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Khyal Model: A New Approach of Optimum Integrated Management and Allocation of Water Resources Tool within Water Scarcity in Egypt

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Abstract: Egypt has been exposed to serious water crises. The per capita water share is 600 $m^3 year^{-1}$, less than water poverty limit, which will be more decreased due to the construction of Great Ethiopian Dam. The problem is how Egypt safeguards its water requirements for rapidly growing of population; potable, industry and agriculture that is still needed to expand that, socially, is very important issue of finding jobs for agricultural labor to prevent their immigration to urban centers creating additional increased population density problems. To achieve these main targets, integrated water resources management and optimum cropping patterns procedure must be applied to attain the high benefit of our water resources, which can cultivate the strategic crops and crops of low irrigation water consumption and import crops that consume much water. Therefore, *KHYAL MODEL* has been originated by the author with multi systems of flow concerned to define and develop an integrated methodology to activate the optimum use of limited several water resources available in Egypt to maximize the irrigation water revenue as a key need for proper water management, with simulating its conveyance and distribution in irrigation network. These concepts have been applied as a study case, El-Nasr Canal Region (NCR) of about 210, 000 hectares, located on northern west of Nile Delta, Egypt. The model consists of six sub-models, with time horizon of a complete year and ten days' intervals; *DEMAND, SUPPLY, MATCH, WATER YIELD, WATER COST and MANAGEMENT & OPTIMIZATION* sub-models. The model estimates the daily water demand and supply as well as determines the matching between demand and supply at branch canal intakes. The model calculates the accumulated cost of conveying and lifting of irrigation water including construction, working and maintenance costs and estimates the net-benefit of irrigation water unit (IWU) for each crop at each branch canal. In addition, two sub-models have been developed for water management and linear programming to determine the optimum cropping pattern, considering economical and social approach. The study revealed that the main problem of irrigation in NCR is the mismatch between supply and demand on time & quantity on annual and daily basis. This caused some problems in land irrigation and affected, inversely, crop productivity; therefore, it is recommended that Ministry of Water Resources and Irrigation (MWRI) would supply irrigation water with respect to the actual crop water requirements and the existing cropping pattern at appropriate times. The study indicated that the rotational flow regime is better than continuous one in minimizing annual water conveyance losses in both lined and earthen canals; besides, winter tomatoes, winter potatoes and banana crops are the highest of net-benefit of IWU, while sugarcane, summer onion, rice and summer sorghum crops are the lowest; in addition, meat production that is depending on irrigated green provender is more expensive in water policy aspects. Therefore, the study recommends importing public meat requirements. Although wheat crop has low net-benefit of IWU, the study recommends planting in such reasonable level to conserve national independence and to insure essential food requirements in Egypt.

Key words: Allocation of water resources · Continuous and rotational flow regimes · Conveyance and lifting cost · Demand and supply mismatch · El-Nasr Canal · Optimum water resources management · Pumped or gravitational canals · Net-Benefit of irrigation water unit

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INTRODUCTION

Preamble: The objective of a National Water Policy is normally to “Generate the maximum possible economic value for the nation”. Under water scarcity situations water should be allocated so that users who generate higher value of income per cubic meter of water are given priority over those who generate less income. Therefore, each user must compare the value of water with the “*Opportunity Cost*” of alternative uses.

Water Policies in Egypt: In Egypt, with the permanent water scarcity caused by its fixed water budget, the sharp increase in population and the increased standard of living, which increase the pressure on the water systems, Egypt started to review its strategies, policies and programs in order to overcome its existing circumstances and to prepare for the future. The growing population and related industrial and agricultural activities has increased the demand for water to a level that reaches the limits of the available supply. To relieve the pressure on the Nile Valley and Nile Delta the government has started a program to increase the inhabited area in Egypt by means of horizontal expansion projects in agriculture and the creation of new industrial areas and cities in the desert. All these developments require water. The main challenge of the country is how Egypt can safeguard its water resources in the future under the critical conditions. According to rapidly growing of Egyptian population and changing in cultures and attitudes it was realized that the country can never depend solely on agriculture. Therefore, to increase the standard of living of its population heavy industry, other industries, services and tourism came to the country's agenda as advanced priorities. The amount of potable water and industrial requirements come up to almost 25% of Egypt's share of the Nile water. Obviously this amount has to be *deducted* from the share of agriculture that is still needed to expand in order to cover the requirements of 1.25 million new Egyptian born every year. In addition, agricultural expansion, socially, is very important issue of finding jobs for agricultural labor to prevent their immigration to urban centers creating additional increased population density problems. To achieve this main target *optimum cropping patterns* procedure must be applied to attain the high benefit of our water resources, which can cultivate the strategic crops and crops of low irrigation water consumption and import crops that consume much water, taking into consideration that current major imports in Egypt are wheat, maize, sugar, oil, red meat, fish and milk. It is remarkable that after adopting the economic liberalization policies, the cropped pattern in Egypt has changed, according to profit maximization from the point of view the farmers. Consequently, for the above situation of fresh water limitations in NCR, a linear programming model for decision-makers was formulated in *spreadsheet* using *SOLVER Numerical tool of Microsoft Excel (ver. XP).* This is to suggest the optimal water allocation *among branch canals* due to the optimal cropping pattern to maintain the social constraints on the Egyptian fields and optimum use of the lands, with regarding the sources of water, the network capacity and its locations in order to give the maximum net return at different water availability levels.

Overview: Egypt has about 1.0 million square kilometers of land, but the area that Egyptians inhabit on is only 4.0 % of its gross area located on Nile Valley and Nile Delta, while the other 96% is barren desert. Egypt is now exposed to serious problem of the need to increase the growth rate in agricultural production in order to match the annual rate of population, which is estimated at about 90.0 million in 2016 and the total cultivated land is 3.27 million hectares [1, 2]. The per capita of cultivated land stands now at 0.04 hectare, while, it was 0.2 hectare in 1950 [3]. Egypt, practically, is a semi-arid country, which depends on the Nile River to irrigate its lands and other water requirements, such as: municipal, industry, navigation requirements. Nile River provides Egypt with about 97.0 % of its water requirements, while the remaining 3.0 % comes from ground water and rainfall. Egypt has a fixed share of fresh water from the Nile River, which is limited by the agreement between Egypt and Sudan in 1959, the share of Egypt is fixed of 55.5 billion (m^3/year) at Aswan. Therefore, the average annual per capita share of fresh water in Egypt is about 600 m^3. This amount is less than 1000 m^3 per capita which is considered as the "*water poverty limit*".

Egypt Water Budget: Egypt water budget consists of the following resources: *1) Nile surface water* that is fixed of 55.5 billion (m^3/year) at Aswan; *2) ground water abstraction*, which exist in the aquifer in the Western Desert, which is about 7.2 billion m^3/year [4]; *3) reuse of drainage water*, which the annual quantity of drainage water is about 13.31 billion m^3/year in 1998 go to the Mediterranean Sea and the coastal lakes [5, 6]. Whereas the amount of the drainage water that has been reused in the southern part of the Nile Delta is about 8.1 billion m^3/year; *4) rainfall* that is estimated at about 1.5 billion m^3/year [6]. Otherwise, the effective rainfall is estimated at about 1.25 billion m^3/year [7]. The precipitation ranges from 100-200 mm/year along the Mediterranean coast [8], the average rainfall is roughly 50 mm/year in the Nile Delta, 25 mm/year in the Middle Egypt and 10 mm/year in the Upper Egypt [6]; and 5) *Reuse of treated sanitary sewage* that is estimated about 1.1 billion m^3/year. Otherwise, the water requirements are: *1) Agricultural Sector*, which the annual quantity is about 58.1 billion m^3/year; *2) Domestic demands* are about 4.8 billion m^3/year, with average annual growth rate 7.4%; *3) Industrial Sector*, which the annual quantity is about 7.6 billion m^3/year, with average annual growth rate 5.2% [6]; *4) Evaporation from Fish Farming* that its amount is estimated about 0.4 billion m^3/year; *5) Evaporation from Irrigation Network* that its amount is estimated about 2.1 billion m^3/year; and *6) Hydro-power generation & Navigation requirements* are about 0.2 billion m^3/year [4].

Problem Identification: The Egyptian population by the year 2050 will exceed 150 million capita. At the present level of per capita share of municipal and domestic water supply, the country will need a minimum of 10 billion (m^3/year). The growing industry will require almost a similar quantity. Agriculture will be left with 30-35 billion m^3/year. If the cultivated land by 2050 is as planned (11 million feddan at cropping intensity of 200%), this amount of water will not be sufficient unless changes take place, simply because the average irrigation water quantity per feddan would be 3000 m^3/year; half as much as the existing level of 6000 m^3/feddan/year [9]. It seems as if it is now at the right time to take important decisions with respect to the country's future water policy. Certainly Egypt can not continue with "*Water Development Policy*" defined as "Actions affecting the increase of quantities of water available for distribution and use" which was applied up till now aiming at satisfying all expected future requirements with extra quantities of water allocated directly by default to agriculture. This is simply because of the fact that agricultural requirements have now reached the limit that unless additional quantities of water are made available to increase the water budget, in this case agriculture has to allow for other activities to cut from its share. In other words, the country will move towards the direction of "*Water Allocation Policy*", where actions will be taken to distribute the given quantity of water among different users and uses. Allocation will be based on "*Integrated Water Resource Management*" and in this case titles like more crops per drop, more Job per drop and more care per drop will come into the picture. Concerning the more crops per drop approach the country has to consider seriously decisions of the following nature; how can the cropping pattern be divided between different agro-climatic regions, between human nutrition, animal feed and fish farming and between old lands and new lands. Therefore, water allocation related to *optimum cropping patterns* procedure must be applied to attain the high benefit of our water resources, which can cultivate the strategic crops and crops of low irrigation water consumption and import crops that consume much water [10], taking into consideration the available water for agriculture will be decreased to satisfy the increasing of potable, industrial & tourism water requirement.

The Objectives: The general target of this study is to define and develop an integrated methodology to activate the optimum use of several water resources available in Egypt to maximize the irrigation water revenue as a key need for proper water management by: 1) Setting-up an integrated methodology for available water resources in irrigation management; 2) Setting a computational model to estimate the daily water requirements for multi purpose use for the irrigation network; 3) Evaluation of the current applied water resources management in quantity and on timing (*the response efficiency of Irrigation Directorate in its management of available water resources*); 4) Determination of the mismatch between water demand and supply to overcome irrigation network problems; and 5) Setting an optimization model to maximize the water unit benefit taking into account the irrigation water cost and suggested cropping pattern.

The Study Area (NCR): Egypt is subdivided into three main agro climatic zones; Upper Egypt, Middle Egypt and Lower Egypt or Nile Delta. The Nile Delta region is subdivided into three regions; the Eastern, the Middle and the Western Nile Delta. The boundaries between these regions are the two Nile Branches; Rosetta branch and Damietta branch. The study area as a portion of North West Delta, is situated between the north latitudes of 30° 15\ N to 30° 35\ N and east longitudes of 29° 30\ E to 30° 15\ E covering an area of about 2100 km^2. NCR is located west of El-Noubaria Canal as shown in Fig. 1. NCR can be categorized into four distinct areas with its own particular topographic features, irrigation methods and soil types, as shown in Table 1 [11]; (1) Part 1 from branch canal No. 1

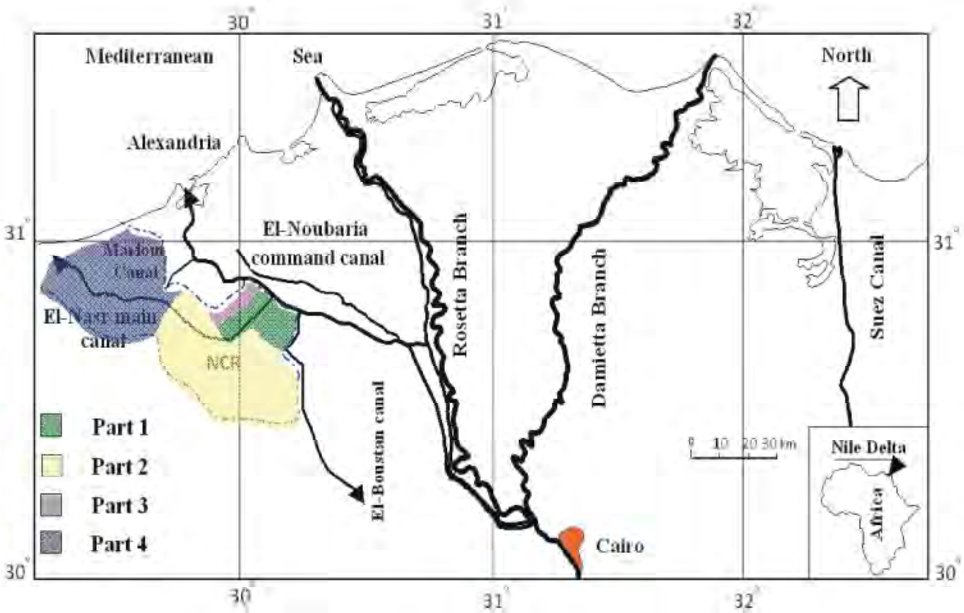


Fig. 1: General View of Nile Delta region

(*BRCR1*) on km (2.500) to branch canal No. 5 (*BRCR5*) on km (18.700), is a silt clayey sandy soil (medium) with Electrical Conductivity of soil solution extract (EC_{ss}) is 1.23 mmhos/cm (*1.0 mmhos/cm = 640 ppm*) and surface irrigation method is applied; (2) Part 2 from branch canal El-Rash El-Sharkkia (*ERASHBRC*) on km (20.100) to surface irrigation branch canal (*SURFIRRBRC*) on km (38.550), is a loamy sandy soil (light) of EC_{ss} 2.72 mmhos/cm and modern irrigation system is applied, which sand represent about 90 % of soil texture; (3) Part 3 for Mechanized farm feeder (*MECFARMFED*) branch canal on km (30.850), is a silt clayey sandy soil (medium) of EC_{ss} 4.56 mmhos/cm [12] and surface irrigation method is applied; and (4) Part 4 from branch canal project No. 1 (*PBRCR1*) on km (49.200) to the end of El-Nasr canal (*NASRCEND*) on km (82.330), is calcareous soil (medium) of EC_{ss} 4.56 mmhos/cm and surface irrigation method is applied, which the soil contains a calcium carbonate of 20 - 40 % and PH No. is 8 - 8.5 [13].

In addition, the average monthly values of wind speed, sun shine hours, m aximum temperature, minimum temperature and relative humidity for January are 5.04 m/sec, 6.1 hours, 18.7°C, 7.7°C and 68 % respectively, but for July they are 6.32 m/sec, 12.3 hours, 33.0°C, 20.4°C and 67 % respectively for the study area [14]. The main irrigated crops grown in NCR during winter season are wheat, berseem, bean, sugar beet, barely, potatoes and tomatoes, while those of summer are maize, tomatoes, watermelon, sunflower, groundnuts and potatoes, besides, planted fruits in NCR are banana, apple, grapes and mandarin. Irrigation water is diverted to El-Nasr Canal at km (57.500) at its left side of El-Noubaria Canal as shown in Fig. 1. The average annual discharge of El-Nasr Canal is 2.035 billion m^3 [15]. The main source of irrigation water at NCR is El-Nasr Main Canal, which it is considered to be the oldest lined canal in Egypt. El-Nasr canal and its branches, except branch canal Bahig feeder (*BAHIGFED*), are lined with plain concrete. A cascade of 5 pump stations is used for raising water upgrade. The total lift of 5 pump stations is about 60 m. The network of NCR consists of 45 branch canals, as shown in Table 1. The irrigation water salinity of El-Nasr canal is about 0.65 and 0.73 m. mhos/cm in winter and summer respectively [16]. There is neither directly official reuse of drainage water nor ground water abstraction [17, 18, 19]. The main canal and its branches network are designed and operated by MWRI that supplies water assuming 24-hour irrigation, with assuming a constant daily water duty of surface and developed irrigation systems to be 30 & 22 (m^3/fed/day) respectively, without consideration of crop physiology, growth stage & actual cropping pattern. The flow in branch canals is rotational flow regime (RFR). The prevailing water supply in NCR is surface fresh water fed from Nile River. During water resources limitation, in most cases, irrigation demand & supply mismatch occurs. Therefore, at water scarcity like the current situation in Egypt, an optimum use of the water resources and accurate estimation of irrigation water demand are so essential.

Table 1: The location (kilo), area served, electrical conductivity (EC_{soil}), irrigation methods, soil types, the designed discharge, the working days (IW) and closing days (IU) for branch canals supplied from El-Nasr main canal

C	Branch Canal	Kilo. (km.)	Side	Area served (feddan)	(EC_{soil}) (mmohs/cm)	Irrigation method	Soil type	Des. Disch. (m^3/sec)	IW day	IU day
1	BRCR1	2.500	Right	800	1.23	Surface	Medium	0.2778	6	8
2	BRCL1	3.450	Left	5000	1.23	Surface	Medium	1.7361	6	8
3	BRCR2	7.200	Right	6400	1.23	Surface	Medium	2.2222	365	0
4	BRCL2	11.500	Left	7000	1.23	Surface	Medium	2.4306	365	0
5	BRCR3	11.550	Right	4200	1.23	Surface	Medium	1.4583	6	8
6	BRCL3	12.550	Left	6000	1.23	Surface	Medium	2.0833	365	0
7	BRCR4	12.750	Right	6500	1.23	Surface	Medium	2.2569	365	0
8	BRCR5	18.700	Right	8000	1.23	Surface	Medium	2.7778	365	0
9	ERASHBRC	20.100	Left	34000	1.23	Developed	Light	8.6574	6	1
10	BRCR6	20.650	Right	10040	1.23	Surface	Light	3.4861	365	0
11	IRRINTL	20.750	Left	250	2.72	Developed	Light	0.0637	365	0
12	IRRINTR	21.900	Right	1800	2.72	Developed	Light	0.4583	365	0
13	PUMPSTA301	23.550	Right	1000	2.72	Developed	Light	0.2546	365	0
14	WRASHBRCL1	24.300	Left	20000	2.72	Developed	Light	5.0926	365	0
15	PUMPSTA302	25.825	Right	1200	2.72	Developed	Light	0.3056	365	0
16	WRASHBRCR2	28.300	Left	2500	2.72	Developed	Light	0.6366	365	0
17	ASSOCIAFED	28.800	Left	10500	2.72	Developed	Light	2.6736	365	0
18	WOODCOMINT	29.600	Right	2000	2.72	Developed	Light	0.5093	365	0
19	MECFARMFED	30.850	Left	10000	4.56	Surface	Medium	3.4722	365	0
20	BRCL20	31.000	Left	42000	2.72	Developed	Light	10.694	365	0
21	NASRBRCR1	31.800	Right	2000	2.72	Developed	Light	0.5093	365	0
22	NASRBRCL4	32.075	Left	2400	2.72	Developed	Light	0.6111	365	0
23	NASRBRCR2	34.100	Right	4500	2.72	Developed	Light	1.1458	365	0
24	NASRBRCL5	35.025	Left	3500	2.72	Developed	Light	0.8912	365	0
25	NASRBRCR3	35.875	Right	1000	2.72	Developed	Light	0.2546	365	0
26	VEGTABLBRC	38.150	Left	5000	2.72	Developed	Light	1.2731	365	0
27	SURFIRRBRC	38.550	Right	10000	2.72	Developed	Light	2.5463	365	0
28	ALMMARKBFED	41.400	Right	8000	2.72	Surface	Medium	2.7778	365	0
29	ABOMSODFED	46.000	Right	16000	4.56	Surface	Medium	5.5556	365	0
30	PBRCR1	49.200	Right	2400	4.56	Surface	Medium	0.8333	8	19
31	PBRCR2	53.200	Right	3000	4.56	Surface	Medium	1.0417	8	19
32	PBRCL17	55.725	Left	19370	4.56	Developed	Medium	4.9322	19	8
33	PBRCR3	55.900	Right	5260	4.56	Surface	Medium	1.8264	8	19
34	PBRCR6	57.175	Right	6590	4.56	Surface	Medium	2.2882	8	19
35	PBRCR8	62.890	Right	4609	4.56	Surface	Medium	1.6003	8	19
36	PBRCL9	65.115	Left	1113	4.56	Surface	Medium	0.3865	11	16
37	PBRCL11	67.370	Left	1932	4.56	Surface	Medium	0.6708	11	16
38	PBRCR10	67.770	Right	1176	4.56	Surface	Medium	0.4083	11	16
39	PBRCR14	70.600	Right	1550	4.56	Surface	Medium	0.5382	11	16
40	PBRCL12	72.440	Left	2006	4.56	Surface	Medium	0.6965	8	19
41	PBRCR15	74.640	Right	14380	4.56	Surface	Medium	4.9931	19	8
42	PBRCL13	76.715	Left	1543	4.56	Surface	Medium	0.5358	8	19
43	PBRCL16	77.300	Right	10240	4.56	Developed	Medium	2.6074	8	19
44	HAMMAMBRC	79.000	Left	65000	4.56	Developed	Medium	16.551	365	0
45	BAHIGFED	82.000	Right	12000	4.56	Surface	Medium	4.1667	11	16

Source: El-Nasr Canal Directorate, Ministry of Water Resources and Irrigation, Alexandria, Egypt.

1.0 Fed. = 0.42 hectare

MATERIALS AND METHODS

Methodology: In order to achieve the study objectives, *KHYAL MODEL* [20] has been originated by the author with multi systems of flow concerned to define and develop an integrated methodology to activate the optimum use of limited several water resources available in Egypt to maximize the irrigation water revenue as a key need for proper water management, with simulating its conveyance and distribution in irrigation network, taking

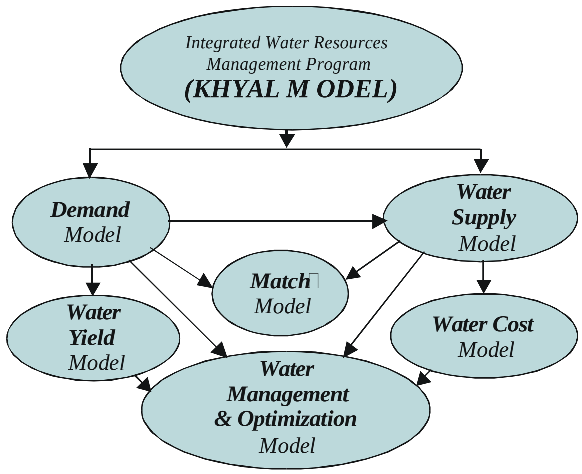


Fig. 2: Study Methodology Layout

into account the irrigation water conveyance cost (C_c) & irrigation water lifting cost (L_c) in order to estimate the net-benefit of IWU for forty-four possible crops planted at branch canals in NCR and setting the optimal cropping pattern that achieve the maximum revenue of irrigation water of main canal considering economical, social approach. The model, as shown in Fig. 2, consists of six sub-models, with time horizon of a complete year and ten days' intervals; *DEMAND, SUPPLY, MATCH, WATER YIELD, WATER COST and MANAGEMENT & OPTIMIZATION* sub-models. *DEMAND Model* is a computer program in FORTRAN and Visual Basic languages with time horizon a complete year and time increment is one third of month (10 days). The objectives of this model may be summarized as follows: *(1) To estimate* the reference evapo-transpiration (ET_o) by using either FAO Penman-Monteith method or Evaporation Pan one for the climatic data and the effective rainfall that contributes the soil moisture at the roots zones; *(2) To calculate* the crop water requirements (*CWR*) for cropping pattern of forty-four possible crops for any type of used irrigation method, the leaching water requirements (V_{LR}) for any soil type & fresh water, the water conveyance losses due to evaporation and seepage depending on the type of canal lining and the total demand water of each branch canal intake of network; *(3) To consider* available water types such as; drainage water that may be reused and effective rainfall, the multi water requirements such as; Agricultural, Leaching, Municipal & Industrial requirements, the flow regime of any branch canal of the network, which is continuous flow regime (*CFR*) or rotational one (*RFR*), the type supply of reused drainage water, which either by gravity, or pumped; and the electrical conductivity of fresh water, reused drainage water and soil solution extract; *(4) To analyze* flow regime on the conveyance losses for any branch canal and total demand water in comparison with branch canal capacity; *(5)* The model sets a methodology of designing irrigation network cross sections due to maximum values of discharges (Q_{max}) and water levels (*MWSL*) [21]. *SUPPLY Model* is a computer program in FORTRAN and Visual Basic languages with time horizon of a complete year and one day intervals. It computes the daily water supplied at branch canals intakes for either pumped main canal or gravitational one for either CFR or RFR of each branch canal, taking into account direct irrigation & conveyance water losses due to evaporation and seepage that depend on main canal lining type. *MATCH Model* is a computer program in FORTRAN and Visual Basic languages, with time horizon of a complete year and the time increment is one day. The main objective of this model is the estimation of the matching (daily water shortage or excess at branch canals intakes for either pumped canal or gravitational one for either CFR or RFR) between supply and demand in quantity and on timing for daily and annual basis for available irrigation water (AIW) with demand irrigation water (DIW) of existing cropping pattern to evaluate the response efficiency of irrigation directorate in its management of available water resources in quantity and on timing, consequently, to determine is there a problem in irrigation process or not [22]. *WATER YIELD Model* is a computer program in FORTRAN and Visual Basic languages, with time horizon of a complete year. The main objective of this model is: *(1)To estimate* the annual water benefit ($W_{benefit}$) per one cubic meter of demand fresh water for each branch canal *of the summation of crops* per a complete year, in (L.E/m^3); *(2) To calculate* for possible 44 crops planted on the area study, the annual production cost; and the annual net-income (N_{incom}) on-farm; *(3) To consider* the flow regime type of any branch canal of the network, either CFR or RFR and for crops; the average yield of crop, the price of crop on-farm; the construction cost for the perennial orchards, the virtual age of the perennial orchard, the annual working cost of the crop and the interest rate. *WATER COST Model* is a computer program in FORTRAN and Visual Basic languages, with time horizon of a complete year. The main objective of this model is: *(1) To estimate* the actual cost (lift & conveyance) of IWU at each branch canal intake for either CFR or RFR; *(2)To calculate* the annual lifting cost of IWU for each pump station, the annual cost of irrigation water conveyance & lifting for 1.0 fed at branch canal and the lifting cost of reused drainage water unit; *(3)*

To consider the *Fixed costs* (construction cost) of lining, civilian works of pump stations, mechanical units and electrical equipments related to its construction dates & their virtual ages and the interest rate and the *Working costs*, such as: the electrical power, the fuel cost and the salaries of each the irrigation pump stations & irrigation directorates respectively, the flow regime of any branch canal of the network, which is either, a CFR or RFR, the type of main canal, which is either, pumped main canal or gravitational one, the interest rate, the annual salaries of irrigation directorate employees of main canal and the control regulators cost through the main canal; and *(4) To analyze* the flow regime type of each branch canal on L_c & C_c of IWU [23]. *MANAGEMENT Model* is a computer program in FORTRAN and Visual Basic languages, with time horizon of a complete year. The main objective of this model is: *(1) To estimate* the net-benefit of IWU for each crop at each branch canal ($N_{benefit}$) and an appropriate policy of an available irrigation water management; *(2) To consider* the conveyance cost (*C*-) & lifting cost (L_c) of IWU at each branch canal, the lining type of each branch canal & main canal, the flow regime of any branch canal of the network, which is either, CFR or RFR, the type of main canal, which is either, pumped main canal or gravitational one, the location of each branch canal at the main canal, the meteorological data of the area served, the irrigation method applied at each branch canal, the soil type of each branch canal, the application efficiency on farm of each branch canal, the decadal evaporation losses & decadal seepage losses of each branch canal, the multi available water resources of each branch canal, such as, the effective rainfall on the area served by each branch canal, the electrical conductivity of the irrigation fresh water & the soil solution extracts and for crops planted on the study area; (a) the average yield of crop, (b) the price of crop on-farm, (c) the construction cost for the perennial orchards, (d) the virtual age of the perennial orchard, (e) the annual working cost of the crop, (f) the planting dates, (g) the harvest dates, (h) the theoretical decadal crop water requirements, for 1.0 feddan and (i) the annual net-income of each crop and for each irrigation method equipments; the construction cost, the virtual age and the construction date; and *(3)To analyze* the policies of the available irrigation water management at each branch canal & main canal scales [24]. *OPTIMIZATION Model* is a computer program formulated in *spreadsheet optimizer SOLVER Numerical tool* through *Microsoft Excel (ver. XP) to make a decision about the suggested cropping pattern on NCR that produce the maximum irrigation water benefit in an economical procedure*. There are two scenarios to activate the *SOLVER tool*: *Branch Canal Scale* with respect to the actual available water, which there are seven scenarios of cropping pattern constraints; and *Main Canal Scale* with respect to the actual available water, which there are two scenarios of cropping pattern constraints. *Scenario No. 1 respects the constraints of social Egyptian fields, while Scenario No. 7 is free of social constraints*. Therefore, the objective function is considered to be each of: *a) Benefit Objective Function:* The aim of the objective function is to maximize the Net-benefit. The benefit was defined as the summation of the suggested area to be planted with crops (A_{crop}) associated with both the area served by each branch canal and the actual annual crop water requirements for unit area, associated, also, with the net actual average annual crop water benefit for unit cubic meter for each crop at each branch canal; *b) Water Unit Benefit Objective Function:* The aim of the objective function is to maximize the net water unit benefit.

Finally, the scenarios are: (1) *Benefit Objective Function of Scenario No. 1 (BOFS1); (2) Water Unit Benefit Objective Function of Scenario No. 1 (WUBOFS1); (3) Benefit Objective Function of Scenario No. 7 (BOFS7); and (4) Water Unit Benefit Objective Function of Scenario No. 7 (WUBOFS7). The Optimization Model (Main Canal Scale): SOLVER* numerical tool is limited with a small number of trials of iterations and many unknowns. They were related to many constraints and formulas, which are in application on the study case of *El-Nasr Main Canal Scale*. It supplies 45 branch canals with 44 crops of 3 types of irrigation system. Therefore, the variables equal (45 * 44 * 3 = 5940 unknown crops area; ($A_{C(j,m,k)}$). Therefore, *SOLVER* numerical tool can not be executed. Consequently, in this study, *SOLVER* tool is used for four branch canals represent the different four distinct physiographic areas of NCR (*BRCR1*, *BRCL20, ABOMASODFED and PBRCR15*) with forty-four crops for each. As a maximum limit, the *SOLVER* tool can be executed with variables ($A_{C(j,k)}$) become (4 * 44 = 176). So, it is recommended to apply another tool to solve that problem, like *GENATIC ALGORITHM* technique. Consequently, in this study for main canal scale, it is considered that the main canal feeds four branch canals (*BRCR1, BRCL20, ABOMASODFED and PBRCR15*) with forty-four crops for each. Each model is compounded by numerical tools, as presented in Fig. 2. The main equations used in *KHYAL MODEL* are:

$d_{ET} = Et_o, * K_c$ where: ET_o, the decadal reference evapo-transpiration in (mm/10days); and K_c, the crop coefficient. Based on FAO paper No. 56 [25], the formula of FAO Penman-Monteith is:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where: ET_o, reference evapo-transpiration in (mm/day);

R_n, net radiation at the crop surface in (MJ/m^2/day); G, soil heat flux density [MJ m^{-2} day^{-1}]; T, air temperature at 2 m height in (C°); u_2, wind speed at 2 m height in (m/sec.); e_s, saturation vapor pressure in (kPa); e_a, actual vapor pressure in (kPa); e_s - e_a, saturation vapor pressure deficit in (kPa); Δ, slope vapor pressure curve in (kPa/ C°); and γ, psychrometric constant in (kPa/ C°). LR = $\frac{EC_{FW}}{(5EC_{SS} - EC_{FW})} * \frac{1}{L_e}$, after [26, 27]; $EC_{FW,}$ the electrical conductivity of the irrigation fresh water in (mmhos/cm); $EC_{SS,}$ the average electrical conductivity of the soil solution extract in (mmhos/cm); and L_e, the leaching efficiency.

USDA soil conservation service method is used to estimate effective rainfall [28]:

P_e = P (125-02 P)/125 for P < 250 mm/month and P_e = 125 + 0.1 P for P > 250 mm/month, where: P, precipitation; and P_e, the effective rainfall.

Estimation of evaporation losses (V_E) by Combined Aerodynamic and Energy Balance Method from [29], which the formula is:

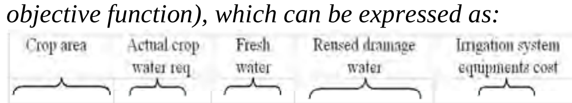
$$E = \frac{\Delta}{\Delta+\gamma} * \frac{R_n}{(2500 - 2.36 * T_{mean})\rho_W} + \frac{\gamma}{\Delta+\gamma} * \frac{0.622k^2 \rho_a u_2}{p\rho_W[\ln(z_2/z_0)]^2} * (e_s - e_a),$$

where: E, The evaporation rate; e_s, saturation vapor pressure [kPa]; e_a, actual vapor pressure [kPa]; k, The von Karman constant, usually taken =0.4; ρ_a, The air density, is taken at elevation 0.0 km height = 1.16 kg/m^3; u_2, wind speed at 2 m height [m s^{-1}]; p, The air pressure; ρ_w, The water density; z_2, The height over water level = 2.0 m; z_0, The roughness height of the surface, is taken for water = 0.03 cm; Δ, _slope vapor pressure curve [kPa C°$^{-1}$]; γ, psychrometric constant [kPaC°$^{-1}$].

Estimation of seepage losses (V_S):a) For earthen canals, Molesworth & Yennidumia formula is applied by MWRI; $V_S = C*L*P*R^{1/2}$ after [30], where V_S, the water conveyance losses due to seepage, in (m^3/sec.); L, the length of each branch canal, in (km.); P, the wetted perimeter, in (m.); R, the hydraulic radius of the water cross sectional area, in (m.); and C, seepage loss factor for each branch canal depends on soil type & its temperature, which it is 0.0015, 0.002, 0.003 and 0.004 for clayey & silt clayey soil, sandy silt, sandy and gravely sandy soil respectively. *Also, Moritz formula is applied:* $S = 0.65C\sqrt{\left(\frac{Q}{V}\right)}$ after [31, 32]; Volume 3; lined irrigation networks; pages 1-5 and 1-6), where: S, the seepage losses in *m^3/ sec per km* length of the canal; Q, the canal discharge in *m^3/ sec;* V, the mean velocity of flow through canal in *m / sec;* C, a constant depending on soil type and is taken as 0.125, 0.125, 0.2, 0.592 and 0.1 for Clayey soil, Silt Clayey, Sandy silt, Sandy soil and consistent gravely sandy soil respectively; *b) For concrete lined canals, an empirical formula used by MWRI* [32] *is applied;* $V_S = K\, Y_{max} \left(\frac{B}{Y_{max}} + \frac{b}{t_1} + \frac{Y_{max}}{t_2} * \sqrt{1+Z^2}\right)$ after [33], where V_S, seepage losses, in (m^3/m'/year); K, coefficient of permeability of concrete, which it varies from 0.0001 for excellent concrete (low water-cement ratio) ~ 0.003 (m/year) for bad concrete (high water-cement ratio); $Y_{max,}$ the maximum water depth of each branch canal, in (m); b, branch canal bed width, in (m); B, water surface width at Y_{max}, in (m); Z, branch canal side slope (horizontal: vertical); t_1 & t_2 are lining thickness of branch canal bed & side slopes respectively, in (m).

The annual discount rate = $\frac{1}{\left((1+\alpha)^{(Yr\text{- Construction Date})}\right)}$ [34]; where, Yr, the year of module application; α = the interest rate.

For Cropping Pattern Optimization, Main Canal Scale Scenario; the Objective Function is to maximize the summation of the Net-Benefit at each branch canal (Benefit objective function) and (Water Unit Benefit objective function), which can be expressed as:



$$Z_1 = \sum_{k=N2}^{k=N3} \sum_{j=1}^{j=44} \sum_{m=1}^{m=3} \left(A_{S(k)} * \frac{A_{C(j,m,k)}}{100} * \left\langle \left(\sum_{i=1}^{36} V_{f(i,j,m,k)} \right) * \left[N_{benefit(j,m,k)} + \beta(i,k) * \left(A_{benefit(j,m,k)} - Dw_C \right) \right] - IC_{(j,m)} \right\rangle \right)$$

$$Z_2 = \frac{Z_1}{\sum_{k=N2}^{k=N3} V_{FS_{an(k)}}}$$

, where: $Z_{1,}$ the *summation of* the *Net-benefit* at *branch canals*, in (L.E./year); $Z_{2\,,}$ the *Net-benefit of water unit* of the *summation of branch canals*, in (L.E./m^3); V_{FSan}, the actual annual irrigation water requirements of suggested crops at main canal, in (m^3); m, subscript represents the rank of the applied irrigation method (Ir_m); A_S, the area served by branch canal, in (feddan); A_c, the suggested area planted with crop of irrigation method at branch canal as a percentage of its area served, in (%); $V_{f(an)} = \sum_{i=1}^{36} V_{f(i,j,m,k)}$, the actual annual *fresh* water volume of crop water requirements for 1.0 feddan for each crop at each branch canal with irrigation method m, in (m^3/year/feddan); $N_{benefit}$, the net-benefit of IWU (*fresh*) for crop at branch canal with irrigation method, in (L.E/m^3); β, the decadal mixture ratio of reused drainage water volume that may be reused related to irrigation fresh water volume at each branch canal; $A_{benefit}$, the actual benefit of IWU (*fresh and drainage*) for crop at branch canal with irrigation method, in (L.E/m^3); Dw_c, the lifting cost of reused *drainage* water unit, in (L.E/m^3), *from Water Cost Model outputs*; and I_C, the seasonal cost of irrigation system equipments for 1.0 feddan and for each crop, in (L.E/fed./year).

RESULTS AND DISCUSSION

Then it can get for each branch canal at any decade (10 days), the final of daily values of each CWR, V_{LR}, V_E, V_S and V_T. Also, it can get their percentages related to passing flow, such as, PCWR, PV_{LR}, PV_E and PV_S. Fig. 3 illustrates the comparison of the decadal values of ET_o for NCR for periods estimated between CropWat Model and DEMAND Model. Fig. 4 shows the percentages of annual ideal crop water requirements ($PCWR_{(an)}$), annual leaching water requirements ($PVLR_{(an)}$), annual evaporation losses ($PV_{E(an)}$) & annual seepage losses ($PV_{S(an)}$) relative to annual total demand fresh water, for RFR. For concrete lined branch canal (*BRCR1*) from Part 1 of NCR, they are 42.5%, 21.6%, 0.064% and 0.0008% respectively because of application of surface irrigation method, irrigation water salinity that varies from 0.65 mmhos/cm in winter to 0.73 mmhos/cm in summer [16] and electrical conductivity of soil solution extract respectively. Furthermore, the remaining percentage ratio (35.8%) is representing the water losses due to irrigation application efficiency on farm. It is remarkable that seepage loss is about 1.33% of evaporation loss. Otherwise, for RFR, for earthen branch canal (*BAHIGFED*) from Part 4 of NCR, they are 52.6%, 0.0%, 0.02% and 0.036% respectively, which seepage losses are about 188% of evaporation losses.

Furthermore, the percentages of *annual conveyance losses* related to annual total demand fresh water of *BRCR1* branch canal for both CFR & RFR as shown in Fig. 5, which they are 0.115% & 0.065% for CFR & RFR respectively. Therefore, the ratio of annual conveyance losses due to RFR relative to other of CFR is 56.4%. Otherwise, for *BAHIGFED* branch canal, they are 0.56% & 0.055% for CFR & RFR respectively. Therefore, the ratio of annual conveyance losses due to RFR relative to other of CFR is 9.84%.

With more details, in Figs. 6 & 7 respectively for CFR & RFR, for *BRCR1* branch canal, $PV_{E(an)}$ is 0.114% & 0.064% for CFR & RFR respectively, while $PV_{S(an)}$ is 0.0011% & 0.0008% for CFR & RFR respectively, therefore, the ratio of evaporation losses due to RFR relative to other of CFR is 56.15%, otherwise, for seepage losses it is 78.2%. Otherwise, for *BAHIGFED* branch canal, $PV_{E(an)}$ is 0.036% & 0.019% for CFR & RFR respectively, while $PV_{S(an)}$ is 0.52% & 0.036% for CFR & RFR respectively, therefore, the ratio of evaporation losses due to RFR relative to other of CFR is 53.7%, otherwise, for seepage losses it is 6.87%.

Fig. 8 shows the comparison between annual demand & annual supply water for RFR, which, by using this Fig., it can calculate the annual demand water & annual supplied water at the intake of El-Nasr Main Canal, which they are 2, 878, 708, 172 & 1, 981, 361, 571.3 m^3/year respectively with annual shortage ratio = 31.2%. Furthermore, Fig. 9 shows the comparison between daily demand & daily supplied water at El-Nasr Canal intake for RFR.

For annual scale, the percentages of annual water shortages related to annual water demand, for RFR, are illustrated in Fig. 10, which there is mismatch between demand irrigation water (DIW) and available irrigation water (AIW) pumped by El-Nasr main canal. It can notice that there is excess of annual AIW at some branch canals, such as; *BRCR1, BRCR2, BRCL2, BRCL3, BRCR4, ALMMARKBFED and ABOMASODFED*, which their percentages are 32.76%, 19.86%, 3.35%, 3.34%, 3.36%, 22.73% and 22.77% respectively (Fig. 10). Otherwise, there is shortage of annual AIW for the residual branch canals, such as; *BRCL20, ERASHBRC, PBRCR15 & NASRBRCR3*, which their percentages are 47.89%, 61.5%, 39.78% & 44.24% respectively. Otherwise, *for daily scale*, there is mismatch of DIW & AIW, for every branch canal, especially, shortage on summer & excess on winter, although there is rainwater, which Fig. 11 shows the daily shortages (*DSH*) of AIW for RFR for *BRCR1* of part 1, which it can be noticed that the excess is concentrated in Jan., Feb., Mar, Sep., Oct., Nov. and Dec.

Otherwise, the shortage is concentrated in Apr., May, Jun., Jul. and Aug. Furthermore, for RFR for *BRCL20* of part 2, both *DSH* of AIW are shown in Fig. 12, which it can be noticed that the excess is concentrated in Jan., Feb. and Dec.

Otherwise, the shortage is concentrated in other months. The annual net-income of the crops on farm (N_{income}) is shown in Fig. 13, which N_{income} of banana fruit is 20312 (L.E/fed.). Besides, for rice, wheat, berssem, bean,

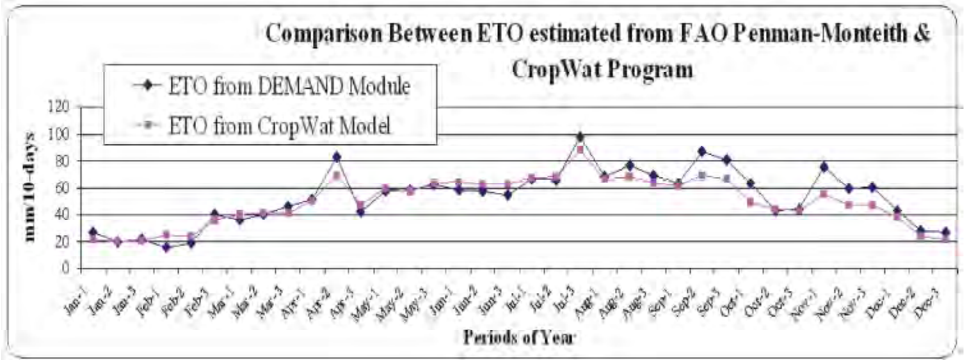


Fig. 3: The comparison between ET_o values obtained by application of DEMAND model through FAO's Penman-Monteith method and the others obtained by application of CROPWAT model

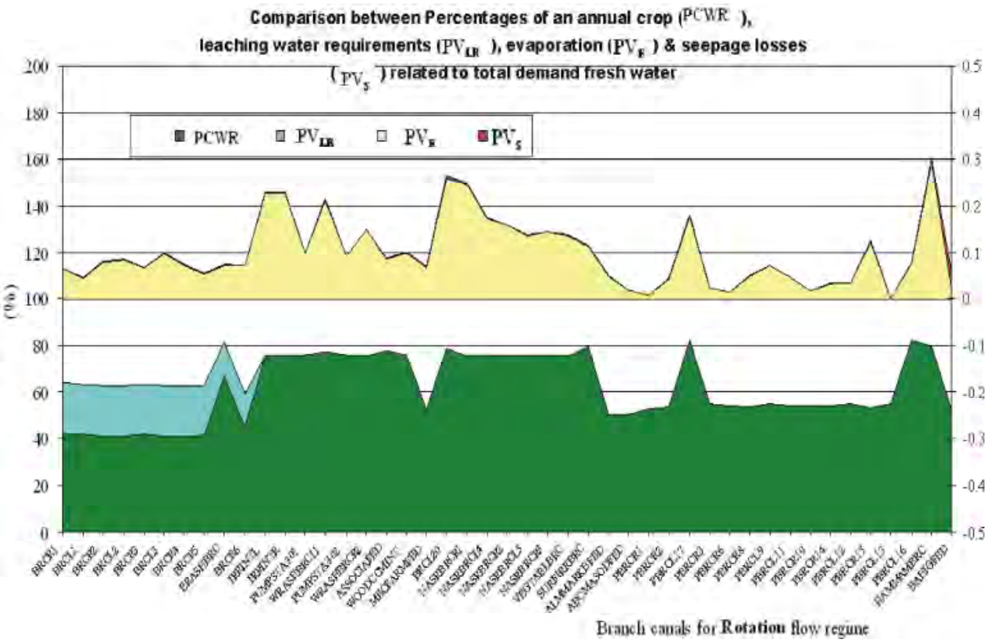


Fig. 4: The percentages of annual ideal crop water requirements, annual leaching water requirements, annual evaporation losses & annual seepage losses relative to annual total demand fresh water, for RFR

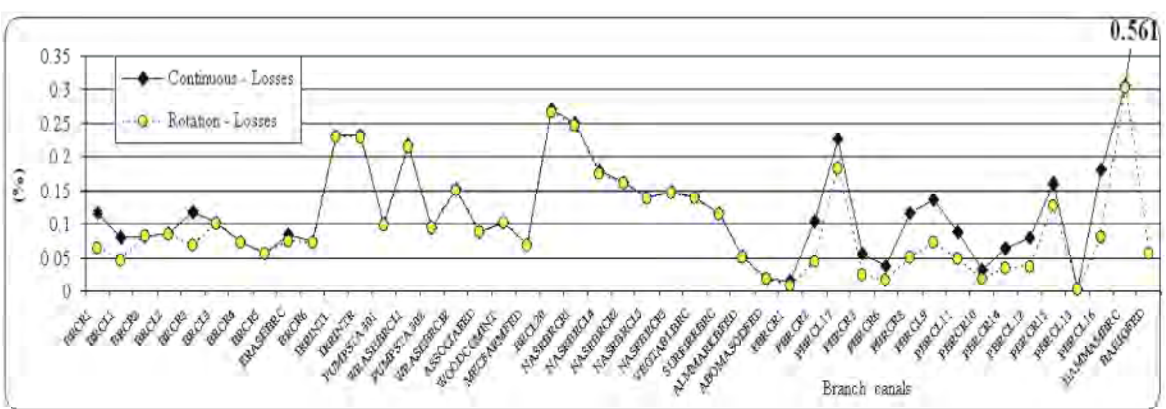


Fig. 5: The comparison between percentages of annual conveyance losses related to annual total demand fresh water for branch canals for CFR & RFR.

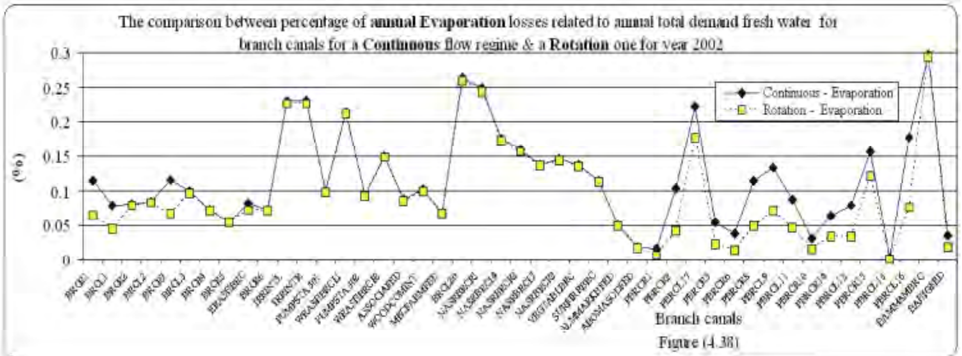


Fig. 6: The comparison between percentages of annual evaporation losses related to annual total demand fresh water for branch canals for CFR & RFR

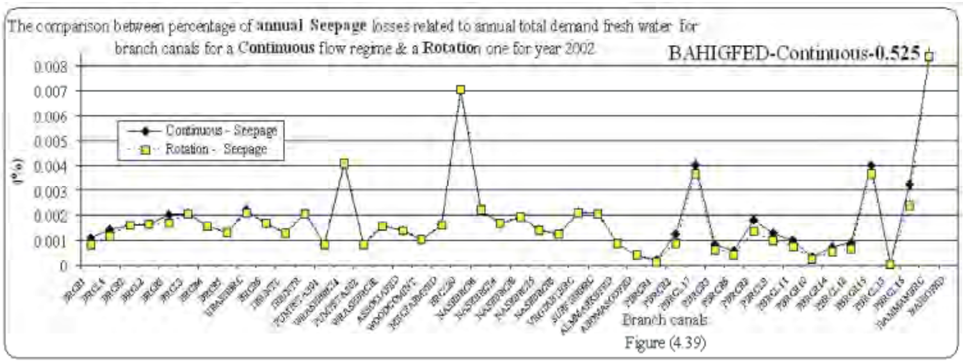


Fig. 7: The comparison between percentages of annual seepage losses related to annual total demand fresh water for branch canals for CFR & RFR.

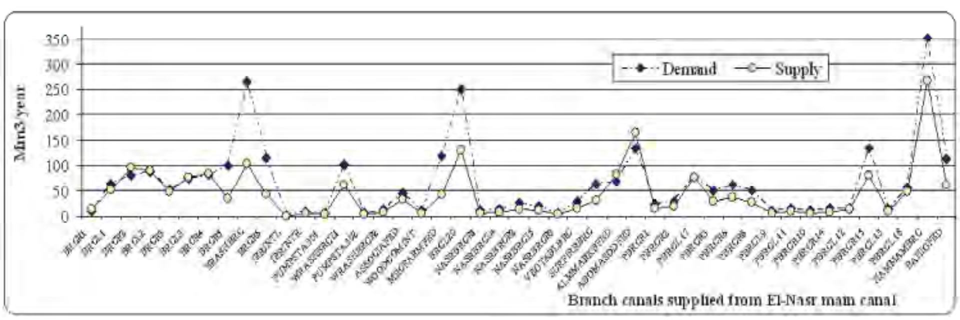


Fig. 8: Comparison between annual demand & annual supplied water for RFR

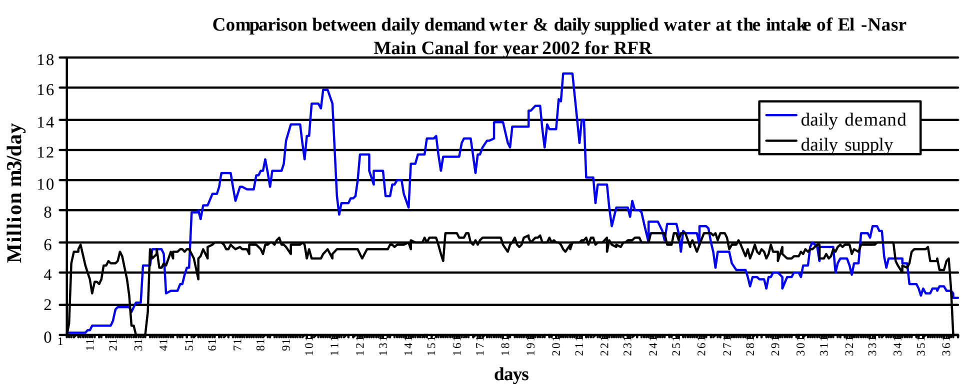


Fig. 9: Comparison between daily demand & daily supplied water at El-Nasr Canal intake for RFR

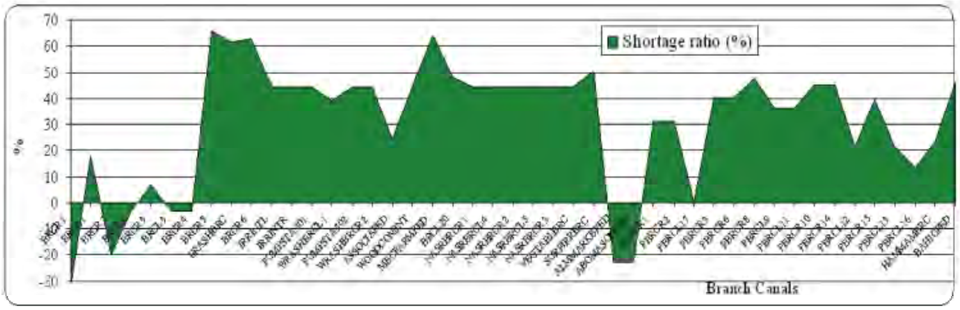


Fig. 10: The percentage of annual irrigation water supply shortage for each branch canal fed from El-Nasr main canal for RFR

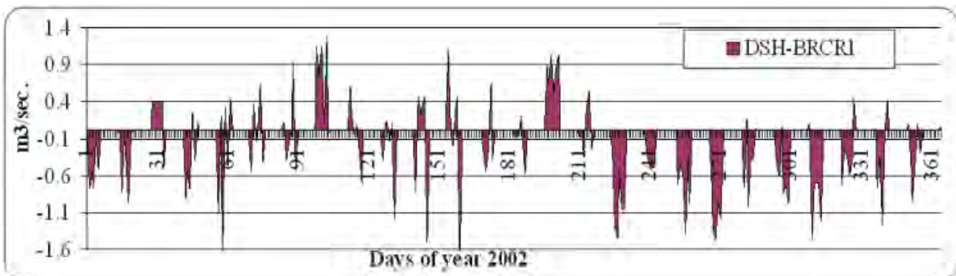


Fig. 11: Daily shortage of water supply of BRCR1 branch canal on year 2002 for RFR

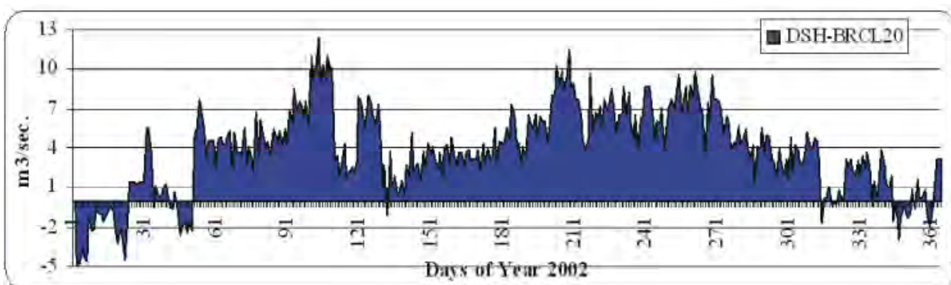


Fig. 12: Daily shortage of water supply of *BRCL20* branch canal on year 2002 for RFR

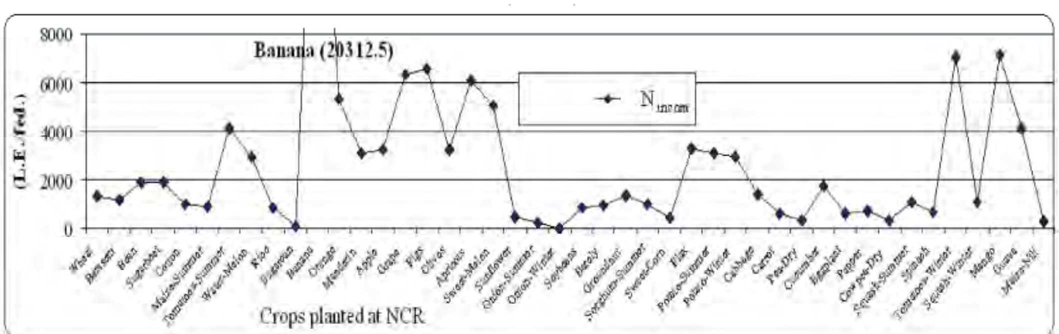


Fig. 13: Annual net-income of Crop on farm at El-Nasr canal region for year 2002

summer maize, summer tomatoes and winter tomatoes crops they are 840, 1329, 1210, 1900, 881, 4127 and 7067 (L.E/fed.) respectively. The comparison between the annual lifting cost & annual conveyance cost for IWU at each branch canal, for both RFR is shown in Fig. 14, which L_c varies from 0.0075 to 0.0437 L.E/m^3, besides, C_c varies from 0.000399 to 0.00396 L.E/m^3 for RFR. Consequently, it is clear that conveyance cost represents about 6.28 % ~ 7.66 % of the irrigation total cost along El-Nasr Canal longitudinal direction.

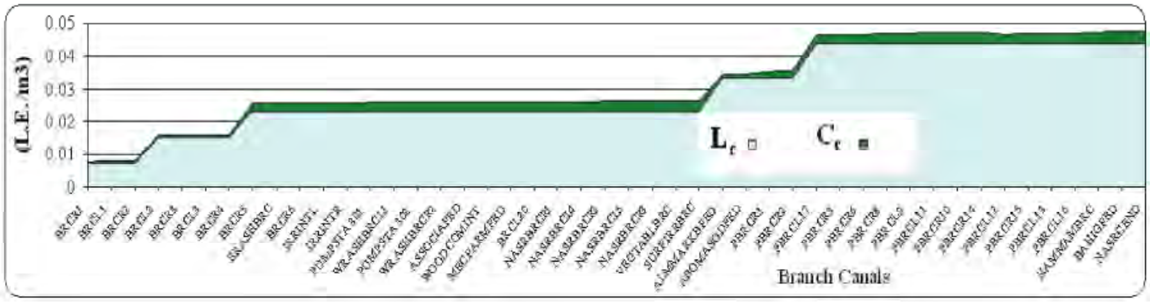


Fig. 14: The annual Lifting Cost (L_c) & Conveyance Cost (C_c) of IWU delivered to each branch canal of El-Nasr main canal for year 2002 for RFR in (L.E/m^3)

The net-benefit of IWU (*NBIWU*) of each crop at branch canals of El-Nasr Canal are shown for *winter crops, winter vegetables, summer vegetables, summer crops and perennial crops & fruits* in Figs. 15, 16, 17, 18 and 19 respectively.

From these Figures, it is clear that winter tomatoes, winter potatoes, flax, banana, sweet-melon, grapes, summer potatoes, bean, summer tomatoes, watermelon and mango crops are the highest of *NBIWU*, which are 1.38, 1.24, 1.09, 1.01, 0.74, 0.724, 0.57, 0.526, 0.44, 0.437 and 0.369 (L.E./m^3) respectively for *BRCR1* of applied surface irrigation method (*ASIM*), but they are 2.44, 2.19, 1.91, 1.78, 0.42, 1.29, 1.01, 0.92, 0.78, 0.24 and 0.65 (L.E./m^3) respectively for *BRCL20* of applied developed irrigation method (*ADIM*).

Otherwise, wheat, berseem, sugarcane, rice, summer maize, nili maize, summer onion, summer sorghum and sweet-corn crops are the lowest of *NBIWU*, which are 0.26, 0.16, -0.002, 0.06, 0.108, 0.034, 0.015, 0.14 and 0.05 (L.E./m^3) respectively for *BRCR1* of *ASIM*, but they are 0.454, 0.27, -0.02, 0.015, 0.044, -0.001, 0.016, 0.242 and 0.085 (L.E./m^3) respectively for *BRCL20* of *ADIM*.

Fig. 20 shows at main canal, which consists of (*BRCR1, BRCL20, ABOMASODFED & PBRCR15*), the comparison between *water supplied* & *water requirements* of suggested cops planted for *BOFS1, BOFS7, WUBOFS1* and *WUBOFS7* scenarios, which the irrigation water supplied for four branch canals are restricted at April, June and July months for *BOFS.* Also, it is restricted in July month for *BOFS.* It is also restricted in April, June and July months for *WUBOFS1*. Otherwise it is not restricted allover the year for *WUBOFS7.* Therefore, the needed irrigation water for each scenario must not exceed the irrigation water supplied for those months. Furthermore, it is clear that the *BOFS1* and *WUBOFS1* are almost coinciding. It is also clear that *BOFS7* is the closest scenario to the irrigation water supplied for majority of year months. This scenario is the most scenarios of freely constraints, which mainly depends on the financial benefit. But this scenario is out of actual application in the Egyptian social environment. Furthermore, it is clear that *WUBOFS7* is more far from the irrigation water supplied for several months. Therefore, they are not an optimum use for the supplied irrigation water, although it is the scenario with the greatest benefit and water unit benefit as well. Therefore, the scenario with maximum usage for the available irrigation water supply is *BOFS7*. The scenario with the greatest water unit benefit is *WUBOFS7*. Also, the scenario of getting the annual benefit of irrigation water supply is *BOFS7.* Also, the most scenario of using the area of cultivated lands is *WUBOFS1*. Otherwise, the *WUBOFS7* is the scenario of using the smallest area of cultivated lands. Finally, *BOFS1* is the most applicable scenario of the real practice in our Egyptian social environment for local consumption, social constraints. Otherwise, *WUBOFS7* is the most applicable scenario to have the maximum annual benefit for maximum use of irrigation water for export agricultural crops. Thus, to maximize the annual benefit for a branch canal, it must reallocate the supplied irrigation water to it for several months to be convenient for the suggested planted area for each date, values to maintain the social constraints on the Egyptian fields and optimum use of land. Otherwise, in Fig. 21, it can be recognized that the total irrigation water supplied to the four branch canals of scenario *Branch canal scale* is restricted to April, while for scenario *Main canal scale*, it is restricted in each of full April, June and July months and also almost in May. Therefore, the irrigation water needs for each scenario must not exceed the irrigation water supplied for this month. Furthermore, it is clear that scenario *Main canal scale* is the closest rather than the other scenario for the irrigation water supplied in summer months, which is better than *Branch canal scale* scenario in irrigation water utilization through summer season months, which are considered mismatch periods.

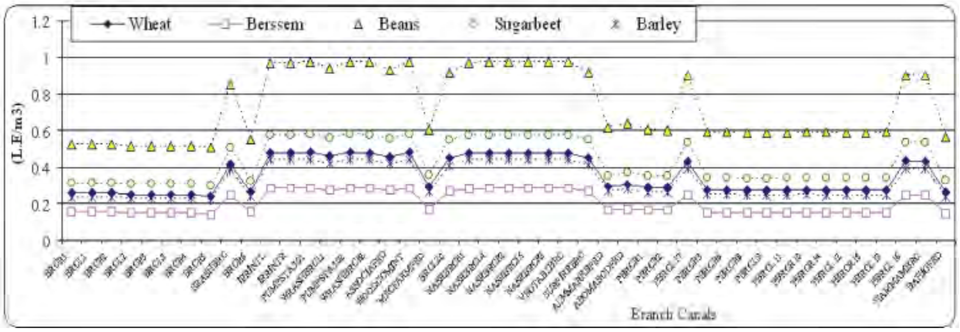


Fig. 15: Net-benefit of IWU for crops planted at NCR on Year 2002 for Winter Crops

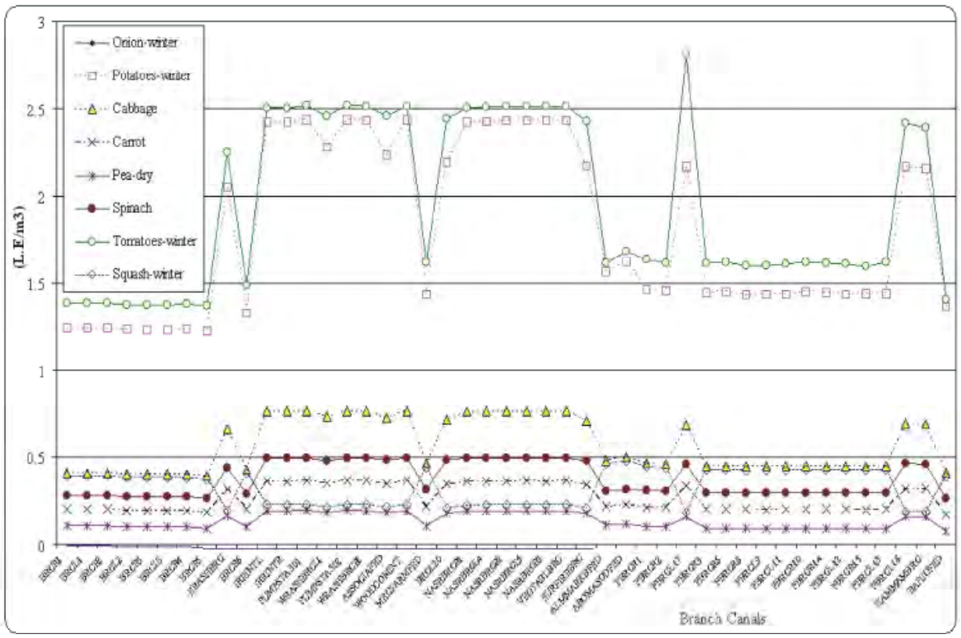


Fig. 16: Net-benefit of IWU for crops planted at NCR on Year 2002 for Winter Vegetables

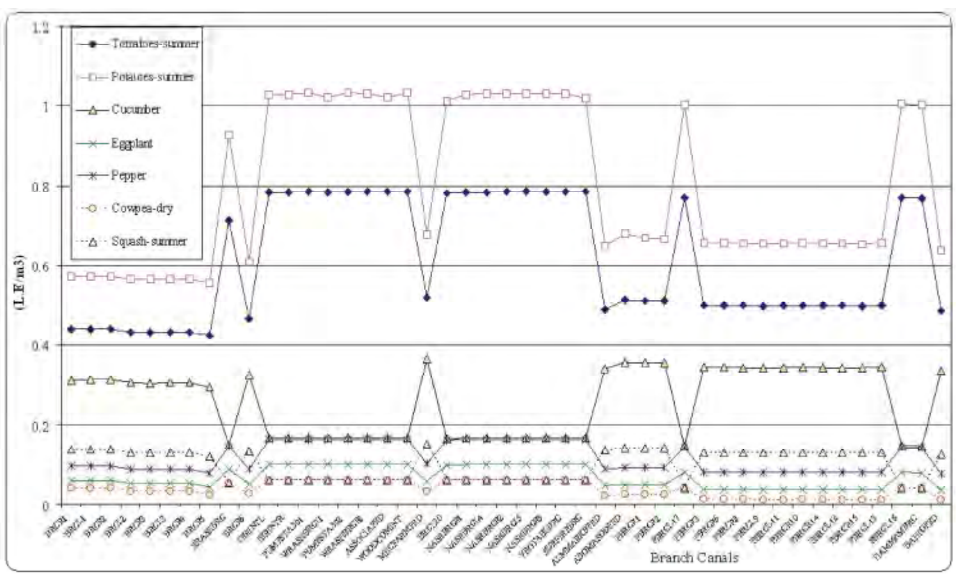


Fig. 17: Net-benefit of IWU for crops planted at NCR on Year 2002 for Summer Vegetables

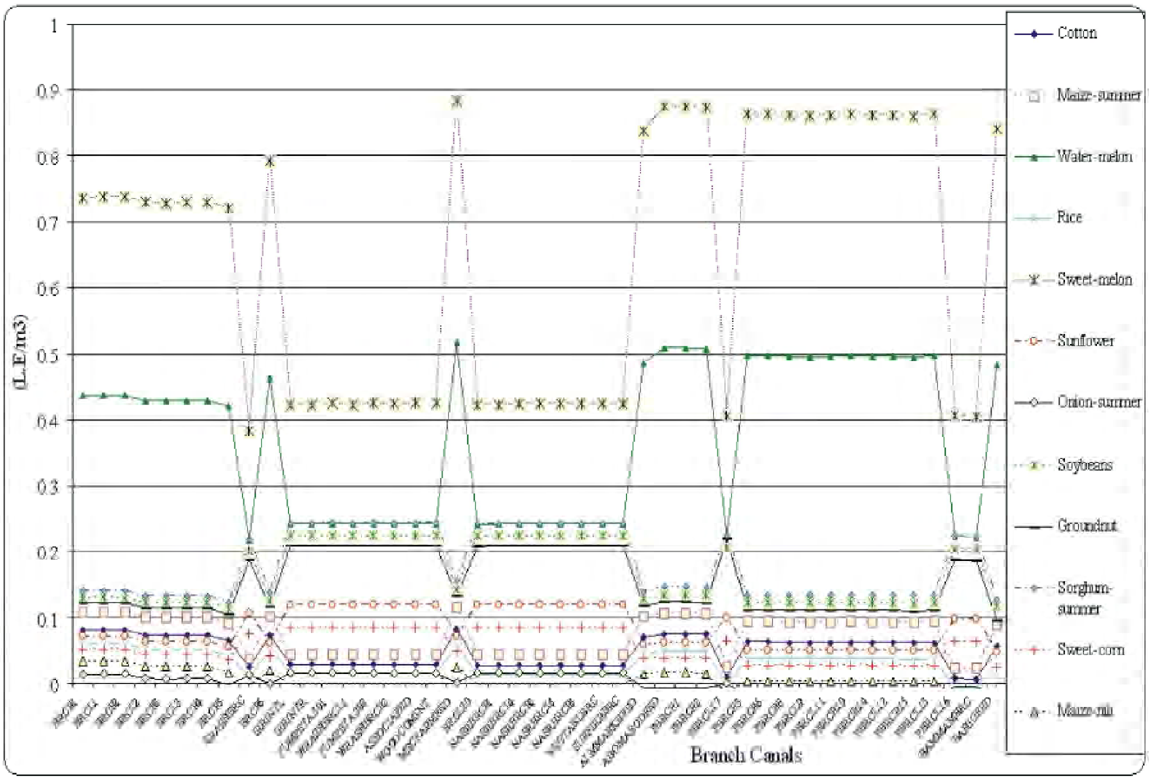


Fig. 18: Net-benefit of IWU for crops planted at NCR on Year 2002 for Summer Crops

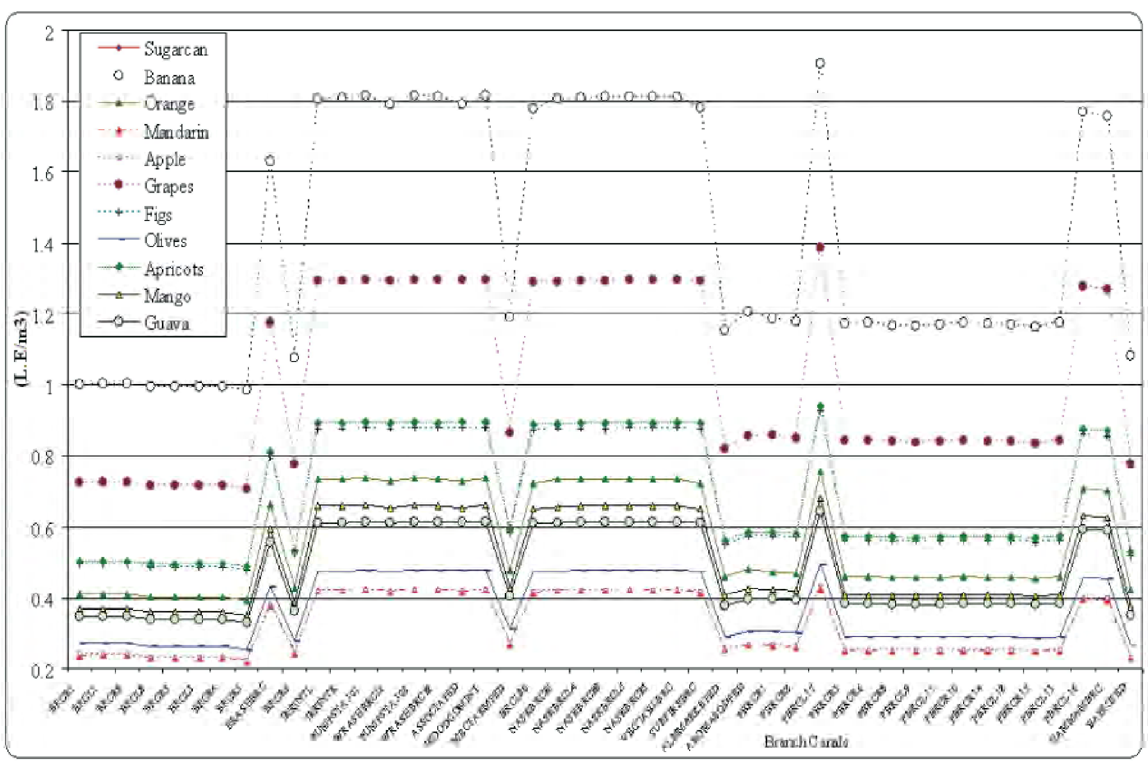


Fig. 19: Net-benefit of IWU for crops planted at NCR on Year 2002 for Perennial Crops & Fruits

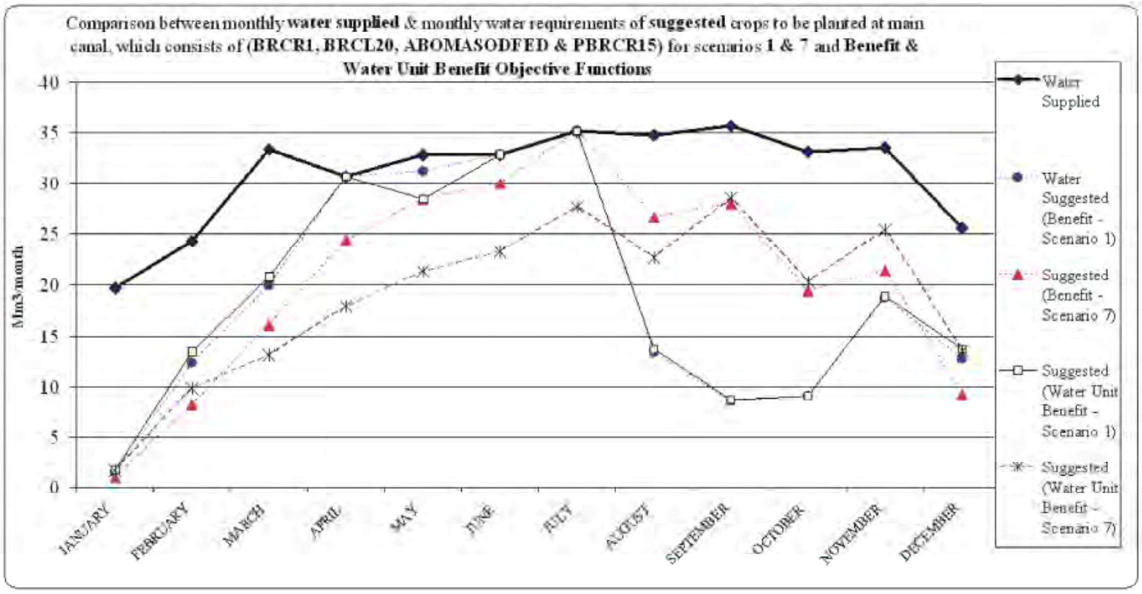


Fig. 20: The comparison between *water supplied* & *water requirements* of suggested cops planted for *BOFS1*, *BOFS7*, *WUBOFS1* and *WUBOFS7*scenarios

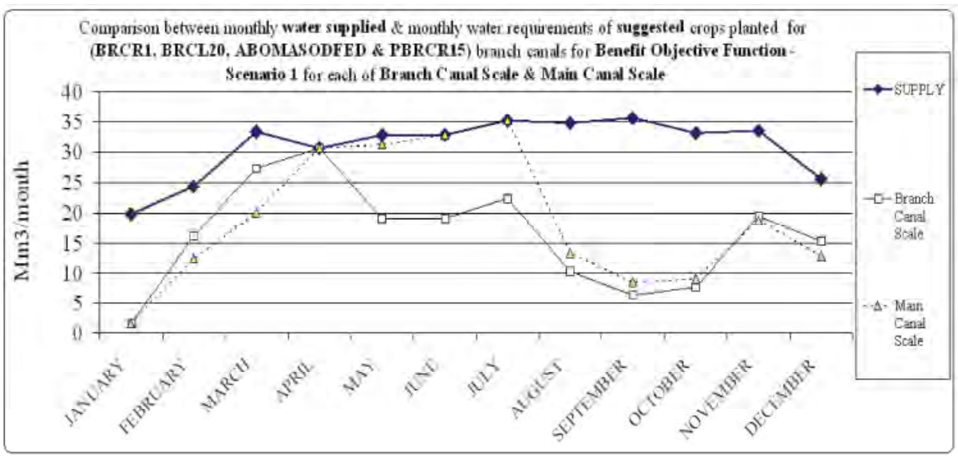


Fig. 21: The comparison between *water supplied* & *water requirements* of suggested cops planted for Branch canal scale and Main canal scale scenarios

CONCLUSIONS AND RECOMMENDATION

The study revealed that the ratio of *annual conveyance* losses due to rotational flow regime (RFR) relative to other of continuous flow regime (CFR) is 56.36% for *lined* branch canals, otherwise for *earthen* branch canals, is 9.84%. Furthermore, the ratio of *annual seepage* losses due to RFR relative to *annual evaporation* losses is about 1.33% for *lined* branch canals; otherwise, for *earthen* branch canals, is 188.7%. *With more details*, the ratio of *annual evaporation* losses due to RFR relative to others of CFR is 56.15% for *lined* branch canals; otherwise, is 53.73% for *earthen* branch canals. Therefore, *branch canal lining type, almost, does not affect the annual evaporation losses ratio.* Furthermore, the ratio of *annual seepage* losses due to RFR relative to others of CFR is 78.2% for *lined* branch canals; otherwise, is 6.87% for *earthen* branch canals. This is owing to concrete lining is more effective in preventing of percolation. Therefore, *in temperate region, like NCR, the seepage losses are the main factor on conveyance losses, especially in earthen canals, but in lined canals the evaporation losses are the prevailing one*. But in such regions with hot weather, evaporation losses become a reasonable factor in conveyance losses. *The study shows that RFR is better than CFR in* *minimizing of annual water conveyance losses in both lined and earthen branch canals in NCR.* This study examined and estimated the *matching on time and quantity, between demand and supply* for demand irrigation water (*DIW*) with available irrigation water (*AIW*) of existing cropping pattern. Therefore, the study *evaluates the response efficiency* of Irrigation Directorate in its management *of available water resources* in quantity and on timing. In NCR, *for annual scale*, there is *mismatching* between *DIW* and *AIW*, *where there is an excess of annual AIW at some branch canals*, such as; *BRCR1, BRCR2, ALMMARKBFED and ABOMASODFED*. Their percentages equal 32.76%, 19.86%, 22.7% and 22.8%, respectively. Otherwise, there is *a shortage of annual AIW for the residual branch canals*, such as; *BRCL20, ERASHBRC, PBRCR15* and *NASRBRCR3*. Their percentages equal 47.9%, 61.5%, 39.8% and 44.24%, respectively; otherwise, *for daily scale*, there is *mismatch of DIW and AIW, for every branch canal*, especially, *shortage on summer and excess on winter*; For *BRCR1* of part 1 and *ABOMASODFED* of part 3, the *excess* is concentrated *on autumn and winter*. Otherwise, the *shortage* is concentrated *on spring and summer*, although they have *excess of annual supplied water*; For *BRCL20* branch canal of part 2 and *PBRCR15* branch canal of part 4, the *excess* is concentrated *on winter*. Otherwise, the *shortage* is concentrated *on spring, summer and autumn*. In addition, they have *shortage of annual supplied water*. Therefore, *the main problem of irrigation process is mismatching*, which AIW is not compatible, in discharge and timing, with DIW of existing cropping pattern. This problem led farmers suffer in irrigating their lands and that affects, inversely, the crops productivity. *The main reason of this mismatching-problem is inaccurate procedure of crop water requirements (CWR) estimation*. This come because MWRI in Egypt supplies irrigation water in NCR with assuming constant daily water duties of surface and modern irrigation systems of area served unit, which they are 30 and 22 m^3/fed./day, respectively. But, in fact, the actual CWR must be estimated conveniently with the crop physiology, growth stage and existing cropping pattern; and *there is another main reason that surface irrigation method is ruling on the lands that considered to be irrigated with developed irrigation method in NCR*. The study illustrated that banana, winter tomatoes and winter potatoes are the highest of annual Net-income. Their values equal 20312, 7067 and 2965 (L.E/fed.), respectively. Otherwise, sugarcane, summer onion, sweet-corn, rice, summer maize, berseem and wheat are the lowest. Their values equal 114, 252, 416.8, 840, 881, 1211 and 1329 (L.E/fed.), respectively. Also, the annual average water duty (AAWD) for branch canals in both CFR and RFR is almost the same. The study reveals that the annual average lifting cost (L_C) of the irrigation water unit (IWU) delivered from pump station No. 1 is less than the others of sequent pump stations. That is because of the annual discharge through station No. 1 is greater than others. LC varies from 0.0075 to 0.044 L. E/m^3. Besides, the conveyance cost (C_C) varies from 0.0005 to 0.0036 L. E/m^3 in CFR. It varies from 0.0004 to 0.00396 L. E/m^3 in RFR. Therefore, it can be noticed that conveyance cost represents about 6.28 % ~ 7.66 % of the irrigation total cost along El-Nasr Canal longitudinal direction. The model outputs indicate that the irrigation total cost, for unit area, varies from 79 to 336 L.E/feddan for CFR. Otherwise, it varies from 77 to 356 L.E/feddan for RFR. Therefore, the flow regime, approximately, does not affect of the average annual irrigation water cost for the area unit. The study revealed that sugarcane, banana, rice, mango fruits and berseem crops are the *greatest of water consumption*. These consumptions equal 20578, 20137, 12195, 18912 and 7227 (m^3/year/fed.) respectively for *BRCR1* branch canal of applied surface irrigation method (*ASIM*), the values become 34427, 11235, 20296, 10556 and 4061 (m^3/year/fed.) respectively for *BRCL20* branch canal of applied developed irrigation method (*ADIM*), respectively. This means that winter tomatoes, winter potatoes, flax, banana, sweet-melon, grapes, summer potatoes, bean, summer tomatoes, watermelon and mango crops are the *highest of NBIWU*. Their associated values equal 1.38, 1.24, 1.09, 1.01, 0.74, 0.72, 0.57, 0.526, 0.44, 0.44 and 0.37 (L.E/m^3) for *BRCR1* branch canal of *ASIM*, respectively. The values become 2.45, 2.19, 1.91, 1.78, 0.42, 1.29, 1.01, 0.92, 0.78, 0.24 and 0.65 (L.E/m3) for *BRCL20* branch canal of *ADIM*, respectively. Otherwise, wheat, berseem, sugarcane, rice, summer maize, nili maize, summer onion, summer sorghum and sweet-corn crops are the *lowest of IWUNB*. Their associated values equal 0.26, 0.16, -0.002, 0.06, 0.108, 0.034, 0.015, 0.14and 0.05 (L.E/m^3) for *BRCR1* branch canal of *ASIM*, respectively. The values become 0.45, 0.27, -0.023, 0.015, 0.04, -0.001, 0.016, 0.24 and 0.085 (L.E/m3) for *BRCL20* branch canal of *ADIM*, respectively. Consequently, sugarcane, rice, summer maize and summer onion are not appropriate for NCR. Although wheat's *NBIWU* is low, the study recommends it is planting in such reasonable level to conserve national independence and to insure essential food requirements in Egypt [24]. Besides, red meat production that is depending on irrigated green provender on NCR is more expensive in water policy aspects. Therefore, the study recommends importing public meat requirements. The Main canal scale scenario is an appropriate one for available irrigation water management. Therefore, it is the most preferred scenario in real practice applications for Egyptian social environment for local consumption, social constraints of getting the maximum annual benefit for maximum use of irrigation water for agricultural crops export. Therefore, to maximize the annual benefit for the available irrigation water supplied to branch canals for several months must be reallocated. Thus, it can be convenient with the suggested area planted for each date and value to maintain the social constraints on the Egyptian fields and so the optimum use of the lands can be achieved. In Fig. 21 it is remarkable that the peak periods of water supply are April, May, June & July months, therefore, for both Branch Canal Scenario & Main Canal Scenario, if the irrigation water supplied to each branch canal equals to its designed discharge within those peak periods, the expected benefit of IWU of this additional water through those periods will be higher than its value before adding the surplus of water, which the suggested additional water in peak periods can be deducted from the other periods within the year. With other meaning, the required additional water dos not maximize the annual share of the main canal. Thus, for maximizing the annual benefit for the branch canal, it must reallocate the irrigation water supplied to it for several months. This comes in order to be convenient with the suggested area planted for each date and value. Thus, the social constraints to be maintained on the Egyptian field and so optimum use of the lands can be achieved.

The following suggestions for possible future research are recommended:

(1) the actual CWR must be estimated conveniently, with the crop physiology, growth stage and existing cropping pattern. Therefore, it is recommended that Egyptian Ministry of Water Resources and Irrigation has to supply irrigation water to canals with respect to the actual crop water requirements and the existing cropping pattern in the appropriate times by using a suitable *DEMAND Model;* (2) It is recommended that the annual excess water at some branch canals must be reallocated to the others of shortage water; (3) In case of demand and supply mismatching, there are some resolves to be applied as follows: either by increasing water supplied if the demand is too large, decreasing the demand water by increasing irrigation efficiency, changing the irrigation methods, staggering the growing season, decreasing the irrigated area, growing a crop with water shortages and lower production, or growing a crop of low water demand with high economic return with importing crops that consumes large amount of water; (4) The government of Egypt is called to re-discuss the policy of agriculture liberation and return of suitable agricultural circulation that matches with the applied procedure in this study for each region individually and applying a policy that encourages farmers to plant crops that achieves the objectives of this study; (5) The procedure of this study is recommended to be applied on Toshka development project in order to evaluate both the watery and economical topics; (6) Carrying out a lot of studies and measurements well-versed in estimation of water management efficiency at many places in the country; (7) *GENATIC ALGORITHM technique* is recommended to be applied to estimate the optimum cropping pattern , which can maximize the water unit benefit in case of application cases of big main canals; (8) Areas planted with both berssem in winter and green fodder in summer must be diminished to some limits to insure the necessary requirements of milk and cheese only. Otherwise, meat must be imported to satisfy the internal requirements of animal protein instead of its production because it is more expensive. This will allow planting some other profitable crops. Wheat crop must be increased in planting to maintain both the alimentary safety and the country economic independence.

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REFERENCES

1. Bayoumi, *et al.*, 1997. A study on developing a revised. Integrated Land and Water Plan; APRP-DRI Unit Report No 24, Cairo, Egypt.
2. Zhu, Z., Laila, Abed Nagy and G. Yakoub, 1995. Revised Nile River water balance years 1987-1993, Strategic Research Program, Ministry of Water Resources and Irrigation, Cairo, Egypt.
3. El-Ganzory, A., 1991. Numerical simulation of irrigation water distribution in Eastern Nile Delta, Ph.D. Thesis, Irrigation and Hydraulics Department, Civil Engineering, Cairo University, Giza, Egypt.

4. Sakr, H., 2007. Economic efficiency for use of water resources in the Egyptian agricultural sector, Ph.D. Thesis, Faculty of Agriculture, Cairo University, Cairo, Egypt.
5. DRI, 1998. Reused of drainage water, Drainage Research Institute, Ministry of Water Resources and Irrigation, Cairo, Egypt.
6. NWRP, 2000. Crop water use and water balance of the Nile System, National Water Resources Plan for Egypt, Technical Report No 8, Ministry of Water Resources and Irrigation, Cairo, Egypt.
7. Attia, B., 1996. A framework for the development of Egypt's national water policy, Ministry of Water Resources and Irrigation, Cairo, Egypt.
8. Amer, K.M., 1999. Rainfall Forecasting and Strategic Irrigation Management, Ph.D., Thesis, Civil Engineering, Cairo University, Giza, Egypt.
9. El-Quosy, D.A., 2006. Community based optimization of the management of scarce water resources in agriculture in West Asia and North Africa (WANA), irrigated agriculture benchmark site-Egypt, activity 4, policies and institutional setups. International Center for Agricultural Research in Dry Areas (ICARDA), Cairo, Egypt, October 2006.
10. Hasyan Kifah Mohamad, 2009. Utilization of virtual water concept to analyze the water scarcity problem in the Arab World, PhD Thesis, Irrigation and Hydraulics Department, Cairo University, Giza, Egypt.
11. Zahra, Khyal A., 1997. Irrigation and drainage problems in new reclaimed lands west of Noubaria Canal, MSc Thesis, Irrigation and Hydraulics Department, Civil Engineering, Alexandria University, Alexandria, Egypt.
12. IFAD, 2002a. Chemical analysis results of soil for Bangar El-Sokkar Region. International Fund for Agricultural Development Project in West Noubaria, United Nations, New Lands Agricultural Services Project, Laboratory of Soil & Water, Noubaria, Egypt.
13. Fathey, A.M., 1993. Agricultural irrigation book. Faculty of Agriculture, Alexandria University, Alexandria, Egypt.
14. EMA, 2000. The average monthly meteorological data for Borg El-Arab and Janakleis Meteorological Stations, The Egyptian Meteorological Authority, Cairo, Egypt.
15. CAWD, 2002a. Water requirements for all principal canals (Mm^3), The Central Administration for Water Distribution, Ministry of Water Resources and Irrigation, Cairo, Egypt.
16. IFAD, 2002b. Irrigation water salinity of Bangar El-Sokkar Region. International Fund for Agricultural Development Project in West Noubaria, United Nations, New Lands Agricultural Services Project, Laboratory of Soil & Water, Noubaria, Egypt.
17. RIGW, 2002. Ground water levels statistics – monthly of map sheet NH3614 and NH36M1, Research Institute for Ground Water, Ministry of Water Resources and Irrigation, Cairo, Egypt.
18. GWS, 2002. Ground water levels statistics – monthly of map sheet NH3614 and NH36M1, Ground Water Sector, Ministry of Water Resources and Irrigation, Cairo, Egypt.
19. CAWD, 2002b. Groundwater summary for Lower Egypt (Mm^3/month), The Central Administration for Water Distribution, Ministry of Water Resources and Irrigation, Cairo, Egypt.
20. Zahra, Khyal A., 2011. A computational model on optimum management, conveyance and allocation of water resources – Study case: El-Nasr Canal Region, PhD Thesis, Irrigation and Hydraulics Department, Civil Engineering, Alexandria University, Alexandria, Egypt.
21. Zahra, Khyal A. and D.A. El-Quosy, 2007a. Flow regime effect on conveyance water losses of open channel in Nile Delta, Middle East Regional Conference on Civil Engineering Technology and International Symposium on Environmental Hydrology, Cairo, Egypt in 3-5 September 2007.
22. Zahra, Khyal A. and D.A. El-Quosy, 2007b. Evaluation of water resources management in El-Nasr Canal Region, Egypt, Second ICID African Regional Conference, Glenburn Lodge, Johannesburg, South Africa, 6 - 9th November 2007.
23. Zahra, Khyal A. and D.A. El-Quosy, 2007c. Irrigation water unit economics: conveyance & lifting costs and benefit for crops in El-Nasr Canal Region in Egypt, Second ICID African Regional Conference, Glenburn Lodge, Johannesburg, South Africa, 6 - 9th November 2007.
24. Zahra, Khyal A. and D.A. El-Quosy, 2007d. Net-benefit of irrigation water unit for crops in northern west of Nile Delta, Middle East Regional Conference on Civil Engineering Technology and International Symposium on Environmental Hydrology, Cairo, Egypt in 3-5 September 2007.
25. Allen, R.G., L.S. Pereira, D. Raes and M. Smith, 1998. Crop evapo-transpiration - Guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper No 56, Food and Agriculture Organization of the United Nations, Rome, Italy.

26. Ted Sammis, Esteban, Herrera, 2000. Leaching requirements of pecan and fruit trees, Guide H-644, College of Agriculture and Home Economics, New Mexico State University, Mexico, http://aces.nmsu.edu
27. Ayers, R.S. and D.W. Westcott, 1985. Water quality for agriculture, FAO Irrigation and Drainage Paper No. 29, Food and Agriculture Organization of the United Nations, Rome, Italy.
28. Smith, M., 1992. CROPWAT - a computer program for irrigation planning and management, FAO irrigation and drainage paper No 46, Food and Agriculture Organization of the United Nations, Rome, Italy.
29. Chow, V.T., D.R. Maidment and L.W. Mays, 1988. Applied hydrology, Page 88, McGraw-Hill series in water resources and environmental engineering, McGraw-Hill, New York, N.Y, USA.
30. Younan, N.A., 1995. Irrigation engineering, Vol. II, Delta Typography Center, Alexandria, Egypt.
31. El-Gamal, F.A., 1997. Seepage from canals and streams under transient conditions, PhD Thesis, Irrigation and Hydraulics Department, Civil Engineering, Cairo University, Giza, Egypt.
32. Code, 2002. The Egyptian code for water resources & irrigation works; Volume 3; lined irrigation networks; pages 1-5 and 1-6, Ministry of Water Resources and Irrigation, Cairo, Egypt.
33. El-Fitianey, F.A., M.A. Abou-Rohayiem, H.M. Moghazy, Hassan and A.A. Abd-Allah, Goubran, 2004. Irrigation & drainage networks: Planning and engineering design, Irrigation and Hydraulics Department, Civil Engineering, Alexandria University, Alexandria, Egypt.
34. Gittinger, J. Price, 1978. Economic analysis of agricultural projects, The Economic Development Institute, World Bank Publication, The Johns Hopkins University Press, Baltimore and London, USA.