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Hydrological Analysis of Flooding Wastewater Lake in Jeddah, Saudi Arabia

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Abstract. Wastewater Lake, known as Almisk Lake, has been the dumping site of Jeddah's sewage for the last ten years. The lake was created as a stopgap measure to deal with the increasing amounts of wastewater in the growing city. It is located along wadi Bani Malek; the biggest wadi in east Jeddah (302 km^2). The lake covers an area of 2.88km^2 at a site 130 m above the mean sea level. A non-engineered earthen dike was built to prevent the wastewater polluted by toxic industrial wastes from flowing back to the city. About 40,000 m^3 of wastewater are transported to the lake every day and expanding significantly. Water levels are continuously rising. With winter rainfall, dangerous environmental consequences from wadi Bani Malek floods arise. Residents in the east of the Jeddah highway are in fear over the dam collapsing. Fears of Sewage Lake could overflow and flood Jeddah city are growing strongly. The purpose of the present paper is to simulate the floods of wadi Bani Malek at the lake site for various return periods to evaluate the threats on the lake, to develop conceptual model to evaluate the impacts on the subsurface flow to Jeddah city. Hydrological conditions for the study area were sought. The Watershed Modeling System (WMS) and Hydrological Modeling System (HEC-HMS) models were used. Water budget components' for the lake were calculated. Proposed measures to alleviate the threats of the lake have been recommended. Results of the paper will promote ongoing solutions for sewage disposal in the city of Jeddah.

Introduction

People just don't like to talk about or deal with waste water. They just want it out of the way, which means that waste water ends up to receiving resources or to the ground, leading to pollution or high water table. Proper disposal of waste water is therefore very important for the management of water resources. Waste water which is disposed to the ground can be rendered safe if disposal points are at safe distances from other water sources so it doesn't pollute them. In rural communities, with lots of space, low groundwater tables, and small quantity of waste water this is more easily achieved than in crowded urban areas as Jeddah.

Jeddah has more than three million residents. The estimated water use is 200 liters per capita per day. Typically, 80% of potable water used for municipal purposes returns to the environment as wastewater. Since 85% of Jeddah area is not connected to sewerage pipelines, waste water accumulates in underground cesspools and later is transported by truck tankers to the lake for the past 10 years.

Wastewater Lake near Jeddah suffers from various debates about its dangerous effects on Jeddah city. The sewage lake, which is also sarcastically known as "Almisk Lake," was created as a stopgap measure to deal with the increasing amounts of wastewater in the growing city. The lake lies in east of Jeddah within the catchment of wadi Bani Malek at about 130m above mean sea level, Fig. 1. It contains 9.5 million cubic meters of sewage water spread over a 2.88 square kilometer area. About 800 tanker trucks dump 40,000 cubic meters of sewage into the lake every day and the amount is expanding significantly. Some water from these truck tankers was used to irrigate the vegetation in some farmlands. The lake water is infected with toxic industrial wastes. The sewage lake has also caused some wells to become poisoned due to raw sewage leaking into aquifers.

An earth fill dam has been constructed by gradual increasing its height. The upstream core of the dam has been built by non-engineered fill. The water level of Almisk Lake began to reach dangerous levels. As a result, a concrete emergency dam was built four years ago about 10 km downstream the earth dam to hold the water back and to prevent spillover into city. Recently, it was noticed leakage of water beneath the new dam.

The Lake could overflow to Jeddah due to either massive flooding and/or any breach in either dam. With winter rains, probabilities of dangerous environmental consequences from wadi Bani Malek floods arise. Fears that Sewage Lake could overflow and flood Jeddah city are growing strongly. Residents in the east Jeddah highway are afraid of the dam collapsing.

Many studies were performed concerning the lake. Most studies are interested in the safety of the earth dam. ASMA (2006) carried out environmental management plan for the lake. It was concerned of the stability of the earth dam and necessary precautions for safety. Van Gerven and Akkerman (2006) performed technical feasibility studies about closing breaches in earthen flood dam. Royal Haskoning (2008) carried out stability assessment and risk analysis for earth and rock fill dam. Preliminary water balance results indicated lowering of the lake level by 1.3 m. The main lake water level in October 2008 has been reported at 125.4 m (8.8 m). It was found that dam stability is not critical for such condition, despite the safety factor is lower than that would be required by modern standards. Although most studies are interested in water level variation in the lake as a result of sewage inflow, no one considered risks of wadi Bani Malek floods on the dam.

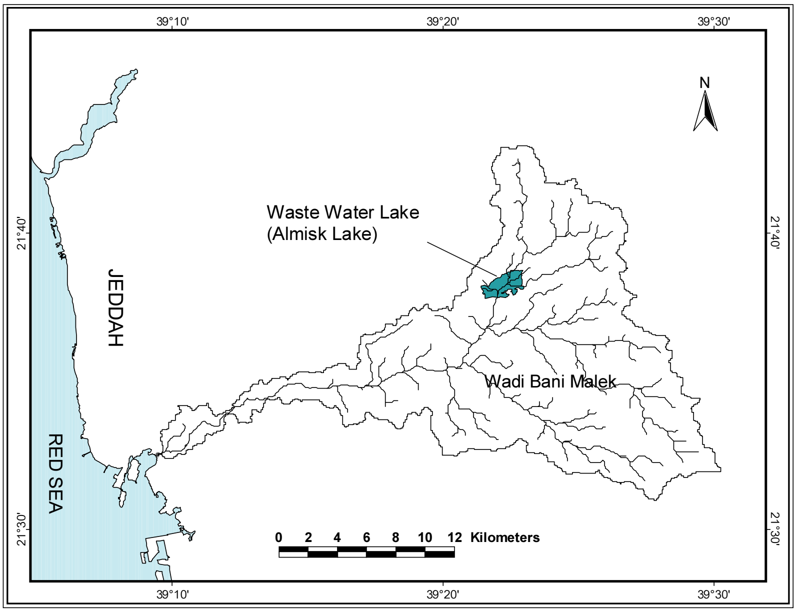

Fig. 1. Location of study area.

The purpose of the present paper is to simulate the floods of wadi Bani Malek at the lake site for various return periods, to develop conceptual model evaluates the threats of Almisk Lake and to introduce proposed measures for flood mitigations on Jeddah city.

Hydrological conditions for the study area were sought. The watershed modeling system WMS 7.1 and HEC-HMS 3.3 models were used. Water budget components' for the lake were calculated. Integrated management for the lake management has been recommended. Results of the paper will promote ongoing solutions for sewage disposal from Jeddah city.

Description of the Study Area

Geology

The general geology of the study area was based on the geology of Makkah Quadrangle mapped by Moore and Al-Rehaili (1989). The rock types in the study area are mainly igneous and metamorphic rocks of Precambrian age (Brown, *et al*., 1963). The rocks in the study area are formed of namely gabbro, granite, granodiorite, schistosed and andesite. Granodiorite is the predominant rock mass in the study area. Major faults are observed in the field. The major fault is striking northeast-southwest. Other minor faults are scattered north-west south, as shown in Fig. 2.

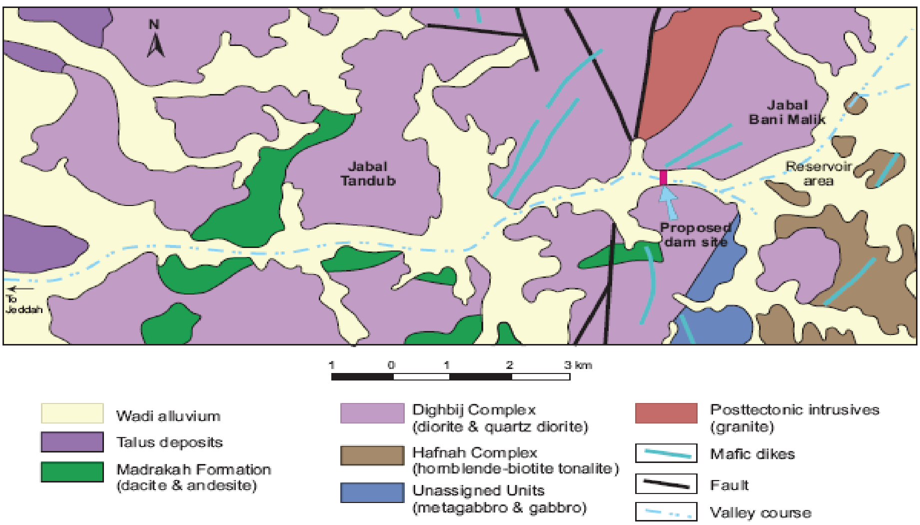

Fig. 2. Geology of the study area (After Moore and Al-Rehaili, 1989).

Joints are extremely important in some rock masses. Even though the rock substance itself may be strong or impermeable, the system of joints may create significant weakness and fluid conductivity. Rock structure and rock mechanics determine the hydraulic conductivity and the flow paths of the rock mass.

Structural distribution of the joint sets in the banned and used dumping sites is described by Qari, *et al*. (2003). Sewage water possibly percolates through the intersection of the joint sets of the major planes towards many directions. The engineering properties are inhomogeneous all over this part of the study area (Qari, *et al*., 2003).

Hydrogeology

The main aquifer that could be identified in the area is the alluvial sand with relatively high permeability. The basement rocks are considered as aquiclude. Investigation of groundwater level shows that some areas east of the highway have very high groundwater level. The main direction of flow is towards the sea. Many wells become poisoned due to raw sewage leaking into the aquifer.

Many basins drain their surface runoff into the Jeddah city with different flow rates depending on the size of the catchment area. Wadi Bani Malek is the largest one and discharges to the north middle Jeddah. Subsurface flow from such basins cannot be ignored. Vulnerability Map of the Groundwater Rise in Jeddah city was prepared by Alquhtani, *et al*. (2005). The map shows that the high groundwater rise in Jeddah city is at the Jeddah middle north, which is possibly related to polluted subsurface flow from wastewater lake.

Waste water discharged into the aquifer controls the quality and pollution of groundwater. According to Alquhtani, *et al*. (2005) the concentration of chlorides ranges between 1,496 and 48,507 ppm, sulfates between 369 and 7,027 ppm, and Total Dissolved Salts (TDS) between 3,300 and 114,368 ppm.

Hydrological Modeling of Wadi Bani Malek

The overall size of wadi Bani Malek, which contains Almisk Lake is 302 km^2. An intense rainfall often occuring in winter results in surface runoff from the wadi. Only sub catchment of the wadi designated as

(Bsub) of an area of 62.55 km^2 drains the flood discharge into the lake, as shown in Fig. 3. Estimates of probable maximum runoff at certain return periods and the corresponding impact on the lake stages is of utmost important. A hydrologic model was generated to estimate the runoff potential at various return periods of the sub-catchment of Wadi Bani Malek. Two models were used, Watershed Modeling System (WMS 7.1) and hydrological modeling systems (HEC-HMS 3.3).

Models Description

Modeling Watershed integrates Geographic Information System (GIS) and hydrological models. Two robust models were used, Watershed Modeling system (WMS 7.1) and Hydrological Modeling System (HEC-HMS 3.3).

The Watershed Modeling System, version WMS 7.1 was developed by the Environmental Modeling Research Laboratory of Brigham Young University (2004). It is a comprehensive graphical modeling environment for all phases of watershed hydrology and hydraulics. WMS 7.1 can perform operations such as automated basin delineation, geometric parameter calculations; GIS overlay computations, cross-section extraction from terrain data, floodplain delineation and mapping, storm drain analysis, runoff, and more. WMS is organized into eight modules. These are Drainage, Map, Hydrologic, River, GIS, 2D Grid and 2D Scatter Point MODULS. Each module is associated with a particular object type and can be purchased separately. Data of primary importance to WMS 7.1 include Digital Elevation Models (DEMs), images, soil type and land use. Other data types such as Triangulated Irregular Networks (TINs), hydrographs, precipitation and stream stage can also be essential to a hydrologic model. Model output depends on which module you run, but may include: watershed and sub-basin delineations, flow paths on the entire terrain model, floodplain delineation and mapping flood extents and flood depth maps, storm drain networks, 2D finite-difference grids. Data of WMS can be directly exported to HEC- HMS 3.3 where th hydrologic computations are performed and results analyzed. Details of the model are found at Environmental Modeling Research Laboratory (2004).

Hydrologic Modeling System (HEC-HMS), version 3.3 was developed by the US Army Corps of Engineers. It is designed to simulate the precipitation–runoff processes of dendritic watershed systems. The program contains three main components, basin model, and meteorological model and control specifications component. The model enables parameter estimation using optimization theory. HEC-HMS allows the modeler to choose between numerous infiltration loss and unit hydrograph parameterizations (HEC, 2000). The program uses data input for lag parameter L to compute peak flow and time to peak from the following equations:

$$Q_p = \frac{2.08A}{T_p} \tag{1}$$

$$T_p = \frac{\Delta t}{2} + L \tag{2}$$

where

Q_p: Unit hydrograph peak flow for 1 cm of effective rainfall in cubic meters per second, A : Catchment area in square kilometers, T_p : Time to peak in hour, T: Duration of effective rainfall in hours, and L: lag time from the center of rainfall excess to the time of peak in hour. Lag time is estimated from the time of concentration with the equation L = 0.6 Tc.

Using the curve number method, the lag is expressed by the following formula (Ponce, 1989):

$$T_L = L^{0.8} \frac{(2540 - 22.68CN)^{0.7}}{14104CN^{0.7}S^{0.5}} \tag{3}$$

where

T_L: catchment lag in hours, L: hydraulic length (length measured along principal watercourse) in meters, CN = runoff curve number and S : average catchment slope in meters per meters.

In practice, catchment lag is empirically related to catchment characteristics. A general expression for catchment lag is the following (Ponce 1989):

$$T_L = C\left(\frac{LL_c}{S^{0.5}}\right)^N \tag{4}$$

where

T_L: time Lag (hr.) , L : catchment length , L_c : length to catchment centroid and s: average slope. C, N are empirical parameters determined according to the catchment surface type. For Transposing Unit

Hydrographs, in case of mountain drainage areas, the estimated values for C, N are 1.2, 0.38 respectively (Linesly, 1975).

Modeling Methodology

The execution of a simulation requires the specification of three sets of data. The first, labeled Basin Model contains parameters and connectivity data for hydrologic elements. Types of elements are: sub-basin, routing reach, junction, reservoir, source, sink and diversion. The second set, labeled Precipitation Model consists of meteorological data and information required to process them. The model represents historical or hypothetical conditions. The third set, labeled Control Specifications specifies time-related information for the simulation. A project can consist of a number of data sets of each type. A "run" is configured with one data set for basin model, precipitation model and control specifications.

To transfer the generated data layers as ASCII file into the HEC-HMS interface, the watershed modeling system model (WMS 7.1) was used. This model was designed and developed to extract topographic, topologic and hydrologic information from digital spatial data of a hydrologic system, and to prepare ASCII file format for the basin and precipitation components of HEC-HMS. The following procedure was adopted to construct a basin model for the study area:

- The first step was preparing a Digital Elevation Model (DEM) (Stefan, 1996). Watershed modeling system (WMS 7.1) used a DEM with 90 m cell size to construct the stream network. Since DEMs include pits or ponds, it should be removed before being used in hydrological modeling (Ashe, 2003). These are cells where water would accumulate when drainage patterns are being extracted. Pits are a sign of errors in the DEM arising from interpolation.

- After filling the DEM sinks, a flow direction map was computed by calculating the steepest slope and encoding into each cell the eight possible flow directions towards the surrounding cells. Flow direction is then used to generate the flow accumulation map. The flow accumulation, generated by addressing each cell of the DEM, counts how many upstream cells contribute to flow through the given cell. Flow direction and accumulation maps are then used to delineate the stream network. The stream network can be divided into segments, which will determine the outlet of the basin. The generated stream network has a dendritic shape.

- The last step is the basin delineation process, which depends on the generated flow direction and accumulation map. Furthermore, it also depends on a user-specified number known as threshold (Djokic, *et al.*, 1997). This threshold determines the minimum number of pixels within each delineated sub-basin. A value of 1.0 was chosen to delineate the Wadi Bani Malek sub basin. Figure 3 shows the generated sub-basin along with the stream network.

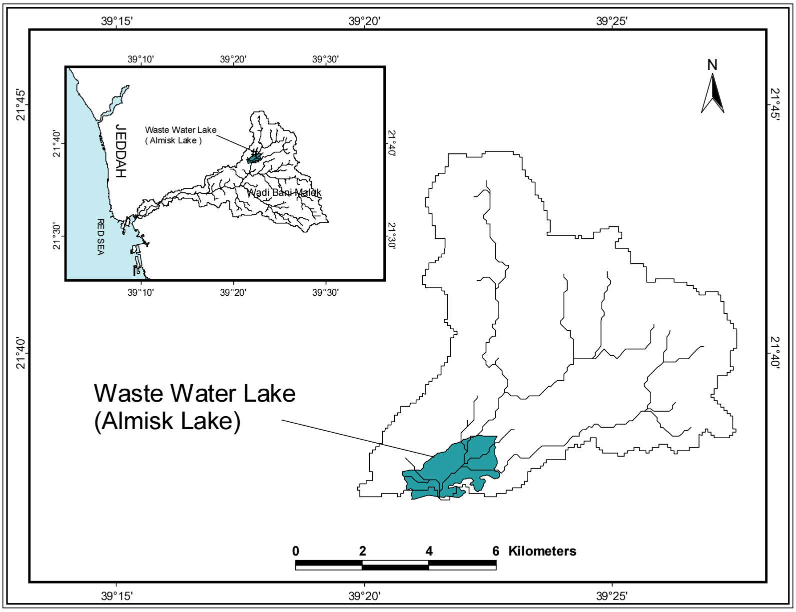

Fig. 3. Sub catchment (Bsub) of Wadi Bani Malek flooding to the lake.

The sub-basin parameters (area, lag-time and losses parameters) were calculated with the WMS7.1 model. Other parameters, needed for estimating the lag-time, such as length and slope of the longest flow path, were also calculated and stored in the sub-basin attribute table. These files, when opened in HEC-HMS, automatically create a topologically correct schematic network of sub-basins and reaches with hydrologic parameters. Table 1 shows some calculated hydrologic parameters of the wadi Bani Malek. The following procedure was adopted to construct the rainfall-runoff model for the wadi:

- A schematic representation of the Wadi Bani Malek network was created by dragging and dropping icons that represent hydrological elements, and connections between them were established.

- The hydrologic parameters for the sub-basin were entered using HEC-HMS sub-basin editor. Required data consist of sub-basin area, loss rate method (initial and constant rate method was used), transform method (SCS Unit Hydrograph method was used), and baseflow method (baseflow was set to zero for Bsub).

Table 1. Main parameters of Bani Malek basin.

Wadi	Area (km^2)	Length (km)	Slope (m/m)	Mean basin elevation (m)
Wadi Bani Malek	300.50	35.10	0.0493	148.73
Bsub	62.55	10.97	0.0632	172.77

- Land use in wadi Bani Malek basin is largely unclassified. Soils in the study area are derived from the local bedrock. The two major soil texture classes are silty clay loam (SiCL) and silty loam (SiL). The initial losses and uniform loss method was used since it is generally accepted for flood hydrology. Nassar, *et al*. (2004) applied Green Ampt infiltration equation in wadi Bani Malek to obtain the average distribution of the losses parameters (Table 2). Such parameters were considered in flood estimation. Considering that the time span of the storm event was short, it was assumed that evaporation was zero.

Table 2. Losses parameters for wadi Bani Malek (Nassar, *et al.* 2004).

Losses type	Min value (mm)	Max value (mm)	Notes
Start loss	28.8	38.4	Due to seepage and infiltration
Constant loss	3.6	4.0	After reaching the steady-state

- A precipitation model is the next component of the HEC-HMS model. Volumes and peak discharges of floods are function in the rainfall characteristics as intensity, duration and frequency. Accordingly, maximum daily rainfall for stations south and north Jeddah have been examined and analyzed. Statistical analysis has been performed to specify maximum rainfall depth for a 50 and 100 year return period. Results are shown in Table 3.

Table 3. Maximum daily rainfall for various return periods.

Station No	Average rainfall	50 year rainfall (mm)	100 y rainfall (mm)
North Jeddah	31.9	102.6	117.4
South Jeddah	25.8	59.8	66.9
Makkah	34.9	85.0	94.5

• Rainfall analysis has revealed that north Jeddah area receives more rainfall depths than the South Jeddah and Makkah. It has been decided to employ rainfall data from North Jeddah area to obtain maximum depth for 50 and 100 year return periods. To overcome the shortcoming of available data, rainfall depth obtained from North Jeddah area has been distributed uniformly over the whole catchment. Finally, the control specification of 0.25 hour time interval was selected.

Results of the Model Application

Table 4 shows a summary of the computed direct runoff volume and peak discharge for the sub-basin of wadi Bani Malek. The peak discharge for the 24-hour design storm with a 50 and 100 years return period was 163 and 177 m^3/s respectively.

Table 4. Summary of the computed direct runoff volume and peak discharge.

Return period	Peak discharge (m^3/s)	Runoff volume (1000 m^3)	Equivalent runoff depth over the lake (m)
50	163	2601	0.90
100	177	2829	0.98

Furthermore, the hydrographs for the sub-basin are shown in Fig. 4. The amount of runoff that would have been summed to the lake storage ranged from 2.6 million m^3 to 2.8 million m^3 respectively. Such volumes correspond to an increase in the lake water level between 0.90 and 0.98 m respectively.

Water Balance of the Lake

Analyses of the hydrogeological and hydrological situations and the recent data gained have made it possible to compile the following estimates of the water balance components. In general terms, the water balance of the lake can be drawn tentatively as follows:

$$P+W+R-E-T-F=\delta s/dt \qquad (5)$$

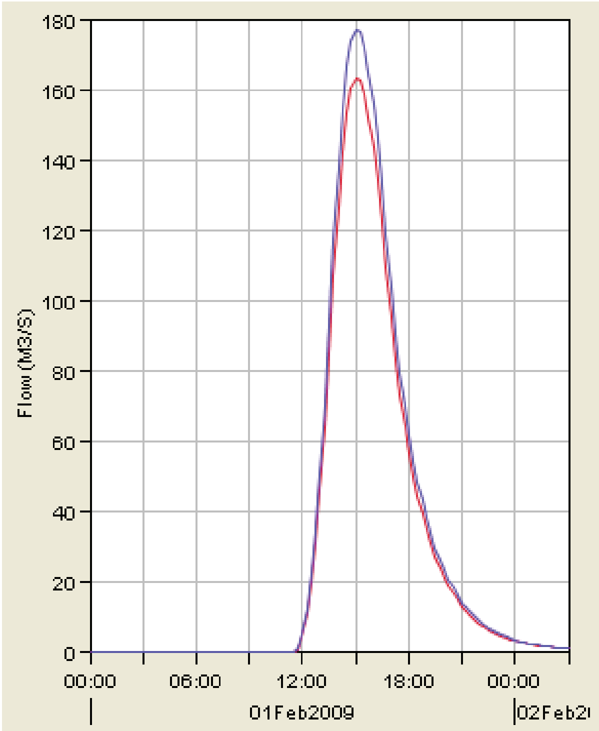

Fig. 4. Runoff hydrographs for 50 and 100 year design storm.

In which, P: Local rainfall through the surface area of the lake in million m^3/year; W: waste water inflow by truck to the lake in million m^3/year; R: Runoff of the sub-catchment of wadi Bani Malek in million m^3/year; E: annual evaporation from the lake in million m^3/year; T: actual pumping rate by Sewage Treatment Plant in m^3/year, F: Subsurface groundwater seepage to Jeddah in million m^3/year; δs: Storage variation in million m^3/year.

Direct Rainfall (P)

Direct rainfall occurs from the rain falling over the lake surface area. The surface area is 2.88 km^2. The active precipitation stations in the surrounding area are located at Jeddah, Bahara and Usfan area. The precipitation data are available for the most recent 30 years period from 1973/1974 to 2002/2003 water years. Analyses of rainfall data in Jeddah and Usfan indicate an average annual fall range between 46.1 and 63.3 mm as shown in Table 5. As a consequence, direct rainfall over the lake area is between 132,538 and 181,988 m^3/year.

Table 5. Average annual rainfall in (mm) around the study area.

Station name	Usfan	Jeddah	Bahra	Average
Years of records	1971-2004	1970-2005	1966-2006	
Annual rainfall	46.1	52	63.3	53.8

Wastewater Discharge (W)

Daily waste water discharge via tanker trucks was estimated at a range of 40000-50000 m^3/day in and before year 2008 by Jeddah Municipality. Since such figure is always difficult to determine directly with better than 50% accuracy, one will therefore admit a range between 14.4 and 18.0 million m^3/year.

Runoff from Wadi Bani Malek (R)

Temporal variability of runoff is very high, typically as arid environment. Annual runoff is not common. The worst case occurs with floods of higher return periods. Therefore, floods of 50 and 100 year return periods have been estimated as shown in the previous section. It has been found that the amount of runoff that would have been summed to the lake storage ranged from 2.6 million m^3 to 2.8 million m^3 respectively. Such volumes correspond to an increase in Lake water level between 0.90 and 0.98 m respectively.

Evaporation (E)

Evaporation is the largest component emergencies from the lake. Evaporation measurement via pan class A around the lake is shown in Fig. 5. Daily evaporation was estimated by Al Sabbagh (2005) at 8.6 mm. The annual evaporation is 3132 mm. Since the pan's data does not reflect the geographic variability in heat transfer through the sides of pan, pan measurements are always higher than the reality. Available data indicate that the annual ratio of lake evaporation to pan evaporation is essentially 0.7 (Viessman, 2003). So a range between 6.3 and 9.0 million m^3/year will be considered.

Sewage Treatment Plant (T)

Sewage Treatment Plant (STP) takes water from the lake by a pumping station. Maximum capacity of STB is now 30000 m^3/day, but may be increased within the near future to 60000m^3/day. Pumping rates based on actual STP operating capacity data (July 2006) was 9000 m^3/day (Royal Haskoning, 2008).

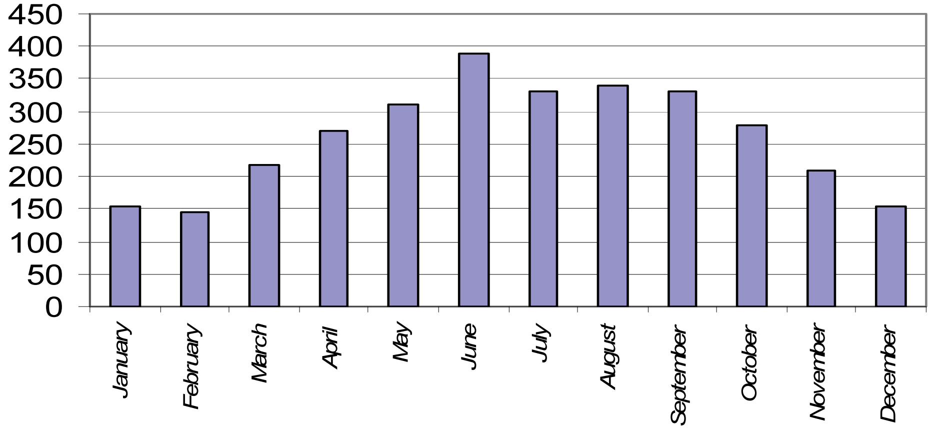

Fig. 5. Evaporation measurements in the lake area in (mm).

Groundwater Seepage (F)

Our understanding of groundwater seepage process is complicated by the considerable spatial heterogeneity observed in flow rates within and among lakes. Schneider, *et al*. (2005) investigated spatial patterns in groundwater seepage around the shoreline of Oneida Lake, a 207 km^2 lake located in central New York, USA with a mean depth of 6.8 m and maximum of 16.8m. Replicated, shielded seepage meters, with associated controls, were used to quantify rates and directions of groundwater flow along a 120 m stretch of shoreline throughout the summers of 1997–1999. These reference meters exhibited an average flow rate of 72 ml/ m^2/h. The highest groundwater flow rates, were averaging 100ml/ m^2/ h. It was found that spatial patterns in groundwater flow were surprisingly unrelated to substrate texture despite wide variability observed around the lake edge, from silty-clays, to sands, gravels and boulders. Broad-scale factors of underlying bedrock geology and regional precipitation patterns appear to be driving the observed spatial patterns in Oneida Lake's groundwater contributions. As a result, groundwater seepage rates were assessed. For seepage rate range between 72 ml/ m^2/h and 100 ml/ m^2/h, groundwater seepage results between 1.81 and 2.52 million m^3/year.

Results

Table 6 gives the summary of various components of water balance in million m^3/year. It is not seriously possible to go little beyond these figures with such short data. At least they show the feasible value range based on clearly established data. Thus, the provisional balance could be generalized as shown in Table 6. The table indicates that the present evaporation (7.7 million m^3) represents 41% of the balance. The annual outflow to Jeddah area is 2.20 million m^3. It is augmented by recharge from wadi Bani Malek. Considerable number of geological structures that dissected the aquifer in the past could be worked as a conduit allowing the transmission of polluted water to vast area either in north or in south direction. It enhances considerably in rising water table problem in north Jeddah. With the continuous growing of Jeddah's population, the underground water situation in Jeddah is horrendous.

The increase of water balance is 3.30 x 10^6 m^3/ year. This is corresponding to 1.1 m increase in the water level of the lake annually. Fortunately, control measures have been enforced to reduce the sewage water dumped into the lake.

Table 6. Annual water balance for wastewater lake before year 2009.

Symbol	Item	Unit	Min	Max	Reliable
	Inflow				
P	Rainfall	m^3	132,538	181,988	157,263
W	Waste water	m^3	14,400,000	18,000,000	16,200,000
R	Flood water	m^3			2,829,000
					19,186,263
	Out flow				
E	Evaporation	m^3	6,303,150	9,004,500	7,653,825
T	Treatment plant	m^3	3,240,000	3,240,000	3,240,000
F	Groundwater seepage	m^3	1,813,320	2,518,500	2,165,910
					13,059,735
δs	With 100 year flood	m^3			6,126,528
		m			2.1
δs	Without 100 year flood	m^3			3,297,528
		m			1.1

In March 2009, an estimate relying on number and capacity of tanker trucks dumping into the lake has been performed. Results indicated that about 25000-30000 cubic meters of sewage have been dumped every day. The outflow towards the Sewage Treatment Plant has been assessed between 20000-30000 m^3/day. In such case, the decrease in water balance is (-8.8×10^6) m^3 / year (Table 7).

This is corresponding to (-3.0) m lowering in water level. Despite an uncertainty of up to 2 to 1 on some components not more, this balance is globally realistic. It constitutes measured advancement for the hydrological knowledge of Wastewater Lake.

Table 7. Annual water balance for wastewater lake in the year 2009.

Symbol	Item	Unit	Min	Max	Reliable
	Inflow				
P	Rainfall	m^3	132,538	181,988	157,263
W	Waste water	m^3	9,000,000	10,800,000	9,900,000
R	flood water	m^3			2,829,000
					12,886,263
	Out flow				
E	Evaporation	m^3	6,303,150	9,004,500	7,653,825
T	Treatment plant	m^3	7,200,000	10,800,000	9,000,000
F	Groundwater seepage	m^3	1,813,320	2,518,500	2,165,910
					18,819,735
δs	with 100 year flood	m^3			-5,933,472
		m			-2.1
δs	without 100 year flood	m^3			-8,762,472
		m			-3.0

Conclusion

Hydrological analysis of the Almisk Lake indicated that sewage influx, sewage outflow to Sewage Treatment Plant and evaporation were the major factors in the water balance. Sewage influx is currently reduced to 27500 m^3/day and account for 53% of the balance. Sewage outflow to the Sewage Treatment Plant has been increased to 25000m^3/ day. Evaporation is very high (7.6 million m^3/y) and accounts for 41 % of the balance. Continuation of the present situation, where the outflow of the lake is higher than the inflow by 8.76 million m^3/y, will lead to substantial lowering of the lake level by 3m per year. Within the near future, when the capacity of Sewage Treatment Plant reaches 60000m^3/ day, there will be an extreme shortage of water input to the lake and the lake may be dried up.

Fears that Almisk Sewage Lake could overflow and flood Jeddah due to floods of wadi Bani Malek are not warranted. Extreme rain storm of 100 year return affect the balance by 15% and could increase the water level in the lake by 1 meter only.

Recommendations

Longer term control is needed by the strategic control of the waste water dumps and the influx to the waste water treatment plant in such a way that the lake levels could be maintained within the framework of the ongoing projects of wetlands. All appropriate measures should be taken to stop subsurface polluted water from the lake to Jeddah. Remedial measures for the consequences of such water on groundwater levels and quality is a must. Integrated management for the lake is the key for reducing the negative consequences on the environment, and achieving economic welfare.

References

Al Sabbagh, G. (2005) *Project to Establish a Dam and a New Lake for Wadi Al Aslae, Jeddah,* The study submitted to the secretariat of Jeddah.

Alquhtani M. B. and **Shehata W. M**. (2006) *Vulnerability map of the groundwater rise in Jeddah, Saudi Arabia.* Available at:

http://www.kiso.co.jp/jgs/pdfs/pdf_files/309_Chap_3-3_Groundwater.pdf.

Ashe, R. (2003) Investigating Runoff Source Area for an Irrigation Drain System Using Arc Hydro Tools, *Proceedings of the Twenty-Third Annual ESRI User Conference, San Diego,* CA.

ASMA (2006) *Jeddah East Lake: Environmental Management Plan for the Lake Enhancement Project, Phase 1A: Dam Stability Assessment*, Final Report, ASMA-DFBENAFTAMORE SND BHD, Sptember, 2006.

Brown, G.f., Jackson, R.O., Bogu, R.G. and **Maclean, W.H.** (1963) *Geology of the Southern Hijaz Quadrangle, Kingdom of Saudi Arabia; Saudi Arabian.* Directorate General of Mineral Resources miscellaneous geological investigation map I-210A, 1:500,000 scale.

Djokic, D., Ye, Z. and **Miller, A**. (1997) Efficient Watershed Delineation Using A review and Spatial Analyst, *Proceedings of the 17th Annual ESRI User Conference, San Diego,* CA.

Environmental Modeling Research Laboratory (2004) *(url).I* Available at: *http://www.ems-i.com/WMS/WMS_Overview/wms_overview.html*

HEC Hydrologic Modeling System (2000) *Technical Reference Manual,* US Army Corps of Engineers Hydrologic Engineering Center, Davis, CA.

Linesly, R.K. (1975) *Hydrology for Engineers,* McGraw-Hill series in water resources and environmental engineering.

Moore, T.A. and **Al-Rehaili, M.H.** (1989) *Geologic Map of the Makkah Quadrangle,* Sheet 21D, Kingdom of Saudi Arabia, Ministry of Petroleum and Mineral Resources, Deputy Ministry For Mineral Resources Publication, Jeddah, S.A.

Nassar, A.A., Khattab A.F., Kotb G. and **Badawy, H.A.** (2004) Hydrological Analysis of Wadi Bani Malek, *J. Eng. Res*., **94**: 133-144.

Ponce V.M. (1989) *Engineering Hydrology, Principle and Practices,* Prentice Hall, New Jersy.

Qari, M.H., Sadagah, B.H., Al-Dakheel, A., Bajabaa, S.A. and **Al –Sari, A.M.** (2003) *Using Remote Sensing Technology to Determine Environmental Impacts and to Select New Sewage Dumping Site in Jeddah,* Research supported by King Abdul Aziz City for Sciences and Technology, Grant no. AR-17-27, revised final Report, 269p.

Royal Haskoning (2008) *Stability Assessment and Risk Analysis and Earth and Rock Fill Dam Sewage Lagoon Jeddah,* Municipality of Jeddah, finial draft report.

Schneider, RL., Negley, T.L. and **Wafer, C.** (2005) Factors influencing groundwater seepage in a large, mesotrophic lake in New York*, Journal of Hydrology,* **310**: 1–16.

Stefan, W.K. (1996) Using DEMs and GIS to define input variables for hydrological and geomorphological analysis. In: Kovar, K. and Nachtnabel, H.P. (eds.), *Application of Geographic Information Systems in Hydrology and Water Resource Management*, International Association of Hydrological Sciences, Series of Proceedings and Reports, 235, 183-190

Van Gerven, K. and **Akkerman, G.J.** (2008) *Closing Breaches in Earthen Flood Defense.* Technical Feasibility of Emergency Closure Concept, ICSE Toronto, 2008.

Viessman, W. and **Lewis, G.L.** (2003) *Introduction to Hydrology*, Fifth edition, Prentice Hall, USA.

التحليل الهيدرولوجي لفيضان بحيرة الصرف الصحي في جدة بالمملكة العربية السعودية

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المستخلص. تلقى مياه الصرف الصحي لمدينة جدة في بحيرة مياه الصرف، المعروفة باسم بحيرة المسك منذ عشر سنوات. وقد تم إنشاء البحيرة كتدبير مؤقت للتعامل مع الكميات المتزايدة من المياه العادمة في المدينة المتنامية. وتقع البحيرة في حوض وادي بني مالك؛ أكبر الوديان فى شرق جدة (٣٠٢ كم^{٢})، على ارتفاع ١٣٠م فوق مستوى سطح البحر، وتبلغ مساحتها ٢,٨٨ كم^{٢}. ويوجد حاجز ترابي لمنع تدفق المياه العادمة الملوثة بالنفايات الصناعية السامة إلى المدينة، وسد ركامي على بعد ١٠كم من الحاجز. وتبلغ حجم المياه المنقولة إلى البحيرة كل يوم نحو ٤٠٠٠٠ م^{٣} تعمل على رفع مستوى المياه في البحيرة بصورة مستمرة. ومع هطول الأمطار في فصل الشتاء، وخطورة فيضانات وادي بني مالك، يخشى الكثير من سكان المدينة، وخاصة سكان الجزء الشرقي من طريق جدة السريع، من فيضان بحيرة الصرف، وانهيار السد الترابي. ويهدف هذا البحث إلى محاكاة فيضانات وادي بني مالك عند موقع البحيرة، وتقدير السيول المتوقعة عند فترات عودة مختلفة، ووضع نموذج هيدرولوجي للبحيرة لتقييم التهديدات المتوقعة عند تدفق فيضان وادي بني مالك إلى البحيرة، وتقدير تدفق المياه الجوفية الملوثة إلي

مدينة جدة. وقد تم دراسة الظروف الهيدرولوجية لمنطقة الدراسة، ونمذجة سيول وادي بني مالك باستخدام النموذج WMS7.1، ونموذج HEC– HMS3.3، وعمل ميزان مائي للبحيرة. كما تم اقتراح التدابير اللازمة للتخفيف من حدة تأثيرات البحيرة على مدينة جدة. وسوف تعزز نتائج هذا البحث الجهود الحالية في حل مشكلة البحيرة.