Commissioning of Abandoned Drainage Water Reuse Systems in Egypt: A Case Study of Upgrading the Umoum Project, Nile Delta

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Abstract

In the 1980s, the reuse of agricultural drainage water became a policy in Egyptian water resources management practice. Since 1992, seven of the twenty three main reuse mixing stations have been entirely or periodically closed. In the western Nile Delta, the Umoum is a mega-project for water reuse, which has been constructed but hasn't started operation. In order to upgrade and operate efficiently drainage reuse system of the Umoum project, developing promising water management alternatives are investigated by applying flow-water quality model prediction. As a valuable research tool, the DUFLOW model was applied incorporating sufficient work on the technical details of the channels in the study area.

Covering the drainage water salinity and relevant water quality parameters, DUFLOW was used to compare the results of the model-based alternatives with both the analyzed situation and the environmental standards. The simulations showed that the most suitable scenario is the alternative based on reducing the anticipated amount of 1 BCM/year drainage water for reuse by 20 %. By developing a mixing ratio of 5:1, the mixed irrigation water in Nubaria canal complies with local standards and can be abstracted for irrigation and drinking water intakes. Finally, this study has successfully identified the problematic location and brought a significant outcome for commissioning the abandoned drainage reuse system of the Umoum project.

Keywords: Drainage Water Reuse; Umoum Drain; Nile Delta; Water Quality Modeling.

Introduction

The use of drainage water is an important strategy for supplementing water resources in areas where irrigation water is scarce. Furthermore, reuse may help alleviate drainage disposal problems by reducing the volume of drainage water involved. In general, reuse measures consist of reuse in conventional agriculture; reuse to grow salt tolerant crops; integrated farm drainage management systems; reuse in wildlife habitats and wetlands; and reuse for initial reclamation of salt-affected lands (SJVDIP, 1999). By 2050, the Ministry of Water Resources and Irrigation of Egypt expects irrigation demand to increase to 61.5 BCM/year (FAO, 2002). The projected total water demand cannot be met by developing new water resources. Besides increasing water use efficiency, drainage water reuse is the most promising immediate and economically attractive option to make more water available for agriculture. In the 1980s, the reuse of agricultural drainage water became a policy to increase Egypt's fixed freshwater resources and to close the gap between supply and demand.

Reuse is centrally organized with the pumping of water from the main drains into the main canals. In 1994/95, the amount of water pumped at the reuse mixing stations was 4.4 BCM with an average salinity of 1150 mg/l (FAO, 2002). The total quantity of drainage water released to the Mediterranean Sea and coastal lakes was 12.4 BCM with an average salinity of 2690 mg/l (FAO, 2002). Therefore, Egypt has committed another 3 BCM of the drainage water for reuse within the new reclamation areas of the El Salam Canal and Umoum Drain projects. The volume of drainage water officially reused for irrigation is expected to increase to 8.8 BCM/year in the 2017 (NWRP, 2005). The official strategy for drainage water reuse has not caused major increase in soil salinity levels on a large scale. In terms of maintaining a favorable salt balance in the Nile Delta, drainage reuse in Egypt has been successful. Since the 1990s, pollution of the drains as a result of large-scale urbanization and industrialization has received increased attention.

The degraded water quality threatens the expansion and even the continuation of the reuse of drainage water from the main drains (official reuse) in the Nile Delta. Many reuse mixing stations have been under the increasing pressure of water quality deterioration. Indeed, since 1992, seven of the twenty three main reuse mixing stations have been entirely or periodically closed. In the western Nile Delta, the Umoum is a mega-project for enhancement of the drainage water reuse, which has been constructed but hasn't started operation. The objective of this study is to commission the abandoned drainage water reuse system of the Umoum project by developing promising water management alternatives. With the aid of water quality modeling, DUFLOW was applied to predict results of implementing the suggested measures and to enable decision-making. This project aimed to reuse 1.0 BCM of drainage water from the tributaries of the Umoum drain in order to reclaim an extension area of 140,000 hectare.

Study Area

Nubaria canal, the largest main canal in Western Nile Delta, is mainly fed from El Behery Rayah and El Rayah El Nassery (Figure 1). Serving a total area of 373,800 hectare, the canal has been developed several times to cope with the horizontal expansion in the newly reclaimed areas in western desert. Behind the intake at Km 46, there is an area of 280,000 hectare has to be irrigated with 5 BCM per year (MWRI, 1992). Therefore, it was important to develop and execute the drainage water reuse system of the Umoum project to cope with the water demands at these areas. The details of Umoum Drainage catchment area is shown in Figure 2. The water reuse for the project is based on collecting the drainage water from the three sub-catchments of Umoum drain and directing it in a channel from north to south. These sub-catchments are Abu-Hummus; Shereshra; and Truga. The project includes the construction of a dam at 25 km, which forces the flow opposite to the direction of the drain. Serving an area of 19,320 hectare, the Abu Hummus is drained by gravity to the Umoum drain. The Shereshra P.S. lifts the drainage water of the Shereshra catchment (63,000 hectare) into the Umoum drain. In addition, Truga P.S lifts the drainage water from its catchment area of 43,260 hectare into the Umoum drain (MWRI, 1992).

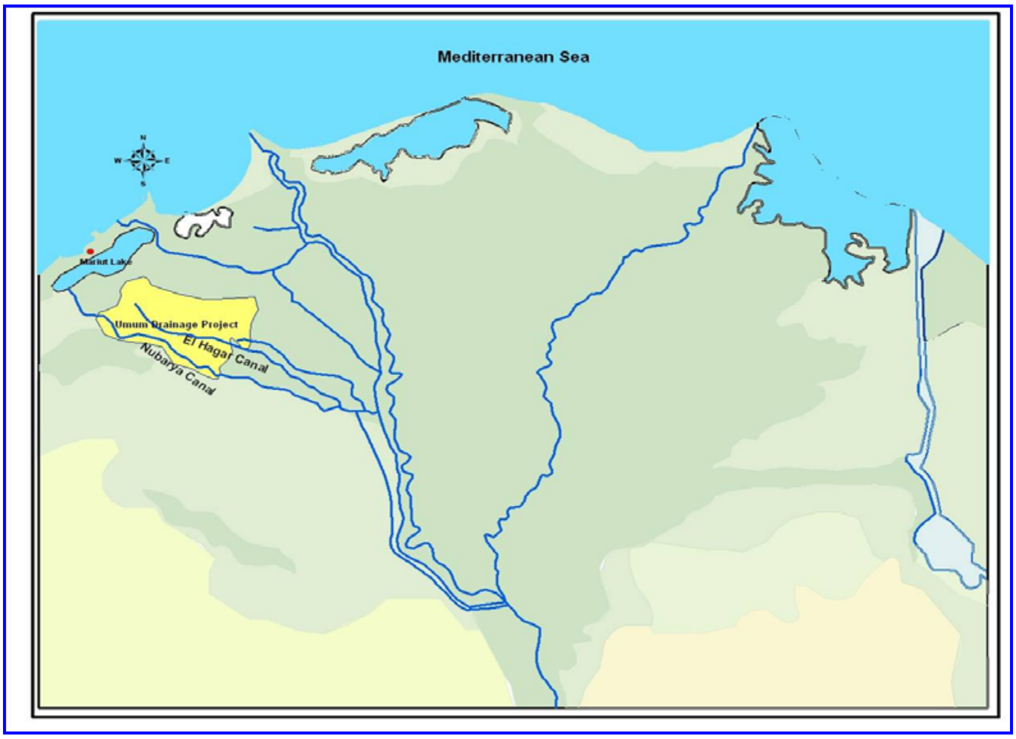


Figure 1**.** Location of the Umoum catchment area

The Umoum catchment area is a part of the area served by the Max pumping station. The drainage water from the Umoum catchment area, the Nubaria area and water spilled from the ship locks in the Nubaria canal, and the Qalaa pumping station flow into the Mariut Lake (Figure 2). The Max pumping station lifts water from this lake into the Mediterranean Sea. A canal, 2 km downstream of Truga P.S., connects the Umoum drain with the Mariut P.S. Since 1982, this pump station became operational and pumps drainage water into the Nubaria irrigation Canal. At 25 km upstream of Shereshra P.S., a new pump station (No. 1) was built with a capacity of 50 m^3/sec. For this purpose, the Shereshra drain was enlarged, for the discharge of Truga P.S., Shereshra and Abu Hummus catchment areas to flow by gravity to this pump station. The same quantity of drainage water will be lifted by a second pump station (No. 2), with a capacity of 62.5 m^3/sec. Finally, a pump station (No. 3), with a capacity of 62.5 m^3/sec, will pump the drainage water in a drain flow by gravity into the Nubaria Canal at Km 46 (upstream of Nasr canal intake).

DUFLOW Model

DUFLOW is a computer package for simulating 1D unsteady flow and water quality in open watercourses. In the computation of flow hydraulics, the model (DUFLOW, 2000) solves the full de Saint Venant equations of motion for unsteady flow. This hydraulic model can be directly coupled with one of two predefined water quality models: EUTROF1 and EUTROF2. EUTROF1 is based on the EUTRO4 model from WASP4 developed by the U.S. Environmental Protection Agency (Ambrose et al. 1988). It includes the cycling of nitrogen, phosphorous, and oxygen. The growth of one phytoplankton species also is simulated. In EUTROF2, three algal species are included and interactions between the sediment and the overlying water column are taken into consideration while other water-quality kinetics are simulated in a similar way as in EUTROF1.

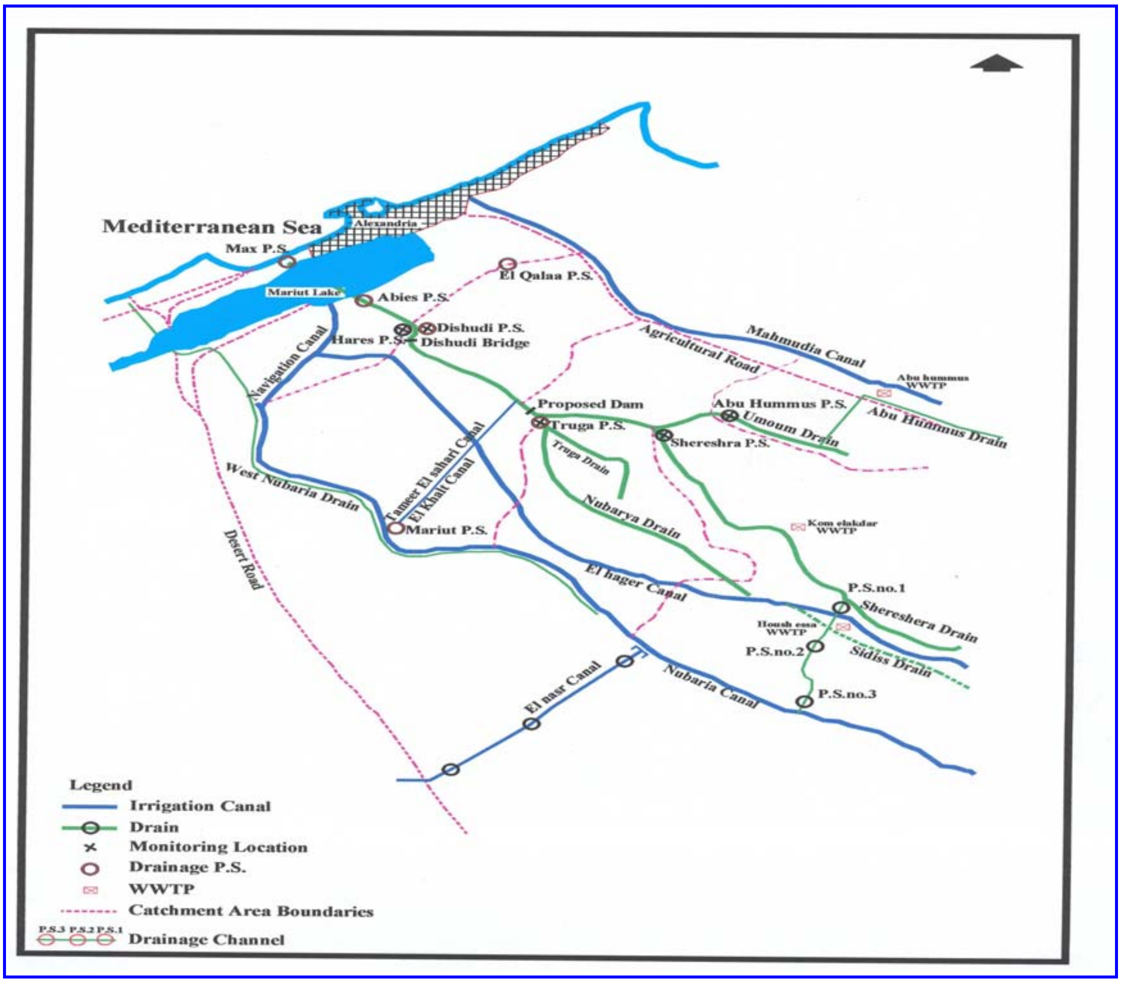


Figure 2. Layout of the proposed project for the Umoum drainage water reuse

Because the hydraulic and water quality models are directly coupled, DUFLOW offers computational advantages over the versions of WASP available. DUFLOW has been applied with great success to several river systems (Manache and Melching, 2004). DUFLOW is compatible with geographical information systems, which facilitate representation and display of the open water system. It is compatible with Microsoft Windows and data can be imported easily from and output can be exported easily to Microsoft Excel, and it also has a versatile graphical user interface for displaying output and processing input. Given these capabilities and advantages, DUFLOW was selected for modeling the main Umoum project**.** In this study, EUTROF1, one of the two predefined eutrophication models included in DUFLOW, is used to simulate water quality. Constituents that can be simulated in EUTROF1 are dissolved oxygen (DO), carbonaceous biochemical oxygen demand (CBOD), algal biomass, components of the nitrogen cycle (organic nitrogen, ammonia, nitrate), components of the phosphorous cycle (organic and inorganic phosphorus), and suspended solids.

Model Network

In DUFLOW, the network consists of four sub networks represented by Umoum, Abu Hummus, Shereshra and Truga channels. The DUFLOW model network of both channels: Abu Hummus and Shereshra drains are shown in Figure 3. Hydraulic structure such as the constructed dam is represented in the model as a control element. Each element is limited by two nodes. Discharges and pollutant loads are represented in two ways: constant loads, and time-varying loads. Effluent sources from industries, households, and wastewater treatment plants are considered to have a constant value for the entire simulation period and are added to the system at the nodes. Effluent sources coming from agricultural activities are added to the system at the nodes and are given as time series for the considered simulation period. Discharges and pollutant concentrations for the upstream boundary are also given as a time series that covers the entire simulation period.

In the present study, the pollutants simulated, to investigate the commissioning of abandoned drainage water reuse systems include total dissolved solids (TDS), biochemical oxygen demand (BOD_5), nitrates (NO_3), ammonia (NH_4), and total phosphorous (TP). As shown in Figure 2, the water quality observations and laboratory analysis were determined at 5 sampling sites located on main channels and tributaries that drain the major rural and agricultural areas (DRI, 2007). The designed water supply from the Umoum project, which is located upstream the dam, are subjected to pollution from untreated sewage disposed in some of the drains such as Abu Hummus drain. This is a result of unregulated sewers being constructed by the public in some villages and subvillages located in the catchment areas of the Belaktar and Elserefi drains. Furthermore, sewage from villages connected with septic tanks is disposed directly to the nearest drains.

Despite the availability of Abu Hummus wastewater treatment plant (WWTP), with a design capacity of 20000 m^3/day, the treated water accounts for only one third of the total quantity of sewage produced from Abu Hummus city. The remainder is disposed without treatment in the open drain. These conditions are expected to remain in place until the lift stations are completed bringing the treatment plant into full operation. Furthermore, Kom elakdar WWTP (Figure 3) is operating with a capacity of 400 m^3/day, while the designed capacity is 2000 m^3/day because of the uncompleted sewerage network lines for the rest of the villages and subvillages. Abu Almatamir WWTP is operating with the full capacity (12000 m^3/day), discharging its outflow into Tharwat drain, a branch of Abu Almatamir drain disposing into the Nubaria drain - located in the catchment area of Truga pump staion (P.S.). The latter with low water quality is considered one of the sources feeding the main Umoum drain until the dam. It was found that Housh essa WWTP, working with 60% of the 20000 m^3/day actual capacity, discharging its effluent into Sede essa drain. The latter is discharging into Shershra drain at recently built channel conveying the draiange water into Nubaria canal. The type of treatment for all plants is oxidation ditch except Abu Almatamir WWTP is operating with activated sludge.

The quantity of disposed sewage at Abu hummus P.S., Shereshra P.S. and Truga P.S are 25%, 5% and 10% of the total drain discharge, respectively. Furthermore, disposed sewage water is 10 % of the total discharge which accounts for the supply to the Umoum project. It was observed that there are nine 0.7-1 m^3/sec irrigation pumps are operated for drainage reuse under the agreement of irrigation and drainage districts. There are openinings on the main Umoum drain, upstream of the dam, to feed irrigation channels such as Elwestani canal. In addition, 722 irrigation mobile units owned by farmers are used for direct irrigation from the drainage water produced from the agricultural land owned by them.

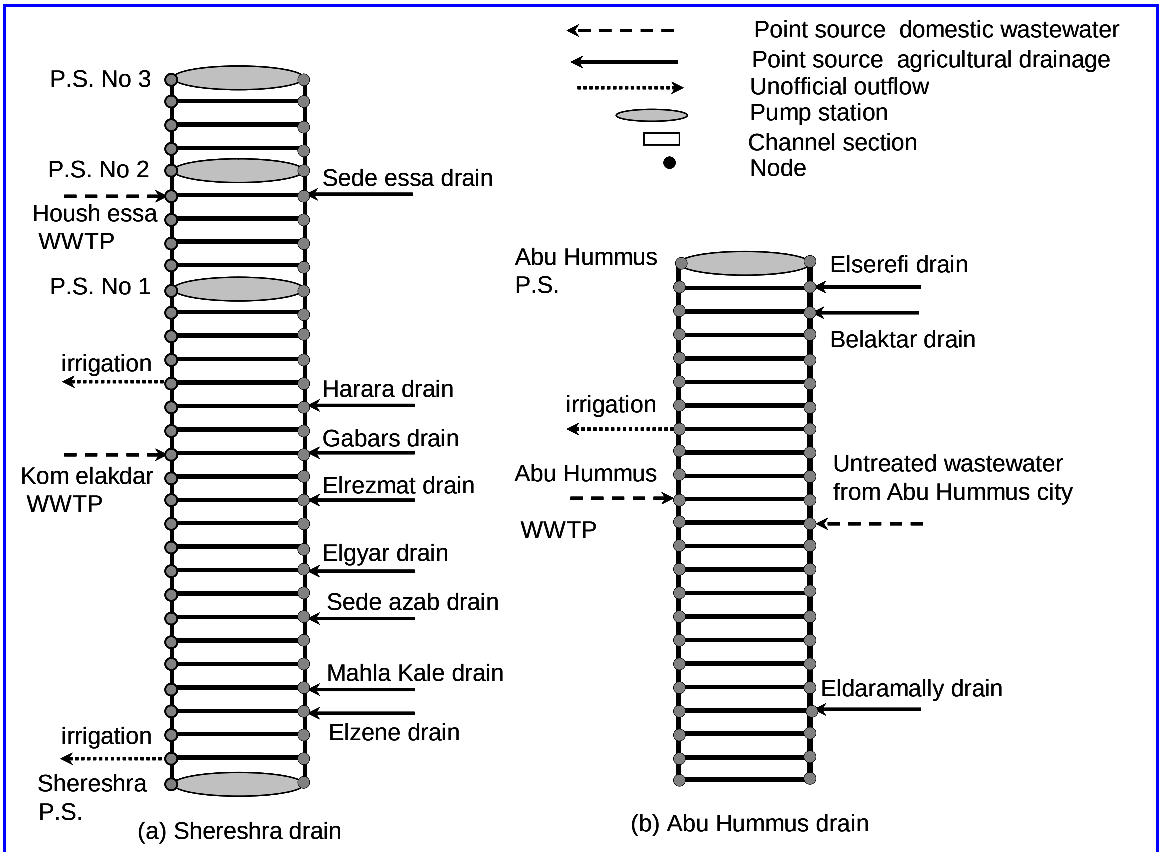


Figure 3. DUFLOW model network of Shereshra drain (a) and Abu Hummus drain (b)

Results and Discussions

1 Salinity based Scenarios' Selection

The actual quantity and salinity of drainage water which could be made available is calculated as average of actual measurements over the period of 2003-2006. In the present situation, drainage water at several locations along the Umoum Drain is being reused for irrigation and leaching purposes. It has been observed that the drainage water from Truga PS (with salinity ranged between 1459 and 3871 mg/l), Shereshra PS (1376-1993 mg/l) and the water drained by gravity from the Abu Hummus area (881-2979 mg/l) can be reused. The available quantities of drainage water of the mentioned sources are respectively 642, 625 and 151 MCM yearly which in total is 1.42 BCM per year. Because of the high salinity of the drainage water from Dishudi pump station (1520-5371 mg/l) and the very high salinity of the drainage water form Hares Pump Station (1641-8390 mg/l), only the Umoum Drain upstream of Dishudi Bridge is suitable for reuse purposes (Figure 2). Therefore, the present study considers only 1 BCM per year for reuse through the Umoum drainage water reuse project. The discharge of Truga pumping station during months of January, February, November and December, will be discharged into Lake Maruit due to its high salinity.

In order to assess water management alternatives, the model incorporated sufficient work on the technical details of the channels in the Umoum project. Moreover, water quality parameters (TDS, BOD_5, NO_3, NH_4 and TP) were used to compare the results of the model-based alternatives with both the analyzed situation and the environmental standards. In the first alternative, all the drainage water of Truga, Abu Hummus, and Shereshra pump stations were considered in the Umoum project starting and retained by the constructed dam at km 25 of the Umoum drain, located 1.0 km north of Truga P.S. This drainage water was pumped into Nubaria canal after a series of pump stations. In the second alternative, the water of Abu Hummus, and Shereshra drains were considered, starting and retained by a dam constructed at km 27 of the Umoum drain, located 1.0 km south of Truga P.S.. The drainage water of Truga pump station was diverted to the north reaches of the Umoum drain.

2 Calibration and Validation

The model was calibrated based on monthly water quality and flow data collected for 2003/2004 at three monitoring locations located upstream of the proposed dam (Figure 2). The relative mean error between the simulated and observed value for flow is 12%. R^2 value which indicates the effectiveness and interrelationships between the observed and simulated value is 0.98. The relative mean errors and R^2 values (inside brackets) for TDS, BOD_5, NO_3, NH_4, and TP, are 20.9% (0.97), 26.1% (0.85), 30.2% (0.97), 23.9% (0.94), 21% (0.95). The differences between the measured and simulated data sets could be because monthly water quality data are based on the collection of point measurements (once per month), which do not represent the average monthly water quality data. Besides, for the continuous measurement required in the model inputs, the daily water quality data were linearly interpolated from the point measurements of monthly water quality data. In spite of the differences between measured and simulated data sets, the calibration results are quite acceptable.

To validate the model, the calibrated model was run with new independent data collected in 2004/2005 without changing the calibrated model parameters. The relative mean errors and R2 values (inside brackets) between the simulated and observed values for TDS, BOD_5, NO_3, NH_4 and TP are 15.5% (0.97), 31.0% (0.86), 18.8% (0.73), 21.2% (0.61), and 15.5% (0.55), respectively. In spite of the differences between measured and simulated data sets at some points, the calibration and validation results are within the limit which is acceptable.

3 Variations in Monthly Concentrations

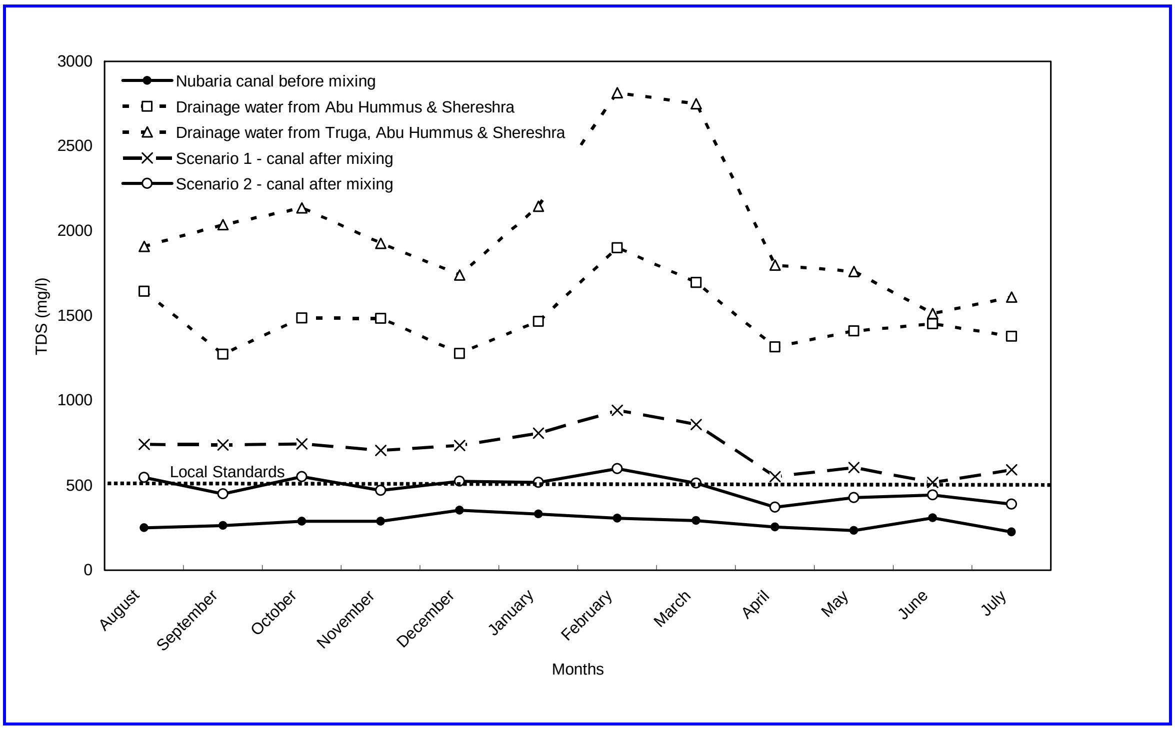
DUFLOW simulations show that reusing the drainage water from Abu Hummus, Shereshra, and Truga pump stations by mixing with Nubaria irrigation water in the first scenario results in the following (Figure 4):

The TDS of drainage water collected from Abu Hummus, Shereshra and Truga drains varies between 1500 and 2800 mg/l which is 3 to 5.6 times the value of the water to be mixed (as presented by local standards - law 48/1982). The TDS of the Nubaria irrigation canal, after mixing with drainage water, ranges from 500 to 900 mg/l throughout the year. From April to July, the TDS values are close to 500 mg/l which is in agreement with the local standards. From August to January, the TDS values are around 750 mg/l. During the period of winter closure (February and March), the TDS value reaches 900 mg/l which exceeds the local standards by 80% resulting from blocking the irrigation to allow maintenance of the system. The biochemical oxygen demand of the drainage water, before mixing, varies from 16 to 39 mg/l. After mixing, the BOD_5 of the irrigation water in Nubaria canal varies from 8 to 19 mg/l which is higher than the local standards of fresh water (6 mg/l). This is attributed to the pollution from untreated domestic wastewater in the mixing drainage water.

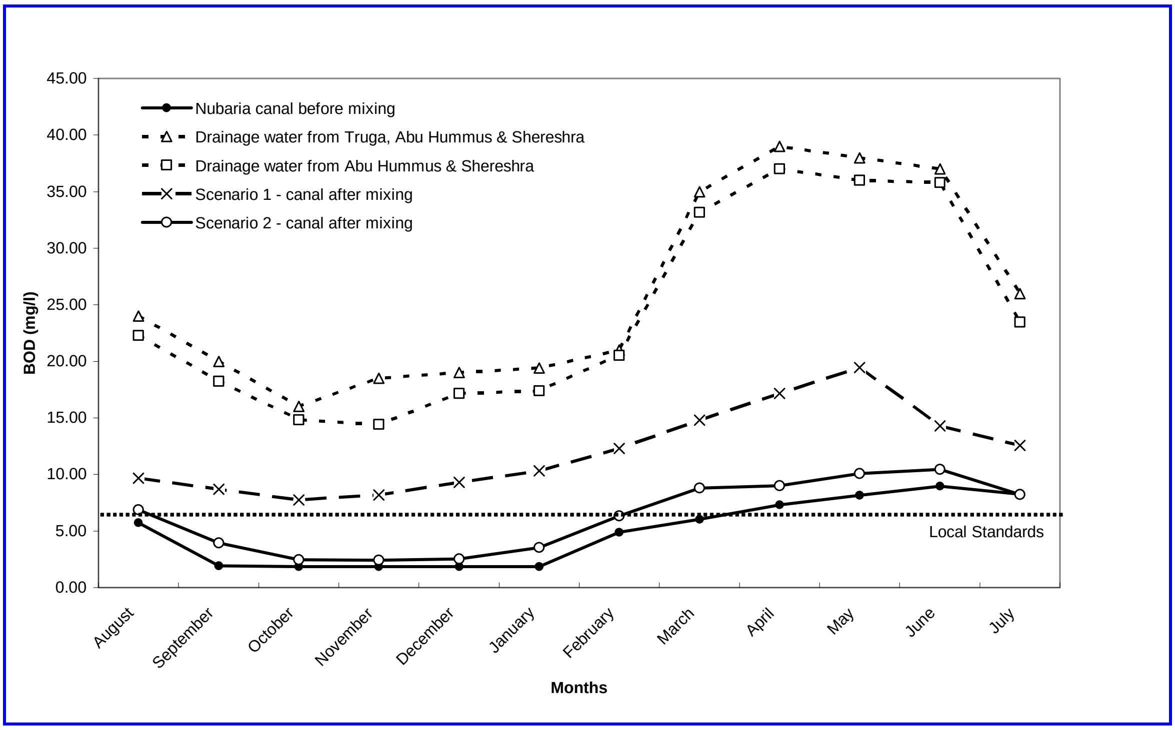
The nitrates of the drainage water ranges from 6 to 23 mg/l. The No_3 values in the Nubaria irrigation canal after mixing vary between 3 and 6.4 mg/l which are significantly below the local standards (45 mg/l). Throughout the year, the ammonia in the Nubaria canal ranges from 0.3 to 0.8 mg/l. It should be noted that most of the time the value is close to the standard (0.5 mg/l) except for May and June which are slightly higher. The natural seasonal fluctuation may be attributed to the activity of aquatic organisms. Before mixing, the total phosphorous of the agricultural drainage water varies from 0.3 to 0.6 mg/l. The TP values of the mixed irrigation water ranges from 0.13 to 0.28 mg/l which is less than the local standards (1.0 mg/l).

Based on the second scenario finding, mixing the agricultural drainage water of Abu Hummus and Shereshra with the Nubaria canal show the following results (Figure 4):

According to the annual range of TDS values (1300 to 1900 mg/l), the agricultural drainage water can be reused for agricultural purposes according to FAO guidelines but with slight to moderate effect on crop production. After mixing, the TDS values of Nubaria canal vary from 370 to 590 mg/l which is accepted by the local standards for reuse. The BOD_5 values range from 15 to 36 mg/l for agricultural drainage water which is higher than the local standards for direct reuse. The values of irrigation water after mixing ranges from 2.5 to 9 mg/l with an average value less than the local standard (6 mg/l).



(a)



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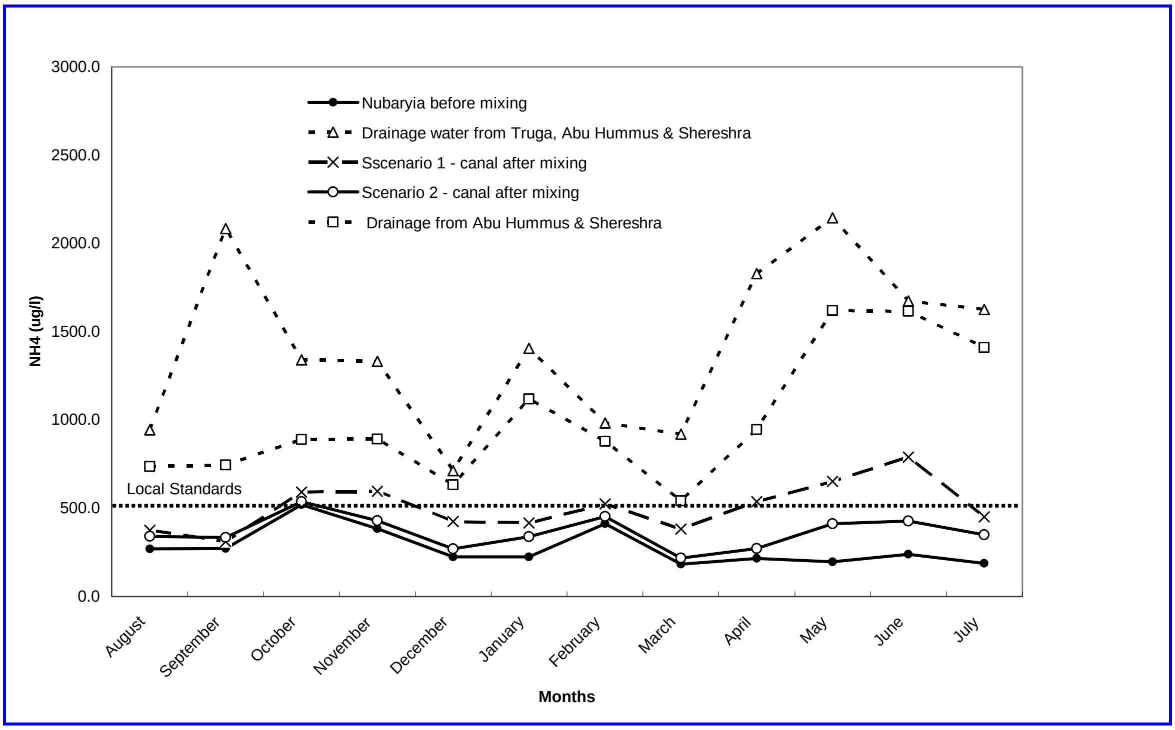

(c)

Figure 4. Simulated monthly TDS (a) BOD_5 (b) NH_4 (c) concentration for the period August to July, 2005/2006 before and after mixing

The values of NO_3 for both irrigation and drainage water are less than the local standards. For Nubaria canal after mixing, the values range from 1.8 to 4.3 mg/l. The NH_4 values of agricultural drainage water vary between 0.6 and 1.6 mg/l which is higher than the local standards for reuse without mixing in direct irrigation. The values of NH_4 for Nubaria irrigation after mixing range from 0.2 to 0.5 mg/l which is less than the local standards for fresh water. The mixed irrigation water is acceptable for direct reuse. The TP values in the irrigation canal ranges from 0.1 to 0.13 mg/l which is significantly less than the local standards of fresh water. The low values of TP decrease the chances of algae biomass in water courses facilitating the operation and maintenance of the lifting drainage pump.

Based on the differences between the two scenarios in complying with the local standards, the second scenario is selected to support drainage water management in the study area by maximizing reuse of drainage water of acceptable quality. This scenario requires reusing 0.8 BCM per year of agricultural drainage water which is less than the water requirements in the water resources plan of the Umoum project. The recommended reuse application in scenario 2 is based on mixing ratio between irrigation water (Nubaria canal) to the available drainage water from Umum project to be 5:1. Considering only the drainage water salinity, the first scenario can be a viable option throughout the year, except for January, February and March where the TDS is high. By reusing 1 BCM per year of drainage water, the first scenario is very important to compensate for the deficit in water requirements for future land reclamation. The success of this scenario is conditional on compliance of the effluent levels of treated domestic water with the local guidelines.

Conclusions

On the basis of the Umoum project description, a drainage water system model was developed by DUFLOW. The model included all the probable activities related to collecting the drainage water from the upstream catchments of Umoum, Abu Hummus, Shereshra and Truga drains and lifting it at Km 46 of Nubaria canal. From the spatial and temporal profile of water quality variables, the simulations produced by the model calibration and validation were in good agreement with the measured values. The first proposed scenario offered an annual agricultural drainage water of 1 BCM as an anticipated amount sufficient for future water resources management. Considering water quality parameters (TDS, BOD_5, NO_3, NH_4 and TP), this scenario did not comply with the local environmental standards regarding fresh water that can be abstracted for irrigation and drinking water intakes.

Findings from model simulations showed that the most suitable scenario on the Umoum drainage water reuse system is the second alternative based on annual discharge of 0.8 BCM from only Abu Hummus and Shereshra reuse pump stations catchments. The direction of flow is changed to the south by constructing a dam at km 27 of the Umoum drain. With a mixing ratio 5:1, the water quality variables of Nubaria canal after mixing showed that the simulated concentrations downstream the mixing point at Nubaria canal, complied with Egypt Law 48. The study is intended to provide the responsible authorities with information on the potential locations and quantity for reusing drainage water in irrigation as well as support the Ministry of Water Resources and Irrigation in evaluating strategies and scenarios for the future planning of water resources management.

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