Simulation for flood routing and tidal propagation in coastal drains

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Excess agricultural drainage water in Egypt is mainly disposed into the sea through a complex network of drains. Most of main drains are discharging water into natural lakes, which are extended along the northern coast and connected to the sea through small bays. Recently, the area around Edko Drain in the West Delta region faced problems of frequent flooding by storm water during rainy seasons. Such problems cause water logging in agricultural lands, reduction of agricultural production and cutting of urban roads, which in turn causes harmful effects on transportation, industries and economical activities. This paper presents a simulation of unsteady flow model representing the Edko Drain. The drain discharges its water by gravity into a natural salt lake (Edko Lake), which is connected with the Mediterranean Sea through a bay called the Maadia Bay. The cause of flooding in the downstream reach of the drain was unrevealed and under extensive investigation. The analysis of the problem is presented in this paper through numerical simulation for flood routing in a drainage network, where the surface water level is affected by the released drainage flow, the lake water level, and the tide in the Mediterranean Sea. From the model, it is concluded that the influence of tidal flow is restricted in the lake area and not extended to the drain reaches. As for flood mitigation, lowering of drain water levels is suggested through dredging the cumulative sedimentation and local mounds in the drain cross section. The drain cross sections should be redesigned to prevent sedimentation process in the bottom of drain. The study reveals the importance of the lake since it works as a buffering zone for sudden excess discharges from the sea or the drain itself.

تعانى مؤخرا المناطق المجاورة لمصرف إدكو بمنطقة غرب الدلتا من مشاكل الفيضانات المتكرره وذلك أثناء موسم الأمطار. هذه المشاكل تسبب غمر للأراضى الزراعية المجاورة وقطع طرق المواصلات فى مدينة إدكو، وهذا يؤثر على قطاع النقل والصناعة ومختلف الأنشطة التجارية بالمنطقة. هذا البحث يقدم محاكاة رياضية لنموذج الجريان الغير مستقر الذى يمثل حالة الجريان فى مصرف إدكو أثناء فيضان مياه المصرف. وقد تم تمثيل المصرف حيث يصب مياهه فى بحيرة طبعية تسمى بحيرة ادكو تتصل بالبحر المتوسط من خلال خليج المعدية. وتم فى هذا البحث تمثيل الفيضان فى شبكة المصارف والتى يؤثر على مناسيب المياه فيها كل من كمية مياه الصرف الزراعى ومنسوب المياه فى بحيرة إدكو وحركة المد والجذر فى البحر المتوسط. ومن خلال البحث، تم التيقن بأن تأثير حركة المد ينتهى فى البحيرة ولا تصل الى المصرف. كما تبين من دراسات المقارنة أن سبب ارتفاع منسوب المياه عن الجسور فى بعض الأحيان نتيجة زيادة كمية الرواسب فى قاع المصرف وارتفاع منسوب عن المنسوب التصميمى مما يؤثر على قدرة المصرف لنقل كميات المياة الزائدة. ولوضع الحلول لهذه المشكلة تبين أنه يجب تطهير قطاع المصرف حتى الوصل الى المناسيب والقطاعات التصميمية، مع زيادة الشرعة فيه لمنع حدوث الترسيب. كما أوضحت الدراسة أهمية وجود البحيرة حيث أنها تعمل كمنطقة حماية للمصرف لإمتصاص أى تصرفات زائدة ومفاجئة سواء كانت من البحر أو من مياه الصرف الزاراعى.

Keywords: Open channel flow, Coastal drains, Edko drain, Flood routing, Numerical simulation, Drainage water management

1. Introduction

Most of excess drainage water in the Nile Delta region is disposed into the northern natural lakes, which in turn surge into the Mediterranean Sea. Open channel networks provided with drainage pump stations represent the drainage conveyance system. Networks are designed to carry the optimum discharge of agricultural drainage water. The Edko Drain is one of the largest drains in the north west of the Nile Delta. The Edko drainage system consists of a main drain fed by seven pump stations, and a natural salt lake called Edko Lake. The lake is connected with the sea through the Maadia Bay, as shown in fig. 1. The Edko Lake has a great importance not only for drainage purpose but also for fishery wealth. One of the drain problems is that fishermen are illegally used to cut the drain embankments to allow the drainage water to feed their fish farms. Such openings cause a reduction of flow velocity in the drain, and consequently a sedimentation process takes place. Accumulative sedimentation in the drain coarse, the lake and the bay are recorded through a regular survey of depth measurements. The maximum sedimentation depth reaches to about 2.25 m in the Magror (the last reach of the drain which located inside the lake with two side embankments for 8 kilometers [1]).

Recently, frequent flood occurs in the lower reach of the drain every winter season (rainy season in Egypt) at the high intensity of rainfall. In January 2002, the largest flood occurred. The excess water overtopped embankments, and covered roads, agriculture lands and residential areas around the downstream reach of the drain. One of the reasons for high flood frequency in this year is the reduction in some parts of the lake cross section due to accumulation of temporary landfill inside the lake during the construction of a new highway bridge crossing the lake. That reason is not taken into consideration in this study because the flood problems took place even before constructing the bridge, and also the data at such flood time are not available. In present time, the landfill accumulation problem is no more existed after the extensive dredging processes followed the end of the project.

Canal hydraulic models are giving a discrete representation of a complex and continuous flow situation in channel networks to evaluate their performance and to improve the operation and management of such systems at low cost. The potential of any model for reproduction and prediction of real flow events, and the potential quality of its calibration, depends on the amount and quality of topographic and hydraulic data available for watercourse under study. In the last decade, a number of canal hydraulic models have been developed and tested. A survey of literatures shows that mathematical simulation of flow in channel networks, even in a single channel, is mostly been attempted through finite difference schemes [2]. A few models used finite element method [3]. Some of the presented canal hydraulic models are CANALMAN, DUFLOW and MIKE II. All literatures are included in the reference of Kumar et al. [4]. Some models consider the entire network with full details of branches, such as [5]. Other models use simpler analysis that considers the main canal system with the branches treated as bulk lateral outflows [6]. The Node-Branch model developed by [7] can be applied for a large range of applications, such as flood waves in rivers, operation of irrigation and drainage systems. The Node-Branch model implicitly solves an integrated form of the Saint-Venant equations of continuity and momentum. Kantoush et al. [8] have successfully used the model to numerically analyze the flow in the tree-type channel network in the delta of the Nile River.

This study simulates a one–dimensional unsteady flow in the Edko Drain by using the Node-Branch model. The model represents the entire network as a main stream with some tributaries providing incremental flows. The model is been enhanced by adding effects of tide and reversed flow to the algorithm. The numerical analysis considered flood routing in a drainage network, where the flow is affected by the released drainage flow, the Edko Lake water level, and tidal flow in the Mediterranean Sea.

Two cases of study were considered; the first case represented the discharging of a maximum flow rates in the originally designed cross sections, while the other represented the discharging of the same flow in the drain with

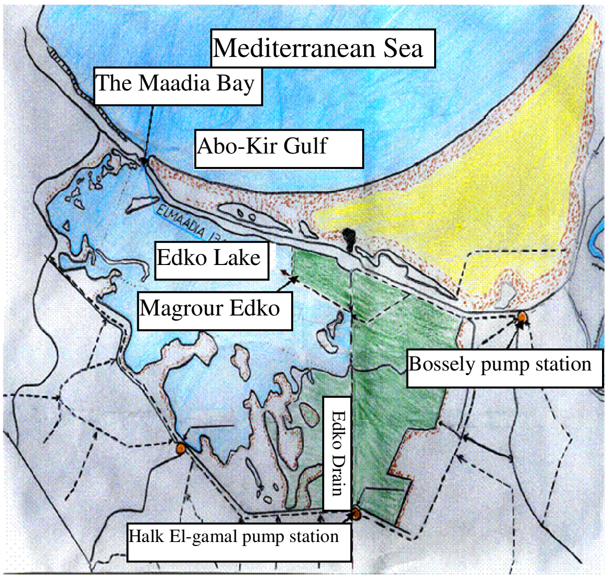

Fig. 1. Map of northern lake (Edko).

the actual measured cross sectional dimensions. Each case was examined for both high and low tidal flow conditions. Documentary maps and field survey data were used for calibrating parameters, verifying the model and estimating water surface profiles for the required flow rates in the drain. The effect of tide was investigated and the cause of flood was discussed. As a result, the reversed discharge and the rise of water level due to tidal effect are not extending into the drain reaches. A solution for flood prevention was suggested and examined by the calibrated model.

2. Site description

The drainage network system consists of main drain (the Edko Drain) fed with seven pump stations distributed along the drain as source points, as shown in fig. 2. Total basin area served by the drain is 120.54 thousand hectare. [1]. The drain is ended by a natural salt lake called Edko Lake connected with the sea through the Maadia Bay. The lake has an average length of 13.0 km and width of 7.0 km. The Maadia Bay has average length of 1.2 km and width of 50.0 m. The drain length is about 48.8 km started from the Shubrakhit pump station to the mouth of the Maadia Bay. The existing drain reaches have the following properties:

1. The reach from km (0.0) to km (1.2) is called the Maadia Bay. The bed width for the bay is 50.0 m, length is 1.2 km. and bed level is about (- 2.00) m.
2. The reach from km (1.2) to km (8.0) is a natural lake with average water depth 0.8 m to 1.2 m, and the bed level is about (- 0.80) m.
3. The reach from km (8.0) to km (14.0) is called the Magror Edko. It was constructed inside the lake as a channel with two side banks. It has an approximately trapezoidal cross section of bed width ≅ 50.0 m, and bed level of about (-3.00).
4. The longest reach from km (14.0) to km (48.8) is the Edko Drain. This drain was constructed about 50 years ago, as a channel having trapezoidal cross sections with bed width varying from 10.0 m to 50.0 m, and side slopes of 2:1. The design bed level of the drain ranges from (-1.80) m to (-4.27)/(5.00) m.

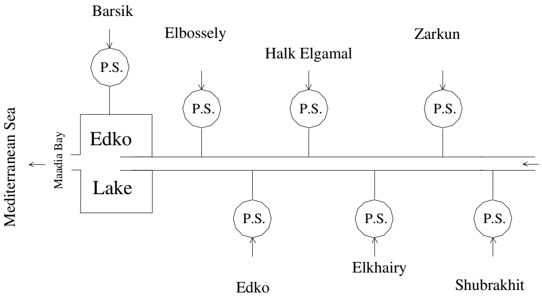

Fig. 2. Schematization of the model components.

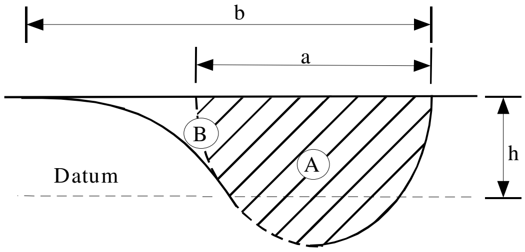

Fig. 3. Definition sketch of channel cross-section.

Recently, the design cross sections have been deformed by several floods and cumulative sediments where the later are resulted from failure of the drain embankments. In the Magror reach, and from km (14.0) to km (17.5), left banks have many vents cut by the fishermen to allow the passage of drainage water to their farms in the lake.

3. Approach and methodology

3.1. Mathematical formulation of the model

The model governing equations are the two Saint-Venant equations for one-dimensional unsteady flow. The mass conservation equation represents continuity equation:

$$\frac{\partial B}{\partial t} + \frac{\partial Q}{\partial x} = 0 , \tag{1}$$

where B is the total wet cross-sectional area available for storage in (m^2), fig. 3, $b=dB/dh$ is the width of storage in (m), h is the water level from a specific datum, x is the distance in (m), t is the time and Q is the flow rate in (m^3/s). For natural watercourses, the wet cross-sectional area, B, represents the cross section, which includes overbank areas. Because of its high resistance to flow, the overbank area may contribute only to storage, conveying virtually no discharge, and it can be represented only in the continuity equation. The momentum equation for unsteady one dimensional flow

$$\frac{\partial Q}{\partial t} + \frac{\partial (Q\,V)}{\partial x} + g\,A\,\frac{\partial h}{\partial x} + J(Q,h) = 0\,, \quad (2)$$

where V is the flow velocity (momentum for unit mass), and A is the flow 'live' cross-sectional area in (m^2), fig. 3. In the last term, J is the rate of force due to friction [9], which is written in some text books in the form of gAS_f, where S_f is the so-called friction slope. Using finite difference scheme, the previous equations are transformed from partial differential form to non-linear algebraic equations by integrating with respect to the independent variables of time (t) and distance (x). The model can include various mathematical boundary conditions to describe the hydraulic behavior of control structures such as gates, pumps, weirs and culverts.

3.2. Model setup and calibration

The schematized channel network, shown in fig. 4, is analyzed through the computational procedures of the Node-branch model. The goals of investigation can be summarized in simulating flood propagation, revealing the cause of flood and presenting mitigation procedures. The input variables in the model are channel characteristics, boundary conditions for downstream water level and the inflow for the source node into the network. In the study, three scenarios were carried out for the channel network, and the procedures can be briefly summarized as follows:

- Design model; unsteady flow with the designed cross-sections and the designed bed levels.
- Actual model; unsteady flow with the actual cross sections and the actual bed levels.
- Proposed synthetic model; characteristics and the boundary conditions for this model are assumed the same as the actual model with cutting the local mound and dredging the excess sedimentation from km (14.0) to km (20.8).
- At the beginning, trials were carried out for calibrating the model parameters for steady flow conditions. Cross sectional properties were obtained from the documentary drawings of the Edko Drain after construction [1]. The Edko Lake was simulated as a rectangular channel with width of 7.0 km and length of 6.8 km. The area cross section of the lake consists of virtual live area and storage area [9]. The flow rate in the drain is presented as the sum of discharges from the source nodes shown in fig. 4. The maximum discharge capacity from the pump stations in the rainy season is shown in table 1. The sum of input discharges to the network is 78.1m^3/sec. Fig. 5 shows the results of calibration.
- The second scenario was used for model verification. It represents the flow in drain for the real time situation. Geometrical and hydraulic properties of the drain reaches are obtained from the field measurements taken by the Deputy of Drainage, Ministry of Water Resources and Irrigation [1]. The tidal effect of the Mediterranean Sea is taken into consideration as a boundary condition at the downstream end. The mean sea water level is (0.00) m and the tidal range is 0.4 m [10]. For numerical stability, difference in time steps was three minutes and the simulation period was three days.
- The third scenario is proposed for flood mitigation by applying the same second model properties with cutting the local mound and dredging the excess sedimentation from km (14.0) to km (20.8) in the second model.

3.3. Tidal flow simulation

The tidal effect was simulated for free tidal movement. The effect of tide and reversed flow are added to the algorithm and the daily tide records are considered. First, the model was utilized to examine the tidal characteristics in the Edko Lake. Fig. 6 shows a comparison between peak discharges at the high and low tides for both actual and designed models, when pump stations are shut down, i.e. the only discharge comes from the sea. It was found in the actual model that the maximum offshore discharge from the sea towards the Edko Lake is 86.8 m^3/sec and the maximum out flow discharge to the sea is 77.3 m^3/sec. Net offshore

Table 1
Flow discharges at source nodes

Pump station	Node number	Maximum discharge (m^3/sec)
Shubrakhit	1	11.50
Zarkun	12	11.00
Elkhairy	20	11.25
Halk Elgamal	33	11.46
Edko	44	10.00
Elbossely	48	11.46
Barssik	58	11.43
Total		78.10

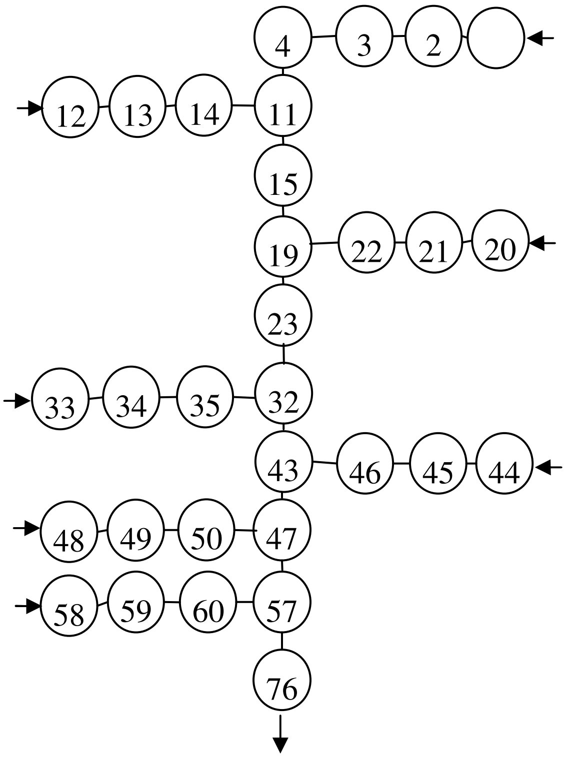

Fig. 4. Schematization of the model nodes and elements.

and onshore discharges for the design model are about four times of the actual model. In addition, the tidal flow influence is gradually diminishing at the end of the lake at km (8.0). It can be concluded that the lake is functioning as a buffering zone for tidal flow, and the reflux by tide does not appear in the drain.

3.4. Dynamic flood routing

For flood prediction, the drain is simulated with the full capacity of pump stations discharges in the rainy season (January). Figs. 7 and 8 demonstrate the variation of water levels and discharges at km (4.5) in the lake for the actual and design models to evaluate the drainage performance in both cases. Fig. 7 illustrates the oscillation of water levels. It can be seen that the mean water level for the actual model is about 13.0 cm higher than that for the design model. Moreover, the oscillation of the actual model is almost dissipated in the lake. Absolute values of peak discharges at the low and high tides for the actual model are significantly reduced comparing with the design model as shown in fig. 8. It is also clear that the tidal characteristic time for the actual model is delayed by 1.0 hour after the design model as shown in figs. 7 and 8. Results indicate that the flow resistance is high in shallow lake and the hydrodynamics of submerged channel in the lake is noticeably sensitive to the tidal volume in the lake.

Fig. 9 shows the difference between high and low water levels (tidal range) for the actual and design models. It is observed that the tidal effect rapidly decreases near the bay and almost disappears for the actual model inside the lake. However, the small waves with height of 3.0 cm are remained in the whole upstream area for the design model. Fig. 10 demonstrates the variations of peak discharges at the low

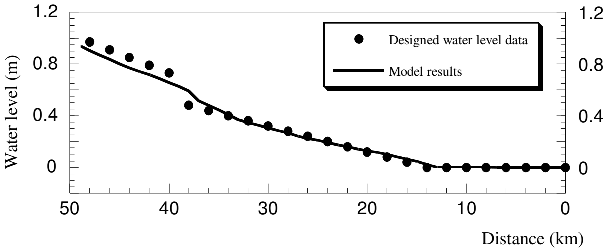

Fig. 5. Comparison between designed and estimated water levels.

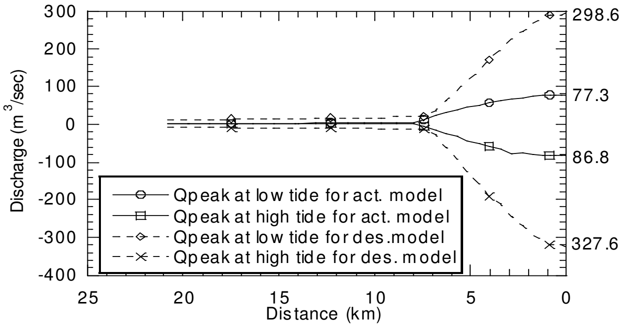

Fig. 6. Peak discharges by tide.

and high tides for the actual and the design models when pump stations are in duty. It is also noticed that no negative tidal flow occurs for the actual model. This is owing to the downward discharges from the pump stations. For the actual model, salt water does not intrude the lake when pump stations are in duty with maximum capacity of 78.1 m^3/sec, as shown in table 1. It can be seen that the tidal effect on the discharge is gradually decreased from the mouth to the km (8.0) in the same manner as the case illustrated in fig. 6.

Fig. 11 illustrates the difference between the peak discharges at the low and high tides for the actual and design models. The decreasing rate for differences of discharges for the actual model is smaller than that for the design model as shown in fig. 11. This indicates that the lake is very important for tidal resistance. It is concluded that the lake is a reservoir for the offshore and onshore discharges.

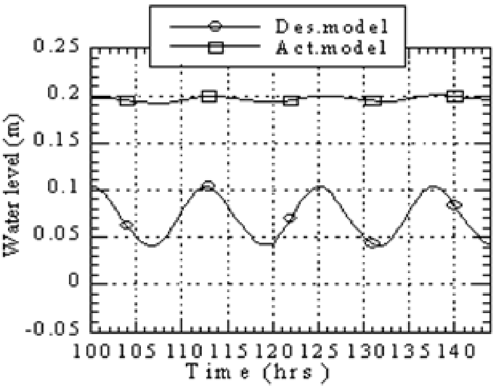

Fig. 7. Tidal water level at km (4.5) in the Edko Lake.

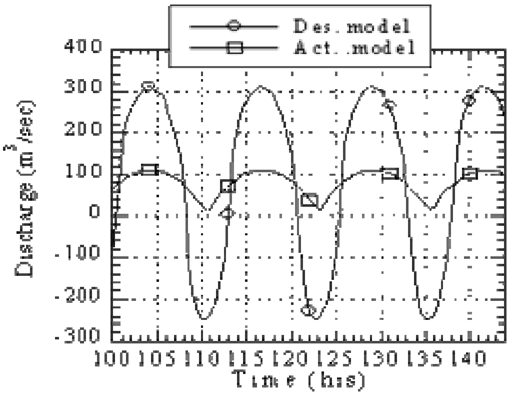

Fig. 8. Comparison between the tidal flows for actual and design models.

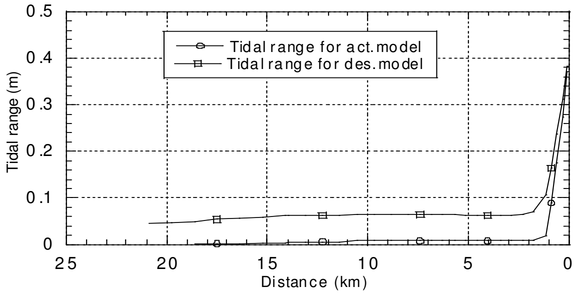

Fig. 9. Tidal range variations for the actual and design models.

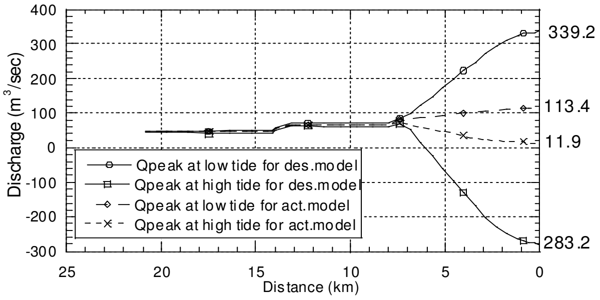

Fig. 10. Peak tidal flow for actual and design models at high and low tides.

Fig. 12 shows the high water levels with road level for the three models. The flooded zone along the Edko Drain can be found from this figure. It can be seen that the high water level for the design model is less than the road level along the whole length of the drain. However, the high water level for the actual model significantly increases near the downstream end of the drain, and it is higher than the road level from km (25.0) to the downstream end. It is considered that the sediment accumulation in the drain and the formed local mound between km (14.0) and km (20.8) causes the rise of water level.

4. Flood mitigation

Generally, flood control stands for the prevention or reduction of flood damages. For this task, two countermeasures may be considered: the peak flow rate must be reduced, or the stream capacity must be increased enough to prevent overtopping of banks. Reduction in peak flow may be accomplished by diverting part of flow to another bypass stream. Expanding drain capacity can be achieved through the removal of excess sediments and

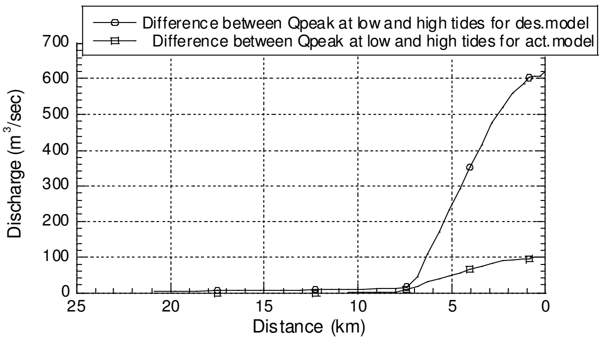

Fig. 11. Discharge differences for low and high tides.

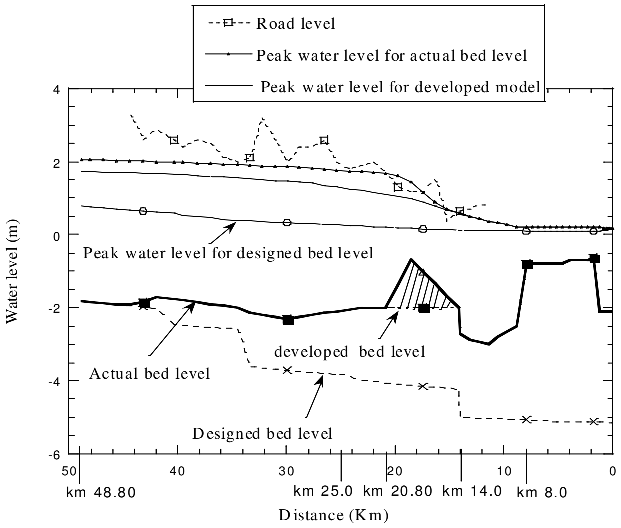

Fig. 12. Comparison of the peak water levels for the three models.

increasing the area of the drain cross section. A cost effective solution for the Edko Drain flood prevention is suggested by cutting the local mound from km (14.0) to km (20.8) to the bed level of (-2.00) m, as illustrated in Fig. 12. As a result, high water level in the flooded area is dropped by 0.6 m, and the flooded zone is reduced from 24.5 km in length to total length of 3.0 km. Raising banks in this part of the drain is the optimal solution to prevent water from overtopping drain banks.

5. Conclusions

The Node-Branch model has been applied for flood routing in a part of the drainage network in the West Delta region in Egypt. Since water flows under gravity from the main drain to the sea through the lake, one of the main contributions of this paper is the understanding of the interaction between the drainage system, the lake and the sea. For this purpose, the model algorithm is improved by adding the tide and reversed flow effects. From the model calibration it is concluded that:

- The actual maximum net offshore and onshore discharges are 86.8 and 77.3 m^3/sec, respectively. Such discharges are approximately one-fourth the discharges for the original designed model.
- The tidal water level is rapidly decreased in the bay owing to the resistance of shallow water depth in the Edko Lake. On the other hand, the tidal discharges passing through the bay are gradually decreased.
- Owing to the formation of a submerged channel in the lake, the peak tidal discharge in the lake for the design model (before occurrence of sedimentation) is extremely larger than that for the actual model. The tidal flow effect is restricted only in the lake for both models. This indicates that the Edko Drain is not affected by tide.
- High water levels during flood time in the Edko Drain don't exceed the road levels for the design model. For the actual model, water levels exceed the road levels in some locations in the downstream reach due to sediments accumulation.
- For flood mitigation, reduction in water levels in the drain results by removing the excess sediments from the drain from km (20.8) to km (14.0) to a bed level of (-2.00) m. Raising banks is urgently needed in some parts to prevent overtopping flow. Drain cross-sections and slopes should be modified to prevent sedimentation. Illegal vents in the drain banks should be closed to keep flow velocity relatively high to prevent sedimentation.

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