LOWLAND TECHNOLOGY INTERNATIONAL Vol. 5, No.2,27-38, December 2003
International Association of Lowland Technology (IALT), ISSN 1344-9656

EVALUATION OF DRAINAGE WATER QUALITY FOR REUSE - A CASE STUDY OF THE UMOUM DRAIN IN EGYPT

Hossam M. Nagy[1] and Adel A. S. Salem[2]

ABSTRACT: Water resources in Egypt, being fixed in quantity, are under heavy pressure due to a continuously increasing population. As such, reuse of drainage water for irrigation is an attractive proposition and is possible if the drainage water is of satisfactory quality. The Umoum Drain, one of the largest drains in the West Delta region, receives more than one billion cubic meters per year of agricultural drainage water. Moreover, the drain receives both raw and treated wastewater from several defined and undefined sources. In this study, the quality of the drain water was investigated. Flow and water quality profiles have been estimated along the drain through the mathematical model, QUAL2E. The model is used for calibrating the deoxygenation rate in the drain by utilizing measured field data reported by the Drainage Research Institute (DRI), National Water Research Center in Egypt. The study concentrated on two nonconservative constituents: biochemical oxygen demand, BOD_5, and dissolved oxygen, DO, and one conservative constituent representing the water salinity in terms of total dissolved solids, TDS. A parametric study is presented to investigate the effects of the deoxygenation rate on the values of BOD_5, and DO concentrations in drainage water. A dynamic management strategy is presented as part of the scheme for improving water quality before discharge into the irrigation network. Primary treatment wastewater plants are proposed in specific locations along the drain. The study presents a design chart identifying the optimal amount of fresh water needed for the dilution of drainage water.

Key words: Water quality, drainage water reuse, biodegradation, water salinity

INTRODUCTION

In Egypt, due to water scarcity and increasing population, recycled agricultural drainage water is considered one of the main sources of water for irrigation purposes. More than 4.141 billion cubic meters per year, DRI (2000) of drainage water are already reused after being mixed with fresh water in large irrigation canals. Still, large amounts of drainage water go into the sea and are not yet used. In addition, treated wastewater is one of the nonconventional sources for irrigation. It is restricted for irrigation of cereal crops, fodder crops, industrial crops, and trees. Effluent from wastewater treatment plants (WWTPs) exceeds 3 billion cubic meters per year in the Nile Delta area. The effluents are discharged into agricultural drains as they do not meet the stringent limits for disposal into irrigation canals; i.e. < 6 mg/l of biochemical oxygen demand (BOD_5).

Several reports have been presented regarding water quality monitoring in the drains of the Nile Delta. El-Sayed et al. (1994) have established a monitoring program for water quality in the Bahr El-Baqar drain system in the East Delta region. Their study showed that microbiological health hazards are a major problem in the drain system. Heavy metals were detected, but below safety limits. El-Sayed and Abdel Gawad (2001) have applied the water quality model QUAL2E-UNCAS for the San Gerg and Kabkab Drains in the Elmenya Governorate in Upper Egypt. Average kinetic rates were assumed, and the model was calibrated. Different scenarios were conceived for several flow conditions with and without wastewater treatment plants. They recommended construction of secondary treatment plants to reduce the pollution in the two drains. Abdel Khalik (1996) has applied the SIWARE Model Package to evaluate the short-term impacts of the use of drainage water for agricultural land expansion in the western desert of Egypt through mixing the Umoum drainage water with fresh water in the Nobaria Canal. The study showed that the average salinity of the receiving canal will increase, and this in turn will affect soil salinity and municipal water quality. Morsy (2000) has updated Abdel Khalik data and developed a quantitative and qualitative study of the same project of reusing the Umoum drainage water. Morsy used an algorithm that depended on temporal control of the discharged amount of drainage water according to salt concentrations, which vary from

---

1 Associate Professor, Irrigation Engineering and Hydraulics Department, Faculty of Engineering, Alexandria University, Alexandria, EGYPT.
2 Lecturer, Irrigation Engineering and Hydraulics Department, Faculty of Engineering, Alexandria University, Alexandria, EGYPT.
Note: Discussion on this paper is open until June 1, 2004.

Table 1 Summary of discharging rates from pump stations

Pump Station	Code	Kilometrage km	Catchments area (10^3 feddan #)	Discharge 10^6 m^3/y	Reuse 10^6 m^3/s
Abu Hommous P. S.	WU1	41	50	138	-
Shereshera P. S.	WU2	33	150	635	-
Truga P. S.	WU3	25	103	563	-
Nobaria Khalt P. S.	WU10	23	0	0	62
Deshudy P. S.	WU5	12	63	602	-
Hares P. S.	WU6	11.5	62	546	-
Abis P. S.	WU7	5.5	8	48	-
Al-Qalaa P. S.	WU8	2.8	14	214	-
Al-Max P. S.	WU9	1	726	2558	-

Feddan = 4200 m^2

month to month. Both studies ignored the impact of other pollutants in the drain.

The modeling of water quality in drains is a difficult problem; many uncountable sources of pollution such as algae, chemicals, and pesticides are gained from excess drainage water. Such sources produce many constituents, resulting in a complicated mechanism controlling the DO deficit in water. Moreover, the decay rate of organic matter in drains is affected by photosynthesis, evaporation, temperature, chemical reactions, surface reaeration, bacterial degradation, and settling of particles. Lifting devices such as pump stations and control devices such as weirs or sluice gates are another challenging point for the estimation of kinetic coefficients in drains. Such devices have a great influence on the uniformity of flow, velocity, dispersion coefficient, reaeration coefficient, decomposition rate, and settling removal rate.

In the past decade, several mathematical models have been presented for evaluating and predicting water quality in streams. The QUAL2E is a well-known model developed by the U.S. Environmental Protection Agency, Brown and Barnwell (1987). Drolc and Koncan (1996) have investigated the water quality of the River Sava in Slovenia by using the QUAL2E model. They used the calibrated model to estimate the maximum BOD of discharged wastewater to maintain DO concentrations higher than 5 mg l^{-1} in all sections of the river. Ghosh and Mcbean (1996) have used the QUAL2E model for predicting the water quality in terms of BOD_5 and DO for the Kali River. Chaudhury et al. (1998) have calibrated and validated the QUAL2E model for mapping the DO amount along the Blackstone River using extensive measured data.

In this paper, a proposal for improving surface water quality is presented. The case study involves the Umoum Drain in the West Delta region in Egypt. The important objectives for improving water quality, besides justifying the safety standards, were to achieve cost-effective analysis, economical and environmental balance, and sustainable use of water in quantity and quality. Further objectives included minimizing the cost of treated wastewater and maximizing the assimilative capacity of pollution loading along the stream. The water quality model, QUAL2E, is applied to calibrate the equivalent kinetic parameters for the Umoum Drain. The data used in calibration are obtained from the technical report No. 52 prepared by the National Water Research Center, Egypt, DRI (2000). A proposed scheme is

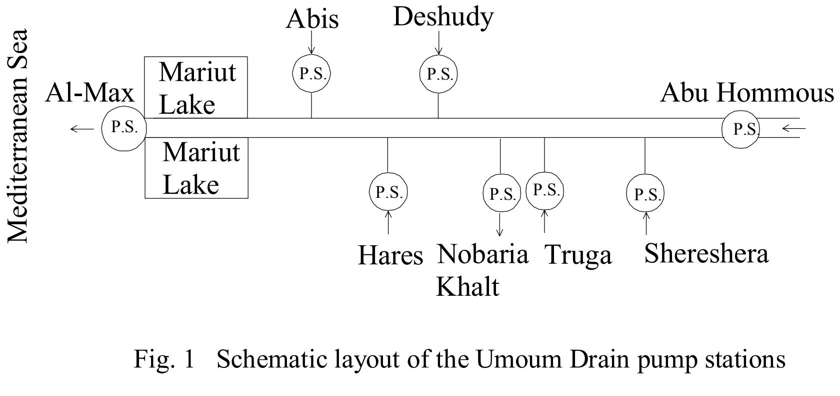

Fig. 1 Schematic layout of the Umoum Drain pump stations

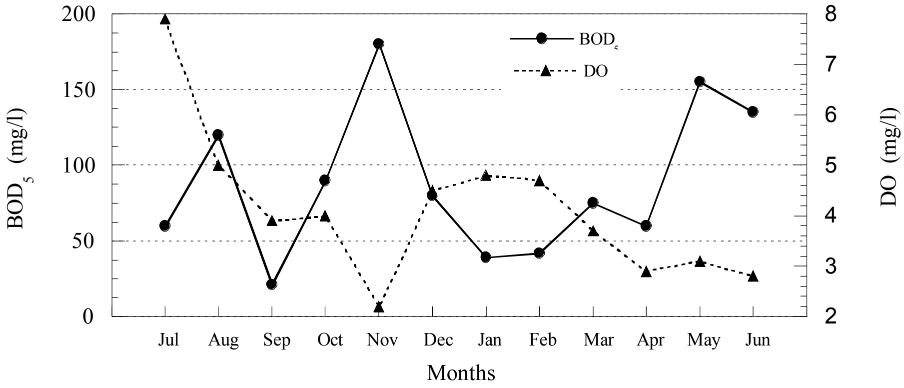

Fig. 2 Monthly concentrations for DO and BOD$_5$ in the Umoum Drain outlet (1997/98)

presented through reversing the flow direction in the Umoum Drain, and the drainage water is discharged into the Nobaria Canal. To enhance water quality before it is mixed with canal water, two approaches have been proposed; one is to install wastewater treatment plants in specific locations to purify polluted water before reaching the drain, the other is to consider a dilution technique for the polluted drain to maintain the safety limits before reaching the canal. The second approach was considered in this study for the following reasons:

As for purifying water, it is not enough to isolate the impact of wastewater loads from other pollutant sources that feed the drain since the water salinity is relatively high.

Construction and maintenance of wastewater treatment plants are relatively expensive, especially for tertiary treatment projects.

Not all sources of pollution are under control since some of them are indeterminate or illegally sited.

GEOENVIRONMENTAL CHARACTERISTICS OF THE DRAIN

The Umoum Drain is one of the largest drains in the West Delta region. Geographically, the drain catchment area is located on latitude of 33^o N and longitude of 33^o E. The ambient atmospheric temperatures near the drain range from a minimum of 10 ^{o}C to a high of 36 ^{o}C. Water temperatures are relatively stable, varying between 17~20 ^{o}C (in the absence of significant pollutant loads).

The drain catchment area covers approximately 422,860 feddan (1776 km^2) with a travel length of approximately 41 km. The drain starts from the Abu-hommous catchments with an area of 50,000 feddan (210 km^2). Water is discharged through the Abu-hommous pump station, P.S., and surged into the sea through Al-max P.S.. The drain conveys flow of one billion cubic meters per year. Several pump stations feed the drain along its course with drainage water such as the Shereshera P.S., Truga P.S., Deshudy P.S., Hares P.S., Abis P.S., and Qalaa P.S, as shown in Fig. 1. A withdrawal station is located halfway along the drain course at Nobaria Khalt P.S.. Water quality in the drain had previously been monitored by the Drainage Research Institute (DRI, 2000). The observed data show that drainage water has several pollutants with concentrations greater than acceptable standards. Table 1 lists a summary of average water quantities at all pump stations and intakes along the drain.

MONTHLY VARIATION OF DRAINAGE WATER QUALITY

Drainage water quality in the West Delta region near the Al-max pump station ranges from 21 to 180 mg/l for BOD$_5$, 2.2 to 7.9 mg/l for DO and 4500 to 8500 mg/l for TDS (DRI, 2000). In Fig. 2, it can be seen that the BOD$_5$ values are higher than standards all year. The large BOD$_5$ values reveal the insufficiency of WWTPs in the area served by the drain. Also, Fig. 3 shows the high salinity in the receiving drain, which indicates that drainage water quality is not suitable for mixing with potable or irrigation water in canals. The relatively low values of salinity are shown during the months of flood (July, August, and September).

Spatial Variation of Water Quality in Drain Branches

Figure 4 shows the annual average measured BOD$_5$ and DO concentrations at the pump stations feeding the drain. Figure 5 shows the TDS concentrations at the same measuring locations. The figures reveal the low quality of water in the downstream branches of the drain compared with upstream branches. In fact, waste disposal increases as a result of increasing population to the north. Also, the salinity increases in newly reclaimed lands near the seashore due to salt-water intrusion.

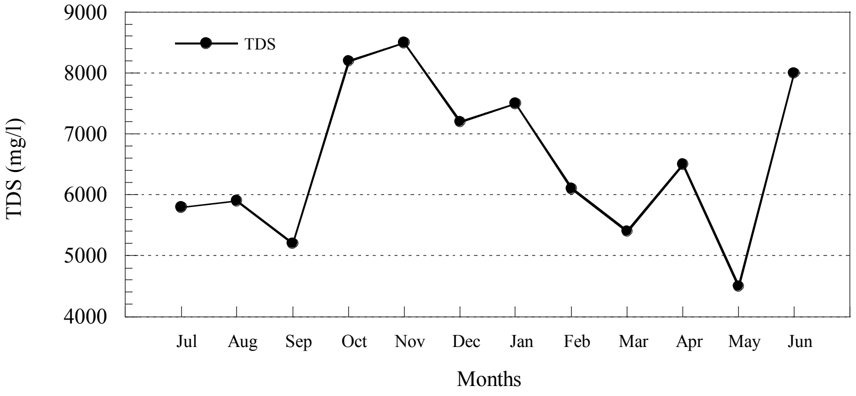

Fig. 3 Monthly concentrations for TDS in the Umoum Drain outlet (1997/98)

Simulation of Water Quality in Drains

Simulation of water quality in the drains is complicated by the existence of many point and nonpoint sources adding several pollutants along the stream. It is difficult to identify biological and chemical processes occurring in drains without fully characterizing all inputs. Also, it is difficult to isolate the impacts of the water treatment plant loads from the impact of other sources. Deriving the kinetic decay coefficients for the water quality modeling is the key step in water quality simulation. The kinetic coefficients values can be obtained in four ways: direct measurements, field data, literature values, or model calibration, Lung (2001).

The QUAL2E Model Formulation

To simulate the drain water quality, the QUAL2E model (Brawn and Barnwell 1987) is utilized. The model permits the simulation of 15 water quality constituents in a one-dimensional branching stream system. In the model, the finite difference solution of the one-dimensional advection and dispersion mass transport and reaction equation for steady nonuniform flow was used for the mathematical formulation. A mass balance equation, which is numerically integrated across space and time for each water quality constituent, can be written generally (after Chapra 1997) as:

$$V\frac{\partial c}{\partial t} = \frac{\partial\left(A\ E\frac{\partial c}{\partial x}\right)}{\partial x}dx - \frac{\partial\left(A\ U\right)}{\partial x}dx + V\frac{dc}{dt} + s \qquad (1)$$

where V is the volume, c is the constituent concentration, t is the time, A is the element cross-sectional area, E is the longitudinal dispersion coefficient, x is the distance, U is the average velocity, and s is the external sources positive or sinks negative of the constituent.

The reactions of constituents and their interrelationships are represented in the model. The most important considerations in determining the waste assimilative capacity of the stream is its ability to maintain an adequate DO concentration. The most accurate DO concentration balance in streams considers all constituent reactions, including atmospheric reaeration, photosynthesis, plant and

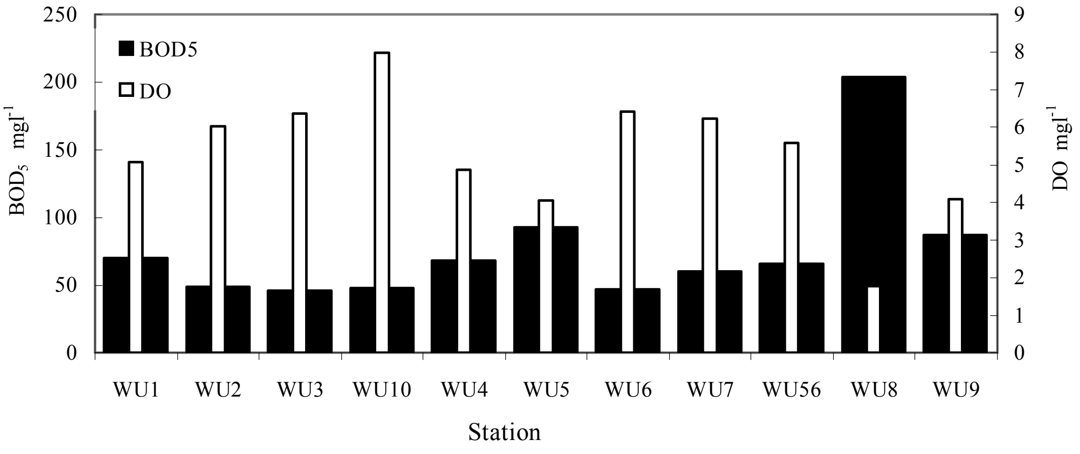

Fig. 4 Average values of annual BOD_5 and DO concentrations at pump stations discharging into the Umoum Drain

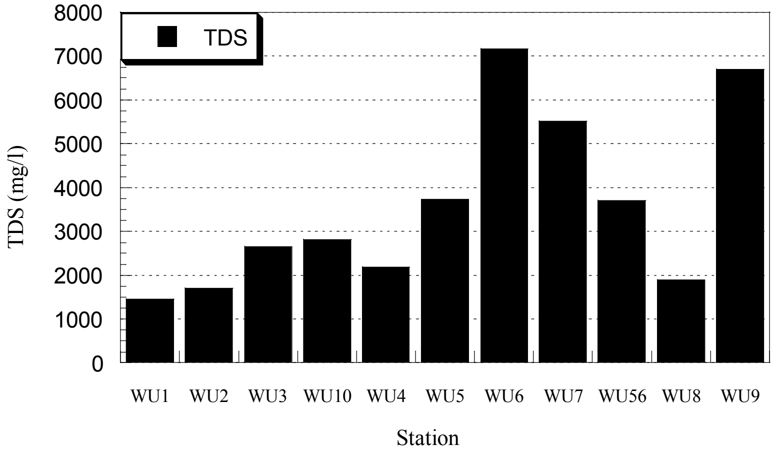

Fig. 5 Average values of annual TDS concentration at pump stations discharging into the Umoum Drain

animal respiration, biochemical oxygen demand, nitrification, salinity, and temperature, among other factors. The direct field measurements helped to eliminate the constituents of insignificant effects. This study focused on the reaeration and deoxygenation rates. The differential equation used in QUAL2E to describe the rate of DO change is shown below. Each term represents a major source or sink of oxygen.

$$\frac{dO}{dt} = k_2\left(O^* - O\right) + \left(\alpha_3\mu - \alpha_4\rho\right)A - k_1L - k_4/h - \alpha_5\beta_1N_1 - \alpha_6\beta_2N_2 \qquad (2)$$

where O is the concentration of dissolved oxygen (mg/l), O^* is the saturation concentration of dissolved oxygen at the local temperature and pressure (mg/l), α_3 is the rate of oxygen production per unit of algal photosynthesis (mg-O/mg-A), α_4 is the rate of oxygen uptake per unit of algae respired (mg-O/mg-A), α_5 is the rate of oxygen uptake per unit of ammonia nitrogen oxidation (mg-O/mg-N), α_6 is the rate of oxygen uptake per unit of nitrite nitrogen oxidation (mg-O/mg-N), μ is the algal growth rate, temperature dependent (d^{-1}), ρ is the algal respiration rate, temperature dependent (d^{-1}), A is the algal biomass concentration (mg-A/l), L is the concentration of ultimate carbonaceous BOD (mg/l), h is the mean stream depth (m), k_2 is the reaeration rate in accordance with the Fickian diffusion analogy, temperature dependent (d^{-1}), k_1 is the carbonaceous BOD deoxygenation rate, temperature dependent (d^{-1}), k_4 is the sediment oxygen demand rate, temperature dependent (g/m^2- d), β_1 is the ammonia oxidation rate coefficient, temperature dependent (d^{-1}), β_2 is the nitrite oxidation rate coefficient, temperature dependent (d^{-1}), N_1 is the ammonia nitrogen concentration (mg-N/L), and N_2 is the nitrite nitrogen concentration (mg-N/L). The simple form of Eq. 2, representing the BOD/DO model, yields

$$\frac{dO}{dt} = k_2\left(O^* - O\right) - k_1 L \qquad (3)$$

Table 2 Average water quality parameters for sampling locations

Station code	BOD	DO	TDS	NO_3-N	NH_4-N	P	Cd	Ca	Na	Zn
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
WU56*	66	5.58	3700	0.95	1.994	0.408	0.014	8.19	37.59	0.021
WU7	60	6.24	5511	0.948	1.246	0.514	0.012	9.24	58.71	0.033
WU6	47	6.42	7167	0.894	1.852	0.546	0.012	12.62	79.57	0.03
WU5	93	4.06	3729	1.194	1.837	0.551	0.012	7.83	37.64	0.034
WU4*	68	4.88	2181	1.776	1.127	0.367	0.012	5.79	21.18	0.025
WU10	48	7.99	2807	1.184	1.114	0.203	0.013	9.28	24.44	0.031
WU3	46	6.37	2655	1.229	1.031	0.329	0.013	6.33	26.21	0.03
WU2	49	6.02	1699	1.966	1.151	0.351	0.011	4.97	15.81	0.029
WU1	70	5.09	1463	0.85	1.069	0.525	0.011	4.03	13.34	0.033

NO_3: Nitrate NH_4: Ammonia P: Total Phosphate Cd : Cadmium Ca : Calcium Na : Sodium Zn : Zinc
WU4* : Deshudy Bridge Point WU56* : Sampling location at Desert Road Crossing

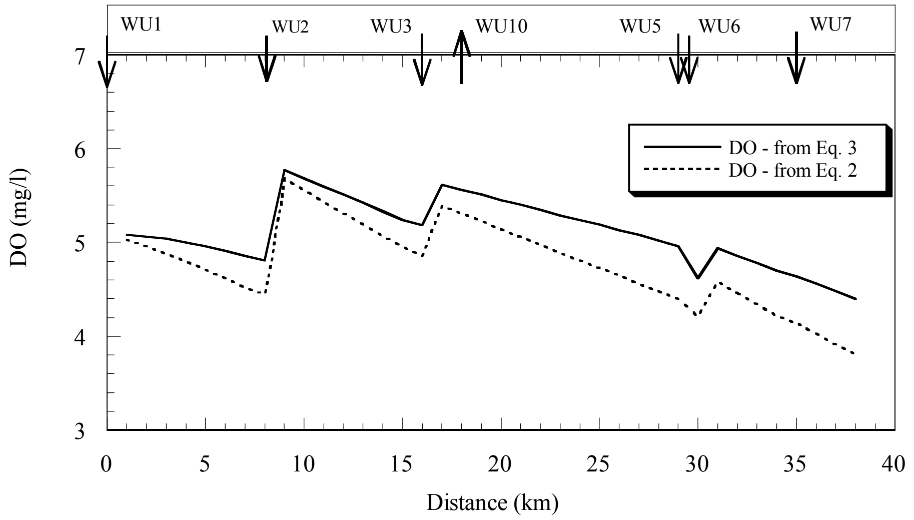

Fig. 6 Estimation of dissolved oxygen along the drain course

THE UMOUM DRAIN MODEL SIMULATION

Drain modeling was based on steady flow conditions in the drain section from Abu Hommous P. S. at Km. 41 to the crossing with Desert Road at Km. 3, i.e. before reaching the Mariut Lake. The last three kilometers are not considered in this study because of their undefined cross section, in which the flow is mixed with the lake water, where discharges are collected from indeterminate polluted sources.

Geometrical and Hydraulic Properties

The drain course is divided into four reaches. Each reach has a specific geometrical bed width. The computational element is 1.0 km. in length. The drain is considered a conveyor drain without incremental lateral inflows. Discharges from each feeding branch are pumped into the drain through six pump stations in several locations, as shown in Fig. 1. In the simulation, the pump stations are considered as source points. Only one pump station, which is considered a withdrawal point, takes its water from the drain for reuse purposes. The geometrical properties of the drain reaches are obtained from the water synoptic diagrams developed by the Deputy of Drainage, Ministry of Water Resources, according to the field measurements. Manning's coefficient is calculated from the geometrical and hydraulic properties of different reaches. The average value for Manning's coefficient is 0.03. The longitudinal dispersion constant value, K, for all reaches is selected according to the geometrical and hydraulic properties of each reach (after Table 5-3, Brown and Barnwell (1987)). For the first and second reaches, K is equal to 140, while for the third and fourth, K is equal to 210. Temperature in the area is relatively moderate, about 20^{o}C, without rapid change.

SELECTION OF KINETIC COEFFICIENTS

It is difficult to identify biochemical processes occurring in drains without fully characterizing all parameters of pollutants. For depicting the dissolved oxygen profile, DO, the simple form of the BOD/DO model is not sufficient. The data provided by the monitoring program (DRI, 2000) give the most substantial constituents, which are considered input variables to simulate the drain water quality, see Table 2.

To identify the significance of applying all constituents in Eq. 2, compared with the simplified form of BOD/DO, Eq. 3, the model is applied for both cases. Kinetic coefficients of Eq. 2 are taken equal to default values, (see Brown and Barnwell (1987)). As for the reaeration rate coefficient, k_2, the hydraulic conditions of the drain reaches, i.e. water depth and mean velocity, are similar to the conditions of the expression of O'Connor et al. (1958).

Table 3 Measurements on three stations along the Umoum Drain

Station	Index	Distance	TDS	BOD	DO
		km	mg/l	mg/l	mg/l
Nobaria Khalt P.S	WU10	23	2807	48	7.99
Deshudy Bridge Point	WU4*	12	2181	68	4.88
Desert Road Crossing	WU56*	3	3700	60	6.24

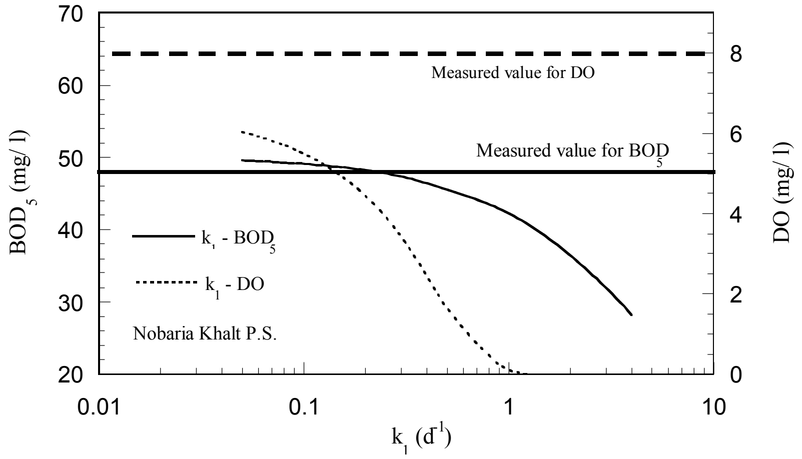

Fig. 7 Effect of k_1 variation on BOD_5 and DO values at location of Nobaria Khalt P. S. (km 23)

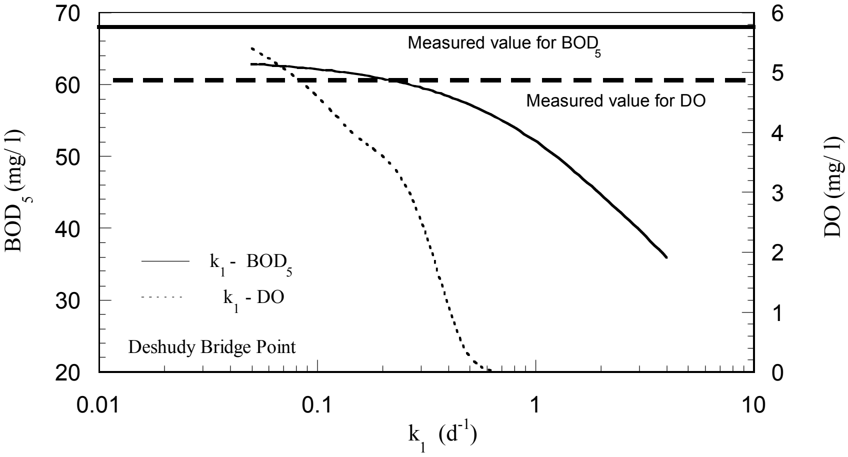

Fig. 8 Effect of k_1 variation on BOD_5 and DO values at location of Deshudy Bridge Point (km 12)

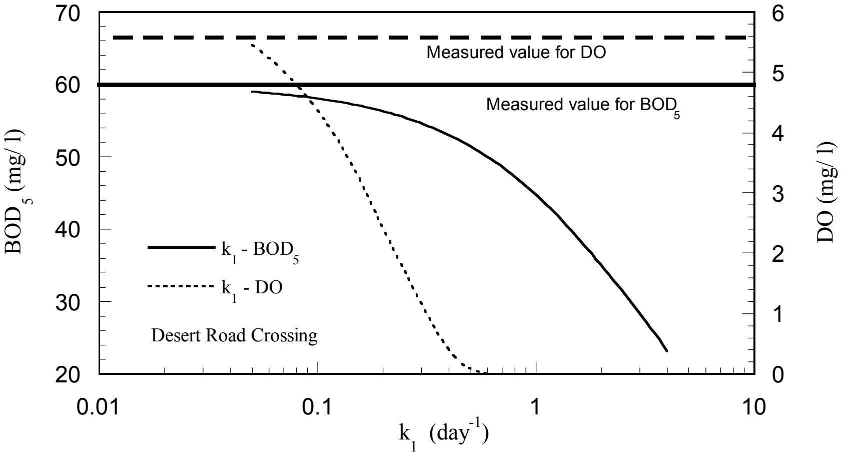

Fig. 9 Effect of k_1 variation on BOD_5 and DO values at location of Desert Road Crossing (km 3)

Fortunately, QUAL2E offers this expression as an option for estimating the coefficient k_2. Because water is discharged into the drain through several pump stations, there is little possibility of the discharged water carrying sediments or suspended matter. Moreover, the mean velocity in the drain cross-sections ranges from (0.25~0.42) m/sec. This velocity is sufficient to retain the suspended sediment in the water column. The monitoring program records total suspended solids of 180 mg/l as an average value in the drain. Thus, the rate of loss for BOD due to

Table 4 Estimated values of the coefficient k_l

Station	k_l (from BOD_5 results)	k_l (from DO results)
	(d^{-1})	(d^{-1})
Nobaria Khalt P.S.	0.21	underestimated
Deshudy Bridge Point	underestimated	0.08
Desert Road Crossing	0.05	0.05

settling, k_s , is considered insignificant. The temperature correction factors are taken as the default values. Figure 6 shows the comparison of DO values along the drain by using Eqs. 2 and 3, respectively. The figure shows gradual increases in the difference between the two curves. Neglecting nutrient constituents gives error in predicting the DO concentration values. The drop in the DO curve for the first case is almost twice that in the second. Such results suggest that biodegradation processes in the drains are only a partial, not dominant, effect in consuming DO in water when other constituents are present.

Calibration of the Deoxygenation rate (k_l)

The QUAL2E model is examined with one set of observed field data for studying the effects of k_l variations on BOD_5 and DO values along the drain.

Averaged measurements along the drain are available at three points, Nobaria Khalt P.S., Deshudy Bridge Point, and Desert Road Crossing, as shown in Table 3.

Figures 7, 8, and 9 show the results of applying the QUAL2E model on the drain quality for various values of k_l at three points on the drain longitudinal section. The values of k_l are selected between the reasonable literature values (0.02 ~ 4 d^{-1}). The model results for BOD_5 and DO concentrations decreased rapidly with the increases in k_l values. The dissolved oxygen concentration DO reaches its zero value rapidly for k_l values less than 1.0.

To estimate the average value of k_l along the drain, the results of the model application are compared with the observed values of BOD_5 and DO at the three locations given in Table 3. The estimated values are shown in Table 4.

Table 4 shows that the deoxygenation coefficient, k_l, in the drain is relatively small compared to literature values for irrigation channels. A short stream distance and excessive discharge of polluted water from several point sources through pump stations along the drain cause the biodegradation process to have a minor effect on self purification of the stream and on the successive consumption of dissolved oxygen. Focusing on the above results, it is recommended that the k_l coefficient be set to an average value of 0.1.

Simulation of Water Quality along the Drain

A numerical analysis was carried out to simulate the cumulative multi-sources flow and water quality conditions in the drain by using observed field data and the pre-estimated model parameters. Figure 10 shows the computed profiles of flow rates, Q, along the drain, and the locations of source and withdrawal pump stations.

Figures 11 and 12 show the computed concentration profiles of BOD_5, DO, and TDS along the Umoum Drain. In Fig. 11, the compatibility between both curves of BOD_5 and DO clearly show the opposing relation between them, as increases in the BOD values consumethe amount of DO in the water. The sharp decrease in BOD_5 after Shereshra

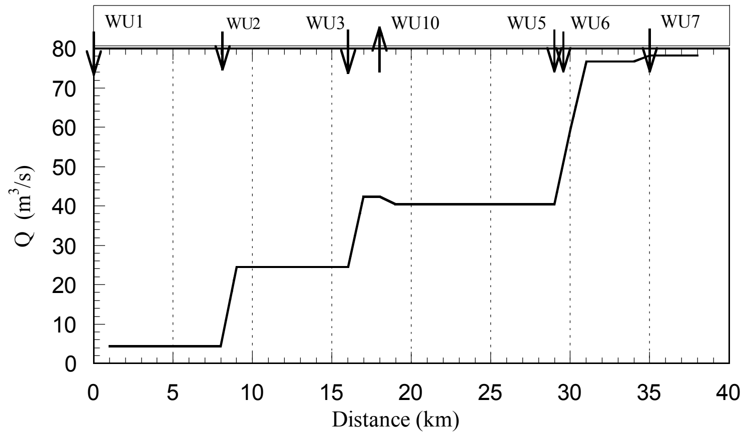

Fig. 10 Cumulative discharges along the Umoum Drain

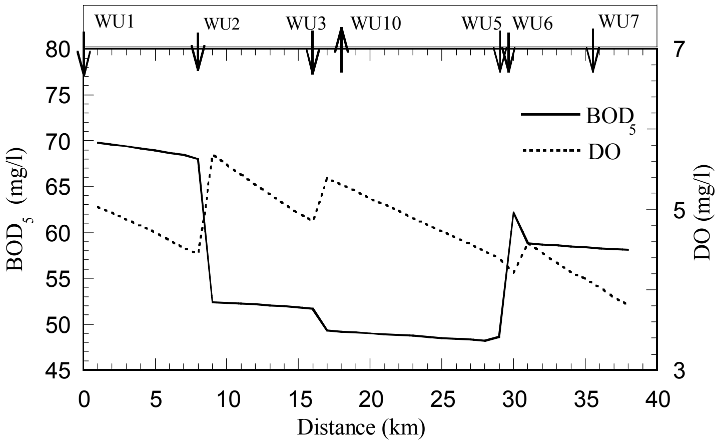

Fig. 11 Predicted BOD_5 and DO concentrations along the Umoum Drain

P.S. (WU2) is due to dilution rather than biodegradation, while the sharp increase after Deshudy P.S. is due to the high concentrations of BOD_5 coming from Deshudy P.S. Generally, the stream is deteriorated because the BOD_5 concentrations are much higher than the standards in all reaches of the drain. The curve of DO concentrations shows serial sags due to consumption, and serial recovery due to dilution. All DO values exceed zero, suggesting that aerobic conditions prevail along the drain. Only the reach after Deshudy P. S. has DO concentrations less than the standard (< 6 mg/l for BOD_5 and > 5 mg/l for DO). Figure 12 shows the increase in water salinity downstream, with all salinity concentrations being higher than the standard (500 mg/l). In conclusion, water quality in the drain is rather low, and mitigation procedures are needed before using this water for irrigation purposes.

Dynamic Management for Reuse of Drainage Water

The Nile water supply to the West Delta region is fixed at about 10.3 x $10^9 m^3/y$. This budget is already consumed by existing projects. Any future water management projects and land reclamation need additional nonconventional water supplies. The reuse of agricultural drainage water for irrigation is one of the most feasible and sustainable alternatives when environmental safety measures are achieved. Reuse of the Umoum drainage water has previously been investigated. The proposed plan has been to mix the drainage water with the water of the Nobaria Canal, according to Abdel Khalik (1996) and Morsy (2000). However, this project was halted due to environmental precautions and excessive salinity.

The analysis in the above paragraphs provides an opportunity to resume an acceptable scheme for reusing the drainage water of the Umoum Drain. The procedures of the solution should fulfill the following objectives:

1) Detecting the optimal location in the drain at which a separation between the water of relatively better quality and highly deteriorated water is achieved.

2) Changing drain water quality to maintain the safety measures of the environmental code of standards before reaching the Nobaria Canal intake location.

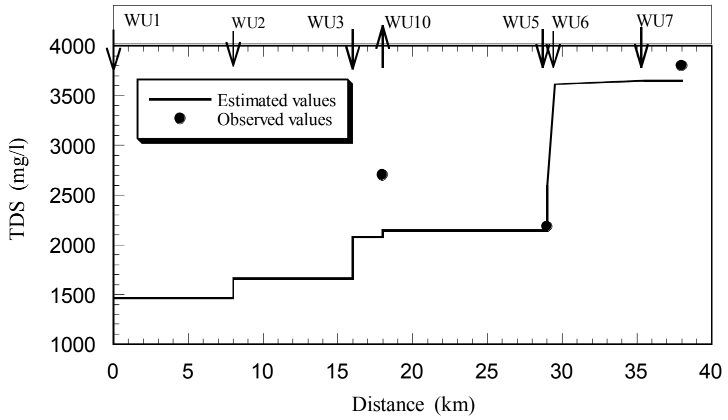

Fig. 12 Predicted TDS concentration along the Umoum Drain

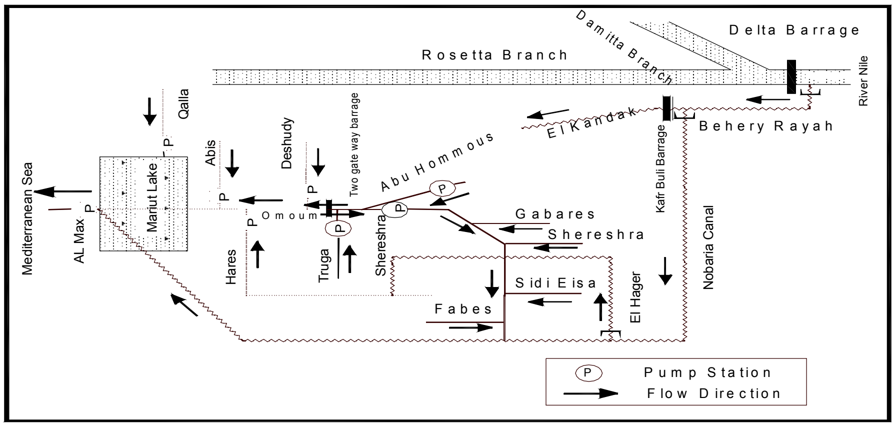

Fig. 13 Schematic layout for the drain and canal location

3) Checking the drain capacity for receiving additional discharges for an augmentation process, and improving the drain area cross section if necessary.

4) Constructing the necessary infrastructures for the purpose of providing dynamic management for the whole system.

WATER QUALITY OF THE DRAIN

From Figs. 10, 11, and 12, it clear that salinity and biochemical deterioration increase as the drain travels toward the sea. Starting from Deshudy P.S., the drain water salinity and BOD_5 steadily increase. Our proposed solution begins with identifying the best location for constructing a barrage with sluice gates at some point located downstream from Truga P. S. at km 25. This location in the drain separates the water to be reused from that to be disposed off into the sea. The total discharge from Truga P.S., Abu-Hommous P.S., and the Shereshra Drain will be reversed toward the Shereshra Drain and collected in a new drain discharging its water into the Nobaria Canal. The total amount of water expected to be reused is 1.3 x 10^9 m^3/y.

The expected average salinity of the water might be 1500 mg/l, with an average BOD_5 concentration of 55 mg/l. Both values are still higher than the standard for discharging into irrigation canals, i.e. 6 mg/l of BOD_5 and 500 mg/l of TDS after mixing with fresh water.

WATER QUALITY OF THE RECEIVING CANAL

The Nobaria Canal is the largest main canal in the West of the Nile Delta. The annual discharge released to the canal is 4.137 billion cubic meters, i.e. 131.2 m^3/sec. The BOD_5 value in the canal is lower than the standard (5 mg/l). The average salinity in the canal upstream of the proposed intake location is 350 ppm (Morsy 2000).

OPTIMAL SCHEME FOR WATER QUALITY IMPROVEMENT

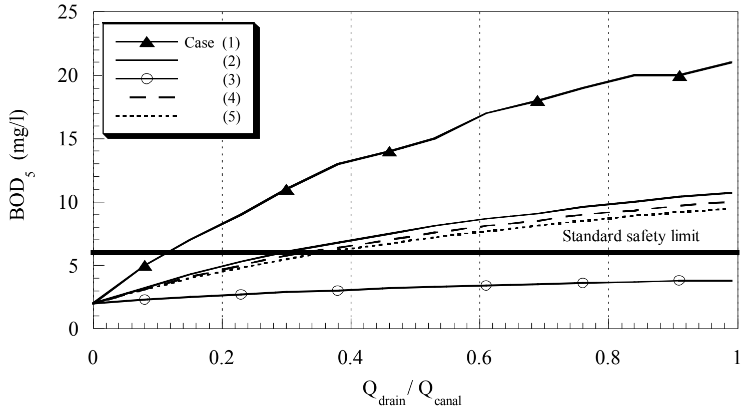

Fig. 14 Comparison between cases according to BOD_5 measures

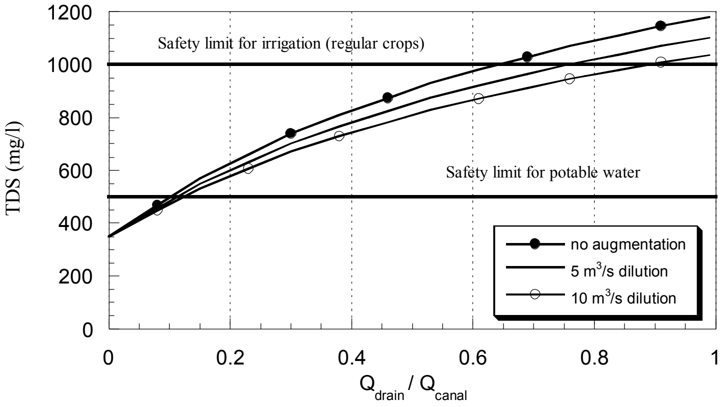

Fig. 15 Comparison between cases according to TDS measures

Enhanced primary wastewater treatment plants, WWTPs, and a flow augmentation technique are proposed as a solution for improving drain water quality before the mixing process. Five cases of study are proposed for the investigation. The first is discharging the drainage water into the canal without treatment or dilution with fresh water. The second is constructing two WWTPs before Abu-Hommous and Truga pump stations with an effluent capacity of 21,600 m^3/d and a BOD_5 concentration of 20 mg/l for each, see Fig. 13. The third proposal is to add more four small WWTPs with a capacity of 2160 m^3/d along the Shereshra Drain. The fourth solution represents two WWTPs and flow augmentation with fresh water from the El-Hager Canal with a capacity of 5 m^3/s. The fifth one is similar to case four, but with flow augmentation of 10 m^3/sec, respectively. Simulating the proposed scenarios in the QUAL2E model gave a relation between BOD_5 and TDS concentration versus the ratio of canal and drain discharges, as shown in Figs. 14 and 15.

The most acceptable and cost-effective idea which decreases the concentrations of both salinity and biochemical deterioration in the water to within safety limits is represented in case 4, i.e. using two WWTPs and dilution inside the drain with a fresh water capacity of 5 m^3/s.

For canal discharge of 131m^3/s, the suitable mixing ratio for drainage water, which meets the standards for BOD_5 and TDS values, is 3 to 1.

Because the discharge and water quality in the Nobaria Canal and in the Umoum Drain are not fixed throughout the year, dynamic management would be the dominant factor with regard to the success of the pre-mentioned procedures. The control of barrage openings will regulate the amount of drainage water to be reused according to need, and according to the suitable mixing ratio that preserves water quality under the safety limits. Moreover, the amount of fresh water needed for dilution in the drain should be managed according to the state of drain water quality from time to time. Figures 14 and 15 represent a design charts for providing the suitable mixing ratio that meets the standard of salinity and BOD_5.

THE NEED FOR REGULATING WASTEWATER REUSE

As mentioned above, effluents from wastewater treatment plants (WWTPs) exceeding 3 billions m^3/y are primarily discharged to agricultural drains. So far, no regulation of BOD_5 concentrations in wastewater reuse in irrigation exists in the FAO, USEPA and WHO (see Rowe and Abdel-Magid (1995)). While there appears to be wide agreement that current guidelines are insufficient, there is so far no general consensus on the best approach to follow, Angelakis et al. (1999). The Egyptian code rigidly specifies general guidelines for a maximum BOD_5 limit of 6 and 60 mg/l for canals and drains, respectively. This standard practically inhibits the development of wastewater reclamation and reuse projects. More detailed guidelines are strongly recommended. Standard for potable water should be more restricted than the water used for irrigation purposes. Moreover, important specific local conditions should be considered for water use in irrigation, including the quality of reclaimed wastewater, the dilution ratio, the type of soil, the climate, the relevant crops, and the local agricultural practices. In conclusion, values for BOD_5 concentrations higher than 6 mg/l should be considered to be beyond the safety limit for nonpotable water use.

CONCLUSIONS

The following conclusions can be drawn from the present study:

Spatial and temporal integrated evaluation of drain water quality is essential to the management of agricultural drainage water and wastewater as sustainable sources of nonconventional water resources.

From the results obtained, the QUAL2E model appears to be useful for estimating water quality in drains. Moreover, it can be used as a good tool for determining the kinetic coefficients of drains having problems of water quality that lead to an ability to assess the waste load allocation, and to calculate the salt and waste assimilative capacity of a drain.

The model is used to estimate dissolved oxygen concentrations along the Umoum Drain reaches. It can be concluded that effluents of wastewater from the sewage stations in Abu Hommous and Truga should be treated in a WWTP to reach BOD_5 values under 20 mg/l. Improving the BOD_5 values together with flow augmentation in the drain will raise the concentrations of dissolved oxygen in the Umoum Drain near the outlet to the Nobaria Canal to higher than 5 mg/l, as is recommended by the Egyptian environmental standard.

For drains, neglecting nutrient constituents in the model application leads to overestimate in of the values for dissolved oxygen concentrations. Such a result indicates that the biodegradation process is not the only dominant reaction in consuming DO in drainage water if there are other constituents.

The biodegradation process in short drains has a minor effect on the self-purification of the stream and on the successive consumption of dissolved oxygen. It is clear that the deoxygenation coefficient in the drain is relatively low compared with literature values of irrigation channels.

Because water quality along the drain is temporally and spatially varied, dynamic management is the most appropriate solution for controlling water quantity and quality of drainage water expected to be reused through mixing with fresh water.

Design charts are presented for providing the suitable mixing ratio between fresh and drainage water that meets the standards of salinity and BOD_5.

There is a need for detailed guidelines regarding the reuse of drainage and wastewater for irrigation purposes.

REFERENCES

Abdel Khalik, M. A. (1996). Impacts of reusing drainage water for agricultural expansion in the Western Nile Delta. Proceedings of the sixteen Congress of the International Commission on Irrigation and Drainage, Cairo, Q.47- R.2.01: 117-130.

Angelakis, M. H. F., Marecos Do Monte, Bontoux, L. and Asano, T. (1999). The status of wastewater reuse practice in the Mediterranean basin: need for guidelines. Water Resources Research. 33(10): 2201-2217.

Brown, L. C. and Barnwell, Th. O. (1987). The enhanced stream water quality models QUAL2E and QUAL2E-UNCAS: documentation and user manual. Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, Georgia.

Chapra, S. (1997). Surface water quality modeling. The McGraw-Hill Companies, Inc., New York.

Chaudhury, R. R., Sobrinho J., Wright, R. and Sreenivas, M. (1998). Dissolved oxygen modeling of the Blackstone River (Northeastern United States). Water Resources Research. 32(8): 2400-2412.

Drolc, A. and Koncan, J. Z. (1996). Water quality modelling of the River Sava. Water Resources Research. 30(11): 2587-2592.

El-Sayed, A. and Abdel Gawad, S. T. (2001). Wastewater reclamation and reuse potential in rural areas of Egypt. Proceedings of ICID International Workshop on Wastewater Reuse Management, Seoul, Rep. Korea.

El-Sayed , A. Abdel Gawad, S., Abdel-Gawad, S. M. and Ibrahim K. (1994). Bahr El Baqar drain system, Eastern Nile Delta. Proceeding of the VIII IWRA World Congress on Water Resources, Cairo, T4-S1: 5.1-5.15.

Ghosh, N. and Mcbean, E. (1996). Water quality modeling of the Kali River, India. Water, Air, and Soil Pollution. 102: 91-103.

Drainage Research Institute (2000). Monitoring and analysis of drainage water quality project. Technical Report No. 52, National Water Research Center, Egypt.

Lung, Wu-Seng (2001). Water quality modeling for wasteload allocations and TMDLs. John Wiley & Sons, New York.

Morsy A. M. (2000). Update of data and information of the umoum drainage water reuse project. Proceedings of Journal of Water Science, National Water Research Center, Delta Barrages, Cairo, Egypt, 27th Issue: 27-35.

O'Connor, D. J. and Dobbins W. E. (1958). Mechanism of reaeration in natural streams. ASCE Transactions. 123: 641-684.

Rowe, D. R. and Abdel-Magid, I. M. (1995). Handbook of wastewater reclamation and reuse. Lewis Publications, USA.