DETERMINING OPTIMAL ALLOCATION AND CROP PATTERN IN EGYPT BY THE USE OF LINEAR PROGRAMMING

LA DETERMINATION DE L'ALLOCATION OPTIMALE ET DE L'ASSOLEMENT CULTURAL EN EGYPTE PAR L'UTILISATION DE LA PROGRAMMATION LINEAIRE

By Hesham M. Ali and Mohamed R. Mahmoud

Granada
Spain
1999

1999

Prize - Winning paper for Dr. Hassan Ismail Memorial International Award for Young Professionals

Presented at the 7th Nile 2002 Conference
Cairo, Egypt, 1999

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ABOUT THE AUTHORS

The 4th Dr. Hassan Ismail Memorial International Award, 1999 has been jointly awarded to Mr. Hesham M. Ali and Mr. Mohamed R. Mahmoud for their paper "Determining Optimal Allocation and Crop Pattern in Egypt by the use of Linear Programming" which they jointly presented at the 7th Nile 2002 Conference held in Cairo in March 1999.

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The two authors have been awarded by President, ICID a citation plaque each and prize money of US $ 1000 shared between them, at the 17th International Congress held at Granada, Spain from 11-19 September 1999.

INTERNATIONAL COMMISSION
ON IRRIGATION AND DRAINAGE

Seventeenth Congress
Granada 1999

Best Paper for
4th Hassan Ismail Award

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Hesham M. Ali[1] Mohamed R. Mahmoud[2]

ABSTRACT

The Nile River is the main source of water in Egypt. According to the 1959 Sudan treaty, Egypt has a quota of 55.5 billion cubic meters of Nile water per year. Eighty six percent of Egypt's quota of water goes to agriculture, and demand is increasing, due to agricultural expansion and other factors. In addition to the rapidly increasing population, the two great new projects in north Sinai and south valley will demand an annual water volume of more than 9 billion cubic meters per year. Egypt is facing the challenge of increasing water demand by implementing different projects and strategies to conserve water and develop its water resources. Irrigation Improvement Project, Reuse of Drainage Water, and

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Groundwater Development are some of these projects. Reducing the highly water consumptive crop areas is another alternative to conserve water.

Crop consumptive use depends on many factors. Two of these factors are the temperature and humidity which differ in Egypt considerably from north to south. Making use of this folumina, this study determines the optimal allocation of the different cultivated crops in Egypt. The actual crop pattern of year 1993 is chosen to be compared with the optimal crop pattern of that year. A linear programming mathematical model is developed. Different alternatives have been investigated where the crop areas are constrained to differ from the actual areas within a certain limits. The amount of irrigation water saved in each alternative is estimated.

RESUME

Le Nile est la principale source de l'eau en Egypte. D'après le traité de Soudan de 1959, l'Egypte a un quota de 55,5 billion mètres cubes de l'eau du Nile par an. Quatre vinght six pourcent du quota de l'eau de l'Egypte va pour l'agriculture, et la demande est augmentée à cause de l'expansion de l'agriculture et des autres facteurs. En addition à l'augmentation rapide de la population, les deux grands nouveaux projets au Nord du Sinai et au Sud du Vallée va demander un volume d'eau annuel de plus de 9 billion mètres cubes par an.

L'Egypte affronte le défi de l'augmentation de la demande de l'eau par l'exécution de differents projets et les stratégies pour conserver l'eau et developper ses ressources. Le projet de l'amélioration de l'irrigation et la réutilisation de l'eau de drainage, et le developpement des eaux souterraines sont parmi ces projets. La réduction des régions des récoltes qui consomment une grande quantité d'eau et une autre alternative pour la conservation de l'eau. L'utilisation de la consommation des récoltes dépend de plusieurs facteurs. Deux de ces facteurs sont la temperature et l'humidité qui different en Egypte considerablement du Nord au Sud. En utilisant ce folumina, cette étude determine cette optimale allocation de differents récoltes cultivées en Egypte. Le système optimal des récoltes de cet an. Un model mathématique de programmation linéaire est developpé. De differentes alternatives ont été examinées car les régions de récoltes sont contraintes d'ètre différentes de régions actuelles par certaines limites. La quantité de l'eau de l'irrigation sauvée dans chaque alternative a été estimée.

INTRODUCTION

Water management in irrigated agricultural areas is the most important way to get the optimal crop yield with the optimal use of the available water resources. The two main limits for increased agricultural production are the availability of additional cultivable land and the adequate irrigation water. Agriculture consumes about 85% of Egypt water resources.

Due to shortage of irrigation water, the optimal allocation of crop area in irrigated agriculture could be considered. Crop consumptive use depends on many factors. Two of these factors are the temperature and the humidity, which differ considerably from north to south Egypt. Taking into consideration this folumina, the optimal allocation and crop pattern of the different cultivated crops in Egypt have been determined. Seven cases have been studied where the crop areas have been allowed to be changed from the actual areas.

A linear programming mathematical model is developed and the amount of irrigation water is estimated in each case. Development of mathematical models to generate optimal irrigation policies has been performed by researchers since 1970. Most of optimization models adopted linear programming (LP) and dynamic programming (DP). The use of LP is limited that the object function and constraints are linear.

MODEL FORMULATION

The object function of the crop area allocation model is to minimize the amount of irrigation water used. As the object function and the constraints are of the linear form, a linear programming model can be used. The linear programming technique is utilized to determine the optimal allocation of the cultivated crops taking into consideration the specified constraints. The Egyptian agricultural land is divided into three main regions : Upper (u), Middle (m), and lower (l). Each region is characterized with its climate and consequently its crop consumptive use.

Objective Function

$$Min\ z = \frac{1}{E_1}\left(\sum_{i=1}^{c_w} C_d \times W_{il}\right) + \frac{1}{E_m}\left(\sum_{i=1}^{C_w} C_{im} \times W_{im}\right) + \frac{1}{E_u}\left(\sum_{i=1}^{C_w} C_{iu} \times W_{iu}\right) + \frac{1}{E_1}\left(\sum_{i=C_w+1}^{C_w+C_s} Cd \times W_{il}\right)$$
$$+ \frac{1}{E_m}\left(\sum_{i=C_w+1}^{C_w+C_s} C_{im} \times W_{im}\right) + \frac{1}{E_u}\left(\sum_{i=C_w+1}^{C_w+C_s} C_{im} \times W_{im}\right)$$

Where :

Z = Irrigation water volume

C_w = No. of winter crops

C_s = No. of summer nili crops

E_t = Lower Egypt irrigation efficiency

E_m = Middle Egypt irrigation efficiency
E_u = Upper Egypt irrigation efficiency
C_{il} = Area of crop No. i Cultivated in Lower Egypt
C_{im} = Area of crop No. i cultivated in Middle Egypt
C_{iu} = Area of crop No. i cultivated in Upper Egypt
W_{il} = Water consumptive use of crop i cultivated in Lower Egypt
W_{im} = Water consumptive use of crop i cultivated in Middle Egypt
W_{iu} = Water consumptive use of crop i cultivated in Upper Egypt

Constraints

The object function is subject to the following constraints :

$$\sum_{i=1}^{C_w} C_{il} = A_{l1}$$

$$\sum_{i=C_w+1}^{C_w+C_s} C_{il} = A_{l2}$$

$$\sum_{i=1}^{C_w} C_{im} = A_{m1}$$

$$\sum_{i=C_w+1}^{C_w+C_S} C_{im} = A_{m2}$$

$$\sum_{i=1}^{C_w} C_{iu} = A_{u1}$$

$$\sum_{i=C_w+1}^{C_w+C_S} C_{im} = A_{m2}$$

$$C_{il} \times A_i \le C_{il} + C_{im} + C_{iu} \le C_{i2} \times A_i ,$$

$$i = 1 \rightarrow C_w + C_s$$

Where :

A_{l1}, A_{ml},And A_{u1} are the available winter agricultural areas in lower, middle, and Upper Egypt while A_{l2}, A_{m2} and A_{u2} are the available Summer and Nili agricultural areas

$C_{il} \times A_i$ = minimum allowable area of crop *i*

$C_{i2} \times A_i$ = maximum allowable area of crop *i*

A_i = Total actual crop *i* area

MODEL APPLICATION

The model is used to determine the optimal allocation and the crop pattern of the different crops in Egypt. The actual crop pattern of the year 1993 is used to be compared with the optimal crop pattern. The total cultivated area and the cultivated areas of lower, middle, and Upper Egypt are kept without change. The areas of the different crops within the three regions will be allowed to change so that the optimal allocation of these crops is determined. Different cases will be studied where the total area of each crop is allowed to change within a certain limits. These limits include : 100%, 95% - 105%, 90% - 110%, 80% - 120%, 70% - 130%, 60% - 140%, 50% - 150%.

The optimal allocation of the crop areas and amount of water volume saved in each case will be determined. Table (1) shows the crop consumptive use in lower, middle, and upper Egypt while Table (2) shows the actual crop pattern in year 1993. Winter crops are the crops from No. 1 to 14 while Summer and Nili crops are the others.

Assuming the same irrigation water efficiency in lower, middle, and upper Egypt, the object function can be written as :

$$Min\ \ Z = \sum_{i=1}^{14} C_{il} \times W_{il} + \sum_{i=1}^{14} C_{im} \times W_{im} + \sum_{i=1}^{14} C_{iu} \times W_{iu} +$$

$$\sum_{i=15}^{28} C_{il} \times W_{il} + \sum_{i=15}^{28} C_{im} \times W_{im} + \sum_{i=15}^{28} C_{iu} \times W_{iu}$$

Subject to :

$$\sum_{i=1}^{14} C_{il} = A_{l1}$$

$$\sum_{i=15}^{28} C_{il} = A_{l2}$$

$$\sum_{i=1}^{14} C_{im} = A_{m1}$$

$$\sum_{i=15}^{28} C_{im} = A_{m2}$$

$$\sum_{i=1}^{14} C_{iu} = A_{u1}$$

$$\sum_{i=15}^{28} C_{iu} = A_{u2}$$

Table 1. Crop Consumptive Use

Crop No.	Crop Name	Crop Consumptive Use (m^3/feddan)		
		Lower Egypt	Middle Egypt	Upper Egypt
1.	Wheat	1608.6	1996.6	2195.3
2.	Horse Beans	1281	1588.8	1827
3.	Barly	1408	1800	2154
4.	Fenugreek	1000	1080	1242
5.	lupine	980	1080	1242
6.	Check peas	1012	1105	1270.8
7.	Lentiles	1335	1503.6	1617
8.	Clover, short	877.8	1092	1188.6
9.	Clover, full	2364.6	2842.2	3120.7
10.	Flax	1407	1512	1550
11.	Onion, winter	1629.4	1722	1722
12.	Garlic	1360.8	1608.6	7608.6
13.	Winter veg.	1360.8	1608.6	1608.6
14.	Other winter plants	1113	1218	1218
15.	Cotton	2818.2	3541.5	3881.2
16.	Rice	4691.4	4691.4	5395.1
17.	Maize, summer	2430.2	2612.4	2805.6
18.	Sorgum, summer	2338	2545.2	2751
19.	Say beans	2020.2	2587.2	2975.4
20.	Sesame	2047.6	2255	2593.3
21.	Groundnuts	3399	3680	4232.2
22.	Summer veg.	1925.2	2343.6	2343.6
23.	Other summer plant	2070.6	2402.4	2625
24.	Maize, Nili	2251.2	2310	2370
25.	Sorgum, Nili	2178.6	2256.8	2340
26.	Nile vegetables	1541.4	1604.4	1670
27.	Gardents	4014.8	4141	5418
28.	Sugarcane	—	7167.8	9190.6

Table 2. Actual Crop Pattern in Year 1993

Crop No.	Area (Feddan)		
	Lower Egypt	Middle Egypt	Upper Egypt
1.	1051853	382582	394797
2.	102095	48988	50295
3.	44831	11717	5453
4.	970	10789	3207
5.	3475	2002	1989
6.	1216	595	18537
7.	6489	355	10697
8.	586346	10382	45915
9.	1160295	340524	168027
10.	28553	369	0
11.	12941	11588	4554
12.	3519	13675	1421
13.	284362	88239	87741
14.	3110	31322	12075
15.	660915	158615	64780
16.	1254452	21843	0
17.	946658	421965	226908
18.	0	48921	284607
19.	9151	28048	6095
20.	11418	14697	28747
21.	15567	10184	5518
22.	285009	104885	28980
23.	86587	43679	26415
24.	113471	156138	41336
25.	0	11571	468
26.	61122	65496	13057
27.	382207	91346	46722
28.	0	37249	236508
Total	7116612	2260944	1814846

$$C_{il} \times A_i \leq C_{il} + C_{im} + C_{iu} \leq C_{i2} \times A_i$$

$$i = 1 \rightarrow 28$$

$$C_{28i} = 0$$

Where :

A_{l1} = 3290055 feddan
A_{l2} = 3826557 feddan

A_{m1} = 1046307 feddan
A_{m2} = 1214637 feddan
A_{u1} = 804708 feddan
A_{u2} = 1010141 feddan

RESULT ANALYSIS

The linear programming Model is solved to determine the optimal allocation of the 28 crops in lower, middle, and upper Egypt. Seven different cases have been studied where both the minimum and maximum allowed total crop area is changed from the actual crop area cultivated in the year 1993 these cases are :

1. C_{i1}, C_{i2} = 100%, 100%
2. C_{i1}, C_{i2} = 95%, 105%
3. C_{i1}, C_{i2} = 90%, 110%
4. C_{i1}, C_{i2} = 80%, 120%
5. C_{i1}, C_{i2} = 70%, 130%
6. C_{i1}, C_{i2} = 60%, 140%
7. C_{i1}, C_{i2} = 50%, 150%

Figures 1 - 3 show the actual and the optimal crop allocation in lower, middle, and upper Egypt for the seven different cases. It is clear from these figures that the allocation and the distribution of all the crops have been changed from the actual case. The cultivated area of these crops with high consumptive use has been decreased while those with low consumptive use have been increased.

The main objective of this study is to minimize the irrigation water used through the optimal allocation of the crop area. The total water volume saved in the seven cases have been estimated. Assuming irrigation efficiency 0.65, Figure 4 shows the total water volume saved in the seven cases. It is clear that the total water volume saved ranges between 0.974 billion m^3 and 8.185 billion m^3.

CONCLUSION AND RECOMMENDATION

A linear programming mathematical model has been developed to determine the optimal allocation and the crop pattern of an agricultural area to minimize the amount of the irrigation water used. The model is applied on the agricultural area of Egypt considering that it is divided into three regions; lower, middle, and upper Egypt. The optimal crop area allocation is determined for the year 1993. Seven different cases have been studied where the crop area has been allowed to change within a certain limits.

The results show that a considerable amount of water volume can be saved. The saving is increased by increasing the limits within which the crop area is

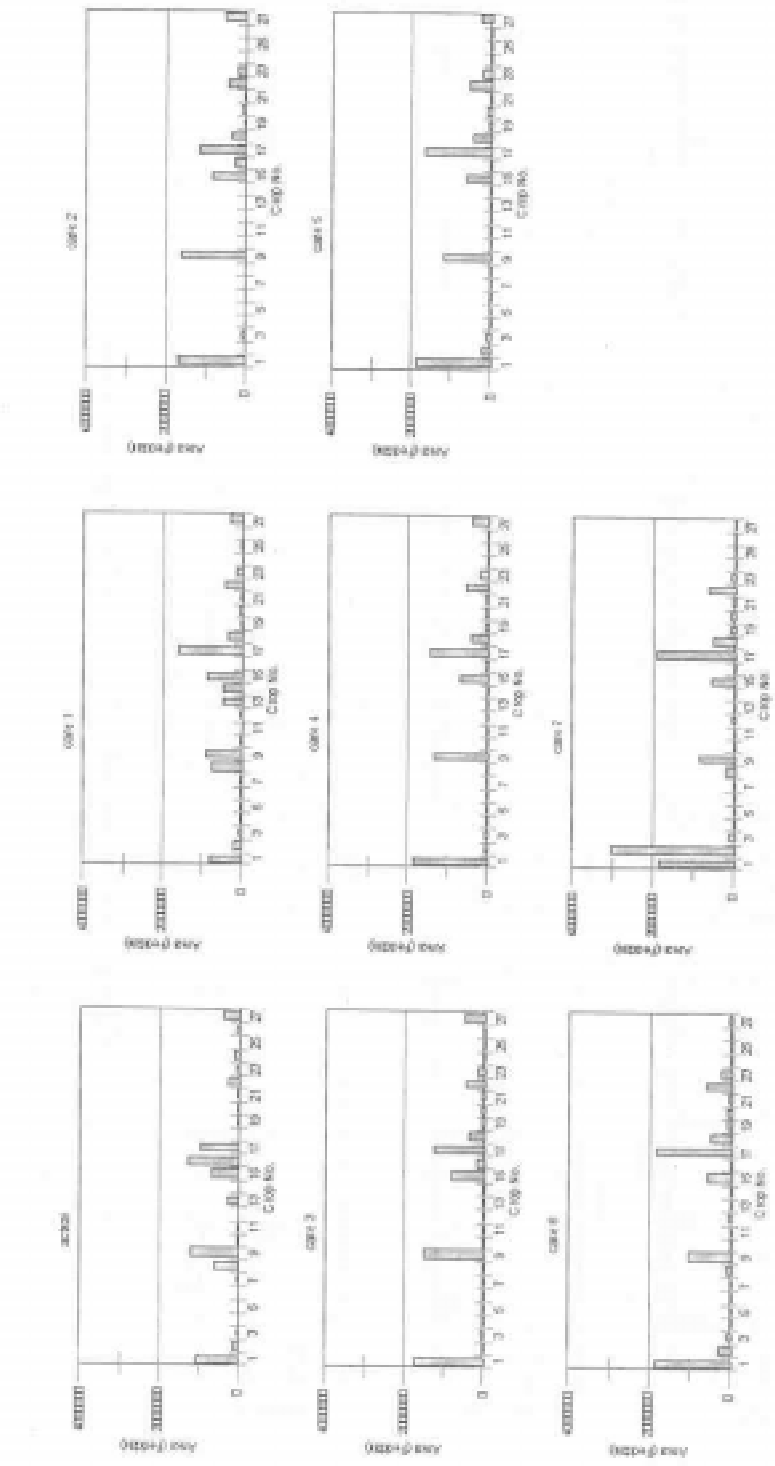

Figure 1. Actual and optimal crop allocation (Lower Egypt)

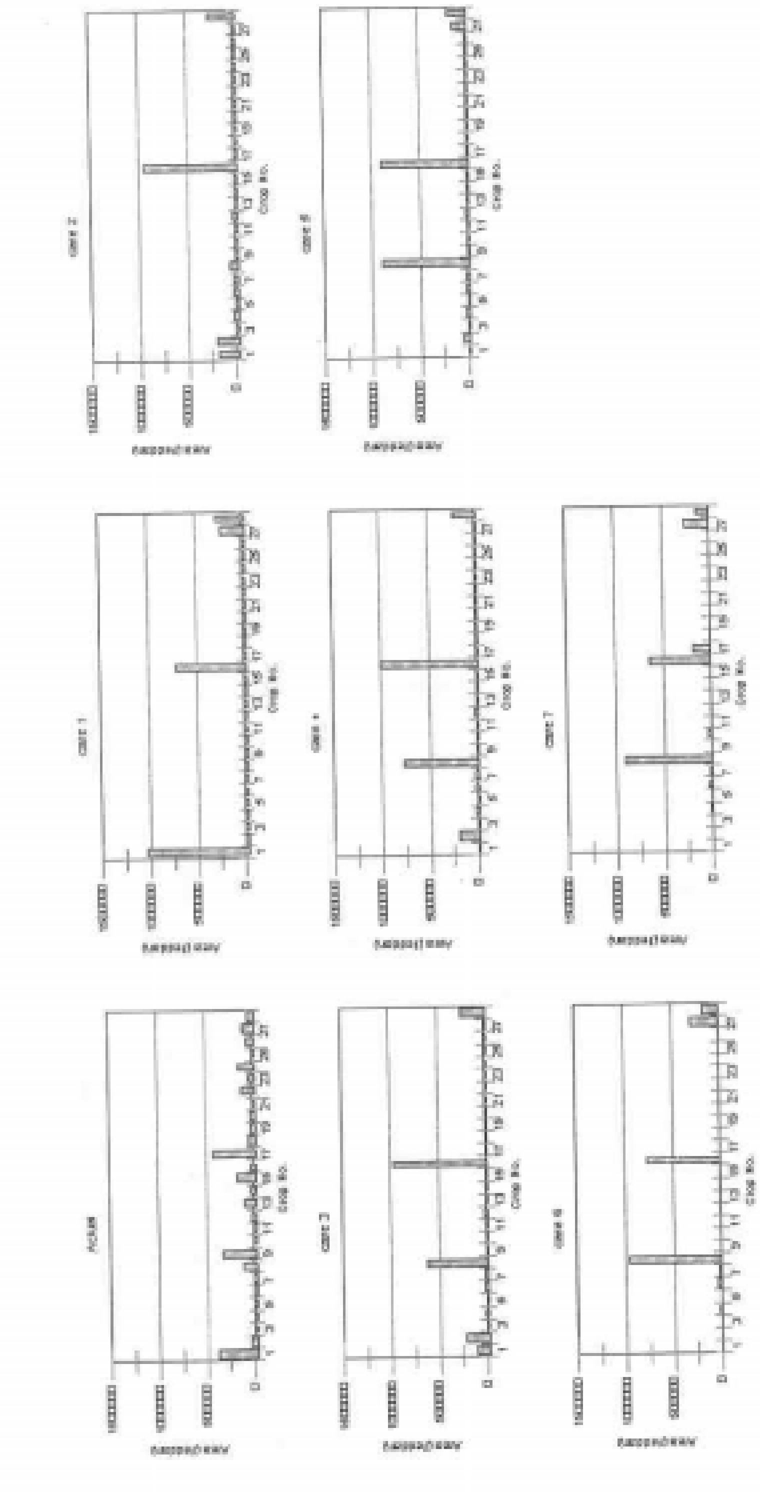

Figure 2. Actual and optimal crop allocation (Middle Egypt)

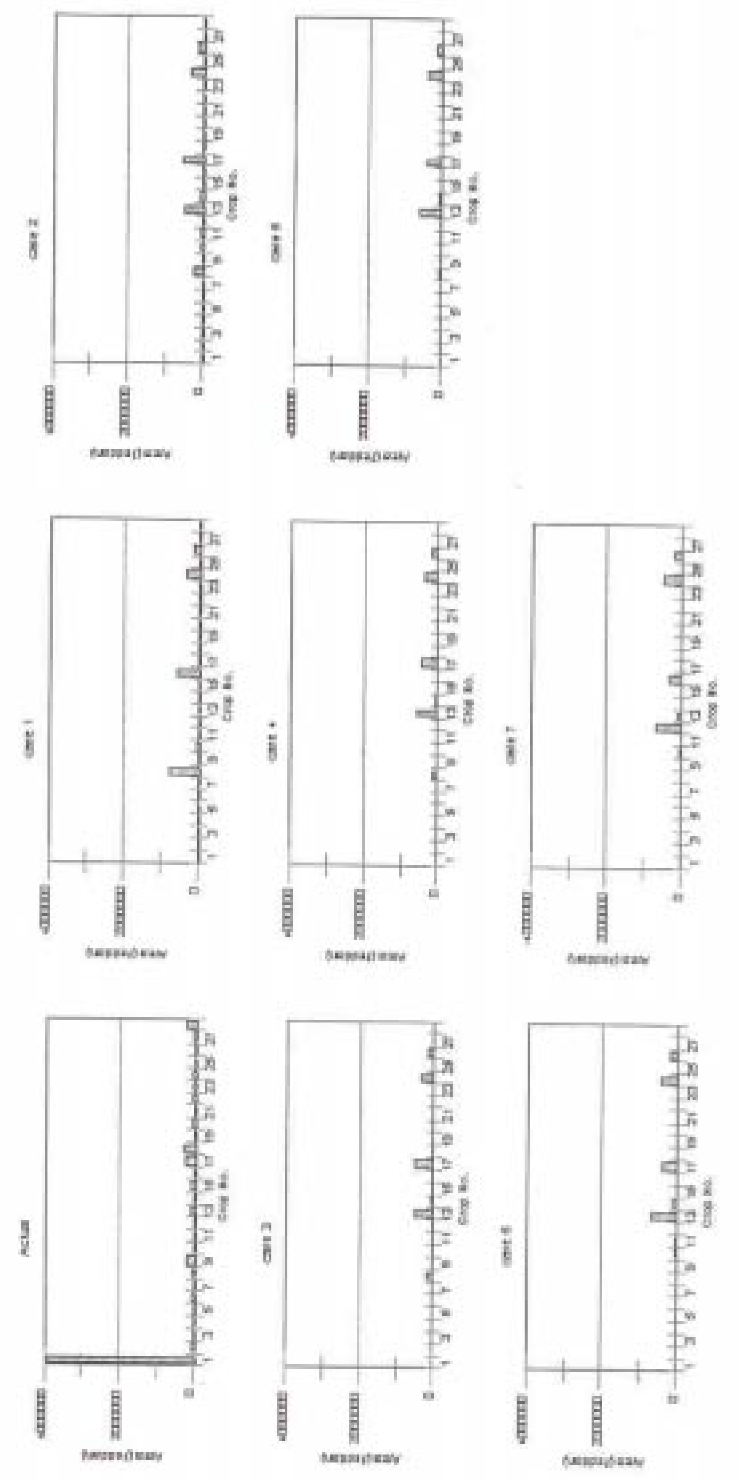

Figure 3. Actual and optimal crop allocation (Upper Egypt)

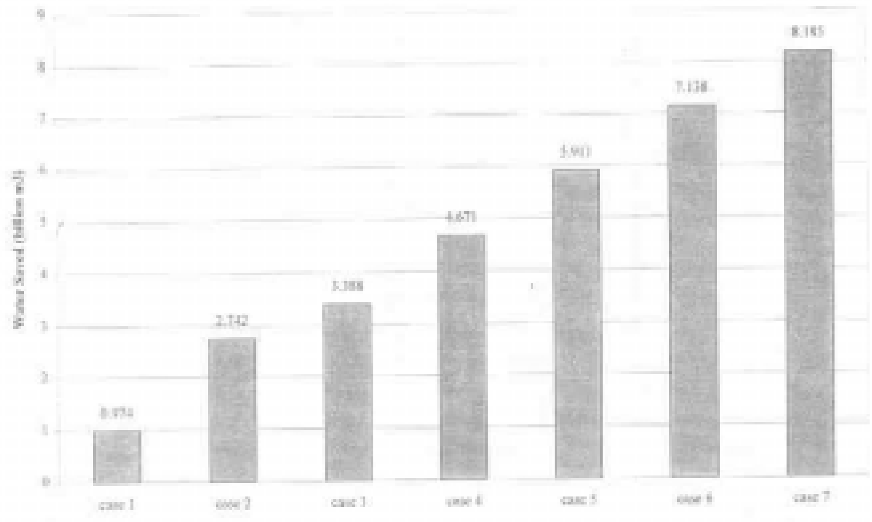

Figure 4. Water volume saved in the seven different cases

allowed to change. The water volume saved is estimated to be about 8.185 billion m^3 when the crop area are allowed to change between 0.5 and 1.5 the actual cultivated crop area. This study helps to cultivate the total agricultural area in Egypt when there is a shortage of the irrigation water.

It is recommended that a further study to be conducted to investigate the economic of applying this model and a study to be conducted on another different years.

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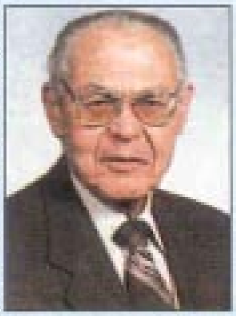

Late Dr. Hassan M. Ismail was a highly respected national and international personality. He was Professor of Hydraulics and Dean of Faculty of Engineering, Cairo University. Later he became the President of Cairo University, President of the Academy of Science, Egypt and Minister of Higher Education. He was also the President of the leading consultancy firm PACER and member of several international organizations, associations and societies. Dr. Ismail Hassan dedicated his entire life to the development of science and to educating generations of irrigation and drainage engineers in Egypt. He firmly believed in the role of ICID in ensuring international cooperation in the advancement of the world knowledge and experience in irrigation and drainage. Dr. Ismail had a great faith in young professionals, especially from Africa to carry out creative work in water management and sustainable development in irrigated agriculture.

Dr. Hassan Ismail was the Chairman of the Egyptian National Committee on Irrigation and Drainage for about 16 years.

"The Dr. Hassan M. Ismail Memorial International Award" has been established with effect fro the 16th ICID Congress at Cairo in 1996 to be awarded to a young professional for the best paper on the development of irrigation, drainage and flood control in Africa, submitted to an ICID Congress or ICID's Afro-Asian Regional Conference or an African Conference.

The award is made from the proceeds of a fund established by the Egyptian National Committee with donations from the family of Dr. Hassan Ismail and his admirers.

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