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Proposed Scenarios for Management the Inundated Areas at Delta Water, South Sinai, Egypt

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توجد العديد من الأنشطة التجارية والصناعية والسياحية والزراعية على جانبي مخر السيل (حرم مخر السيل) بدلتا وادي وتير كما يوجد ثلاثة حواجز ركامية بالدلتا لحماية هذه الأنشطة من أخطار السيول وتتراوح ارتفاع هذه الحواجز من ٠,٥ متر اتجاه خليج العقبة إلى ٤ متر بأعالي الدلتا، يقع وادي وتير بجنوب سيناء مصر وتبلغ مساحته حوالي ٣٥٢٠ كم٢ ويتعرض سنوياً للسيول الشديدة لكونه من أنشط الأودية هيدرولوجياً بجنوب سيناء، وعليه فإن هذا البحث يهدف إلى تحديد المناطق التي تغمرها السيول بدلتا وادي وتير مع تحديد الأعماق والسرعات المختلفة لمياه السيل عند هذه المناطق وأيضاً وضع سيناريوهات لإدارة هذه المناطق أو كيفية تقليل الأخطار المتوقعة على منشآت البنية الأساسية القائمة بهذه المناطق وذلك باستخدام هيدروجراف مياه السيول المستنتج للزمن التكراري ١٠٠ عام. ولتحقيق أهداف البحث فقد تم استنتاج خرائط الغمر من السيول بدلتا وتير كما تم استنتاج أعماق وسرعات السيل المختلفة، وذلك بعمل محاكاة لمياه السيل باستخدام نموذج هيدروليكي ثنائي الأبعاد HEC – RAS 2D ويعد هيدروجراف مياه السيل المستنتج بمخرج الوادي للزمن التكراري ١٠٠ عام أحد المدخلات الأساسية لهذا النموذج حيث تم استنتاج هذا الهيدروجراف من خلال استخدام النموذج الهيدرولوجي HEC – HMS واعتماداً على المعاملات الهيدرولوجية الأخرى مثل رقم المنحنى وزمن التأخير والتي تم ضبطها أثناء معايرة التصرف المقاس يوم ٢٧ يناير ٢٠١٣، وكذلك تم الأخذ في الاعتبار عند استنتاج الهيدروجراف كمية المياه المتوقع تخزينها للزمن التكراري ١٠٠ عام بالمنشآت الصناعية القائمة في أعالي الوادي. أخيراً وبناءً على خرائط الغمر المستنتجة فقد تم التأكد من وجود منشآت مغمورة من السيول كما تأكد وجود قيم عالية في أعماق وسرعة مياه السيول حول هذه المنشآت بالرغم من وجود الحواجز الركامية القائمة بالدلتا، لذلك فقد تم اقتراح ثلاثة سيناريوهات لتقليل الأخطار على المنشآت المغمورة وهم: السيناريو الأول يحدد الحدود الآمنة من مخر السيل والتي يجب الالتزام بها وعدم التعدي عليها بينما يقدم السيناريو الثاني اقتراح نقل البنية التحتية المتضررة من السيل إلى المناطق الآمنة التي لا توجد بها غمر، أما السيناريو الثالث فيشمل اقتراح زيادة ارتفاع الحواجز الركامية القائمة بالدلتا بمقدار ٢ متر وبطول يتراوح بين ١,٢ كم إلى ٢ كم. وقد تم محاكاة هذا السيناريو بنموذج HEC – RAS 2D وأوضحت النتائج أنه لا يحدث غمر على الإطلاق وقد تم انحصار مياه السيل بين الحواجز القائمة، لذلك يعتبر هذا السيناريو هو الأفضل من حيث تقليل الأضرار والأقل تكلفة والأسهل في التنفيذ.

1- <u>Abstract</u>

Delta wadi Water has a very important commercial, tourist, industrial activities and agricultural activities in floodplains and there are three existing dikes (north, middle and south) to protect these activities against floods. The height of these dikes is 4 meters in the delta upstream and it decreases to 0.5 meters at the downstream or at the Gulf of Aqaba. Wadi Water is located in south Sinai (Egypt) and it has a 3520 km^2 area. This Wadi is one of the most active wadis in south Sinai and it always exposes to flash floods every year. So the objectives of this paper are summarized into defining the inundated areas from floods at delta Water with various depths and velocities and suggest many scenarios for management these areas using the predicted runoff hydrograph for 100 years return period. In order to execute paper objectives, flood inundation map at delta water was produced and flood depths, velocities were determined through a simulation of flood movement which was performed by a hydraulic model HEC – RAS 2D and

predicting the runoff hydrograph for 100 years return period. This hydrograph set as inputs to HEC – RAS model and predicting the hydrograph depends on the adjusted hydrological model parameters which were calibrated using significant flood event of January 2013 on HEC –HMS hydrological model and includes calculating the storage of the existing hydraulic structures at the upstream of Watir catchment. Finally and depending on the flood inundation map, it showed that there are inundated infrastructures in floodplains at Water delta in spite of the existence of dikes. Therefore three scenarios were suggested for management the inundated infrastructures; the first scenario is to determine the safe distances from floodway stream (floodplain boundaries) and the second one is to move the damaged infrastructures to safer areas which have no inundation. While the last scenario is to increase the heights of the existing dikes with 2 m high and defined lengths range from 1.2 to 2 km. The proposed dimensions of the dikes set as input to the hydraulic model and another simulation was created and it is showed that there is no inundation and the flow is bounded between the dikes. So this scenario is suitable and practical than the others.
Keywords: Hydrologic model HEC–HMS, 2D hydrodynamic model HEC – RAS,
Flood inundation maps

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2- Introduction

Flash floods cannot be ignored and it should mitigate the damages from these floods. Producing flood inundation maps and defining the extent of flooding helps decision makers to be able to make choices about how to mitigate the damages and prevent the disasters. The hydraulic model (HEC-RAS) is suitable for generating flood inundation maps. In early 2016 new version of HEC-RAS-v5 with 2D capabilities was developed in order to solve problems which can't solve by 1D model. Wadi Water Watershed is located in south Sinai governorate, Egypt as shown in Figure (1). The existing infrastructures at delta wadi Water are exposed to several damages from extreme floods as shown in figure (2). The downstream of this watershed ends at Nuweiba city and Aqaba gulf. The watershed area is approximately 3520 square kilometers and the elevations are varying from 1590 m at the south west of the watershed to about 0.2 m at the delta of the watershed as shown in figure (3). Also there are different slopes at the surface of Water where steep slopes spread at the upstream of the wadi and gentile slopes spread at the delta where the infrastructures located. Water is fed by many tributaries streams as example: Zalaga from the southwest and Quadeira from the west, etc. It was constructed 18 protection structures on some of these tributaries in order to protect Wadi Water and its infrastructures from floods as shown in figure (4). Delta Watir have a lot of existing infrastructures such as (agricultural fields, industrial or commercials units, hotel resort, dikes and roads …etc.) as shown in figure (4) and most of these infrastructures expose to inundation due to extreme floods

3- Background

According to the importance of using the flood inundation maps for controlling the floods and mitigating the damages, many researchers created these maps for the rivers and wadis using River Analysis System (HEC-RAS 1D with HEC-Geo RAS and HEC-RAS 2D).
Goodell and Warren used (HEC-RAS 1D) to produce water surface profiles to the Cameron Run Watershed then he used HEC-Geo RAS integrated with GIS utility to convert the estimated water surface profiles to flood inundation maps. Finally he mentioned the steps of performing the flood inundation maps in his paper and ensured that these maps are useful for planning purposes and flood mitigation.
Quiroga et al simulated the February 2014 flood event of the Llanos de Moxos using the 2D capabilities of the new HEC-RAS version 5.0 beta at Mamore River. The simulation showed good performance when comparing the simulation results with flood extent registered by satellite images. Also the simulation provided additional information like flood depth, flow velocity and flood duration. Their study showed that the west margin of the Mamore River is the most hazardous one; it has bigger flood extent, it has deeper flood depths and longer flood duration. Finally they ensured from this study that the new HEC-RAS version 5 is an important tool for studying and understanding flood events.
Mahmoud S. Mohamed generated flood inundation maps in wadi El-Arish using a significant flood event for the year 1975. A hydrological model of wadi El-Arish basin, using HEC-HMS was coupled with a 1D-hydraulic model of wadi stream, using HEC-

RAS to generate flood inundation depth and extent of this event. Finally he presented an appropriate estimation of the flood water depth, velocities, flood extent, and risk zones in wadi El-Arish.

4- Hydrological model calibration

Producing flood inundation maps requires simulated flow hydrograph. It was selected HEC – HMS as a hydrological model to simulate this flow hydrograph and this model was calibrated. The steps of calibration are described in the next items.

4.1 Delineation of Wadi Water and sub-basins

Digital elevation model (DEM) and watershed modeling system (WMS) were used to delineate all watershed of Wadi Water and its sub-basins as shown in figure (5). Morphological Parameters were calculated such as (area, length, slope and mean elevation).

4.2 Rainfall data preparation

Five rain gauges Sora, Ras Khazala, Matamer, Themed and Nuweiba which operated by water resources research institute (WRRI) were used in the calibration. These gauges are shown in figure (6) and most of these gauges are located around Water watershed boundary. The data belong these gauges are records of 27 January 2013 storm at each gauge which estimate 13.1, 23.9, 5.7, 0 and 5.5 millimeter for Sora, Ras Khazala, Matamer, Themed and Nuweiba, respectively.
The total value of the storm in each gauge was prepared and set as an input to the ARC GIS software. Then the ARC GIS was used in order to calculate the average rainfall depth over Water sub basins using Inverse Distance Weighted (IDW) method and zonal statistics option.

4.3 Runoff data preparation

In 2009, WRRI constructed a Stage Discharge Recorder station (SDR) to measure the runoff depth at the outlet of Wadi Water. Figure (7) shows the observed runoff depth versus time on 27 January 2013 which was used in the calibration. This observed depth was converted to flow using manning equation (1) and the characteristics of the cross section at the location of SDR station such as area and perimeter were estimated. The value of slope was calculated from survey works (S = 0.009). The Manning roughness coefficient was estimated according to the type of the soil (0.03) and it was classified as a natural stream channels (clean, straight stream) as mentioned in Chow et al, 1988.

$$\frac{Q}{A} = \frac{k}{n} R^{2/3} S^{1/2} \qquad (1)$$

Where:

- V is the cross-sectional average velocity (L/T, ft/s, m/s);
- n is Manning coefficient;
- R is the hydraulic radius (L, ft, m);
- S is the channel bed slope when the water depth is constant (L/L);
- K is a conversion factor between SI and English units. k=1 for SI units, and k=1.49 for English units.

- Q is the flow rate (m^3/s).

4.4 SCS Curve Number and SCS unit hydrograph determination

Estimation of rainfall losses and unit hydrograph represent one of the main inputs to the hydrological model, so the next paragraphs describe the methods for determination these inputs. First and about rainfall losses; the SCS Curve Number method was used for estimation these losses. The application of this method requires using equations (2, 3, 4, 5, and 6).

$$P_e = \frac{(P-0.2\,S)^2}{P+0.8S} \qquad (2)$$

$$I_a = 0.2S \qquad (3)$$

$$S = \frac{25400}{CN} - 254 \qquad (4)$$

$$CN(I) = \frac{4.2CN(II)}{10-0.058CN(II)} \qquad (5)$$

$$CN(III) = \frac{23CN(II)}{10+0.13CN(II)} \qquad (6)$$

Where:

P: Areal Average Precipitation
I_a: Initial abstraction
P_e: Depth of excess rainfall or direct runoff
S: potential maximum retention
CN (I): Curve number for normal condition
CN (II): Curve number for dry condition
CN (III): Curve number for wet condition

This method depends on the classification of the soil type and land use. According to wadi Water, the soil type was defined using (the surface geological map for wadi Watir, WRRI 2010) and it included Alluvial, Sandstone, Limestone and Basement rocks. And the CN values were determined for each type of soil to be 68, 79, 86, 89 and according to the classification of the land use (Chow et al., 1988). Accordingly the average curve number values for Water sub-basins were calculated.

Second and about determination the unit hydrograph; SCS unit hydrograph method was used to convert the rainfall into runoff using HEC-1 model through WMS program. SCS method requires determination the lag time (T_{lag}), which is calculated using the Riverside Mountain Method which recommended in a study for wadi Al-Arbain area in Sinai area (Sonbol, et al., 2005).

4.5 Calibration process

The Hydrological model was built using HEC-HMS software and all the input data were prepared such as; the characteristics of Water sub-basins, rainfall data, runoff data, CN value and Lag time. Then a lot of steps carried out to adjust the simulated hydrograph. First step the whole watershed of Water delineated, other parameters calculated and optimization trial created in order to adjust the values of CN and Lag time. Seven objective functions simulated and two objective functions only selected (percent error in peak and percent error in volume) as it suitable functions produce realistic results. However the results of this step didn't match the observed hydrograph. Second step Watir sub-basins were delineated and the value of the initial abstraction I_a in SCS CN method was adjusted to be 0.12 S instead of 0.2 S (the default value in HEC-HMS) but it still didn't match the observed hydrograph. Finally and the last step is to use the Muskingum-Cunge method for reach routing. Muskingum-Cunge depends on the physical channel characteristics of the stream reach (Iowa Storm water Management Manual, 2008). Therefore the geometry of Water reaches was extracted from ASTER_DEM with resolution 30*30 m. While the manning roughness coefficient was assumed 0.03 for natural channel (Chow et al, 1988). The results of this step are shown in figure (8). It can be noticed from the figure that the simulated hydrograph has three peaks similar to the observed but their values are different. Also, the simulated runoff volume is relatively different from the observed runoff volume.

However, a comparison between simulated and observed values was performed and the relative errors are computed. The relative error in peak flow and runoff volume for a given event i, the error in peak flow (RE_{Qi}) and runoff volume (RE_{Vi}) were defined by the following equations (7) and (8).

$$RE_{Qi} = \frac{Q_{si} - Q_{oi}}{Q_{oi}} \qquad (7)$$

Where:

Q_{si} = simulated peak flow rate.

Q_{oi} = observed peak flow rate.

$$RE_{Vi} = \frac{V_{si} - V_{oi}}{V_{oi}} \qquad (8)$$

Where:

V_{si} = simulated runoff volume.

V_{oi} = observed runoff volume.

Using equation (7), the relative error of the three peaks was calculated. The (RE) of the first and third peaks flow are **0** and for the second peak is **2**. And in order to calculate the relative error for runoff volume equation (8) was used and the error value is approximately **2.5**.

According to the results of the calibration process, the output parameters of this calibration were used to adjust the hydrological model and to estimate the flow hydrograph for different return periods.

5- Reservoir routing and runoff results

Due to existence of protection structures at the upstream of Watir; it should consider the storage of these structures through estimating the predicted flow hydrograph for 100 years return period at Water outlet. So the hydrological model HEC – HMS was set up to use the reservoir routing technique and reservoirs allocated. Also the weighted rainfall depth for 100 years of each sub basin was used using the rain gauges (Ras Al-Naqb – Nuweiba – Saint Catherine which are operated by general meteorological authority GMA). Then it was determined the required data for using this technique are the elevation - storage curve and storage – discharge curve for each reservoir. Finally and from the results of routing; it was estimated the flow hydrograph for 100 years return period at Water outlet as shown in figure (9).

6- Hydraulic model setup and flood inundation maps generation

The flow hydrograph for 100 years return period at Water outlet set as input to the hydraulic model HEC – RAS 2D which was built in order to determine different flood depths and velocities for 100 years return period at delta Wadi Water. Also it defines the inundated areas at the delta by generation the flood inundation maps. The Saint-Venant equation was used to describe the two-dimensional unsteady flow and to develop the model according to the following steps.

- Creating the 2D Computational Mesh;
- Creating boundary conditions;
- Running 2D model;
- Results of 2D model.

6.1 Creating the 2D Computational Mesh

HEC-RAS describes the computational mesh for 2D modeling with the 2D flow area. The 2D flow area defines the boundary for which 2D computations occur. Therefore 2D flow area of delta Water was added with defining the boundaries of this area based on the terrain background. Then it defined the computation point spacing of the mesh spacing DX and spacing DY that set as 10*10 meters.

6.2 Creating boundary conditions

Flow hydrograph for 100 years return period at Water outlet was used as upstream boundary condition and stage hydrograph of the sea water level is used for the downstream boundary condition as shown in figure (10).

6.3 Running 2D model

Running the 2D model depends on adjusting many parameters which considering in the simulation of the model. The first parameter is the computation interval. This interval should be small enough to accurately describe the rise and fall of the hydrograph and the value is selected to be 0.3 second. Then the second parameter is defining different Manning’s coefficient. Manning values for different land cover are 0.05 for floodplains and 0.03 for the main channel according to the classification mentioned in (Chow et al, 1988). The final parameter is to select the equation of simulation. HEC-RAS 2D computational module has the option of either running (the 2D Diffusion Wave equation, or the 2D Saint Venant (Full Momentum) equation). The 2D Saint Venant equation was selected due to accuracy and suitability for flash flood analysis (HEC RAS 5 User's Manual).

6.4 Results of 2D model

Flood inundation map for 100 years return period at delta Watir was generated as shown in figure (11). This figure shows the inundation boundaries at delta wadi Watir and figure (12) illustrates the different flood depths. The flood depths are varying from 0 m to 4.8 m

and these values represent the highest values through the simulation time, because it represents the flood depths corresponding to the peak flow. Also, it is noticed from the figure that the flood depth is getting high as the width of the cross section of the channel becomes small and that occurs only at upper and lower channels but not at the middle channel. The flow overtops the existing dikes where the height of the dikes decrease less than 0.5 m at the downstream as shown in figure (12). Finally figure (13) shows the flood velocities at the delta and it vary from 0 to 5.5 m/s.
According to the resulting maps, some areas are inundated with high depths and high velocities. The land use classification of these areas is agricultural and residential. The risk of the agricultural areas is lower than the residential areas because the flood water may cause damage for the building, infrastructures and loss of lives in residential areas. Therefore it is recommended to manage these inundated areas.

7- Proposed scenarios for management the inundated areas

According to the results of 2D model, this research suggested many scenarios for managing the inundated areas at delta Wadi Watir. These scenarios can be summarized as follows:

First scenario: Determination the safe distances from the floodway stream or floodplain boundaries at delta Water. Generally it is difficult to give constant value to these distances in the wadi, because the cross section of the wadi channel is varying from one place to another. Especially at delta watir it is also difficult to define these distance as a result of presence the protection dikes. These distances should be determined in empty area without any infrastructures. As example, karima Attia et al., 2010 defined in their research the management lines to the river Nile in Egypt and they introduced it as a tool for management the encroachments around the river. The main purpose mentioned in this research is to secure the Nile against encroachments. Also they determined the safe distance from the cross- section of the river and classified into two areas. The areas between channel and terrace lines can be used for temporal activities such as parks and agriculture. While the other area which located outside the terrace lines plus a safety zone of 30 m width; it will be suitable for permanent activities.

Second scenario: Possibility of moving the inundated infrastructures to another safe areas where no inundation. Figure (14) shows the location of the safe areas which are suitable to move inundated infrastructures and these areas are located at the upstream of the delta. It should be mention that this scenario may requires high costs due to establishing new buildings in the safe areas.

Third scenario: Increasing the height of the existing dikes with 2 m and with defined lengths 1.2 km for north dikes and 2 km for south dikes. This scenario may be has low costs than the second scenario. A new hydraulic simulation was created using the proposed dimensions of the dikes and figure (15) shows the results of this simulation as well as the flood inundation map. Castellarin et al, 2010 presented a similar case for a river in Italy. They analyzed a reach of 350 km length of the river Po in Italy as a case study. This river content of floodplains areas protected against floods by a system of minor dikes. Their study aimed to investigate the predicted effects from suggesting different floodplain management strategies (e.g. raising, lowering or removing the minor dike system) on the hydrodynamics of the river Po and flood-risk mitigation. Finally, the optimal dike height was defined according to the simulation of 200 years return period which may cause higher water depths in the downstream reach.

Figure (15) shows that there are no inundated areas. The flow is bounded between the dikes and there is no overtopping. The resulting flood inundation map ensured that this scenario is suitable and practical than the others.

8- Conclusion

Flood inundation map at delta Wadi Water for 100 years return period was created and different depths, velocities were predicted. Also the inundated areas were defined and it are located in the downstream of delta Water where the dikes height is low. This is means that the height of the existing dikes is un sufficient to protect delta Water from floods and it need to modify at the downstream. The research results were produced depending on two main types of analysis hydrological and hydraulic analysis using different models HEC – HMS and HEC – RAS 2D. Finally, the authors proposed different scenarios for management the inundated areas. The first one is to define and implement the safe zones from the floodway stream. The second scenario is to move the damaged infrastructures to safer areas. The last scenario is to increase the heights of the existing dikes 2 m high with a specific length. The simulation of the last scenario was created using HEC – RAS 2D, this scenario is suitable, practical and visible than the others. In addition to previous scenarios, it's recommended to use other flood management methods which based on non-structural measures such as the early warning system or government preparation for evacuation plan.

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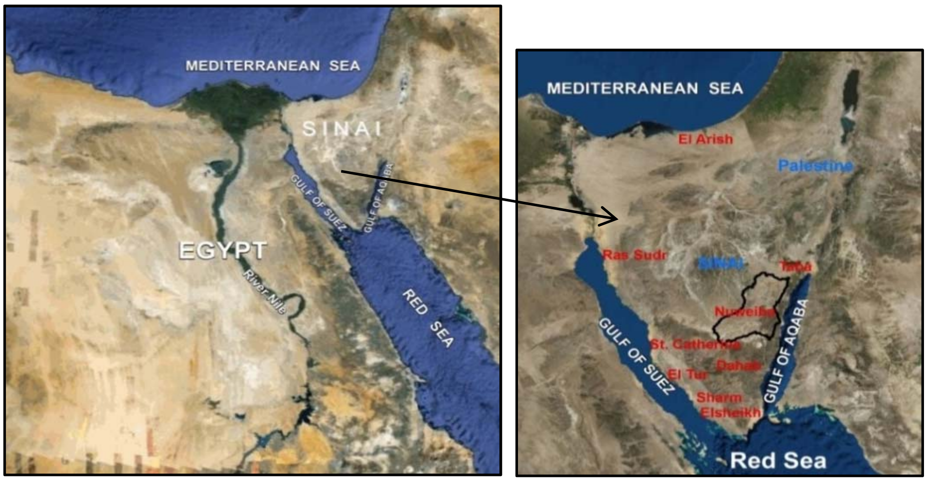


Figure (1) Location map of Water catchment

Movement of concrete blocks Destruction in roads

Figure (2) Destructive effects in existing infrastructures due to floods

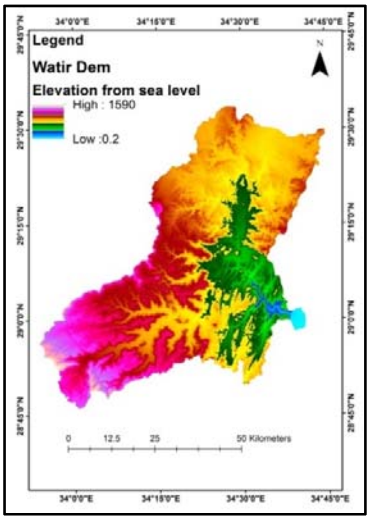


Figure (3) Digital Elevation Model for Water catchment

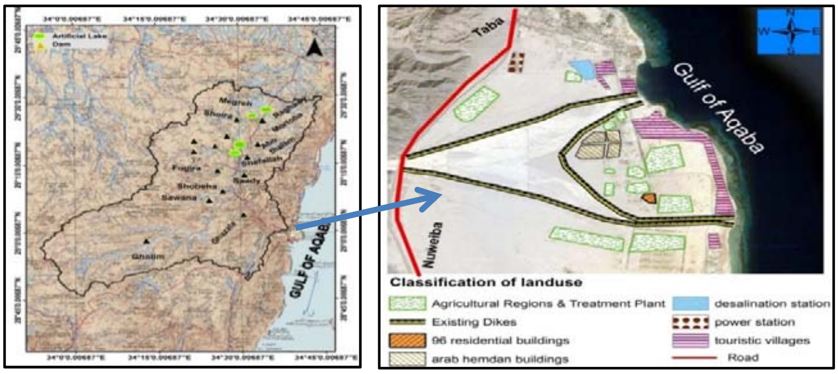


Figure (4) Existing protection structures and infrastructures at the upstream and the delta of wadi Water

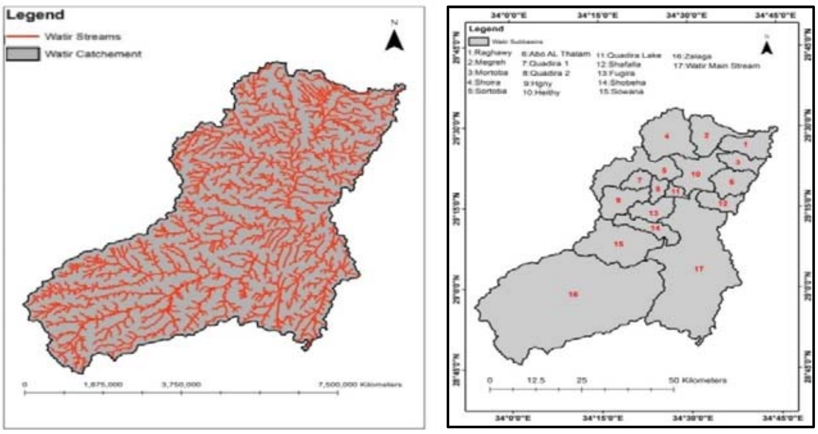


Figure (5) Delineation of Water watershed and its sub-basins

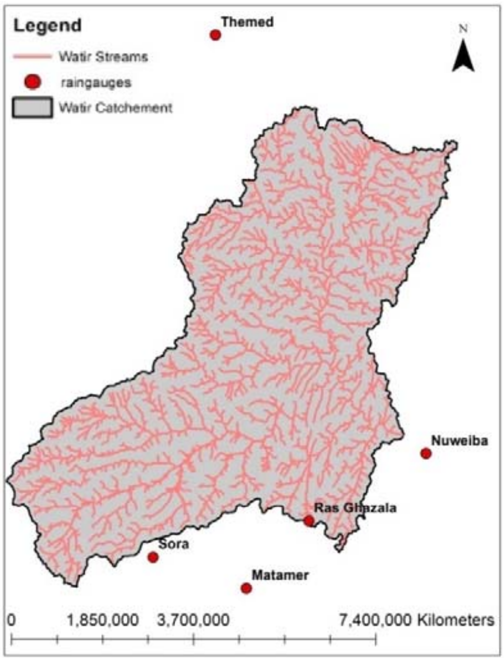


Figure (6) the location of WRRI rain gauges

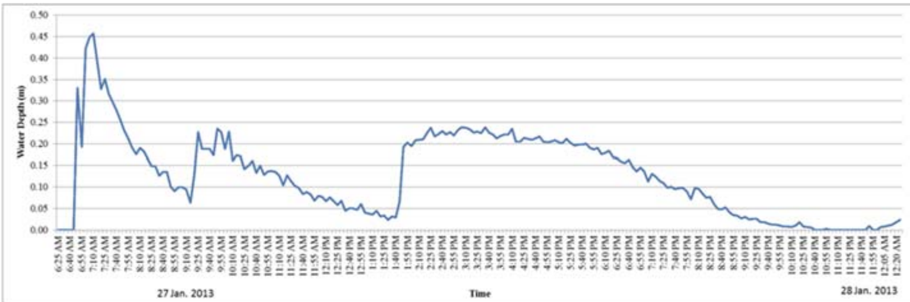
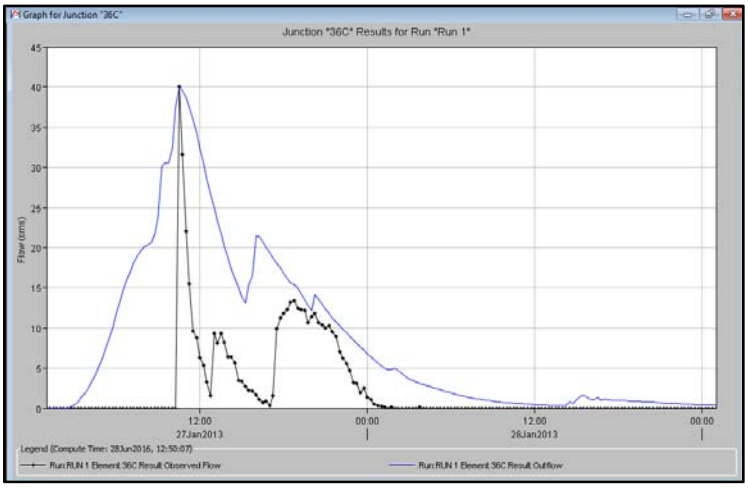


Figure (7) Observed runoff depth chart for 27 Jan 2013 storm



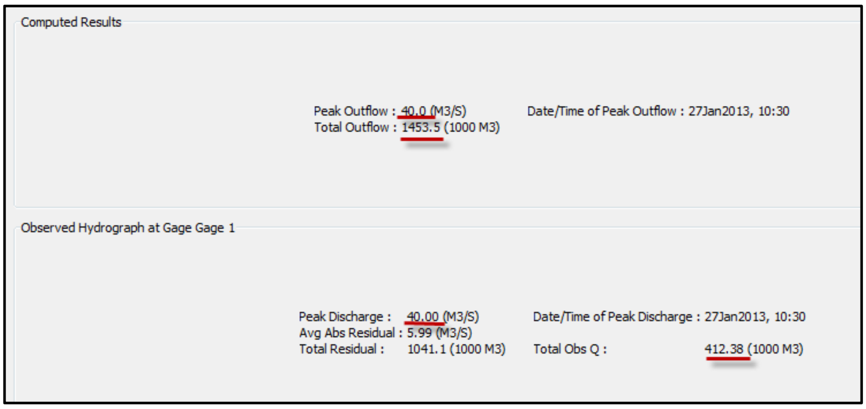


Figure (8) Summary results of the calibration process

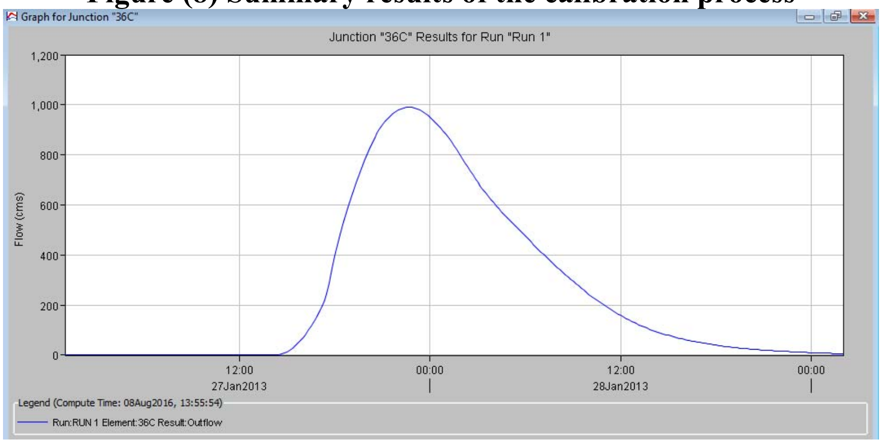


Figure (9) Predicted flow hydrograph for Wadi Water at 100 yr. return period

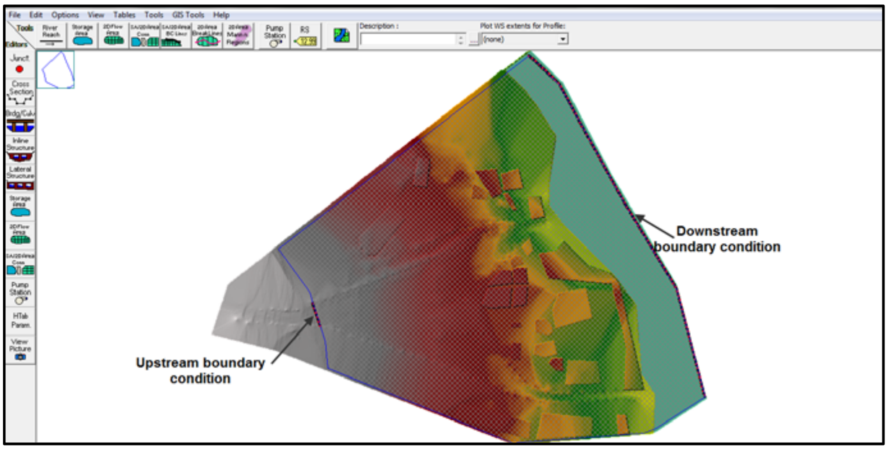


Figure (10) upstream and downstream boundary conditions in 2D model

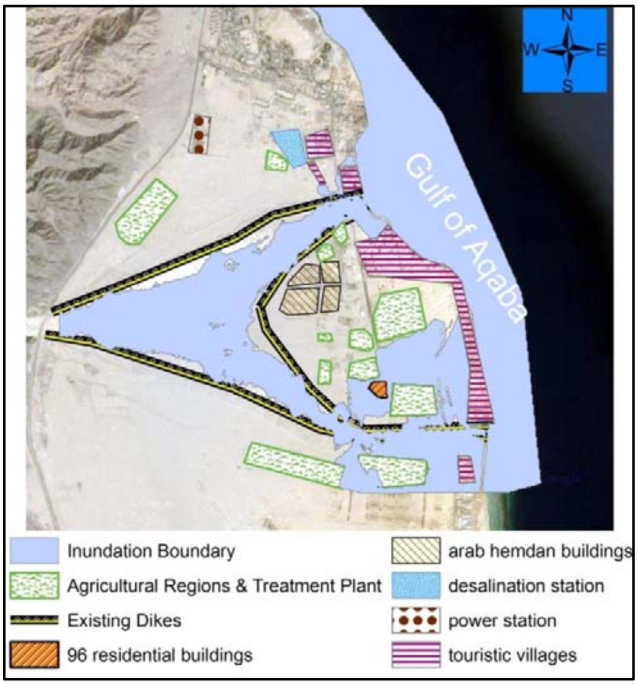


Figure (11) Inundation Boundaries at delta Water

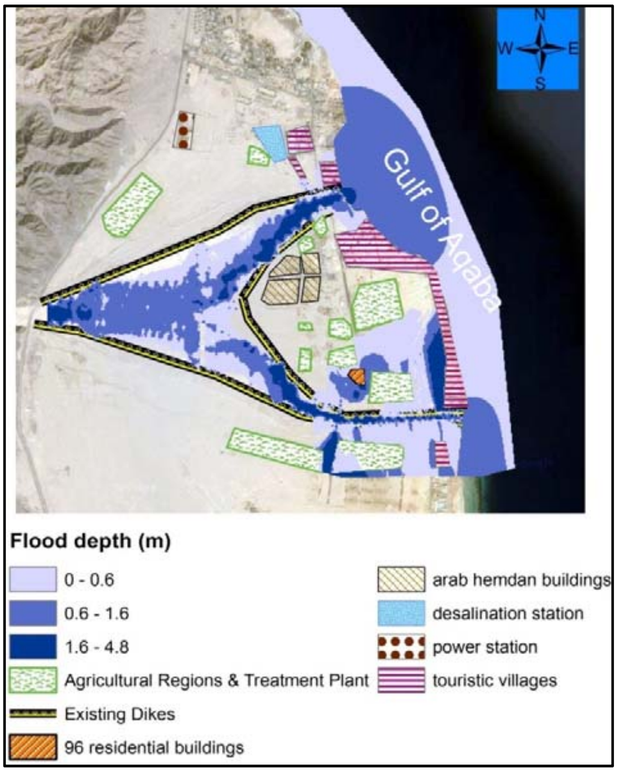


Figure (12) Flood depths for 100 years return period at delta Water

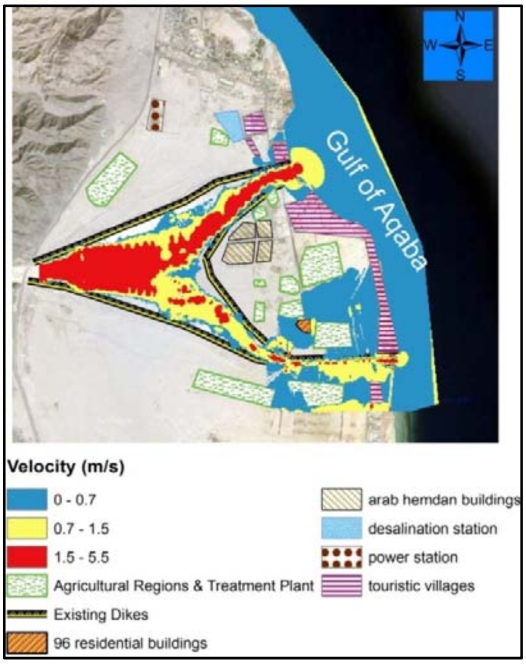


Figure (13) Flood velocities for 100 years return period at delta Water

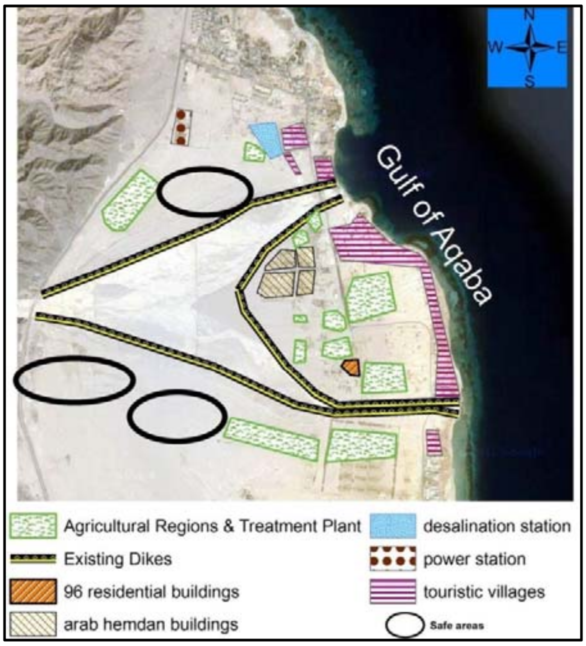


Figure (14) Safe areas at delta wadi water

Figure (15) Flood depths at delta Water after increasing the height of dikes