A WASTE LOAD MODEL ANALYSIS FOR EL NOUBARIYA CANAL DRINKING WATER ABSTRACTION, EGYPT

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ABSTRACT

El Noubariya Canal is a second order irrigation canal diverted from El-Beheiry Rayah. The canal length is approximately 100 km and serves a command area of 1,200,000 feddan. There are five intakes for drinking water treatment plants along the Canal. However, due to illegal irrigation and agricultural practices, the water quality of the Noubariya canal is significantly impacted. First, the water quality index for drinking water abstraction has been calculated for the canal. The assessment revealed that the water quality at the water drinking plants intakes is characterized at some locations poor and at other locations marginal. Second, a waste load model is applied to support the water quality management of the canal in order to be used as a safe drinking water abstraction source for the present water drinking plants and the planned ones.

DUFLOW model is applied to simulate the water quality management scenarios in the canal. The first scenario investigates water quality status in case of full operation of drinking water treatment plants at planned and designed abstraction. It was concluded that the water quality will deteriorate and exceeds the standards. The second scenario determines the optimum treatment of pollution loads to improve the water quality of the canal. The results of scenario revealed that 90% reduction at least in present load is needed in order to satisfy with the drinking water abstraction standards. The third scenario investigates the effect of increasing the inflow of the canal. The results suggested that increase of 4 million m^3/ day to El-Beheiry Canal and 8 million m^3 per day to El-Nassery Canal is required for improving the water quality in Noubariya canal for drinking water abstraction.

Keywords: Waste load Model, El Noubariya Canal, Water Quality Modeling

1. INTRODUCTION

Mathematical models have been used for many years to assist in the management of water quality, (Chapra, 1997). The total maximum daily load (TMDL) process is no exception; models represent the means by which the assimilative capacity of a water body can be quantified and a waste load allocation can be determined such that the assimilative capacity is not exceeded, (Pinto et al., 2002). Many research studies had been conducted to assess Noubariya water quality, among these are (Ragab, 1996), (Zahra, 1999), (Abdo, 2000) and (Osman et al., 2002). Most of the previous studies objective was to evaluate the present water quality of the river and potential effects of some pollutants with respect to certain uses; Almost no researches have focused on solving the problem by waste allocation principle or by specifying the total maximum daily loads allowed to be discharged into the river in order to maintain water quality within specification. This research objective is to study the current water quality of Noubariya canal and conduct many scenarios for the waste load in order to improve the water quality of Noubariya canal using a developed waste load model.

2. DESCRIPTION OF El-NOUBARIYA CANAL

Noubariya canal is considered the major canal in the West-Delta area. Noubariya Canal is the main canal which serves El Noubariya and El Nasr General Irrigation Directories. Total length of this canal is 100.00 km and cultivated land area on this big canal is 1.150.000 feddan. At present the average discharge of the Noubariya Canal is 23 million m^3 per day serving a command area of about 1 million acres. Of this flow, 13 million are supplied from the Beheiri Canal. The remaining 10 million m^3 were originally designed to be supplied from El-Nassery Canal. Due to illegal abstractions from El-Nassery Canal, only 7 million are discharged from El-Nassery Canal to the Noubariya Canal. El-Noubariya canal suffers from pollution by agriculture drainage water at seven locations, which are shown in Figure (1).

About 2.126 MCM/day of drainage water is added to El-Noubariya canal at different locations, which is about 8.67% of its maximum discharge. A percentage of 57% of such drainage water is coming from El-Nasr-3 main drain. After the completion of reclamation of the served area of El-Nasr-3 main drain, its discharge is expected to be about 2.736 MCM/day, which raise the drainage water discharged to El-Noubariya canal to 3.652 MCM/day, 75% of them is coming from El-Nasr-3 main drain. This tends to a deterioration of El-Noubariya canal water quality especially downstream El-Nasr-3 main drain outfall that influence the all intakes water quality locating downstream km (52,960) on El-Noubariya Canal. The water of Noubariya Canal is used to provide drinking water to parts of the governorates of El-Beheira and Alexandria, as well as the cities of Borg El-Arab and El-Noubariya. Further, it provides a source for drinking water for tourist villages along the north coast and Marsa Matruh Governorate. Further, it provides a source for drinking water for tourist villages along the north coast and Marsa Matruh Governorate. There are five drinking water plants intakes along the Noubariya canal as shown in Table (1).

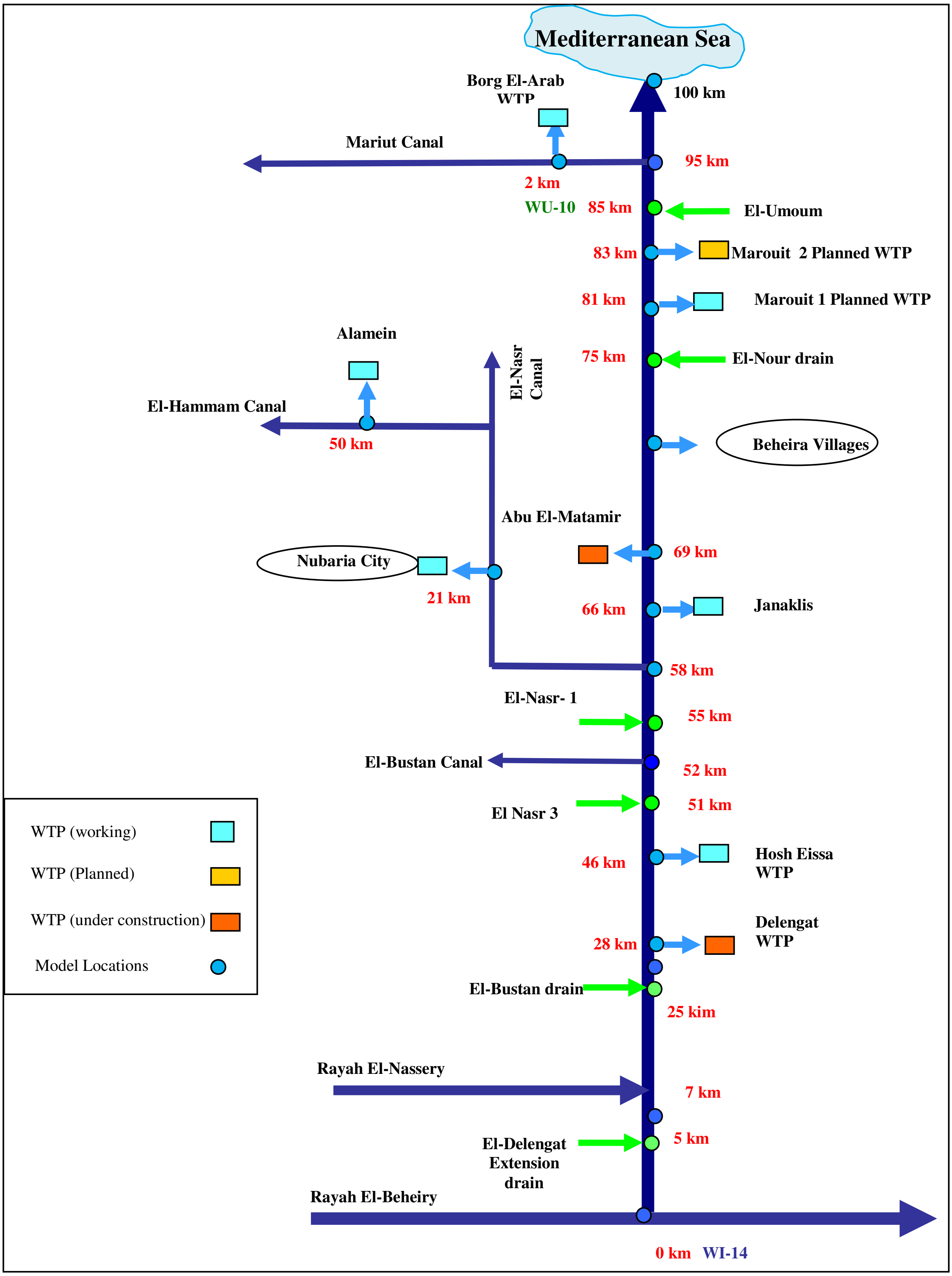

Figure 1 Noubariya canal, sample point locations, drainage inflows and water drinking plants locations

Table (1) Drinking water treatment plants fed from the Noubariya Canal

No.	Operating Authority	Plant Name	Plant Type	Source of Feed Water		Intake Location	Status	Discharge (1000 m^3/d)	
				Secondary	Main	(Km)		Design	Future
First – Location of Water Stations Downstream Km 46 on Noubariya Canal									
1	El-Beheira Water Company	Janaklis	Rapid Filtration	Noubariya Canal		66	In Service	9	9
2		Abu El Matamir	Direct Filtration	Noubariya Canal		69	Under Construction	52	78
3		Station for feeding El-Beheira Villages within the 240 Villages Project	Rapid Filtration	Noubariya Canal			Under Construction	26	26
4		Canal Head	Rapid Filtration	Noubariya Canal		83	Planned	13	13
5	Alexandria Water Company	Canal Head (Maryot 1 – Noubariya)	Main	Noubariya Canal		81	In Service	315	510
6		Borg El-Arab	Main	Maryot Canal	El-Noubariya	1.9	In Service	566	566
7		El-Alamein	Main	El-Hammam Canal	El-Nasr / El-Noubariya	49.5	In Service	167	334
8		New Noubariya (Noubariya City)	Main	El-Nasr	El-Noubariya	21	Under Construction	35	69
9		New Borg El-Arab (Borg El-Arab City)					In Service	166	566
	Total							1,348	2,170
Second – Location of Water Stations Upstream Km 46 on Noubariya Canal									
1	El-Beheira Water Company	Noubariya (Hosh Eissa)	Main	Noubariya Canal		45.5	In Service	45	121
2		El-Delengat	Main	Noubariya Canal		28	Under Construction	61	242
	Total							106	242
	All Total							1,454	2,412

Further, in order to satisfy the water demands of the Western Delta irrigation improvement project (irrigation of 255 thousand acres); three pumping stations shall be constructed to abstract irrigation water from El-Nassery Canal. The first station is at km 22 on the Nassery Canal, abstracting 4 million m^3 per day to irrigate 190,000 acres. The second station is at km 49.65 on El-Nassery Canal, abstracting 1.4 million m^3 per day to irrigate 66,000 acres. The third station shall be at km 56 to abstract 3.6 million m^3 per day to irrigate 170,000 acres. In order to compensate water abstractions for the Western Delta Project, pumping stations on Rosetta Branch shall be constructed at km 66 on Rosetta Branch to supply El-Beheiry Canal with 4 million m^3 per day and the Nassery Canal with 8 million m^3 per day. The intake from Rosetta Branch is located downstream the outfall of El-Rahawy drain, and thus this water is expected to negatively impact the water quality of the Noubariya Canal, which is fed partly by El-Nassery Canal and partly by El-Beheiry Canal. It should be noted that El-Nassery Canal shall be supplying 10 million m^3 per day to the Noubariya Canal, of which 8 million shall be from the polluted Rosetta Branch water. Since the pumping station from Rosetta Branch discharges towards the end of El-Nassery Canal, no sufficient stream length is available for water quality assimilation.

3. WATER SAMPLING AND INDEX CALCUALTIONS

Water quality samples were taken at the abstraction points of the five water drinking plants (Hosh-Esa, Tharwat, Canal-Head, Borg El-Arab and El-Fangry) for the period 2003/2004, (DRI, 2003). The analyses of water samples were carried out according to the standard methods for the examination of water and wastewater (APHA, 1989). Ten major parameters were taken into consideration due to their significance to the drinking water abstraction criteria. The physio-chemical parameters are (Dissolved Oxygen (DO), chemical oxygen demand (COD), Biochemical Oxygen Demand (BOD)). The major anions (Ammonia (NH4), Nitrate (NO3), Total suspended solids (TSS)), The microbiological parameters (Total and Faecal coliform counts) and the trace metals are (Cupper (Cu) and iron (Fe)).

3.1 Average Water Quality Index (AWQI)

In fact WQI has been used by many authors for the assessment of water quality of many rivers around the world (Bath-Ks et al., 1998) and Demuynck et al., 1997). In this research, the water quality index is calculated using the equation developed by (Tiwari and Mensour, 1987) with some modifications, to suit the River Nile condition in order to be able to discriminate between locations and to give an overview on the overall water quality conditions developed by (El-Sherbini and El-Moattassem, 1994). The quality rating q_i, for the i^{th} water quality parameter can be obtained by the following relation:

$$q_i = 100\left(\frac{V_i}{S_i}\right) \tag{1}$$

Where V_i = observed value of the i^{th} parameter at a given sampling site and S_i = stream water quality standard. Equation (1) ensures that q_i = 100 if the observed value is just equal to its standard value. Thus, the larger the value of q_i, the more polluted the water is, with respect to the corresponding pollutant value (mg/L). Thus q_i = 0, when V_{DO} =

Saturation level (in mg/L) and q_i = 100, when V_{DO} = 5 mg/L; for simplicity, V_{DO} will be taken as saturated whenever exceeds the saturation level

To calculate the water quality index, the quality rating q_i corresponding to the i^{th} parameter can be determined using the Equation (1). The overall water quality index was calculated by aggregating these quality ratings linearly as follows:

$$WQI = \sum_{i=1}^{n} q_i \tag{2}$$

Where n = number of parameters.

The average water quality index (AWQI) for n parameters was calculated using this equation:

$$AWQI = \frac{\sum_{i=1}^{n} q_i}{n} \tag{3}$$

The standards used for the calculation of water quality index are the EEC standards by (Tebbutt, 1998). The first Average water quality index (AWQ1) was calculated taking into consideration that the simple physical treatment and disinfection option will be used in the water treatment plant. The second Average water quality index (AWQ2) was calculated taking into consideration that the normal full physical and chemical treatment with disinfection standard option will be used in the water treatment plant. The third average water quality index (AWQ3) was calculated taking into consideration that the Intensive physical and chemical treatment with disinfection option will be used in the water treatment plant.

The AWQI index calculated at the measuring locations is shown in Figure (2). From this figure, the least water quality is occurring at Tharwat, El-Fangry and Hosh-Esa due, this is most probably due to discharging different waste loads from point sources of pollution such as industrial effluent and agriculture located just upstream of the measuring locations. Another interesting feature is that at all the drinking water intakes along the branch the AWQ1 is above 100 due to the accumulation of industrial effluents and agricultural discharges into the stream. Therefore, the Intensive physical and chemical treatment with disinfection is the most suitable option that must be used in Tharwat, El-Fangry and Hosh-Esa drinking water treatment plants along the canal. The normal full physical and chemical treatment with disinfection option can be used in Canal-Head, Borg El-Arab the water treatment plant. As any reuse scenario will deteriorate and affect the water quality condition at these intakes, many scenarios have been conducted for the reuse of drainage water affecting the water quality of the canal. In order to study the impact of these scenarios on the water quality of Noubariya canal, a modeling study was carried out as described in the following section.

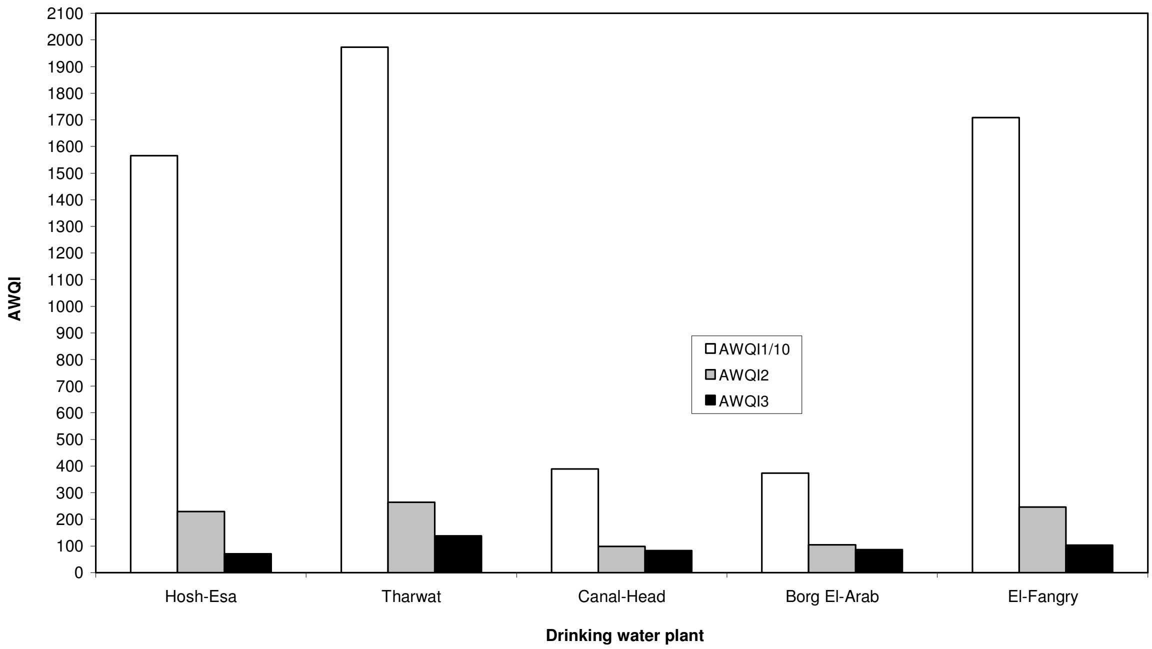

Figure 2 Water quality index at water drinking plants along Noubariya canal

3.2 Egyptian Water Quality Index (EWQI)

The Egyptian Water Quality Index will provide an easy to use and scientifically defensible methodology for evaluating water quality based on its intended use and for converting water quality data into information and then into knowledge. In December 2007 a beta version of the Egyptian Water Quality Index (EWQI), based on the Canadian Council of Ministers of the Environment (CCME) Water Quality Index (WQI) was developed, (Khan et al., 2001). The CCME WQI provides a measure of the deviation of water quality from water quality guidelines. The CCME WQI model consists of three measures of variance from selected water quality objectives (Scope; Frequency; Amplitude). These three measures of variance combine to produce a value between 0 and 100 that represents the overall water quality. The CCME WQI values are then converted into rankings by using an index categorization schema that can be customized to reflect expert opinion by users. The detailed formulation of the WQI is described in the Canadian Water Quality Index 1.0 – Technical Report (CCME 2001). The detailed formulation of the WQI is described in the Canadian Water Quality Index 1.0 – Technical Report (CCME 2001). It consists of three measures which are described as follows:

Scope, F_1

The measure for scope is F_1. This represents the extent of water quality guideline noncompliance over the time period of interest.

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total Number of variables}} \right) * 100 \quad (4)$$

Frequency, F_2

The measure for frequency is F_2. This represents the percentage of individual tests that do not meet objectives ("failed tests").

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total Number of tests}} \right) * 100 \tag{5}$$

Amplitude, F_3

The measure for amplitude is F_3. This represents the amount by which failed tests do not meet their objectives. This is calculated in three steps:

Step 1- Calculation of Excursion: Excursion is the number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective. When the test value must not exceed the objective:

$$\text{excursion}_{\text{i}} = \left(\frac{\text{Failed Test Value}_{\text{i}}}{\text{Objective}_{\text{j}}} \right) - 1 \tag{6}$$

When the test value must not fall below the objective:

$$\text{excursion}_{\text{i}} = \left(\frac{\text{Objective}_{\text{j}}}{\text{Failed Test Value}_{\text{i}}} \right) - 1 \tag{7}$$

Step 2- Calculation of Normalized Sum of Excursions: The normalized sum of excursions, *nse*, is the collective amount by which individual tests are out of compliance. This is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives).

$$\text{nse} = \frac{\sum_{i=1}^{n} excursion_{i}}{\text{Number of tests}} \tag{8}$$

Step 3- Calculation of F_3: F_3 is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives to yield a range from 0 to 100.

$$F_3 = \left(\frac{\text{nse}}{0.01\,\text{nse} + 0.01} \right) \tag{9}$$

The WQI is then calculated as:

$$\text{WQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \tag{10}$$

The WQI values are then converted into rankings by using the categorization schema presented in Table 2. The index is based on water quality guidelines so it is able to evaluate water quality based on the intended use of the water (i.e. drinking water guidelines are used for evaluating drinking water use; irrigation water guidelines are used for evaluating irrigation water use, etc.) and is not restricted by the number of variables. This allows all relevant variables for each designated water use to be included in the computation. The index uses a vector based mathematical function to compute the WQI scores. This allows one to exactly identify what is causing a water body to score poorly. This clarity allows the index to be used as a simple and effective communication tool. The derivation of water quality guidelines using background concentrations and its implementation in a WQI are explained in detail by Khan et al. (2005).

Table (2) CCME WQI Categorization Schema

Rank	WQI Value	Description
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels; these index values can only be obtained if all measurements are within objectives virtually all of the time.
Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
Marginal	45-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
Poor	0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

EWQI based upon the CCME WQI was calculated for the five water drinking water plants intakes as shown in Figure (3), by interpretation of results from Table 2 it is concluded that the water quality Hosh-Esa (EWQI = 43.2), Tharwat (EWQI = 39.46) and El-Fangry (EWQI = 40.61) water treatment plants intakes is poor otherwise the water quality at Canal-Head (EWQI = 52.72) and Borg El-Arab (EWQI = 55.39) water treatment plants intakes is marginal. This is complying so well with the calculated average water quality index.

4. WASTE LOAD MODEL FOR EL-NOUBARIYA CANAL

The one-dimensional unsteady flow model in open channel (The DUFLOW package, Version 2.05) was utilized to determine the TMDL, for non-conservative pollutants (BOD and NH4) for discharging drains, (ICIM, 1995). The model was designed to simulate a system where polluting substances are entering the stream from point source effluents. Noubariya canal was presented was represented by a network of 30 nodes and 29 sections. The nodes are taken at the points of wastewater discharge, at the abstraction points, at sampling locations and also at the different cross sections along the branch. Three scenarios were run using the model.

First scenario includes the variation in water quality in Noubariya canal after operation of drinking plants at planned and designed abstraction. The model is used to simulate the BOD, DO and NH4 concentrations along the branch at present situation compared to designed and planned operation of water drinking plants. The details of simulation are shown in Figures (4) and (5) for BOD in high and low requirements season and Figures (6 and 7) for NH4 water quality parameters in high and low requirements season. Using the developed model, it was obvious the at the water quality will deteriorate in case of full operation of all water treatment plants especially at the Mariut canal abstraction carrying water to Alexandria governorate.

Second scenario includes the variation in water quality in Noubariya canal due to the change in inflowing drains pollution loads to the permitted load of law 48 and to 90% reduction in pollution load. The details of simulation are shown in Figures (8) and (9) for BOD in high and low requirements season at present operation of water drinking plants. The details of simulation are shown in Figures (10) and (11) for NH4 in high and low requirements season at present operation of water drinking plants. Using the developed model, it was concluded that the total maximum daily loads for the Noubariya Branch from the discharging drains must be reduced from the current permitted load for the drains to 90% reduction in the present load. This reduction of load can be done by using the biofilm with aeration option as efficient drain treatment alternative, (Arceivela, 1996). This reduction was in order to satisfy with the Law 48 and drinking standards downstream until km 50 but will not satisfy afterwards upstream due to the water abstraction of el-Nasr canal. For the canal upstream km 50, more water must be fed into the canal in order to satisfy with the Law 48 and drinking standards because this part of the canal is affected by high abstraction quantity of water into el-Nasr canal that influences a lot the water quality of the canal especially in high flow requirements season.

Third scenario includes increasing the water flow of Noubariya canal to improve the water quality. The value added is 4 million m^3, day to El-Beheiry Canal and 8 million m^3 per day to El-Nassery Canal. Figures (11) and (12) show the comparison between BOD and NH4 concentrations along Noubariya canal between present flow and the increasing water inflow. The graphs show that the water quality is improving along the canal and almost are within the standards.

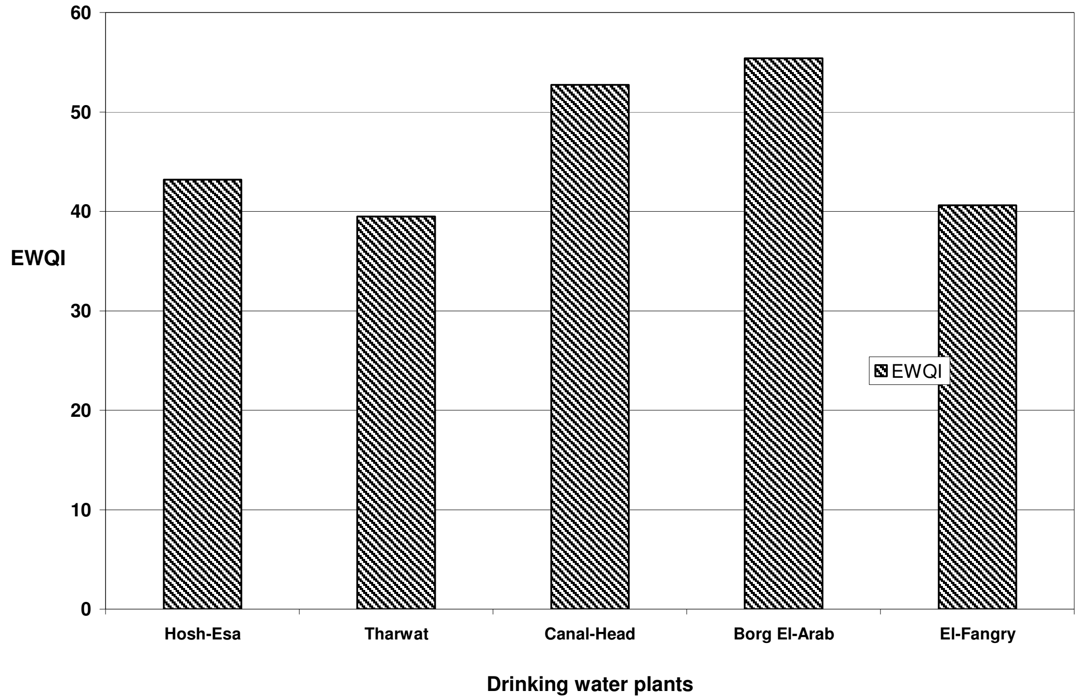

Figure 3 Egyptian Water quality index at water drinking plants along Noubariya canal

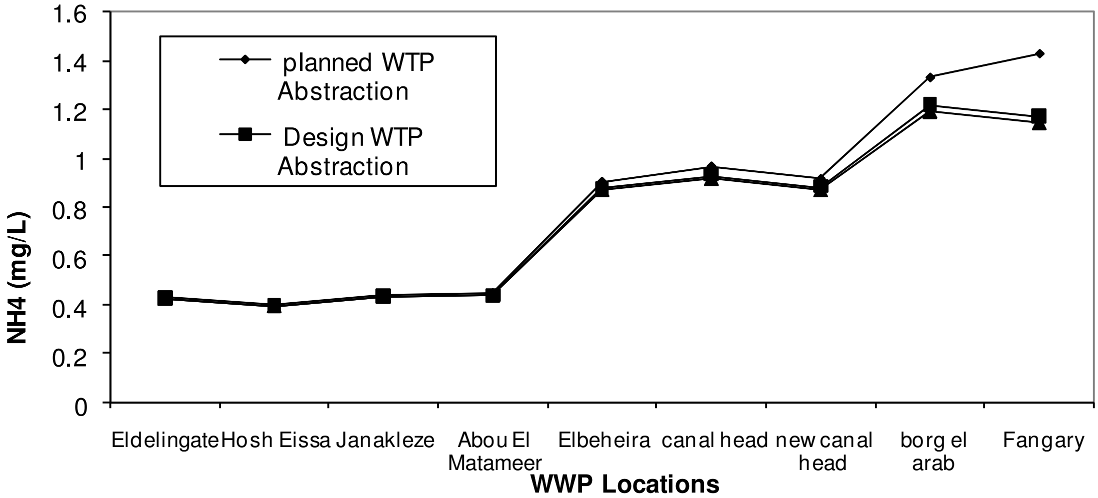

Figure 4 NH4 Concentrations along Noubariya canal at different WTP Abstractions (High requirements season)

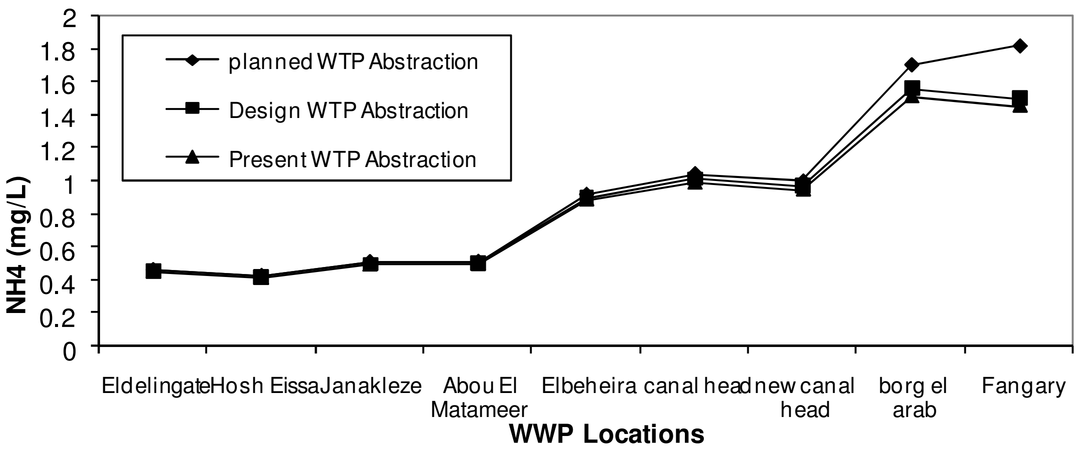

Figure 5 NH4 Concentrations along Noubariya canal at different WTP Abstractions (Low requirements season)

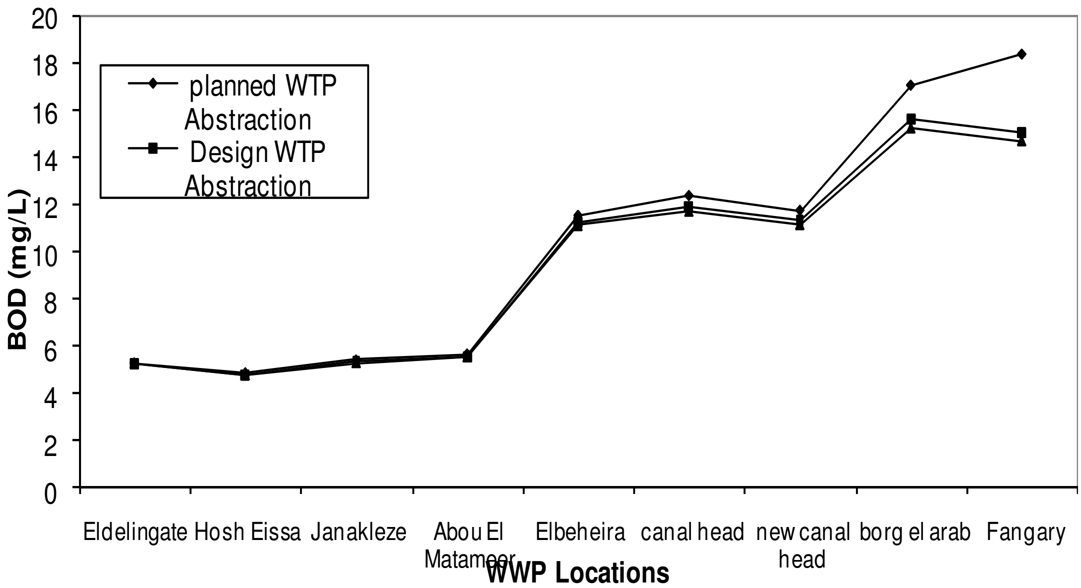

Figure 6 BOD Concentrations along Noubariya canal at different WTP Abstractions (High requirements season)

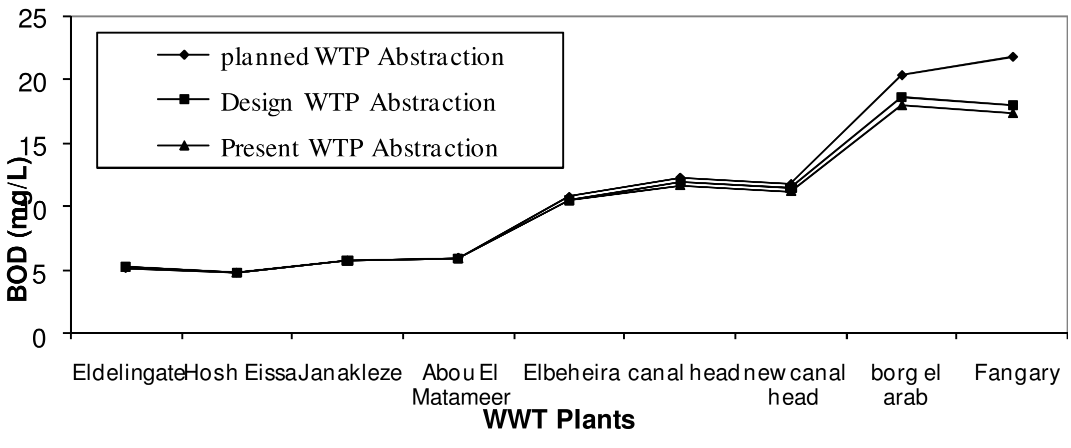

Figure 7 BOD Concentrations along Noubariya canal at different WTP Abstractions (Low requirements season)

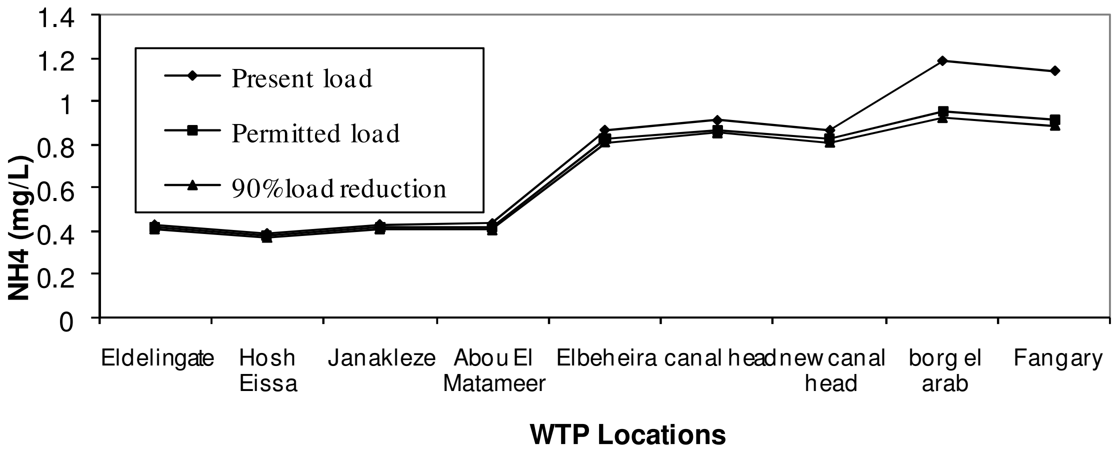

Figure 8 NH4 at WTP locations along Noubariya canal at different pollution loads (Low requirements season)

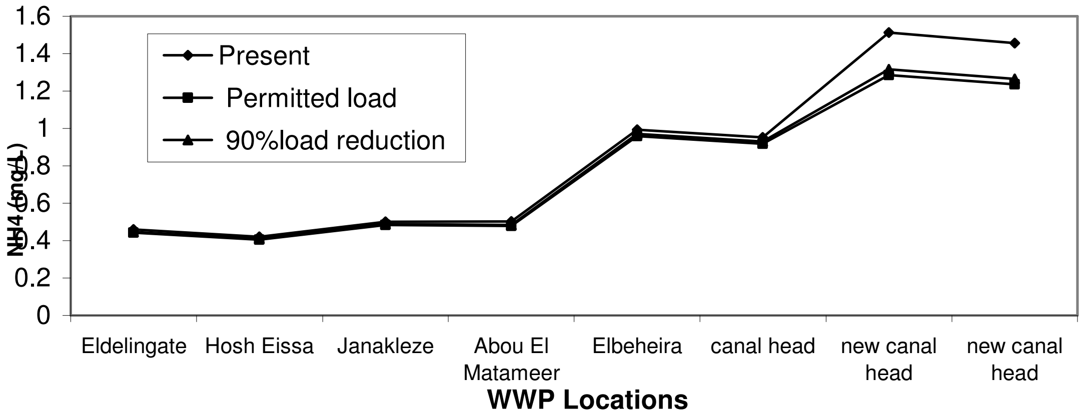

Figure 9 NH4 Concentrations along Noubariya canal at different pollution loads (High requirements season)

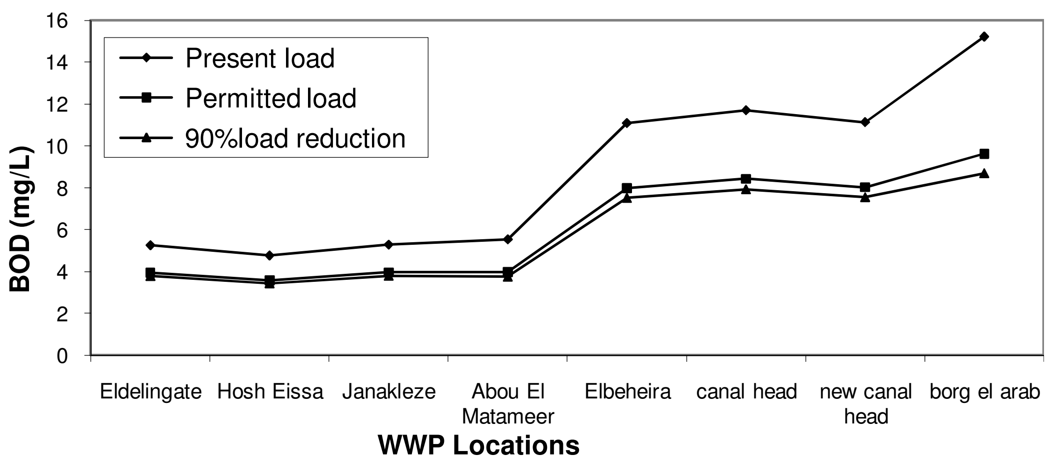

Figure 10 BOD Concentrations along Noubariya canal at different pollution loads (Low requirements season)

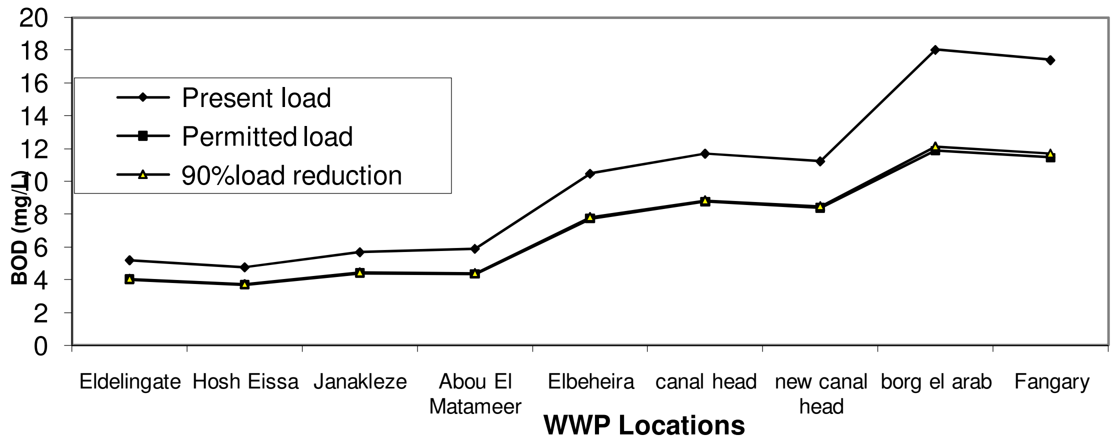

Figure 11 BOD Concentrations along Noubariya canal at different pollution loads (High requirements season)

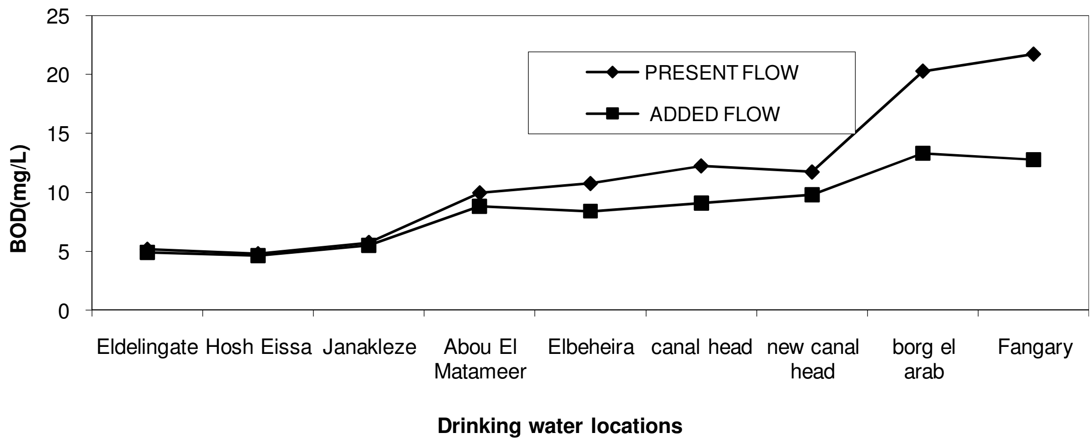

Figure 12 BOD Concentrations along Noubariya canal at increasing water inflow

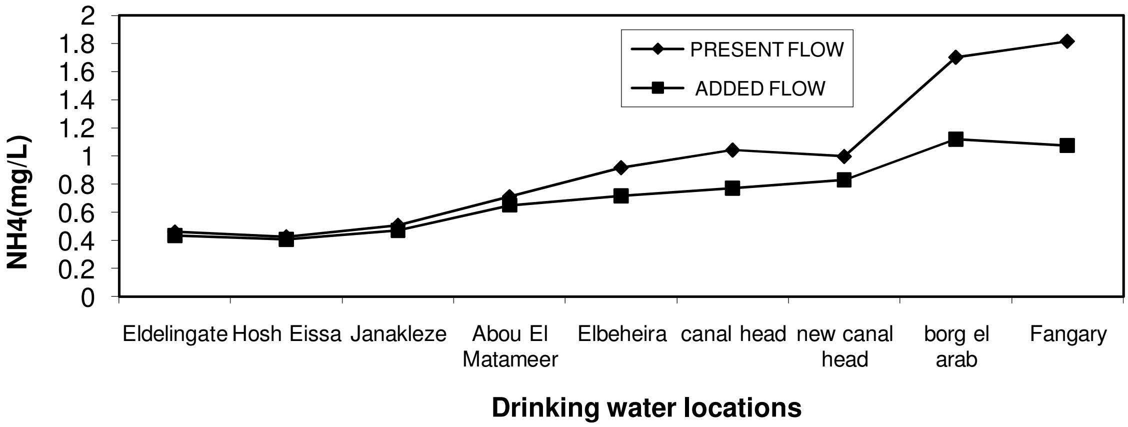

Figure 13 NH4 Concentrations along Noubariya canal at increasing water inflow

5. CONCLUSIONS AND RECOMMENDATIONS

The AWQI index was calculated at the drinking water plants intakes. From this figure, the least water quality is occurring at Tharwat, El-Fangry and Hosh-Esa due, this is most probably due to discharging different waste loads from point sources of pollution such as industrial effluent and agriculture located just upstream of the measuring locations. Another interesting feature is that at all the drinking water intakes along the branch the AWQ1 is above 100 due to the accumulation of industrial effluents and agricultural discharges into the stream. Therefore, the Intensive physical and chemical treatment with disinfection is the most suitable option that must be used in Tharwat, El-Fangry and Hosh-Esa drinking water treatment plants along the canal. The normal full physical and chemical treatment with disinfection option can be used in Canal-Head, Borg El-Arab the water treatment plant. Also, EWQI based upon the CCME WQI was calculated for the five water drinking water plants intakes, it is concluded that the water quality Hosh-Esa, Tharwat and El-Fangry water treatment plants intakes is poor otherwise the water quality at Canal-Head and Borg El-Arab water treatment plants intakes is marginal. This is complying so well with the calculated average water quality index.

A water quality model was successfully developed for the Noubariya carnal and many scenarios have been conducted using the developed model. The first scenario is comparing the water quality of the canal at present situation and when all drinking water treatment plants are in operation as designed or as planned and how this will affect the water quality of the canal. Also, the pollution loads were calculated in order to improve the water quality of the canal. It was concluded from the model results that the optimum load reduction id 90%, this means carrying a biofilm with aeration treatment option of the inflowing drains into the canal. But unfortunately this will not satisfy with the law 48 standards especially at the upstream part of the canal. Therefore, it sis recommended to increase the water inflow into the canal especially at high requirements season in order to improve the water quality of the canal to be used as a safe drinking water abstraction source for the present water drinking plants and the planned ones.

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