

NUMERICAL SIMULATION FOR POLLUTANTS TRANSPORT IN OPEN DRAINS

محاكاة عدديه لانتقال الملوثات في المصارف المكشوفة

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ملخص:

إن عملية تقييم وتحليل تلوث المياه، بالإضافة إلى التقديرات الموثوق بها للأضرار البيئية، قد تساعد في وضع اللوائح الحكومية لحماية البيئة. مع ذلك، فإن الاستفادة من واستخدام مثل هذه التقديرات هي مستحيلة دون معرفة مختلف العمليات، على سبيل المثال يتم التعرف على تشكيل خط المياه في المجرى المائي، وانتقال الملوثات، والقدرة على التنظيف الذاتي، وما إلى ذلك. هذه العمليات معقدة، ولها تفاعلات عالية وانتشارها مكانيا كبير مما يجعل تحليل ووصف ونمذجة ومحاكاة ذلك من المهام الصعبة. ومع ذلك، فإنه من الممكن إيجاد حلول صريحة لبعض الحالات البسيطة جدا والتي تكون مفيدة بما فيه الكفاية لتكون ذات أهمية هندسية. بالنسبة للحالات الأقل بساطة، فإنه يمكن تطوير التقنيات العددية التي تسفر عن حلول ذات دقة مرضية. لذلك يهدف هذا البحث إلى التحقق من إمكانية تطبيق المحاكاة العددية لانتقال الملوثات في المصارف المكشوفة باستخدام نموذج جودة المياه (QUAL2K). هذا النموذج تم تطبيقه على نظام مصرف بحر حادوس حيث تم تنفيذه ثم معايرته باستخدام معاملات تم تحديدها من أجل فترة المعايرة (العشرة أعوام الأخيرة). حينئذ تم التحقق من صحة هذا النموذج وتقييمه وذلك بمقارنة تنبؤات النموذج بكل دقة مع البيانات المرصودة. في نفس الوقت كانت هناك سيناريوهات مختلفة لمحاكاة المصرف للتنبؤ بنوعية المياه على طول المصرف من خلال النموذج. حيث حاكي السيناريو الأول والثاني الحالة التي تقل فيها التصريفات في مصرف بحر حادوس وفروعه بنسبة تتعدى 10%، 25% على التوالي وحاكي السيناريو الثالث الحالة التي تقل فيها الملوحة إلى نسبة أكبر من 25%. وقد مثل نموذج QUAL2K البيانات الحقلية بشكل جيد تماما بالنسبة للمعايير السابقين (التصريفات، الملوحة). وأيضا كان قادرا على محاكاة السيناريوهات الثلاثة السابقة على نحو فعال وهذا يؤكد أن هذا النموذج هو أداة قوية في محاكاة انتقال الملوثات، ويمكن استخدامه بشكل فعال في إدارة نوعية المياه في المصارف المكشوفة.

ABSTRACT:

Evaluation and analysis of water pollution in addition to reliable estimates of the environmental damages may help in establishing governmental regulations for environmental protection. Utilization and introduction to such estimates require knowledge of some processes, e.g. formation of a water line in the water stream, transport of pollutants, capability of self-cleaning, etc. These processes are recognized as complex, highly interacting and spatially distributed making analyzing, describing, modeling and even simulating them are challenging tasks. However, explicit solutions are possible in certain cases, which are physically very simple but are real enough to be of engineering importance. On the other hand, for the less simple cases, numerical techniques can be developed which yield solutions of satisfactory accuracy. This research aims to investigate the possibility of applying numerical simulation for pollutants transport in open drains using the water quality model QUAL2K. The QUAL2K model was applied for Bahr Hadus drain system, then, calibrated using coefficients determined for the calibration period (water year 2010). Then, the model was verified and evaluated within a precise comparison for its predictions with the field observed data. Some different scenarios were simulated for Bahr Hadus drain and the model was used to forecast the selected water quality parameters along different locations on the drain. These scenarios were as follows: Scenario A and B simulated the cases when the discharges that pass through the Bahr Hadus drain and its tributaries were reduced up to 10% and 25% respectively. Scenario C simulated the case when the salinity was reduced up to 25%. The QUAL2K model represented the field data quite well in the two examined parameters and was able to simulate the previous scenarios A, B and C, effectively.

1-INTRODUCTION:

Nile River is the support of almost all economic activities in Egypt. It provides some 97% of the country's freshwater resources. Groundwater resources cover the

remaining 3% of the supply and the potential for increasing the supply is limited. The contribution from rainfall, except for the Mediterranean coastline is negligible. Agriculture is the predominant water use sector representing nearly 85% of the water demand. The remaining 15% of the water demand is shared amongst municipal, industrial, and navigational needs (NAWQAM, 2008). Water is needed to irrigate vast areas of agriculture land, to generate electrical energy, to meet the growing demands of expanding villages and cities, industrial needs, and navigation.

In contrast to the increasing demand, the availability of water and land resources is limited and the per capita share of fresh water is quickly reaching scarcity levels. Consequently, the threat of Nile water resources being insufficient in quantity and quality in the near future requires immediate, efficient and coordinated actions (Shaban, 2001). Reuse of agricultural drainage water in irrigation purposes appears to be one of the most promising, practical and economical means of increasing the Egyptian water budget (Colombo, 1987).

However, reuse of drainage water has its limitations and drawbacks. Since the available information shows that the river Nile, its branches, canals and the drains are suffering from an alarming increase in the pollution through wastewater. The drainage

system particularly is receiving the heaviest pollution loads.

The major sources of water pollution are agricultural chemicals [salts, nutrients and pesticides], municipal and rural domestic sewage and industrial wastewater (NBI, 2005). The previous facts called for intensive studies that investigate the causes and impacts of the water deterioration in Egypt especially in connection to the agricultural drainage water reuse strategy that is practiced since early seventies.

2-PROBLEM DEFINITION:

Assessment of water resources requires full understanding for the water quality processes. The quality of water itself is a significant factor to put limits on the amount of available water that may be used for various purposes. That is, what nature provides as available quantities may be reduced if the quality of water does not permit its use for a specific purpose (Sanders, 1998).

In Egypt, Lake Manzala is a good example for the case when the quality of water threatens significantly its potential uses. It is one of the Northern lakes located adjacent to the Mediterranean Sea and receives the final effluent of some major drains such as Bahr Hadus, Lower Serw and Bahr El-Baqar drains. Lake Mnazala in addition to the other Northern lakes contributed with about 135.6

thousands tons in the fish production of the country during 2003 (Shakweer, 2006).

The available information shows that the feeding drains are dumping significant amounts of pollutants to the lake deteriorating its ecosystem. Consequently, the information related to water qualities and quantities of these drains play vital role in any environmental assessment of the lake. This information is also essential for deciding whether drain water is suitable for reusing in agricultural purposes. The evaluation and analysis of drains water pollution in addition to reliable estimates of the environmental damages may help in establishing governmental regulations for environmental protection.

However, the introduction and utilization of such estimates are impossible without knowledge of various processes, e.g. formation of a water line in the drains, transport of pollutants, capability of self-cleaning, etc. These processes are recognized as complex, highly interacting and spatially distributed making analyzing, describing, modeling and even simulating them are challenging tasks.

These complications may be attributed to the fact that many flow phenomena of great importance to the engineers are unsteady in character, variable with time and cannot be reduced to steady flow. Unsteadiness implies that the velocity may be increased

and the streamlines themselves may be shifted.

The equations of motion are not solvable in the most general cases. However, explicit solutions are possible in certain cases, which are physically very simple but are real enough to be of engineering importance. For the less simple cases, approximations and numerical techniques can be developed which yield solutions of satisfactory accuracy. *In view of the above discussion, the simulation is needed to be improved, in order to, understanding of pollutant transport processes of open drain flow would be gotten.*

3-OBJECTIVES:

The numerical solutions and computer systems play a major role in establishing scientifically justified and practically reasonable programs for long-term measures for a rational use of water resources, reduction of pollutants discharge from particular sources, estimation of the impact in the environment of possible technological improvements, development of methods and monitoring facilities, and quality management of the environment (Seppelt, 2003).

The success of these numerical solutions in solving practical problems in many respects depends on the adequacy for the simulation of the real processes. In this research, the author aims at investigating the possibility of

applying numerical simulation for pollutants transport in open drains using the water quality model QUAL2K. In this model the stream is conceptualized as a one-dimensional string of completely mixed segments that are linked sequentially via the mechanisms of advective transport and dispersion.

The model uses a finite-difference solution, a powerful computational technique for approximate solutions to a variety of "real-world" engineering problems having complex domains subjected to general boundary conditions, for the advective-dispersion mass transport equations. It has also the capability of performing an uncertainty analysis and permits the simulation of 36 water quality constituents.

More specifically, the objectives of this research can be formulated as follows:

- Reviewing the literature for similar studies that are primarily concerned with numerical solutions in water resources management in general and focusing mainly on pollutant transport in open streams.

4-POLLUTANT TRANSPORT PROCESSES:

This research mainly aimed to assist in the quantitative understanding and ability to predict the various transportation parameters of contaminants in open drains. Thus,

fundamental processes should be emphasized and described. However, any attempt to understand and predict contaminant transport inevitably leads to mathematical models, occasionally simple conceptual or analytical models, but often more complex numerical models.

The major limitation in the usefulness of these models is the existence of an inadequate knowledge of the processes included (Lick, 2009). The basic processes that are significant and needed to be quantitatively understood to develop quantitative and accurate models of contaminant transportation.

- **Physical Processes:**

An understanding of the transport and fate of contaminants in the environment is required to evaluate the potential impact of contaminants on human health and the environment. Such knowledge is needed to conduct risk assessments, such as evaluating the probability that a contaminant spill would result in surface water pollution and to develop and evaluate methods for remediating environmental contamination. There are four general processes that control the transport and fate of contaminants in the environment. These are advection, dispersion, inter-phase mass transfer, and transformation reactions (Brusseau, 2006).

- **Chemical Processes:**

The transport behavior of contaminants in the environment is influenced by their partitioning or transfer among the well known environment phases (solid, liquid and gas) and also by transformation reactions.

- **Biological Processes:**

The presence of microorganisms in soil and water can affect the distribution, movement, and concentration of pollutants through a process called biodegradation. It is defined as, the breakdown of organic compounds through microbial activity.

5-POLLUTANTS

TRANSPORT MODELING:

Relating to the pollutants transport and water quality modeling using QUAL2K model, **Gupta and Ismail (2011)** collected water samples from a part of Yamuna River along different points between ITO to Okhla stretch. These samples were analyzed for various water quality parameters during non-monsoon periods. The study was conducted by the ITO to Okhla portion of Yamuna River, which is significant, owing to the presence of various drains joining it. The

physical and chemical parameters at a different points of the surface layer of the water were involved in this study to be determined.

The QUAL2K model was applied to simulate and predict the, dissolved oxygen (DO), biochemical oxygen demand (BOD5), pH and alkalinity profiles of Yamuna river in a stretch of 12.45 kilometer. The simulation results were verified and showed that, the predicted values were in agreement with the measured values. To clearly display the model outcomes and demarcate polluted zones in the river stretch, results were interfaced with a Geographical Information System (GIS) to produce cartographic outputs.

QUAL2K MODELING:

The modeling process began with a planning phase in which the questions to be answered using the model were established. Then, the model schematization was determined. Schematization describes how the model will be used to represent the water bodies being studied (**WRDMAP, 2010**). The following steps for model development are given in **Figure (1)**.

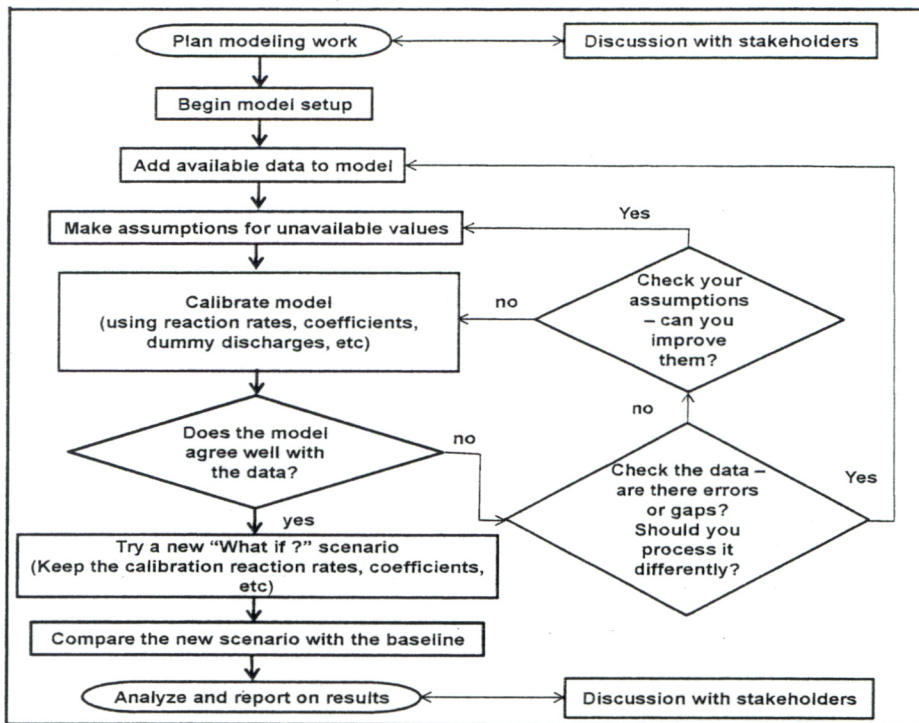


Fig. (1): Overview of modeling process (After WRDMAP, 2010)

QUAL2K Model:

QUAL2K (or Q2K) is a river and stream water quality model that is intended to represent a modernized version of the QUAL2E (or Q2E) model (Brown and Barnwell, 1987). The Qual2K model is a one dimensional model and so it is assumed to be well-mixed in the vertical and lateral directions. It is a steady state model, Non-uniform, so the flow and water quality cannot evolve over time. Diurnal variations in water quality (due to the diurnal variation in temperature and sunlight) can be simulated.

The model uses a finite-difference solution of the advective-dispersive mass transport and reaction equations and it specifically uses a special steady-state implementation of

an implicit backward difference numerical scheme which gives the model an unconditional stability (Walton and Webb, 1994). In each compartment, the model computes the major interactions between up to 15 state variables.

- BOD-Ultimate carbonaceous biochemical oxygen demand (BOD) is modeled as a first-order degradation process in the model, which also takes into account removal by settling and does not affect the oxygen balance.
- DO - The process discussed above represents the primary internal sink of dissolved oxygen in the program. Other sinks include sediment oxygen demand (SOD), modeled as a zero order reaction, respiration by algae, and nitrification which includes the oxidation of both

ammonia and nitrite. The major source of dissolved oxygen, in addition to that supplied from algal photosynthesis, is atmospheric re-aeration. Nine methods are available to calculate the re-aeration coefficient in case of free water surface. Re-aeration under ice cover and above dams are also considered. All sources and sinks (but SOD) are modeled as first order reactions.

- The nitrogen cycle is composed of four compartments: organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen. The nitrogen balance considers mineralization and settling of the organic nitrogen, nitrification which is divided into the oxidation of ammonia in nitrite and then the oxidation of nitrite into nitrate, uptake by the algae, regeneration from the sediment and from algal respiration. Both nitrification reaction rates can be corrected to take into account inhibition at low DO concentrations.
- The phosphorus cycle is similar to, but simpler than the nitrogen cycle, having only two compartments. The phosphorus balance considers the settling and the mineralization of the organic phosphorus into inorganic phosphorus, regeneration from the sediment, uptake and respiration from the algae.
- Algae – The model uses chlorophyll (a) as an indicator of planktonic algae biomass. The model assumes a first order

reaction to describe the accumulation of algae biomass. The accumulation of biomass is calculated as a balance between growth, respiration and settling of the algae. Maximum growth rate is modeled as being light and nutrient limited. There are three mathematical options to estimate nitrogen and phosphorus limitations. For nitrogen uptake, the model favors ammonia uptake by algae over nitrate uptake by an algal preference factor. Three light functions are available to calculate the light limitation factor.

- They express light limitation due to: (1) the diurnal and climatic changes of radiation, (2) the light extinction in the water column due to turbidity, and (3) self-shading. It should be noted that the term respiration is used in a rather general meaning since, the same coefficient is used to describe oxygen uptake by the algae and the release of organic nitrogen and phosphorus as a result of algae degradation.
- Temperature - All reactions between all state variables expressed above are temperature dependent and the model calculates a correction factor for all coefficients in the source/sink terms using a Streeter-Phelps type formulation. Water temperature is automatically calculated by the model. On each compartment, a full heat balance at the air-water interface is computed between the total incoming

short-wave radiation, the total incoming atmospheric radiation, the back radiation from the water surface, the heat loss by evaporation and the heat loss by conduction to the atmosphere.

- Coliforms are used as an indicator of pathogen contamination in surface waters. A simple first order decay function is used, which only take into account coliform die-off.
- One non-conservative constituent concentration can be modeled. Three reactions are considered: a first-order decay, a first order settling and a zero order regeneration from the sediment.
- Three conservative constituents can also be traced along the modeled river or stream. The framework of QUAL2K modeling for simulating river and stream water quality includes the following elements:
 - Software Environment and Interface: QUAL2K is implemented within the Microsoft Windows environment. It is programmed in the Windows macro language: Visual Basic for Applications (VBA). Excel is used as the graphical user interface.
 - Model segmentation: QUAL2K segments the system into river reaches comprised of equally spaced elements. In contrast, QUAL2K uses unequally-spaced reaches. In addition, multiple loadings and

abstractions can be input to any reach, **Figure (2).**

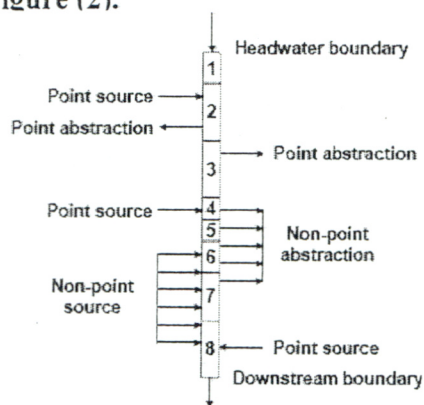


Fig. (2) : The QUAL2K scheme

Carbonaceous BOD speciation: QUAL2K

uses two forms of carbonaceous BOD to represent organic carbon. These forms are a slowly oxidizing form (slow CBOD) and a rapidly oxidizing form (fast CBOD). In addition, non-living particulate organic matter (detritus) is simulated. This detrital material is composed of particulate carbon, nitrogen and phosphorus in a fixed stoichiometry.

- **Anoxia:** QUAL2K accommodates anoxia by reducing oxidation reactions to zero at low oxygen levels. In addition, denitrification is modeled as a first-order reaction that becomes pronounced at low oxygen concentrations.

Sediment-water interactions: Sediment-water fluxes contained dissolved oxygen and nutrients are simulated internally rather than being prescribed. Those, oxygen (D.O.) and nutrient fluxes are simulated as a function of settling particulate organic matter, reactions

within the sediments, and the concentrations of soluble forms in the overlying waters.

- **Bottom algae:** The model explicitly simulates attached bottom algae.
- **Light extinction:** Light extinction is calculated as a function of algae, detritus and inorganic solids.
- **pH:** Both alkalinity and total inorganic carbon are simulated. The river's pH is then simulated based on these two quantities.

Pathogens: A generic pathogen is simulated. Pathogen removal is determined as a function of temperature, light, and settling.

6- BAHR HADUS DRAIN SYSTEM:

The Bahr Hadus drainage system, **Fig. (3)**, starts a few kilometers before the Gemeeza bridge (EH14), and ends at its outfall to Lake Manzala (EH17). It has a total length of approximately 60 kilometers. Four kilometers after its starting point Hanut pumping station (EH02) extracts a considerable part of its discharge to the Hanut irrigation canal. Next along the main drain, it receives a feed of water through the Sadaqa pumping station (EH03) on a side branch.

The Nizaam branch drain that receives the effluent of El-Mansura city Waste Water Treatment Plant (WWTP) feeds into main

Hadus drain before El-Dawar bridge (EH15). The Beni Abied (EH06), Additional Qassabi (EH07), and Main Qassabi (EH08) pumping stations discharge their water into the main Hadus drain respectively before receiving a discharge of a branch carry the outflow of the Erad pumping station (EH10) and the Geneena pumping station (EH09 which is used partly for irrigation purposes) into the main Hadus.

The Saft drain (a branch of Bahr Hadus) discharges into the main Hadus before the Hadus outfall (EH17), which is located just before the siphon of El-Salam canal. Water quality of Bahr Hadus is of special importance, as considerable part of its water is diverted to the El-Salam canal Project. The remainder is discharged into Lake Manzala. The water quality of the downstream location (EH17) represents part of El-Salam canal water. The area served by El-Salam canal extends South of Lake Manzala and the North part of the Sinai.

Looking at the water functions of the whole catchment area, fishery activities are observed at the downstream sites. In addition of that the downstream part of the Bahr Hadus is reused unofficially due to the shortage of fresh irrigation water. Besides of that two drainage pumping stations are in use officially, these are Hanut and Saft (EH02 & EH12) pumping stations.

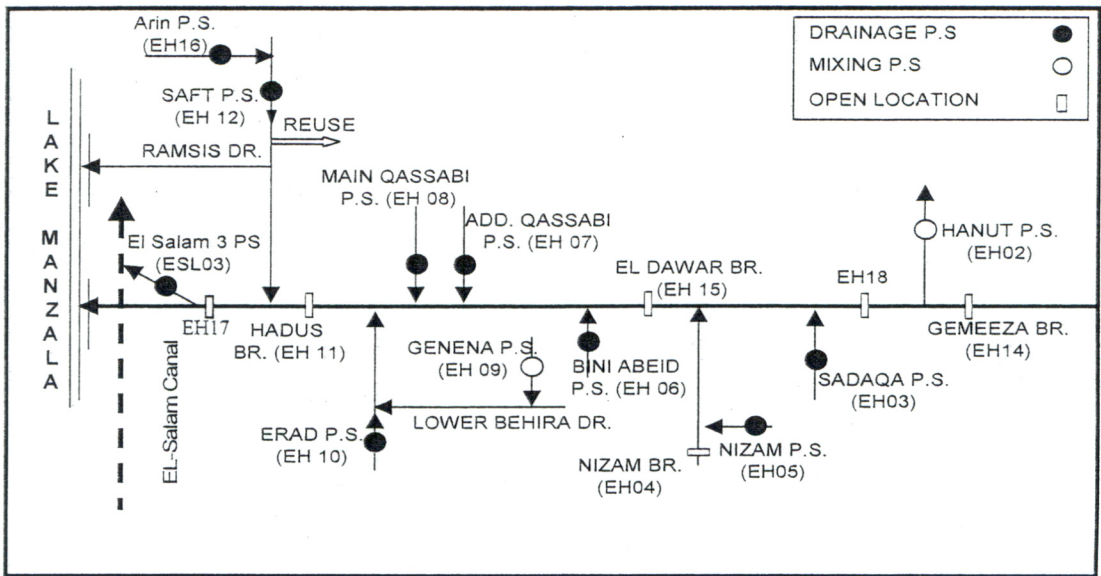


Fig. (3): Scheme of Bahr Hadus Drain System

The QUAL2K model was applied for Bahr Hadus drain system. Based on the drain characteristics as well as the model structure, each reach was subdivided into uniform computational elements, which form the basis for model's finite difference numerical solution. The subdivision process was carried out basically to assure that each section must have similar hydraulic characteristics (water depth, cross section widths, side slopes, canal slopes and soil type). The model was applied to forecast the water quality parameters based on the information given in the Input Data Phase. The model was then calibrated using coefficients determined for the calibration period (water year 2010) and for other model coefficients, which were not available for this research work, default values were used. Then, the model for Hadus drain has been verified and evaluated based

on a point-to-point comparison of model predictions with observed data.

Modeling Alternative Scenarios:

Three different scenarios were considered for Bahr Hadus drain and the model was asked to forecast selected water quality parameters along different locations on the drain starting from its initial point to its outfall at Manzala Lake . These scenarios are :

Scenario A: This scenario simulated the case when the discharges that pass through Bahr Hadus drain and its tributaries are reduced up to 10%.

Scenario B: Similar to Scenario A, scenario B simulated the case when the discharges that pass Bahr Hadus drain and its tributaries are reduced up to 25%.

Scenario C: When the water quality measured at Hadus drain system, it was noticed that the water salinity showed a significant increase along the longitudinal section of the main drain. This phenomenon

is clear starting from a point at the Km 21.00 and continues till the outfall at Manazala lake. Therefore, this scenario simulated the case when this salinity problem was reduced up to 25% .

7-RESULTS DISCUSSION

AND

Model Calibration Results:

QUAL2K was calibrated and verified in steady-state mode using water quality and quantity data that were collected from 2000–2009. Generally, most steady-state conditions were obtained in the drain flow and pollution loads. The field data were collected within the framework of the National Water Quality Monitoring Network executed by the National Water Research Center, Ministry of Water Resources and Irrigation. The considered parameters in the model were:

- Discharges (Q),
- Temperature (Temp),
- Conductivity (EC),
- Dissolved Oxygen (DO),
- Carbonaceous Biological Oxygen Demand (CBOD) (slow and fast)

○These parameters were modeled in a steady-state mode. Using the input conditions, the model was run and the results compared to the field measurements. System coefficients (rates) were appropriately adjusted until reasonable agreement between

model results and field measurements were achieved.

○The values of system coefficients were based on the typical values cited in the model documentation (**Bowie et al., 1985; Brown and Barnwell, 1987**).

Factors affecting the calibration process:

1-The hydraulic and hydrological data required for the water section such as:

- Flow rates (m^3/s) at headwaters, point discharges / abstractions and diffuse discharges / abstractions;
- Dimensions for each drain reach (reach length, bed width, bank slopes and bed slope);
- Locations for upstream and downstream ends of each reach;
- Height, width and shape of any weires, dams and waterfalls; Rating curve parameters where available (e.g. at gauging stations);
- Manning's n for river reaches.
- Rainfall runoff data.

2-The available information concerning the water quality parameters were introduced to the model such as temperature, electrical conductivity, inorganic solids, dissolved oxygen, biological oxygen demand, nitrate, ammonia, pathogens and acidity.

3-The meteorological data such as air temperature, dew point temperature, wind

speed, cloud cover, the percentage of shade over the water stream.

4-Introducing the elements that are used for calculating the water quality parameters (Rates) in addition to the factors used for calculating the amount of light penetrates to the water and the exchangeable heat between the water and surrounding air and also between the different water layers themselves.

5-Introducing the diffuse (Non-point) sources that can be understood as the sources of

pollution distributed along the longitudinal drain section.

The information related to the distances that are affected with the previous diffuse sources on the stream reaches and the water discharges for each source in addition to the average water quality parameters for such sources.

○The calibration of QUAL2K model results were compared with the field measurements as shown in figures (4) to (7):

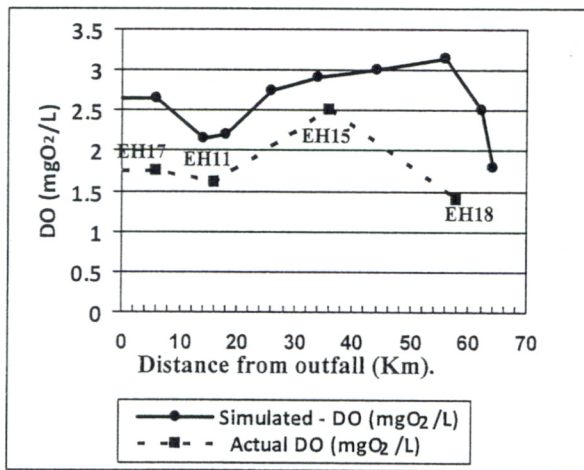


Fig. (4): Dissolved oxygen (mgO₂/L) before the calibration process

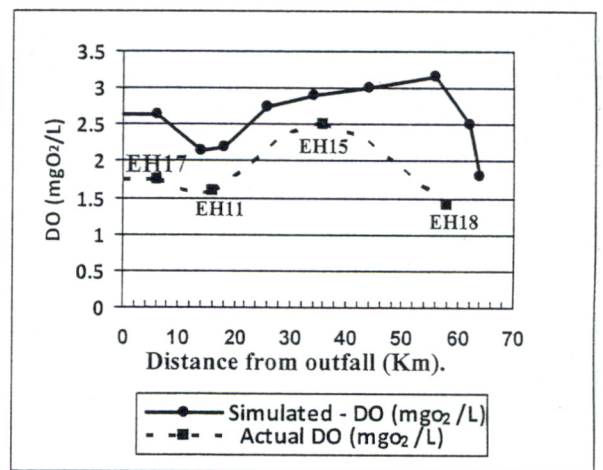


Fig. (5): Simulation of Dissolved oxygen (mgO₂/L) after the calibration process

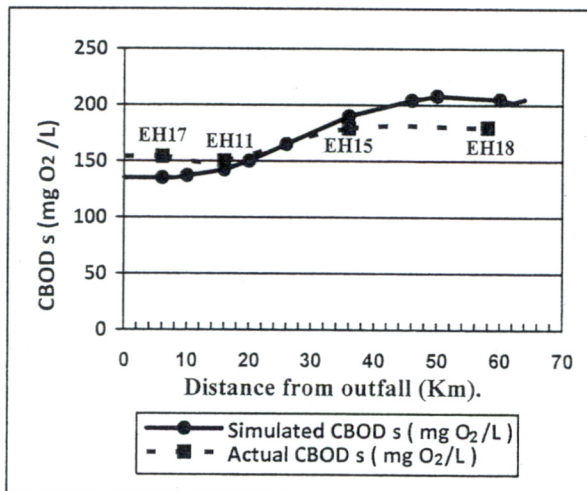


Fig. (6): CBODs (mgO₂/L) before the calibration process

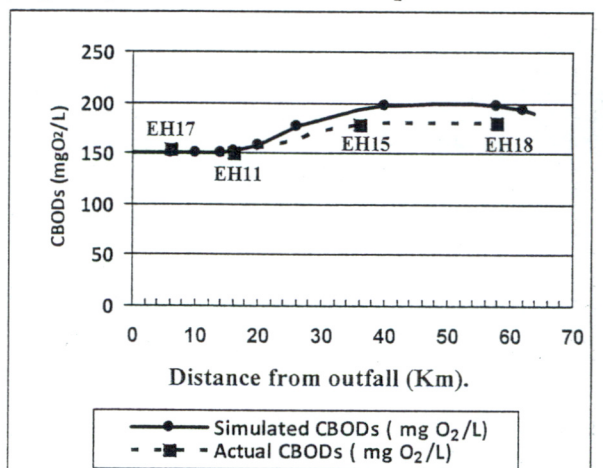


Fig. (7): CBODs (mgO₂/L) after the calibration process

○ Referring to figures above, it is noticed that QUAL2K showed a good agreement with the field measurements. The figures show that, the model represents the field data quite well in the two examined parameters, DO and CBODS, and the model prediction lines are relatively near to the real field measurements.

Finally it can be concluded that, the model represented the field data quite well in most of the examined parameters. This ensures that the model is a powerful tool in simulating the pollutant transport and can be effectively used in water quality management in surface drains.

Modeling Results for Alternative Scenarios (A, B and C):

Scenario A simulated the case when the discharges that are drained to Bahr Hadus drain and its tributaries are reduced up to 10% then the model was used to forecast the expected drainage water quality and quantity for such case. Similarly to Scenario A, *Scenario B* simulated the case when the discharges that are drained to Bahr Hadus drain and its tributaries are reduced up to 25% and the model was again used to forecast the expected drainage water quality and quantity for such case. In this scenario, it is assumed that, the following situations may occur:

- Significant improvement in the irrigation efficiency is achieved as a result of the

efforts done to reduce water losses (for example Irrigation Improvement Projects, switching to modern irrigation technology such as sprinkler or drip irrigation and reducing the rice and sugarcane cultivation areas.

- Significant reduction in the current Egyptian water budget from the Nile water as a result of possible political conflict with the Nile Basin countries. This is due to the highly saline discharges that come from the drain tributaries within this range causing salinity increase.

In *Scenario C*, it is assumed that significant improvements in the drainage water quality in the drain reaches especially, at the *Main and Additional Qassabi* pump stations (EH07 and EH08) are achieved as a result of the efforts done to control salinity related problems such as reducing the amount of chemical fertilizers used in agriculture through public awareness campaigns. This scenario simulated the case when this salinity problem was reduced up to 25% and the model was used to forecast the expected drainage water quality for such case.

- **Dissolved Oxygen:**

Figure (8), shows the Dissolved Oxygen variation along the Hadus main drain. The current records varied in relatively wide range from 1.8 up to 3.1 (mgO₂/L) with an overall average equals to 2.6 (mgO₂/L). All scenarios (A, B and C) may cause significant reductions in the Dissolved Oxygen records.

The average Dissolved Oxygen (mgO_2/L) for the examined scenarios (A, B concentrations may reach 1.7, 1.7 and 1.8 and C), respectively.

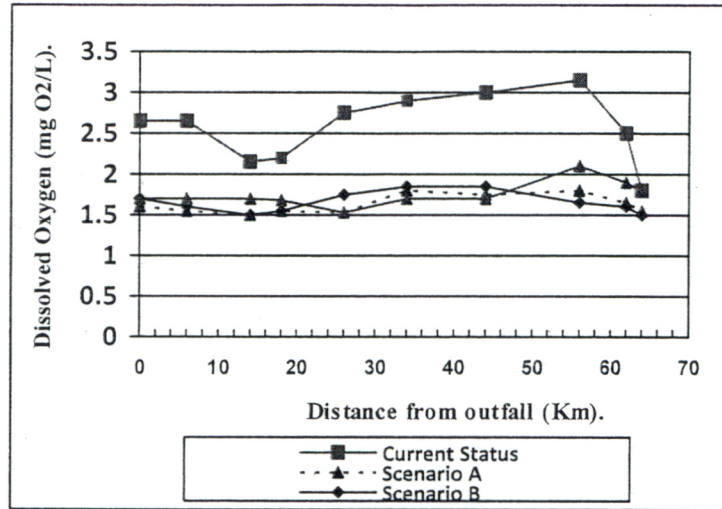


Fig. (8): Current and estimated Dissolved Oxygen (mgO_2 /L)

• *Carbonaceous Biological Oxygen Demand*

Similarly to the Dissolved Oxygen, **figure (9)** shows that, the Carbonaceous Biological Oxygen Demand (Slow) varied from 13.9 up to 23.3 (mgO_2/L) with an overall average equals to 18.5 (mgO_2/L). All scenarios may increase the (B. O. D_s) records, significantly. **Figure (10)** shows the Biological Oxygen Demand (fast) variation along the Hadus main drain. The current records varied in relatively wide range from 18.8 up to 26.8

(mgO_2/L) with an overall average equals to 22.9 (mgO_2/L). All scenarios may increase the (B. O. D_f) records, significantly. The average (B.O.D_f) concentrations may reach 23.9, 26.1 and 24.7 ($\text{mg O}_2/\text{L}$) for the three examined scenarios, respectively. One can also recognize that reducing the salinity at EH07 and EH08 that are in current situation neutralizing the high BOD values upstream the drain, may cause relative increase of BOD downstream, especially, at the monitoring locations EH11 and EH17.

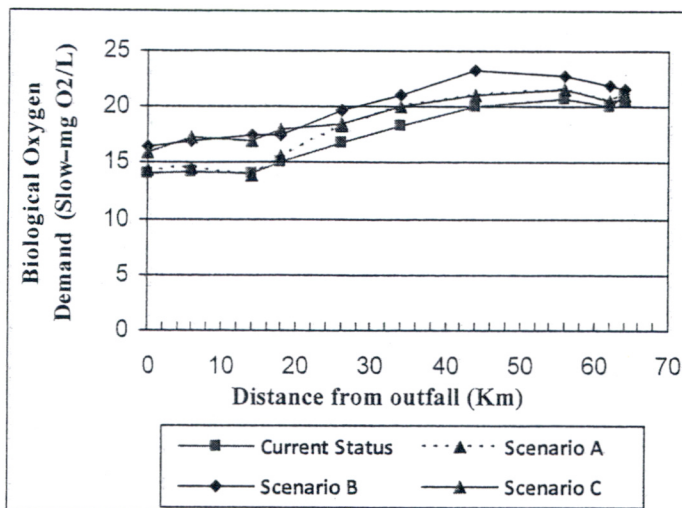


Fig. (9): Current and estimated Biological Oxygen Demand (Slow-mg O₂/L)

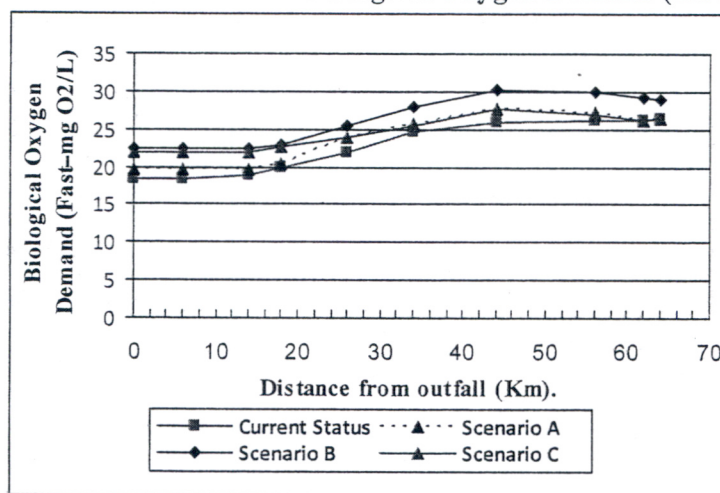


Fig. (10): Current and estimated Biological Oxygen Demand (Fast-mg O₂/L)

8- SUMMARY, CONCLUSIONS AND RECOMMENDATIONS:

8.1 Summary:

In Egypt, Lake Manzala is a good example for the case when the quality of water threatens its potential uses. It is one of the Northern lakes located adjacent to the Mediterranean Sea and receives the final effluent of some major drains such as Hadus, Lower Serw and Bahr El-Baqar drains. The available information

shows that, the feeding drains are dumping significant amounts of pollutants to the lake deteriorating its ecosystem.

Consequently, the information related to water qualities and quantities of these drains play vital role in any environmental assessment of the lake. This information is also essential for deciding whether drain water is suitable for reusing in agricultural purposes. The evaluation and analysis of drains water pollution in addition to reliable estimates of the environmental damages may help in establishing governmental

regulations for environmental protection. However, the introduction and utilization of such estimates are impossible without knowledge of various processes, e.g. formation of a water line in the drains, transport of pollutants, capability of self-cleaning, etc. These processes are recognized as complex, highly interacting and spatially distributed making analyzing, describing, modeling and even simulating them are challenging tasks. However, explicit solutions are possible in certain cases, which are physically very simple but are real enough to be of engineering importance.

For the less simple cases, numerical techniques can be developed which yield solutions of satisfactory accuracy. However, there is a continuous need to improve the simulation and hence, understanding of pollutant transport processes of open drain flow. The present research thus, aims to investigate the possibility of applying numerical simulation for pollutants transport in open drains using the water quality model QUAL2K. The model uses a finite-difference solution, a powerful computational technique for approximate solutions to a variety of "real-world" engineering problems. More specifically, the objectives of this research can be formulated as follows:

- Reviewing the literature for similar studies that focus mainly on pollutant transport in open streams. The modeling

process began with a planning phase in which the questions to be answered using the model were established. Then, the model schematization was determined. Schematization describes how the model will be used to represent the water bodies being studied. The QUAL2K model was applied for Bahr Hadus drain system. Based on the drain characteristics as well as the model structure, each reach was subdivided into uniform computational elements, which form the basis for model's finite difference numerical solution.

The subdivision process was carried out basically to assure that each section must have similar hydraulic characteristics (water depth, cross section widths, side slopes, canal slopes and soil type). The model was executed to forecast the water quality parameters based on the information given in the Input Data Phase. The model was then calibrated using coefficients determined for the calibration period (water year 2010) and for other model coefficients, which were not available for this research work, default values were used. Then, the model for Hadus drain has been verified and evaluated based on a point-to-point comparison of model predictions with observed data. Different scenarios were simulated for the Bahr Hadus drain and the model was asked to forecast selected water quality parameters along different locations on the drain starting

from its initial point at 0.00 Km and ending at its outfall to Lake Manzala 64.00 Km.

8.2 Conclusions:

The following items can be concluded from the study's results:

- The QUAL2K model calibration results showed good agreement with the field measurements. The model represented the field data quite well in most of the examined parameters. This ensures that the model is a powerful tool in simulating the pollutant transport and can be effectively used in water quality management in surface drains.
- The current discharge measurements increased gradually up to the monitoring location EH11 where a sudden increase occurs.
- Reducing the discharges to Hadus drain may cause slight increase in the water temperature. In the meantime, reducing the salinity at EH07 and EH08 may cause a slight decrease for the water temperature.
- Reducing the discharges up to 10% (Scenario A) did not cause significant change in the estimated conductivity. In the meantime, reducing the discharges up to 25% (scenario B) may cause a significant conductivity increase along the drain. Moreover, reducing the salinity of the water that is pumped from Main and Additional Qassabi pump stations (EH07 and EH08) up to 25% (Scenario C) will significantly enhance the water salinity of the drain.

- All scenarios (A, B and C) may cause significant reductions in the Dissolved Oxygen records. They may also cause significant increases in the Biological Oxygen Demand (Fast) records. One can also recognize that reducing the salinity at EH07 and EH08 that are in current situation neutralizing the high BOD values upstream the drain may cause relative increase of BOD downstream especially at the monitoring locations EH11 and EH17.

- Scenario A may cause relatively small changes in the estimated Organic Nitrogen. In the meantime, reducing the discharges up to 25% (scenario B) may cause a significant Organic Nitrogen increase along the drain. Moreover, Scenario C will not significantly change the Organic Nitrogen downstream the drain.

- All scenarios (A, B and C) may cause significant increases in the Ammonia, pH and Total Coliform records along Hadus drain.

- All scenarios (A, B and C) may cause significant decreases in the Nitrates records along Hadus drain.

8.3 Recommendations:

Recommendations for future research work are given as follows:

- The-by far- most demanding challenge which has been faced during this research work was the data limitation. For future research, an effective

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continuously water quality monitoring program, which provides daily or weekly water quality records – including new parameters is essential.

- Although QUAL2K model simulates well the hydrodynamic and water quality characteristics of the drain, a comparative study is recommended using a two or three-dimensional model.
- The investigated water quality drain reaches should be assigned to different water uses according to its water quality states.
- Past long-term records of hydrodynamic and water quality characteristics of the Hadus drain should be examined to investigate the impacts of the land use and climate changes.

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