Regression Based Modeling and Numerical Simulations for the Assessment of Water Management Practices for El-Salam Canal Project, Egypt

M. Shaban[1] and E. A. Elsayed[2]

[1]Researcher, Drainage Research Institute, National Water Research Center, Egypt, salamashaban@yahoo.com
[2]Researcher, Drainage Research Institute, National Water Research Center, Egypt, ehab7878@hotmail.com

Abstract

In Sinai Peninsula, rainfall is low all the year around and is particularly lacking during the dry season, which may last for several months. In general, rain-fed agriculture is uncertain except at limited areas. However; to achieve higher yields and to produce vegetables, fiber and cash crops in these climatic conditions, irrigation is vital. Therefore the El-Salam Canal Project (**ESCP**) was established by the Egyptian Government to reclaim an estimated 260,000 ha of desert located at the western and eastern sides of Suez Canal.

The main sources of project water are the re-use of agricultural drainage water (2240 Mm^3) from the Lower Serw and Bahr Hadous drains that collect their water from old lands in the Nile Delta, by means of mixing it with fresh water from the River Nile (Damietta Branch) using variable mixing proportions (up to 1:1) through the year. The recent measurements showed that there is a substantial reduction of drainage water available from Hadous drain that is one of the main project sources. This may be related to the water rationalization programs and the public awareness campaigns carried out by the Ministry of Water Resources and Irrigation (**MWRI**).

The overall objectives of this research are to first predict the future drainage water quantity and quality for the project feeders and then propose different water management scenarios for operating the **ESCP** and finally analyze their suitability in relation to quantity and quality of El-Salam Canal water.

The analysis started by developing regression based mathematical models for water quantity and quality data collected monthly during the period from 1984 to 2010. These regression models were then used to forecast the water quantity and quality of Lower Serw, Bahr Hadous, Farsqur and Upper Serw Drains. Based on the forecasted quantity and quality information, different operating scenarios were proposed. Finally, the water quality model **QUAL2K** was used to simulate these operating proposals on the El-Salam Canal water quality.

The study presented two optimal water management scenarios for the future operation of ESCP. The results showed that drainage water reuse provide significant contribution to the challenges facing rain-fed agriculture in dry seasons. In addition, the research explored the utility of simple water quality model (QUAL2K) as an efficient and user friendly tool for regional water management.

***Key words*:** Water Resources Management, Regression Models, Numerical Simulation and El-Salam Canal Project

1. INTRODUCTION

Egypt's population is growing gradually, the standard of living and the related demand for water are both growing, and freshwater sources are becoming increasingly polluted. As a result, the amounts of fresh water available to agricultural, industrial and domestic uses have been declining. Therefore conservation of water, mainly by recycling agricultural drain water in irrigation, has become the core of Egypt's water management.

The Government of Egypt is undertaking major projects to divert considerable amount of drainage water to nearly reclaimed area after blending with the Nile water. El-Salam Canal Project (**ESCP**) (Figure 1) as one of those projects diverts annually around 2240 Mm^3drainage water of the Bahr Hadous and Lower Serw drain basins to be mixed with fresh water (2210 Mm^3) from the River Nile (Damietta Branch) with variable mixing proportions (up to 1:1) through the year.

This ratio is determined to reach Total Dissolved salts (TDS) not more than 1000– 1200 mg/l to be suitable for cultivated crops. The project aims at reclaiming 92,000 ha west of Suez Canal in the fringes of the Eastern Delta and 168,000 ha east of the Suez Canal in Sinai Peninsula. (**APRP, 1998, Mostafa, 2002 and Mostafa et al., 2002**). The overall project objective is not only to introduce agricultural development to barren lands and developing job opportunities by creating new communities. It is also the integrated development, which combines agriculture with agro-industry, mining, production of energy, other industrial activities and tourism (**MWRI website, 2012, El-Quosy, 2001 and World Bank, 1995**).

The agriculture plan of the project is divided into several phases. In phase I, about 168,000 ha aimed to be cultivated with the utilization of 3000 $Mm^3$of water obtained from El-Salam canal (**ESC**), (**Mason, 2004**). However, no decision has been taken as yet with regard to the development of the El-Sir and Kawarir area located North Eastern Sinai between 50 and 150 m above sea level, which implies a high energy demand for lifting water.

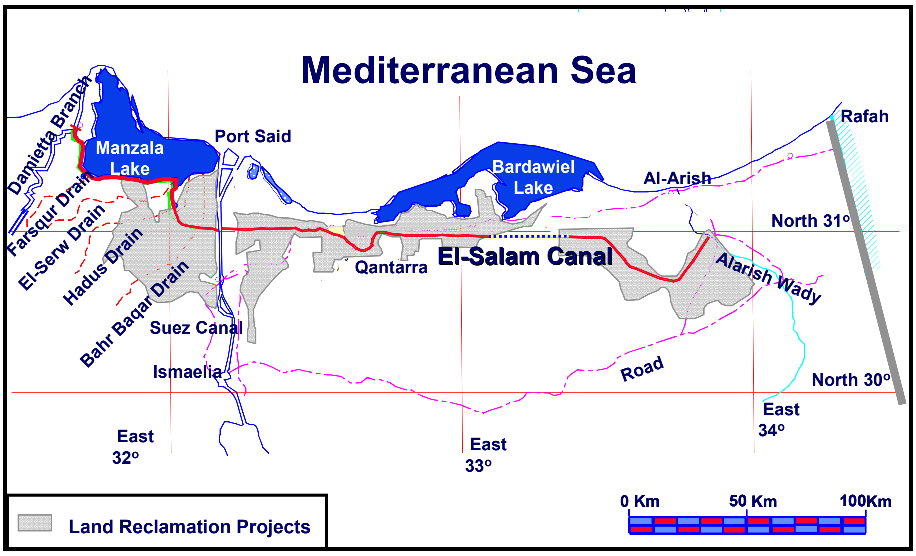


Figure 1: ESCP and its main water resources

The project now achieves clear success in reclaiming vast desert areas and creating new job opportunities to the Egyptian people causing significant improvement in their socio-economic conditions. However, some negative impacts are also expected including upsetting and increasing pressure on the natural ecosystems, building up of soil salinity leading to soil degradation and increased seepage of contaminated groundwater into aquifers and Lake Bardawil (**Othman et al., 2012**). Most of these negative impacts may be attributed to the water quality of the ESCP especially drainage water.

The canal water salinity shows high variations due to the seasonal variation of water quantity and meteorological conditions (Air Temperature, Humidity and etc). In general, relatively high biological and chemical Oxygen demands (BOD and COD) were recorded near to the mixing points of El-Serw and Hadous drains with Nile water. However, the concentrations of COD and BOD decrease in the East Suez Canal to the acceptable limits as water flows due to the natural aeration in the canal and referring to lifting water by using mechanical pumping several times (**Hafez, 2008**).

However, recent research (**Shaban, 2012**) indicated that significant improvements in water quality were recorded. These improvements are largely attributable to the pollution control measures in the catchment areas of Hadous and Serw drains, especially the continuous effort in providing new public sewers and in enforcing environmental legislation.

The project water quality is a significant factor to put limits on the amount of available water that may be used. Therefore, there is a continuous need to monitor and delineate the current and future water quality status of the project main feeders. This enables the project managers to formulate effective water policies that ensure project sustainability. Based on that concept, this research attempts to first predict the future drainage water quantity and quality for the project feeders and then propose different water management scenarios for operating the **ESCP** and finally analyze their suitability in relation to quantity and quality of El-Salam Canal water.

2. ESCP WATER POLICIES

The initial proposal for the ESC assumed at the onset of the project that the total drainage water available in Hadous and Lower Serw drains was around 3450 Mm^3/year (2720 and 730 Mm^3respectively). This policy employed a minimum of 10% from the available drainage water in the Lower Serw drain (73 Mm^3/year) and a minimum of 20% in the Hadous drain (540 Mm^3/year) to continue to flow towards Lake Manzala to protect its ecosystem. According to this proposal always 2200 Mm^3/year from drainage water are guaranteed for the project (**DRI, 1985**).

However, later measurements showed that the average annual water budget for Hadous drain reached to 1750 Mm^3/year, which represent only 64% from the initial estimation 2720 Mm^3/year (Drainage Research Institute, 2011). This may be attributed to the increase of irrigation efficiency as a result of rationalizing programs carried out by the Ministry of Water Resources and Irrigation (**MWRI**) such as Irrigation Improvement Projects (**IIP**) and using the Media to increase the public awareness about the water scarcity problems. In general this reduction should be more investigated in detail to figure out the exact explanation for this phenomenon.

The water shortage for Hadous drain called for modifying the water policy for the ESCP. Consequently, it was decided to add some drainage water from Farsqur drain especially after the completion of the new Farsqur Pump station which is located at 1.8 km left side of the ESC. It is expected that this pump station will divert around 1.0 Mm^3/day during the high demands period. In addition, adding drainage water from the Upper Serw drain to the previous proposals can be also considered for increasing the water budget of the project **(DRI, 2001)**.

3. ESCP DESCRIPTION

ESCP as shown in Figure (1) is located in the Eastern Nile Delta of Egypt. The total length of the canal is 242 km. It takes its supply of water from the Damietta Branch at km 219, upstream Farskour Dam that was designed to balance the Nile water level to allow feeding the ESCP with water. The canal moves in south-eastern direction, passing the Harna Drain, until the delivery side of the Lower Serw Pumping Station.

At km 13.5 of the canal, a pumping station lifts the water from Lower Serw drain into ESC. Downstream this pumping station, the canal moves to the eastern direction parallel to the Tawil Drain. At km 36.65 the Tawil drain is crossed. Then the canal moves in southern direction till it crosses the Bahr Hadous Drain at km 48.500. This point is situated at the Bahr Hadous Outfall. A pumping station at this point lifts the water from Bahr Hadous drain into the canal. The canal moves south and then to the east until it faces the Suez Canal at km 82.00 (south Port Said City). The total length of the canal till this location is 82 km (**Hafez, 2005**).

Then the water is transported through a siphon (about 1300 m length) under the Suez Canal to bring its water to Sinai. The Canal in west Sinai is named as Sheikh Gabber Canal extending over 160 km long to irrigate the lands of proposed expansion in Sinai in Sahl El-Tina and the coastal area between Romanna, El-Arish, Alsir and Qwareer. The project area is divided over three administrative regions: the Port Said Governorate (10%), the Ismailiya Governorate (20%) and (70%) in the North Sinai Governorate (**El-Quosy, 2001**).

4. MATERIALS AND METHODS

4.1. Curve Fitting Technique

Curve fitting refers to fitting curved lines to data. These curved lines come from regression techniques or interpolation. The main objective of curve fitting is to gain insight into the data set. This will lead to improve data acquisition techniques for future experiments, accept or reject a theoretical model, extract physical meaning from fitted coefficients, and draw conclusions about the data's parent population. Many monotonous time series data can be adequately approximated by a linear function.

For the purpose of this study, ***DataFit software*** as a tool that simplifies the tasks of data plotting, regression analysis and statistical analysis was used to elaborate simple formulae that can help predicting the future drainage water quantities (Q) and quality (Biological Oxygen Demand (BOD), and Total Dssolved Salts (TDS)) for the El-Salam Canal feeders (Bahr Hadous, Lower Serw, Farsqur and Upper Serw drains).

The fitting curve process was carried out on monthly basis using the collected data from 1984 till the year 2010. The regression models were developed for each month, and then sorted according to the goodness of fit criteria (Residual Sum of Squares and Relative Mean Error). In all cases, the formula that has higher coefficient of determination (R^2) and less Relative Mean Error (RME) was selected as a best fitted formula. Fortunately, the square of the correlation coefficient provides exactly the value of coefficient of determination.

4.2. Water Management Scenarios For Operating ESCP

Based on the forecasted drainage water quantities of Lower Serw, Bahr Hadous, Farsqur and Upper Serw drains, five different scenarios were proposed for the future operation of ESCP. These scenarios ensure a minimum of 10% and 20% from the available water in Lower Serw and Bahr Hadous drains respectively to continue flowing towards Lake Manzala. This is to comply with the initial project policy in protecting Lake Manzala ecosystem **(DRI, 1985)**.

Table (1) displays the proposed scenarios for operating ESCP. Scenario 1 (Initial proposal) assumed that most of Bahr Hadous and Lower Serw drainage water will be guaranteed for the project. While, in scenarios 2 and 3, various discharges of Farsqur drain will be added and diverted into El-Salam canal. Meanwhile, for scenarios 4 and 5, Upper Serw drainage water will be used to increase the water budget of El-Salam canal project. For each scenario, the expected project water balance for the year 2022 was estimated. This is to clarify the expected relation between supply and demand of ESCP in addition to investigate the possible Nile water inflow reduction.

4.3. Numerical Modeling and Simulations

During the past few decades there has been significant development in water quality modeling. This applies to methodologies, as well as computer software and hardware **(Laszlo, 1997)**. At the moment, the U.S Environmental Protection Agency (USEPA)'s QUAL2E has been the most widely used stream quality model which can be adopted on personal computers. The model is numerically accurate and includes an updated kinetic structure for most conventional pollutants **(Chapra and Pelletier, 2003)**. QUAL2K, the newest version of the QUAL2E, is used for the present study.

The surface water quality model QUAL2K assesses parameters that characterize the surface water status like pH, temperature, suspended solids, Electrical Conductivity (EC), Biological Oxygen Demand (BOD), nitrogen and phosphorus forms, Dissolved Oxygen, Pathogen, phytoplankton, detritus, alkalinity, total inorganic carbon and bottom algae. Furthermore, Total Dissolved Solids (TDS) can be calculated as a function of EC **(Peeter Ennet et al. 2008)**.

For the purpose of this research, the reach of the El-Salam Canal that starts from its intake at Damietta branch of the River Nile at km 0.00 until it meets the Suez Canal at km 82.00 was modeled. This reach comprises the most effective water quality and quantity interventions along the El-Salam Canal.

The selected reach was subdivided into 20 different units according to the geometry of the canal. Schematic of the system segmentation is displayed in Figure (2), along with locations of tributary flow input and abstraction sources.

Based on the fact that the variations of BOD, TDS and Q in 2009/2010 were relatively in small ranges, the model was calibrated with monthly average field measurements data of 2009/2010. It was assumed that all input and output discharges, as well as relevant water quality parameters (BOD and TDS) of all inputs were constant during each month. Thereafter, several runs were carried out to simulate discharge, BOD, and TDS along the canal for the five proposed operating scenarios using the expected quantity and quality data estimated from the regression models for the year 2022. This is to assess the proposed scenarios for the future operation of ESCP.

Table 1: The proposed scenarios for operating El-Salam Canal project

Scenarios	Available discharge from drains (%)			
	Bahr	Lower	Farsqur	Upper
Scenario 1 (Initial)	80%	90%	--	--
Scenario 2	80%	90%	60%	--
Scenario 3	75%	90%	80%	--
Scenario 4	80%	90%	--	100%
Scenario 5	55%	90%	70%	100%

5. RESULTS AND DISCUSSION

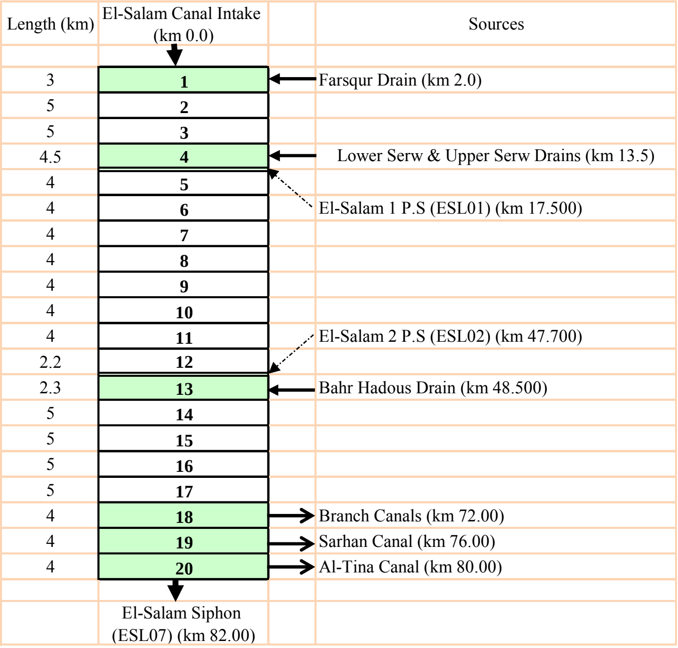
5.1. Empirical Formulae

The fitting curve technique was used in order to elaborate simple formulae that can be used as helpful tools for predicting the future drainage water qualities and quantities for ESC feeders. The fitting curve process was carried out on monthly basis using the collected data from 1984 till the year 2010. This data is regularly collected within the framework of the National Water Quality Monitoring Network executed partially by the Drainage Research Institute (DRI).

As an example, Table (2) and Figure (3) show the output of the curve fitting process applied for monthly discharges and BOD of Farsqur drain outfall. The estimated drain discharges for the years 2007, 2015 and 2022 are presented. The measured and estimated values for the discharge measurements in the year 2007 were presented in order to give an idea about how much far the estimated discharges from the measured ones. It has to be mentioned here that the forecasted drain discharges were inspected in the light of their physical feasibility such as drain capacities. All obtained discharges were then compared with the collected data and were found to be within the historical range. In addition, it was assumed that no drastic changes in future managerial actions will exist.

The coefficient of determination values (R^2) for the obtained formulae ranged from 0.61 to 0.98 indicating significant correlation coefficients. Moreover, the mean value of RMEs for the estimated monthly discharges in the year 2007 did not exceed 4%. Thus, these formulae proved to perform well in predicting monthly discharges of Farsqur drain outfall.

Furthermore, similar formulae were developed for monthly discharges for the other ESC feeders (Bahr Hadous, Lower Serw, and Upper Serw drains). Similar relations were also developed for BOD and TDS for all the considered drains.



Length (km)	El-Salam Canal Intake (km 0.0)	Sources
3	1	← Farsqur Drain (km 2.0)
5	2	
5	3	
4.5	4	← Lower Serw & Upper Serw Drains (km 13.5)
4	5	
4	6	El-Salam 1 P.S (ESL01) (km 17.500)
4	7	
4	8	
4	9	
4	10	
4	11	El-Salam 2 P.S (ESL02) (km 47.700)
2.2	12	
2.3	13	← Bahr Hadous Drain (km 48.500)
5	14	
5	15	
5	16	
5	17	
4	18	→ Branch Canals (km 72.00)
4	19	→ Sarhan Canal (km 76.00)
4	20	→ Al-Tina Canal (km 80.00)
	El-Salam Siphon (ESL07) (km 82.00)	

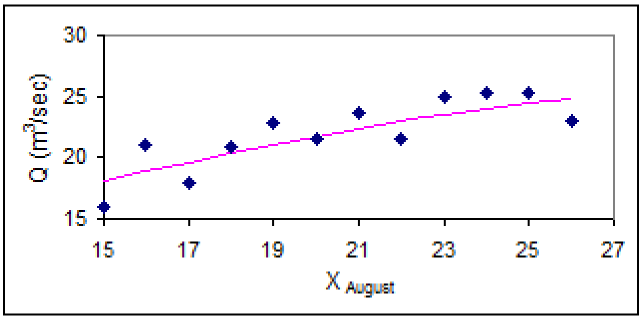
Figure 2: QUAL2K segmentation scheme for El-Salam canal

Table 2: Output of the curve fitting technique for Farsqur drain outfall discharges (m^3/sec)

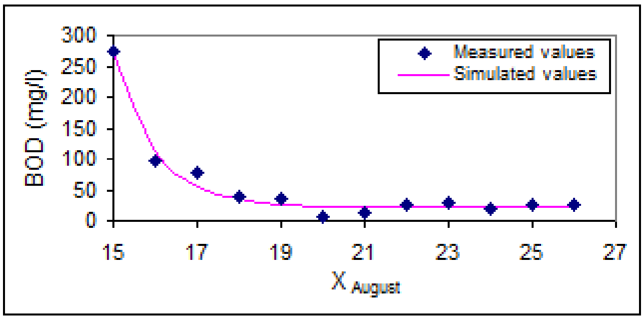
Month	Curve fitting	R^2	Q_{2007} (m^3/sec)			Q_{2015} (m^3/sec) Estimated	Q_{2022} (m^3/sec) Estimated
			Measured	Estimated	%RME		
Aug	Y = 11.96-18.82*ln(x)+43.61*ln(x)^2-33.52*ln(x)^3+10.73*ln(x)^4-1.19*ln(x)	0.87	26.9	23.9	10.8	25.9	24.7
Sep	Y = -5.64*(x)^3+3.44*(x)^2-0.25*(x)+13.74	0.84	18.6	19.8	-6.5	22.6	23.0
Oct	Y = -6.71*(x)^3+4.71*(x)^2-0.61*(x)+11.78	0.87	15.6	15.1	3.4	18.6	19.9
Nov	Y = 7.44+6.24*ln(x)-0.6*ln(x)^2+1.44*ln(x)^3	0.61	13.1	13.0	0.7	17.1	20.7
Dec	Y = 5.77+6.98*ln(x)-5.76*ln(x)^2+1.30*ln(x)^3	0.78	11.3	11.3	-0.6	14.7	17.7
Jan	Y = 6.46+2.11*ln(x)-3.01*ln(x)^2+0.9*ln(x)^3	0.95	10.8	11.5	-6.8	14.9	17.8
Feb	Y = 3.91+7.55*x*ln(x)+13.33*ln(x)/x^2	0.74	9.4	9.7	-3.9	12.3	14.7
Mar	Y = -7.8*(x)^3+4.15*(x)^2-0.414*(x)+8.31	0.83	12.8	11.5	10.1	12.0	9.1
Apr	Y = 24.3-396.2/x+3140.5/x^2-10627.3/x^3+15291.8/x^4-7426/x^5	0.91	14.4	12.6	12.9	14.7	16.1
May	Y = 8.21+3.6*x^2-4.88*x^2.5	0.90	16.7	15.2	9.3	16.8	16.6
Jun	Y = 11.1-18.5*ln(x)+41.5*ln(x)^2-30.7*ln(x)^3+9.5*ln(x)^4-1.03*ln(x)^5	0.96	22.9	20.9	8.9	22.2	21.0
Jul	Y = 12.57-10.9*ln(x)+31*ln(x)^2-26.3*ln(x)^3+8.97*ln(x)^4-1.04*ln(x)^5	0.98	26.6	24.1	9.6	25.5	23.8
TOTAL			16.6	15.7	4.0	18.1	18.8

In which:

Y: The estimated drainage water discharge and
X: Number of steps after the starting point in August 1984. For Example for the estimation of Q_{2022} in the month of August: $x_o = x_{\text{August 1984}} = 1$ and $x_{\text{August 2022}} = 39$.



(a)



(b)

Figure 3: Results of regression techniques in August for Farsqur drain outfall. (a) Q, and (b) BOD

5.2. Water Balance For ESCP Operating Scenarios

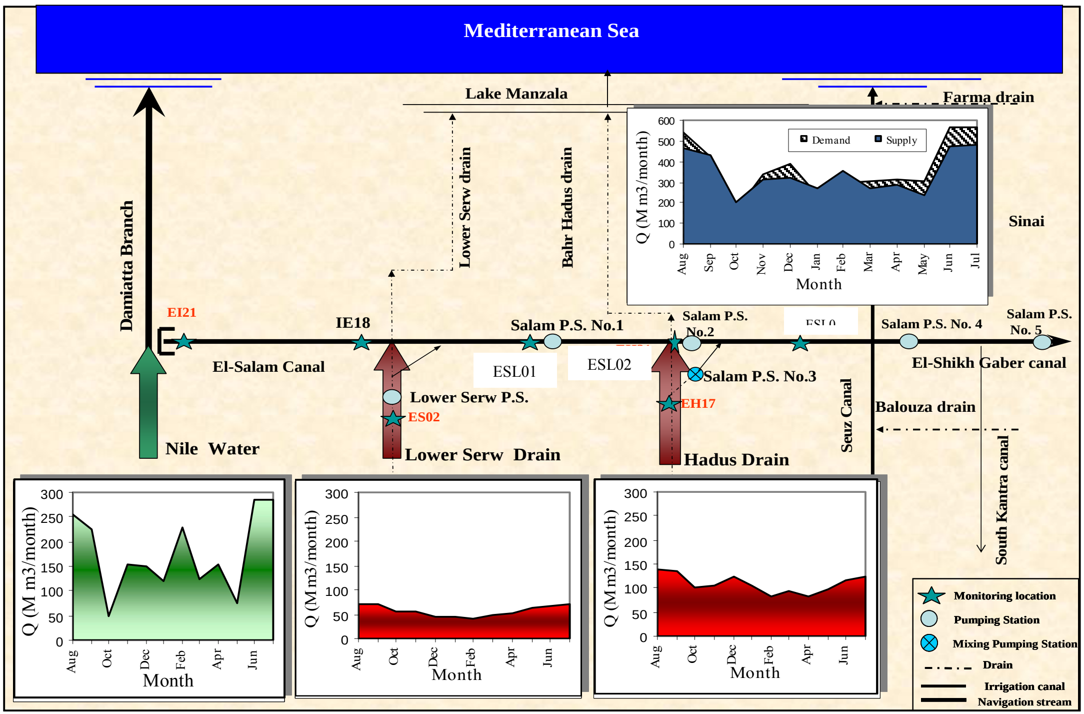
The estimated monthly discharges for ESC feeders and the water balance of the proposed scenarios for ESCP in year 2022 are presented in Table (3) and Figures (4 and 5). In case of applying scenario 1 (initial proposal), the project may have water shortage for 8 months (March to August, November and December) during the year 2022 with a total amount of 489.36 Mm^3. On the other hand, a possibility of Nile water inflow reduction of 139.44 Mm^3 may exist during the other 4 months. As a result, the net deficit in water budget of ESCP may reach about 350 Mm^3/year, assuming that the Nile water inflow reduction can be used during the months of high demands.

Meanwhile, for the other scenarios (2, 3, 4, and 5), the water shortage may amount to the possible Nile water inflow reduction. It is thus evident that all proposed scenarios (except scenario 1) may cover the deficit in the water budget of ESCP for the year 2022. This is only possible in case of using the Nile water inflow reduction during the months of high demands.

Concerning scenarios 4 and 5, it is proposed to add and divert Upper Serw drainage water into El-Salam canal in order to increase the water budget of ESCP. Nevertheless, Upper Serw pumping station (ES01) was constructed in the year 1928 in the north-eastern part of the Nile Delta to lift water from the Upper Serw drain and blend it with fresh water of Damietta Branch. The apparent reason for this is the urgent need for additional supply of water at the tail-end of Damietta Branch to fulfill its water demands. Consequently, applying scenario 4 or 5 will result in substantial decrease of the Damietta Branch water quantity especially at its tail-end. This reduction has to be compensated from the Nile water which increases the pressure and burden on the limited fresh water resources.

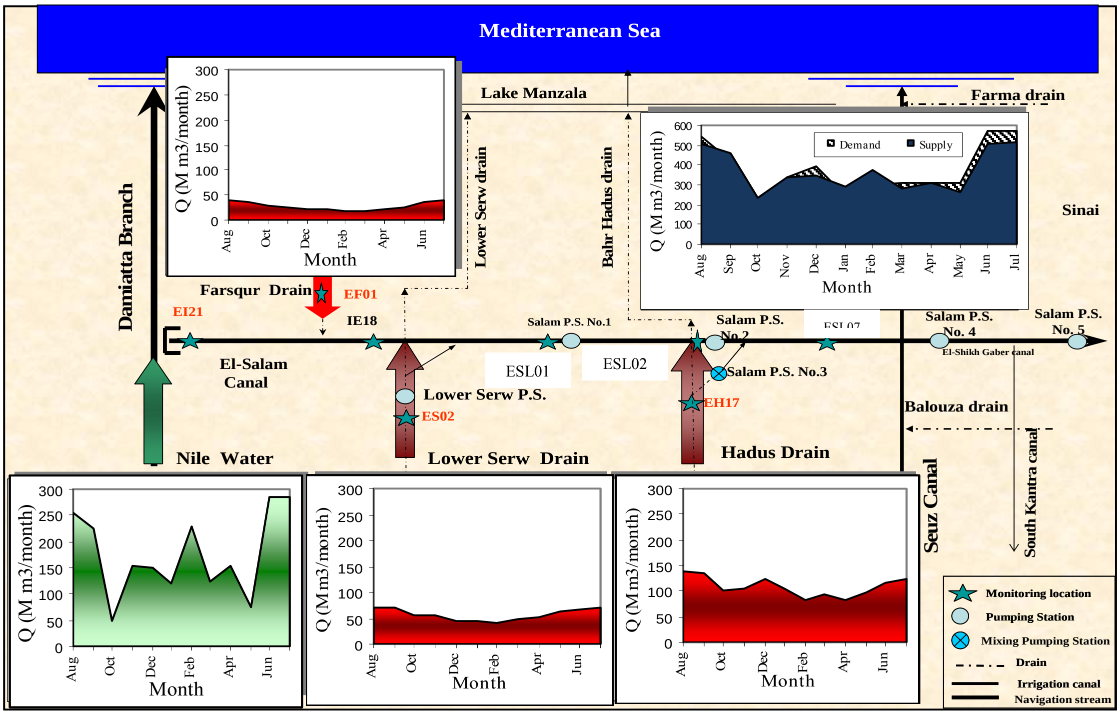
Table 3: The estimated water balance (Mm^3) of the proposed scenarios for ESCP in 2022

Months		Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Total
Total demand for the final stage of ESCP		540	420	160	340	390	240	300	305	310	305	570	570	4450
Required Nile fresh water to the ESCP		255	225	50	155	150	120	230	125	155	75	285	285	2110
Drainage water resources in 2022 (Million m^3/Month)	Hadous drain outfall	172.7	169.1	124.8	131.6	155.5	132.9	104.2	118.1	102.3	121.7	147.4	155.7	1635.9
	Lower Serw drain	80.2	76.2	62.8	60.6	50.1	49.1	44.9	52.0	59.1	69.4	75.4	77.3	757.1
	Farsqur drain	67.2	58.5	48.1	44.2	38.0	38.6	31.9	31.2	38.1	43.5	57.5	66.1	563.0
	Upper Serw drain	80.2	39.0	18.8	24.1	18.9	15.3	23.7	26.5	22.3	25.4	30.4	34.9	359.5
Scenario 1	Total drainage re-use	210.4	203.8	156.3	159.8	169.5	150.5	123.8	141.3	135.0	159.8	185.7	194.1	1990.1
	Drainage to Lake Manzala	190.0	138.9	98.2	100.7	93.0	85.4	81.0	86.5	86.8	100.2	125.0	139.8	1325.4
	Water shortage	74.6	—	—	25.2	70.5	—	—	38.7	20.0	70.2	99.3	90.9	489.4
	Nile water reduction	—	8.8	46.3	—	—	30.5	53.8	—	—	—	—	—	139.4
Scenario 2	Total drainage re-use	250.7	238.9	185.2	186.3	192.3	173.7	142.9	160.0	157.9	185.9	220.2	233.8	2327.9
	Drainage to Lake Manzala	149.7	103.8	69.3	74.2	70.2	62.2	61.8	67.8	63.9	74.1	90.4	100.2	987.6
	Water shortage	34.3	—	—	—	47.7	—	—	20.0	—	44.1	64.8	51.2	262.0
	Nile water reduction	—	43.9	75.2	1.3	—	53.7	72.9	—	2.9	—	—	—	249.9
Scenario 3	Total drainage re-use	255.5	242.1	188.6	188.6	192.1	174.8	144.1	160.3	160.4	188.6	224.4	239.2	2358.7
	Drainage to Lake Manzala	144.9	100.6	65.9	71.9	70.4	61.1	60.6	67.5	61.4	71.4	86.3	94.7	956.8
	Water shortage	29.5	—	—	—	47.9	—	—	19.7	—	41.4	60.6	45.8	244.9
	Nile water reduction	—	47.1	78.6	3.6	—	54.8	74.1	—	5.4	—	—	—	263.6
Scenario 4	Total drainage re-use	290.6	242.8	175.2	183.9	188.4	165.8	147.5	167.8	157.3	185.2	216.2	229.0	2349.6
	Drainage to Lake Manzala	109.8	99.9	79.4	76.6	74.1	70.1	57.3	60.0	64.5	74.8	94.5	104.9	965.9
	Water shortage	—	—	—	1.1	51.6	—	—	12.2	—	44.8	68.8	56.0	234.6
	Nile water reduction	5.6	47.8	65.2	—	—	45.8	77.5	—	2.3	—	—	—	244.2
Scenario 5	Total drainage re-use	275.5	244.1	183.6	187.4	190.2	170.8	146.4	164.2	160.1	188.2	222.3	236.8	2369.6
	Drainage to Lake Manzala	124.9	98.6	71.0	73.1	72.4	65.1	58.3	63.6	61.7	71.8	88.3	97.1	945.9
	Water shortage	9.5	—	—	—	49.8	—	—	15.8	—	41.8	62.7	48.2	227.8
	Nile water reduction	—	49.1	73.6	2.4	—	50.8	76.4	—	5.1	—	—	—	257.4



Water Shortage 489.36 million m³/year **Possible Nile water inflow reduction 139.44 million m³/year**

Figure 4: Diagram for the project feeders in Scenario 1 with hydrographs for the estimated monthly discharges in the year 2022



Water Shortage 262.03 million m³/year **Possible Nile water inflow reduction 249.92 million m³/year**

Figure 5: Diagram for the project feeders in Scenario 2 with hydrographs for the estimated monthly discharges in the year 2022

5.3. Validation Of QUAL2K Model

Figure (6) shows TDS, BOD, and Q profiles along the modeled reach of ESC for the validation process. The resulting solute concentrations output by QUAL2K were compared to mean field values of 2009/2010 at three locations, El-Salam P.S.1 (ESL01), El-Salam P.S.2 (ESL02), and upstream the El-Salam canal siphon at the Suez Canal (ESL07). The statistical evaluation of the measured and simulated values showed that the values of mean relative error for TDS, BOD, and Q were 1.54%, 0.64%, and -0.9%, respectively. This indicates that the simulated parameters showed a good level of agreement with the field measurements. Consequently, the validated model can be used for predicting the water quantity and quality for the proposed future operating scenarios of ESCP.

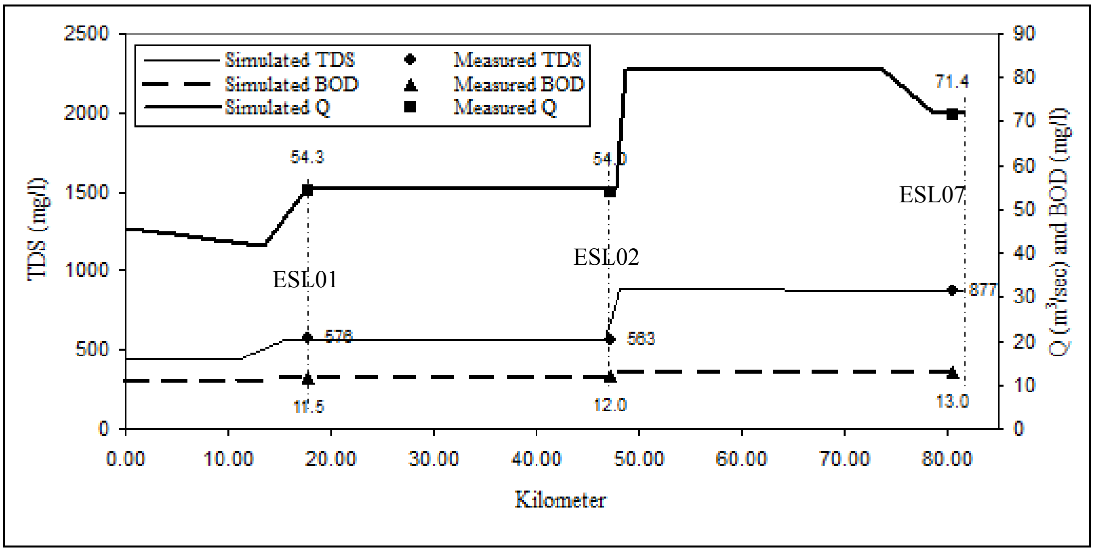


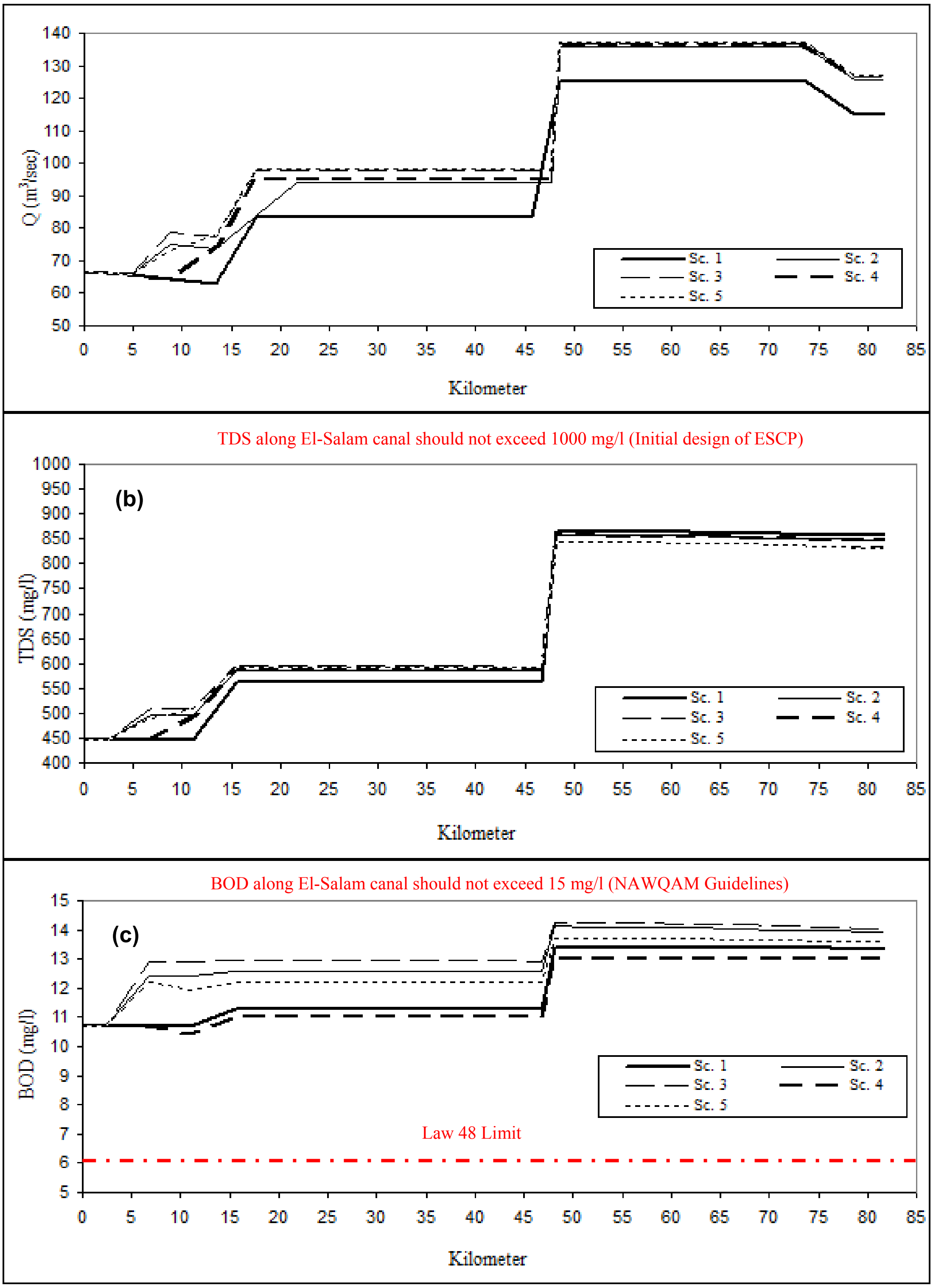
Figure 6: Verification of Q, TDS, and BOD along the modeled reach of El-Salam Canal

5.4. QUAL2K Simulation Results

Figure (7) shows the results of QUAL2K simulations including Q, TDS, and BOD for the proposed operating scenarios of ESCP in the year 2022. According to Figure (7.a), Q profiles of scenarios (2, 3, 4, and 5) did not vary significantly. Meanwhile, scenario (1) gave smaller values of Q (along El-Salam canal) than the other scenarios. This is because the total available drainage water in Hadous and Lower Serw drains may reach to 2.39 bcm/year in the year 2022. As a result, applying Scenario 1 where only 80% and 90% from the available drainage water from Hadous and Lower Serw outfalls will be reused respectively, may result in project water shortage up to 0.489 bcm/year .

As a general result, TDS levels increased in the downstream direction indicating discharge of drainage water into the ESC (Figure (7.b)). It is obvious that TDS values of the considered scenarios did not vary significantly. Moreover, for all proposed scenarios, TDS was lower than 860 mg/l at the modeled reach of the canal. This coincides with the initial proposal of the ESCP that recommended TDS not more than 1000 mg/l.

Referring to Figure (7.c), it was found that scenario (4) provided the minimum values of BOD, while scenario (3) led to maximum values of BOD along the modeled reach of El-Salam canal. Similar to TDS, BOD levels increased in the downstream direction. It was indicated that BOD values in all scenarios complied with NWQAM guidelines for irrigation (15 mg/l); although, these values violated the allowable limit of 6 mg/l of Law 48/1982. Accordingly, model simulation results for all proposed scenarios proved that TDS and BOD values are suitable for irrigation purposes (consistent with NAWQAM guidelines **(ODWRGs, 2007)** and initial proposal of ESCP **(DRI, 1985))**.



TDS along El-Salam canal should not exceed 1000 mg/l (Initial design of ESCP)

BOD along El-Salam canal should not exceed 15 mg/l (NAWQAM Guidelines)

Law 48 Limit

Figure 7: Results of QUAL2K simulations along El-Salam Canal. (a) Q, (b) TDS, and (c) BOD

6. CONCLUSION AND RECOMMENDATIONS

The total available drainage water in Hadous and Lower Serw drains may reach to 2390 Mm^3/year in the year 2022. Consequently, applying Scenario 1 where only 80% and 90% from the available drainage water from Hadous and Lower Serw outfalls will be reused respectively, may result in project water shortage up to 489 Mm^3/year . In this scenario, the drainage water, which will be disposed from the two drains to the Laka Manzala may reach to 1325 Mm^3/year in the year 2022. However, the average water shortage can be reduced up to around 49% (242 Mm^3/year) without significant changes in water quality parameters TDS and BOD when using additional water from Farsqur and Upper Serw drains (Scenarios 2 to 5). The project average water shortage (242 Mm^3/year) can be even eliminated if using the average Nile water inflow reduction (254 Mm^3/year) is possible during the months of high demands.

In general, there are three main factors which influence the final decision concerning the optimal scenario that can be proposed for the future operation of the ESCP. Two factors are related to the water quality of the main project feeders, these are the relative high TDS and BOD levels recorded at Hadous and Farsqur outfalls respectively. The third factor is the fact that Upper Serw drain is currently fully reused by mixing with Damietta Branch to fulfill its water demands. Consequently, applying scenario 4 or 5 will result in substantial decrease of the Damietta Branch water quantity creating more pressure on the limited fresh water resources.

According to the previous discussion, it is recommended to apply either scenario 2 or scenario 3 in order to meet the future water demands for the ESCP. Nevertheless, scenario 2 has relative advantage since the expected BOD levels along the canal are relatively lower. However, the project managers may vary the proposed water quantities abstracted from the drains and the fresh water mixing ratios according to the actual water quality information that is produced by the NAWQAM.

7. REFERENCES

1. Agricultural Policy Reform Program (APRP), 1998, *National Policy for drainage water reuse - Water Policy Reform Activity*, Contract PCE-I-00-96-00002-00, Task Order 807, Report No. 8.
2. Chapra S.C. and Pelletier G.J., 2003, *QUAL2K; A Modeling Framework for Simulating River and Stream Water Quality*: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.
3. Drainage Research Institute (DRI), 2011, *Drainage Waters Status in the Nile Delta,* Yearbook 2009/2010, Rep. No. 80, NWRC, MWRI, Delta Barrages, Egypt.
4. Drainage Research Institute (DRI), 2001, *Water quality monitoring program for El-Salam Canal, Drainage Research Institute*, second technical report.
5. Drainage Research Institute (DRI), 1985, *Estimation of available water for the El-Salam Canal Project,* Reuse of drainage water project, Report 3
6. El-Quosy D., 2001, *Agricultural development in Egypt across two millenniums, paper presented in The World Development Federation*, Virtual, Global Super Projects Conference, (http://www.wdf.org/gspc/virtual2001/pdf/ElQuosyPaper.pdf)
7. Hafez, A., 2005, *Investigation of El-Salam Canal Project in Northern Sinai, Egypt – Phase-I: Environmental Baseline, Soil and Water Quality Studies*, IWTC9, Sharm El-Sheikh, Egypt.
8. Hafez A., Khedr M., El-Katib K., Gad Alla H. and Elmanharawy S., 2008, *El-Salaam Canal project, Sinai, II,* Chemical water quality investigations, Desalination, 227, 274–285
9. http://www.mwri.gov.eg/En/index.htm (Apr. 2012), Ministry of Water Resources and Irrigation (MWRI) – website.
10. Law 48, 1982, *Pollution protection of the River Nile and water channels*, Ministerial Decree 8, Articles 60, 65 and 68 (Check this)
11. Lazlo S., 1997, *Use of optimization models in river basin water quality planning*, Water Science and Technology, 36 (5), 209-218.
12. Mason, S., 2004, *From conflict to cooperation in the Nile Basin. Ph. D. thesis, Swiss Federal Institute of Technology*, *ETH*. Switzerland. Online available at www.css.ethz.ch/publications
13. Mostafa, A.M., 2002, *Development of water quality indicators and atlas of drainage water quality using GIS tools*, CIDA-DRTPC-MWRI, Technical report submitted to the NAWQAM project-Egypt, pp: 85.

14. Mostafa, A.M., S.T. Gawad and S.M. Gawad, 2002, *Development of water quality indicators for Egyptian drains*, ICID, Montreal, Canada, Paper No. Q50/R.01.
15. Operational Drainage Water Reuse Guideline – (ODWRGs), 2007, NAWQAM project, Report No. DR-TE-0410-012-FN
16. Othman A. A., Rabeh S. A., Fayez M., Monib M., Hegazi N. A., 2012, *El-Salam canal is a potential project reusing the Nile Delta drainage water for Sinai desert agriculture: Microbial and chemical water quality*, Journal of Advanced Research, 3, 99–108
17. Peeter Ennet, Karin Pachel, Vladimir Viies, Lembit Jürimägi, and Rain Elken, 2008, *Estimating Water Quality in River Basins Using Linked Models and Databases*, Estonian Journal of Ecology, Vol. 57, No. 2, 83-99.
18. Shaban M., 2012, *Non-parametric trend detection to evaluate water pollution control measures in Egypt*, Scientific Journal of National Water Research Center, Egypt, issue 51.
19. The World Bank, 1995, *Middle East and North Africa Environmental Strategy*.

8. LIST OF SYMBOLS

BOD : Biological Oxygen Demand,
DRI : Drainage Research Institute,
EC : Electrical Conductivity,
ES01 : Upper Serw Pumping Station,
ESL01 : El-Salam P.S.1,
ESL02 : El-Salam P.S.2,
ESL07 : upstream El-Salam canal siphon at the Suez Canal,
ESCP : El-Salam Canal Project,
IIP : Irrigation Improvement Projects,
MWRI : Ministry of Water Resources and Irrigation,
NAWQAM : The National Water Quality and Availability Management,
ODWRGs : Operational Drainage Water Reuse Guideline,
Q_i : Water discharges in year i,
R^2 : Correlation factor,
RME : Relative Mean Error,
TDS : Total Dissolved Solids,
USEPA : U.S Environmental Protection Agency,
X : Number of steps after the starting point in August 1984. For Example for the estimation of Q_{2022} in the month of August: $x_o = x_{\text{Aug 1984}} = 1$ and $x_{\text{August 2022}} = 39$.
Y : The estimated drainage water discharge.