WATER QUALITY MANAGEMENT SCENARIOS IN ROSETTA RIVER NILE BRANCH, EGYPT

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ABSTRACT

The increase in population, urbanization and industrialization put a pressure on water resources management. Discharges from untreated wastewater cause serious surface water quality problems. Scenarios for water management in River Nile Rosetta branch are presented to describe the status and trends of water quality. The different scenarios were simulated using QUAL2K water quality model.

Two different scenarios are proposed and assessed to avoid water quality deterioration in the Rosetta branch during the low demand period. The first is based on dilution approach to dilute the organic loads and to achieve the local guidelines regarding water quality. The second scenario is to divert the wastewater from Abo Rawash WWTP to dessert lagoons and reuse it for wooden trees.

It was concluded that the second scenario reduced the concentrations of Ammonia and organic-Nitrogen and made it comply with the local guidelines at the water supply intakes. This scenario was the best environmental and economical sound solution. This indicates that the reuse of wastewater from Abo Rawash WWTP in irrigation can solve the high ammonia concentration problem, which arises every year and also can save about 0.9 billion m^3 per month in the low demand period and also improve the water quality.

Keywords: Water Quality, Nitrogen; Ammonia, QUAL2K, Rosetta River Nile Branch, Egypt

1. INTRODUCTION

Water resources in Arab States Region are becoming scarce due to the shortage of natural renewable water resources, dependency on Rivers and groundwater shared with countries outside the region, and deteriorations of water quality. Egypt is facing increasing water needs, demanded by a rapidly growing population, increased urbanization, higher standards of living and an agricultural policy, which emphasizes expanded production in order to feed the growing population.

The policy of the ministry of Water Resources and Irrigation (MWRI) in Egypt relies on using all the available water resources in a rational way to cover the increasing water needs. The major challenge of this policy is the degradation of surface and groundwater quality by domestic and industrial pollution. A great amount of water is spilled yearly in the Mediterranean Sea to dilute the pollution in Rosetta branch which is the main water supply source for many cities in the Nile Delta as Kafr Elzayat, Menofya and Disuq. Also, preserving the aquatic life in Rosetta branch specially fish is another important issue.

Rosetta River Nile Branch represents the main freshwater stream that extends northwards for about 236 km on the western boundary of the Nile Delta from Egypt's Delta Barrage (Figure 1). Rosetta branch has an average width of 180 m and depth from 2 to 4 m. The estuary is delimited by a barrage for controlling water discharge at Edfina City, 30 km upstream the sea. It was estimated that the aquatic environment of this branch receives more than 3 million cubic meters daily of untreated or partially treated domestic and industrial wastes and in addition to agricultural drainage water.

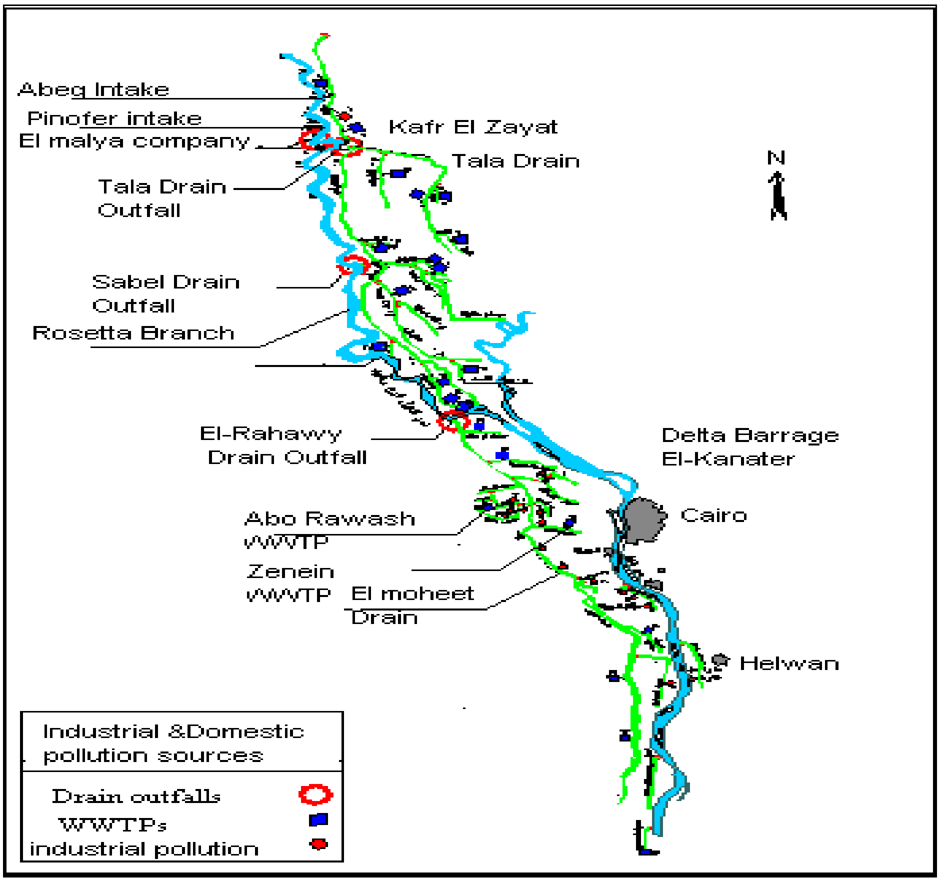

Figure (1): Pollution Sources on Rosetta River Nile Branch

Rosetta Nile Branch receives relatively high concentrations of organic compounds, nutrients and oil & grease. Major sources of pollution are Rahawy drain (which receives part of Greater Cairo wastewater), Sabel drain, and Tala drain as follows:

- El Rahawy drain receives about 400,000 m^3/day primary treated wastewater from Abo Rawash WWTP besides 600,000 m^3/day untreated wastewater as a bypass from this planet. It also receives 430,000 m^3/day of secondary treated wastewater from Zeinen WWTP. Average values of ammonia concentrations in the wastewater effluent are about 26 and 12 mg/l from Abo Rawash and Zeinen, respectively.

- Sabel drain receives untreated and partially treated wastewater from Menof, Sheiben, Shama, Ashmon, Samadon and Santareis. The primary treated wastewater is about 180,000 m^3/day.

- Tala drain receives untreated and partially treated wastewater from Tala, El-Shohada, and El Kom El Akhdar. The primary treated wastewater is about 72,000 m^3/day.

At Kafr El-Zayat, Rosetta branch receives also industrial effluents from Maleya and Salt and Soda companies. Rosetta branch receives also drainage water from agricultural areas fertilized by animal manure and chemicals. As a result, there is a marked increase of phytoplankton (floating and submerged aquatic plants) production in Rosetta branch.

Scenarios for water management in the low demand period of Rosetta River Nile branch are presented to describe the status and trends of water quality along the branch. The scenarios are simulated using QUAL2K water quality model.

2. IMPACT OF AMMONIA ON SURFACE WATER

Ammonia is very soluble in water; approximately 90 g dissolve in 100 ml of distilled water at 0°C. In solution, some of the ammonia reacts with the water resulting in the following equilibrium:

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^- \qquad (1)$$

The term ammonia refers to two chemical species, which are in equilibrium in water, NH_3, un-ionized and NH_4^+, ionized. Tests for ammonia usually measure total ammonia (NH_3 plus NH_4^+). The toxicity of ammonia is primarily attributable to the un-ionized form (NH_3), as opposed to the ionized form (NH_4^+). In general, more NH_3 and greater toxicity exists at higher pH. However, limited data also indicate that less NH_3 is needed at lower pH to produce its toxic effects. In the pH range of most natural waters, ammonia nitrogen will exist principally as NH_4^+. Ammonia is present in most waters as a result of the biological degradation of nitrogenous organic matter, although it may also reach groundwater and surface waters from industrial waste discharges. Ammonia in water can be determined quantitatively by several methods, including titration (1-25 mg/L), indophenol reaction (10-2000 µg/L), potentiometry (0.05-1400 mg/L) and reaction with Nessler's reagent (1-25 mg/L, or as low as 20 µg/L as ammonia nitrogen under optimum conditions.

The presence of ammonia at higher levels in surface water is an important indicator of faecal pollution. Taste and odour problems as well as decreased disinfection efficiency are to be expected if drinking-water is containing more than 0.5 mg of ammonia per litre. Ammonia in drinking water may increase the chlorine demand, which may lead to a "break-point" chlorination phenomenon. During chlorination, up to 68% of the chlorine may react with the ammonia forming chloramines and becomes unavailable for disinfection. Dissolved organic nitrogen (DON) is an issue for the water field primarily due to the formation of disinfection by-products of health concern, and its potential role in membrane fouling. Drinking water containing massive doses of ammonium chloride (52-105) g by human adults over three days may result in headache, insomnia, nausea, diarrhea and a failure in glucose tolerance. A dose of 6-8 g daily for 6-9 days resulted in increased urinary output of renal ammonia and urinary magnesium, calcium and phosphate. The presence of the ammonium cation in raw water may result in drinking-water containing nitrite as the result of catalytic action or the accidental colonization of filters by ammonium-oxidizing bacteria. Also, the presence of elevated ammonia levels in raw water may interfere with the operation of manganese-removal filters because too much oxygen is consumed by nitrification resulting in mouldy and earthy-tasting water.

3. AMMONIA TOXICITY TO FRESHWATER FISH

Ammonia NH_3 levels are directly related to the temperature and pH, for a given pH and temperature, the percentage of NH_3 can be determined (EPA, [1]). The percentage of NH_3 increases with temperature and pH. Some relevant numbers for most freshwater aquarium fish are presented in Table 1. It is clear that NH_3 is much more dependent on pH than temperature. Within the pH range shown, an increase of one pH unit will increase the NH_3 concentration about 10-fold.

Table 1: Un-ionized NH_3 as a percentage of total ammonia

Temp (°C)	Percentage NH_3 of Total Ammonia				
	pH 6.5	pH 7.0	pH 7.5	pH 8.0	pH 8.5
20	0.13	0.40	1.24	8.82	11.2
25	0.18	0.57	1.77	5.38	15.3
27	0.22	0.70	2.17	6.56	18.2
30	0.26	0.80	2.48	7.46	20.3

The USEPA publishes water quality criteria for aquatic organisms. They base these criteria on published studies on fish and other aquatic life and focus on lethal concentrations, typically the concentration at which 50 percent of the test animals' die. EPA's criteria are presented in terms of pH and temperature for both total ammonia and un-ionized ammonia (NH_3), for 1-hr values and 4-day averages.

EPA recommends that these levels not be exceeded more than once in three years to permit system to recover from the stress caused by the ammonia pollution. EPA recognizes that some mortality is acceptable in order to protect most ecosystems and that the criteria are inappropriate when there are sensitive, locally important organisms. The present levels for 25 degrees based on published values for the more sensitive Salmon (EPA, [1]) are illustrated in Table 2.

Table 2: Lethal ammonia concentrations at 25°C

pH	Duration	Lethal* Ammonia Concentration (mg/l)	
		Total	NH_3
6.5	1-hr	14.3	0.036
	4-day	0.73	0.002
7.0	1-hr	11.6	0.093
	4-day	0.74	0.006
7.5	1-hr	7.3	0.181
	4-day	0.74	0.019
8.0	1-hr	3.5	0.26
	4-day	0.47	0.035
8.5	1-hr	1.3	0.26
	4-day	0.17	0.035

*Lethal concentrations are derived from levels at which half of the exposed individuals die.

Ammonia is extremely toxic and even relatively low levels pose a threat to fish health. Raised levels affect fish health in several different ways. At low levels (< 0.1 mg/l), it acts a strong irritant especially to the gills. Prolonged exposure to sub-lethal levels can lead to skin and gill hyperplasia. Gill hyperplasia is a condition in which the secondary gill lamellae swell and thicken, restricting the water flow over the gill filaments. This can result in respiratory problems and stress and as well as creating conditions for opportunistic bacteria and parasites to proliferate. Elevated levels are a common precursor to bacterial gill disease.

4. MODEL DESCRIPTION

QUAL2K (Q2K) is a stream water quality model that is intended to represent a modernized version of the QUAL2E (Q2E) model (Brawn and Barnwell, [2]).

Q2K assumptions are as follows (Chapra and Pelletier, [3]):

- One-dimensional well mixed vertically and laterally flow;
- Non-uniform steady state flow is simulated;
- Diurnal heat budget. The heat budget and temperature are simulated as a function of meteorology on a diurnal time scale;
- Diurnal water-quality kinetics. All water quality variables are simulated on a diurnal timescale;
- Heat and mass inputs. Point and non-point loads and abstractions are simulated.

4.1 Major Biochemical Reactions

The following chemical equations are used to represent the major biochemical reactions that take place in the model (Stumm and Morgan, [4]):

Ammonium as Substrate:

$$106CO_2 + 16NH_4^+ + HPO_4^{2-} + 108H_2O \underset{R}{\overset{P}{\rightleftarrows}} C_{106}H_{263}O_{110}N_{16}P_1 + 107O_2 + 14H^+ \quad (2)$$

Nitrate as Substrate:

$$106CO_2 + 16NO_3^- + HPO_4^{2-} + 122H_2O + 18H^+ \underset{R}{\overset{P}{\rightleftarrows}} C_{106}H_{263}O_{110}N_{16}P_1 + 138O_2 \quad (3)$$

Nitrification:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+ \quad (4)$$

Denitrification:

$$5CH_2O + 4NO_3^- + 4H^+ \rightarrow 5CO_2 + 2N_2 + 7H_2O \quad (5)$$

Based on the mechanisms depicted in Figure 2, mass balances can be written for total Ammonium in the aerobic layer and the anaerobic layers.

$$H_2\frac{dNH_{4,2}}{dt} = J_N + \omega_{12}\left(f_{pa1}NH_{4,1} - f_{pa2}NH_{4,2}\right) + K_{L12}\left(f_{da1}NH_{4,1} - f_{da2}NH_{4,2}\right) + w_2\left(NH_{4,1} - NH_{4,2}\right) \quad (6)$$

$$H_1\frac{dNH_{4,1}}{dt} = \omega_{12}(f_{pa2}NH_{4,2} - f_{pa1}NH_{4,1}) + K_{L12}\left(f_{da2}NH_{4,2} - f_{da1}NH_{4,1}\right) - \omega_2 NH_{4,1} + s\left(\frac{n_a}{1000} - f_{da1}NH_{4,1}\right) - \frac{k^2{}_{NH4,1}}{s}\theta_{NH4}^{T-20}\frac{K_{NH4}}{K_{NH4} + NH_{4,1}}\frac{o}{2K_{NH4,O2} + o}f_{da1}NH_{4,1} \quad (7)$$

Where:

H_1	The thickness of the aerobic layer [m],
$NH_{4,1}$, $NH_{4,2}$	The concentration of total ammonium in the aerobic layer and the anaerobic layers, respectively [gN/m^3],
ω_{12}	Particle mixing due to bioturbation between the layers [m/d],
na	The ammonium concentration in the overlying water [mgN/m^3],
$kNH_{4,1}$	The reaction velocity for nitrification in the aerobic sediments [m/d],
θ□NH_4	Temperature correction factor for nitrification [dimensionless],
K NH_4	Ammonium half-saturation constant [gN/m^3],
O_2	The dissolved oxygen concentration in the overlying water [$gO2/m^3$],
K NH_4, O_2	Oxygen half-saturation constant [mgO2/L],
JN	The digenesis flux of ammonium [$gN/m^2/d$],
W_2	The burial velocity [m/d].

The fraction of ammonium in dissolved (f_{dai}) and particulate (f_{pai}) form are computed:

$$f_{dai} = \frac{1}{1 + m_i \pi_{ai}} \quad (8)$$

$$f_{pai} = 1 - f_{dai} \quad (9)$$

Where:

m_i	The solids concentration in layer i [gD/m^3], and
π_{ai}	The partition coefficient for ammonium in layer i [m^3/gD].

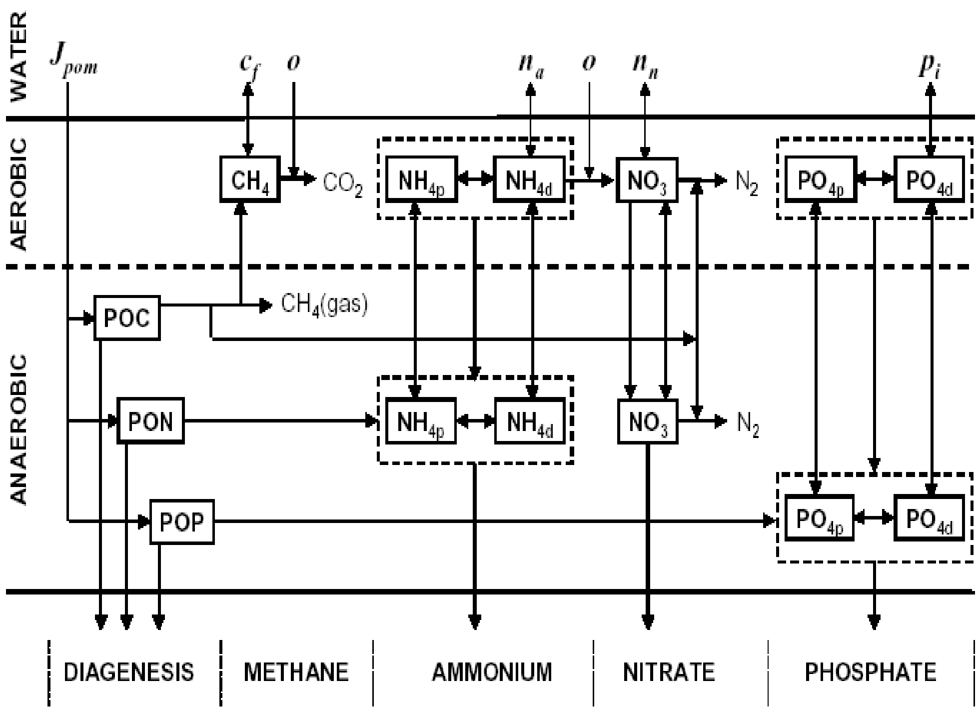

Figure 2: Schematic diagram of the SOD- nutrient flux model of the sediments

4.2. Model Application

The input data to the QUAL2K model consists of the following:

- Headwater data which is monitored by the Nile Research Institute (NRI) through winter and summer campaigns (NRI, [5]).
- Water quality data of domestic, industrial and agricultural sources from El Rahawy, Sabel, and Tala drains which are monitored monthly by the Drainage Research Institute (DRI, [6]).
- Water quality data of observed locations (Maleya Company, Pinofer Treatment Plant, and Abeg Treatment Plant) which represents the water quality status along Rosetta River Nile branch which is monitored by the ministry of Health and Population (MOHP, [7]).

The required information was input into QUAL2K and the model can be run to simulate the following parameters: slow and fast carbonaceous biological oxygen demand, dissolved oxygen, ammonia, nitrate, organic nitrogen, dissolved organic phosphorus, inorganic phosphorus, temperature, fecal coliform bacteria, chlorophyll-a, conductivity, chloride, detritus (particulate organic matter), phytoplankton, and pH. A simulation of Ammonia (NH_4) was done. Following a calibration process described in Chapra (1997), the kinetic reaction rate constants for each simulated water quality parameters were then systematically altered, within the ranges identified in Brawn and Barnwell ([8]), in an effort to reach an optimum level of compatibility between the measured and the simulated values.

The resulting solute concentrations output by QUAL2K were then compared to mean field values measured across Rosetta branch at 3 locations, one of them is Maleya Company (Km 123.05) and the others are the water supply intakes at Pinofer and Abeg, which take their water from the branch at Km 124.5 and Km 134, respectively (Table 3).

As recommended by Chapra ([8]), the results of the calibration of the QUAL2K model were assessed objectively through statistical analysis of the level of error between the simulated and observed ammonia concentrations at the above locations in February 2004. As a rule, calibration of the model for a particulate water quality parameter was deemed to be good if the median relative error was 10% or less.

Table 3: Measured and Simulated ammonia concentration at the observed locations

Location	Measured NH_4 (µmg/l)			Modeled NH_4 (µmg/l)		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Maleya Company	3400	3200	3300	4100	2300	3200
Pinofer Treatment Plant	4000	3100	3200	4050	2200	3125
Abeg Treatment Plant	3000	2300	2400	3050	1800	2425

The statistical analysis of the measured and simulated values shows that the relative error varied from 2.5 to 3.3% and the variation coefficient was about 2.5%, which indicates that the simulated values for total ammonia show a good level of agreement with the observed values. The model is tested with an additional set of field data under different environmental conditions (stream flow, waste load etc.) to further examine the range of validity of the calibrated model. Collection of data for validation is such that, calibrated and validated data are fully independent. The model so verified that it can be used for forecasting of water quality under a variety of perturbed environmental conditions.

5. WATER QUALITY MANAGEMENT SCENARIOS

In order to achieve the allowable concentration of ammonia in Rosetta branch according to the local guidelines, two Scenarios are designated. The first Scenario is based on Releasing discharges of 10 and 30 million m^3/day at the headwater of Rosetta branch to reduce the high concentrations of ammonia during the period of low demands (January-February) (Figure 3). The main concept is to dilute the organic load by increasing Rosetta river Nile branch discharge.

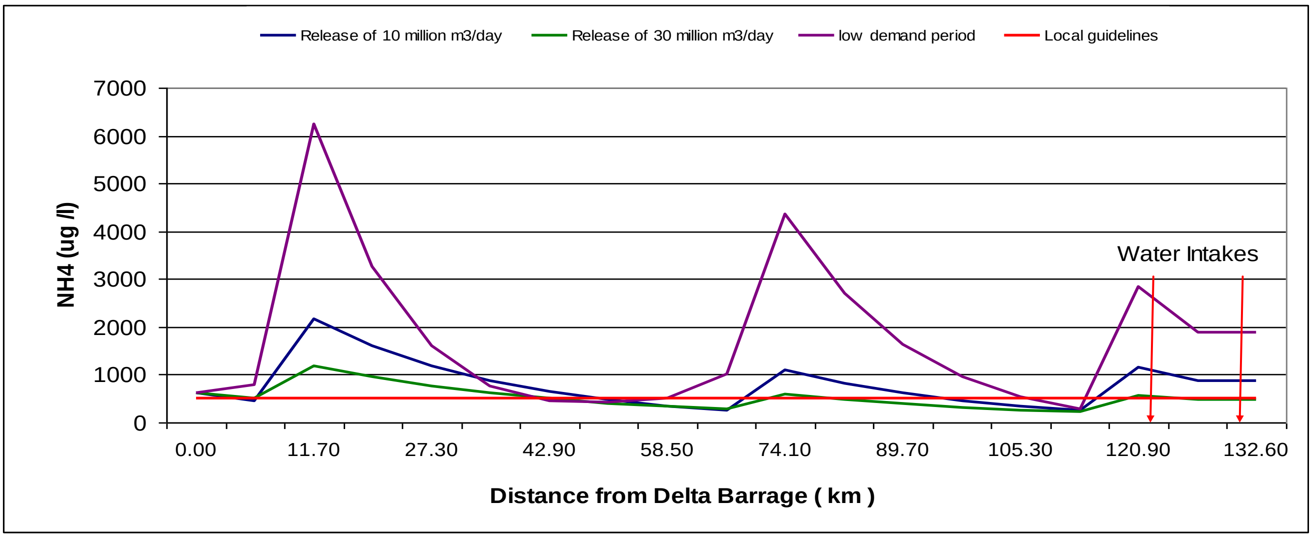

Figure 3: Ammonia Concentrations in Rosetta River Nile Branch for the First Scenario

In the upstream reach of Rosetta river Nile branch, the ammonia (NH_4) concentration is 500 µg/l which agrees with the local guidelines. Due to the effluent from El Rahawy drain, the concentration reaches to 6100 µg/l in the low demand period and reaches to about 2000 and 1000 µg/l after releasing discharges of 10 and 30 million m^3/day, respectively.

The concentration starts to decrease gradually and even goes close to the local guidelines due to the self purification process. The NH_4 starts to increase due to the wastewater discharge from Sabel drain. It reaches 4000 µg/l in the low demand period and to 1000 and 500 µg/l after releasing discharge of 10 and 30 million m^3/day, respectively.

Downstream the wastewater discharge, the NH_4 starts to decrease and reaches to local guidelines where the length of river reach is sufficient to enhance the self purification process. The process starts again and the NH_4 reaches to about 2800 µg/l in the low demand period. After releasing discharges of 10 and 30 million m^3/day, the NH_4 decreases to about 1000 and 500 µg/l, respectively.

Due to releasing a daily discharge of 30 million m^3/day in the low demand period at the Delta barrage, the ammonia concentration is reduced to 500 µg/l before the water supply intakes (Pinofer and Abeg) located at Km 124.5 and Km 134, respectively. Releasing a daily discharge of 10 million m^3/day is not sufficient either to reach the local guidelines or to preserve the ecosystem. The impacts of high organic loads in Rosetta branch during the low demand period has been mitigated by releasing about 30 million m^3/day from Nile water at the Delta barrage which represents 900 million cubic miters of fresh Nile water. This represents 18% of the total Nile inflow to Rosetta branch.

The second scenario is based on stopping the domestic wastewater effluent from Abo Rawash WWTP to Rosetta branch via Barakat and El Rahawy drains and divert it to the western desert of El Fayoum to irrigate Wooden trees and palm trees according to the proposed plan submitted by the Ministry of Housing (Figure 4). This can be a solution to the deteriorated water quality in Rosetta branch due to increasing ammonia concentrations which threat drinking water and aquatic life especially fisheries.

In the upstream reach of Rosetta River Nile branch, NH_4 value is 500 µg/l which agrees with the local guidelines. Due to wastewater effluent from El Rahawy drain, the concentration increases to 6000 µg/l.

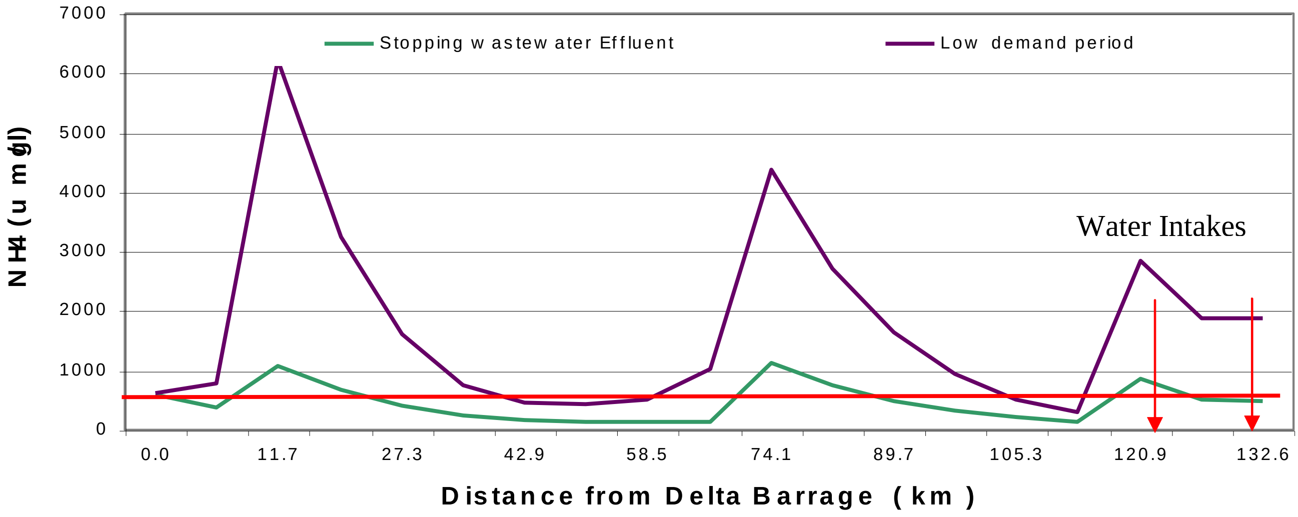

Figure 4: Ammonia Concentrations in Rosetta River Nile Branch for the Second Scenario

Stopping the domestic wastewater effluent from Abo Rawash Wastewater treatment plant, the NH4 decreases to 1000 µg/l which represents a reduction of 83 percent in the ammonia concentration. The NH_4 decreases rapidly and reaches to 500 µg/l after 15 km downstream El Rahawy drain.

Due to self purification process, the concentration decreases and reach to about 200 µg/l before discharge from Sabel drain. Discharges from Tala and Sabel increase the NH_4 concentration to about 1000 µg/l. The concentration decreases and reaches to 500 µg/l before the water intakes which agrees the local guidelines. Stopping the domestic wastewater from Abo Rawash WWTP reduces NH_4 concentration in about 70 percent of Rosetta River Nile branch before the water intakes.

6. CONCLUSIONS AND RECOMMENDATIONS

The main objective of water quality management regarding nitrogen forms is the prediction of trophic state of the water body and the assessment of the proposed control strategies. A common tool used to make predictions is the modeling along the Rosetta branch with extensive field data.

The approach can describe the relationship between sources of pollution, their dispersion through surface water, their transformation processes, and their accumulation in aquatic organisms.

Simulation of organic nitrogen and ammonia using QUAL2K model in the low demand period showed possible improvements in the Rosetta branch due to applying source control strategies and in-water control methods.

The following conclusions summarize the observed findings:

- Rahawy drain has serious effects on the water quality of Rosetta branch due to its high organic loads, which affect its availability as a source of drinking water supply for many cities located along the branch. This is due to the high concentrations of ammonia in the branch recorded during the low demands period which affect the purification and chlorination processes in the treatment plants.
- The high concentrations of ammonia and organic nitrogen observed in Rosetta branch during the low demands period has a serious effect on the aquatic life in the branch especially for fish. Ammonia is extremely toxic and even relatively low levels pose a threat to fish life.
- The impacts of high organic loads in Rosetta branch during the low demand period can be mitigated by releasing 30 million m^3 from Nile water at the Delta barrage. QUAL2K modeling proved that this solution reduced the concentrations of ammonia and organic nitrogen below the limits of the local guidelines.
- 0.9 billion m^3 from Nile fresh water can be saved and the NH_4 concentration is reduced to 70 percent in the low demands period by stopping the wastewater

effluent discharges from Abo Rawash WWTP to Rosetta branch via Barakat & El Rahawy drains. The primary treated wastewater effluent can be diverted to the western desert to irrigate trees according to the proposed plan submitted by the Ministry of Housing.

- It is recommended to make a master plan for sewage treatment with identified target in rural areas. Using aerobic or anaerobic low cost wastewater treatment plants should be encouraged with the involvement of private sectors and civil society. The institutional setup for rural sanitation should be studied and evaluated.

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