne of grain has embedded tonnes of "virtual water" because this amount of water is used to raise one tonne of grain (Allan, 1999). The "virtual water" concept is one of the most discussed concepts. It can contribute to a change in water management because it makes very obvious that the water embodied in the crops imported and exported in international trade should be recognized. Virtual water can be used to analyse the flows of resources from one economic sector to another. It converts all water flows in crop production.

The idea behind this measure is that Egypt could aim at importing products that require a lot of water in their production (water-intensive products) and producing and exporting products that require less water (water-extensive products). Egypt's water use would be minimised by importing commodities that have embedded a lot of water from other countries. The thereby saved water resources can be used for purposes with higher economic returns. Since this water is virtually embedded in the commodity, it is called virtual water. The problem with this concept is at one side foreign exchange, because Egypt does not have sufficient exports to pay for imports. Furthermore and probably more severe is a conceptual weakness of concepts. The concept is only valid when water cost would be the only cost in agricultural production.

Economic Efficiency

Economic Efficiency (EE) of water allocation is achieved when the marginal benefit from the use of the water resource is equal across all users. The definition of economic efficiency presupposes that as well technical as allocative efficiency is attained. A farm is technically efficient in its water use when it produces the maximum level of crop production for a given volume of water with the assumption that technology and other inputs are fixed. Technical efficiency can be defined as given when a selected level of crop production is accomplished at the lowest possible irrigation water requirement. A farm is allocative efficient when water resources are allocated in a way that allows the maximum possible net benefit from their use. It occurs when price of output equals marginal cost of input. Allocative efficiency can play an important role to increase the return to water.

A farm is economically efficient if the farm is both technically and allocatively efficient. EE is a criterion describing the conditions that must be satisfied to guarantee that water resources are being used to generate the highest possible net return, while the irrigation efficiency (hydraulic) only refers to the relation of the fraction of water beneficially used over total water applied. Any improvement of this type of efficiency increases the beneficially used fraction of water, while enhancing economic efficiency considers both physical measures and allocation of water to the highest valued uses. Economic efficiency can be expressed in terms of the maximum revenue, profit or added value that can be generated from a unite of water or a unit of land, and its general approach compared to technical efficiency allowing an analysis of private and social costs and benefits. Net private benefits are defined as the market value of all outputs minus the individual cost of all inputs. In opposite to that net social return values all inputs and outputs at social prices.

Economic efficiency should be used to assess irrigation water strategies when examining private and social efficiency as well. Simple reflections about the efficiency criterion demonstrate the advantage of the usage of economic parameters against the pure technical ones in irrigation water management. It can be argued as follows: economic efficiency includes the impacts of prices and incentives for farmers to move to high net return crops, whereas the hydraulic efficiency is only determined by the percentage of water used beneficially, but do not consider whether the water can be utilised in a more beneficial way. The definition of technical irrigation efficiency that is included in the concept of economic efficiency implies that the beneficially used share of irrigation water is as large as possible and that it is used with maximum possible value.

A further advantage of economic efficiency over the presently used technical term of efficiency is visualised if private and social optimality have to be considered as well. In order to determine a difference between social and private optimum, the calculations and measurements have to be performed with the private and social prices as well. In case those social prices are applied in the calculation, the Pareto optimality EE refers to the maximization of overall social net return from different irrigation water projects by equating the shadow prices of water in all competing uses. These economic criteria are appropriate parameters that can be used in determining optimal allocation of scarce water to competing water consuming activities and regions in Egypt by using appropriate mathematical models.

From the environmental viewpoint, the concept of economic efficiency can be also defined in a way that it adequately includes environmental impacts resulting from irrigation at farm level and regional level. Therefore, EE should include factors involving technical efficiency, opportunity cost of water, and externality costs generated by the irrigated agriculture.

3.3 Normative Analysis of Irrigation Water Use in Egypt[2]

3.3.1 Goals and Framework of Modelling

The objective of this section is to elaborate the types of model that is elaborate suited to make the right choices about optimal use and optimal allocation of water among potential users on the basis of a partial equilibrium model incorporating the environmental impacts in the economic assessment of water. Insight into the marginal value of alternative water uses is important for making the right choices about optimal use and allocation of water as a scarce resource. Economic analysis of irrigation water use have to consider the value generated by production activities and the costs to carry through these activities including the opportunity costs for alternative water uses and costs for the economic externalities arising.

The scope of costs and benefits is different when describing efficient use of water resources at the farm level viewed from the farmer's standpoint or from a social perspective. The major reasons for the difference between social and private benefits, and social and private costs in Egypt's agriculture are: i) The irrigation water is delivered to farmers without charging the true costs, hence, the volume of water used by farmers will differ from the socially optimal volume. ii) The rent of agricultural land does not reflect the marginal value of production. iii) Many markets of agricultural products are characterised through market failure due to imperfect competition and imperfect information. iv) Prices are biased due to food subsidies and other governmental decisions. Furthermore, environmental degradation is not internalised adequately.

An appropriate modelling framework for water planning will depend upon the particular management problem. A very multilateral model is necessary to include all possible productive uses of water, all possible production regions and the externalities that occur by the proposed activities. Furthermore, the model should be suited to represent the farm decision-making structure and also the viewpoint of a central "social planner". Approximately these demands can be satisfied by the application of two slightly different models. A static linear programming model is formulated to calculate the economic shadow prices. A dynamic framework is required that explicitly accounts for decline or improvement in land and water quality over a long time period that result from water use. Outlined below are the main distinguishing features of static and dynamic models.

[2] *Ibid. Bader and Hanf (2003), except 3.3.5.*

3.3.2 The Static Models

The objective of the static models is to maximise either the social or private returns. The results from social model are compared with those from the private model. The comparison is made in order to analyse policy implications and to generate policy options, which can serve to stimulate farmers to consider the social economic value of water.

3.3.2.1 National Optimum

The national goal of maximising the net social benefits generated with the Nile River water can be described in a simultaneous model that includes all agricultural regions simultaneously. The detailed analysis is necessary because of the existing differences in the economic values of water from one region to another. The objective function (Z) is the net social return from all crops (j), to be maximised subject to the total irrigation water available. The amount of water allocated to each region (W_{ij}) is the decision variable. For the sake of simplicity, all other constraints besides the water constraint are here neglected. The mathematical model is then as follows:

$$Max\,Z = \sum_{i}^{n}\sum_{j}^{r} P_{ij}Y_{ij}(W_{ij}, X_{ij}) - \sum_{i}^{n}\sum_{j}^{r} C_{ij}(W_{ij}) - \sum_{i}^{n}\sum_{j}^{r} C_{ij}(X_{ij})$$

Subject to:

$$\sum_{i=1}^{n}\sum_{j=1}^{r} W_{ij} \leq W$$

Thereby is, (Z) the total net social return from all crops, (P_{ij}) price of crop j in region i, (Y_{ij}) crop production function for each region, (X_{ij}) non–irrigation inputs including labour and capital for agricultural production, $(C_{ij}(W_{ij}))$ cost functions of water for each region, this costs include operation and maintenance costs of irrigation and drainage system, $(C_{ij}(X_{ij}))$ cost functions for non-irrigation inputs, (W_{ij}) irrigation water requirements of the crop j in region i, (W) total amount of water. The constraint indicates that the total amount of water used in all competing uses equals the amount available. The lagrangean for this problem is:

$$L = \sum_{i}^{n}\sum_{j}^{r} P_{ij}Y_{ij}(W_{ij}, X_{ij}) - \sum_{i}^{n}\sum_{j}^{r} C_{ij}(W_{ij}) - \sum_{i}^{n}\sum_{j}^{r} C_{ij}(X_{ij}) + \lambda(W - \sum_{i=1}^{n}\sum_{j=1}^{r} W_{ij})$$

Assuming that all functions are increasing and concave and all variables are positively valued guarantees the optimality of first-order conditions. These conditions for this optimisation problem can be determined via partial differentiation of lagrangean function with respect to the decision variable as follows:

$$\partial L / \partial W_{ij} = P_{ij} \partial Y_{ij}(W_{ij}) / \partial W_{ij} - \partial C_{ij}(W_{ij}) / \partial W_{ij} - \lambda = 0$$

The equation is the maximum principle, which requires that decision maker equate the marginal return with operation and maintenance costs of irrigation and drainage system and opportunity cost of water (λ). The equation requires that the shadow price (λ) of irrigation water to each user is the same in all regions at the optimal allocation of irrigation water. This value must be considered when making the optimal allocation decisions of scarce irrigation water resources to each user in all region of Egypt.

3.3.2 Farm Optimum

The farmers objective function is describe as maximising net return from their farm activities subject to their resource endowments, the availability and prices of inputs, and their expectation regarding crop return. The most important difference between the national model and the farm models are the following:

- The national model is a simultaneous model enclosing all agricultural regions simultaneously, whereas the farm models have to be calculated for all regions separately.
- The farm model has no restriction on water use. The optimal water demand is satisfied by equating marginal costs of water use to its marginal benefits.
- The farm model employs private prices and costs, whereas the national model uses social prices and costs.

This maximisation problem for any farmer (j) in any region (i) can be formulated as follows:

$$Max\, Z = \sum_{i}^{n} P_i^* \, Y_i(W_i, X_i) - \sum_{i}^{n} C_i^*(X_i) - \sum_{i}^{n} C_i^*(W_i) \quad \forall\, j = 1,...r$$

The farmer cost level of diverting irrigation water for use in their farm activities is described by the irrigation cost function $(C_i^*(W_i))$ which is the cost of irrigation (lifting water from a below–grade tertiary canal) and, for the maintenance of the private canals (mesqas) and ditches that are attached to their fields, for which farmers are responsible. And $(C_i^*(X_i))$ cost function of non-irrigation inputs.

The first order condition for maximisation of net returns, regard to the diverted water (W_i), is as follows:

$$\partial Z / \partial (W_i) = P_i \partial Y_i (W_i) / \partial W_i - \partial C_i (W_i) / \partial W_i = 0$$

This equation requires that farmer will choose the amount of irrigation water that equates the farm marginal return of irrigation water in crop production with the marginal cost of irrigation. To gain further more information, $MP_i = MC_i / P_i$, the right hand side of this equation must be positive since both the inverse of price and irrigation cost must be positive and non-zero. This equation indicates that the profit maximisation will be found in the rising part of the production function. Thus a profit maximising strategy will use less water per unit of land than a yield maximising strategy. From above, it is indicated that if farmers receive prices, which do not reflect the true value of crops or if the marginal cost of water is less than the true marginal cost of delivery, the volume of water used will differ from the socially optimum.

3.3.3 The Dynamic Models

Water scarcity is forcing policy maker to exploit unconventional water resources to meet growing demand from competing uses. However, because of water resource has social costs, the decision-maker need a framework for explicitly incorporating environmental impacts of irrigation water into system of water planning and management. The national water management may be improved through a dynamic economic model. The following dynamic model allows for changes in environmental impacts of irrigation water use and can determine optimal dynamic strategies on national level.

3.3.3.1 National Optimum

In a dynamic setting the objective of the social planner is to maximise the present value of the net economic return from water use over a fixed time horizon subject to quality and quantity of water. In the case of incorporating the environmental impacts resulting from the use of water in crop production, the problem can be formally stated as:

$$Max\ V = \sum_{0}^{T} \beta^t \left[\sum_{i}^{n} \sum_{j}^{r} P_{ij} Y_{ij} (W_{ij}, X_{ij}, E_{ij}) - \left(\sum_{i}^{n} \sum_{j}^{r} C_{wij} (W_{ij}) + \sum_{i}^{n} \sum_{j}^{r} C_{Xij} (X_{ij}) \right) \right] \quad (1)$$

Subject to:

$$E_{ij(t)} = g(W_{ijNile(t-1)}, W_{ijdraining(t-1)}, W_{ijmixed(t-1)}, E_{ij(t-1)} \quad \forall t = 0, T-1 \quad (2)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{r} W_{ij} \leq W \quad (3)$$

where V is the net present value of cumulative net return over the planning horizon, T denotes the period and the interval $(0, T)$ is planning horizon, $\beta^t = 1/(1+r)^t$ is the discounted factor for the given interest r, P is the output price, Y is the period production function, which is a function of the non-irrigation inputs (X), irrigation water (W) (control variables), E_t is environmental characteristics for example land quality (state variable), which result from the use of irrigation water in period t and previous period $(t-1)$ and changes over time, as a function of water quantity and quality and the primary state of production environment(the initial conditions), g is the rate of change in the environmental quality parameter which is a function of water quality along the Nile River in Egypt. The current value Hamiltonian is maximised along these optimal paths, as follow:

$$H = \sum_{i}^{n}\sum_{j}^{r} P_{ij} Y_{ij}(W_{ij}, X_{ij}, E_{ij}) - \left(\sum_{i}^{n}\sum_{j}^{r} C_{wij}(W_{ij}) + \sum_{i}^{n}\sum_{j}^{r} C_{xij}(X_{ij}) \right) + \beta\left[(\lambda_1 g(E_{ij}) + \left(\lambda_2 (\sum W - \sum W_{ij})\right)\right] \quad (4)$$

The Hamiltonion function is the net return obtained from an existing level of control and state variables. The equations of motion (λ_1, λ_2) represent the change in accumulated quality and quantity of water. The costate variable λ_1 represents the marginal external cost or/and return of environmental impacts (user cost or benefit) from irrigation projects, it change as affected by state and control variables. The $g(.)$ function indicates the rate of change in production environment corresponding to irrigation water use. When this function is multiplied by the costate variable (λ_1), it converted to a monetary value and represents the change rate of the economic value of externalities and then social net return. (λ_2) represents the opportunity cost of water. The dynamic optimisation problem presented in this section differs to the static maximisation in the static model in that the future externalities, income and or costs, from current period decisions are explicitly included in the current period return. An optimal solution to the above problem must satisfy the following conditions:

$$\frac{\partial H}{\partial W} = \sum_{i}^{n}\sum_{j}^{r} P_{ij} Y'_{ij} - \left(\sum_{i}^{n}\sum_{j}^{r} C'_{Wij} + \beta\lambda_1 \frac{\partial g}{\partial W} + \lambda_2 \right) = 0 \quad (5)$$

$$\frac{\partial H}{\partial X} = \sum_{i}^{n}\sum_{j}^{r} P_{ij} Y'_{Xij} - \left(\sum_{i}^{n}\sum_{j}^{r} C'_{Xij} + \beta\lambda_1 \frac{\partial g}{\partial X} \right) = 0 \quad (6)$$

$$\frac{\partial H}{\partial E} = \sum_{i}^{n}\sum_{j}^{r} P_{ij} Y'_{Eij} + \lambda_1 \frac{\partial g}{\partial E} + \frac{\partial \lambda_1}{\partial t} = 0 \quad (7)$$

$$\frac{\partial H}{\partial \lambda_1} = g(E_{ij}) = 0 \tag{8}$$

$$\frac{\partial H}{\partial \lambda_2} = (\sum W - \sum W_{ij}) = 0 \tag{9}$$

Equation (5) is the maximum principle, the standard condition for maximisation with respect to irrigation water applied, which requires that decision maker equate the marginal return product plus the marginal value gained by reducing the negative impacts with cost of water and the marginal damage caused by negative impact. The full economic cost of providing water consists of the full supply costs: Operation and maintenance expenditure as well as capital expenditure for replacement and investments in the existing irrigation and drainage infrastructure (C'_{Wij}), the opportunity costs (shadow prices) (λ_2) from alternative water uses and the economic externalities (λ_1) arising from changes in economic activities.

Positive externalities impose benefits and occur for example when surface irrigation is both meeting the needs of crops, fish production and recharging groundwater, and water discharge to wetland and Mediterranean Sea. Negative externalities impose costs caused by irrigation, drainage, reusing of drainage water. Intensification of Egypt's agriculture can lead to groundwater pollution related to the increased use of pesticides and fertilisers, salinization, and water logging. Opportunity cost of water (λ_2) are resulting because increases of water quantities on existing cropping patterns enhance the economic returns, or changes in cropping pattern to more water consuming crops is profitable, e.g. expanding rice areas all over the Delta for alleviating of salinity problems, and finally additional water can be profitably used for reclaiming new lands. The value of (λ_2) will be zero if the water supply is not scarce and positive when the water demand exceeds the available supply.

Equation (6) denotes the first order condition with respect to the non-irrigation inputs used in crop production, which requires that decision makers equate the marginal return product and marginal value gained by reducing negative effects with the cost of those inputs and the marginal cost of reducing negative effect. Equation (7) the necessary condition pertaining to the state variable which describes the marginal effect (positive or negative) on production and the third term of the equation is the rate of change in environmental impacts over time (t). Equations 8 and 9 are the necessary conditions pertaining to the state variables, which describe the water quality and quantity on production.

To gain further insight into the difference between static and dynamic solutions rearrange (5) and obtain

$$Y' = \left[C'_{wij} + \lambda_2 - \beta \lambda_1 \partial g(.) / \partial W \right] / P = 0 \qquad (10)$$

As in the static case, this condition states that optimal irrigation water volume occurs when the marginal product of irrigation water used equals the ratio of water cost to output price, but now water cost is decreased by the value of its future return effect, because this depend on the value of multiplier (λ_1). This will result in higher quantity water used than in the static model. (To understand why, note that $(\lambda_1 \le 0)$, i e. salinization have a negative effect on net return, and $\partial g(.) / \partial W \le 0$, i.e. irrigation water application decrease salt accumulation and salt leashing, since $\beta > 0$ the second term is either negative or zero. The right hand side of the equation (10) is smaller than the right hand side of the static solution. When the $(\lambda_1 = 0)$ means that the dynamic solution is the same as static solution. This occurs at the dynamic farm model, as discussed below. This result may be occurred at the national level when the national planner ignores the environmental impacts of irrigation water use and the national optimal control model (10) does not contain dynamic connection. If it is occurred, the dynamic solution will not converge to the static solution so long as the over irrigation and irrigation with low quality has a negative effect on land quality.

Due to the return effect of the current volume of water used on future profits, a higher level of optimal water volume occurs than when only current profits are maximised. Therefore, including the inter-temporal effects of externalities into the decision-making framework will result in a greater level of optimal water use and a higher economic return than static models.

Consequently, a dynamic economic model is theoretically preferred to static model for either incorporating environmental impacts an economic analysis of water planning and management or providing a framework for decision support systems. But the problem in this case is the data available for analysis and it may thus be out of the scope of this study.

Also, from the equation, if the prices of water will reflect the cost of supply, opportunity cost and economic externalities in the long term, farmers will be motivated to select social optimal levels of irrigation water. But in practice, the economic value of water different from water pricing, which can be used as a policy instrument for demand management and cost recovery. The price does often not reflect the value and cost of water because of social and political goals.

3.3.3.2 Farm Optimum

The dynamic model of national level is characterised by two facts: First, the way of water utilisation in one period influences the environmental state of next period. By this is a dynamic effect given. The second features of the model is that the quality of water is an endogenous control variable. Of course, the Egyptian farmers re-use water themselves from branch drain canals whenever a shortage occurs in tertiary canal. The Egyptian farmer, upon feeling that fresh water is becoming scar, especially during summer periods, directly moves his pump to the drainage canal to irrigate his field; however, farmers do not and must not consider the environmental impacts over time. If farmers neglect the environmental effects, the dynamic connection between the periods gets lost and the maximisation model falls back to the static one described in previous section. Hence, we have omitted to formulate such a model because it would be too artificially.

3.3.4 Farm and National Optimisation

The difference in the farm optimum and national optimum demonstrates that farm decisions of water management are not socially optimal. Farmer's volume of water use will either exceed the socially optimum volume because the cost of water is less than the true marginal cost, or the water is less profitably used in social term. Two components of the true cost of water use are not included in the farm model: The cost of operation and maintenance of irrigation and drainage system and the opportunity cost of water. These costs should be added to the cost of irrigation at the farm level to achieve the socially optimal volume of water per unit of area in the short run. In the long run, the true costs of water include beside operation and maintenance expenditure and the opportunity cost of water in next alternative use, also external costs due to environmental effects. These costs should also be added to the cost of farm level in order to achieve the socially optimum level. When prices of crops are not reflecting off farm environmental effects, or the agricultural policy distort prices and costs, farmer will prefer short term return of water use and the water use is higher than socially wanted, resulting in degradation of environment.

The relevant economic issues must be considered when designing water policies with the goal to maximise social benefits. Economic efficiency of water use provides information for policies that may encourage farmers to choose the optimal cropping pattern and improve water resources use. They must choose crops that generate the highest net return in competitive market. Regional decisions on the allocation of water can be more or less efficient, depending on the economic value of water in its alternative uses.

3.3.5 Economic Analysis of Salinity and Water-logging as Examples

There are environmental problems that have occurred over time resulting from the irrigation projects. These include increased salinity levels in the Nile water along Nile River in Egypt, water-logging and salinistion of soil. Over time this can result in changing in the ecological balance. The aim of the analysis is to assess the feasibility of reducing soil salinity and water-logging for better water management and environmental protection in Egypt.

The over-increasing salinity of land and water resources is one of the most important problems in Egypt's agriculture. Factors contributing to the salinity of soil and water resources include over-irrigation, irrigation with unsuitable water (drainage-water) and improper design of irrigation field system. Inefficient irrigation water use and poor soil drainage allow the soil to become waterlogged and allows water to pond for long periods of time. Kotb *et al.*, 2000, indicate that about 35 % of irrigated land in Egypt is affected by salinity, which is mainly located in the northern part of the Nile Delta, meaning there huge losses in output.

Irrigation with low water quality is a dynamic stochastic process. Salt is accumulated in the soil and is periodically leashed by irrigation. The major natural stochastic element is rainfall other stochastic phenomena are related to uncertainty regarding the physical relationships involved. The dynamic process of irrigation with saline water of a single plot can be characterized by one state variable representing variations of the soil salinity of the plot over time (Yaron, 1986, p. 239). In Egypt, there is little rainfall to dissolve the salts in the soil. Also, high rates of evaporation increase the concentration of the salt remaining in the soil. Yaron (1980, pp. 227 and 257) distinguishes three terms in economic analysis of irrigation with saline water, according to the range of time, and their corresponding models; short term, long term and extension long-term models. These basic approaches to salinity management can applicably be classified as either static or dynamic. The static approach considers the total amount of water available during the growing period, one year or single irrigation season, and considers the initial salinity of soil profile in the root zone at the beginning of irrigation season as a given, and analyse the optimal combination between water quality and quantity. It, however, ignores the effects of salt accumulation over time. A dynamic framework, on the other hand, accounts for the effect of salt accumulation over time in the soil profile, river flows, and aquifers. Such models comprise a succession of static case, the initial conditions of which are affected by salt accumulation in previous periods.

3.3.5.1 Salinity Effect on Crop Production

Salinity in soil becomes a problem when the total amount of salts, which accumulate in the root zone, is high enough to negatively affect plant growth. This negative effect depends on crop salt tolerance and it is related to the productivity of land, expressed as the relative yield decrease for a given level of salt compared to yields under non-saline condition. Mass and Hoffman (1977, p. 115) expressed crop tolerance to salinity in terms of relative Yield Reduction (YR), as follows

$$YR = Y_S / Y_0 = 100 - B(EC_e - S') \quad (1)$$

where

$YR = Y_S / Y_0$ = relative yield decrease from non saline to saline soil (%),

Y_S = yield per unit of water in the area affected salt,

Y_0 = yield per unit of water in the area unaffected salt,

EC_e = average seasonal root zone salinity, expressed in electrical conductivity of a saturated soil extract (dS/m^{-1}),

S' = salinity threshold value (dS/m^{-1}) beyond which there is a yield decrease, and

B = percent yield decrease per unit increase in salinity (dS/m^{-1}), Salinity Yield Decrease (SYD).

A decision in salinity control should reduce the damage to production caused by salinity. The damage avoided is thus one of the benefits of the reducing the salinity. Consider a simple representation for externalities of salinisation, externalities can be written as:

Damage function resulting from salinity over time (C_S)

$$Z = Z_0 - (P - C)(Y_0 - Y_S)A_t = Z_0 - C_S \quad (2)$$

Benefit function from reducing salinity level over time (B_S)

$$Z = Z_0 - (P - C)(Y_0 - Y_S)A_t = Z_0 - B_S \quad (3)$$

Using the above equations (2) and (3), the present value loss of production per cubic meter of water resulting from salinisation can be calculated from the following equation:

$$V_S = \sum_0^T \beta^t \left[(P - C)\left(\frac{Y_0 - Y_S}{Y_0} \right) \right] \quad (4)$$

where

Z_0 = total net returns before salinisation,

A_t = the cumulative area of salinity up to year t,

P = price of crop,

C = cost of production,

V_S = present value of income losses,

β = discount factor, $1/(1+r)^t$,

r = discount rate, and

t = number of years.

3.3.5.2 Modelling of Salinity

This section presents a dynamic model of salinity management in order to analyse the impact of salinisation on production and build a dynamic model of water choice. The modelling of salinity and water logging is based on Some Microeconomics of Agricultural Resource Use by Howitt and Taylor included in Agricultural and Environmental Resource Economics (1993). The first dynamic model starts by assuming that decision maker does not maximise net return on a short run, but rather considers the flow of future discounted net return.

Suppose that a decision maker maximises the sum of discounted net return for rice production per unit of water over time for the planning period (0,$\propto$) with a positive discounted rate ($r > 0$) in northern part of Egypt. And, it is assumed that risk-averse if (ψ`> 0 and ψ``< 0), t is the period–specific production function taking arguments the input vector water (W), the level of salinity in the crop root zone (EC), production cost (C), and the term (e^{-rt}) is the continuous discount factor and r is the discount rate. Under this assumption, a mean preserving spread implies a higher expected marginal damage of production from salinisation. This, in turn, leads to a lower level of salt. The maximum value of the function at period t can be written as the following:

$$Max \int_{t=0}^{\infty} \left[\psi\, P\, Y(W, EC) - CW\right] e^{-rt}\, dt \tag{1}$$

Subject to the equation of motion:

$$\Delta EC = g(W_{Nile}, W_{drainage}, W_{mixed}) \tag{2}$$

From equation (2) it can therefore derive the following policy implication: The level of salt should be lower in situation of uncertainty compared to a situation of certainty; and an increase in uncertainty should lead to a decrease in salinisation. Using control theory in which the control variables are water used for irrigation and leaching (W), the equation of motion

$m(.)$ represents the changes in accumulated quantity of salt. To resolve the optimisation problem outlined in the equations (1) and (2) above, the current value Hamiltonian is:

$$H = PY(W, EC) - CW + m(.) \quad (3)$$

By differentiating Equation (3) with respect to (W) gives:

$$\frac{\partial H}{\partial W} = P\frac{\partial Y}{\partial W} - \left(\frac{\partial CW}{\partial W} + \frac{\partial B_S}{\partial W} + \frac{\partial C_S}{\partial W}\right) = 0 \quad (4)$$

Equation (4) becomes:

$$P\frac{\partial Y}{\partial W} + \frac{\partial B_S}{\partial W} = \frac{\partial CW}{\partial W} + \frac{\partial C_S}{\partial W} \quad (5)$$

Equation (5) is the maximum principle indicating that decision maker equates the marginal return of water plus marginal benefit $(\partial B_S / \partial W)$ at the time from leashing salt with the marginal cost of water plus the marginal damage $(\partial C_S / \partial W)$ at the time caused by adding salts.

3.3.5.3 Modelling of Water-logging and Drainage

Water-logging occurs when applied water is not used by the crop, it can percolate into the groundwater and over time accumulate around the root zone making crop production impossible. Water-logging problem results in salinity problem, as water evaporate and remain the salt. Effective drainage system is important to control the water-logging problem and it takes care of salinity problems. This is through the construction of an effective drainage system and the use of more efficient irrigation technology, which would decrease the levels of excess water applied to the land. The construction of a drainage system requires capital investment, and the drained water has to be deposited in the saline area and will not have negative externalities.

The following model illustrates the impact of drainage consideration on irrigation projects assessment. Suppose that irrigation water percolates and generates a stock of rising water table that affects crop production. The initial stock is the water table (WT_0), the stock at time (t) is (WT_t). The productivity of water declines as (WT_t), which is the stock of water table, rises. The optimisation problem is:

$$Max \int_{t=0}^{\infty} \left[\psi \, PY(W, WT_t) - CW - CD\right] e^{-rt} dt \quad (1)$$

Subject to the equation of motion:

$$\Delta WT_t = g(W) \quad (2)$$

where, the cost of the drainage system is (CD), when drainage is introduced, equation of motion becomes

$$\Delta WT_t = g(W) - CD \qquad (3)$$

The policy implication that can be described from equation (1) is the level of water table should be lower in situations of uncertainty compared to a situation of certainty; in addition, an increase in uncertainty situation should lead to a decrease in water table. Using control theory, in which the control variables are water used for irrigation (W). The equation of motion $m\,(.)$ shows the changes in accumulated quantity of water table. By solving the problem outlined in equations (1) and (3) above, the current value Hamiltonian is:

$$H = PY(W, WT_t) - CW - CD + m(.) \qquad (4)$$

Maximising H with respect to the control variable (W) gives the first order condition

$$\frac{\partial H}{\partial w} = P\frac{\partial Y}{\partial W} - \left(\frac{\partial CW}{\partial W} + \frac{\partial B_{wl}}{\partial W} + \frac{\partial C_{wl}}{\partial W} + \frac{\partial CD}{\partial W} \right) = 0 \qquad (5)$$

By rearranging, one obtains:

$$P\frac{\partial Y}{\partial W} + \frac{\partial B_{wl}}{\partial W} = \frac{\partial CW}{\partial W} + \frac{\partial C_{wl}}{\partial W} + \frac{\partial CD}{\partial W} \qquad (6)$$

Equation (6) suggests that the marginal return of water plus marginal benefit over time $(\partial B_{wl} / \partial W)$ from decreasing water table must be equal to the marginal cost of water, the marginal damage at time caused by raising water table $(\partial C_{wl} / \partial W)$, and the marginal cost of drainage $(\partial CD / \partial W)$.

3.4 Charging Irrigation Water

Water charge policy can be an effective water resource management tool to adopt water conserving technologies or regulate irrigation water demand. Theoretically, there are mainly three objectives of water charging; economic efficiency, equity, and financial. Economic efficiency means maximising the net benefits of irrigation projects to the national economy. Financial source (cost recovery) that has to collect with the sharing net benefits between the Government and system users. Equity is through sharing the net benefits among the users of irrigation system. This section discusses the purpose and mechanisms of a charging system in irrigated agriculture.

3.4.1 Purpose of Charging Irrigation Water

Economic Efficiency

Economic efficiency is concerned with the use of nation's water resources maximising the net benefit. It is achieved when the marginal value equals the marginal cost. The farmer will only apply the water unit as long as the marginal value is more than the marginal cost. Economic losses occur when the farmers apply more water than economical volume. In addition, according to Pareto optimality, the marginal benefit from the use of water resources should be equal across all water users in order to maximise the social welfare from water use. Johansson *et al.* (2002) define the efficiency of water resources allocation as that which maximises net benefit to society using existing technology and available water resources. An efficient allocation maximises net benefits over variable costs in the short run and results in the equalization of marginal benefits from the use of water across sectors to maximise social welfare. And in the long run, it also includes optimal choices of fixed inputs.

Equity

Two major types of equity can be described: horizontal equity and vertical equity. Horizontal equity is concerned with the fairness of cost and benefit allocation between system users and groups who are served. Under the assumption that the system users are like, it may be interpreted to mean that users should "get what they pay for and pay for what they get," unless there is a specific reason to do otherwise. This means that the users should pay water charges that are proportionate to the costs they impose on water supplying entities by their water use.

Vertical equity is concerned with the treatment of users and groups that are unlike. By this principal, the distribution of costs and benefits should reflect people's needs and abilities. This goal is often satisfied through subsides program or adopt different water charge alternatives in order to consider the different income levels. Dinar *et al.* (1997) suggest that an equitable allocation of water resources is achieved when all users, regardless their ability to pay for water, have a basic right to water providing an equal opportunity from using water. Johansson (2000) notes that the majority of water charging mechanisms has a little potential effect in the distribution of income, because equity effects depend on land endowment assuming farmers are homogenous.

It is important to ensure accessibility to water by all social groups; any charging policy must satisfy this objective. These relate to water access and social minimum volume of usage. The charge for the social minimum value should be set low so that as small farmers have the ability to pay. Equity criteria are included to ensure that people at different locations in the system have equitable access to water supply.

Cost Recovery

Cost recovery is the process of capturing and directing to public agencies the service fees, which are collected from individual services recipients in order to fully or partially meet the costs of providing the service. In the case of a water system, the objective is to recover part of the cost of providing water related services, to encourage efficient use of water, and to provide the water service at a reasonable cost.

The Government has invested heavily in projects of irrigation systems development to secure irrigation water supply and meet development needs. These include water supply, delivery, and drainage system facilities and the institutional organizations that must manage the system facilities. Sustainability of this system is essential to ensure continued supplying of the system services in order to avoid severe hardships on society. Sustainability of services can be accomplished by generating enough funds to support the needed actions. The source of such funds could come entirely from the state budget or entirely from the direct beneficiaries or some combination. However, if none comes from the direct beneficiaries, there will be no incentive to conserve water and use it rationally (Abu-Zeid, 2001). Therefore, cost recovery is to improve the system infrastructure, ensuring adequate financial resources as poor maintenance caused infrastructure deterioration and high water losses, and create awareness about the importance of water through the contribution of the users.

Improved control of water supply results in water deliveries that are timely and adequate, maximum benefits securing conservation, and equitably allocated among system users. Timeness and adequacy mean the system should be responsive to irrigation water demand. The farmers must receive an adequate water supply when and where they need it. This encourages the willingness of the system users to pay for the system services that are in a controlled manner. The payments by system users lead to improvement of the operations and maintenance of the system and better investment decisions to the extent possible. They can be leaded to improve the overall irrigation efficiency of the system minimising water losses through good supply control. Controlled water supply leads to greater economic efficiency shifting cropping pattern to reflect the economic value of water. Finally, cost recovery results in more equitable water distribution among users located in different system parts (head-end of the canal) resulting in greater equity. Controlled supply can contribute directly to efficiency and equity.

Abu-Zeid (2001) states that water users in general do not know about efficiency or equity, but they know what they observe which is timely and adequate water supply. If these conditions are not satisfied they will not pay. The ability of system to supply water in a good controlled manner can enhance the users to pay and make the charging mechanism acceptable to the water users.

3.4.2 Mechanisms for Collecting Irrigation Water Charges

Mechanisms for charging irrigation water range from per area, through output and input charging, to various volumetric schemes. Each of them has advantages and disadvantages, which depend largely on the nature of the data available for performing the valuation exercise, reflecting differences in conditions that underlie water allocation. Different types of water charges applicable in different countries of the world can be grouped into two groups: volumetric methods measuring water volume, and non-volumetric method. These alternative charging instruments are discussed in this section dealing with the advantages and disadvantages of these alternatives:

3.4.2.1 Volumetric Charging Methods

Volumetric charge for water depends on using a measurement of the quantity of water used. It is a direct charge based on measured quantities of water at measuring point. This requires information on the quantity of water used by each farmer or a defined group of users below the measuring point. It also requires a central water authority or water users' organisation to set the prices, monitor use and collect fees. Countries employing this mechanism seeking to recover partly operation, management costs and capital depreciation such as U.S.A., Australia, England, France, Mexico, India, and Israel. In Morocco and Jordan the mechanism are seeking to partially recover operation and management costs (Johansson, 2000). This is more practical in developed countries where farmers have extensive holdings.

This method is theoretically very attractive because it is capable of achieving a first best allocation, i.e. the net benefit is maximised from available water resources. It has the advantage of encouraging farmers not to use more than optimal quantities for each crop, thereby avoiding losses, and obtaining economic efficiency. Charging water according to the quantity used provides an incentive to limit water use, and encourage the conservation of water. Farmers will equate the cost of water with its marginal return, and in case of water scarcity, the net return per unit of water will be maximised. Therefore, the cropping pattern adopted reflects the economic value of water. This mechanism can be used in policies aimed at affecting income inequality. From economics standpoint of view, it is the most acceptable mechanism.

Often a major problem with this approach is that the marginal cost of water unit for each farmer must be the same, when social net return to be maximised. The second problem is supply control depending on farmers demand, and this need to measure from the distribution system to the user. The farmers demand is not the same because the differences in cropping patterns and small and scattered land holdings make the mechanism difficult to operate the irrigation system based on the water demand, and the ability of system to control the water supply according this demand. In case of continues water flow when it is not needed by farmers, they can not be charged for water. And when water is in excess uncontrolled in flooded months why water is charged, from economics stand point of view the value of resource is zero.

Moreover, implementation costs such as infrastructure and administration costs associated with measures control that need to be established at the different level from tertiary level to field application are relatively expensive. This needs high implementation costs. In addition there are a number of constraints in Egypt such as limited water resources and its distribution may be not equal over months of year. One of the prominent characteristics of Egyptian irrigated area is the prevalence of small-scale enterprises and fragmentation; the high cost of machine and measurement equipments, the irrigation water requirements for strategic crops such as rice and sugar cane. It can be concluded that volumetric water charging mechanism is impossible in the case of Egypt, because it needs a heavy capital inputs and administrative inputs.

3.4.2.2 Non-volumetric Charging Methods

Non-volumetric methods charge for irrigation water based on a per output basis, a per input basis, a per area basis, or based on land values. These methods often result from inadequate information concerning actual consumption quantities. Output charging methods charge a water fee for each unit of output produced by the water user. This requires knowledge of user outputs, but does not need to measure control. In the case where output is readily observable this method will save on transaction costs. Input charging methods charge users for water consumption indirectly through higher prices (as tax) for inputs purchased from the Government. An example of this might be a per unit charge for each kilogram of fertilizer purchased (Johansson, 2000). These methods are easier to implement and administrative and require less information, but they cannot be used in polices aimed at efficient allocation and income inequality.

Area-based charges

Under area charging mechanism users are charged for water used per irrigated area unit, often depending on crop choice, extent of crop irrigated, irrigation method, and season. This method is the most commonly used in different parts of the world because it is easy to implement and administer and is best suited to continuous flow irrigation. In a global survey of farmers, it was found that more than 60 % of cases, water is charged per hectare. Countries employ per area charging seeking to recover partly operation and management costs such as China, India (groundwater), Iraq, Nigeria, Pakistan, Philippines, and Zimbabwe (Johansson, 2000).

Per area charging has a limited effect on input-output decisions. Farmers have no incentive to avoid the water losses because their payments for water unrelated to the quantity of water delivered. It does not offer any economic incentive to farmers to be more frugal with the water use or to improve their management practices. The farmers would over-irrigate because the water charges in any volume are the same. It may provide an incentive to cultivate agricultural land most intensively. The disadvantages of this alternative originate from the fact that a fixed fee per irrigated area once paid can no longer affect farm decisions regarding irrigation water use.

Area-based water charges can be established in a number of types: *Flat Land Charge,* which is the easiest type to administrative, since the collection needs only to know the cultivable land holding and served by irrigation system for each user regardless of annual or seasonal differences in cropping practices (Hamdy, 2002). This type does not take into account the differences in farm income, cropping intensity, irrigation water use, etc. among users of the irrigation system. Therefore, it is inequitable, as the farmers on the end-tail of the canal who are less supplied have to pay as much as the head farmers who are well supplied with irrigation water. Thus, this type is not consistence with the efficiency and equity.

In China, this mechanism resulted in farmers be not controlling their irrigation bills by changing methods of irrigation and the quantity of water used. Farmers' water use behaviour and production plans are also more or less unchanged. It is concluded that using the charging mechanism as a single policy tool to deal with water scarcity may in many ways lead to results contrary to the objectives of the policy itself (Yang, *et al.,* 2003).

The second type is *Flat Crop Area Charge*: This imposes fixed charge on the actual cropped areas that receive water during the different seasons of the year. This needs more administrative and regulatory effort from irrigation authority, i.e. periodic visiting to each user (Hamdy, 2002). In addition, the efficiency and equity are not considered since water consumption is not considered but it focuses on the crop intensity. This type also creates inequities in income distribution since the head and tail farmers pay the same for water per cropped area. It also does not give information on crop production and water requirements, which are required in planning of water resources decisions.

The third type is *Crop-Based Charge*: A charge for each crop grown based on typical or required water use levels for each crop. Rice and sugar cane that require large a mount of water would be charged much more than beans or wheat (Hamdy, 2002). This type may consider the irrigation requirement but it does not consider the equity of income distribution for small enterprises. This mechanism leads to shifts in cropping patterns towards more water efficient crops. However the decisions of crop selection would reflect the opportunity cost of water and it may be provided minimal distortions in water allocation.

This type of water charges is relatively simple to administer and suitable to recover the operation and maintenance costs of the irrigation system. It may make the farmers awareness about the importance of the valuable and scarce water resource. In addition, water requirements-based crop charge may lead towards to an optimum efficiency of water use.

3.5 Planning and Management of Irrigation Water

Planning and management are critical elements for the sustainable development of water resources. Essentially, irrigation water resources planning and management should combine a space-time-quantity-quality balance. The main purpose of this section is to review literature on the concept of irrigation water management and methods of water resources planning, briefly mentioning linear programming theory as basis for understanding the results of the application models.

3.5.1 Irrigation Water Management

Irrigation water management generally implies management of both water availability and demand for it. It is the most important way to get optimal crop production from an optimal use of the available irrigation water. Irrigation management activities involve: evaluation of irrigation water resources, determination and control of the amount and timing of irrigation water applied to crops, maximising net return for unit of water, formulation and implementation of management strategies, construction, operation and maintenance of irrigation and drainage systems from the sources to the field application, scientific and engineering research, and education and training. Engineers, economists, scientists, planners, and conservationists all involved.

Dudley and Scott (1993, p. 3093) distinguish three terms in decision-making and operation of irrigation system; short term, inter-mediate term, and long term. The short-term decisions involve allocating quantity of water for possible uses in time over an irrigation season, given the available irrigation water resources and currently irrigated area. The inter-mediate term decisions involve deciding what area of the irrigated crop to plant at the beginning of an irrigation season given the area of land available and available water supply. Determining the best area of land to develop and equip for irrigation is a long term or the investment decision.

Reddy (1986, pp. 106-107) describes irrigation water management as the process by which water is controlled and used in the production of food and fibre. He argues that irrigation management is not the water resources, dams, or reservoirs to capture water nor laws or institutions to allocate water, nor farmer’s organisation, nor soils or cropping system. It is the way these skills and physical, biological, chemical, and social resources are utilised to provide water for improved food and fibre production. Improved irrigation performance depends on the overall resource management not only of water but also of irrigation systems as a whole, including management of information and controls of water users and other inputs besides irrigation water.

Irrigation water management involves managing the allocation of water and related inputs in an irrigated crop production, such that economic returns are enhanced relative to the available water. Conservation and allocation of limited water supplies is central to irrigation management decisions, whether at the farm, irrigation-district, or river-basin level. Improvement in Irrigation Water Management can help maintain the long-term viability of the irrigated agricultural sector. It may also reduce expenditures for agricultural inputs, while enhancing revenues through higher crop yields and improved crop quality (Ronald and Marlow, 1999). Sustainable water management attempts to overcome the problem of scarcity and keep the water balance in equilibrium, mitigating negative environmental consequences. Besides food security, achieving high social-economic return over the long term is the motivating factor that sustains agricultural development.

3.5.2 Mathematical Models for Irrigation Water Planning

The mathematical models consist of a set of equations describing the real system. This set of equations identifies the functional relationships among all system's component and elements and its environment, establishes measures of effectiveness and constraints, and thus indicates what data should be collected to deal with the problem quantitatively and qualitatively. These equations could be algebraic, differential, or other, depending on the nature of the modelling system (Haimes, 1977, pp. 3-4). A schematic representation of the mathematical modelling process as shown in Figure 3.1; the same input applied to both the real system and the mathematical model produces two different responses, namely, the system output. The closeness of these responses indicates the merits and validity of the mathematical model. Figure 3.1 also applies solution strategies, often referred to as optimisation and simulation techniques, to the mathematical model. The optimal decision is then implemented on the physical system.

Mathematical programming and simulation techniques have been used on many occasions to find economically optimum solution in irrigation water planning and management strategies. Optimisation models differ from the simulation models in that they are not driven by a predetermined system. Optimisation models determine the "best" water allocations and given a set of economic values of water. In contrast, simulation models can be used to derive the economic impacts from a given a set of water allocation policies arising from a pre-defined management system. These two types of models should be used in conjunction.

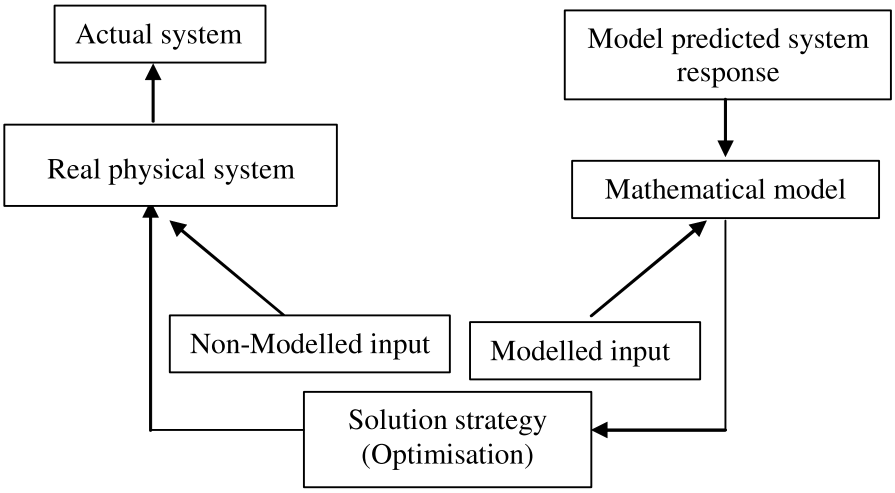


Figure 3.1 System Modelling and Optimisation (Haimes, 1977, p. 4).

3.5.2.1 Simulation Techniques

In decision-making and policy analysis, the application of simulation models is becoming more and more common. Simulation models have an added value in obtaining a better understanding of the modelling system and are powerful in determining the effects of policies proposed. They are widely used to evaluate the consequences of a set of decisions (what-if analysis) over a period of time interest. These decisions may include the implementation of changes in the system and/or its inputs varied. In a simulation model, policies or improved management strategies are determined by a set of predetermined rules. Through a series of simulations these rules can be modified and improved until model results are acceptable. Hanf (1983) defines a simulation as a systematic way of changing the data of a model to represent possible changes in the condition for a firm's activities. He distinguishes two different ways of using simulation:

- The simulation determines the consequences of data change for the value of objective variable and the use of limited resources on the basis of an unchanged implementation of activities i.e., under the assumption that an immediate reorganisation of activities is infeasible.
- The simulation identifies the "stable core" of an organisation i.e., to identify activities, which are relatively intensive to changing conditions. This needs a re-computation of the programming model for each of the simulated changes.

In this study, simulation is used to evaluate the expected performance resulting from different water management policies on the objective function and resources use.

3.5.2.2 Optimisation Techniques

Optimisation problem is the procedure of improving the evaluation strategy of the problem management to make the evaluation more effective. It includes selecting a set of decision variable, which optimises given objective functions subject to all pertinent constraints. Optimisation problems are solved by applying different methods, which include heuristic rules, neural networks, and mathematical programming. Mathematical optimisation techniques are widely used to solve optimisation problems in water resources system. This method is discussed briefly in this section.

Qureshi *et al.* (2001) justify the use of mathematical programming models for economic analysis by these reasons; (1) many activities and restrictions can be considered at the same time, (2) an explicit and efficient optimum seeking procedure is provided, (3) with a once-formulated model, results from changing variables can be calculated easily, (4) new production techniques can be incorporated easily by means of additional activities in the model, and (5) the method does not depend upon time series data which is necessary condition for econometric modelling, thus enabling to predict impacts due to various prices and under different institutional constraints. Howitt (1995) argues also that the use of the mathematical programming models for agricultural economics and policy analysis in order to overcome validation problems as well as excessive specialisation in production. Their popularity stems from several sources: First, they can be constructed from minimal data set, few data compared to econometric models. Second, the constraint structure inherent in programming models is well suited to characterising resource, environmental, or policy constraints. Third, the leontief production technology inherent in most programming models has intrinsic appeal of input determinism when modelling farm production.

Mathematical–optimisation techniques are used if the minimum or maximum of a mathematical description of an objective function has to be determined. They are characterised by a mathematical statement of the objective function and a search procedure within the decision space for finding values of those decision variables that optimise the objective function. The most widely used optimisation methods are linear programming (LP), non-linear programming (NLP) and dynamic programming (DP). They are discussed below.

Linear Programming

Linear programming (LP) is a mathematical procedure by which limited resources are allocated, or evaluated to achieve an optimal solution to a particular objective. LP, therefore, is one of the most applied in optimisation problems where the objective function and constraints are linear functions of the decision variables. Despite the fact that the linearity restriction is severe, LP is a widely used optimisation technique because it is generally applicable and reliable solvers are readily available. Furthermore, non–linear relationships can be included in LP modelling through piecewise linearised approximations. This often proves beneficial due to the ability of linear models to handle large number of decision variables and constraints. However, the objective function is limited being a convex piecewise linear functions of the state and decision variables. An extension of LP is the Successive Linear Programming (SLP). SLP uses an iterative solution approach in which LP problem is solved at each iteration. It helps in solving the linearised problem, where the linearisation can result in inaccurate or even invalid solution (Lobbrecht, 1997).

Non-linear Programming

Non-linear programming (NLP) differs from the LP in that at least one of the functions involved in the model (objective function and/or one or more of the constraint equations) is non–linear function. Such a problem is still considered to be difficult to solve. However, some special-purpose solution techniques or solvers are available that are applicable for certain subclasses of problems, requiring a special properties of the function in the NLP problems such as quadratic programming.

Dynamic Programming

Dynamic programming (DP) is a technique of solving a class of mathematical programming problems because of the fact that non-linear and stochastic features that characterise water resources problems can be incorporated in DP formulations. In addition, DP has the advantage of decomposing complex problems involving a large number of variables into a series of sub-problems that are solved recursively. The idea is to break this large problem down into incremental steps so that, at any given stage, optimal solutions are known to sub-problems.

DP is often used to solve multi-stage scarce resource allocation problems in which limited resources must be allocated among activities over one or more time periods. In these cases, the problem can be represented as a sequence of stages with interdependency, when one or more decision is required at each stage, and the decision at one stage affects the next adjacent stage only. When the sequential nature of the system can be established, and the number of state and decision variables is not large, the computational procedures are practical.

Among these available optimisation techniques, LP is the most widely used mathematical programming technique. Therefore, the following section presents different LP theoretical results, as the technique is also used in this study.

Linear Programming Theory

Linear programming (LP) has been used since the development of the simplex algorithm in wide variety of planning situations. It has the ability to model important and complex management decision problems and the capability for producing solutions in a reasonable amount of time (Bazaraa *et al.,* 1990, p. 1). The characteristics of LP can be grouped into two categories: components and assumptions (Hillier and Lieberman, 1988, p. 22 and pp. 24-26). The main components of any constrained LP problem are:

- Decision variables (x_j): Choices available to the decision maker in terms of either inputs or outputs $(\forall\, j=1,...n)$, their values completely describing the decisions to be made.
- Objective function (z): a mathematical expression of profit, cost, etc. per unit of input or output or any quantity that is to be maximised or minimised which defined in terms of decision variables $z = c_1 x_1 + c_2 x_2 + ... + c_n x_n$
- Functional constraints: a mathematical statement that specifies such elements of the problem as the limitations on the values of one or more of the decision variables. $a_{i1}x_1 + a_{i2}x_2 + ... + a_{in}x_n \le b_1 \quad \forall i = 1,..., m$. Functional constraints can be also including bounds that are the variables on an optimisation problem permitted to take an infinite range.
- Model Parameters $(c_j, a_{ij}, and\, b_i)$: numerical values that are fixed, their values are determined when the LP model is solved

Mathematically, the basic linear programming problem can be described as follows

$$Max\, c_1x_1 + c_2x_2 + ... + c_nx_n$$

Subject to

$$a_{11}x_1 + a_{12}x_2 + ... + a_{1n}x_n \le b_1$$
$$a_{21}x_1 + a_{22}x_2 + ... + a_{2n}x_n \le b_2$$
$$.. \quad\quad .. \quad\quad ..$$
$$.. \quad\quad .. \quad\quad ..$$
$$a_{m1}x_1 + a_{m2}x_2 + ... + a_{mn}x_n \le b_m$$

$$x_1, \quad x_2, \ldots\ldots \quad x_n \geq 0$$

where, (x_j) level of the j activity, within n possible activities (a decision variable), (c_j) contribution of each unit of (x_j) to the objective function, (a_{ij}) is the amount of resource (i) consumed by each unit of activity j, (b_i) is the amount of resource (i) available for allocation within (m) possible resources, parameters in the functional constraints.

The assumptions of a linear program model are:

- Proportionality: The contribution (c_j) of each activity (x_j) in the value of objective function (z) or its usage of the resources is directly proportional to the value of decision variable under the assumption that parameters (a_{ij}) are constant. There are no economies of scale, This assumption rules out decision variable exponents other than 1, but does not rule out cross-product terms,
- Additivity: The objective function is the direct sum of individual contributions of different variables. Similarly, total resource use is the sum of the resource use of each variable. This requirement rules out cross-product terms (linearity implies both the proportionality and additivity properties are satisfied)
- Divisibility requires that each variable be allowed to assume any fractional values, and
- Deterministic: all the parameters $(c_j, a_{ij}, and\ b_i)$ of the model are known with certainty.

Standard matrix form

An understanding of the basic LP solution is important to interpret the results of the model. This section covers LP solution principles by matrix algebra and its interpretation. Bazaraa *et al.* (1990, p. 7 and pp. 90-94) note that the linear programming is more convenient when using matrix notation. The following equation shows general formulation of LP problem.

$$Max \sum_{j=1}^{n} c_j x_j$$

Subject to

$$\sum_{j=1}^{n} a_{ij} x_j = b_i \quad \forall i = 1, \ldots m$$

$$x_j \geq 0 \qquad \forall j = 1, \ldots n$$

The row vector of profit contributions $(c_1, c_2, ..., c_n)$ can be described by **C** and consider the following column vectors a feasible **X** (decision vector) and right hand side **b** (resource vector), and the technological coefficients $m \times n$ matrix **A**.

$$\mathbf{X} = \begin{bmatrix} x_1 \\ x_2 \\ . \\ . \\ x_n \end{bmatrix} \qquad \mathbf{b} = \begin{bmatrix} b_1 \\ b_2 \\ . \\ . \\ b_m \end{bmatrix} \qquad \mathbf{A}_{m \times n} = \begin{bmatrix} a_{11} & a_{12} \,.......\, a_{1n} \\ a_{21} & a_{22} \,.......\, a_{2n} \\ . & . \,.......\, . \\ . & . \,.......\, . \\ a_{m1} & a_{m2} \,......\, a_{mn} \end{bmatrix}$$

The LP problem can be expressed in a matrix form as follows.

$$Max\ \mathbf{CX}$$

Subject to

$$\mathbf{AX} = \mathbf{b}$$

$$\mathbf{X} \geq 0$$

At the optimum, the basic feasible solution of a basis matrix **B** is $\mathbf{B}^{-1}\mathbf{b}$ whose objective value $z_0 = \mathbf{C}_B \mathbf{B}^{-1} \mathbf{b}$ and the associated variables are basic variables $\mathbf{X}_B$, and the other variables are non-basic variables $\mathbf{X}_N$ and set to zero. As a result, the problem can be expressed as:

$$Max\, z = \mathbf{C}_B \mathbf{X}_B + \mathbf{C}_N \mathbf{X}_N$$

Feasibility needs

$$\mathbf{X}_B, \mathbf{X}_N \geq 0$$

$$\mathbf{B}\mathbf{X}_B + \mathbf{N}\mathbf{X}_N = \mathbf{b}$$

Multiplying the last equation by the basis inverse $\mathbf{B}^{-1}$ and rearranging the terms yields the solution for the basic variables in terms of the non-basic variables as follows.

$$\mathbf{X}_B = \mathbf{B}^{-1}\mathbf{b} - \mathbf{B}^{-1}\mathbf{N}\mathbf{X}_N$$

$$= \mathbf{B}^{-1}\mathbf{b} - \sum_{j \in R} B^{-1} a_j x_j$$

where R is the current set of indices of the non-basic variables. From the last equation and the objective function (z) one obtains

$$z = \mathbf{C}_B \mathbf{X}_B + \mathbf{C}_N \mathbf{X}_N$$

$$= \mathbf{C}_B (\mathbf{B}^{-1}\mathbf{b} - \mathbf{B}^{-1} \mathbf{N}\mathbf{X}_N) + \mathbf{C}_N \mathbf{X}_N$$

$$= \mathbf{C}_B \mathbf{B}^{-1}\mathbf{b} - (\mathbf{C}_B \mathbf{B}^{-1} N - \mathbf{C}_N) \mathbf{X}_N$$

$$= \mathbf{C}_B \mathbf{B}^{-1}\mathbf{b} - \sum_{j \in R} (\mathbf{C}_B \mathbf{B}^{-1} a_j - c_j) x_j$$

The last equation is frequently transformed to

$$z = z_0 - \sum_{j \in R} (z_j - c_j) x_j$$

where $z_0 = \mathbf{C}_B \mathbf{B}^{-1} \mathbf{b}$ for basic variable and $z_j = \mathbf{C}_B \mathbf{B}^{-1} a_j$ for non-basic variable. The objective value will increase for any entering non-basic variable if its term $(z_j - c_j)$ is negative. This term is called the reduced cost coefficient. If there are no variables with negative value of $(z_j - c_j)$, then the current feasible solution is optimal.

Interpretation of General LP Solution

The section of matrix form is utilised to interpret the LP solution information as follows (Bazaraa *et al.,* 1990, pp. 118-120).

- Differentiating the objective function with respect to the right hand side $\mathbf{b}$ gives

  $$\partial z / \partial \mathbf{b} = \mathbf{C}_B \mathbf{B}^{-1}$$

  This is called the shadow prices of resources in LP. It gives estimate of the marginal value product of the resource, or scarcity value, and a convenient way of predicting the rate of change in the objective function when the right hand sides are changed.
- The order of partially differentiation of the objective function with respect to a non-basic variable x_j gives

  $$\partial z / \partial x_j = -(\mathbf{C}_B \mathbf{B}^{-1} a_j - c_j)$$

  This shows that the marginal cost of increasing a non-basic variable equals the negative value of the reduced cost term.
- The marginal effect of changes in the non-basic variables on the basic variables is obtained by differentiating, as follows

  $$\partial \mathbf{X}_B / \partial x_j = -\mathbf{B}^{-1} a_j$$

  It is the rate change of the basic variable as a function of the non-basic variable x_j, showing how many units of each basic variable are removed with a marginal change in the non-basic variable.
- Similarly, differentiating the basic variables with respect to the right hand side $\mathbf{b}$ gives

  $$\partial \mathbf{X}_B / \partial \mathbf{b} = \mathbf{B}^{-1}$$

  It indicates that $\mathbf{B}^{-1}$ is the expected rate of change in the basic variables when the right hand side is changed.

3.6 Conclusions

This chapter has presented a framework for interpreting the concept of water use efficiencies. The effective efficiency in Egypt is rather high because of the recycling of irrigation water. However, economic efficiency should be used to assess irrigation water strategies when examining both private and social efficiency.

The irrigation water resources management can benefit from application of economic analysis and methodology of optimisation. Modelling can test alternatives of water use in order to help policy maker and farmer to improve the use of water resources. The social net return from water will be maximised when the shadow value of water is the same in all regions and competing uses. Farmer will not consider the economic value of water in the absence of water charge. Accounting for the economic value of water in the price paid by farmers would help to improve efficiency of water use. Water management can be improved by incorporating the future effects of water use into economic models of water management.

Water-logging and salinisation arise in Egypt largely because irrigation water is not priced or allocated correctly to reflect shadow values. Policy options with respect to irrigation water quality in Egypt are the varying degrees to which drainage water is mixed with fresh Nile water to dilute the salts. Appropriate policies include water charging for farmers to use irrigation methods that reduce deep percolation. These policies may reduce waterlogged and saline areas.

Policies optimising on the water use is different from water charging policies, which can be used as a policy instrument for the rational use of water, demand management, and for providing financial resources for irrigation services. Water charging may be not function very well, since subsidised irrigation water may support development in rural areas. This explains why the Government of Egypt subsidies the use of water. Implementation of Cost Recovery is crucial for improvement of irrigation system. Water charges such as volumetric charging would not be economically, socially, or politically feasible. The basis for irrigation service charges should be crop-based and should reflect crop water consumption.

Mathematical programming models can be used to determine optimal agricultural production activity and agricultural resource input levels. Linear programming (LP) can be used in the analysis of irrigation planning and charging. It can be applied to make decisions about irrigation water management options in conjunction with optimal cropping pattern, to ensure optimal utilisation of available land and water resources in Egypt.

CHAPTER 4

A PRELIMINARY ASSESSMENT OF IRRIGATION WATER USE IN EGYPT

4.1 Introduction

Egypt's agriculture is under pressure to justify its use of water resource, which is scarce due to increased competition for water resources. The main objective of this chapter is to document the actual patterns of crop production and use of irrigation water in Egypt during the years 1999 to 2001, as a basis for comprehensive understanding of irrigation water use patterns and a description of how the technical coefficients for modelling purpose are calculated. This chapter contains four sections: Section 4.2 deals with the actual cropping pattern, while section 4.3 describes irrigation water requirements and the allocation patterns of irrigation water use. Section 4.4 includes an economic analysis of irrigation water use in crop production. Finally, conclusions to the chapter are presented in section 4.5.

4.2 Actual Cropping Pattern

A cropping pattern indicates the kind and sequence of crops grown over a period of time on a given area of land. Cropping patterns are determined by agro-climatic and socio-economic factors. Generally, agro-climatic factors are fairly stable over time, while demographic, social and economic factors are less stable. Agro-climate factors determine the condition under which crops are grown. On the other hand, farmers are increasingly inclined to change cropping patterns in response to changes in economic factors (input-output prices), technological factors (improved efficiency), institutional factors, and policy related factors (prices, irrigation subsides or charges). The aggregate impact of the farmers' decisions leads to the establishment of new cropping patterns in a region.

Choice of cropping pattern can be considered as a strategic decision, which is taken before the planting season. This decision about the irrigable area is made in light of the available water resources and capital and also takes into account economic and regulatory contexts (such as product price, input costs, subsidies, and the area constraints on which crop should be grown in a particular area).

Actually, the Egyptian agricultural policy follows a new cropping system known as indicative planning of cropping pattern, which is based on steering the economy to increase the efficiency of use of the available agricultural resources by providing favourable conditions and free administrative restrictions.

In Egypt, most of the cropped area is devoted to subsistence food crops. Due to spatial differences in the climatic, agronomic, economic, and cultural conditions, there are observable variations in cropping patterns in the regions. There are three cropping seasons, winter, summer, and Nili seasons. In the old lands, an elaborate crop rotation system is followed. The main winter crops are wheat, clover, and broad beans. Maize, rice, and cotton are the dominant summer crops. Vegetable crops such as tomatoes, potatoes, squash, and others are cultivated in all the three seasons.

Table 9, in Appendix, presents the cropping patterns under different seasons and agro-climatic zones. The total cropped area was about 11.69 million Feddans. This area was allocated to the winter, summer, and Nili seasons, and permanent crops in the ratio 45.60 %, 36.88 %, 4.49 %, and 13.03 %, respectively. This allocated to: the Lower, Middle, and Upper Egypt that amounted to 7.48, 2.42, and 1.80 million Feddans, representing 64.17 %, 20.48 %, and 15.35 % of the total cropped area, respectively.

Table 4.1 summarizes the cropping pattern in the presently irrigated areas as follows:

- Cereal crops moved to a higher position in the cropping pattern. Total annual cropped area for the cereals crops collectively was about 46.18 % of total cropped area, constituting for 16.99 %, 13.58 %, 12.47 %, and 3.14 % for wheat, maize, rice, and sorghum, respectively. Wheat is the basic staple crop and farmers retained large proportions of it for food or animal feed. The wheat straw serves as animal forage in the summer season. Maize is also consumed by both humans and animals, while rice is an important staple food consumed mainly by farm households.
- Fodder crops: Clover (Egyptian Berseem) occupied the largest area of winter crops (short and long clover), which constituted 19.48 % of the average cropland. There is growing demand for livestock, which are fed on clover, corn, barley, and wheat, thus competing with humans for the scarce land resources. In addition, clover fixes soil nitrogen. Therefore, a reduction in its cropping area could have an adverse impact on soil fertility.
- Vegetables include mainly potatoes and tomatoes, and others. The collective area under vegetable crops represented 15.55 % of the total cropping area.

- The fibber crops, cotton and flax, constituted about 5.40 % and 0.10 % of the total cropland, respectively.
- The area under fruits accounted for 4.70 % of the total cropland.
- The shares for sugar crops including sugar cane and sugar beet were 2.57 % and 1.06 % of the total cropland, respectively.
- The total share of oil crops; peanut, sesame, soybean, and sunflower represented about 1.09 % of the total cropped area.

Table 4.1 Average Cropped Area by Crops in Egypt during 1999-2001

Crop Group	Area (in Feddan)	% Of the total
Cereals		**46.51**
Wheat	1,987,700	16.99
Barley	38,851	0.33
Maize	1,589,402	13.58
Rice	1, 458,984	12.47
Sorghum	367,494	3.14
Legumes		**2.21**
Beans	254,321	2.17
Lentils	4,809	0.04
Fibbers		**5.50**
Cotton	631,434	5.40
Flax	11,783	0.10
Oil Crops		**1.09**
Peanuts	42,506	0.36
Sesame	36,533	0.31
Soybeans	12,830	0.11
Sunflower	35,992	0.31
Sugar Crops		**3.63**
Sugar cane	300,650	2.57
Sugar beet	124,130	1.06
Vegetables and Onion	**1,234,132**	**15.55**
Fruits	**550,247**	**4.70**
Fodder Crops		**19.48**
Short Clover	570,679	4.88
Long Clover	1,708,370	14.60
Other Crops	**155,607**	**1.33**
Total Cropped Area	11,699,742	100

Source**:** Calculated Based on Data from CAPMAS, Irrigation and Water Resources Bulletin, Various Issues, 1999-2001.

4.3 Irrigation Water Requirements for Actual Cropping Pattern

4.3.1 Crop Water Requirements

The first phase in determining irrigation water requirements for planning purpose is the estimation and prediction of evapotranspiration (ET). Irrigation water requirements include net crop requirement (ET) and irrigation water lost to non beneficial uses during application. Allen *et al.,* 1998, define the ET concept as the quantity of water that should be applied to the crop in order to maximise the crop production. This quantity depends on many factors such as weather parameters, crop characteristics, and management and environmental factors. The irrigation water requirement can be estimated depending on the calculations from FAO (1992). The crop water requirement for a given crop during a month is:

$$ET_C = ET_0.K_C$$

where ET_C is the consumptive water use of crop, which changes from 1 to n for each month of the crop growth cycle; it represents the maximum evapotranspiration of a healthy crop, growing in large field under optimum agronomic and irrigation management.

ET_0 is the reference crop evapotranspiration during the month (mm/month), and

K_C is crop coefficient.

The Reference Crop Evapotranspiration (ET_0)

The effect of climate on crop water requirement is given by Evapotranspiration (ET_0), which measures the ability of the atmosphere to remove water from the surface through the evaporation and transpiration. The evaporation includes water evaporated directly from the soil and the plant. Transpiration includes water lost through the plant surface. Therefore, crop water need in different climatic zones is different. Grass has been used as the reference crop, so ET_0 represents the rate of evapotranspiration from an extended surface of an 8 to 15 cm tall covered by green grass that grows actively, completely shades the ground and, which is not short of water (Brouwer and Heibloem, 1986).

There are a number of empirical methods that have been developed and used to estimate evapotranspiration (ET_0) through either experimentation or theoretical calculations. Theoretical methods include calculations using measured climatic data, for example, Penman method by FAO, (1992). Another method is by Blaney and Criddle (1960's), who worked on the quantitative estimation of vegetation water usages. The Blaney-Criddle formula states that the consumptive use (ET_C) is equal to a seasonal coefficient (K_C) times a monthly consumptive use factor (ET_0). The monthly consumptive use factor (ET_0) is a function of the mean monthly temperature (T) times the monthly percent of day-time hours (P). For example, according to Blaney-Criddle method, the mathematical expression of consumptive water use is as follow (Brouwer and Heibloem, 1986):

$$ET_0 = P\ (0.46T+8.13)$$

where, ET_0 is reference crop evapotranspiration (mm/day) as an average for a period of 1 month, T is the mean daily temperature in °C, and P is the mean daily percentage of annual daylight hours.

Crop Factor (K_C)

Crop factor (K_C) is used to relate ET_C to ET_0. A crop requires different amount of water at different stages of its growth cycle. To account for the effects of crop characteristics, the (K_C) is a measure corresponding to the appropriate month of crop growth and crop type. Crop factor can be used in planning program of water, where the K_C value is an indicator of the degree to which a crop varies from the reference grass with respect to four primary characteristics that distinguish the crop from reference grass: crop height, canopy resistance, reflectance of the crop-soil surface, and the moisture evaporation rate from the soil, resulting in different ET_C levels in different types of crops under identical environmental conditions. The influence of these characteristics differs depending on the climate conditions; K_C is greater in an arid region and lower in humid region (Allen *et al.,* 1998).

Information on irrigation efficiency (IE) is necessary to be able to transform ET as a Net Irrigation Water Requirement (NIWR) into gross irrigation water requirement (GIWR) as:

$$GIWR = \sum_{t=1}^{n} \frac{NIWR(\mathrm{ETc})}{IE}$$

where, t various from 1 to n months of the plant life-cycle (Evans *et al.,* 2002).

The delivery losses are the sum of losses that occur during the application and the conveyance of water. Typically, these losses are aggregated as irrigation efficiency. For example, the irrigation system in Egypt with 70 % efficiency will only deliver 70 % of the pumped water to the plant. Multiplying gross irrigation requirement by the irrigated area gives the Total Irrigation Water Requirement TIWR for cropped area as follows:

$$TIWR = \sum_{t=1}^{n} \sum_{j=1}^{r} GIWR_{jt} . A_{jt}$$

where, the GIWR is the amount of irrigation water per unit of area for each crop j in month t, A is the cropped area of each crop j in month t.

Crop Water Requirements in Egypt

Irrigation water requirements are estimated by the Ministry of Agriculture taking into account the irrigation efficiency and the consumptive use requirements. They are based on field experiments conducted in several field research stations spread in every region of the country.

These research stations have been selected to represent the variation in climate, soil texture, crops, and agricultural and irrigation practices across the entire area of the country.

Crop Water Requirements used in the study were directly taken from government figures available and published by the Central Agency for Public Mobilization and Statistics (CAPMAS) in the Statistical Bulletin of Irrigation and Water Resources. According to CAPMAS (2002), the field crop water requirement is defined as the quantity of water that is actually applied for irrigating a unit crop area.

The available data on irrigation water requirement are available as annual figures, and it is assumed that these annual requirements can be allocated over the months of plant growth-cycle. For modelling purposes, the computations of monthly irrigation water requirements were carried out by multiplying the theoretical monthly percentage crop consumptive water use (Table 10 in the Appendix) by annual irrigation water requirement. The theoretical consumptive water use is compiled by Water Management Research Institute (WMRI) in Egypt.

Table 4.2 indicates that the average water consumption per irrigated Feddan at the different levels of water distribution namely; Aswan, Canal, and Field ranging from highest to lowest respectively. Crop water requirements per Feddan for a certain crop differ from one agro-climate zone to the other. Water consumption per Feddan is highest in Upper Egypt for all crops. A Feddan of wheat in Lower Egypt required about 1,464 m^3 water, increased to 1,621 m^3 and 2,008 m^3 in Middle and Upper Egypt, respectively. Irrigation needs for a Feddan of cotton were 2,863, 3,214, and 3,665 m^3 in Lower, Middle, and Upper Egypt, respectively. Maize in the Nili season required 2,067, 2,328, and 2,820 m^3 for Lower, Middle, and Upper regions, respectively.

Sugar cane and rice had the highest water consumption per Feddan. For sugar cane, its water requirement amounted to about 6,278 m^3 in Lower Egypt, 7,140 m^3 in Middle Egypt and 8,668 m^3 in Upper Egypt. It reached to about 5,521 m^3 for rice in Lower Egypt, and 7,085 m^3 in Middle Egypt, while in Upper Egypt there was no rice under cultivation. Generally, the irrigation requirements per unit area for a particular crop increased in Upper Egypt than in Middle Egypt while it was at minimum in Lower Egypt. This can be attributed to the variation in environmental factors and increase in temperature levels from north to south.

According to the level of irrigation requirements calculations (Aswan, Canals, and Field), irrigation requirement at Aswan is highest, as the canal is higher than the field. Water requirement for wheat of Lower Egypt was 1,684 m^3 and 2,034 m^3 at the heads of the canals and at Aswan, respectively. For wheat of Middle Egypt, it was 1,864 m^3 and 2,252 m^3 at the head of the canals, and Aswan, respectively. In Upper Egypt, the water requirement for wheat increased to 2,309 m^3 and 2,789 m^3 at the heads of the canals and Aswan, respectively. This is due to the water losses, which is called the conveyance efficiency for the transportation of water.

Table 4.2 Annual Water Requirement for Selected Crops at Different Levels (m^3/Feddan)

Location / Crop	At the Field			At the Canal			At Aswan		
	Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper
Winter Crops									
Wheat	1,464	1,621	2,008	1,684	1,864	2,309	2,034	2,252	2,789
Broad Bean	1,140	1,225	1,608	1,311	1,408	1,846	1,583	1,702	2,234
Barley	1,261	1,268	1,627	1,450	1,458	1,871	1,752	1,761	2,275
Fenugreek	1,140	1,225	1,608	1,311	1,408	1,849	1,583	1,702	2,234
Lupine	1,280	1,396	1,822	1,472	1,605	2,095	1,779	1,938	2,530
Chickpeas	1,228	1,320	1,733	1,412	1,518	1,998	1,705	1,833	2,406
Lentil	1,280	1,396	1,822	1,472	1,605	2,095	1,779	1,938	2,530
Short Clover	886	997	1,308	1,019	1,157	1,504	1,250	1,385	1,817
Long Clover	2,453	2,741	3,445	2,821	3,152	3,962	3,407	3,806	4,785
Flax	1,166	1,255	1,672	1,341	1,443	1,923	1,620	1,743	2,322
Onion	1,596	1,789	2,297	1,835	2,057	2,642	2,216	2,485	3,190
Sugar Beet	1,891	2,119	2,641	2,175	2,437	3,037	2,626	2,943	3,668
Garlic	1,163	1,418	1,825	1,337	1,631	2,099	1,615	1,970	2,534
Others	1,443	1,473	1,585	1,649	1,694	1,823	2,075	2,117	2,279
Vegetables	1,853	1,945	2,079	2,130	2,237	2,390	2,664	2,796	2,989
Summer Crops									
Cotton	2,863	3,214	3,665	3,292	3,696	4,251	3,977	4,465	5,090
Rice	5,521	7,085	7,729	6,349	8,148	8,962	9,202	10,028	10,931
Maize	2,525	2,899	3,311	2,904	3,334	3,808	3,507	4,027	4,599
Sorghum	2,130	2,551	2,933	2,450	2,933	3,373	3,063	3,544	4,074
Soybean	2,407	2,797	3,128	2,768	3,216	3,713	3,344	3,885	4,484
Sugar Cane	6,278	7,140	8,668	7,220	8,211	9,937	8,719	9,916	12,033
Sesame	2,170	2,502	2,886	2,496	2,877	3,318	3,014	3,471	4,008
Peanut	3,382	4,028	4,438	3,889	4,632	5,104	4,697	5,594	6,603
Sunflower	1,888	2,206	2,503	2,171	2,537	2,878	2,622	3,064	3,418
Others	2,149	2,270	2,519	2,471	2,611	2,897	2,830	3,145	3,494
Vegetables	2,580	3,032	3,468	2,967	3,486	3,988	3,583	4,211	4,816
Nili Crops									
Maize	2,067	2,328	2,820	2,377	2,677	3,243	2,872	3,234	3,917
Vegetables	2,218	2,479	3,157	2,550	2,850	3,630	3,080	3,444	4,385

Source: CAPMAS, Irrigation and Water Resources Bulletin, Various Issues, 1999-2001.

4.3.2 Irrigation Water Consumption Patterns

Demand for irrigation water is a function of the crop area and crop water requirement per Feddan. Therefore, the quantity of water used should be rationalised through these factors in crop production in order to keep the water balance in equilibrium. The irrigation requirements for the current cropping pattern at the field level is described in different agricultural seasons as a weighted average for the years 1999-2001, as shown in Table 9 in the Appendix. This reached about 34,642 million m^3, which was allocated to three season and fruits, and regions of Egypt. The following section discusses the water allocation patterns and their losses at the different seasonal and regional levels, in order to identify the most important crops and region to help the decision makers in determining the suitable solutions for optimal use of irrigation water in each region of Egypt.

4.3.2.1 Allocation Patterns of Irrigation Water Use

Table 4.3 shows the irrigation water use for major crops in the current cropping pattern according to the season of cultivation and also at the different three levels: the field, heads of the canals, and Aswan. The total water needs of summer crops was the highest, followed by winter crops and Nili crops, representing 59.47 %, 28.62 %, and 3.52 % of total irrigation demand, respectively. Fruits consumed about 8.39 % of the total irrigation water demand.

Winter Crops

Total area under winter crops was about 5.313 million Feddans, which was allocated to Lower, Middle, and Upper Egypt, representing 62.32 %, 20.56 %, and 14.20 % of the total cultivated area, respectively. The corresponding water use reached about 9,913 million m^3, which was allocated to Lower, Middle, and Upper Egypt in proportion of 60.80 %, 20.42 %, and 17.78 %, respectively. Long clover, wheat, vegetables, and short clover are considered the most water consuming crops in winter season, as the irrigation requirements for these crops reached about 4,496, 3,182, 761, and 533 million m^3, respectively, representing 45.36 %, 32.1 %, 7.68 %, and 5.38 % of the total irrigation requirements for winter crops, respectively.

Summer Crops

The area under summer crops amounted to 5.276 million Feddan and its annual water use reached about 20,601 million m^3. Total summer cropped area allocated to Lower, Middle, and Upper Egypt were 64.12 %, 17.98 %, and 17.90 %, respectively, and the corresponding irrigation use represented about 63.51 %, 14.82 %, and 21.67 % of the total irrigation requirements for summer crops, respectively. Rice, maize, sugar cane, cotton, and vegetables are considered the most water consuming crops in the summer season. The irrigation needs for these crops amounted to 8,097, 4,393, 2,543, 1,867, and 1,530 million m^3 of the water consumption respectively, representing about 39.30 %, 21.33 %, 12.34 %, 9.07 %, and 7.43 % of the total irrigation requirements for the summer crops, respectively.

Table 4.3 Average Irrigation Water Use and Water Losses by Agricultural Crops in Egypt during (1999-2001)

Level / Crop	Water Use at Aswan		Water Use at Tertiary		Water Use at Field		Water Losses at the Three Levels			
	Quantity (MCM)	%	Quantity (MCM)	%	Quantity (MCM)	%	Tertiary-Field	Aswan-Tertiary	Aswan-Field	% Aswan-Field
Wheat	4,421	8.78	3,660	9.19	3,182	9.19	478	761	1,239	7.90
Broad Bean	421	0.84	349	0.88	303	0.88	45	73	118	0.75
Short Clover	745	1.48	610	1.53	534	1.54	76	135	212	1.35
Long Clover	6,245	12.41	5,171	12.98	4,496	12.98	675	1,074	1,749	11.15
Vegetables	1,095	2.18	893	2.24	762	2.20	131	202	333	2.12
Winter Crops	13,818	27.46	11,418	28.66	9,913	28.62	1,504	2,400	3,904	24.90
Cotton	2,594	5.15	2,149	5.39	1,868	5.39	281	445	726	4.63
Rice	13,448	26.72	9,311	23.37	8,097	23.37	1,214	4,136	5,351	34.12
Maize	6,103	12.13	5,054	12.69	4,393	12.68	661	1,048	1,709	10.90
Sorghum	1,453	2.89	1,203	3.02	1,046	3.02	157	250	407	2.60
Sugar Cane	3,530	7.02	2,916	7.32	2,543	7.34	373	614	987	6.30
Vegetables	2,091	4.15	1,760	4.42	1,530	4.42	230	331	561	3.58
Summer Crops	30,777	61.16	23,681	59.44	20,602	59.47	3,080	7,097	10,177	64.88
Maize	890	1.77	737	1.85	641	1.85	97	153	250	1.59
Vegetables	570	1.13	472	1.18	410	1.18	61	98	160	1.02
Nili Crops	1,691	3.36	1,400	3.51	1,219	3.52	181	291	472	3.01
Fruits	4,039	8.03	3,344	8.39	2,908	8.39	436	695	1,131	7.21
Total Crops	50,325	100.00	39,843	100.00	34,642	100.00	5,201	10,483	15,684	100.00

Source: Data Calculated from CAPMAS, Irrigation and Water Resources Bulletin, Various Issues.

Nili Crops

Area under Nili crops was about 0.560 million Feddan: This was allocated to Lower, Middle, and Upper Egypt as 40.12 %, 48.92 %, and 10.96 % of the total cultivated area, respectively. The total irrigation requirements were about 1,219 million m^3 for Lower, Middle, and Upper Egypt, which constituted 36.79 %, 49.62 %, and 13.58 % of the total irrigation needs, respectively. Maize and vegetables were the most water consuming crops in the Nili season, consuming 280 and 170 million m^3, respectively. This represented about 50.10 % and 30.36 % of the total irrigation requirements for the Nili crops, respectively.

Fruits

The area under fruits amounted to about 0.550 million Feddan that was allocated to Lower, Middle, and Upper Egypt in ratios of 72.62 %, 19.63 %, and 7.75 % of the total cultivated area, respectively. Irrigation consumption for fruits reached about 2,908 million m^3, which was allocated to Lower, Middle, and Upper Egypt as 69.51 %, 20.44 %, and 10.05 % of the total irrigation requirements for fruits, respectively.

According to the above figures, rice represented the highest proportion of the total irrigation water consumption. It consumed about 8,097 million m^3 annually, representing 23.37 % of the total irrigation water demand in Egypt at the field level and this high water use was due to the high crop water requirement of rice. Long clover occupied the second position in water consumption using 4,496 million m^3 per year thus representing 12.98 % of the total water demand. Maize occupied the third position, consuming 4,393 million m^3 per year representing 12.68 % and followed by wheat, fruits, sugar cane, and cotton that represented 9.19 %, 8.39 %, 7.34 %, and 5.39 % of the total annual irrigation water demand, respectively.

It can be concluded that the major water consuming crops are rice, clover, maize, wheat, fruits, sugar cane, and cotton consuming about 79.34 % of the annual total irrigation water demand and other crops consumed the remaining about 20.66 % during the period.

4.3.2.2 Regional Allocation of Irrigation Water Use

Lower Egypt regions consumed most of the available irrigation water resources. This is shown in Table 4.4. The regions consumed about 21,582 million m^3, representing about 62.30 % of the total water demand (34,642 million m^3/year) at the field level. In this region, Dakahlia governorate was the largest water consuming governorate, its total irrigation water needs were 4,045 million m^3/year representing 11.68 % of the total annual irrigation water demand.

Table 4.4 Average of Irrigation Water Use and Water Losses by Agricultural Regions in Egypt during (1999-2001)

Level / Region	Water Use at Aswan		Water Use at Tertiary		Water Use at Field		Water Losses at the Three Levels			
	Quantity (MCM)	%	Quantity (MCM)	%	Quantity (MCM)	%	Tertiary-Field	Aswan-Tertiary	Aswan-Field	% Aswan-Field
Behaira	5,853	11.63	4,559	11.44	3,965	11.45	593	1,294	1,888	12.04
Dakahlia	6,293	12.50	4,651	11.67	4,045	11.68	606	1,642	2,248	14.33
Sharkia	5,763	11.45	4,445	11.16	3,866	11.16	579	1,318	1,897	12.10
Kafr Elshiekh	4,798	9.53	3,613	9.07	3,144	9.08	468	1,185	1,654	10.54
Gharbia	3,014	5.99	2,306	5.79	2,006	5.79	300	709	1,009	6.43
Menofia	2,064	4.10	1,708	4.29	1,485	4.29	223	356	579	3.69
Damietta	972	1.93	730	1.83	635	1.83	95	242	337	2.15
Ismailia	1,160	2.31	951	2.39	827	2.39	124	209	333	2.12
Lower Egypt	32,201	63.99	24,831	62.32	21,582	62.30	3,249	7,370	10,619	67.71
Giza	1,650	3.28	1,330	3.34	1,186	3.42	144	320	464	2.96
Beni Seuf	1,699	3.38	1,435	3.60	1,247	3.60	188	264	452	2.88
Fayoum	2,469	4.91	2,039	5.12	1,773	5.12	265	431	696	4.44
Menia	3,013	5.99	2,494	6.26	2,168	6.26	326	519	845	5.39
Middle Egypt	8,832	17.55	7,331	18.40	6,375	18.40	956	1,500	2,457	15.66
Assuit	2,475	4.92	2,049	5.14	1,781	5.14	268	426	695	4.43
Suhag	2,421	4.81	2,001	5.02	1,740	5.02	261	419	680	4.34
Qena	3,062	6.08	2,529	6.35	2,203	6.36	325	533	859	5.48
Aswan	1,335	2.65	1,102	2.77	960	2.77	142	233	375	2.39
Upper Egypt	9,293	18.47	7,681	19.28	6,685	19.30	996	1,612	2,608	16.63
Total Egypt	50,325	100.00	39,843	100.00	34,642	100.00	5,201	10,483	15,684	100.00

Source: Data Calculated from CAPMAS, Irrigation and Water Resources Bulletin, Various Issues.

The second largest governorate was EL-Behaira with an annual water consumption of 3,965 million m^3/year representing 11.45 % of the total irrigation water demand. El-Sharkia governorate was third followed by Kafr-EL-Sheikh and their irrigation needs were 3,866 and 3,144 million m^3/year accounting for 11.16 % and 9.08 % of the total irrigation needs respectively. Middle Egypt governorates consumed about 6,375 million m^3/year, representing 18.40 % of the total irrigation demand. EL-Menia governorate used about 2,168 million m^3/year representing 6.26 % of the total irrigation demand, occupying the fifth position in irrigation consumption.

Upper Egypt governorates consumed 6,685 million m^3/year, which was about 19.30 % of the total irrigation water demand. Qena consumed the larger portion of irrigation water, which was about 2,203 million m^3/year accounting for 6.36 % of the total irrigation demand. Gharbia, Fayoum, Assuit, and Suhag governorates consumed about 5.79 %, 5.12 %, 5.14 %, and 5.02 % of the total irrigation demand, respectively.

Based on the above studying, the ten major governorates mentioned above consumed about 77 % of the total irrigation demand during the period based on field water requirement. This indicates the extent of the demand for irrigation water in these governorates.

4.3.2.3 Regional and Seasonal Water Losses

Water productivity can be increased through reducing water losses. Water is lost through seepage from channels during conveyance and distribution stages. There are two stages in water losses, the first is distance between the water flow from Aswan High Dam to the canals, resulting from leakage and evaporation, which is difficult to control due to the high costs of technological requirements. The second stage is from tertiary canals to the field, which can be minimised.

Water losses from watercourses along the Nili between Aswan and the Mediterranean Sea are determined based on the average annual water losses, as shown in Tables 4.3, and 4.4. The total losses occurring are calculated about 15,684 million m^3/year from Aswan to the field level before applied to crops. The conveyance losses between Aswan and tertiary canals reached 10,483 million m^3/year and the total losses between the main canals and the fields amounted to 5,201 million m^3/year. Water losses from Aswan to the field level were estimated for the different regions of Lower, Middle, and Upper Egypt as 67.71 %, 15.66 %, and 16.63 % of the total water losses, respectively. The highest water losses were observed in Northern governorates of Dakahlia, Behaira, Sharika, Kafr El-Sheikh, and Gharbia. It is observed that these governorates constituted about 55 % of the total losses in the Lower Egypt.

As shown in Table 4.3, water losses are also determined by crops and the highest water losses occurred for rice, long clover, maize, wheat, fruits, sugar cane, and cotton. These losses values were 34.12 %, 11.15 %, 10.90 %, 7.90 %, 7.21 %, 6.30 %, and 4.63 % of total water losses, respectively. It is also observed that these crops constituted about 82.21 % of the total annual irrigation water losses in the Egyptian agriculture. The high losses are associated with the high water needs for these crops, but for rice water losses are high reflecting high crop water requirements and losses resulting from the flooding method, since flooding requires application much more water than is required to meet the crop water requirements. Studying the losses as mentioned is important, the major regions and crops that should be taken into account when designing water and agricultural policies to determine the optimal use of irrigation water.

4.4 Economic Analysis of Water Use in Crop Production

Many factors affect the farm decision made in relation to crop production and water use, as shown in Figure 4.1. In making land allocation decisions farmers take into account home food consumption needs, animal fodder requirements, their own cash income, and personal experiences related to expected water availability in the canal over time, and expected market prices.

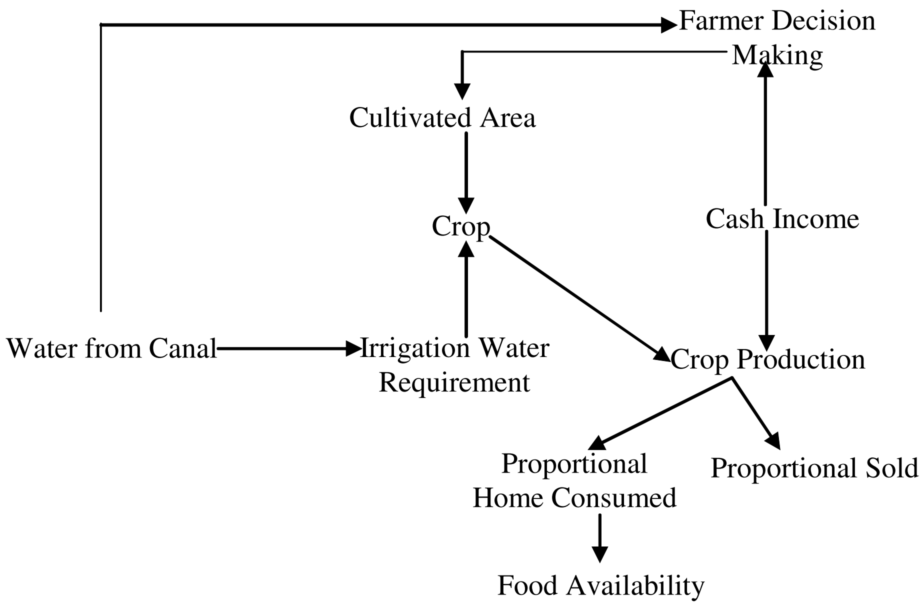


Figure 4.1 Framework of Factors Affecting the Farmer Decision

The most important factor influencing farm decision making is the generation of income from different activities. The farmers choose their crop production activities according to crop profitability. There are number of primary factors influencing the profitability, this include such as production costs, yields and prices received for the produced crop. Several economic parameters can be used to compare the relationship between costs and returns with crop production. The most commonly used measure is the gross margin. Therefore, this section highlights the gross margins of the main agricultural crops, in order to provide a comparison between these crops.

4.4.1 Gross Margin Analysis

Gross margin is an important measure of profitability and a management indicator allowing making of comparisons among alternative cropping patterns. It is useful for measuring returns over variable costs being in line with measuring economic profit and as a first step in the added value evaluation. Fixed costs however will not affect the farmer's decision in this planning horizon (one year for modelling purpose). In addition, the fixed costs may be difficult to calculate and allocate to individual projects. Therefore, gross margins will be used for modelling purpose, because it is a simple indicator and fixed costs remain the same, even if production is stopped.

Gross margins depend on inputs demonstrating the relative profitability of crops in order to make the best use of agricultural resources. Yield and prices are entered into a custom designed sheet in Microsoft Excel, based on the weighted average for the most recent three years (1999-2001) using real values. The effects of inflation have been removed using 2000 as the base year. Using the spread sheet the gross margin is calculated by crop and region in real value term. The crops chosen are the most widespread crops in each region.

The main components of gross margin are total return that is yield multiplied by the farm-gate prices minus total variable costs. The discussion of the gross margin provides guidance in dealing with interpreting the modelling results. It focuses on the national average of Egypt. The profitability of the crops can be delineated by comparison of their real gross margins to the scarce resources of land and water. Table 4.5 reports the profitability to scarce factors land in LE/Feddan and water in LE/1000M^3, in which gross margins per unit of land and water are calculated based on the farm gate prices.

Based on a simple national average, the most profitable crops in winter season were vegetables, with an average gross margin of 4,508.05 LE/Feddan and 2,457.46 LE/Feddan for winter tomatoes and winter squash. Also, gross margins for long clover and wheat were 2,896.43 LE/Feddan and 1,572.47 LE/Feddan, respectively. For the summer crops: vegetable crops were also the most profitable, with the gross margins of summer tomatoes and potatoes were 4,499.65 LE/Feddan and 3,857.31 LE/Feddan, respectively. Sugar cane was among the next most profitable crops for Upper Egypt, with a gross margin of 2,510.83 LE/Feddan. The gross margins were 1,509.60 LE/Feddan and 915.43 LE/Feddan for rice and maize, respectively.

Table 4.5 Average Real Gross Margins (GM) of Field Crops in Egypt, 1999-2001

Crops	Total Return	Variable Costs	GM of Land	GM of Water
Wheat	2,420.80	848.33	1,572.47	981.57
Barley	1,370.32	532.81	837.51	664.16
Broad Bean	1,633.36	728.41	904.95	564.89
Flax	1,740.57	837.34	903.23	623.37
Lentil	1,488.17	684.34	803.83	458.97
Chickpeas	1,912.73	784.13	1,128.60	600.01
Short Clover	1,624.86	193.43	1,431.43	1,530.66
Long Clover	3,252.89	356.46	2,896.43	1,100.35
Lupine	1,556.77	593.02	963.75	673.20
Sugar Beet	2,061.04	834.25	1,226.79	639.46
Fenugreek	1,372.71	537.56	835.15	598.95
Winter Tomatoes	6,626.47	2,118.42	4,508.05	2,366.50
Winter Squash	3,845.48	1,388.02	2,457.46	1,290.05
Green Peas	2,689.42	1,131.50	1,557.92	817.83
Winter Cabbage	3,446.09	1,179.45	2,266.64	1,189.87
Onion	2,589.26	1,561.85	1,027.41	575.87
Garlic	3,951.27	1,674.12	2,277.15	1,833.99
Cotton	2,279.92	1,182.49	1,097.43	371.02
Rice	2,531.54	1,021.94	1,509.60	272.01
Maize	2,189.46	1,274.03	915.43	331.17
Sugar Cane	4,744.72	2,233.89	2,510.83	296.88
Sorghum	1,696.95	711.82	985.13	346.08
Sesame	1,858.78	574.30	1,284.48	492.84
Summer Peanut	2,568.70	853.24	1,715.46	460.61
Soybean	1,228.48	758.04	470.44	168.28
Sunflower	929.07	571.55	357.52	189.36
Summer Tomatoes	6,659.40	2,159.75	4,499.65	1,644.60
Summer Potatoes	6,837.59	2,980.28	3,857.31	1,409.83
Summer Squash	3,432.48	1,297.36	2,135.12	780.38
Summer Cucumber	4,129.78	1,416.58	2,713.20	991.66
Summer Eggplant	3,899.45	1,552.72	2346.73	857.72
Nili Maize	1,636.54	856.79	779.75	341.72
Nili Tomatoes	4,519.33	1,874.30	2,645.03	1,097.16
Nili Potatoes	3,529.63	2,416.55	1,113.08	461.71
Nili Cabbage	3,190.05	1,232.75	1,957.30	811.89
Nili Dry Peas	4,094.35	873.76	3,220.59	1,335.90

Source: Calculated from MALR and CAPMAS.

With regard to water resources, the economic returns to water use were computed as gross margin per unit of water applied (1000 M^3). Water profitability for vegetables was higher than for wheat. The gross margin per unit of water for winter tomatoes reached 2,366.50 LE/1000M^3 while the gross margin for wheat was 981.57 LE/1000M^3. For the summer season, the gross margin for tomatoes (1,644.61 LE/1000M^3) was higher than for sugar cane (296.88 LE/1000 M^3) and rice (272.01 LE/1000M^3) due to the low water needs of vegetables compared to sugar cane and rice. This means that the adoption of a deficit water availability strategy is feasible for vegetable crops, but for rice and sugar cane, it is not economically advantageous to use reduced irrigation strategy.

From the above mentioned indicators, it is most profitable to grow vegetable crops whether in winter or summer season. For the field crops: wheat and clover are considered the most profitable crops from land and water standpoint. From standpoint of land, the most profitable crops in order are sugar cane, rice, and maize in summer, but these crops are not considered profitable from standpoint of water use.

Regional Differences in Gross Margins

Table 4.6 shows the relative profitability of the different crops by region. There are variations in gross margins of crops from region to region. There are many factors that could explain this variation in productivity. These factors can be divided into natural factors that are outside the farmer’s control, and factors within the farmer control. There are combined effects of different natural factors such as climatic conditions, soil type, and sea level in the north. Natural factors influence the productivity of crop in different regions that have different climate conditions.

There are differences in agro-climatic conditions with attributes of resource base for each region of Egypt. Temperatures increase from the north to the south increasing evaporation and salt accumulation. Other factors such as water quantity and its quality, irrigation and drainage facilities, and the incidence of pests also cause variations in productivity from region to region. These natural factors explain the differences in the productivity and the dominance of a crop in one region relative to others.

The differences in gross margins are also affected by the differences in land quality. In Egypt, there are different land fertility classes that influence productivity. Land classes are different from one region to another. Differences in the proprieties of the soil, such as available water capacity, hydraulic conductivity and differences in nutritional soil factor (PH and available plant nutrients), mean that a soil type is suitable for a one crop and not suitable for the other. For example, vegetables are sensitive to soil type. In addition, soil salinity and ground water depth cause differences in potential irrigation and drainage system.

The other factors are farmers related, such as farmer’s cropping experience and differences in cultural practices. For example, vegetables are more sensitive crops that need special practices, depending on farmer’s experience. In addition, most of the farmers irrigate their crops without having prior information about crop water needs. Another factor is what is is right planting time that could contribute to fluctuations in productivity.

Table 4.6 shows that the lowest gross margin was for Ismailia, Qena and Aswan for wheat 1,209.22, 1,228.27, and 1,248.73 LE/Fedddan, respectively. For Maize, the lowest return was in Aswan and Dakahlia representing 992.95 and 1,032 LE/Feddan, respectively.

Table 4.6 Gross Margins for Selected Crops by Region (LE/Feddan)

Crop Region	Wheat	Clover	Winter Tomatoes	Cotton	Maize	Rice	Summer Potatoes
Behaira	1,760.59	2,953.80	1,995.95	1,821.05	1,513.78	1,801.13	4,187.39
Gharbia	1,617.44	3,087.15		1,737.59	1,162.48	1,606.52	3,949.45
Kafr ElShiekh	1,584.42	2,895.68	3,125.56	1,369.84	1,325.53	1,422.35	
Dakahlia	1,421.07	2,720.24	2,541.23	1,175.07	1,032.01	1,381.54	4,611.95
Damietta	1,409.56		1,765.70	1,238.57	1,249.97	1,344.01	3,233.39
Sharkia	1,513.52	2,982.68	2,776.25	1,215.52	1,108.81	1,402.26	4,544.05
Ismailia	1,209.22		7,593.15		1,290.07	820.94	5,652.37
Menofia	1,603.98	2,967.26		1,674.12	1,487.19		3,140.39
Qalyoubia	1,658.26	3,130.96	3,641.09	1,271.28	1,341.10	1,701.34	4,097.83
Giza	1,884.70	3,202.42	4,262.99		1,220.75		3,732.35
Beni Seuf	1,678.63	2,627.62	2,596.26	1,270.20	1,024.68		3,147.04
Fayoum	1,559.80	2,702.60	2,901.37	1,299.75	1,231.14	1,435.53	
Menia	1,521.27	3,057.97	3,373.98	1,175.29	1,264.63		1,385.58
Assuit	1,676.64	2,942.43	4,979.33	1,337.97	1,130.80		4,401.37
Suhag	1,843.01	3,158.88	7,336.61	2,243.72	1,559.06		
Qena	1,228.27		7,612.26		1,105.06		
Aswan	1,248.73		5,383.88		992.95		

Source: Calculated from MALR and CAPMAS.

4.4.2 Economic Value of Water

This section assesses the economic value of a unit of water (1000 m^3) in crop production. By using the residual imputation method (Agudelo, 2001), the contribution of irrigation water unit as the monetary value of crop production can be determined. The method requires that all non-water factor inputs be deducted from the total value of produced crop. Net return per unit of water can be derived by using a production function with production factors: Capital (K), labor (L), land (R) and water (W). Assuming that the value of the marginal product of a production factor equals its price, and the total production value can be divided into shares, the economic value of water used in crop production can be computed by using the following equation:

$$NR_w = \left(TR - \left[(P_K\, Q_K) + (P_L\, Q_L) + (P_R\, Q_R)\right]\right) / Q_W .1000$$

where NR_w is the net return per unit of water 1000 m^3 (shadow price of water), TR is total return. P and Q are the prices and quantities of the non-water inputs, and Q_W is the quantity of water applied.

Net return per unit of water (1000 m^3) is useful for evaluating the economic performance of water use in crop production. It is computed by using the above economic measures, as shown in Table 4.7, providing a comparison of the economic value of water for each crop and region.

Table 4.7 Computed Economic Value of Water (LE/1000 m^3)

Crop / Region	Wheat	Long Clover	Winter Tomatoes	Cotton	Maize	Rice	Summer Potatoes	Sugar Cane
Behaira	835.57	989.64	1,000.00	385.90	465.56	248.74	1,077.33	
Gharbia	612.49	1,048.17		394.14	286.14	174.17	964.65	
Kafr ElShiek	692.80	1,039.01	1,499.01	234.46	327.73	187.93		
Dakahlia	658.92	818.46	1,257.09	227.83	299.97	155.61	1,125.29	
Damietta	647.66		785.64	236.71	330.65	182.60	782.75	
Sharkia	608.24	1,016.42	1,476.30	221.44	207.28	158.05	1,134.96	
Ismailia	550.92		4,437.75		365.27	98.16	1,474.89	
Menofia	672.92	986.61		306.28	434.88		727.06	
Qalyoubia	703.51	1,030.45	1,821.46	213.94	380.52	227.26	1,019.55	
Giza	708.80	951.98	1,822.13		304.40		1,130.70	
Beni Seuf	635.65	777.75	1,066.03	200.22	260.42		905.42	
Fayoum	667.20	819.71	1,252.48	226.07	318.63	310.26		
Menia	606.08	936.98	1,587.54	185.63	311.94		304.44	238.65
Assuit	542.44	704.43	2,163.92	215.26	309.57		1,191.17	
Suhag	663.43	765.34	3,245.89	427.28	391.58			234.06
Qena	388.82		3,514.06		318.45			207.49
Aswan	481.76		2,434.83		229.51			221.37

Source: Calculated from MALR and CAPMAS.

The net return per unit of water applied for vegetables reached the highest value generated from water use in crop production. It represented about 4,437.75 LE for winter tomatoes in Ismailia governorate. However, the net return per water unit decreased for rice to about 98 LE in the same region, and reached about 207.49 LE for sugar cane in Qena governorate.

The differences in water value are significant, providing a rational argument to decision makers for fostering a strategy to promote social welfare improvement via optimal water use. Each region cultivates the crops that make most efficient use of water. Both the farmer and the society would profit from reallocation of irrigation water resources to higher value crops. The economic principle that emphasises the marginal value of water be equal across all uses should be applied. In conclusion, it seems the application of the residual imputation methodology represents a successful way of approaching the problem of water evaluation in the short-term in light of the information available.

4.5 Conclusions

The descriptive analysis of cropping pattern and corresponding irrigation water use showed that:

- The crop water requirement per unit area varied, depending on the crop type and the level of measurement (Aswan, Tertiary, and Field level). Crop water requirements per unit of area were high in Upper Egypt than in Middle Egypt, and the latter was more than in Lower Egypt for the same crop, due to differences in the climatic conditions. The results indicated that the water used in the actual cropping pattern was 50,323, 39,843, and 34,642 million m^3 at the Aswan, Canal, and Field levels, respectively.
- The major water consuming crops are rice, long clover, maize, wheat, fruits, sugar cane, and cotton, which consumed about 79.34 % of the total annual irrigation water demand, the remainder of the crops consuming about 20.66 % of total average annual irrigation water use during the same period. Ten governorates (Dakahlia, Behaira, Sharika, Kafr El-Sheikh, Menia, Qena, Gharbia, Fayoum, Assuit, and Suhag) consumed about 77 % of the total irrigation demand, indicating the concentration of water demand.

Economic analysis showed that there are substantial differences in the total economic returns to the different crops grown in Egypt. It was indicated that water productivity in some regions is low due to the high water consumptive crops that have low value added. Based on this analysis, the following are the suggested strategies to achieve optimum use of water:

- Design an indicative cropping pattern for each region based on climatic conditions, soil characteristics, and water resources availability in order to maximise the net return per unit of land and water in crop production. Farmers should then be advised to follow the indicative cropping pattern.
- Minimise water losses by introducing new technologies for canal maintenance and weed control, improve the irrigation water distribution, and use of modern irrigation methods at the farm level.
- Enhancing the rational use of irrigation through water charging policies, agricultural policies, and improving the agronomic efficiency using modern agronomic practices.

CHAPTER 5

OPTIMISATION MODELS OF IRRIGATION WATER USE IN EGYPT

5.1 Introduction

Basic economic principles of profit maximisation can be used in solving water resources allocation problems faced by decision makers. Optimal use of an input occurs when the marginal value product equals the marginal input cost. In situations where different crops compete for limited resources, the optimum is achieved when the marginal net returns (shadow prices) are equalised for all crops. If marginal net returns are not equal, it is always possible to increase aggregate returns by transferring water from those crops with low marginal net returns to those with higher marginal net returns, thus allowing for resource reallocation. If an agricultural region has different soil types, similar theoretical economic principles can be applied to allocate water among soil types for each crop. Farm income is maximised only when an optimal level of irrigation consumption for each soil type has been attained and marginal productivity of water use is the same for all soil types. Efficiency requires that the marginal net returns for each use across all uses be equal.

Using mathematical optimisation techniques, irrigation planning is a process that simulates complex system of crop production in order to determine the most beneficial cropping patterns and water allocations. They are effective tools that enable irrigation planners to make sound decisions prior to each crop season. In determining the economically optimal patterns of crops and irrigation application, optimisation models in irrigation planning have been employed extensively. For example, Kheper and Chaturvedi (1982) applied a linear programming model to make decisions about options of groundwater management in conjunction with optimal cropping pattern and production functions of water. Panda *et al.* (1983) applied linear programming models for conjunctive use of surface and groundwater to canal command area of Punjab by adopting an optimal cropping. Further, to resolve the complex problem of irrigation management within a large heterogeneous basin, Paudyal and Gupta (1990) applied a multilevel optimisation technique. They determined the optimal cropping patterns in various sub-areas of the basin, the optimal design capacities of irrigation facilities, including surface and groundwater resources, and the optimal allocation policies of water for conjunctive use. Mainuddin *et al.* (1997) used an LP model to determine the cropping pattern to ensure optimal use of available land and water resources in a groundwater irrigation project.

The main objective of this chapter is to determine the optimal cropping pattern, among different alternatives, which satisfies the existing land and water availability constraints, as well as agronomic and economic conditions of crop production for each agricultural governorate of Egypt.

5.2 Methodology

Linear Programming (LP) is used to make decisions about irrigation water management options in conjunction with optimal cropping pattern to ensure optimal utilisation of available land and water resources in irrigation projects. The mathematical models are designed to maximise aggregate gross margin from crop production in each agricultural governorate of Egypt. Each model includes activities and constraints that characterise the nature of actual crop production in each governorate. The technical coefficients that quantify resource requirements are determined as a weighted average for real values of the most recently available three years (1999-2001), based on published and unpublished statistical data from MALR and CAPMAS.

The models determine the optimum allocation of the limited water resources among competing water use activities via optimal cropping patterns. The General Algebraic Modelling System (GAMS) is designed for modelling different optimisation problems (Brooke et al., 1998). It is preferred for this study because of its flexibility. The system is also especially useful for large-scale problems. GAMS language is formally similar to commonly used programming languages and hence it is especially easy to apply for modellers familiar with such language. Using GAMS, data are entered only once in familiar list and table form. Models are described in algebraic statements that are easy to read by modellers and the computer. Statements in the models can be reused without changing the algebra when other conditions of the same or related problems arise.

This program greatly facilitates sensitivity analysis. The modeller can program a model to solve for various values of an element and then generate an output report listing the solution characteristics. GAMS, also, allows the modeller to include explanatory text as part of the definition of any symbol or equation. Therefore, the models can be developed and documented simultaneously.

5.2.1 Cases of the Study

Considering the results of the preliminary assessment of the crop production and irrigation water use (see chapter 4), optimisation models are made at governorate level and Egypt as a whole. The environmental conditions such as soil factors and climate vary among agricultural regions of Egypt, so it is not possible to consider the environmental conditions as one coherent unit in the use of agricultural land. The environmental conditions influencing Lower Egypt zone differ widely from those affecting Middle and Upper Egypt zones. Because gross margins depend on a number of considerations including the productivity of land, the managerial capability of farmers, market prices, and cultural factors, productivity can vary widely between the governorates.

Moreover, the argument is related to the system of irrigation water allocation in the country. Irrigation requirements are calculated for each canal based on the cropping pattern, crop water requirements, cropped area, soil type and expected water losses. Monthly irrigation requirements for each canal are calculated and added to water needs by other sectors to obtain the total water requirements for each canal.

Topographically, Egypt is divided into 3 agro-climatic zones: Lower, Middle, and Upper Egypt. Each zone is characterised by its climate and consequently its crop consumptive uses, irrigation scheduling and drainage requirements, and planting time. Administratively, the country is divided into 26 governorates. This study considers only 17 governorates, which play an important role in crop production. Nine of these governorates are located in the Nile Delta (Lower Egypt: Damietta, Dakahlia, Sharkia, Qalyoubia, Kafr EL-Sheikh, Gharbia, Monoufia, Behaira, and Ismailia), four in the Middle Egypt (Giza, Beni Suef, Fayoum, and Menia), and four in Upper Egypt (Assiut, Souhag, Qena, and Aswan). Each governorate is characterised by a number of features:

- Definition of resources endowments (land and water) and cultivating time,
- A cropping system and traditional agricultural practices,
- Traditional farmers socio-economic and cultural characteristics, which in the models are assumed not to vary within each governorate, and that each farm type maximises it's return to land and water, and
- Regional prices, a specification of the product markets.

As a consequence, the computation process begins separately at the governorate level in the first stage and simultaneous in the next stage, assuming that productivity does not vary among farmers within the same governorate. According to these factors, the models specified for the study are described below.

5.2.2 The Structure of Quantitative Models

Pre-season planning includes a formulation of a plan on the cropping pattern for a season ahead. This plan is based on the expected available water resources, the climate conditions during the irrigation season, the projected market, and the extent to which the plan fulfils the objectives and policies of the system, assuming that they remain as currently observed. Irrigation planning models incorporating optimisation models can be used to help decision making on optimal water and area allocation. In optimal allocation of seasonal irrigation water volumes and area, the mathematical model includes the following components:

The Objective Function

The mathematical models are developed and applied for governorates level and global level, using linear programming. The models' objective function is to maximise producer welfare as measured by aggregate gross margins from crop production subject to limited land and water resources. The objective function Z is the total gross margins from all crops, to be maximised by selecting the optimal mix of crops subject to a set of constraints. It is assumed that the decision maker has perfect knowledge and that there is no risk. The gross margin is chosen, because the net return would require the calculation of some relatively difficult concepts such as return to management, capital and depreciation that do not affect the farm's short run decisions. In addition, maximisation of net return in the short run is equivalent to maximisation of gross margin. LP models are essentially static, allocating irrigation water in a single year among different users. The objective function for each level of mathematical analysis can be written as:

Governorate Level

$$Max\ Z = \sum_{j}^{r} (P_j Y_j - C_j) X_j \qquad \forall\, i = 1, \ldots 17$$

Global Level

$$Max\ Z = \sum_{i}^{n} \sum_{j}^{r} (P_{ij} Y_{ij} - C_{ij}) X_{ij}$$

where:

Z = the objective function value (LE),

n = the number of regions,

r = the number of crops within each region,

P_{ij} = vector of the unit price of crop j in region i (LE/ton), which are paid to the producer,

Y_{ij} = vector of yield per area unit (ton/Feddan=0.42 ha),

C_{ij} = vector of variable input costs per area unit (LE/Feddan), and

X_{ij} = vector of crop area under j crop in region i (a decision variable).

The yield is a function of the inputs, where it is assumed that the optimal level of water per Feddan and production costs are also function of inputs. The optimal number of Feddans of each crop depends on the total amount of water and the crop water requirement. Including the crop water requirement allows the decision maker to choose the optimal number of Feddans of each crop for which the optimal quantity of water will be applied. The maximisation of gross margin per unit of area is equivalent to the maximisation of gross margin per unit of water. This then determine the total quantity of water that will applied to a given crop. Thus $X_j = W^t / W_j$. Specifically, the decision maker's problem becomes;

Governorate Level

$$MaxZ = \sum_{j}^{r} (P_j Y_j - C_j) W^t / W_j \quad \forall i = 1,....17$$

Global Level

$$Max\, Z = \sum_{i}^{n} \sum_{j}^{r} (P_{ij} Y_{ij} - C_{ij}) W^t / W_{ij}$$

where

W_{ij} = crop water requirement in cubic meter/Feddan for crop j and region i in month m,

W^t = represents the total amount of water available for irrigation, and

All other variables are as defined above.

The Constraints

The maximisation process is constrained by the following series of linear constraints.

I- Land constraints

In a planning unit, the area allocated to different crops in any season is almost equal to the total cultivable area. The equation for the land constraints is of the form:

$$\sum_{j}^{r} \alpha_m X_j \leq A_{im} \quad \forall\, i = 1,...\,17\ ,$$

$$\alpha_m = (0\ or\ 1)$$

where X_j is the area of crop j, A_{im} represents the total area available in season m of a year for different crops in each governorate. The constraint means that the allocated land will be not more than the land used in a particular governorate.

This study considers only the old lands that are irrigated from the surface Nile water. The total available cropped areas in all agricultural governorates of Egypt for the modelling was about 9,723.05 thousand Feddans, representing about 83 % of the total cropped area in Egypt during (1999-2001). It is distributed over the 2 seasons of the year: 4,869.96 thousand Feddans for winter season and 4,830.50 thousand Feddans for summer and Nili seasons, representing land restrictions. Due to limitations of the data on fruits and other field crops that occupied an area of less than 1000 Feddan in each governorate, they are excluded from this study.

II- Water constraints

The model is based on a short run water constraint, in the sense that the quantity of water is fixed at any given time, and this quantity should be allocated among competing crops. In any month irrigation water demand of all crops should not exceed the water available in that particular month. Assuming that there is no recharge of water during irrigation season, irrigation water constraints can be written as:

Governorate Level:

$$\sum_{m}^{12} \sum_{j}^{r} W_{jm} X_{j} \leq \sum W_{im}^{t} \quad \forall\, i = 1,\dots 17$$

Global Level:

$$\sum_{m}^{12} \sum_{i}^{n} \sum_{j}^{r} W_{ijm} X_{ij} \leq \sum_{i}^{n} W_{m}^{t}$$

where W_{ijm} represents a matrix of the water requirement coefficients (m^3/Feddan) for crop j and region i in month m. W_{im} is a vector of the total amount of water resources available for irrigation in month m in the region i.

The total annual volume of water for the modelling amounted to about 28 billion m^3, accounting for 82 % of the total irrigation water used at the field level. It was distributed over the 12 months, representing monthly water constraints, after excluding the quantity of water resources available for crops that are not included in the models.

III- Labour constraints

According to the estimation of CAPMAS, there is a surplus in the agricultural labour, which reached about 36.70 % of the overall supply of the agricultural labour (Abdel-Fattah, 2002). Therefore, there is no labour constraint in this modelling, as Egypt is a labour abundant country. Labour costs are reflected in the objective function.

IV- Organisation constraints

To fulfil the high food demand, it is necessary to bring the cultivated area under lower and upper bounds of cultivation. These constraints are frequently needed for the sake of

maintaining commodity prices and to keep the market stability of crops. The suggested cropping pattern should ensure the supply of the minimum quantities of food commodities (cereals, sugar, and oils) and raw materials (cotton). To consider these factors and to prevent one high value crop from dominating the maximum benefits, maximum and minimum areas should be considered for each crop. The upper and lower limitations on corresponding acreage were based upon the maximum and minimum levels of historical cultivation over the period from 1997 to 2001 for each crop within each governorate. Because of the inability of the farmers to provide inputs like seeds, chemical and fertilizer to vegetable crops and the limited capacity of the market, the maximum areas were limited to 150 % of the existing areas under these crops. These organisation constraints can be expressed mathematically as follows:
For each region i

$$LB_j \leq X_j \leq UB_j$$

where X_j is the existing area under j crop (Feddan). UB_j is the maximum area of crop j during the study period. LB_j is the minimum area of crop j during the study period.

V- Non- negativity constraints

$$X_j \geq 0$$

The constraint states that the algorithm must not allocate negative amounts of land use in order to maximise the farm income.

The first two constraints are obligatory while the organisation constraints are optional; the planner can introduce them to take into account other non-explicitly defined limitations such as technical or market constraints.

Models Technical Coefficients

The input and output coefficients for crop production are specified for each unit of land, that is on Feddan basis. The technical coefficient matrix of the model is comprised of two basic categories. The first category represents the quantity of water resources required to produce a Feddan of crop. The values for these coefficients reside in their resource constraint equation. These resource constraint coefficients are monthly for irrigation water and seasonal for land resource. The other category is the per Feddan yield coefficients. These are captured in objective function converted into monetary output.

Assumptions of the Models

Beyond the assumptions of conventional linear programming model, the following assumptions are made for this study:

1. Farmers wish to maximise their cash income (gross margin), which is the objective of LP model, assuming that farmers are risk neutral,
2. All farmers located on one governorate are assumed to have identical production function except their accessibility to water,
3. The amount of water resources available for each governorate is known to farmers at the beginning of agricultural season,
4. The distribution of water resources is done on monthly basis and known for farmers, and
5. The prices of crops in the planning period remain as currently enacted.

Model Layout

At the first stage of development of the Irrigation Water Allocation Model (IWAM), the optimisation model is calculated under the actual policies and no additional actions are assumed to be taken in the future (Figure 5.1). The results will be compared to the current system and policy implications can be generated. This is taken as the basic situation to be compared with the results of other scenarios. The model also includes a simulation section at the second stage to generate new data inputs to be used in the optimisation section measuring the impact of different future irrigation policies on farm income, resource use, and crop production (see chapter 6).

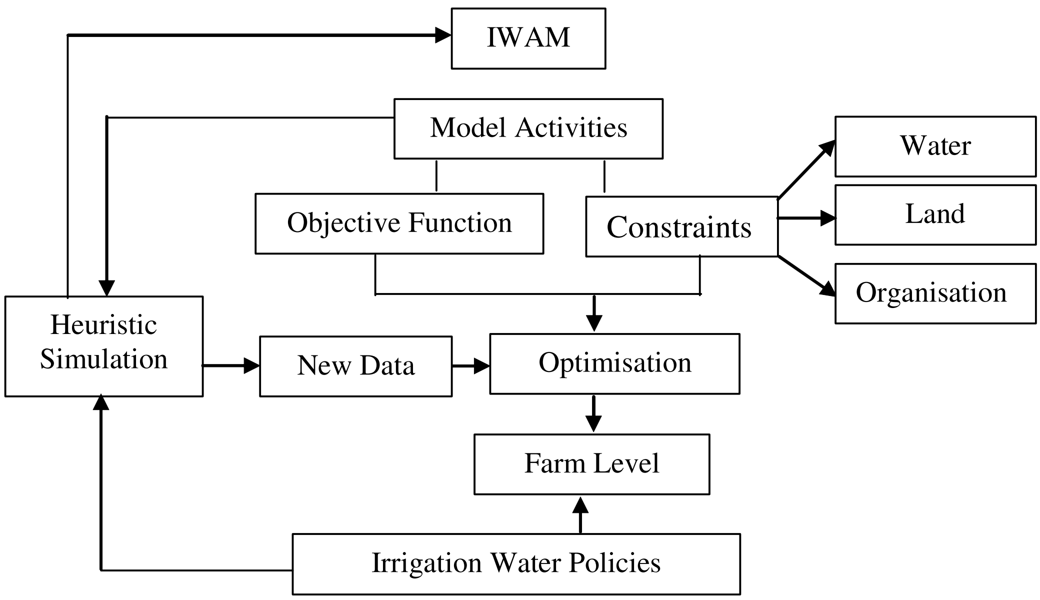


Figure 5.1 Representation of the Layout of IWAM Model

5.2.3 Data Needed for the Models

In order to solve for the above model, the data necessary including the crop water requirement as well as cost and price data were collected from the official statistical institutions as follows:

- The Ministry of Agriculture and Land Reclamation (MALR); Central Administration for Agricultural Economics and Statistics, Department of Statistics: (i) published data, in Annual Bulletin of Agricultural Economics, and (ii) unpublished data, regional data about Egypt's agricultural governorates,
- Ministry of Water Resources and Irrigation (MWRI); National Water Research Centre, Water Management Research Institute, WMRI, and
- Central Agency for Public Mobilisation and Statistics (CAPMAS); Annual Bulletin of Irrigation and Water Resources, various issues.

Data gathered on each crop include:

Crop Data

Cultivated Areas were taken from published statistical data compiled by MALR. And returns and costs (LE/Feddan) were obtained from unpublished statistical data compiled by Department of Statistics (Prices and Costs) MALR. Prices represent the farm-gate prices.

Water Data

Crop consumptive use was based on report from National Water Research Centre (Water Management Research Institute), MWRI, Cairo, Egypt. Real crop water requirements and irrigation water available were calculated based on published statistical data from Irrigation and Water Resources Bulletins compiled by CAPMAS.

5.3 Results and Discussion

In order to calibrate the model, the actual water allocation and cropping plans for the reference average of years (1999-2001) are compared with the results generated by the optimisation models. These results are gradually obtained in 4 stages (from Alternative No. 1 to alternative No. 4) in order to determine the impact of each policy alternative separately and the simultaneous affects under alternative No. 4. This is to show the optimal plan under different policies, as follows:

Alternative No. 1 (A_1) considers only land and water constraints that included 12 constraints of irrigation water resources, thus providing the impact of water constraints on the cropping patterns. It maximises total gross margins without constraints placed on the area planted to each crop within each region. This is an interesting alternative especially under agricultural liberalisation policy. A_1 is also intended to identify the magnitude of the possible crop reallocation and the advantage of each region in crop production under the existing situation. The liberalisation of crop production does not mean that the role of the state is belittled; rather, it means the state takes on more legitimate responsibilities, giving the private sector space to operate. Therefore, the following alternatives were selected placing constraints on the area of each crop.

Alternative No. 2 (A_2) differs from (A_1) by limiting the maximum area to be allocated to each crop. The upper limit on corresponding area was based on the maximum levels of historical cultivation over the period 1997 to 2001 in each governorate. A_2 is designed to prevent high value crop from dominating the maximum benefits providing maximum market capacity and avoiding the marketing problems that could be caused by huge increases in profitable crops in the A_1. For example, potatoes and tomatoes are required to be produced in quantities that processing facilities, marketing system in the vicinity of the production area are capable of handling without causing price distortions.

Under **Alternative No. 3** (A_3) a lower limit over the same period is placed on the area planted to each crop within each governorate. It resulted in permit all crops to come up in the solution, ensuring the minimum nutritional and industrial requirements.

Alternative No. 4 (A_4) considers simultaneous upper and lower limitations of the crop area over the same period within each governorate. This alternative was modified to suite the Egyptian conditions and to avoid deficiencies and marketing problems. The model under this alternative was to reproduce the farmers' decisions under free market reflecting the minimum and maximum production that may be produced. The use of this alternative is consistent with the short run nature of the model ensuring the minimum levels of crop diversity. The implementation of organisation constraints resulted in permitting all crops to come up in the solution, stabilise and secure farm income time round, and ensure the minimum nutritional and industrial requirements. Moreover, a change in the cropping pattern is relatively difficult in the short run. Farmers prefer plans that provide a satisfactory level of security even if it means sacrificing farm income on average.

The outputs of the optimisation models are shown in terms of percentage of actual values. The discussion will consider in details only A_1 and A_4, giving the maximum and minimum potential change, respectively. The maximum change is not achievable, while the minimum change is achievable in the short run. The results obtained for A_4 should be considered as a minimum change. The results of optimal solutions and the percentage changes are presented in Tables 5.1 to 5.18 at governorates level and at global level in Table 5.21, under the four policy alternatives.

5.3.1 Governorates Level

5.3.1.1 Optimal Cropping Pattern

Behaira Governorate

Table 5.1 presents model results on cropland under different policy alternatives. Under policy A1, most of the crops completely disappeared. The areas under winter onion and summer potatoes are the maximum imposed area for both crops. In winter season, the area under wheat increased by approximately 18.74 % above the actual cropped area. There was a huge increase in area under winter onion by about 3,716.80 % above the current area. In summer season, area under rice declined by 29.10 % while area under summer potatoes showed a huge increase of about 2,787.28 % above the existing area because of its high gross margins.

Table 5.1 Existing and Normative Cropping Patterns for Behaira Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	2,339	24.82	1.63	4.14	1.54
Total Water Used (MCM)	3,221	-18.48	-0.47	-0.55	-0.45
Winter Land Used (Feddan)	654,409	-3.45	-0.45	-0.25	0.00
Summer Land Used (Feddan)	587,670	-7.21	-0.28	-1.67	0.00
Cropping Pattern					
Wheat	213,104	18.74	6.69	-2.19	2.45
Long Clover	184,403	0.00	0.34	-3.79	0.51
Short Clover	164,526	84	2.05	7.39	2.05
Barley	5,884	0.00	-19.58	46.79	3.57
Broad Bean	55,147	0.00	-37.23	-13.68	-13.68
Winter Onion	1,993	3,716.80	0.00	-49.78	-49.78
Sugar Beet	2,738	0.00	0.00	-49.99	-49.99
Winter Tomatoes	9,783	0.00	26.27	-15.82	26.27
Winter Squash	4,058	0.00	21.20	272.21	21.20
Winter Green Peas	6,281	0.00	10.31	-42.72	-42.72
Winter Cabbage	6,492	0.00	16.19	-27.77	-9.15
Summer Maize	118,777	0.00	10.27	-10.87	10.27
Rice	219,939	-29.10	-2.10	2.16	-1.89
Peanut	5,565	0.00	25.38	39.16	25.38
Sunflower	5,153	0.00	0.00	-50.00	-50.00
Summer Potatoes	13,484	2,787.28	45.32	299.94	45.32
Summer Tomatoes	22,341	0.00	30.76	-4.85	30.76
Summer Eggplant	5,718	0.00	-50.00	-50.00	-50.00
Summer Squash	7,106	0.00	0.00	-50.00	-24.28
Summer Cucumber	4,191	0.00	9.53	-12.02	9.53
Nili Maize	17,893	0.00	29.04	-24.76	29.04
Nili Potatoes	4,150	0.00	0.00	-50.00	-50.00
Nili Tomatoes	4,331	0.00	0.00	-50.00	-50.00
Nili Cabbage	1,292	0.00	6.15	-6.47	6.15
Nili Dry Bean	10,276	0.00	37.94	-87.61	-7.47
Cotton	147,454	0.00	-4.59	-10.82	-10.82

Source: Mathematical Programming Models Results.

This alternative increased total gross margins by 24.82 % more than the actual total gross margins. Results on water consumption show that water surplus amounted to about 18.48 % of the total actual water used. Although there was a dramatic change in gross margin, this alternative is not logical practical. This change is unlikely in the short run, and can result in problems associated with nutritional and industrial requirements because maize, rice, and cotton crops totally disappeared in the summer season. A_1 gives an indicator about the area of some crops that should be cultivated more without intervention in areas showing the importance of organisation policies in the crop production.

An attempt was also made to examine the effect of upper and lower limitations separately represented in A_2 and A_3, respectively, as shown in Table 5.1. The solution of A_2 refers to the combinations of crops more than A_1. However, A_2 may not be logical practicable because the area under sugar beet disappeared and the industrial needs will not be supplied. A_3 permitted all crops to come up in the solution ensuring the minimum nutritional and industrial requirements. The total gross margins increased by 4.14 % above the actual total gross margins. This alternative is logical, if the increases in production of winter squash and summer potatoes are absorbed by the Alexandria market, which neighbours this governorate.

More reliability and market stability is shown under A_4 from Table 5.1. In winter season, the area under wheat increased by 2.45 % above the existing cropped area. Areas under broad beans and sugar beet decreased by 13.68 % and about 50 % below the actual cropped area, respectively, due to their low or lack of profitability. On the other hand, because of high profitability of vegetable crops, areas under winter tomatoes and squash recorded high increases representing about 26 % and 21 %, respectively.

In summer and Nili seasons, the areas under summer and Nili maize increased by 10.27 % and 29.04 % over their current areas, respectively. For rice this decreased by 1.89 % below the actual area grown to rice due to the low water requirements of maize compared to cotton and rice. Because of their high profitability, tomatoes and potatoes recorded sharp increases in the optimal solution at 45.32 % and 30.76 %, respectively. The area under cotton would decrease to its minimum level due to its low profitability relative to other summer crops such as potatoes and tomatoes.

Compared to A_1, the solution in A_4 indicates that all crops appeared in the normative cropping pattern resulting in the availability of the crop in the market thus maintaining stability of agricultural prices and nutritional requirements. Fallow lands disappeared. Therefore, this alternative is reasonable practicable.

The corresponding water allocation to crops indicates the shifts in water allocation through the areas reallocated to each crop. There is a small potential for water saving of about 0.45 % of the actual water used. The total gross margins increased by 1.54 % more than the actual total gross margins. There is a potential for increasing wheat self-sufficiency ratio through mixing whole-maize flour with wheat flour in the production of bread. A_4 also provides the proper area to cultivate forage required for animal production. Finally, the area grown under cotton could contribute to the minimum requirement of raw material used in industries and for export purpose.

Gharbia Governorate

The optimal cropping patterns for Gharbia are shown in Table 5.2. Regarding A_1, the area under wheat increased sharply by 83.84 % more than the actual area allocated to wheat in winter season. Area under long clover declined by 33.31 % since it consumes more water than wheat. In the summer season, the area under tomatoes would dramatically increase this could be as a result of high profitability. Areas under rice and Nili maize would decline by 32.52 % and 13.38 %, respectively. Other crops would not appear in this normative plan.

Table 5.2 Existing and Normative Cropping Patterns for Gharbia Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	1,148	40.60	2.93	10.60	1.85
Total Water Used (MCM)	1,797	-20.17	-0.88	-4.29	-0.29
Winter Land Used (Feddan)	311,777	0.00	-0.64	-0.64	0.00
Summer Land Used (Feddan)	308,904	-6.74	0.00	-1.62	0.00
Cropping Pattern					
Wheat	124,149	83.84	8.82	7.04	6.54
Long Clover	125,281	-33.31	0.38	-20.77	-2.62
Short Clover	23,092	0.00	79.56	60.83	29.94
Broad Bean	14,187	0.00	0.00	-18.72	-18.72
Flax	3,244	0.00	0.00	-49.26	-49.26
Winter Onion	8,326	0.00	-19.01	127.72	-27.00
Sugar Beet	6,790	0.00	0.00	-50.01	-50.01
Winter Green Peas	5,469	0.00	0.00	-29.17	-29.17
Winter Cabbage	1,239	0.00	0.00	-21.38	-21.38
Summer Maize	72,769	0.00	1.17	-25.22	-1.47
Rice	148,245	-32.52	-0.26	-6.14	0.54
Summer Potatoes	10,178	0.00	49.14	-10.59	49.14
Summer Tomatoes	1,905	8,595.54	49.76	2,130.66	49.76
Nili Maize	25,852	-13.38	-6.49	-16.08	-9.57
Nili Potatoes	2,078	0.00	0.00	-25.04	-25.04
Cotton	47,877	0.00	-5.55	-26.55	-5.61

Source: Mathematical Programming Models Results.

The total gross margins under this alternative would increase by about 40.60 % more than the actual values. The surplus in water resources reached about 20.17 % of the current water use. Despite the increase in gross margin, flax and cotton disappeared. On the other hand, there was a huge increase in tomatoes resulting in excess production.

With constraints imposed on upper cropped area A_2 as shown in Table 5.2, the areas under beans and flax disappeared. When lower limits are placed on each crop area (A_3), there is a huge increase in area cultivated to summer tomatoes. Although the total gross margins increased by 10.60 % under A_3, this alternative may not be logical because the huge increase in tomatoes production can not be absorbed by the market and also fallow lands appeared.

By comparing the existing cropping pattern with the normative cropping pattern under A_4 as shown in Table 5.2, it is observed that in winter season, area under wheat increased by 6.54 %. Whereas areas under long clover, broad bean, flax, onion, and sugar beet would decline by 2.62 %, 18.72 %, 49.26 %, 27.00 %, and 50.01 %, respectively. Similarly, in the summer season, areas under potatoes and tomatoes recorded sharp increases of 49.14 % and 49.76 %, respectively. Cultivated area under rice remained unchanged. Areas under Nili maize, Nili potatoes and cotton would decrease by 9.57 %, 25.04 %, and 5.61 % below the actual cropped areas, respectively. This may be attributed to more water consumption for these crops in relation to their gross margins. The fallow lands disappeared and optimal water use decreased by 0.29 % below the actual water use. The suggested cropping pattern gained an increase in total gross margins of 1.85 % through efficient allocation of water use along with other complementary inputs.

Kafr EL-Shiekh Governorate

Table 5.3 represents the normative cropping patterns in Kafr El-Shiekh. In the case of A_1, areas under long clover, barley, and sugar beet totally disappeared in winter season. The area under wheat showed a sharp increase of 83.82 %. Similarly, areas under broad bean and flax also increased. In summer season, area under rice declined by 36.81% whereas area under tomatoes increased dramatically by 3450 %. Areas under summer maize and cotton crops disappeared altogether. Total gross margins increased by 39.94 % above the actual total gross margins. Water saving was about 19.74 % of the actual water used.

As shown in Table 5.3, the area under flax disappeared under A_2 while cultivated area under summer tomatoes showed a sharp increase for A_3. Although the A_3 increased the total gross margins by 9.63 % compared to the actual total gross margins, this alternative may not be logical, because of the excess production in summer tomatoes.

Table 5.3 Existing and Normative Cropping Patterns for Kafr El-Shiekh Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	1,639	39.94	2.19	9.63	1.53
Total Water Used (MCM)	2,923	-19.74	-1.05	-5.62	-0.51
Winter Land Used (Feddan)	523,795	0.00	-2.29	-1.92	0.00
Summer Land Used (Feddan)	444,351	-1.53	0.00	0.00	0.00
Cropping Pattern					
Wheat	169,576	83.82	11.35	14.22	3.37
Long Clover	171,595	0.00	7.05	-20.33	1.58
Short Clover	62,514	-36.78	-15.30	-10.41	-9.70
Barley	5,116	0.00	0.00	-30.20	-30.20
Broad Bean	31,086	331.67	-12.89	115.67	-3.22
Flax	1,019	2,598.00	0.00	-17.40	-17.40
Sugar Beet	76,596	0.00	-33.87	-35.57	-2.48
Winter Tomatoes	6,293	72.60	35.99	4.25	35.99
Summer Maize	46,453	0.00	49.93	-31.41	46.63
Rice	279,927	-36.81	-1.90	-9.77	-1.76
Summer Tomatoes	7,342	3,450.00	49.84	848.95	49.84
Cotton	110,628	0.00	-19.46	-18.42	-18.42

Source: Mathematical Programming Models Results.

Generally, vegetables have very high variable costs, and liquidity constraints discourage the adoption of vegetables crops by most of the farmers. Results of A_4 indicate that the areas under wheat and long clover increased by 3.37 % and 1.58 % above the current areas, respectively, due to their high gross margins compared to other field crops. Also, winter tomatoes showed a sharp increase by 35.99 %. Similarly, in summer season, area under summer maize and tomatoes increased by 46.63 % and 49.84 %, respectively. However, rice and cotton crops declined by 1.76 % and 18.42 %, respectively, resulting from low water productivity for rice and cotton. This crop mix resulted in increase in the total gross margins of 1.53 % and water saving about 0.51 % compared to actual cropping pattern.

Dakahlia Governorate

The data in Table 5.4 shows the results of the mathematical analysis in Dakahlia governorate. Under A_1, long clover, which occupied a considerable area, would totally disappear. Similarly, the area under broad bean, flax, sugar beet, and green peas would not come up at all. On the other hand, area under wheat would increase by 14.16 %. Winter onion would increase dramatically by 2,497 % more than the actual area. In summer and Nili seasons, areas under summer maize, rice, summer tomatoes, Nili potatoes and cotton would totally disappear while summer potatoes would drastically increase to the maximum level. This crop mix may not be logical practical because strategic crops such as long clover, maize, rice, and cotton disappeared.

Table 5.4 Existing and Normative Cropping Patterns for Dakahlia Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	1,874	33.57	9.92	10.24	2.29
Total Water Used (MCM)	3,880	-45.53	-0.53	-15.92	-0.36
Winter Land Used (Feddan)	598,050	-8.15	-1.00	-7.52	0.00
Summer Land Used (Feddan)	613,160	0.00	0.00	0.00	0.00
Cropping Pattern					
Wheat	229,946	14.16	0.47	-8.64	-2.77
Long Clover	184,984	0.00	9.24	-16.25	7.93
Short Clover	72,027	136.15	4.06	17.75	4.06
Broad Bean	70,648	0.00	-4.78	-20.11	1.35
Flax	4,767	0.00	0.00	-49.42	-30.40
Winter Onion	4,494	2,497.00	5.60	457.46	5.60
Sugar Beet	19,751	0.00	0.00	-50.00	-50.00
Winter Green Peas	11,433	0.00	7.69	-10.87	-9.59
Summer Maize	55,753	0.00	23.95	-19.79	23.95
Rice	437,266	0.00	-0.84	-35.59	-0.82
Summer Potatoes	7,123	4,162.00	49.28	1,268.03	49.28
Summer Tomatoes	2,820	0.00	50.00	-40.25	50.00
Nili Maize	25,746	1,102.00	17.17	395.70	17.17
Nili Potatoes	2,614	0.00	0.00	-50.00	-50.00
Cotton	81,838	0.00	-20.03	-28.22	-21.72

Source: Mathematical Programming Models Results.

Regarding A_2, areas under flax and sugar beet disappeared in the solution, meaning industrial needs could not be supplied. Although policy A_3 resulted in an increase in total gross margins of 10.24 % above the actual total gross margins, this alternative may not be logical due to the excess in production of winter onion and summer potatoes.

Comparing A_4 with the actual situation, as shown in Table 5.4, the area under wheat decreased by 2.77 % in the winter season. Also, the area under sugar beet appeared at the minimum level due to lack of profitability, while the area under long clover increased by 7.93 % due to its high gross margin. In summer and Nili seasons, the areas under summer maize and Nili maize increased by 23.95 % and 17.17 %, respectively, above their existing areas because of their low water needs compared to other crops in the same season. The area under cotton appeared at minimum level due to its lack of profitability compared to vegetables and rice crops. From Table 5.4, the alternative saved water by about 0.36 % of the total water used. Also, the gross margin could increase by 2.29 % through the optimal use of water.

Damietta Governorate

The optimal cropping patterns in Damietta are depicted in Table 5.5. In case of physical constraints only, sugar beet and winter tomatoes disappeared altogether. While the area under broad bean and wheat increased by 132.25 % and 21.49 % above their existing area, respectively. In the summer season, the area under potatoes increased largely due to their high profitability. However, the area under tomatoes, Nili maize, and cotton crops did not come up at all. This could be explained by the effect of low land quality causing low productivity. Under this alternative the returns from fixed resources increased by 10.53 % through efficient allocation of limited water resources. It is not a logical practical alternative, because of the huge increase in potatoes production.

Table 5.5 Existing and Normative Cropping patterns for Damietta Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	292	10.53	1.96	3.43	1.92
Total Water Used (MCM)	561	-6.78	-0.52	-1.04	-0.22
Winter Land Used (Feddan)	94,497	0.00	0.00	0.00	0.00
Summer Land Used (Feddan)	80,128	-1.97	0.00	-1.25	0.00
Cropping Pattern					
Wheat	21,366	21.49	14.86	5.18	0.58
Long Clover	50,163	-22.98	0.25	-4.02	0.28
Short Clover	11,268	8.42	11.35	-2.19	-6.47
Broad Bean	7,617	132.25	-25.19	32.85	13.95
Sugar Beet	2,567	0.00	-84.02	-50.00	-20.81
Winter Tomatoes	1,516	0.00	-64.45	-4.16	-4.16
Summer Maize	3,009	0.00	56.00	-13.29	56.00
Rice	58,384	-8.57	-0.24	-0.92	-0.29
Summer Potatoes	1,135	2,119.84	38.45	486.33	38.45
Summer Tomatoes	1,685	0.00	49.97	-72.05	49.97
Nili Maize	2,451	0.00	-28.27	-45.49	-21.18
Cotton	13,464	0.00	-15.81	-18.66	-16.87

Source: Mathematical Programming Models Results.

With optimised plan A_2 as shown in Table 5.5, all of crops would appear. It is a logical policy alternative. Regarding policy A_3, the total gross margins increased by 3.43 % above the actual total gross margins, it can be suggested as one alternative for the governorate.

When upper and lower constraints are to be fulfilled A_4, area under broad bean would increase by 13.95 % due to its considerable profitability and low water needs. While, cultivated areas under short clover, sugar beet, and winter tomatoes decreased by ratios of 6.47 %, 20.81 %, and 4.16 %, respectively, less than their current areas. In the summer season, summer maize and tomatoes appeared at the maximum level due to the high profitability of tomatoes and low water needs for summer maize compared to cotton. Summer potatoes and tomatoes increased by 38.45 % and 49.97 % above their actual cropped area, respectively. However, areas under Nili maize and cotton declined by ratios of 21.18 % and 16.87 % below the actual cropped areas, respectively. The corresponding water use decreased by 0.22 %. The results showed that the returns from fixed resources could increase by 1.92 % through efficient water use along with other complementary inputs.

Sharkia Governorate

It can be seen from Table 5.6 that under A_1, most of crops in different seasons totally disappeared. In winter, the area under wheat decreased by 22 % below the actual area. There were huge increases in areas under winter onion and garlic by 8,348 % and 15,180 % above the existing areas, respectively. Similarly, area under lupine would dramatically increase by 2,272 % more than the existing area. In summer season, area under rice declined by 73 %.

Table 5.6 Existing and Normative Cropping Patterns for Sharkia Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	1,934	45.89	3.43	8.14	2.34
Total Water Used (MCM)	3,218	-36.00	-1.18	-3.52	-0.35
Winter Land Used (Feddan)	592,822	-6.80	0.00	0.00	0.00
Summer Land Used (Feddan)	561,062	-24.00	-0.53	-3.56	0.00
Cropping Pattern					
Wheat	246,352	-22.00	2.62	-1.83	-4.12
Long Clover	202,008	0.00	9.59	-5.40	5.07
Short Clover	65,407	0.00	35.69	-12.71	4.75
Barley	8,503	0.00	-57.11	-32.53	-32.53
Broad Bean	33,830	0.00	0.00	-8.73	-4.21
Flax	1,382	0.00	0.00	-31.32	-31.32
Winter Onion	1,523	8,348.00	0.00	-37.24	-37.24
Garlic	1,312	15,180.00	17.84	2,789.86	17.84
Sugar Beet	1,654	0.00	0.00	-21.46	-21.46
Winter Tomatoes	18,434	0.00	33.98	-9.04	33.94
Winter Squash	4,478	0.00	0.00	-19.17	-19.17
Winter Green Peas	3,832	0.00	0.00	-50.01	-50.01
Winter Cabbage	2,279	0.00	0.00	-28.57	-28.57
Lentil	520	0.00	0.00	-22.31	-22.31
Lupine	1,308	2,272.00	0.00	-45.26	-45.26
Summer Maize	185,076	0.00	28.07	-2.64	9.72
Rice	253,429	-73.00	-3.23	-5.59	-1.33
Peanut	5,165	0.00	0.00	-10.70	-10.70
Summer Potatoes	3,356	10,578.00	50.00	1,188.68	50.00
Summer Tomatoes	10,618	0.00	50.00	-3.49	50.00
Summer Eggplant	6,558	0.00	4.47	-38.74	4.47
Summer Squash	2,686	0.00	49.98	-4.14	49.98
Summer Cucumber	1,313	0.00	5.89	-40.50	5.89
Nili Maize	25,664	0.00	3.08	-50.37	3.51
Nili Potatoes	1,841	0.00	0.00	-50.03	-50.03
Nili Tomatoes	1,866	0.00	0.00	-50.00	-50.00
Nili Cabbage	829	0.00	0.00	-22.56	-22.56
Cotton	62,661	0.00	-73.35	-34.52	-34.52

Source: Mathematical Programming Models Results.

Summer potatoes showed a huge increase in cultivated area of 10,578 % more than the existing area. This alternative provided a tremendous increase in total gross margins amounting to 45.89 % above the actual total gross margins. The surplus in water resources was about 36 % of the actual total water used. The change is unlikely in the short run resulting in problems associated with marketing capacity due to excess production of onion, garlic, and potatoes. The minimum required industrial crops could not be supplied. However areas under flax and cotton disappeared.

Regarding A_2 as shown in Table 5.6, area under flax and sugar beet disappeared in the solution resulting in the industrial needs being not supplied. Although A_3 caused an increase in the total gross margins by 8.14 % above the actual total gross margins, this policy alternative may not be logical, because there is a huge increase in production of winter garlic and summer potatoes.

Comparing the existing plan with the A_4 as shown in Table 5.6, area under wheat would decrease by 4.12 % while cultivated area under long clover would increase by 5.07 % due to the high gross margin of long clover. Because of the high profitability of vegetable crops, area under winter tomatoes recorded a rapid increase, representing about 33.94 % more than the actual cropped area of winter tomatoes. From Table 5.6, the area under summer maize increased by 9.72 %. Areas under peanut and cotton decreased by 10.70 % and 34.52 %, respectively, due to lack of profitability compared to vegetables. Tomatoes and potatoes recorded sharp increases at the maximum level incorporated in the optimal solution of 50 % more than the existing area. Water surplus amounted to about 0.35 % of the actual total water used. Total gross margins increased by about 2.34 % above the actual total gross margins. It is obvious that water allocation between crops was inefficient in the existing plan.

Ismailia Governorate

As shown in Table 5.7, area under long clover under A_1 declined by 77.92 % below its existing area while area under barley and broad bean increased sharply by 349.23 % and 51.50 %, respectively. Area under wheat, squash, and green peas would disappear altogether. In summer season, area under potatoes would dramatically increase by 3,303 % above its actual cropped area. Area under other crops would not appear in the normative plan.

Total gross margins increased by 55.30 % more than the actual total gross margins. And water saving accounted for 36.08 % of the total actual water used. The results are unlikely in the short run resulting in problems associated with a huge increase in summer potatoes and then marketing surpluses and price variability.

When upper constraints are applied under A_2 total gross margins increased by about 15.70 % above the actual total gross margins and this policy may be achievable. Also, A_3 may be reliable depending on the market capacity for summer tomatoes produced.

Table 5.7 Existing and Normative Cropping Patterns for Ismailia Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	337	55.30	15.70	16.19	14.23
Total Water Used (MCM)	351	-36.08	-3.90	-7.67	-1.40
Winter Land Used (Feddan)	67,642	-65.32	-2.90	-10.44	0.00
Summer Land Used (Feddan)	81,127	-10.00	-1.20	0.00	0.00
Cropping Pattern					
Wheat	25,670	0.00	7.83	-1.37	2.51
Long Clover	22,074	-77.92	-12.38	-38.06	-12.23
Barley	2,796	349.23	0.00	124.99	-38.76
Broad Bean	2,699	51.50	0.00	-36.24	-36.24
Winter Tomatoes	10,899	-82.25	49.99	1.81	49.99
Winter Squash	2,476	0.00	5.63	-50.01	-49.20
Winter Green Peas	1,028	0.00	0.00	-10.94	-10.94
Summer Maize	36,687	0.00	17.74	-11.94	1.61
Rice	4,734	0.00	-61.17	-15.37	-15.33
Peanut	13,242	0.00	12.19	-39.72	-2.47
Sesame	6,434	0.00	0.00	-26.42	6.24
Summer Potatoes	2,144	3,303.00	49.98	-38.66	49.98
Summer Tomatoes	4,879	0.00	47.91	334.38	47.91
Summer Eggplant	1,870	0.00	-70.21	-3.74	-3.74
Summer Squash	1,882	0.00	9.80	-12.77	-12.77
Summer Cucumber	2,091	0.00	2.34	-1.43	1.91
Nili Maize	5,036	0.00	-45.67	-39.97	-39.97
Nili Tomatoes	2,128	0.00	19.93	-50.02	-50.02

Source: Mathematical Programming Models Results.

In comparison with the existing cropping pattern, the area under winter tomatoes would rapidly increase by 50 % under A_4 due to its high gross margin. Similarly, in the summer season, area under potatoes and tomatoes recorded sharp increases of 50 % and 47.91 %, respectively, because of their high returns. The area allocated to rice crop would decline by 15.33 % below the actual cropped area for rice. Optimal total water use declined by 1.40 % of the actual water used. It is observed that the farmers are not optimising their returns to agricultural resources. However the total gross margins could increase by 14.23 % in this governorate through efficient allocation of water use.

Menoufia Governorate

Table 5.8 represents the normative cropping patterns for Menoufia governorate. When there are no organised restrictions, area under wheat would decrease by 14.90 % less than the actual area in the winter season. However, the area under short clover would increase by 75.05 %

more than the current cropped area. The area under broad bean and green peas would disappear. In the summer season, the area under maize would decline by 5.72 % of its existing area while the area under summer potatoes would increase dramatically by about 550 % of the existing area. Area under Nili maize, Nili dry bean, and cotton crops would disappear altogether.

Table 5.8 Existing and Normative Cropping Patterns for Menoufia Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	1,020	5.80	2.66	2.74	2.20
Total Water Used (MCM)	1,189	-3.71	-0.37	-2.40	-0.27
Winter Land Used (Feddan)	263,369	-0.13	0.00	0.00	0.00
Summer Land Used (Feddan)	268,232	-1.80	0.00	-1.49	0.00
Cropping Pattern					
Wheat	88,273	-14.90	-10.17	-11.38	-8.90
Long Clover	137,087	-6.37	3.89	-5.37	2.80
Short Clover	34,013	75.05	22.46	56.49	16.02
Broad Bean	1,470	0.00	0.00	-35.85	-10.27
Winter Green Peas	2,526	0.00	0.00	-50.47	-50.47
Summer Maize	217,071	-5.72	0.85	-9.29	-0.21
Summer Potatoes	9,028	549.80	46.44	286.61	46.44
Nili Potatoes	9,204	0.00	-64.51	-50.00	-50.00
Nili Dry Bean	4,484	0.00	83.94	-60.93	65.28
Cotton	28,445	0.00	-14.67	-7.27	-7.27

Source: Mathematical Programming Models Results.

This alternative gained an increase in income of 5.80 % above the actual total gross margins, with water surplus of about 3.71 % of the actual water use. It may be logic practical ignoring the contribution of cotton to the minimum requirement for raw material and export.

Under A_2, the area under broad bean and green peas would disappear. This may be achievable. Also, the results under A_3 may be practical depending on market capacity for summer potatoes.

A comparison of existing cropping pattern with A_4 is shown in Table 5.8, the area under wheat recorded a decrease of 8.90 % while cultivated area under long clover increased by 2.80 %. In summer and Nili seasons, area under summer potatoes and Nili dry bean recorded a sharp increase of 46.44 % and 65.28 %, respectively, while area grown under cotton would decline by 7.27 % below their existing areas.

Total gross margins would increase by 2.20 % through efficient allocation of water with water saved being about 0.27 % of the actual water used. The suggested cropping pattern could contribute to minimum nutritional and raw material requirements. Area grown to long clover and short clover increased in the optimal solution resulting in increased soil fertility.

Qalyoubia Governorate

The details of normative plans for crop production in Qalyoubia governorate are shown in Table 5.9. Under A_1, in winter season, area under wheat decreased by about 7.66 % less than the actual cropped area. There was a huge increase in the cultivated area under broad bean of about 34,972 % more than the existing area. In the summer season, the area under summer maize declined by 67.63 %. Area under summer potatoes showed a huge increase of about 4,491 % more the existing area, because of its high return.

Total gross margins increased by 41.31 % above the actual total gross margins. In addition, water saving was about 25.98 % of the actual water used. The results are not logical practical because there is a huge increase in potatoes production and the area under cotton disappeared.

Regarding A_2 as shown in Table 5.9, the area under cotton disappeared in the solution resulting in the industrial needs being not supplied. Total gross margins increased by 4.95 % above the actual total gross margins under A_3. This could be a logical alternative because the market could absorb the increased production of winter squash and summer tomatoes because it is near Cairo Markets.

Table 5.9 Existing and Normative Cropping Patterns for Qalyoubia Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	506	41.31	3.89	4.95	2.77
Total Water Used (MCM)	621	-25.98	-1.29	-2.09	-0.44
Winter Land Used (Feddan)	130,023	0.00	0.00	0.00	0.00
Summer Land Used (Feddan)	124,848	-7.53	-0.64	-0.80	0.00
Cropping Pattern					
Wheat	42,672	-7.66	10.03	7.41	6.14
Long Clover	55,574	-86.85	4.23	-5.00	-1.52
Short Clover	12,978	122.58	1.01	-12.54	3.81
Broad Bean	1,513	34,972.00	14.47	285.13	-27.36
Winter Onion	7,425	0.00	-75.92	-49.71	-19.26
Winter Squash	1,232	0.00	49.98	365.62	49.98
Winter Green Peas	4,732	0.00	-69.51	-53.15	-50.04
Winter Cabbage	3,897	0.00	34.06	-38.16	34.06
Summer Maize	83,142	-67.63	9.53	-2.09	-0.05
Rice	20,075	0.00	-6.94	-10.19	-1.43
Summer Potatoes	1,928	4,491.00	49.97	-12.72	49.97
Summer Tomatoes	4,572	0.00	50.00	139.15	50.00
Summer Eggplant	2,973	0.00	4.32	-47.15	-47.15
Summer Squash	1,323	0.00	11.89	-25.91	11.89
Nili Cabbage	1,254	0.00	0.00	-7.50	-7.50
Cotton	9,581	0.00	0.00	-16.50	-16.50

Source: Mathematical Programming Models Results.

The normative cropping pattern related to A_4 is also shown in Table 5.9. In winter season, area under wheat would increase by 6.14 % above its existing cropped area. Cultivated area under winter onion decreased by 19.26 %. Area under summer maize remained unchanged. Tomatoes and potatoes recorded sharp increases at the maximum level incorporated in the optimal solution, while, the area under cotton, eggplant, and Nili cabbage would decrease. This crop mix resulted in water surplus of about 0.44 % of the actual water used and an increase in the total gross margins by 2.77 % above the actual total gross margins. The results of A_4 can help increase the wheat self-sufficiency ratio and contribute to the minimum requirement of raw material used in industries and for export purpose.

Giza Governorate

The normative cropping patterns for Giza are shown in Table 5.10. In winter season under A_1, area under wheat would increase by 181.77 % above its actual cropped area while area under long clover would decline by about 84 % below the existing area. Winter squash, green peas and cabbage would disappear altogether.

Table 5.10 Existing and Normative Cropping Patterns for Giza Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	591	54.77	9.25	10.71	7.01
Total Water Used (MCM)	662	-23.22	-0.25	-1.86	-0.50
Winter Land Used (Feddan)	116,230	0.00	0.00	-2.84	0.00
Summer Land Used (Feddan)	147,470	-23.58	0.00	0.00	0.00
Cropping Pattern					
Wheat	24,421	181.77	2.87	17.47	18.89
Long Clover	58,829	-84.26	-3.49	-7.84	-7.84
Short Clover	13,374	106.32	8.72	-7.58	-7.58
Winter Tomatoes	11,610	-8.98	50.09	-6.92	18.21
Winter Squash	3,152	0.00	0.00	-5.84	-5.84
Winter Green Peas	1,989	0.00	0.00	-10.88	-10.88
Winter Cabbage	2,855	0.00	-17.23	-24.48	-24.48
Summer Maize	68,056	0.00	-4.17	-8.09	-5.76
Peanut	4,559	0.00	15.32	-31.73	15.32
Sesame	1,687	0.00	-38.64	-77.06	22.61
Summer Potatoes	5,498	1,342.00	45.28	-7.92	45.28
Summer Tomatoes	9,368	0.00	36.60	105.34	36.60
Summer Eggplant	2,296	0.00	50.91	-12.06	-12.06
Summer Squash	2,493	0.00	0.00	-3.41	-3.41
Summer Sorghum	1,230	0.00	0.00	-19.65	-19.65
Summer Cucumber	4,444	0.00	21.23	-32.69	-25.92
Nili Maize	34,169	0.00	4.25	-9.51	-5.47
Nili Potatoes	5,113	0.00	0.00	-20.84	-20.84
Nili Tomatoes	6,919	382.75	29.24	76.67	29.24
Nili Cabbage	1,638	0.00	7.34	-25.31	-25.31

Source: Mathematical Programming Models Results.

In the summer season, the area under summer potatoes and Nili tomatoes would increase drastically by 1,342 % and 382.75 % more than their actual cropped area, respectively. Other summer crops would not appear in this normative plan. According to this alternative the total gross margins increased by 54.77 % more than the actual total gross margins, with water savings of about 23.22 % of total water used. This alternative ignored important crops such as maize and sorghum.

Under A_2, area under sorghum, which is an important crop, would disappear. It may be practical. Also, A_3 provided an increase in the total gross margins of 10.71 %, this alternative may be logical because the market could absorb this increase in production of summer tomatoes as it is near Cairo Markets.

Table 5.10 also compares the existing cropping pattern with the normative cropping pattern under A_4. Areas under wheat and winter tomatoes increased by 18.89 % and 18.21 %, respectively, because of their high profitability. Similarly, in the summer season, cultivated area under peanut and sesame recorded increases of 15.32 % and 22.61 %, respectively. Summer potatoes and tomatoes would increase by 45.28 % and 36.60 %, respectively, while eggplant, squash cucumber, Nili potatoes, and Nili cabbage crops could decline in the optimal plan. Total water used in this alternative would decrease by 0.50 % below the actual water used. Total gross margins of this cropping pattern represented 7.01 % above the actual total gross margins. This means farmers are not optimising their gross margins in this governorate.

Beni-Seuf Governorate

The details of normative plans for Beni-Seuf governorate is shown in Table 5.11. According to A_1, the area under wheat decreased by about 14.25 % less than the actual cropped area in the winter season. However, area under garlic would increase sharply by 243.03 % more than its existing cropped area. In summer season, area under tomatoes increased dramatically by 1,635.23 % more than its current area. Other summer crops would not appear in the solution. This alternative caused an increase of the total gross margins of 55.85 % more than the actual total gross margins. In addition, water saving was about 12.41 % of the total actual water used.

For A_2, area under cotton, which is an important crop, would disappear. Therefore, A_2 is not reasonable. Total gross margins under policy A_3 increased by 10.07 % above the actual total gross margins, this alternative may be logical, if the market capacity could absorb the increased production of summer tomatoes.

The normative cropping pattern related to A_4 is as shown in Table 5.11. In the winter season, the area under wheat would increase by 10.09 % more than the actual cropped area, because of the low water needs compared to long clover. Winter onion crop appeared at the minimum level in the solution at 50 % due to the lack of profitability. It is found that in the summer season, the area under summer maize and sesame increased by 19.70 % and 83.33 %, respectively, due to their low water needs compared to cotton. Tomatoes recorded a sharp increase at the maximum level incorporated in the optimal solution at 45.97 %. The potential for water saving was about 2.76 % of the actual water used. Under the alternative, the total gross margins for this cropping pattern increased by 4.11 % above the actual total gross margins. It can help to decrease the cereal food gap. The produced quantity of cotton could contribute to the minimum requirement for raw material.

Table 5.11 Existing and Normative Cropping Patterns for Beni-Seuf Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	647.99	55.85	7.31	10.07	4.11
Total Water Used (MCM)	1,046.41	-12.41	-3.63	-4.96	-2.76
Winter Land Used (Feddan)	202,166	0.00	-0.50	-2.66	0.00
Summer Land Used (Feddan)	235,331	41.96	-3.56	-2.13	0.00
Cropping Pattern					
Wheat	84,277	-14.25	-4.96	5.76	10.09
Long Clover	62,323	-10.91	30.75	-4.50	-3.98
Short Clover	30,279	67.50	-26.06	19.84	-8.97
Broad Bean	1,091	0.00	0.00	-47.59	-47.59
Winter Onion	9,145	0.00	0.00	-50.00	-50.00
Garlic	4,355	243.03	49.99	-50.01	49.99
Fenugreek	3,283	0.00	0.00	-50.02	-50.02
Winter Tomatoes	7,413	0.00	45.76	45.76	16.86
Summer Maize	107,748	0.00	36.91	-7.29	19.70
Cucumber	4,999	0.00	24.81	-16.68	24.81
Summer Tomatoes	7,871	1,635.23	45.97	305.03	45.97
Sesame	1,128	0.00	83.33	-50.00	83.33
Summer Peanut	1,730	0.00	0.00	-86.59	-86.59
Soybean	1,735	0.00	0.00	-50.03	-50.03
Summer Sorghum	2,381	0.00	0.00	311.35	-50.01
Sunflower	4,473	0.00	0.00	-46.39	-46.39
Nili Maize	65,194	0.00	-18.14	-17.18	-17.18
Nili Tomatoes	5,658	0.00	10.72	-44.65	-27.98
Cotton	32,414	0.00	0.00	-26.55	-26.55

Source: Mathematical Programming Models Results.

Fayoum Governorate

Table 5.12 shows the normative cropping patterns for Fayoum governorate. Under A_1, where water is the only constraint on crop production, the area under wheat, onion, and winter tomatoes would sharply increase by 33.58 %, 92.46 %, and 416.46 % of their actual cropped area, respectively, while the area under long clover would decrease by 28.99 % of its existing area. Other winter crops would disappear altogether. In summer season, the area under sesame and Nili tomatoes would dramatically increase by 4,040 % and 216.66 % of their current cropped areas, respectively. However, area under rice would decline by 66.27 % of the existing area. Other summer crops would not come up at all. There is a large increase in the total gross margins, reaching about 17.06 % above the actual total gross margins. Water saving was about 10.48 % of the actual water used.

With policy A_2 as shown in Table 5.12, the area under cotton would not come up in the solution, resulting in the industrial needs not being provided. Under A_3 the total gross margins increased by 8.72 % above the actual total gross margins, it may not be logical practical, because there is a dramatically increase in sesame production.

Table 5.12 Existing and Normative Cropping Patterns for Fayoum Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	867	17.06	7.10	8.72	5.95
Total Water Used (MCM)	1,326	-10.48	-1.80	-5.35	-0.27
Winter Land Used (Feddan)	323,752	0.00	-0.93	-2.16	0.00
Summer Land Used (Feddan)	205,279	0.00	-6.83	0.00	0.00
Cropping Pattern					
Wheat	145,625	33.58	-3.71	-2.24	-1.96
Long Clover	121,224	-28.99	17.32	-1.24	4.23
Short Clover	23,068	0.00	0.64	-12.44	0.46
Barley	9,723	0.00	0.00	-49.63	-49.63
Broad Bean	3,768	0.00	0.00	-24.42	-24.42
Fenugreek	2,575	0.00	0.00	-50.01	-50.01
Sugar Beet	2,015	0.00	0.00	-50.02	-50.02
Onion	5,603	92.46	0.00	200.12	17.21
Garlic	1,369	0.00	102.78	-27.03	102.78
Winter Tomatoes	6,267	416.46	49.99	-20.86	49.99
Cabbage	2,515	0.00	6.10	-47.76	6.10
Summer Maize	43,695	0.00	81.92	-53.87	77.71
Rice	26,564	-66.27	0.81	-25.69	-3.76
Sesame	3,679	4,040.00	31.54	1,411.96	31.54
Sunflower	9,740	0.00	0.00	-35.91	-35.91
Sorghum	48,581	0.00	-11.94	-50.00	-50.00
Cucumber	2,481	0.00	88.31	-50.02	-35.67
Nili Maize	31,913	0.00	-72.38	-50.00	-27.44
Nili Tomatoes	13,899	216.66	49.99	201.12	49.99
Nili Cabbage	2,147	0.00	35.38	-7.06	35.38
Cotton	22,580	0.00	0.00	-19.47	-19.47

Source: Mathematical Programming Models Results.

By comparing the existing cropping pattern with A_4, in the winter season, the area under wheat decreased by 1.96 % whereas the area under long clover would increase by 4.23 % due to its high water productivity relative to wheat. Fenugreek and sugar beet would appear at minimum level. In the summer season, the area under summer maize, sesame, and Nili tomatoes would rapidly increase by 77.71 %, 31.54 %, and 49.99 % of their current cropped area, respectively. However, areas under rice and cotton would decrease by 3.76 % and 19.47 %, respectively, above their actual area.

Total gross margins could increase by 5.95 % through efficient allocation of water along with other complementary inputs. The corresponding water used was less than the actual water used by 0.27 %. The results of A_4 can help to increase maize self-sufficiency ratio and agricultural exports through increases in the area allocated to onion, garlic, tomatoes, and potatoes.

Menia Governorate

In Menia governorate under A_1 (Table 5.13) wheat would decrease by 15.47 % while the area under long clover would increase by 7.21 %. Sugar beet increased largely by 161.76 %. Beans, garlic, and fenugreek did not come up at all. Similarly, for summer season the area under summer tomatoes increased sharply by 2,897.36 % above its current cropped area.

Table 5.13 Existing and Normative Cropping Patterns for Menia Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	1,146	41.48	7.02	8.48	4.42
Total Water Used (MCM)	1,811	-15.08	-1.39	-3.28	-1.04
Winter Land Used (Feddan)	335,534	-1.12	0.00	0.00	0.00
Summer Land Used (Feddan)	350,765	-10.07	-3.42	-1.71	0.00
Cropping Pattern					
Wheat	167,198	-15.47	-4.67	-3.93	-4.79
Long Clover	104,093	7.20	10.69	-2.82	6.47
Short Clover	10,555	397.28	41.00	113.35	-19.21
Broad Bean	12,388	0.00	0.00	-19.14	-19.14
Garlic	11,440	0.00	16.96	-21.76	-6.28
Fenugreek	7,183	0.00	100.45	-50.01	-50.00
Sugar Beet	10,069	161.76	33.76	76.46	43.00
Winter Tomatoes	12,608	0.00	44.88	-13.59	44.88
Summer Maize	225,804	-80.00	18.43	-13.65	5.92
Summer Potatoes	3,871	0.00	10.44	-16.64	-16.64
Summer Tomatoes	5,300	2,897.36	32.19	505.66	32.19
Sesame	5,898	88.95	39.00	291.05	5.09
Peanut	4,542	0.00	-4.78	28.64	-16.84
Soybean	10,037	0.00	0.00	-46.59	-26.66
Sunflower	5,412	0.00	0.00	-28.23	8.71
Summer Sorghum	8,380	0.00	-16.62	-16.62	-16.62
Nili Potatoes	15,841	0.00	0.00	-24.75	-8.58
Nili Tomatoes	1,685	0.00	0.00	-50.03	-50.03
Cotton	33,852	0.00	-50.68	-11.40	-11.40
Sugar Cane	30,143	0.00	0.50	-14.26	-14.26

Source: Mathematical Programming Models Results.

Also, the area under sesame crop showed an increase of 88.95 %. Other summer crops did not emerge at all. Although the total gross margins increased by 41.48 % above the actual total gross margins, with water saving of about 15.08 % of the actual water use. This alternative is not practicable because the important industrial crops of cotton and sugar cane totally disappeared.

With policy A_2, the total gross margins increased by 7.02 % above the actual total gross margins, this alternative may be logical. Under A_3 the total gross margins increased by 8.48 % more than the actual situation due to the expanding of the area under summer tomatoes, which would sharply increase by 505 % of the actual area allocated to summer tomatoes. This may not be practical.

Comparing A_4 with the actual situation, as shown in Table 5.13, the area under wheat decreased by 4.79 %. That for long clover showed an increase of 6.47 % more than the actual cropped area. Areas under sugar beet and winter tomatoes increased by 43.00 % and 44.88 %, respectively, above the existing cropped areas. Similarly, in the summer season, the area under summer maize and summer tomatoes recorded increases of 5.92 % and 32.19 %, respectively, because of their high returns to water.

Water saving was about 1.04 % of the actual water used. The increase of total gross margins represented about 4.42 % more than the actual total gross margins. The results of A_4 would increase maize and oil self-sufficiency ratios through increasing the area allocated to maize and sesame. And there is potential for increasing sugar production through increasing areas under sugar beet in the optimal solution.

Assuit Governorate

The optimal cropping patterns for Assuit governorate are given in Table 5.14. Under A_1, in the winter season, the area under wheat increased by 32.48 % above the existing area. Also, long clover and short clover crops increased by 5.72 % and 51.62 %, respectively. However, other winter crops did not come up at all. In the summer season, sesame, peanut, and summer tomatoes crops increased sharply by 1,507 %, 1,111 %, and 603 %, respectively, due to their high gross margins with respect to water.

Water surplus was about 5.30 % of the total actual water used. Under this alternative, it would be seen that the existing water allocation among crops was found to be inefficient and the farmers could increase their gross margins by 13.86 % through optimal allocation of water along with other complementary inputs.

With policy A_2, the total gross margins increased by about 5.39 % above the current situation. It may be a practical alternative. Also A_3 may be logical, where the total gross margins increased by 6.49 % above the actual total gross margins.

Regarding to A_4, in the winter season, the area under wheat increased by 8.50 %. Winter tomatoes increased sharply at the maximum level, which was 49.99 % above the actual area. The area under long clover would decline by 4.56 % due to the low water productivity compared to wheat. Other winter crops would appear at the minimum level. In the summer season, areas under sesame and cotton would sharply increase by 66.34 % and 20.81 %, respectively, while the area under other summer crops would decrease.

Table 5.14 Existing and Normative Cropping Patterns for Assuit Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	859	13.86	5.39	6.49	3.74
Total Water Used (MCM)	1,491	-5.30	-1.51	-0.62	-0.38
Winter Land Used (Feddan)	276,144	0.00	0.00	0.00	0.00
Summer Land Used (Feddan)	264,231	-12.39	-3.40	-0.75	0.00
Cropping Pattern					
Wheat	131,238	32.48	9.62	10.28	8.50
Long Clover	83,582	5.72	1.90	-2.18	-4.56
Short Clover	9,174	51.62	101.48	-3.01	-3.01
Broad Bean	18,287	0.00	0.00	-12.41	-12.41
Lentil	4,133	0.00	0.00	-7.39	-7.39
Chickpeas	16,574	0.00	-35.51	-38.99	-38.99
Onion	4,931	0.00	13.68	-43.44	-43.44
Winter Tomatoes	8,225	0.00	49.99	-2.63	49.99
Summer Maize	83,209	0.00	7.48	-14.68	-4.28
Sesame	3,917	1,507.00	66.34	132.16	66.34
Peanut	2,708	1,111.00	51.14	79.87	-14.59
Sunflower	9,419	0.00	0.00	-56.51	-56.51
Sorghum	132,202	-18.29	-7.62	-1.49	-0.98
Summer Tomatoes	3,942	603.46	49.96	248.51	49.96
Cotton	28,834	0.00	-5.31	3.46	20.81

Source: Mathematical Programming Models Results.

Total gross margins could increase by 3.74 % through efficient allocation of water. Water use decreased by 0.38 % of the total actual water used. The results of A_4 can help to decrease the food gap through increasing the area allocated to wheat and sesame. The produced quantity of sesame could contribute to increased oils production. Increasing the quantity of cotton could help to ensure the minimum requirement for raw material used for the industries.

Suhag Governorate

Table 5.15 presents the normative cropping patterns for Suhag governorate. From the results under A1, in the winter season, the areas under long clover and winter tomatoes increased by

26.43 % and 132.75 %, respectively. However, short clover, broad bean, and fenugreek did not come up at all. In the summer season, the area under maize decreased by 26.46 %, while the area under peanut and sesame increased. This crop mix increased farm income by 14.92 % more than the actual total gross margins. In addition, water saving was about 14.27 % of the total actual water use. It may not be practical because the important industrial crops cotton and sugar cane totally disappeared.

A_2 may be reliable, as most of crops would appear in the solution, with an increase in the total gross margins of 3.06 % above the existing income. Also, A3 is a logical cropping pattern with an increase of income about 2.45 % above the actual income.

Table 5.15 Existing and Normative Cropping Patterns for Suhag Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	1,049	14.92	2.45	3.06	2.28
Total Water Used (MCM)	1,591	-14.27	-0.35	-2.66	-0.43
Winter Land Used (Feddan)	266,167	0.00	0.00	0.00	0.00
Summer Land Used (Feddan)	272,663	0.00	0.00	0.00	0.00
Cropping Pattern					
Wheat	143,287	0.70	2.05	3.93	2.06
Long Clover	77,825	26.43	6.37	-6.33	-6.23
Short Clover	27,516	0.00	-36.93	-6.25	-6.25
Broad Bean	3,888	0.00	0.00	-37.97	-37.97
Fenugreek	1,022	0.00	0.00	-38.26	-38.26
Winter Tomatoes	10,088	132.75	50.00	34.51	50.00
Winter Onion	2,541	0.00	83.57	-23.72	17.37
Summer Maize	113,370	-26.46	9.15	-3.61	0.76
Peanut	3,759	231.28	77.39	23.09	-15.19
Sorghum	124,458	5.52	-4.61	-1.42	-2.66
Sesame	2,405	846.68	61.68	24.72	61.68
Cucumber	1,717	1,224.00	4.25	187.65	4.25
Cotton	6,840	0.00	61.32	41.31	45.52
Sugar Cane	20,114	0.00	-66.08	-8.21	-8.21

Source: Mathematical Programming Models Results.

Comparing the existing cropping pattern with the normative cropping pattern A_4 as shown in Table 5.15, it can be seen that in the winter season, the area under wheat increased by 2.06 % due to the high water productivity compared to long clover. However, long clover area decreased by 6.23 % below the actual cropped area. Winter tomatoes increased sharply to 50% above the existing area. However, the area under short clover, broad bean, and fenugreek declined by 6.25 %, 37.97 %, and 38.26 %, respectively.

Similarly, in the summer season, sesame would sharply increase by 61.68 % more than its actual cropped area. The area under cotton increased sharply by 45.52 % in the optimal situation due to the high land and water productivity of cotton in this governorate. The area under sorghum, and sugar cane would decline by 2.66 % and 8.21 %, respectively. Water surplus was a about 0.43 % of the actual water used. The total gross margins increased by 2.28 % more than the actual total gross margins. The results of A_4 contribute to the increase in the cereals and oils self-sufficiency ratios and agricultural exports.

Qena Governorate

In Qena governorate, the normative plans are shown in Table 5.16. Under A_1, the area under winter tomatoes increased sharply by 362.97 % more than its existing area in the winter season. However, the areas under other winter crops would disappear altogether. In the summer season, the area under sesame would dramatically increase by 2,266 % more than its actual area, because of its high return to water. Areas under maize and sugar cane would decline by 97.11 % and 44.63 %, respectively, and other crops would not appear.

Table 5.16 Existing and Normative Cropping Patterns for Qena Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	636	63.26	2.59	6.23	2.28
Total Water Used (MCM)	1,571	-17.02	-0.64	-1.80	-0.64
Winter Land Used (Feddan)	89,644	0.00	0.00	0.00	0.00
Summer Land Used (Feddan)	189,415	0.00	0.00	0.00	0.00
Cropping Pattern					
Wheat	65,425	0.00	-2.51	-0.33	-0.12
Barley	1,308	0.00	0.00	-50.00	-50.00
Broad Bean	1,509	0.00	0.00	-30.62	-30.62
Winter Tomatoes	19,363	362.97	33.55	12.13	11.42
Fenugreek	2,039	0.00	-50.02	-50.02	-50.02
Summer Maize	18,150	-97.11	37.33	0.03	-0.64
Summer Sorghum	22,032	0.00	-17.37	-2.72	-2.72
Sesame	4,599	2266.00	55.11	49.22	51.89
Sugar Cane	14,4634	-44.63	-3.79	-1.16	-1.15

Source: Mathematical Programming Models Results.

According to this alternative, the total gross margins increased by 63.26 % above the actual total gross margins. It saved also about 17.02 % of the current total water use. These results are unlikely in the short run resulting in problems associated with marketing, where there is a huge increase in produced winter tomatoes.

With constraints imposed on maximum area for each crop, total gross margins increased by 6.23 % above the current total gross margins. It is logical practicable, where, most of crops would appear in the solution and there is no fallow land. Also, under A_3, an increase in income of about 2.59 % above the actual total income was realised.

In comparison with the existing cropping pattern, the area under winter tomatoes increased by 11.42 % regarding A_4 due to its high profitability while area under other crops would decline.

In the summer season, area under sesame recorded a sharp increase of 51.89 % above the existing area, resulting from high water productivity. Total gross margins could increase by 2.28 % more than the existing gross margins, with water saving of about 0.64 % of the actual total water used.

Aswan Governorate

Table 5.17 shows the normative cropping patterns for the Aswan governorate. When there are no lower and upper restrictions on cropped area, in the winter season wheat, broad bean, and barley would totally disappear, while, the area under tomatoes would show a dramatic increase by 610.47 % more than the actual area. Similarly, in the summer season, the area under tomatoes increased sharply by 231 % because of high returns. It resulted in increased total gross margins by 233.66 % more than actual total gross margins. Water surplus was about 49.34 % of the current water use. The change may not be logical practicable because the dramatic increase in winter and summer tomatoes may result in marketing problems. In addition, sugar cane, which is the most important industrial crop for this governorate, would disappear.

With A_2 and A_3 the total gross margins increased by 6.23 % and 24.17 %, respectively, above the actual gross margins and there was no fallow land. These policy alternatives may also be reliable cropping patterns. This will depend on the market capacity for the summer tomatoes.

Table 5.17 Existing and Normative Cropping Patterns for Aswan Governorate

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	271	233.66	6.23	24.17	5.53
Total Water Used (MCM)	775	-49.34	-1.34	-4.47	-1.50
Winter Land Used (Feddan)	23,938	0.00	0.00	0.00	0.00
Summer Land Used (Feddan)	95,867	0.00	0.00	0.00	0.00
Cropping Pattern					
Wheat	17,716	0.00	6.59	-11.54	-8.15
Broad Bean	1,006	0.00	0.00	68.09	-8.45
Barley	1,847	0.00	0.00	-50.14	-8.45
Winter Tomatoes	3,369	610.47	50.00	67.81	50.00
Summer Maize	8,049	0.00	11.70	-12.68	6.68
Summer Sorghum	5,452	0.00	-14.09	-14.09	-14.09
Sesame	2,803	0.00	43.15	-14.92	43.15
Summer Tomatoes	2,480	3,666.00	49.94	366.19	49.94
Sugar Cane	77,083	0.00	-2.85	-8.92	-2.88

Source: Mathematical Programming Models Results.

When upper and lower constraints are imposed (A_4), the area under winter tomatoes recorded an increase at the maximum level in winter season whereas the area under other winter crops would decline. In the summer season, sesame and summer tomatoes increased sharply by

43.15 % and 50 % more than their actual cropped area, respectively. However, sorghum and sugar cane crops would decline by 14.09 % and 2.88 % less than their actual cropped area, respectively.

The total gross margins could increase by 5.53 % through efficient allocation of water, with water savings of about 1.50 % of the actual total water used. The results of A_4 can help to the increase oil self-sufficiency ratio through increasing sesame production. Moreover, the produced quantity of sugar cane could contribute to the minimum requirement of raw material used in sugar industries.

Total Egypt

To study the cropping pattern for Egypt as a whole, the aggregated results for the four policy alternatives from the above 17 models are reported in Table 5.18. Under A_1, area under wheat would increase by 12.51 % above its total existing area because it consumes less water compared to long clover. Area under long clover and sugar beet would sharply decrease by 56.62 % and 78.43 % less than their total current cropped area, respectively. There were huge increases in areas under winter onion and garlic by about 622.59 % and 1,113.08 % more than their total existing area, respectively.

In the summer season, the area under maize, rice, sorghum, and sugar cane would sharply decline by 75.75 %, 61.12 %, 30.57 %, and 70.56 % below their total cropped areas, respectively. They are more water consuming with respect to water needs. Area under cotton would not appear in the optimal solution while the areas under summer potatoes and tomatoes would increase dramatically by 2,282.67 % and 893.09 % above their total actual cropped area, respectively, due to their high gross margins.

According to this alternative (A_1), total gross margins increased by 37.05 % above the actual total gross margins. Water saving was about 22.82 % of the total actual water use. Although there is a dramatic change in total gross margins and water use, this alternative is not applicable due to problems associated with marketing and price variability. The market will be oversupplied with the huge increases in production of vegetable crops such as potatoes and tomatoes. The minimum required industrial crops would not be supplied, for example, the cotton crop disappeared resulting in the minimum requirements of cotton for raw material and export is not being assured.

An attempt was also made to examine the effect of upper and lower limitations separately under A_2 and A_3, respectively, as shown in Table 5.18. The solution under A_2 refers to the combinations of crops above A_1 including most of the crops, as a logic. Under this alternative, total gross margins increased by 4.11 % above the actual total gross margins.

Table 5.18 Existing and Normative Cropping Patterns for Total Egypt

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	17,151	37.05	4.11	7.60	3.01
Total Water Used (MCM)	28,029	-22.82	-1.21	-4.67	-0.59
Winter Land Used (Feddan)	4,869,967	-3.29	-1.19	-0.88	0.00
Summer Land Used (Feddan)	4,830,502	-8.91	-3.91	-1.31	0.00
Cropping Pattern					
Wheat	1,940,295	12.51	2.62	0.71	0.64
Long Clover	1,641,045	-56.62	6.73	-9.02	1.33
Short Clover	559,791	35.35	7.93	9.62	1.52
Barley	35,176	-64.30	-12.70	-12.70	-30.76
Broad Bean	260,134	-19.12	-47.57	2.23	-7.79
Flax	10,412	164.14	0.00	-35.12	-35.12
Onion	45,981	622.59	-48.79	64.89	-22.42
Garlic	18,476	1,113.08	31.16	194.42	20.39
Sugar Beet	122,180	-78.43	-88.22	-8.79	-12.31
Lentil	4,653	0.00	0.00	-9.05	-9.05
Lupine	1,308	2,273.09	0.00	-45.26	-45.26
Chickpeas	16,574	0.00	-38.99	-38.99	-38.99
Fenugreek	16,102	0.00	-93.67	-49.27	-49.27
Winter Tomatoes	125,868	53.17	40.44	3.70	33.12
Winter Squash	15,397	0.00	-39.06	86.21	-5.09
Winter Green Peas	37,290	0.00	-44.53	-30.99	-30.20
Winter Cabbage	19,277	0.00	-7.66	-31.68	-3.77
Summer Maize	1,486,818	-75.75	17.36	-11.67	8.77
Rice	1,448,564	-61.12	-1.82	-14.61	-1.22
Sorghum	344,716	-30.57	-51.34	-6.85	-9.60
Peanut	41,270	9.64	2.20	-5.44	-1.98
Sunflower	34,197	175.70	0.00	-43.86	-43.86
Sesame	32,550	1,307.87	13.80	224.76	39.51
Soybean	11,772	0.00	0.00	-47.09	-47.09
Summer Potatoes	57,745	2,282.67	44.78	347.59	43.56
Summer Tomatoes	85,123	893.09	41.85	236.54	41.85
Eggplant	19,415	0.00	-28.02	-36.82	-22.23
Summer Squash	15,490	0.00	-51.09	-30.57	-3.55
Summer Cucumber	21,236	7.05	23.41	-6.46	-2.66
Nili Maize	233,918	41.92	-11.86	20.02	-6.97
Nili Potatoes	40,841	0.00	-92.00	-35.29	-35.29
Nili Tomatoes	36,486	112.19	5.82	70.52	10.55
Nili Cabbage	7,160	0.00	-15.70	-13.00	2.00
Nili Dry Bean	14,760	0.00	51.92	-79.51	14.63
Cotton	626,468	0.00	-28.52	-18.03	-14.70
Sugar Cane	271,974	-70.56	-7.66	-9.61	-3.62

Source: Mathematical Programming Models Results.

A_3 permitted all crops to come up in the solution ensuring the minimum nutritional and industrial requirements. Also, this alternative may be logical, if the increases in production of winter garlic, summer potatoes, and summer tomatoes could be absorbed by the market. This plan gained an increase in total gross margins of 7.60 % compared to the actual total gross margins, with water saving of about 4.67 % of the actual water used.

A comparison of the existing situation with the optimal plan A_4 shown in Table 5.18 would reveal that in the winter season areas under wheat, long clover and garlic increased by 0.64 %, 1.33 %, and 20.39 %, respectively. In the summer season, the areas under maize and sesame would increase by 8.70 % and 39.51 %, respectively.

Due to their high profitability, tomatoes and potatoes recorded sharp increases at 41.85 % and 43.56 %, respectively, while the areas under rice, sorghum, cotton, and sugar cane would decline by 1.22 %, 9.60 %, 14.77 %, and 3.62 % below their total existing areas, respectively. Total gross margins could increase by 3.01 % above than the existing total gross margins in the country through efficient allocation of water use.

The suggested plan is A_4 because fallow land disappeared in all studied governorates, meaning an optimal use of land is attained. Moreover, the results under A_4 can help to increase the cereal self-sufficiency ratios when the area under wheat and maize crops are increased. Maize is considered both as a food and a fodder crop. It is also the major input in starch and maize oil industries. Similarly, the suggested cropping pattern also contributes to increased cooking oil self-sufficiency through increased area under sesame and maize. Also, it provides the required area to cultivate forage required for increasing animal production through increasing area under clover.

The total produced quantities of tomatoes in different seasons could be absorbed in the market, however the total quantities consumed and exported in year the 2000 was produced from 334.38 thousand Feddans in different seasons but in the model results this reached about 327.69 thousand Feddans. Similarly, consumed and exported quantities of potatoes in the year 2000 can be obtained from 117.81 thousand Feddans showing also a slight decrease from the normative area, which were about 147.17 in the model results. The increased portion can be exported to the world market.

Finally, the area grown to cotton is more than the total actual cropped area in the year 2000, which was about 518 thousand Feddans. This means that the produced quantities could contribute to the minimum requirement of raw material used in industries and for export purposes. Similarly, area under sugar cane decreased from 271.97 thousand Feddans to 262.14 thousand Feddans, producing about 13.14 million tons under the existing productivity. It is more than the minimum requirements for sugar processing plants that are about 9.9 million tons.

It can be seen that there has been a small change in the cropping pattern, which might have caused changes in income, marketing and price stability. This is the minimum change that could happen in the short run securing farm income through market and price stability. These changes in farm income resulting from reallocation of the agricultural resources, the changes values can be considered as net values. These changes do not require extra investments. Therefore, it is recommended that the cropping pattern suggested by A_4 be implemented in the short run.

5.3.1.2 Irrigation Water Surplus

The corresponding surplus water allocation in conjunction with optimal cropping patterns under A_4 is indicated in Table 5.19. It can be seen that there is no significant surplus that can be transferred between the governorates. This is primarily due to the scarcity of irrigation water. In Lower Egypt governorates, water is utilised in full in the months of April and November. In all other months, a small amount of water remained unutilised. In Middle, and Upper Egypt governorates, a small portion of water remained unutilised in all the months. But the water surplus was not significant enough to transfer between the governorates.

5.3.1.3 Marginal Productivities of Irrigation Water

Irrigation water is the critical input for food production development in Egypt. Knowledge regarding its marginal productivity is very important as it can guide the decision maker to make efficient adjustments in water resource allocations. Mathematical programming analysis using GAMS yields shadow prices, which are the marginal productivities of water. The shadow price is assigned a zero to the resource whose supply is not completely exhausted.

Marginal values provide information regarding changes in net income due to change in water supply under the assumption that other production factors are constant. However, in mathematical programming models, the marginal value of water is defined as the change in the value of objective function resulting from a unit change in the limiting water resources. Because the water resource constraints are defined on a monthly basis in this study, shadow prices of water reflect marginal return on water to the farmer in each month. Shadow prices of water vary by region and by month as shown in Table 5.20. The variations in water value over time and space indicate the effects of the existing water allocation and water policies. The shadow prices of water in all models occurred in the months of April, May, June, October, August, and November. April and November turned out to be the most critical months in all models. During these months, vegetable crops, wheat, broad bean, clover, cotton, and

Table 5.19 Monthly Surplus of Irrigation Water under Optimal Plan A4 for the Different Regions of Egypt, (MCM)

Region	Jan	Feb	March	April	May	June	July	August	September	October	November	December
Lower Egypt												
Behaira	0.00	0.12	2.27	0.00	1.06	0.00	3.01	0.00	6.35	0.95	0.00	0.83
Gharbia	0.53	0.07	1.51	0.00	1.27	0.00	0.00	0.77	0.00	0.70	0.00	0.33
Kafr-El-Shiekh	0.00	0.03	0.00	0.11	3.61	0.14	2.47	0.00	7.82	0.66	0.00	0.04
Dakahlia	0.09	0.38	0.74	0.00	3.16	4.59	0.99	0.00	4.13	0.00	0.00	0.00
Damietta	0.05	0.01	0.01	0.00	0.45	0.00	0.12	0.00	0.51	0.10	0.00	0.00
Sharkia	0.18	0.21	3.02	0.00	0.00	0.00	2.74	0.00	5.18	0.01	0.00	0.00
Ismailia	0.00	0.13	0.89	0.00	0.00	0.31	0.00	1.88	1.74	0.00	0.00	0.01
Menofia	0.27	0.25	0.00	0.00	0.00	0.28	0.39	0.67	0.54	0.52	0.00	0.33
Qalyobia	0.32	0.17	0.24	0.00	0.00	0.02	0.88	0.70	0.37	0.00	0.00	0.04
Middle Egypt												
Giza	0.19	0.49	0.00	0.25	1.11	0.00	0.31	0.40	0.33	0.14	0.00	0.10
Beni Seuf	1.01	1.40	0.00	1.10	0.00	7.70	0.00	2.67	0.31	0.00	14.10	0.41
Fayoum	0.00	0.76	0.65	0.00	0.00	0.00	0.00	0.14	2.01	0.00	0.03	0.06
Menia	1.39	2.15	2.37	0.00	0.32	0.00	0.00	0.67	1.37	1.33	0.00	9.12
Upper Egypt												
Assuit	0.05	1.00	0.31	0.00	0.00	2.49	4.05	0.00	0.35	0.08	0.00	0.25
Suhag	0.00	1.04	0.98	0.94	0.00	0.21	0.40	0.00	2.95	0.12	0.00	0.19
Qena	0.87	1.35	1.66	1.48	0.86	0.81	0.95	0.71	0.00	0.00	0.90	0.46
Aswan	0.93	1.36	1.74	2.40	1.23	0.52	1.01	1.30	0.79	0.01	0.00	0.40

Source: Mathematical Programming Models Results.

Table 5.20 Monthly Marginal Value Productivities of Irrigation Water under Optimal Plan A4 for the Different Regions of Egypt, (LE/m³)

Region	Jan	Feb	March	April	May	June	July	August	September	October	November	December
Lower Egypt												
Behaira	2.15	0.00	0.00	3.03	0.00	994	0.00	0.88	0.00	0.00	2.32	0.00
Gharbia	0.00	0.00	0.00	2.48	0.00	0.66	0.57	0.00	0.24	0.00	5.64	0.00
Kafr-El-Shiekh	0.50	0.00	3.45	0.00	0.00	0.00	0.00	0.09	0.00	0.00	6.84	0.00
Dakahlia	0.00	0.00	0.00	2.53	0.00	0.00	0.00	0.44	0.00	0.50	4.09	1.37
Damietta	0.00	0.00	0.00	1.56	0.00	0.78	0.00	0.65	0.00	0.00	3.86	3.45
Sharkia	0.00	0.00	0.00	0.73	2.12	0.00	1.34	0.69	0.00	0.00	0.69	6.06
Ismailia	0.00	0.00	0.00	2.13	0.44	0.00	0.00	0.00	0.00	2.51	6.21	0.00
Menofia	0.00	0.00	0.22	1.30	1.05	0.00	0.00	0.00	0.00	0.00	4.09	0.00
Qalyoubia	0.00	0.00	0.00	0.66	2.53	0.00	0.00	0.00	0.00	1.90	2.26	0.00
Middle Egypt												
Giza	0.0	0.00	3.45	0.00	0.00	2.09	0.00	0.00	0.00	0.39	8.36	0.00
Beni Seuf	0.0	0.00	1.02	0.00	1.47	0.36	0.00	0.00	1.53	0.83	2.62	3.97
Fayoum	1.67	0.00	0.00	0.29	2.16	0.15	0.50	0.00	0.00	0.48	0.00	0.00
Menia	0.00	0.00	0.00	2.20	0.00	0.09	0.99	0.00	0.00	0.00	1.18	0.00
Upper Egypt												
Assuit	0.00	0.00	0.00	0.51	1.06	0.00	0.00	0.93	0.00	0.00	2.42	0.00
Suhag	0.06	0.00	0.00	0.00	1.71	0.00	0.00	0.49	0.00	0.00	1.12	0.00
Qena	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.06	11.95	0.00	0.00
Aswan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.13	0.00

Source: Mathematical Programming Models Results.

sugar beet in the northern regions and sugar cane in the southern regions compete for water with each other. In June, rice begins to compete for water with cotton, vegetables, and sugar cane. High values of water occurred in June due the high crop water requirements for vegetables and rice in these months. In November, the prices are high because during this period production begins for winter crops such as wheat and clover. These crops occupy most of the cropped areas in winter season. In addition, high water requirement for winter vegetables occurs in November. The shadow prices showed an increasing tendency as water scarcity increased over time and space, especially in the Lower Egypt governorates.

The analysis of monthly scarcity values (shadow prices) helps in examining the possibilities of alternative schedules of water control and distribution. The current government policy of canal closure during February month is consistent with the mathematical programming results. The models results suggested that an appropriate time for winter closure in Egypt is February. Another important finding is that irrigation water in Egypt is a scarce resource limiting increases in food production. Increasing water supply through improving distribution efficiency of the irrigation system can be very beneficial.

5.3.2 Global Optimum

5.3.2.1 Optimal Cropping Patterns

Table 5.21 compares the existing cropping pattern to the normative cropping patterns for Egypt. It would be seen through global optimum and under A_1 that there were huge increases in areas under lupine, chickpeas, and winter tomatoes by about 5,929 %, 5,971 %, and 478 %, respectively, in the winter season. Also, the area under wheat increased by 50 % above the actual area allocated to wheat. However, the areas under long clover and short clover decreased by 95.49 % and 84.10 %, respectively. Other winter crops disappeared. In the summer season, the area under potatoes increased dramatically by 4,754.10 % above the existing cropped area while the area under tomatoes declined by 3.41 % below the actual area. Other crops would not appear in the normative plan. Although the total gross margins increased by 58.09 % with a huge water saving of about 38.06 % compared to actual cropping pattern. Thus, this alternative is not logical practicable because about 40 % of the actual land in the summer season was left fallowed, with an upper bound imposed on the crop area (A_2), the total gross margins increased by 6.71% above the actual total gross margins. It may be a reliable alternative. When lower bound is imposed (A_3), the total gross margins increased by 10.33 %. This alternative is not logical, because there were huge increases in areas allocated to lupine and chickpeas by 5,044.95 % and 669.25 %, respectively, in the winter season. Also, in the summer season, there was a dramatic increase in area under potatoes by 1,070.56 % compared to the actual situation. This excess could not be absorbed in the market.

Table 5.21 Existing and Normative Cropping Patterns for Egypt (Global Level)

Indicators	Existing Plan	Normative Plans			
		A_1	A_2	A_3	A_4
	Value	Δ %	Δ %	Δ %	Δ %
Total Gross Margins (MLE)	17,151	58.09	6.71	10.33	3.82
Total Water Used (MCM)	28,029	-38.06	-1.48	-7.75	-0.27
Winter Land Used (Feddan)	4,869,967	0.00	0.00	-0.63	0.00
Summer Land Used (Feddan)	4,830,502	-40.55	-1.17	-4.65	0.00
Cropping Pattern					
Wheat	1,940,295	50.61	-1.05	8.63	2.96
Long Clover	1,641,045	-95.49	23.84	-20.40	5.07
Short Clover	559,791	-84.10	-3.10	-13.13	-9.85
Barley	35,176	0.00	0.00	-26.81	-26.81
Broad Bean	260,134	0.00	-87.03	-16.22	-16.22
Flax	10412	0.00	0.00	-43.88	-43.88
Onion	45,981	0.00	-42.45	-43.86	-43.86
Garlic	18,476	0.00	35.73	547.88	-28.34
Sugar Beet	122,180	0.00	-85.78	-49.01	-39.28
Lentil	4,653	0.00	0.00	-9.05	-9.05
Lupine	1,308	5,928.75	0.00	5,044.95	-45.26
Chickpeas	16,574	5,971.79	0.00	669.25	12.12
Fenugreek	16,102	0.00	0.00	-38.99	-20.90
Winter Tomatoes	125,868	478.49	50.00	75.24	50.00
Winter Squash	15,397	0.00	23.21	-16.47	-16.47
Winter Green Peas	37,290	0.00	17.22	-21.60	-21.60
Winter Cabbage	19,277	0.00	10.76	-30.64	-30.64
Summer Maize	1,486,818	0.00	31.43	-15.87	11.39
Rice	1,448,564	0.00	0.03	-22.85	-1.23
Sorghum	344,716	0.00	-18.55	-19.76	-12.97
Peanut	41,270	0.00	27.02	-38.04	27.02
Sunflower	34,197	0.00	0.00	-30.26	-30.26
Sesame	32,550	0.00	9.44	-25.43	23.98
Soybean	11,772	0.00	0.00	-31.01	-31.01
Summer Potatoes	57,745	4,754.10	46.90	1,070.65	46.90
Summer Tomatoes	85,123	-3.41	43.52	74.11	43.52
Eggplant	19,415	0.00	27.31	-20.15	-19.38
Summer Squash	15,490	0.00	17.74	-15.84	-15.84
Summer Cucumber	21,236	0.00	14.00	-18.37	14.00
Nili Maize	233,918	0.00	-45.30	-25.76	-25.76
Nili Potatoes	40,841	0.00	-92.44	-18.20	-18.20
Nili Tomatoes	36,486	0.00	47.17	-34.54	30.45
Nili Cabbage	7,160	0.00	11.08	-13.00	-13.00
Nili Dry Bean	14,760	0.00	65.43	-79.51	65.43
Cotton	626,468	0.00	-40.84	-17.84	-17.84
Sugar Cane	271,974	0.00	-47.13	-5.33	-5.33

Source: Mathematical Programming Models Results.

Results of A_4 indicate that the area under wheat and long clover increased by 2.96 % and 5.07 %, respectively, in the winter season. Also, winter tomatoes and chickpeas increased by 50 % and 12.12 % more than the existing area, respectively.

Similarly, for the summer season, the area under summer maize increased by 11.39 %, while rice declined slightly by 1.23 % below its actual cropped area. Due to their high profitability, potatoes and tomatoes recorded sharp increases at 46.90 % and 43.52 %, respectively. It would be interesting to note that the area under peanut and sesame increased by 27.02 % and 23.98 % above their actual cropped areas, respectively. However, sunflower crops declined by 30.26 % due to lack of profitability. Although the area under cotton decreased by 17.84 % this quantity produced would ensure the minimum requirements of raw material used for industrial and export purpose, since the optimal area is higher than the existing area for the year 2000. Similarly, the area under sugar cane declined by 5.33 % below the actual area grown to sugar cane during the study period, representing about 13 million tons under the actual productivity. This is more than the minimum requirements for sugar processing plants, which are about 9.9 million tons.

Results of A_4 can help to increase cereal self-sufficiency ratios through mixing whole-maize flour (20 %) with wheat flour (80 %) in the production of bread where areas of both crops increased. Moreover, maize is considered a food and fodder crop. It is also a major input in starch and maize oil industries. Similarly, this suggested cropping pattern can contribute to increase cooking oils self-sufficiency through increasing areas under peanut and sesame. It can also contribute to employment absorbing a large portion of rural work force during the growing seasons for maize, vegetables, and cotton. Also, the model provides the appropriate area to cultivate the forage required for increasing animal production by increasing the area under clover. The produced quantities of tomatoes and potatoes in different seasons could be absorbed in the market. Finally, the area grown under cotton could contribute to the minimum requirement of raw material used in industries and for export purpose.

There is insignificant potential for water saving under the actual level of irrigation system development. However, water saving was about 0.27 % of the actual water used constituting about 28,028.98 million m^3. Total gross margins could increase by 3.82 % through efficient allocation of water use along with other complementary inputs. From the above normative cropping patterns, it is clear that water allocation among crops is inefficient and the farmers are not optimising their returns to the agricultural resources.

5.3.2.2 Marginal Productivities of Irrigation Water

At the global level, the shadow prices of water reflect marginal returns of water to the farmer in each month under policy A_4, as shown in Table 5.22. The highest shadow prices for water occurred in the months of April and November. These months turned out to be the most critical months in the optimal situation. In addition a unit of water (1000 m³) would increase the total farm income by 2,070 LE in April and 4,320 in November, as shown in Table 5.22.

Table 5.22 Monthly Marginal Value Productivities of Irrigation Water for Egypt (Global Level)

Month	Value (LE/m^3)	Month	Value (LE/m^3)
Jan.	0.00	Jul.	0.14
Feb.	0.00	Aug.	0.00
Mar.	0.00	Sep.	0.00
Apr.	2.07	Oct.	0.87
May.	0.00	Nov.	4.32
Jun.	0.64	Dec.	0.24

Source: Mathematical Programming Models Results.

During these months vegetable crops, wheat, broad bean, clover, cotton, and sugar beet in the northern regions and sugar cane in the southern regions compete with each other for water. In June, rice starts high competing for water with cotton, vegetables, and sugar cane. In November, the prices are high because during this period production for wheat and clover begins. In addition, the high crop water requirements for vegetables in this month. From the global optimum, the current governmental policy of canal closure during February is also consistent with the mathematical programming results, as the model results suggested that an appropriate time for winter closure in Egypt can be in February. Another important finding is that irrigation water in Egypt is a scarce resource limiting the increase in food production.

Generally, comparing the results of the global solution with the totals of separately solution (governorates level) under policy alternative A4, there was no significant differences and no potential for reallocation of irrigation water between governorates due to regional organised constraints. This means that the system of regional water allocation is fairly good.

5.4 Conclusions

This research was conducted to develop a methodology that can be used to explore optimal water use in the irrigated agriculture of Egypt. This was achieved by developing an LP model that can simulate crop production process in each agricultural governorate. Based on the application of the models, the following conclusions can be drawn:

- From the mathematical programming analysis, it can be inferred that there is scope for improvement in returns to farm resources in all the agricultural governorates of Egypt through optimisation of irrigation water use under the actual situation.
- Land resources under suggested optimal plan A_4 had an optimal use in all agricultural regions where it is fully used in all models.
- Comparison among governorates; the cropping pattern management practised by farmers is fairly good in Behaira, Gharbia, Kafr-El-shiekh, and Damietta governorates in Lower Egypt zone. In these governorates, there were small changes from the optimum ones. This may be because water scarcity in these governorates is high in the critical months, or because of the nature of the cropping pattern employed in these regions. On the other hand, water can be used more efficiently in the middle and south Egypt governorates for this reason as the sensitivity of gross margins to change was relatively high in most of the Middle and Upper Egypt governorates.
- There is a need for the governmental co-ordination in agricultural production ensuring food security and industrial requirements in ways that do not discourage the free market conditions.
- Potential development of the system will be based on vegetable crops. Traditional crops still contribute to positive economic results, particularly rice and wheat. However, production models oriented more towards vegetable crops that can increase land and water productivity.
- Cultivation of sugarcane and rice should be reduced.
- Expanding the area under sugar beet area in the delta regions would have a negative impact on water resources development and put pressure on the water required by the agriculture sector.

- Water is a scarce resource in the Egyptian agriculture, where there is no significant potential for water savings in irrigation water use under the existing development of water resources. Therefore, introducing modern irrigation technology (drip irrigation) is the only option available in the situation of water savings for new lands in Egypt.
- There is no potential for re-allocating irrigation water among Egypt's regions, meaning that the system of regional water allocation is fairly good.
- The models can be used to provide useful information to decision makers about likely optimal returns under different policy alternatives for growing crops in each governorate.

CHAPTER 6

THE FUTURE ECONOMIC IMPACT ANALYSIS OF IRRIGATION WATER MANAGEMENT STRATEGIES

6.1 Introduction

Irrigation planning in the short run includes allocating water quantity in time for the agricultural season, given the expected available resources. Once a decision on the cropping pattern is made, delivery of irrigation water can be planned for each season in anticipation of future expected conditions. Moreover, alternative water management policies can be evaluated and their effectiveness can be compared in case of a change in water availability. As simulation and optimisation models become useful tools in irrigation management, it will be possible to perform analyses of water management strategies and to optimise the use of the limited water resource.

This chapter provides economic impact analysis of future strategies on farm income, resource use, and cropping pattern, which can be implemented in Egypt. The implemented approach is a useful way of predicting how a set of planning decision variables might influence the performance of the Egyptian irrigation system. Impact analysis measures mainly the impact of changes on the farm income and decision. According to Doppler (1989) impact analyses of alternative irrigation improvements consider:

- The availability of resources, their mobility and their potential increase;
- Investment in resource improvements by farmers, irrigation authorities and the government;
- Production processes, marketing techniques, and available credit to use the available resources; and
- The objectives of those making decisions in irrigation development and management, and the quantification of goal achievement through innovations.

To assess future strategies that can be generated by different methods especially mathematical programming models, there are different studies that have been done in this field. Wightman (1990) tested the influence of various water regimes and changing of output prices at the farm level using a discrete stochastic linear programming approach in India. Salman (1994) examined the impact of increasing water supply and the efficiency of water as well as the effects of an increased water price on the farm system using a linear programming model in the Jordan valley, Jordan. Adam (1996) tested the improvement of production technologies, marketing and credit supplies to use water resources more efficiency in the irrigated scheme of Gezira, Sudan.

Mathematical programming models have also been used to determine demand for water and water pricing policies and the impact of these policies on water demand. Amir and Fisher (1999) used an optimising model to analyse crop production under various water quantities, qualities and pricing policies and determined water demand curves for various districts in Israel. Berbel and Gomez-Limon (2000) applied an LP model to three farms in three different irrigation units and examined the impact of water price policy on farm income and on regional employment in Spain.

For this case study, considering the results of the planning models (in chapter 5), irrigation policies are formulated in this chapter. Water resource availability, which limits crop production, is considered as an important factor. Therefore, three strategies related to water resource are selected in order to measure their future impacts. The first strategy is concerned with increasing available water resources through increasing water distribution efficiency. As opposed to strategy one, the second strategy deals with the expectation that the scarcity of water resources will increase in the future due to water drought policy that may be adopted in order to save water for new irrigation projects, or during times of drought.

The third strategy is to introduce water-charging policies without and with efficiency improvement. Improvement of efficiency refers to technical efficiency or the efficiency of water distribution system, resulting in minimisation of water losses and adequate of the quantity of irrigation water at the right time. In order to increase the efficiency of water use, the improvement costs should be collected from the system users to enhance awareness about the scarce water resource. Therefore, the Egyptian farmers may accept an introduction of a water charge under the strategy of increasing water availability. To show the impact of water charging policies on farm income, resource use, and farm income, two alternatives are tested under the existing development of irrigation system and under the increasing irrigation efficiency. According to these water polices, the models are specified for these testes and are described in the following section.

6.2 Methodology

The planning models in chapter 5 are applied to each governorate and the country as a whole, which include land, water resources, and organization constraints maximising the total gross margins. These static linear programming models that have been developed in GAMS and interpreted in a comparative static analysis are used to test responses to various water policies comparing them with the basic scenario. The impact (Δ) is determined by comparing the model results under the "with-and-without" future policy, as shown in figure 6.1. The difference between the situation of with and without future policy is defined as the impact of the tested strategies.

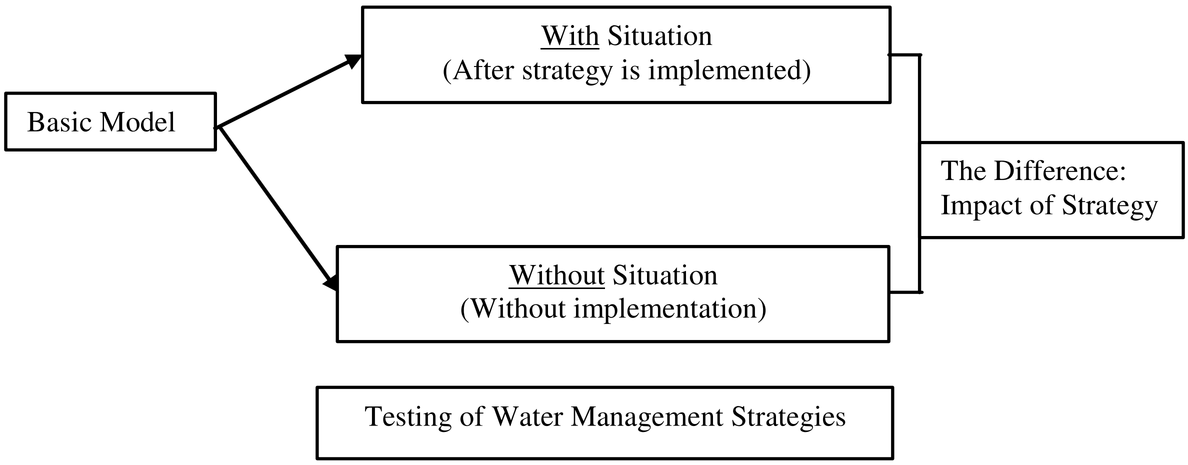


Figure 6.1 Application Models of Impact Analysis

Validation of the Planning Models

The model validation is the process of refining the model so that the prediction of the model approximates the real-world situations. It is to find out how closer the results of the build up model is to the reality and how suitable the model is in studying various policies and testing future plans. The validation is determined by the confidence of the analyst, which determines whether the model comes up to his subjective validation criteria. The criteria are the closeness of model results to reality, since the organised constraints depend on the upper and lower restrictions on cropped area over the last 5 years from 1997 to 2001. These lower and upper limitations occurred in the real world under free market. Therefore, the results of the basic model are close to the reality, and suitable for future strategy testing.

On the other hand, in optimisation models perfect knowledge is assumed and the optimum is achieved immediately. In reality, farmers make their decisions about the next season after getting the new information. Therefore, the farmer decision may require time for optimal development while the mathematical models give the optimum immediately. As a consequent, the basic models give better results compared to actual values. This act as indicators for policy makers because this simplified structure of income maximisation under certainty can not cover all actions of complex system in a real world.

In this study, criteria for validation of the models include farm income, use of limited scarce resources of land and water, the crop type and the area allocated to each crop in the cropping pattern. These criteria are compared with regard to the existing situation and the optimal situation of irrigation water use. The results of basic LP model (A_4) in chapter 5 show that farm income under the model was higher than the actual farm income in all regions of Egypt. Land resources have an optimal use in all models. Water used for crop production in the existing plans was slightly higher than in the optimal plans over all regions. Peak periods were found to be in April, June, July, October, November, and December due to competition of the crops for water requirements during these months.

6.3 Results and Discussion

The designed models that were tested and assessed in chapter 5 were then applied for impact analyses by measuring their impact on farm income, resources use and cropping patterns. These polices were tested in all agricultural governorates and in Egypt as a whole.

6.3.1 Impacts of Water Availability on Crop Production

In this section, the influence of different surface water regimes on the farm decisions and the resultant incomes, resources used, and cropping pattern is discussed. The base scenario is used to analyse the effects of water supply changes.

The first scenario simulated a situation of an increase in water supply for irrigation by 5 % through improving either water distribution efficiency or technical efficiency. Increasing efficiency by 5 % decreased losses by about 5 % meaning more water available for agricultural lands.

The second scenario modelled a situation of water scarcity given a reduction in water supply for irrigation by 5 % for horizontal expansion of new agricultural lands, or in time of drought. These models are useful in informing water policy makers about the likely impact of change in water availability on the crop production in old lands.

The models of efficiency improvement work under the following assumptions:

- The current water distribution system is not efficient therefore the irrigation system could operate with less water losses,
- There are no costs incurred in the improvement of the efficiency, and

- The improvement of the efficiency results in increased water productivity because adequacy and timeliness of water and water productivity is not yet at the maximum possible yield for each region.

The 5 % is selected because it is easy to save by reorganisation among farmers and more control in water distribution under the actual development of irrigation system. Increasing water supply through minimising water losses requires investments by farmers and the Government. In addition, it is not possible to increase surface water supply because of the limited quota of the Nile water.

On the other hand, reduction of water supply may be made by the Government in old lands to meet the needs of new lands reclamation. Therefore, the impact of a decrease in irrigation water supply by 5 % is tested to determine the influence of water cuts on gross margins, and cropping pattern. This percentage is also used because it represents a small portion that can be met in order to meet the new lands demand.

The results of the future scenarios are compared with the results of the basic models (A_4) obtained in chapter 5, as shown in Tables 6.1 to 6.19. By increasing water supply, farm income increased. Since all farmers were able to meet their subsistence requirements, the cropping patterns changed in favour of more water consuming crops like clover, rice, cotton, vegetables, and sugar cane. Farm income decreased as water became more scarce because more water was needed for crop production but less water was available for crop production leading to the respective decreases in the production activities. This implies that the cropping pattern in old lands should be changed dramatically in order to save water for new land projects. Results of these policy options are discussed in the following section.

6.3.1.1 Governorates Level

Behaira Governorate

Compared to the basic solution, farm income and area under strategic crops changed following water supply changes (Table 6.1). There is a substitution effect between the crops. By increasing water supply, wheat and clover increased by 1.10 % and 2.82 % above the basic level, respectively. However, short clover and barley decreased by 6.75 % and 20.87 % below the basic level, respectively. This is because wheat and long clover crops have relatively higher gross margin and need more water than other winter crops. In summer and Nili seasons, area under summer maize and Nili maize decreased by 30.26 % and 41.70 %, respectively. While area under rice and cotton increased by 10.75 % and 21.99 % above the basic level due to their high profitability compared to summer maize and Nili maize.

Furthermore, areas of some crops such as tomatoes and potatoes remained unchanged even at increased water supply because they appeared at the maximum level. Due to this change in cropping pattern, the total farm incomes increased by 1.35 % above the basic level.

Table 6.1 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Behaira Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	2,375	2,407	1.35	2,246	-5.41
Total Water Used (MCM)	3,206	3,307	3.13	3,049	-4.89
Winter Land Used (Feddan)	654,409	654,409	0.00	621,019	-5.10
Summer Land Used (Feddan)	587,670	587,670	0.00	563,048	-4.19
Cropping Pattern					
Wheat	218,321	220,717	1.10	208,430	-4.53
Long Clover	185,350	190,580	2.82	177,410	-4.28
Short Clover	167,900	156,570	-6.75	158,940	-5.34
Barley	6,094	4,822	-20.87	4,822	-20.87
Broad Bean	47,605	47,605	0.00	47,605	0.00
Winter Onion	1,001	1,001	0.00	1,001	0.00
Sugar Beet	1,369	1,369	0.00	1,369	0.00
Winter Tomatoes	12,354	12,354	0.00	8,236	-33.33
Winter Squash	4,919	4,919	0.00	4,919	0.00
Winter Green Peas	3,598	6,929	92.58	3,598	0.00
Winter Cabbage	5,898	7,543	27.89	4,689	-20.50
Summer Maize	130,980	91,339	-30.26	128,430	-1.95
Rice	215,790	238,984	10.75	204,580	-5.19
Peanut	6,977	6,977	0.00	2,599	-62.75
Sunflower	2,576	2,576	0.00	2,576	0.00
Summer Potatoes	19,595	19,595	0.00	19,125	-2.40
Summer Tomatoes	29,213	29,213	0.00	21,258	-27.23
Summer Eggplants	2,859	7,386	158.34	2,859	0.00
Summer Squash	5,381	6,244	16.04	3,553	-33.97
Summer Cucumber	4,590	4,590	0.00	3,687	-19.67
Nili Maize	23,089	13,462	-41.70	23,089	0.00
Nili Potatoes	2,075	2,075	0.00	2,075	0.00
Nili Tomatoes	2,165	2,165	0.00	2,165	0.00
Nili Cabbage	1,371	1,371	0.00	1,371	0.00
Nili Dry Bean	9,509	1,273	-86.61	13,387	40.78
Cotton	131,500	160,420	21.99	131,500	0.00

Source: Mathematical Programming Models Results.

The results show that when water is limited, the cropping pattern changes in favour of less water demanding crops. Also, cultivated winter and summer areas would decline by 5.10 % and 4.19 % below the basic level, respectively. This means that the fallowed lands appeared due to water becoming more scarce. Consequently, cropped area under most of the crops decreased. Area under wheat and clover would decrease by 4.53 % and 4.28 %, respectively. Despite the high profitability of winter tomatoes, its area also declined also by 33.33 % below the basic level due to its high water requirement. Similarly, in the summer season, area under summer maize and rice declined by 1.95 % and 5.19 %, respectively. Some crops remained unchanged because they appeared at the minimum or maximum level. Consequently, the total gross margins decreased by 5.41 % below the basic scenario.

Gharbia Governorate

The impacts of water availability on farm income, resources use, and cropping pattern for Gharbia governorate are presented in Table 6.2. When irrigation water increased, areas under long clover and cabbage increased by 6.86 % and 56.06 % above the basic level, respectively, because of their high water needs. However, the area under wheat and short clover decreased by 1.92 % and 21.27 %, respectively. For the summer and Nili seasons, the area under summer maize and Nili maize decreased by 24.11 % and 7.20 %, respectively. However, the areas under rice and cotton increased by 3.12 % and 31.70 % more than the optimal basic solution due to their high profitability compared to summer maize and Nili maize. Other crops remained unchanged because they appeared at the maximum or minimum levels. As a result farm income increased by 1.91 % above the basic solution.

Table 6.2 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Gharbia Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	1,169	1,191	1.91	1,111	-4.98
Total Water Used (MCM)	1,791	1,823	1.77	1,702	-4.97
Winter Land Used (Feddan)	311,777	311,777	0.00	296,970	-4.75
Summer Land Used (Feddan)	308,904	308,904	0.00	294,986	-4.51
Cropping Pattern					
Wheat	132,274	129,740	-1.92	127,450	-3.65
Long Clover	122,000	130,370	6.86	114,880	-5.84
Short Clover	30,006	23,624	-21.27	27,143	-9.54
Broad Bean	11,531	11,531	0.00	11,531	0.00
Flax	1,646	1,646	0.00	1,646	0.00
Winter Onion	6,078	6,078	0.00	6,078	0.00
Sugar Beet	3,394	3,394	0.00	3,394	0.00
Winter Green Peas	3,874	3,874	0.00	3,874	0.00
Winter Cabbage	974	1,520	56.06	974	0.00
Summer Maize	71,700	54,415	-24.11	70,732	-1.35
Rice	149,044	153,689	3.12	140,870	-5.48
Summer Potatoes	15,179	15,179	0.00	15,179	0.00
Summer Tomatoes	2,853	2,853	0.00	2,853	0.00
Nili Maize	23,379	21,695	-7.20	23,819	1.88
Nili Potatoes	1,558	1,558	0.00	1,558	0.00
Cotton	45,191	59,515	31.70	39,975	-11.54

Source: Mathematical Programming Models Results.

Reducing water supply by 5 % reduced the total planted winter and summer areas by 4.75 % and 4.51 %, respectively, below the basic solution. Decreasing water supply affects the planted area of clover, rice, and cotton. Consequently, total gross margins decreased by 4.98 % below the basic level.

Kafr El-Shiekh Governorate

Table 6.3 presents the impacts of water availability on farm income and crop production for Kafr El-Shiek governorate. Results showed that under increased water availability, wheat, long clover, and short clover increased by 7.72 %, 5.39 %, and 4.28 % above the basic solution, respectively. However, sugar beet decreased by 33.93 % below the basic solution. For summer season, area under summer maize decreased by 53.22 % while for rice and cotton the area increased by 5.80 % and 22.50 % more than basic solution, respectively, due to their high profitability as compared to other summer crops that have high water requirements. As a result the associated total farm income increased by 1.60 % above the basic solution.

Table 6.3 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Kafr El-Shiekh Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	1,664	1,690	1.60	1,582	-4.94
Total Water Used (MCM)	2,908	2,960	1.79	2,763	-4.98
Winter Land Used (Feddan)	523,795	523,795	0.00	493,921	-5.70
Summer Land Used (Feddan)	444,351	444,351	0.00	426,160	-4.09
Cropping Pattern					
Wheat	175,293	188,830	7.72	171,440	-2.20
Long Clover	174,300	183,693	5.39	164,640	-5.54
Short Clover	56,449	58,865	4.28	56,008	-0.78
Barley	3,571	3,571	0.00	3,571	0.00
Broad Bean	30,085	30,085	0.00	30,085	0.00
Flax	842	842	0.00	842	0.00
Sugar Beet	74,697	49,351	-33.93	61,081	-18.23
Winter Tomatoes	8,558	8,558	0.00	6,254	-26.92
Summer Maize	68,114	31,862	-53.22	59,393	-12.80
Rice	274,988	290,930	5.80	261,430	-4.93
Summer Tomatoes	11,002	11,002	0.00	11,002	0.00
Cotton	90,247	110,557	22.50	94,335	4.53

Source: Mathematical Programming Models Results.

On the other hand, decreasing irrigation water quantity resulted in the cultivated winter and summer areas declined by 5.70 % and 4.09 % below the basic model, respectively. Consequently, the total area under clover, sugar beet, winter tomatoes, summer maize, and rice decreased. An exception was found in the area allocated to cotton that increased by 4.53 % as compared to the basic model. This is may be attributed to high water profitability of cotton. Total gross margins declined by 4.94 % below that of the basic model without policy option.

Dakahlia Governorate

As shown in Table 6.4, and comparing with the basic model, the areas under long clover and green peas increased by 9.97 % and 41.28 %, respectively. However, short clover, broad bean, flax, and winter onion decreased. This happened because wheat and long clover crops have relatively higher gross margins and they also need more water than the others. In summer and Nili seasons, the area under summer and Nili maize decreased by 35.28 % and 35.22 %, respectively. The area for rice and cotton increased by 6.37 % and 10.78 %, respectively, due to their high profitability compared to summer maize and Nili maize. Total farm income would increase by 2.56 % more than the basic solution.

Table 6.4 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Dakahlia Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	1,917	1,966	2.56	1,825	-4.80
Total Water Used (MCM)	3,865	3,988	3.16	3,672	-5.00
Winter Land Used (Feddan)	598,050	598,050	0.00	567,545	-5.10
Summer Land Used (Feddan)	613,160	613,160	0.00	586,961	-4.27
Cropping Pattern					
Wheat	223,570	224,630	0.47	218,480	-2.28
Long Clover	199,650	219,565	9.97	186,370	-6.65
Short Clover	74,952	68,694	-8.35	74,952	0.00
Broad Bean	71,602	56,433	-21.19	60,521	-15.48
Flax	3,618	2,411	-33.36	2,411	-33.36
Winter Onion	4,746	1,838	-61.27	4,746	0.00
Sugar Beet	9,875	9,875	0.00	9,875	0.00
Winter Green Peas	10,337	14,604	41.28	10,190	-1.42
Summer Maize	69,105	44,721	-35.28	69,105	0.00
Rice	433,660	461,263	6.37	409,620	-5.54
Summer Potatoes	10,633	10,634	0.01	10,634	0.01
Summer Tomatoes	4,230	4,230	0.00	4,230	0.00
Nili Maize	30,167	19,541	-35.22	30,167	0.00
Nili Potatoes	1,307	1,807	38.26	1,434	9.72
Cotton	64,058	70,964	10.78	61,771	-3.57

Source: Mathematical Programming Models Results.

By decreasing irrigation water quantity, the seasonal cultivated winter and summer areas declined by 5.10 % and 4.27 % below the basic solution, respectively. The policy negatively affected the cultivated area of wheat, long clover, broad bean, flax, and green peas in winter. In the summer season, the area under rice and cotton declined. An exception was the increased area under Nili potatoes by 9.72 % due to its higher water productivity than other crops. The farm income would decrease by 4.80 % below the basic level.

Damietta Governorate

As compared to the basic solution (Table 6.5) the areas under wheat, long clover, short clover, and winter tomatoes increased by 14.20 %, 1.71 %, 14.35 %, and 13.97 %, respectively. However, broad bean and sugar beet decreased. Area under rice increased by 5.02 % above its cropped area in the optimal basic solution because of its high profitability compared to other summer crops in the governorate. Due to lack of profitability, cotton decreased by 2.15 % below the basic solution. This cropping pattern resulted in an increase in farm income by 1.05 % above the basic solution.

The reduction in water quantity resulted in decreased seasonal cultivated areas in winter, and summer seasons by 4.97 % and 5.89 % below the basic solution, respectively. Consequently, the total area of the crops in general decreased except for sugar beet. The increase in planted area of sugar beet is attributed more to the low crop water requirement. Total gross margins decreased by 5.23 % below the total gross margins of the basic solution without policy option.

Table 6.5 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Damietta Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	1,979	2,010	1.55	1,873	-5.35
Total Water Used (MCM)	560	571	1.87	533	-4.92
Winter Land Used (Feddan)	94,497	94,497	0.00	89,803	-4.97
Summer Land Used (Feddan)	80,128	80,128	0.00	75,410	-5.89
Cropping Pattern					
Wheat	21,490	24,541	14.20	20,344	-5.33
Long Clover	50,305	51,166	1.71	47,616	-5.35
Short Clover	10,538	12,050	14.35	10,652	1.08
Broad Bean	8,679	3,801	-56.20	7,260	-16.35
Sugar Beet	2,032	1,283	-36.86	2,478	21.95
Winter Tomatoes	1,453	1,656	13.97	1,453	0.00
Summer Maize	4,694	2,609	-44.42	3,451	-26.48
Rice	58,212	61,134	5.02	55,844	-4.07
Summer Potatoes	1,570	1,570	0.00	1,570	0.00
Summer Tomatoes	2,527	2,527	0.00	2,257	-10.68
Nili Maize	1,932	1,336	-30.85	1,336	-30.85
Cotton	11,193	10,952	-2.15	10,952	-2.15

Source: Mathematical Programming Models Results.

Sharkia Governorate

For Sharkia governorate, Table 6.6, as a result of increasing water supply for irrigation, the area under long clover increased by 4.30 % above the basic solution. However, short clover and broad bean decreased by 16.66 % and 4.72 % below the basic level, respectively. Furthermore, areas of some crops such as winter squash and cabbage increased. For summer season, the areas under summer maize and Nili maize decreased by 11.26 % and 52.02 % less than the basic solution, respectively. The area under rice, peanut, and cotton increased by 9.51 %, 32.91 %, and 27.78 % more than their basic optimal cropped areas, respectively. Also, the total farm income would increase by 1.55 % above the basic level.

Table 6.6 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Sharkia Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	1,979	2,010	1.55	1,873	-5.35
Total Water Used (MCM)	3,207	3,312	3.27	3,046	-5.02
Winter Land Used (Feddan)	592,822	592,822	0.00	566,306	-4.47
Summer Land Used (Feddan)	561,062	561,062	0.00	532,691	-5.06
Cropping Pattern					
Wheat	236,203	236,770	0.24	236,200	0.00
Long Clover	212,240	221,370	4.30	192,580	-9.26
Short Clover	68,513	57,097	-16.66	65,661	-4.16
Barley	5,737	5,737	0.00	5,737	0.00
Broad Bean	32,405	30,877	-4.72	30,877	-4.72
Flax	949	949	0.00	949	0.00
Winter Onion	956	956	0.00	956	0.00
Garlic	1,546	1,546	0.00	1,546	0.00
Sugar Beet	1,299	1,299	0.00	1,299	0.00
Winter Tomatoes	24,690	24,694	0.02	22,217	-10.02
Winter Squash	3,620	5,834	61.16	3,620	0.00
Winter Green Peas	1,916	1,916	0.00	1,916	0.00
Winter Cabbage	1,628	2,657	63.21	1,628	0.00
Lentil	404	404	0.00	404	0.00
Lupine	716	716	0.00	716	0.00
Summer Maize	203,061	180,190	-11.26	189,020	-6.91
Rice	250,070	273,860	9.51	238,810	-4.50
Peanut	4,612	6,130	32.91	4,612	0.00
Summer Potatoes	5,034	5,034	0.00	5,034	0.00
Summer Tomatoes	15,927	15,922	-0.03	15,927	0.00
Summer Eggplant	6,851	6,851	0.00	6,851	0.00
Summer Squash	4,029	4,029	0.00	4,029	0.00
Summer Cucumber	1,390	1,390	0.00	781	-43.81
Nili Maize	26,565	12,737	-52.05	24,104	-9.26
Nili Potatoes	920	920	0.00	920	0.00
Nili Tomatoes	933	933	0.00	933	0.00
Nili Cabbage	642	642	0.00	642	0.00
Cotton	41,028	52,424	27.78	41,028	0.00

Source: Mathematical Programming Models Results.

By decreasing irrigation water quantity, cultivated areas of winter and summer areas reduced by 4.47 % and 5.06 % below the basic solution, respectively. Consequently, some of the areas under main crops decreased. Total gross margins decreased by 5.41 % less than total gross margins of basic solution without policy option.

Ismailia Governorate

For Ismailia as reported in Table 6.7, the area under long clover increased by 5.24 % more than the basic solution. However, the area under wheat decreased by 3.79 % due to the lack of profitability. In the summer season, the area under maize decreased by 7.78 % less than the basic solution because of lack of profitability compared to vegetables crops. The areas under vegetable crops such as eggplant, squash, cucumber, and Nili tomatoes increased. As a result, the farm income increased by 1.60 % above the basic solution.

Under decreasing irrigation water quantity, the fallowed lands constituted 5.42 % and 3.60 % of the cropped area in winter and summer and Nili seasons, respectively. The cropping pattern changed in favour of less water requiring crops, as shown in the table below. Consequently, total gross margins declined by 5.94 % less than the total gross margins of basic solution without policy option.

Table 6.7 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Ismailia Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	381	387	1.60	358	-5.94
Total Water Used (MCM)	346	354	2.28	330	-4.74
Winter Land Used (Feddan)	67,642	67,642	0.00	63,979	-5.42
Summer Land Used (Feddan)	81,127	81,127	0.00	78,206	-3.60
Cropping Pattern					
Wheat	26,313	25,317	-3.79	25,317	-3.79
Long Clover	19,375	20,391	5.24	17,838	-7.93
Barley	1,712	1,712	0.00	2,250	31.43
Broad Bean	1,721	1,721	0.00	1,721	0.00
Winter Tomatoes	16,347	16,347	0.00	14,699	-10.08
Winter Squash	1,258	1,238	-1.59	1,238	-1.59
Winter Green Peas	916	916	0.00	916	0.00
Summer Maize	37,278	34,378	-7.78	34,669	-7.00
Rice	4,008	4,006	-0.05	4,006	-0.05
Peanut	12,915	16,348	26.57	11,562	-10.48
Sesame	6,835	4,734	-30.74	7,948	16.28
Summer Potatoes	3,215	3,215	0.00	3,215	0.00
Summer Tomatoes	7,216	7,216	0.00	7,216	0.00
Summer Eggplant	1,800	1,914	6.33	1,800	0.00
Summer Squash	1,642	2,067	25.88	1,642	0.00
Summer Cucumber	2,131	2,140	0.42	2,061	-3.28
Nili Maize	3,023	3,023	0.00	3,023	0.00
Nili Tomatoes	1,064	2,086	96.05	1,064	0.00

Source: Mathematical Programming Models Results.

Menoufia Governorate

When irrigation water increased, as indicated in Table 6.8, there is a substitution effect between the crops. Areas under wheat and long clover increased by 9.89 % and 1.07 %, respectively, more than the areas of basic solution. However, areas under short clover and broad bean decreased by 23.03 % and 28.51 % below the basic solution, respectively. Similarly, in the summer season the areas under Nili dry bean and cotton increased by 11.29 % and 38.55 %, respectively, while for summer maize the area decreased by 5.08 % below the cropped area in the optimal basic solution. As a result, the total farm income increased by 0.60 % above the basic solution.

Decreasing the quantity of water resulted in seasonal cultivated areas of winter and summer areas declined by 4.35 % and 4.77 % less than the basic solution. Areas under long clover, broad bean, summer maize and dry bean decreased. Consequently, total gross margins declined by 4.96 % less than the total gross margins of basic solution without policy option.

Table 6.8 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Menoufia Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	1,043	1,049	0.60	991	-4.96
Total Water Used (MCM)	1,186	1,196	0.85	1,127	-4.97
Winter Land Used (Feddan)	263,369	263,369	0.00	251,920	-4.35
Summer Land Used (Feddan)	268,232	268,232	0.00	255,447	-4.77
Cropping Pattern					
Wheat	80,419	88,374	9.89	79,736	-0.85
Long Clover	140,916	142,424	1.07	130,650	-7.29
Short Clover	39,464	30,377	-23.03	39,340	-0.31
Broad Bean	1,319	943	-28.51	943	-28.51
Winter Green Peas	1,251	1,251	0.00	1,251	0.00
Summer Maize	216,621	205,616	-5.08	204,140	-5.76
Summer Potatoes	13,221	13,221	0.00	13,221	0.00
Nili Potatoes	4,601	4,601	0.00	4,601	0.00
Nili Dry Bean	7,411	8,248	11.29	7,107	-4.10
Cotton	26,378	36,546	38.55	26,378	0.00

Source: Mathematical Programming Models Results.

Qalyoubia Governorate

The results in Table 6.9 show that when water supply is increased, the area under long clover and green peas increased by 6.78 % and 67.98 % more than the basic solution, respectively. However, the areas under wheat, short clover, and onion decreased by 2.06 %, 15.75 %, and 37.71 %, respectively. In summer, the area under maize and rice decreased by 1.48 % and 1.51 %, respectively, while for eggplant, its area increased sharply by 97.39 % above the basic level. Total gross margins increased by 1.82 % more than the basic solution.

On the other hand, the cultivated winter and summer areas declined by 4.14 % and 5.19 % below the basic solution as a result of decreasing water supply. The areas under most of the crops decreased. An exception was found in the area allocated to broad bean that increased due to its higher water productivity than other crops in this governorate. The total gross margins decreased by 6.51 % below the basic solution.

Table 6.9 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Qalyoubia Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	520	529	1.82	486	-6.51
Total Water Used (MCM)	618	623	0.77	588	-4.92
Winter Land Used (Feddan)	130,023	130,023	0.00	124,640	-4.14
Summer Land Used (Feddan)	124,848	124,848	0.00	118,369	-5.19
Cropping Pattern					
Wheat	45,291	44,356	-2.06	45,070	-0.49
Long Clover	54,728	58,439	6.78	52,797	-3.53
Short Clover	13,473	11,351	-15.75	13,114	-2.66
Broad Bean	1,099	1,099	0.00	1,668	51.77
Winter Onion	5,995	3,734	-37.71	3,734	-37.71
Winter Squash	1,848	1,848	0.00	1,848	0.00
Winter Green Peas	2,364	3,971	67.98	2,217	-6.22
Winter Cabbage	5,225	5,225	0.00	4,192	-19.77
Summer Maize	83,099	81,867	-1.48	81,401	-2.04
Rice	19,788	19,490	-1.51	18,425	-6.89
Summer Potatoes	2,892	2,892	0.00	1,683	-41.80
Summer Tomatoes	6,858	6,858	0.00	4,950	-27.82
Summer Eggplant	1,571	3,101	97.39	1,571	0.00
Summer Squash	1,480	1,480	0.00	980	-33.78
Nili Cabbage	1,160	1,160	0.00	1,359	17.16
Cotton	8,000	8,000	0.00	8,000	0.00

Source: Mathematical Programming Models Results.

Giza Governorate

Table 6.10 indicates that when irrigation water is increased, the areas under long clover and winter tomatoes increased by 6.68 % and 13.32 % above their basic solutions, respectively. However, area under wheat decreased by 18.77 % below the basic solution. In the summer season, the area under summer maize, and Nili maize decreased by 1.07 % and 7.34 %, respectively, whereas for eggplant, squash, and cucumber increased by 71.62 %, 50.21 %, and 63.64 %, respectively, above their cropped areas in the base model. This resulted in an increase in income of 2.62 % more than the basic solution.

By cutting irrigation water quantity by 5 %, seasonal cultivated areas in winter and summer declined by 6.51 % and 5.31 %, respectively, below the basic solution. The decrease in water supply negatively affected the planted areas of wheat and winter tomatoes, and for summer season, the area under peanut, sesame, summer potatoes, Cucumber, and Nili maize declined. Consequently, total gross margins decreased by 5.37 % below the basic level.

Table 6.10 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Giza Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	633	649	2.62	599	-5.37
Total Water Used (MCM)	658	666	1.14	624	-5.26
Winter Land Used (Feddan)	116,230	116,230	0.00	108,664	-6.51
Summer Land Used (Feddan)	147,470	147,470	0.00	139,642	-5.31
Cropping Pattern					
Wheat	29,033	23,583	-18.77	24,109	-16.96
Long Clover	54,215	57,837	6.68	54,215	0.00
Short Clover	12,360	12,360	0.00	12,360	0.00
Winter Tomatoes	13,725	15,553	13.32	11,083	-19.25
Winter Squash	2,968	2,968	0.00	2,968	0.00
Winter Green Peas	1,773	1,773	0.00	1,773	0.00
Winter Cabbage	2,156	2,156	0.00	2,156	0.00
Summer Maize	64,138	63,450	-1.07	62,553	-2.47
Peanut	5,257	5,257	0.00	4,582	-12.84
Sesame	2,068	378	-81.72	387	-81.29
Summer Potatoes	7,988	7,988	0.00	6,782	-15.10
Summer Tomatoes	12,797	12,797	0.00	12,797	0.00
Summer Eggplant	2,019	3,465	71.62	2,019	0.00
Summer Squash	2,408	3,617	50.21	2,408	0.00
Summer Sorghum	988	988	0.00	988	0.00
Summer Cucumber	3,292	5,387	63.64	2,991	-9.14
Nili Maize	32,301	29,929	-7.34	29,921	-7.37
Nili Potatoes	4,047	4,047	0.00	4,047	0.00
Nili Tomatoes	8,943	8,943	0.00	8,943	0.00
Nili Cabbage	1,224	1,224	0.00	1,224	0.00

Source: Mathematical Programming Models Results.

Beni Seuf Governorate

Table 6.11 shows that under increasing water supply situation the area under long clover and winter tomatoes increased by 17.79 % and 24.74 %, respectively, above the basic solution. However, area under wheat decreased by 8.90 % above the basic solution. In the summer and Nili seasons, the area under sesame decreased by 72.73 %, while the area under Nili tomatoes increased by 53.74 %. This cropping pattern resulted in an increase in total farm income by 2.16 % above the basic solution.

By decreasing the quantity of irrigation water, the seasonal cultivated winter and summer areas declined by 3.98 % and 6.45 % less than the basic solution. This means that fallowed lands increased due to water becoming more scarce. The total area of crops that have a relatively low gross margin per water decreased, as shown in Table 6.11. Total gross margins decreased by 5.41 % below the basic solution.

Table 6.11 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Beni Seuf Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	675	689	2.16	638	-5.41
Total Water Used (MCM)	1,013	1,028	3.71	956	-5.68
Winter Land Used (Feddan)	202,166	202,166	0.00	194,118	-3.98
Summer Land Used (Feddan)	235,331	235,331	0.00	220,148	-6.45
Cropping Pattern					
Wheat	92,778	84,519	-8.90	85,061	-8.32
Long Clover	59,843	70,492	17.79	59,517	-0.54
Short Clover	27,564	23,031	-16.45	30,237	9.70
Broad Bean	572	572	0.00	572	0.00
Winter Onion	4,573	4,573	0.00	4,573	0.00
Garlic	6,532	6,532	0.00	6,532	0.00
Fenugreek	1,641	1,641	0.00	1,641	0.00
Winter Tomatoes	8,663	10,806	24.74	5,985	-30.91
Summer Maize	128,970	127,919	-0.81	115,170	-10.70
Cucumber	6,239	6,239	0.00	4,385	-29.72
Summer Tomatoes	11,489	11,489	0.00	11,489	0.00
Sesame	2,068	564	-72.73	564	-72.73
Peanut	232	232	0.00	232	0.00
Soybean	867	867	0.00	867	0.00
Summer Sorghum	1,190	1,190	0.00	1,190	0.00
Sunflower	2,398	2,398	0.00	2,398	0.00
Nili Maize	53,993	54,358	0.68	53,993	0.00
Nili Tomatoes	4,075	6,265	53.74	3,132	-23.14
Cotton	23,810	23,810	0.00	23,810	0.00

Source: Mathematical Programming Models Results.

Fayoum Governorate

Compared to the basic solution, the area under long clover increased by 7.48 % when water supply is increased, as shown in Table 6.12. In summer and Nili seasons, area under summer maize, and Nili maize decreased by 2.32 % and 31.09 %, respectively. However, the area under rice increased by 23.19 % above the base solution. As a result, farm income increased by 1.99 % above the basic level.

By decreasing water supply, the seasonal cultivated winter and summer areas declined by 4.56 % and 7.34 % below the basic solution. This means the fallowed lands appeared due to water becoming more scarce. Area under wheat, long clover, short clover, onion, garlic, tomatoes, and cabbage decreased. The area under barley increased in the winter season due to the low crop water requirement. Similarly in the summer season, the area under summer maize and Nili maize decreased, but the area under sesame, sunflower, summer cucumber, and cotton increased. The alternative policy option decreased total gross margins by 7.00 % below the basic level.

Table 6.12 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Fayoum Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	919	937	1.99	854	-7.00
Total Water Used (MCM)	1,322	1,365	3.04	1247	-5.68
Winter Land Used (Feddan)	323,752	323,752	0.00	308,997	-4.56
Summer Land Used (Feddan)	205,279	205,279	0.00	190,202	-7.34
Cropping Pattern					
Wheat	142,770	142,359	-0.29	152,750	6.99
Long Clover	126,350	135,800	7.48	107,440	-14.97
Short Clover	23,175	18,335	-20.88	21,335	-7.94
Barley	4,897	4,897	0.00	7,897	61.26
Broad Bean	2,848	2,848	0.00	2,848	0.00
Fenugreek	1,287	1,287	0.00	1,287	0.00
Sugar Beet	1,007	1,007	0.00	1,007	0.00
Onion	6,567	2,902	-55.81	2,902	-55.81
Garlic	2,776	2,249	-18.98	999	-64.01
Winter Tomatoes	9,399	9,399	0.00	9,218	-1.93
Cabbage	2,669	2,669	0.00	1,314	-50.77
Summer Maize	77,650	75,846	-2.32	63,136	-18.69
Rice	25,565	31,493	23.19	27,608	7.99
Sesame	4,839	4,839	0.00	4,839	0.00
Sunflower	6,243	6,243	0.00	8,243	32.04
Sorghum	24,290	24,290	0.00	24,290	0.00
Summer Cucumber	1,596	4,672	192.73	2,371	48.56
Nili Maize	23,155	15,956	-31.09	15,956	-31.09
Nili Tomatoes	20,848	20,849	0.00	20,848	0.00
Nili Cabbage	2,906	2,906	0.00	2,906	0.00
Cotton	18,185	18,185	0.00	20,005	10.01

Source: Mathematical Programming Models Results.

Menia Governorate

As shown in Table 6.13, when water availability increased by 5 %, the area under long clover increased by 3.46 % above the basic solution. However, garlic, sugar beet, and winter tomatoes decreased by 21.41 %, 6.26 %, and 3.10 % below the basic level, respectively. In summer, the area under summer maize decreased by 2.33 % whereas the area under sugar cane increased by 28.71 %. Therefore, farm income increased by 1.03 % compared to the basic solution.

By decreasing irrigation water quantity, the cultivated winter and summer areas declined by 3.08 % and 5.37 % less than the basic solution. The area under long clover decreased by

12.38 % less than the basic optimal cropped area while areas under short clover and fenugreek increased by 16.67 % and 30.74 %, respectively. In summer, the area under summer maize declined by 7.07 % less than the basic solution due to the reduction in water supply. Consequently, the total gross margins decreased by 5.06 % below the total gross margins of basic solution without policy option.

Table 6.13 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Menia Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	1,196	1,209	1.03	1,136	-5.06
Total Water Used (MCM)	1,788	1,822	1.90	1,702	-4.83
Winter Land Used (Feddan)	335,534	335,534	0.00	325,189	-3.08
Summer Land Used (Feddan)	350,765	350,765	0.00	331,941	-5.37
Cropping Pattern					
Wheat	159,180	159,180	0.00	159,180	0.00
Long Clover	111,370	115,218	3.46	97,578	-12.38
Short Clover	8,253	8,253	0.00	9,629	16.67
Broad Bean	10,017	10,017	0.00	10,017	0.00
Garlic	11,389	8,951	-21.41	11,426	0.32
Fenugreek	3,591	3,591	0.00	4,695	30.74
Sugar Beet	13,468	12,625	-6.26	14,398	6.91
Winter Tomatoes	18,266	17,699	-3.10	18,266	0.00
Summer Maize	240,734	235,125	-2.33	223,720	-7.07
Summer Potatoes	3,572	3,227	-9.66	3,227	-9.66
Summer Tomatoes	7,006	7,006	0.00	7,006	0.00
Sesame	8,198	8,198	0.00	8,198	0.00
Summer Peanut	4,959	4,959	0.00	4,959	0.00
Soybean	5,361	5,361	0.00	5,361	0.00
Sunflower	3,884	3,884	0.00	3,884	0.00
Summer Sorghum	6,987	6,987	0.00	6,987	0.00
Nili Potatoes	11,920	11,920	0.00	11,920	0.00
Nili Tomatoes	2,307	842	-63.50	842	-63.50
Cotton	29,993	29,993	0.00	29,993	0.00
Sugar Cane	25,844	33,263	28.71	25,844	0.00

Source: Mathematical Programming Models Results.

Assuit Governorate

Compared to the basic solution, the area under long clover increased by 6.76 % (Table 6.14) however the area under wheat decreased by 3.79 %. In the summer season, the areas under maize, peanut, and sunflower increased by 21.87 %, 138.22 %, and 48.83 %, respectively, while area under sorghum and cotton decreased by 11.50 % and 15.98 % below the basic level, respectively. As a result, farm income increased by 1.30 % above the basic level.

By decreasing water quantity, fallowed lands appeared due to water becoming more scarce. Cultivated winter and summer areas declined by 3.70 % and 6.64 % below the basic model, respectively. The area under wheat and long clover decreased by 3.04 % and 7.82 % less than the basic optimal cropped area, respectively, while area under winter onion increased by 35.86 %. In the summer season, the area under maize and peanut increased by 4.68% and 51.75 % below the basic solution whereas area under sorghum and cotton decreased by 12.45% and 20.00 %, respectively. Consequently, the total gross margins decreased by 5.26 % below the basic level.

Table 6.14 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Assuit Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	891	903	1.30	844	-5.26
Total Water Used (MCM)	1,485	1,497	0.97	1,406	-5.32
Winter Land Used (Feddan)	276,144	276,144	0.00	265,928	-3.70
Summer Land Used (Feddan)	264,231	264,231	0.00	246,680	-6.64
Cropping Pattern					
Wheat	142,393	137,000	-3.79	138,060	-3.04
Long Clover	79,770	85,163	6.76	73,529	-7.82
Short Clover	8,898	8,898	0.00	8,898	0.00
Broad Bean	16,018	16,018	0.00	16,018	0.00
Lentil	3,828	3,828	0.00	3,828	0.00
Chickpeas	10,111	10,111	0.00	10,111	0.00
Onion	2,789	2,789	0.00	3,789	35.86
Winter Tomatoes	12,337	12,337	0.00	11,695	-5.20
Summer Maize	79,648	97,067	21.87	83,515	4.86
Sesame	6,515	6,515	0.00	5,515	-15.35
Summer Peanut	2,313	5,510	138.22	3,510	51.75
Sunflower	4,096	4,096	0.00	6,096	48.83
Sorghum	130,910	115,860	-11.50	114,610	-12.45
Summer Tomatoes	5,911	5,911	0.00	5,911	0.00
Cotton	34,836	29,272	-15.98	27,523	-20.99

Source: Mathematical Programming Models Results.

Suhag Governorate

It can be seen from Table 6.15 that when water supply for irrigation is increased, the area under long clover increased by 13.44 % compared to the basic solution. However, the area under wheat and winter onion decreased by 5.99 % and 35.01 %, respectively. In the summer season, the area under sesame and cotton decreased by 48.08 % and 47.72 %, respectively, while area under peanut and sugar cane increased by 109.16 % and 10.28 % above their cropped area in the optimal basic solution. This resulted in an increase in farm income by 1.40 % more than the basic solution.

By decreasing irrigation quantity, the seasonal cultivated winter and summer areas declined by 4.97 % and 5.28 % below the basic solution, respectively. The decline in water supply affected the planted area of most of crops that have lower water productivity than other crops in this governorate. As a consequence, the total gross margins decreased by 5.75 % below the basic level.

Table 6.15 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Suhag Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	1073	1,088	1.40	1,011	-5.75
Total Water Used (MCM)	1,584	1,611	1.70	1,502	-5.14
Winter Land Used (Feddan)	266,167	266,167	0.00	252,931	-4.97
Summer Land Used (Feddan)	272,663	272,663	0.00	258,273	-5.28
Cropping Pattern					
Wheat	146,233	137,470	-5.99	141,110	-3.50
Long Clover	72,980	82,787	13.44	67,204	-7.91
Short Clover	25,797	25,797	0.00	25,797	0.00
Broad Bean	2,412	2,412	0.00	2,412	0.00
Fenugreek	631	631	0.00	631	0.00
Winter Tomatoes	15,132	15,132	0.00	13,839	-8.54
Winter Onion	2,982	1,938	-35.01	1,938	-35.01
Summer Maize	114,230	115,263	0.90	109,280	-4.33
Peanut	3,188	6,668	109.16	2,603	-18.35
Sorghum	121,150	121,360	0.17	114,540	-5.46
Sesame	3,889	2,019	-48.08	3,336	-14.22
Cucumber	1,790	1,790	0.00	1,280	-28.49
Cotton	9,954	5,204	-47.72	8,772	-11.87
Sugar Cane	18,462	20,359	10.28	18,462	0.00

Source: Mathematical Programming Models Results.

Qena Governorate

Compared to the basic scenario (Table 6.16), the area under winter tomatoes increased by 19.86 % due to increased water supply. However, the area under wheat decreased by 5.56 %. In the summer season, the area under summer maize and sesame decreased by 5.64 % and 37.90 %, respectively, while area under sugar cane increased by 2.56 %. This resulted in an increase in farm income of 4.85 % above the basic level.

On the other hand, decreasing irrigation water quantity reduced the seasonal cultivated winter and summer areas by 3.37 % and 4.94 % below the basic level. The area under wheat and winter tomatoes decreased in winter. This policy negatively affected the planted area of summer maize, sorghum and sugar cane. Consequently, the total gross margins decreased by 5.07 % below total gross margins of basic solution without policy option.

Table 6.16 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Qena Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	651	683	4.85	618	-5.07
Total Water Used (MCM)	1,561	1,582	1.34	1,488	-4.67
Winter Land Used (Feddan)	89,644	89,644	0.00	86,625	-3.37
Summer Land Used (Feddan)	189,415	189,415	0.00	180,062	-4.94
Cropping Pattern					
Wheat	65,349	61,065	-6.56	63,700	-2.52
Barley	654	654	0.00	654	0.00
Broad Bean	1,047	1047	0.00	1,047	0.00
Winter Tomatoes	21,575	25,859	19.86	20,205	-6.35
Fenugreek	1,019	1,019	0.00	1,019	0.00
Summer Maize	18,034	17,015	-5.64	17,791	-1.35
Summer Sorghum	21,432	21,432	0.00	21,432	0.00
Sesame	6,985	4,338	-37.90	4,759	-31.87
Sugar Cane	142,964	146,630	2.56	136,080	-4.82

Source: Mathematical Programming Models Results.

Aswan Governorate

For Aswan governorate, winter crops remained unchanged by increasing the irrigation water supply. In the summer season, the area under sugar cane increased by 4.26 % above the basic solution. However, the areas under summer maize and sesame decreased by 18.14% and 29.92 % below their basic optimal areas, respectively. As a result, total farm income increased by 1.56 % more than the basic solution.

Table 6.17 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Aswan Governorate

Indicators	Basic	Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	286	290	1.56	275	-3.68
Total Water Used (MCM)	763	781	2.33	727	-4.67
Winter Land Used (Feddan)	23,938	23,938	0.00	23,938	0.00
Summer Land Used (Feddan)	97,867	97,867	0.00	92,470	-5.51
Cropping Pattern					
Wheat	16,273	16,273	0.00	16,273	0.00
Barley	921	1,690	83.60	921	0.00
Broad Bean	1,691	921	-45.54	1,691	0.00
Winter Tomatoes	5,054	5,054	0.00	5,054	0.00
Summer Maize	8,587	7,029	-18.14	8,343	-2.84
Summer Sorghum	6,684	4,684	-29.92	5,996	-10.29
Sesame	4,013	2,385	-40.57	4,013	0.00
Summer Tomatoes	3,718	3,718	0.00	3,718	0.00
Sugar Cane	74,865	78,051	4.26	70,400	-5.96

Source: Mathematical Programming Models Results.

The decrease in water supply reduced the summer areas by 5.51 % below the basic solution. Area under maize and sugar cane would decline by 2.84 % and 5.96 % less the basic level, respectively. As a result, total gross margins decreased by 3.68 % below the optimal basic scenario.

Total Egypt

To study the impacts of water availability changes on farm income, land use and cropping pattern for Egypt as a whole, the aggregated results from the 17 governorates are presented in Table 6.18. Compared to the basic solution, farm income and area under strategic crops increased considerably. The results in Table 6.18 show that when irrigation water is increased, the total cropped area was not affected because the cropped area was fully used in both basic (without policy) and with policy models, but there was a substitution effect between the crops. The areas under tomatoes, squash, green peas, and cabbage increased by 4.71 %, 15.01 %, 35.36 %, and 17.36%, respectively, above the basic level. However, other winter crops decreased below the basic level. This happened because vegetable crops have relatively higher gross margins and need more water than the others. Furthermore, the area of some crops such as lentil, lupine, chickpeas, and fenugreek remained unchanged even with increased water supply because they appeared at the lower limit to the cultivation area under these crops.

In the summer and Nili seasons, areas under summer maize and Nili maize decreased by 9.37 % and 20.95 %, respectively. However, the area under rice, cotton, and sugar cane increased by 7.26 %, 15.25 %, and 6.17 % above the basic optimal level, respectively, due to their high profitability compared to summer maize, and Nili maize. The cropping pattern changed in favour of more water consuming crops with respect to farm income. Some of the vegetable crops increased as a result of increasing water supply. Consequently, total gross margins increased by 1.71 % above the basic level.

The results also showed that when water supply for irrigation is limited, the cropping pattern altered in favour of less water consuming crops. Cultivated winter and summer areas declined by 4.67 % and 4.96 % below the basic level. This means that the fallowed lands appeared due to water becoming more scarce. As a consequence, the area under most of the crops decreased. The area under wheat, and long clover would decrease by 2.05 % and 7.13 % below the basic level, respectively. Similarly, in the summer season, the areas under summer maize and rice declined by 5.77 % and 4.87 % below the basic solution, respectively. As a consequence, the total gross margins decreased by 5.30 % less than the total gross margins of the basic optimal solution without policy option.

Table 6.18 Future Impact of Water Availability on Farm Income, Land Use, and Cropping Pattern for Total Egypt

Indicators	Basic	Water Policy Options			
		Improving Efficiency		Water Drought	
	Value	Value	Δ %	Value	Δ %
Total Gross Margins (MLE)	17,668	17,970	1.71	16,731	-5.30
Total Water Used (MCM)	27,865	28,484	2.22	26,463	-5.03
Winter Land Used (Feddan)	4,869,967	4,869,967	0.00	4,642,493	-4.67
Summer Land Used (Feddan)	4,830,502	4,830,502	0.00	4,590,968	-4.96
Cropping Pattern					
Wheat	1,952,772	1,944,723	-0.41	1,912,709	-2.05
Long Clover	1,662,872	1,765,296	6.16	1,544,264	-7.13
Short Clover	568,295	515,302	-9.32	554,066	-2.50
Barley	24,356	23,084	-5.22	26,622	9.30
Bean	239,881	217,931	-9.15	226,047	-5.77
Flax	6,755	5,848	-13.43	5,848	-13.43
Onion	35,674	25,809	-27.65	29,717	-16.70
Garlic	22,243	19,278	-13.33	20,503	-7.82
Sugar Beet	107,141	80,203	-25.14	94,901	-11.42
Lentil	4,232	4,232	0.00	4,232	0.00
Lupine	716	716	0.00	716	0.00
Chickpeas	10,111	10,111	0.00	10,111	0.00
Fenugreek	8,169	8,169	0.00	9,273	13.51
Winter Tomatoes	167,558	175,446	4.71	148,203	-11.55
Winter Squash	14,613	16,807	15.01	14,593	-0.14
Winter Green Peas	26,029	35,234	35.36	25,735	-1.13
Winter Cabbage	18,550	21,770	17.36	14,953	-19.39
Summer Maize	1,617,168	1,465,708	-9.37	1,523,849	-5.77
Rice	1,430,944	1,534,845	7.26	1,361,193	-4.87
Sorghum	311,633	296,791	-4.76	292,951	-5.99
Peanut	40,453	52,080	28.74	34,659	-14.32
Sunflower	19,197	19,197	0.00	23,197	20.84
Sesame	45,410	33,979	-25.17	39,559	-12.88
Soybean	6,228	6,228	0.00	6,228	0.00
Summer Potatoes	82,900	82,555	-0.42	79,670	-3.90
Summer Tomatoes	120,749	120,749	0.00	110,886	-8.17
Eggplants	15,100	22,717	50.44	15,100	0.00
Summer Squash	14,940	17,437	16.71	12,612	-15.58
Summer Cucumber	20,672	26,208	26.78	17,556	-15.07
Nili Maize	217,615	172,029	-20.95	205,408	-5.61
Nili Potatoes	26,428	26,928	1.89	26,555	0.48
Nili Tomatoes	40,335	42,082	4.33	37,927	-5.97
Nili Cabbage	7,303	7,303	0.00	8,296	13.60
Nili Dry Bean	16,920	9,521	-43.73	20,494	21.12
Cotton	534,372	615,840	15.25	524,042	-1.93
Sugar Cane	262,135	278,306	6.17	250,786	-4.33

Source: Mathematical Programming Models Results.

6.3.1.2 Global Level

When irrigation water supply is increased by 5 % of the total water supply, there are changes in the cropping pattern in which the more water consuming crops are increased, as shown in Table 6.19. The effect of increasing water availability on income is more subsistence as shown in Figure 6.2. All farmers are able to meet their subsistence requirements and the cropping patterns also change considerably. Farm income increased because of increased profitable crops such as wheat, clover, rice, and cotton that need more water than others. As a consequence, the total gross margins would increase by LE 911 million, representing 5.13 % above the actual farm income and LE 256.99 million, or 1.50 % more than the basic optimal solution. Compared to separate solutions, there are no significant differences.

On the other hand, the results show that farm income will decrease as water becomes more scarce because more water will be needed for crop production and which less water is available for crop production. As a result, farm income will decrease. Up to certain point, a 15 % decrease in the water available for crop production would make, the models will be infeasible under the given organisation constraints. This implies that the cropping pattern in old lands should be changed dramatically in order to save water for new land projects. With reduced irrigation water supply of 5% of total water supply, there are changes in cropping pattern for the less water requiring crops, as shown in Table 6.19.

Table 6.19 Future Impact of Water Availability on the Area for some Crops

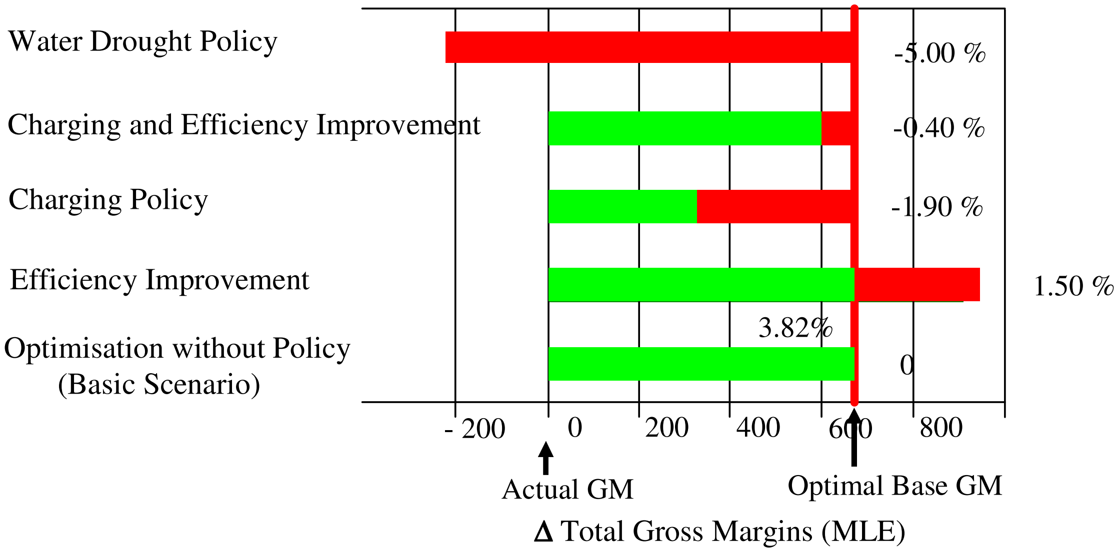
Crop	Existing Area	Basic Scenario (%)	Change in water availability (+5 %)	Change in water availability (-5 %)
Wheat	1,940,295	3.11	-1.18	-1.16
Long Clover	1,641,045	3.64	11.79	-4.76
Summer Maize	1,486,818	11.39	-1.09	3.95
Rice	1,448,563	-1.23	3.79	-5.80
Sorghum	367,297	-12.97	-19.76	-19.69
Cotton	626,468	-17.84	-1.85	-17.84
Sugar Cane	271,974	-5.33	4.53	-5.33

Source: Mathematical Programming Models Results.

By decreasing water supply, the seasonal winter and summer areas declined by 5.13 % and 4.71 % less than the basic solution, and the fallowed lands appeared due to water becoming more scarce. Consequently, areas under most of crops decreased. The alternative with policy option decreased total gross margins by LE 209.41 million, i.e. 5.05 % less than the total gross margins of basic solution without policy option.

One implication from the drought scenario is that when the farmers adjust their cropping patterns their incomes decline. Other implication is that when they irrigate a smaller crop area some crops that have less gross margins are eliminated leaving some land fallow.

Figure 6.2 Economic Impacts of Water Management Strategies on Farm income



6.3.2 Impacts of Water Charging on Crop Production

In the literature, a method for increasing the efficiency of water use is to implement a water charge policy. Therefore, a water charge as a cost recovery strategy is introduced into the basic models to test for the impact of water charging on farm income and crop production. The objective is to recover the costs of irrigation system in the short run (partial operation and maintenance costs) since cost recovery mechanisms have begun receiving increased attention from policy makers in Egypt. It is considered as an approach to help overcome funding shortfalls and generate additional revenue, which could be used to operate and maintain the irrigation system. Setting up a cost recovery in which farmers pay for the maintenance of the irrigation system sensitises the farmers about the importance of water.

Two alternatives of water charging are examined. One is implementing cost recovery without and the other with improving irrigation water distribution efficiency resulting from increasing water availability by 5 %. And in the case of improving water distribution efficiency, the models work under the following assumptions:

- A water charge is introduced under the improvement of water distribution efficiency
- The water charge that is collected by the farmers is used for the operation and maintenance of the irrigation system
- Non–volumetric crop based mechanism of water charging is tested.

The water charge rate is different for each governorate. It was based on a weighted average of per Feddan water consumption for each crop, using the scenario one of ISPAN estimations, which included in the Egyptian working paper by MALR, (2002). There are different rates for Lower, Middle, and Upper Egypt governorates according to the difference in operation and maintenance costs of irrigation water supply.

6.3.2.1 Governorates Level

The seventeen basic models were applied to determine the future impact with and without water charge under two alternatives of “with” and “without” improvement of water distribution efficiency, as shown in Table 6.20. With introduction of water charge policies, the impacts on farm income were negative in all governorates. Also the policies showed no impact on resources uses. Impacts on the cropping patterns were not observed in all the agricultural governorates. The cropping patterns and resource uses under water charge policy without efficiency improvement were the same in the basic models without the water charge.

Table 6.20 Future Impact of Introduction Water Charge “Crop Based” without and with Improvement of Water Distribution Efficiency

Scenarios / Governorate	Basic	Implementing Cost Recovery			
		Without Efficiency Improvement		With Efficiency Improvement	
	Value	Value	Δ %	Value	Δ %
Beharia	2,372	2,340	-1.34	2,373	0.01
Gharbia	1,169	1,151	-1.53	1,175	0.47
Kafr-ElShiekh	1,667	1,637	-1.81	1,663	-0.24
Dakahlia	1,917	1,875	-2.22	1,923	0.30
Damietta	298	291	-2.14	294	-1.14
Sharkia	1,979	1,943	-1.80	1,973	-0.31
Ismailia	381	380	-0.39	387	1.54
Menofia	1,043	1,029	-1.31	1,035	-0.72
Qalyoubia	520	513	-1.35	522	0.46
Giza	633	626	-1.04	642	1.53
Beni Seuf	675	663	-1.69	677	0.40
Fayoum	917	904	-1.51	921	0.43
Menia	1,196	1,169	-2.25	1,180	-1.40
Assuit	891	872	-2.16	878	-1.46
Suhag	1,073	1,057	-1.51	1,072	-0.14
Qena	651	631	-3.10	662	1.71
Aswan	286	276	-3.43	280	-1.96
Total Egypt	17,667	17,356	-1.76	17,657	-0.06

Source: Mathematical Programming Models Results.

Compared to a water charge policy without improving efficiency results, the policy with improving efficiency resulted in less negative impacts on the farm income in all agricultural governorates. Regarding the resource use and cropping pattern, it is to be noted that there was no impact on the resource use and the cropping pattern in all the models. This was the same as improving irrigation efficiency.

The results imply that if water charge policy would guarantee improvement of water distribution efficiency, farm income would increase as the strategy of water distribution efficiency improvement. The purpose of water charge in this case is cost recovery that ensures the improvement of the system by decreasing distribution losses. It is therefore, possible to implement a charging policy "crop based" with the improvement of the irrigation water distribution. The economic impact of water charging was a reduction in farm income as shown in Table 6.20. This reduction resulted from public's return from water fees means a transfer of income from the farmers to the government with the aim of cost recovery.

6.3.2.2 Global Level

Generally, farm income would decrease by introduction of water charging either without or with efficiency improvement, as shown in Figure 6.2. The change in farm income decreased from LE 654 million to LE 311 million (i.e. 1.9 %) below the basic optimal value from the introduction of a water charge without water distribution efficiency improvement. Compared to the basic scenario, the change in farm income decreased to LE 557 million (i.e. 0.40 %). This means that an additional water charge decreased also the farm income gained from improvement in water distribution efficiency. But the improvement of water distribution efficiency resulted in an increase in the farmer ability to pay for irrigation water services, ensuring social objectives (food security and employment are attained). It should be mentioned here that the introduction of the water charging policies had no effect on cropping pattern and water use.

6.4 Conclusion

This chapter developed a methodology that can be used to explore improved management options in irrigated agriculture. This was achieved by developing an LP model that can simulate crop production, policy options and farmer responses. Based on the application of the model, the following conclusions can be drawn:

- Improvement of water distribution efficiency leads to increases in farm income and crop production because adequate water is provided at the right time. More profitable crops that need more water are also cultivated such as different vegetable crops, rice, cotton, and sugar cane.

- Adoption of deficit irrigation strategies is generally difficult and requires not only good planning for irrigation scheduling, but also appropriate evaluation of the economic impacts at the farm level. The strategy had negative impacts on farm income, the irrigated area decreased and fallow lands appeared. The analysis is helpful to support the selection of the optimal irrigation reduction rate to apply for each governorate when water supply is limited.
- Water drought policy is a severe problem since the normal costs of production remain nearly the same under decreased water availability but production losses still occur. It is the direct cost of water drought policy or water scarcity that can be estimated through the calculation of production losses, due to water shortage.
- For future irrigation projects, the non-conventional water sources (recycling drainage water, the reuse of treated wastewater, and drainage water) should be considered as an important element the Water Policy. The Government should also develop new sources of irrigation water before launching of the reclamation project.
- Introducing water charging without increasing water distribution efficiency: Water charging as single tool is not an adequate means of significantly reducing irrigation water consumption. The introduction of water charges generally has no impact on resource use and cropping patterns. Therefore, it indicates that the water charge policy will not produce the desired effects of water conservation in time of water drought.
- Introducing a water charge with increasing water distribution efficiency: Collecting water charges at a level that covers the partial operation and maintenance costs of water supply showed that an additional water charge also decreases the farm income from improvement in water distribution efficiency. However, the income level is still higher than in the proposed strategy of water charging. This offers the opportunity to introduce water charges combined with the increasing water distribution efficiency.
- The models can be used to provide useful information to policy makers about the likely returns from water supply change. They indicate that lower overall farm income will be achieved if water supply is decreased or charged and that higher farm income will be achieved when water supply is increased.
- At policy level, the modelling framework also provides a useful means for testing policy options that affect the availability of water input and its costs. This approach can also be used to examine other farm management options that affect crop yield or crop prices by changing the appropriate coefficients in the basic models.

CHAPTER 7

SUMMERY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 Problem Description and Objectives

Egypt has a per capita availability of renewable fresh water resources of 850 m^3, which is below the poverty line of 1000 m^3 per capita. Water availability per capita is expected to decline further to 650 m^3 by the year 2017. Therefore, the country has to focus on sound water resource management and face the critical challenges in the water sector. On the supply side, Egypt is almost wholly dependent on the Nile water, shared by ten riparian nations. The other sources of water are limited. On the demand side, there is growing competition for water from urban and industrial users, exerting serious pressures on the use of water in agriculture. Moreover, according to the agricultural policy that emphasises augmenting crop production, cultivated land should be increased by about 1.4 million hectares till 2017 in order to feed the growing population and to accomplish higher standards of living.

Due to this increasing water demand caused by a rapidly growing population, agricultural development may be limited. As a result greater emphasis is now being placed on the need to improve the efficiency in the use of the available water resources for crop production. There are many factors to be considered in irrigation management to improve the efficiency in the use of water. One of the key decisions is how much water should be allocated to a particular crop. Against this background, the objective of this study was to determine the optimal cropping patterns to ensure an optimal use of water in agriculture. This study presented a management tool using mathematical models for determining optimal cropping patterns and water allocation systems. Results of the modelling show optimal cropping patterns and the potential to reallocate water resources in an optimal way. The suggested optimal cropping pattern was used as a base to measure the impact of different water policies such as the impact of improvements in irrigation efficiency, water drought, and implementing a water charging policy on farm income and resource uses. The results may provide valuable policy information, which may serve as a guideline in pre-season indicative planning and management for cropping patterns and irrigation water use in the Egyptian agriculture.

7.2 Data and Methodology

This study utilised secondary data obtained from the official statistical institutions: The Ministry of Agriculture and Land Reclamation (MALR), the Ministry of Water Resources and Irrigation (MWRI), and the Central Agency for Public Mobilisation and Statistics (CAPMAS) in Egypt. The data used consisted of crop production (cultivated areas and crop yield), prices of products, and cost of production, crop consumptive use, crop water requirements, irrigation water availability, and availability of cultivated land for the crops.

Linear Programming (LP) model was used to make decisions about irrigation water management options in conjunction with optimal cropping patterns to ensure an optimal utilisation of the available land and water resources. The solution of the LP model was obtained using GAMS modelling language. LP models are essentially static, allocating irrigation water in a single year among different crops in the first stage of mathematical analysis at governorates level and at global level in the second stage. The objective function of the formulated model was to maximise the total gross margins from a cropping pattern selected from crops grown. The constraining variables included water and land availability as well as management constraints. The technical coefficients that quantify resource requirements were determined as average of real values of the three years (1999-2001) based on published and unpublished statistical data from MALR and CAPMAS. Moreover, individual crops are subject to organisation constraints, which are the upper and lower limitations. The upper and lower limitations on corresponding acreage were based upon the maximum and minimum levels of historical cultivation over the period 1997 to 2001 in each governorate.

7.3 Results of Application Models

7.3.1 Optimisation Models of Irrigation Water Use in Egypt

Governorates Level

The aggregated optimal cropping pattern for Egypt suggested that in the winter season, the areas under wheat, long clover, and garlic increased by 0.64 %, 1.33 %, and 20.39 %, respectively. In the summer season, the area under maize and sesame would increase by 8.77 % and 39.51 %, respectively. Due to their high profitability, tomatoes and potatoes recorded sharp increases incorporated in the optimal solution at 41.85 % and 43.56 %, respectively. The area under rice, sorghum, cotton, and sugar cane would decrease by 1.22 %, 9.60 %, 14.70 %, and 3.62 % below their total existing area, respectively.

Total gross margins could increase by 3.01 % above the existing total gross margins through efficient allocation of water use. Water saving was about 0.59 % of the actual water used. Land is fully used in all the studied governorates. Moreover, the suggested plan can help increase cereals self-sufficiency ratios when the areas under wheat and maize crops are increased. It contributes also to increasing cooking oil self-sufficiency ratios through increases in areas under peanut, sesame and maize. The plan also provides the appropriate area to cultivate forages required for increasing animal production through increasing the area under clover. It was found that there has been a small change in the cropping pattern, which might have caused changes in income, accounting marketing and price stability. This is the minimum change that could be achieved in the short run to secure farm income.

The highest shadow prices for water in all regions occurred in the months of April, June, July, October, August, and November. April and November turned out to be the most critical months in all models. The shadow prices showed an increasing tendency in water scarcity over time and space, especially in the Lower Egypt governorates. The model results suggested that the appropriate time for winter closure in Egypt be February.

Global Level

Results for global optimum indicated that in the winter season, areas under wheat and long clover increased by 2.96 % and 5.07 %, respectively. Also, winter tomatoes and chickpeas increased by 50 % and 12.12 % more than the existing area, respectively. In the summer season, the area under summer maize increased by 11.39 %, whereas the rice crop declined slightly by 1.23 % less than its actual cropped area. Due to their high profitability, tomatoes and potatoes recorded sharp increases incorporated in the optimal solution at 46.90 % and 43.52 %, respectively. It was noteworthy that areas under peanut and sesame increased by 27.02 % and 23.98 % above their actual cropped areas, respectively, whereas sunflower crops declined by 30.26 %. The area under cotton decreased by 17.84 %, this quantity could ensure the minimum requirements for raw materials.

The total gross margins at the global level could increase by 3.82 % through efficient allocation of water use. Water saving was about 0.27 % of the actual water used, which was about 28,028.98 million m^3. April and November turned out to be the most critical months in the optimal situation, where an additional unit of water (1000m^3) would increase the total farm income by LE 2,070 in April and LE 4,320 in November.

Generally, comparing the results of the global solution with the totals of separately solution (governorates level) under policy alternative A4, there was no significant differences and no potential for reallocation of irrigation water between governorates due to regional organised constraints. This means that the system of regional water allocation is fairly good.

7.3.2 Future Economic Impacts Analysis of Irrigation Water Management Strategies

An analysis of future policies was carried out using comparative-static planning models. The models estimated the future impact of several water management policies. Results of the various scenarios were as follows:

Impacts of Water Availability Change

Compared to the basic solution, farm incomes and areas under strategic crops increased considerably when the irrigation water supply increased. In the winter season, the areas under tomatoes, squash, green peas, and cabbage increased by 4.71 %, 15.01 %, 35.36 %, and 17.36 % above the basic level, respectively. However, other winter crops decreased below the basic level. In summer and Nili seasons, the areas under summer and Nili maize decreased by 9.37 % and 20.95 %, respectively. The area under rice, cotton, and sugar cane increased by 7.26 %, 15.25 %, and 6.17 %, respectively, above the basic optimal level. Because the cropping pattern changed in favour of more water consuming crops with respect to return, some of vegetable crops increased as a result of increasing water supply. Consequently, total gross margins increased by 1.71 % above the optimal base value.

On the other hand, by decreasing the irrigation water quantity, the cropping pattern changed in favour of the less water consuming crops. Cultivated winter and summer areas would decline by 4.67 % and 4.96 % below the optimal basic level, respectively. This means that fallowed lands appeared, due to water becoming more scarce. Consequently, the areas under most of the crops decreased. Areas under wheat and clover decreased by 2.05 % and 7.13 %, respectively, less than the basic level. Similarly, in the summer season, the area under summer maize and rice declined by 5.77 % and 4.87 % below the basic solution, respectively. And the total gross margins decreased by 5.30 % below the total gross margins of the basic solution without policy option.

Impacts of Water Charging

The basic models were applied to determine future economic impact of policies with and without a water charge under two alternatives; with and without improvement of water distribution efficiency. With introduction of water charge policies the impacts on farm income were negative in all agricultural governorates of Egypt. Also, there was no impact of water charge policies on resources use. No impact on the cropping patterns was found in all the agricultural governorates. The cropping patterns and resource uses under a water charge policy without efficiency improvement were the same as in the basic models without water charge.

Introducing a water charge at a cost recovery with increasing water distribution efficiency showed that water charges decrease the income from the improvement in water distribution efficiency. The introduction of water charges had no impact on water resource use in all regions. Compared to the water charge without improving efficiency results, the water charge with improving water distribution efficiency provided less negative impact on the farm income in all agricultural governorates.

The purpose of a water charge in this study is cost recovery to ensure the improvement of water distribution system thus reducing distribution losses. It is therefore possible to implement a “crop based” water charging policy with improving irrigation distribution efficiency. The economic impact of water charging was a reduction in farm income. This reduction through water fees was a transfer of income from the farmers to the government aimed at cost recovery.

7.4 Conclusions

The main findings of the optimal cropping patterns under actual policies are:

- There is scope for improvement in returns to farm resources in all the agricultural governorates of Egypt through optimisation of irrigation water use.
- Land resources under the suggested alternative (A4) had an optimal use in all agricultural regions.
- Comparison among governorates; the cropping patterns management practised by farmers are fairly good in Behaira, Gharbia, Kafr-El-shiekh, and Damietta governorates in the Lower Egypt zone. On the other hand, water can be used more efficiently in the Middle and Upper Egypt governorates. The sensitivity of total gross margins to change was relatively high in most of the Middle and Upper Egypt governorates.
- Lower Egypt governorates suffered from water scarcity. In some months, water scarcity was observed in regions of Egypt.

- Potential development of irrigation projects will be based on vegetable crops. Traditional crops still contribute to positive economic results, particularly rice and wheat. However agricultural production models oriented more towards vegetable crops that can increase land and water productivity.
- Expanding the area under sugar beet in the delta regions will have a negative impact on water resource development, and put pressure on the water required by the agricultural sector.
- There is no potential for re-allocating irrigation water among Egypt's governorates, meaning that the system of regional water allocation is fairly good.
- Introducing modern irrigation technology like drip irrigation is the only option available in the situation of water savings for new lands.

The main findings of future impact analyses are:

In order to improve water management, different strategies were examined in the short run: increasing water supply through increasing irrigation efficiency, reducing water supply, and introducing water charge policies. Analysis of these future policies was carried out using comparative static planning models. Results of the various scenarios were as follows:

- Improvement of irrigation efficiency leads to increases in farm income and crop production, because more profitable crops that need more water such as different vegetable crops, rice, cotton, and sugar cane are cultivated.
- Adoption of deficit irrigation strategies is generally difficult and requires not only good planning for irrigation scheduling but also appropriate evaluation of the economic impacts at the farm level. The strategy had negative impacts on farm income, irrigated area decreased and fallow lands appeared.
- Introducing water charging without increasing water distribution efficiency. Water charging as a single instrument is not an adequate means of significantly reducing irrigation water consumption. The introduction of water charges generally has no impact on resource use and cropping patterns. This indicates that a water charge policy will not produce the desired effects of conserving water in times of drought.
- Introducing a water charge with increasing water distribution efficiency: Collecting water charges at a level that covers the partial operation and maintenance costs of water supply showed that additional water charges also decrease farm income even under improvement in water distribution efficiency. Under these conditions, the

income level was still higher than under the future strategy of water charging. This offers the opportunity to introduce water charges combined with increasing water distribution efficiency.

- At policy level also, the modelling framework provides a useful means for testing policy options that affect water supply and its costs. This approach can also be used to examine other farm management options that affect crop yield or crop prices, often by changing the appropriate coefficients in the basic models.

7.4 Limitations of the Study and Suggestions for Further Study

The data needed to use all the measures and models discussed in the theoretical chapter were not available to the researcher. The application models were formulated based on the availability of statistical data. The limitations of this study can be summarised as follows:

- The monthly crop water requirements used in this study is based on the theoretical report from Water Management Research Institute in Egypt. A different way to construct the monthly crop water requirement may give different results. Future study may be needed to compare results under different developed monthly crop water requirements data.
- The organised constraints used in this study are also somewhat arbitrary and there is no widely agreed upon standard for constructing such constraints under free agricultural markets. So a different way to develop restrictions on area allocated to each crop in a market economy may yield different results.
- The empirical analysis has not included potential environmental issues (such as salinisation and water logging). Additional work is needed to account for these externalities. Therefore, a dynamic programming approach may be needed that maximises social welfare only at the national level. The dynamic model at the farm level that maximises private welfare is a static model because the farmers neglect the external effects.
- This study assumes that the farmer bases his future plan solely on historical pattern, with a set of projected prices as the expected prices. Once his plan is determined, he carries it out no matter to completion what happens. Information is assumed to be costless. This assumption ignores the possibility that the farmer is also using other information sources such as agricultural extension advice.

7.5 Recommendations

Several recommendations, based on the findings can be made for the future planning and management of irrigation projects. The following are some of them:

- Farmers should be advised to follow the indicative optimal cropping patterns.
- Cultivation of sugarcane in southern regions of Egypt should be reduced based on minimum requirement of raw material for sugar processing plants.
- Cultivation of rice in northern regions should be restricted taking into account the land quality since rice cultivation plays an important role in water-land degradation against sea water intrusion in the northern delta regions.
- The basis for irrigation charges (Cost Recovery) should be crop-based reflecting crop water requirement.
- Water charging should be combined with improved distribution efficiency to increase efficient water use in crop production and so the farmers will be able to pay the collected fees for water services.
- Losses from irrigation systems through evaporation and leakage must be investigated and controlled.
- Regarding new irrigation projects, non-conventional water sources (recycling drainage water, the reuse of treated wastewater and drainage water) should be considered as an important element Water Policy. The Government should develop new sources of irrigation water before launching Reclamation Projects.
- Considering water scarcity and the results of this study, modern irrigation techniques are crucial for the development of agriculture. The Government should encourage investments in new irrigation technologies and improving distribution systems at the farm level by giving the farmers short term loans with low costs. Also, more water saving can be realised through intensive extension programs, with the objective of training farmers in matters such crop water requirements. Such programs would result in increased farmer awareness of optimal uses of water.
- Encouraging the manufacture of drip irrigation equipment needed to provide farmers with low cost micro-irrigation technologies. The use of local materials will minimise the high capital costs for drip irrigation and create employment in rural areas, as this industry is simple and can be built in the rural areas. Moreover, the material for this industry is available using local raw material from the petroleum. It can be gradually

implemented and adopted by the farmers. Drip irrigation leads to reduction in the production costs of grass and pest control especially for vegetables and fruits.

- It is also recommended that effective farm advisory services on the efficient allocation of water resources and appropriate cropping patterns are important and should be built into programs promoting increased agricultural productivity among farmers. Farmers should economise on the use of water and embrace a mixed cropping pattern particularly with less water requirements.
- The applied mathematical model proved to be relatively easy to handle, and has a sufficient level of generality that would allow their use as a decision aid and prognostic tool in any governorate. The model can produce insights for agricultural planners who must allocate scarce water resources among agricultural activities. It also generates estimates of the effects of different water polices. Indeed, water charging, aided by analysis such as provided in this study, could be an appropriate and efficient means of financing irrigation system.
- The implications and conclusions of this study are of relevance not only to Egypt, but could be applied to any irrigated agriculture facing the challenges of increasing crop production, food security, and water allocation.

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Table 1 Number of Land Holding and Area According to Tenure State

Region	Owned		Rented		Sharing		Others		More than one state				
	No	Area	No	Area	No	Area	No	Area	No	Owned Area	Rented Area	Share Area	Others Area
Delta	1,193,414	3,554,692	202,816	425,122	30,361	75,881	8,194	91,475	217,847	346,376	27,0870	59,895	1,056
Upper Egypt	766,249	1,485,361	183,662	246,967	13,929	27,026	2,345	29,393	252,428	424,562	31,9520	26,494	11,793
Desert	8,708	49,797	682	4,979	183	753	27,109	367,328	2,352	12,166	4,252	1,448	2,486
Egypt	1,968,271	5,089,850	387,160	677,067	44,472	103,660	37,648	488,196	472,627	783,104	59,4642	87,837	24,805

Source: MALR, Economic Affairs Sector, Agricultural Economic, Central Administration, Different Issues, 1995-1998.

Area: In Feddan.

Table 2 Number and Holding Area According to Legality of Holders' Type

Region	Total		Persons		Companies		Co-operatives	
	No	Area	No	Area	No	Area	No	Area
Delta	1,652,632	4,834,841	1,051,333	4,209,159	241	290,776	266	61,401
Upper Egypt	1,218,613	2,571,121	1,217,902	2,473,963	123	45,695	107	25,561
Desert	39,034	443,211	38,883	437,061	10	1,639	29	1,467
Egypt	2,910,279	7,849,173	2,908,118	7,120,183	374	338,110	362	88,429

Source: MALR, Economic Affairs Sector, Agricultural Economic, Central Administration, Different Issues, 1995-1998.

Area: In Feddan.

Table 3 Number of Farm and Area According to Irrigation Sources

Region	Total area		Nile water		Groundwater		Drain water		Rain water		Other Sources	
	No	Area	No	Area	No	Area	No	Area	No.	Area	No.	Area
Delta	1,646,471	4,481,404	1,601,848	4,037,689	27,370	306,842	25,605	129,427	2,366	7,381	79	62
Upper Egypt	1,217,654	2,484,208	1,149,927	2,239,254	100,235	239,763	2,127	4,942	-	-	172	247
Desert	39,003	260,077	4,918	32,963	14,904	66,938	-	-	18,554	254,208	3,122	5,966
Egypt	2,903,128	7,325,689	2,756,693	6,309,906	142,509	613,543	27,732	134,369	20,920	261,589	3,373	6,275

Source: MALR, Economic Affairs Sector, Agricultural Economic, Central Administration, Different Issues, 1995-1998.

Area: In Feddan.

Table 4 Number of Farm and Area According to Drainage Types

Region	Total area		Open Drainage & Lateral drain		Open drainage		No lateral drain		Tail drainage	
	No	Area	No	Area	No	Area	No	Area	No	Area
Delta	1,646,471	4,481,404	424,405	1,634,963	43,346	136,311	1,086,705	2,051,864	116,610	658,265
Upper Egypt	1,217,654	2,484,208	225,141	512,851	100,774	177,934	459,044	889,671	491,486	903,751
Desert	39,003	260,077	8,388	45,920	1,254	4,687	1,531	9,186	29,856	300,284
Egypt	2,903,128	7,325,689	657,934	2,193,734	145,574	318,932	1,547,280	2,950,721	637,952	1,862,300

Source: MALR, Economic Affairs Sector, Agricultural Economic, Central Administration, Different Issues, 1995-1998.

Area: In Feddan.

Table 9 Cropping Patterns and their Irrigation Water Requirements at the Field Level during 1999-2001

Region / Crop	Lower Egypt					
	Cropped Area			Water Quantity		
Crop	Feddan	%	%	1000 m^3	%	%
Wheat	1,166,687.67	33.62	15.60	1,708,030.67	28.34	7.91
Bean	209,795.67	6.05	2.81	239,167.00	3.97	1.11
Barley	24,013.00	0.69	0.32	30,280.67	0.50	0.14
Fenugreek	7,646.33	0.22	0.10	8,716.67	0.14	0.04
Lupine	2,317.33	0.07	0.03	2,966.00	0.05	0.01
Chickpeas	365.33	0.01	0.00	448.67	0.01	0.00
Lentil	616.33	0.02	0.01	789.00	0.01	0.00
Short Clover	455,213.00	13.12	6.09	403,318.67	6.69	1.87
Long Clover	1,153,743.00	33.24	15.43	2,830,131.67	46.95	13.11
Flax	11,780.00	0.34	0.16	13,735.67	0.23	0.06
Onion	25,678.00	0.74	0.34	40,982.00	0.68	0.19
Sugar Beet	110,293.67	3.18	1.47	208,565.00	3.46	0.97
Garlic	3,242.33	0.09	0.04	3,770.67	0.06	0.02
Med. Plants	2,182.00	0.06	0.03	2,946.00	0.05	0.01
Others	39,991.00	1.15	0.53	57,707.00	0.96	0.27
Vegetables	256,898.33	7.40	3.44	476,033.00	7.90	2.21
Total Winter	3,470,459.67	100.00	46.41	6,027,588.33	100.00	27.93
Cotton	506,790.00	14.98	6.78	1,450,939.67	11.09	6.72
Rice	1,432,131.67	42.33	19.15	7,906,799.00	60.43	36.63
Maize	850,926.00	25.15	11.38	2,148,588.00	16.42	9.96
Soybean	566.67	0.02	0.01	1,363.67	0.01	0.01
Sugar cane	4,093.67	0.12	0.05	25,700.00	0.20	0.12
Sesame	7,883.67	0.23	0.11	17,107.33	0.13	0.08
Peanut	24,916.67	0.74	0.33	84,268.00	0.64	0.39
Onion	7,184.33	0.21	0.10	36,691.67	0.28	0.17
Sunflower	5,823.33	0.17	0.08	10,994.67	0.08	0.05
Green Fodder	87,753.67	2.59	1.17	259,136.67	1.98	1.20
Med. Plants	2,133.67	0.06	0.03	8,912.33	0.07	0.04
Others	48,918.33	1.45	0.65	105,125.33	0.80	0.49
Vegetable	403,678.33	11.93	5.40	1,041,490.33	7.96	4.83
Total Summer	338,3134.00	100.00	45.24	13,085,159.00	100.00	60.63
Maize	11,2872.67	50.19	1.51	233,307.67	51.99	1.08
Rice	237.67	0.11	0.00	1,403.00	0.31	0.01
Others	33,707.00	14.99	0.45	40,933.00	9.12	0.19
Vegetables	77,980.00	34.68	1.04	172,959.33	38.54	0.80
Total Nili	224,886.67	100.00	3.01	448,770.33	100.00	2.08
Fruits	399,595.00		5.34	2,021,429.00		9.37
Total Crops	7,478,075.33		100.00	21,582,946.67		100.00

Table 9 Continued,

Region / Crop	Middle Egypt					
	Cropped Area			Water Quantity		
	Feddan	%	%	1000 m^3	%	%
Wheat	450,433.67	41.24	18.59	730,152.67	34.39	11.45
Bean	19,618.00	1.80	0.81	24,032.00	1.13	0.38
Barley	10,794.33	0.99	0.45	13,687.00	0.64	0.21
Fenugreek	13,285.00	1.22	0.55	16,274.33	0.77	0.26
Lupine	814.67	0.07	0.03	1,137.00	0.05	0.02
Chickpeas	1,077.33	0.10	0.04	1,422.00	0.07	0.02
Short Clover	77,276.33	7.08	3.19	77,044.33	3.63	1.21
Long Clover	346,469.67	31.72	14.30	949,673.00	44.73	14.90
Onion	20,939.33	1.92	0.86	37,460.33	1.76	0.59
Sugar Beet	13,600.33	1.25	0.56	28,818.67	1.36	0.45
Garlic	19,294.67	1.77	0.80	30,693.00	1.45	0.48
Med. Plants	31,640.33	2.90	1.31	47,333.67	2.23	0.74
Others	1,003.00	0.09	0.04	1,477.33	0.07	0.02
Vegetables	85,939.33	7.87	3.55	167,151.67	7.87	2.62
Total Winter	1,092,202.33	100.00	45.08	2,123,046.00	100.00	33.30
Cotton	88,850.33	9.37	3.67	285,564.67	9.36	4.48
Rice	26,852.33	2.83	1.11	190,248.67	6.23	2.98
Maize	485,796.67	51.22	20.05	1,408,324.67	46.14	22.09
Sorghum	83,151.67	8.77	3.43	212,120.00	6.95	3.33
Soybean	11,772.67	1.24	0.49	32,928.00	1.08	0.52
Sugar cane	34,787.33	3.67	1.44	248,381.67	8.14	3.90
Sesame	11,910.00	1.26	0.49	29,799.00	0.98	0.47
Peanut	9,815.33	1.03	0.41	39,536.33	1.30	0.62
Onion	7,079.67	0.75	0.29	26,873.33	0.88	0.42
Sunflower	20,351.67	2.15	0.84	44,895.67	1.47	0.70
Green Fodder	46,849.67	4.94	1.93	158,726.33	5.20	2.49
Med. Plants	4,165.67	0.44	0.17	19,953.67	0.65	0.31
Others	300.67	0.03	0.01	682.33	0.02	0.01
Vegetables	116,787.67	12.31	4.82	354,100.33	11.60	5.55
Total Summer	948,518.00	100.00	39.15	3,052,326.00	100.00	47.88
Maize	134,425.33	49.01	5.55	312,942.33	51.71	4.91
Sorghum	10,560.67	3.85	0.44	19,283.67	3.19	0.30
Rice	258.67	0.09	0.01	1,680.00	0.28	0.03
Onion	4,789.00	1.75	0.20	13,313.33	2.20	0.21
Sunflower	663.00	0.24	0.03	1,330.00	0.22	0.02
Others	44,272.00	16.14	1.83	60,126.33	9.93	0.94
Vegetables	79,290.00	28.91	3.27	196,560.00	32.48	3.08
Total Nili	274,258.67	100.00	11.32	605,235.67	100.00	9.49
Fruits	107,986.33		4.46	594,373.67		9.32
Total Crops	2,422,965.33		100.00	6,374,981.33		100.00

Table 9 Continued,

Region / Crop	Upper Egypt					
	Cropped Area			Water Quantity		
	Feddan	%	%	1000 m^3	%	%
Wheat	370,579.00	49.39	20.60	744,122.67	42.22	11.13
Bean	24,907.33	3.32	1.38	40,051.00	2.27	0.60
Barley	4,043.67	0.54	0.22	6,579.33	0.37	0.10
Fenugreek	4,031.67	0.54	0.22	6,483.00	0.37	0.10
Lupine	976.00	0.13	0.05	1,778.00	0.10	0.03
Chickpeas	16,830.33	2.24	0.94	29,166.67	1.65	0.44
Lentil	4,180.00	0.56	0.23	7,616.00	0.43	0.11
Short Clover	38,189.67	5.09	2.12	49,952.33	2.83	0.75
Long Clover	208,157.33	27.74	11.57	717,102.00	40.69	10.73
Onion	9,152.67	1.22	0.51	21,023.33	1.19	0.31
Sugar Beet	236.33	0.03	0.01	624.00	0.04	0.01
Garlic	1,698.67	0.23	0.09	3,100.33	0.18	0.05
Med. Plants	7,699.67	1.03	0.43	12,411.67	0.70	0.19
Others	2,708.67	0.36	0.15	4,293.00	0.24	0.06
Vegetables	56,878.67	7.58	3.16	451,583.67	25.62	6.76
Total Winter	750,269.67	100.00	41.71	1,762,553.67	100.00	26.37
Cotton	35,794.00	3.79	1.99	131,185.00	2.94	1.96
Maize	252,679.00	26.76	14.05	836,620.67	18.74	12.51
Sorghum	284,342.33	30.11	15.81	833,975.67	18.68	12.48
Soybean	490.67	0.05	0.03	1,574.67	0.04	0.02
Sugar cane	261,769.00	27.72	14.55	2,268,663.67	50.82	33.94
Sesame	16,739.67	1.77	0.93	48,310.33	1.08	0.72
Peanut	7,774.33	0.82	0.43	34,502.67	0.77	0.52
Onion	700.00	0.07	0.04	2,796.33	0.06	0.04
Sunflower	9,817.33	1.04	0.55	24,572.67	0.55	0.37
Green Fodder	28,901.00	3.06	1.61	115,546.00	2.59	1.73
Med. Plants	4,607.00	0.49	0.26	26,209.33	0.59	0.39
Others	1,456.67	0.15	0.08	3,669.33	0.08	0.05
Vegetables	38,807.67	4.11	2.16	134,585.00	3.01	2.01
Total Summer	944,328.67	100.00	52.50	4,464,475.00	100.00	66.78
Maize	33,540.33	54.60	1.86	94,583.67	57.09	1.41
Sorghum	300.33	0.49	0.02	687.00	0.41	0.01
Onion	2,797.67	4.55	0.16	9,604.00	5.80	0.14
Others	11,894.00	19.36	0.66	20,062.00	12.11	0.30
Vegetables	12,902.33	21.00	0.72	40,732.67	24.59	0.61
Total Nili	61,434.67	100.00	3.42	165,669.33	100.00	2.48
Fruits	42,665.33		2.37	292,326.33		4.37
Total Crops	1,798,698.33		100.00	6,685,024.33		100.00

Table 9 Continued,

Region / Crop	Total Egypt					
	Cropped Area			Water Quantity		
	Feddan	%	%	1000 m^3	%	%
Wheat	1,987,700.33	37.41	16.99	3,182,306.00	32.10	9.19
Bean	254,321.00	4.79	2.17	303,250.00	3.06	0.88
Barley	38,851.00	0.73	0.33	50,547.00	0.51	0.15
Fenugreek	24,963.00	0.47	0.21	34,807.33	0.35	0.10
Lupine	4,108.00	0.08	0.04	5,881.00	0.06	0.02
Chickpeas	18,273.00	0.34	0.16	34,371.00	0.35	0.10
Lentil	4,809.33	0.09	0.04	8,423.00	0.08	0.02
Short Clover	570,679.00	10.74	4.88	533,682.00	5.38	1.54
Long Clover	1,708,370.00	32.15	14.60	4,496,906.67	45.36	12.98
Flax	11,783.33	0.22	0.10	17,073.33	0.17	0.05
Onion	55,770.00	1.05	0.48	99,499.00	1.00	0.29
Sugar Beet	124,130.33	2.34	1.06	238,141.00	2.40	0.69
Garlic	27,569.00	0.52	0.24	34,230.67	0.35	0.10
Med. Plants	41,522.00	0.78	0.35	62,691.33	0.63	0.18
Others	43,702.67	0.82	0.37	63,477.33	0.64	0.18
Vegetables	399,716.33	7.52	3.42	761,435.00	7.68	2.20
Total Winter	5,312,935.00	100.00	45.41	9,913,188.00	100.00	28.62
Cotton	631434.33	11.97	5.40	1,867,689.33	9.07	5.39
Rice	1,458,984.00	27.65	12.47	8,097,047.67	39.30	23.37
Maize	1,589,401.67	30.13	13.58	4,393,533.33	21.33	12.68
Sorghum	367,494.00	6.97	3.14	1,046,095.67	5.08	3.02
Soybean	12,830.00	0.24	0.11	35,866.33	0.17	0.10
Sugar cane	300,650.00	5.70	2.57	2,542,745.33	12.34	7.34
Sesame	36,533.33	0.69	0.31	95,216.67	0.46	0.27
Peanut	42,506.33	0.81	0.36	158,307.00	0.77	0.46
Onion	13,962.33	0.26	0.12	49,691.33	0.24	0.14
Sunflower	35,992.33	0.68	0.31	80,463.00	0.39	0.23
Green Fodder	163,504.33	3.10	1.40	533,409.00	2.59	1.54
Med. Plants	10,906.33	0.21	0.09	55,075.33	0.27	0.16
Others	5,0675.67	0.96	0.43	109,478.67	0.53	0.32
Vegetable	559,273.67	10.60	4.78	1,530,175.67	7.43	4.42
Total Summer	5,275,980.67	100.00	45.09	20,601,960.00	100.00	59.47
Maize	280,838.33	50.10	2.40	640,833.67	52.54	1.85
Sorghum	10,861.00	1.94	0.09	19,970.67	1.64	0.06
Rice	496.33	0.09	0.00	3,083.00	0.25	0.01
Onion	7,668.00	1.37	0.07	23,071.00	1.89	0.07
Others	89,873.00	16.03	0.77	121,121.33	9.93	0.35
Vegetables	170,172.33	30.36	1.45	410,252.00	33.64	1.18
Total Nili	560,580.00	100.00	4.79	1,219,675.33	100.00	3.52
Fruits	550,246.67		4.70	2,908,129.00	100.00	8.39
Total Crops	11,699,742.33		100.00	34,642,952.33		100.00

Source: CAPMAS, Irrigation and Water Resources Bulletin, Various Issues.

Table 10 Monthly Crop Consumptive Water Use (m³/Feddan) for Lower Egypt Zone

Crop Month	Jan.	Feb.	Mar.	Apr.	May	Juni	Juli	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Winter Crops													
Wheat	176.40	231.00	403.20	441.00	142.80	0.00	0.00	0.00	0.00	0.00	29.40	184.80	1608.60
Broad Bean	205.80	289.80	378.00	180.60	0.00	0.00	0.00	0.00	0.00	0.00	54.60	172.20	1281.00
Barley	0.00	335.00	273.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	390.00	410.00	1408.00
Fenugreek	212.00	245.00	284.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	259.00	1000.00
Lupine	210.00	230.00	280.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	260.00	980.00
Chickpeas	212.00	240.00	290.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.00	1012.00
Lentil	189.00	357.00	152.20	0.00	0.00	0.00	0.00	0.00	0.00	58.80	201.60	378.00	1336.60
Short Clover	222.60	264.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	180.60	210.00	877.80
Long Clover	222.60	264.60	394.80	596.40	491.40	0.00	0.00	0.00	0.00	0.00	184.80	210.00	2364.60
Flax	357.00	378.00	147.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	189.00	336.00	1407.00
Onion	323.40	319.20	445.00	323.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	218.40	1629.40
Garlic	218.40	121.80	67.20	54.60	0.00	0.00	0.00	0.00	84.00	285.60	226.80	305.40	1363.80
W. Vegetables	218.40	121.80	67.20	54.60	0.00	0.00	0.00	0.00	84.00	285.60	226.80	302.40	1360.80
Other W. Plants	336.00	378.00	210.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	189.00	1113.00
Summer and Nili Crops													
Cotton	0.00	0.00	113.40	231.00	516.60	646.80	743.40	386.40	180.60	0.00	0.00	0.00	2818.20
Rice	0.00	0.00	0.00	0.00	21.00	130.20	1289.00	1457.00	1424.00	369.60	0.00	0.00	4690.80
S. Maize	0.00	0.00	0.00	0.00	201.20	558.60	843.40	693.40	133.60	0.00	0.00	0.00	2430.20
Soybean	0.00	0.00	0.00	0.00	466.20	819.00	583.80	151.20	0.00	0.00	0.00	0.00	2020.20
Sesame	0.00	0.00	0.00	0.00	261.70	428.40	507.80	504.00	345.70	0.00	0.00	0.00	2047.60
Peanut	0.00	0.00	0.00	0.00	480.00	565.00	1066.00	1248.00	0.00	0.00	0.00	0.00	3359.00
Other S. Plants	0.00	0.00	0.00	0.00	138.60	483.00	537.60	428.40	411.60	71.40	0.00	0.00	2070.60
S. Vegetables	0.00	0.00	46.20	268.80	348.60	403.20	294.00	176.40	189.00	127.40	71.40	0.00	1925.00
Nili Maize	0.00	0.00	0.00	0.00	0.00	0.00	247.80	688.80	739.20	466.20	109.20	0.00	2251.20
Nili Vegetables	0.00	0.00	0.00	0.00	0.00	0.00	37.80	218.40	420.00	390.60	289.80	184.80	1541.40

Table 10 Continued, Monthly Crop Consumptive Water Use (m³/Feddan) for Middle Egypt Zone

Crop Month	Jan.	Feb.	Mar.	Apr.	May	Juni	Juli	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Winter Crops													
Wheat	265.40	328.00	557.30	485.10	70.98	0.00	0.00	0.00	0.00	0.00	47.46	242.30	1996.54
Broad Bean	272.20	302.40	500.20	101.60	0.00	0.00	0.00	0.00	0.00	0.00	143.80	248.60	1568.80
Barley	0.00	495.00	325.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	480.00	500.00	1800.00
Fenugreek.	230.00	265.00	300.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	285.00	1080.00
Short Clover	247.80	352.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	235.20	256.20	1092.00
Long Clover	247.80	352.80	541.80	663.60	550.20	0.00	0.00	0.00	0.00	0.00	234.00	252.00	2842.20
Onion	315.00	373.80	466.20	378.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	189.00	1722.00
Garlic	117.60	67.20	71.40	58.80	0.00	0.00	0.00	29.40	210.00	394.80	373.80	285.60	1608.60
Vegetables	117.60	67.20	71.40	58.80	0.00	0.00	0.00	29.40	210.00	394.80	373.80	285.60	1608.60
Other W. Plants	420.00	399.00	273.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	126.00	1218.00
Summer and Nili Crops													
Cotton	0.00	0.00	127.70	390.60	664.00	806.40	915.20	429.70	207.60	0.00	0.00	0.00	3541.20
Rice	0.00	0.00	0.00	0.00	21.00	130.20	1289.40	1457.00	1424.00	369.90	0.00	0.00	4691.50
Maize	0.00	0.00	0.00	0.00	205.80	638.40	940.80	680.40	147.00	0.00	0.00	0.00	2612.40
Sorghum	0.00	0.00	0.00	0.00	194.30	620.10	930.00	660.80	140.00	0.00	0.00	0.00	2545.20
Soybean	0.00	0.00	0.00	0.00	575.40	945.00	890.40	176.40	0.00	0.00	0.00	0.00	2587.20
Sugar Cane	195.30	294.00	428.40	516.60	716.10	768.60	859.30	950.50	894.60	690.10	541.80	312.50	7167.80
Sesame	0.00	0.00	0.00	0.00	300.00	520.00	550.00	520.00	365.00	0.00	0.00	0.00	2255.00
Peanut	0.00	0.00	0.00	0.00	500.00	580.00	1200.00	1400.00	0.00	0.00	0.00	0.00	3680.00
Vegetables	0.00	16.80	92.40	142.80	260.40	697.20	432.60	201.60	184.80	197.40	117.60	0.00	2343.60
Other S. Crops	0.00	0.00	0.00	0.00	260.40	697.20	432.60	201.60	184.80	197.40	117.60	0.00	2091.60
Nili Maize	0.00	0.00	0.00	0.00	0.00	0.00	147.00	520.80	609.00	527.60	474.60	113.40	2392.40
Nili Vegetables	0.00	0.00	0.00	0.00	21.00	100.80	260.40	403.20	344.40	277.20	197.40	0.00	1604.40

Table 10 Continued, Monthly Crop Consumptive Water Use (m³/Feddan) for Upper Egypt Zone

Crop Month	Jan.	Feb.	Mar.	Apr.	May	Juni	Juli	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Winter Crops													
Wheat	319.20	429.20	572.90	491.40	0.00	0.00	0.00	0.00	0.00	0.00	92.42	290.20	2195.32
Broad Bean	310.00	449.40	519.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	241.90	306.20	1827.00
Barley	0.00	530.00	494.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	550.00	580.00	2154.00
Fenugreek	264.50	304.80	345.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	327.80	1242.10
Lupine	253.00	310.50	345.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	333.50	1242.00
Chickpeas	264.50	304.80	356.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	345.00	1270.80
Lentil	420.00	420.00	294.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	168.00	315.00	1617.00
Short Clover	273.00	399.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	243.60	273.00	1188.60
Long Clover	274.70	418.70	625.40	700.60	587.20	0.00	0.00	0.00	0.00	0.00	241.90	272.20	3120.70
Onion	315.00	373.80	466.20	378.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	189.00	1722.00
Garlic	420.00	399.00	273.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	84.00	126.00	1302.00
Vegetables	117.60	67.20	71.40	58.80	0.00	0.00	0.00	29.40	210.00	394.80	373.80	285.60	1608.60
Other W. Plants	420.00	399.00	273.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	126.00	1218.00
Summer Crops													
Cotton	430.00	521.60	620.80	836.60	976.50	494.80	0.00	0.00	0.00	0.00	0.00	0.00	3880.30
Maize	0.00	0.00	0.00	0.00	243.60	688.80	999.60	735.00	138.60	0.00	0.00	0.00	2805.60
Sorghum	0.00	0.00	0.00	0.00	0.00	428.40	806.40	961.80	554.40	0.00	0.00	0.00	2751.00
Soybean	0.00	0.00	0.00	0.00	661.70	1087.00	1024.00	202.90	0.00	0.00	0.00	0.00	2975.60
Sugar Cane	352.80	415.80	575.40	1016.20	1100.40	1276.80	1243.20	1050.00	844.20	583.80	390.70	260.40	9109.70
Sesame	0.00	0.00	0.00	0.00	345.00	598.00	632.50	598.00	419.80	0.00	0.00	0.00	2593.30
Peanut	0.00	0.00	0.00	0.00	575.00	667.00	1380.00	1610.00	0.00	0.00	0.00	0.00	4232.00
Sunflower	0.00	0.00	0.00	0.00	214.20	596.40	646.80	638.40	529.20	0.00	0.00	0.00	2625.00
Vegetables	0.00	16.80	92.40	142.80	260.40	697.20	432.60	201.60	184.80	197.40	117.60	0.00	2343.60
Other S. Plants	0.00	0.00	0.00	0.00	214.20	596.40	646.80	638.40	529.20	0.00	0.00	0.00	2625.00

Source: MWRI, NWRC; WMRI, Unpublished Data.

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