



Modelling of a drainage system contaminated by wastewater

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AT PRESENT THE East and West Treatment Plants receives raw wastewater for primary treatment and is discharged to Lake Maryout Main Basin, directly at the West Treatment Plant (WTP) for an average (2.6m/s), and via the Kalaa Drain for the East Treatment Plant (ETP) with an average (4.5m/s). Kalaa Drain flows are mixed with additional agricultural drainage (3.5m/s) prior to entering lake system.

Lake Maryout is composed of four basins; Main Basin, Fishery Basin, North-West Basin and South-West Basin which are separated by levees and water ways. This study stress on the Main Basin with an area of 22 km², approx. half of its area is occupied by vegetation, mainly phragmites and floating hyacinths. The Main Basin receives effluent from both treatment plants, but it also receive flows from the Omoum Drain through a large levee breach at Desert Road.

The Omoum Drain and Nubaria Canal, which cross Lake Maryout have depths of 3 to 5m and are bordered by levees with numerous breaches. These breaches allow waters from the Omoum and Nubaria canal to flow through sections of the lake basin, which provide added conveyance to the El-Mex Pump Station. The latter is the sole outflow from the lake Maryout, aside evapo-transpiration and minimal groundwater recharge in the Southwest Basin.

The Omoum Drain is the largest contributor 74 m³/s (on average) to the Lake Maryout system, but its waters have elevated salinity (~4,300 mg/l), being agricultural drainage. The Nubaria Canal is used for navigation and to convey waters from the Nile Rosetta Branch to agricultural areas. Nubaria Canal flows as it enters the Lake Maryout system (~7m³/s) represent mainly unused irrigation water. Additional water enters from the downstream locks ~1m³/s (average). This leakage flow is largely sea water which flows upstream at bottom of the Nubaria canal in a two-layer density current and is gradually entrained in the upper fresh water. This is one of the reasons for the somewhat higher salinity in the Nubaria Canal at Desert Road (~6,700mg/l) compared to that of the Omoum Drain (~4,300 mg/l), which is the origin of the water.

EI Mex pump station discharges to the Mediterranean and controls the water level in Lake Maryout ~(2.4 m) below MSL. Where the Omoum Drain crosses the Nubaria Canal. The areas of Lake Maryout impacted by the wastewater discharges exhibit extremely degraded water quality including low dissolved oxygen levels, zero in extended areas, high turbidity and bacteria concentration.

Wastewater management alternatives

The wastewater management alternatives which are being considered for the city of Alexandria include:

- Upgrade of treatment to secondary, with continued discharge to Lake Maryout.
- Upgrade of treatment to secondary, with lake by-pass by discharging effluents to the Omoum Drain.
- Upgrade of treatment to secondary, with polishing ponds within Lake Maryout to reduce coliform levels.
- Expanded primary treatment capacity with discharge to the Mediterranean through a long (10 km) outfall.

The alternatives, presented in Table 1, vary both in the level of wastewater treatment and in the manner of effluent conveyance.

Material and methods

The model which was selected for this application and simulations is MIKE 21, a model developed by the Danish Hydraulic Institute and continuously improved and tuned through the experience gained from over 300 applications world wide. MIKE 21 is a two-dimensional model with number of modules allowing simulation of hydrodynamics current pattern, water quality, sediment transport and waves. Also, MIKE 21 considers depth-averaged values of the variables such as current speed or concentration. The model use the mathematical formulation and calculates the horizontal distribution of these variables by solving the governing differential equations using finite differences methods. Values of the variables are calculated along a uniform rectangular grid at time intervals, Dt, starting from a user-specified initial condition. The solution is controlled by boundary conditions imposed on the periphery of the simulation domain⁽³⁾.

To assist in the evaluation of the alternatives, a hydrodynamic and water quality model of the Main Basin was developed, calibrated and applied⁽²⁾, by using extensive water quality and physical data collected over a 12-month period in 1996 throughout the system. The products of the model relevant water quality parameters are: salinity, dissolved oxygen, ammonia, nitrate, phosphorus, and coliform.

The boundaries, bathymetry of the lake Main Basin was determined from 1/10,000 orthophotos produced by the Egyptian Survey Authority based on aerial photographs acquired in 1992, as well, as a survey of lake boundaries, water depth in the Main Basin, based on the bathymetric survey conducted in 1996. The water depth is generally on the order of 1m, with somewhat deeper and shallower areas.

Hydrodynamic calibration and dye study

The hydrodynamic model was calibrated using measured water levels at several points to ensure that the model correctly reproduces the flow patterns which exist in the

Lake Maryout Main Basin and will correctly predict changes which would result from implementation of different wastewater management alternatives. Flow patterns are important because they determine the path, residence time and interaction of different flow streams discharged into the lake and ultimately control the water quality. The hydrodynamic calibration was conducted based on measured water surface elevations at several points around the lake, and observed flow patterns, including measurements of velocity at key sections as well as two dye studies.

The lake hydrodynamics are largely controlled by the flows in and out of the lake and those must be specified in the model. The plants flows and concentrations, as affected by the treatment process for each alternative, were derived from mass balances based on 2010 projected flows and plant effluent concentrations (input to the lake).

The dye study took place between May 24-27, 1996. Rhodamine WT dye was discharged in the effluent at the downstream end of the WTP for a period of 12 hours from 6:00 am to 6:00 pm. The discharge concentration was approximately constant and averaged 12.85 ppb. Another study was conducted in Kalaa Drain between June 21-July 3, 1996 just upstream of Desert Road bridge and tracked for several days in the inlet of Lake Maryout. Rhodamine WT is a fluorescent dye specially formulated for use as a water tracer and minimizing its potential for adsorption to solids. It can be detected using a fluorometer whose data were recorded by a computer down to very small concentrations (less than 0.5 ppb). Dye concentrations were measured in Lake Maryout on four surveys respectively 6, 30, 54 and 78 hrs after the start of dye discharge. The module solves the mass transport equation for up to 16 constituents which can be conservative (no decay) or subject to linear first order decay. Dye is an example of a conservative substance, and first order decay can be used to simulate bacteria and carbonaceous BOD. The mass transport equation is solved using an extension of the QUICK-EST scheme⁽⁵⁾. It must be recognized that Lake Maryout is hyper eutrophic, with concentrations of phosphorus on the order of 1 mg/l, when the commonly accepted lower limit of eutrophic lakes is on the order of 0.01 mg/l, i.e. about one hundred times less than observed⁽⁶⁾.

The model simulates both total and fecal coliform using a first order die-off formulation, with a die-off rate calculated as a function of temperature, salinity and light intensity. The Light intensity at any given time in the day is calculated assuming sinusoidal variation of the light intensity over the day, based on a user - specified maximum intensity at noon, and model calculated sunrise and sunset times (based on the latitude and time of year). The depth averaged intensity is calculated based on the specified light attenuation factor or alternatively the Secchi Disk.

Vegetation and levee breaches

The extent of the vegetated areas, primarily phragmites and floating hyacinths was determined from a survey of vegetation boundaries using differential GPS positioning. A range

of Manning's coefficient of 0.27 to 0.70 was determined in wetlands vegetated with soft stem bulrush (*Scirpus validus*), with a significant dependence on plant density⁽⁷⁾. The water depth has also been shown to be an important factor⁽⁸⁾. The Nubaria Canal and Omoum Drain are bounded by earthen levees which contain numerous breaches varying in width from 5 to 50m or more. For model cells containing sections of levees with breaches smaller than 50m, their effect was simulated by increasing the bed friction coefficient,

Model results and discussion

Model simulations were conducted for winter and summer condition for the seven alternatives. Thereby comprising a total of 14 runs. For these simulations, the parameters were kept at same values as for the calibration. This assumption is an approximation in some respects, since some of the reaction rates may differ under some of the alternatives. For example, the rate of degradation of BOD in secondary treated effluent is slightly slower than that of primary. The rates of photosynthesis and respiration were retained for most alternatives because the concentrations of nutrients in the inflows to the lake would remain on the same order. For the Lake By-Pass and Sea Discharge Alternatives, however, the phosphorus and nitrogen concentrations in the effluents would decrease considerably. The same wind conditions as for the calibration runs were used for the alternatives. Currently, the truck by-pass road was assumed constructed, removing 2.3 km² of water surface at the eastern end of the Main Basin. There is a significant sludge blanket at the bottom of the Main Basin in the vicinity of the Kalaa Drain and West Treatment Plant discharges. If the suspended solids content of these discharge decreases, for example through implementation of secondary treatment, the rate of sedimentation will decrease and, by time, a new regime will establish itself. The main factors controlling the deposits are:

- (1) The deposition rate;
- (2) Bio-degradation; and
- (3) Re-suspension (due to wind-induced turbulence in the water) and flushing.

At present bio-degradation is limited in the vicinity of the discharge by the low dissolved oxygen content in the water. If the effluent quality improves, however, demands on dissolved oxygen will lessen, bio-degradation will increase. Estimation for the assuming that sediment oxygen demand (SOD) created by the top 5 cm of sediments leads to bio-degradation time required of is 5.5 years for significant improvement of the benthic deposits in vicinity of the effluent discharge.

No action -1

The main difference between this alternative and present conditions is an increase in East and West Treatment Plant flows. The increased ETP flow results in an increase of the Kalaa Drain BOD. The results is an increase of the lake areas with low dissolved oxygen and high ammonia. At the El Mex outlet, dissolved oxygen is somewhat reduced, but

more importantly, the ammonia concentration is increased substantially, particularly in the summer.

No action -2

In this Alternative, the Central Zone flows are conveyed to the WTP, (including by-pass) is practically doubled compared to present conditions and its BOD is increased substantially. As expected, the areas in the lake affected by low dissolved oxygen and high ammonia increase above the No Action -1 alternative. Almost half of the Main basin area (11.2km²) has an ammonia level exceeding 6mg/l. Also the quality of the water at El-Mex is further degraded.

Common elements

This alternative includes the treatment of the contribution from the Central Zone at the West Treatment Plant. Water quality in the lake is slightly improved compared to No Action -2, but not by a large amount.

Lake discharge

In this alternative, the East and WTP effluents receive secondary treatment, including re-aeration and disinfection. As a result the area in the lake with very low DO concentration (1.0mg/L) decreases substantially but the area with no less than 4mg/l is only slightly reduced. Ammonia levels are not markedly changed from present conditions because the proposed secondary treatment does not result in significant reduction of effluent ammonia concentrations. Ammonia concentrations actually increase at the El-Mex outlet (1.8mg/L) to the lake compared to present condition (1.2mg/L) because the flows and hence the loading are increased. Considerable improvement in coliform levels are apparent.

Lake by-pass

In this Alternative, the ETP and WTP effluents receive secondary treatment and are discharged to the Omoum Drain. The Omoum Drain flow is much larger than that of both plants, pollutant concentrations are reduced considerably by dilution. As a result, areas of the lake with low DO or high NH₃ concentrations are much reduced. Low dissolved oxygen, however, remains prevalent in the vegetated areas. Because of the reduced travel time through the system, the BOD and ammonia at the El-Mex outlet are slightly larger than for the Lake Discharge Alternative.

Polishing ponds

Those are designed to replace chlorination but they have the added effect of reducing outlet BOD and ammonia. Compared to the Lake Discharge Alternative, the addition of polishing ponds reduces the area with low dissolved oxygen from 3.3 to 2.5 Km², but the ponds themselves remove a considerable area of the lake, so that the remaining area suitable for supporting aquatic life is reduced. The ammonia concentration at El-Mex is reduced from 1.8 to 1.1mg/L.

Sea discharge

Discharge from both treatment plants are removed from the lake, but agricultural drainage is still conveyed through the Kalaa Drain so that the stagnation area which devel-

oped under the By-Pass Alternative does not occur. Almost half of the Main Basin area 12.2km² has a DO level less than 4.0 mg/L as compared to the present condition of 21.7km².

Mitigation alternatives

Mitigation alternatives were considered to potentially compensate for the impacts which would result from some of the Base Alternatives:

Mitigation 1

Is a potential enhancement to the Lake Discharge Alternative. It involves pumping water from the Fisheries Basin into the Kalaa Drain to permit use of that basin as a fish facility and also reduce pollutant concentrations in Kalaa Drain discharge, through pre dilution. The flow lifted out of the Fisheries Basin would be provided by the Omoum Drain. A flow of 400 MLD was assumed added to the Kalaa Drain—a 50% increase. In general, this mitigation did not improve water quality conditions in Main Basin.

Mitigation 2

Is a possible enhancement to the Lake By-Pass Alternative. It involves increasing the amount of Omoum waters entering the Main Basin for the purpose of increasing the residence time of East Treatment Plant waters in the system to reduce ammonia concentrations at El-Mex. A simulation was run with this mitigation for summer condition.

Conclusions

- The model considers oxygen uptake due to organic matter, and sediment decomposition, re-aeration of oxygen from atmosphere. The travel time varies from approx. 10 hours for the No Action, and Common Elements alternatives to 16 hours for the Polishing Ponds, Sea Discharge, and Lake By-Pass alternatives. Given these relatively short travel times, only carbonaceous BOD, based on BOD₅ was considered.
- Coliform concentrations for the Drains and for the treatment plant effluent were developed from environmental database. For the No Action and Common Elements alternatives, inputs for ETP effluent coliform values (2.6x10⁹MPN/100mL) were estimated. For Lake Discharge and Lake By-Pass alternatives, a value of 5,000 MPN/100mL, anticipated for the ETP effluent. For these alternatives, the background levels of coliform in the Kalaa Drain significantly exceed the concentrations discharged from ETP. Similarly, for Sea Discharge and Polishing Ponds alternatives, in the absence of ETP effluent, the Kalaa Drain is characterised by high coliform levels. These Options not comply with Egyptian Law 4/94 otherwise chlorination would be required.
- The DO concentration in the Kalaa (DRO6) range from 1.4-2.3 mg/L, the DO rapidly drops to “zero” after it mixes with ETP effluent. In summer the DO carried by Amlak drain is insufficient to raise the DO in the Kalaa Drain above “zero”, however in winter, the DO momentarily reaches 0.3 mg/L before returning to completely anoxic conditions.

For the lake discharge alternative with the lower BOD load associated with secondary treatment the initial DO starts off at 6.0mg/L and dwindles over the course of 14-15 hours to 0.9 mg/L in winter and 2.3mg/L in summer, but never reaches “zero” within the Kalaa drain . For the Polishing Ponds and Sea Discharge alternatives, in the absence of the co-mingling with ETP effluent flows, initial background levels of DO remain extremely low i.e. 2.3 and 1.5mg/L. In winter the DO concentration slowly diminishes falling to 0.8 mg/L at Desert Road Bridge (DR10). In summer the DO concentration reaches “zero” shortly after the kalaa confluence with the Amlak, allows for re-aeration to boost DO levels to 1.4 mg/L by the time the Kalaa flow reaches (DR10).

- For the lake Bypass alternative, the DO levels diminish slowly from an initial concentration of 6.0 mg/L, but do not reach “zero” for either of seasonal simulations. In winter, it reaches its lowest point(1.4mg/L) just before the Abis Drain, however the DO in Abis Drain boosts the levels slightly such that the Do has diminished to 1.7 mg/L by the time it enters the Main Basin. In summer, DO levels remain somewhat higher only drop to 3.0 mg/l before entering the Main Basin.

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<p>Table 1</p>
