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The Impact of Niatak Lateral Spillway Performance on Process of Erosion and Sedimentation of Sistan River of Iran

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ABSTRACT: Sistan River Being located on the tail water of Helmand's very extensive basin, it is prone to deposition of fine sediments, particularly in times of flood. The diversion structures on this river are Zahak and Sistan Dams. In this research the HEC-RAS model which has the ability to calculate the hydraulic parameters, is used to study of Niatakk spillway located in the upstream of Zahak dam. In this regard after the calibration model, the Erosion and Sedimentation process of the river during various conditions of utilization of the Zahak and Sistan dams was studied. The results show due to backwater by Zahak dam and giving the opportunity to the settling of suspended sediments, the rate of sedimentation between Niatak spillway and Zahak dam in situation of full utilization of Niatak spillway has become twice greater than situation which the gates are completely open. In situation of full utilization from Niatak spillway, the accumulated sediment in the interval between the Niatak spillway and Zahak dam is about 45% of the whole accumulated sediment and the accumulated sediments weight in this interval is about 20% of the whole accumulated sediment in situation which the gates are completely open.

Keywords: Sistan River, Niatak Spillway, Erosion, Sedimentation, HEC-RAS model

INTRODUCTION

Sistan river's low slope of the bed makes it prone to sedimentation and the negative effects of improper utilization of the Zahak dam has intensified the sedimentation of the upper river and the uniform changes in substrate profiles in bed from Zahak dam to the two branches of the upstream end of the flow reveals that the increase in the bed of the kohak dam is influenced by the utilization of Zahak dam (Hssanpour, 2000). Bed level rises caused by improper operation of upstream dams during the years 1955-1991 is about 5.2 meters. Considering the average geometrical cross section width of 130 meters, the volume of sediment deposited is over 5.5 million cubic meters (Hssanpour, 2008). The Zahak dam has caused above 5 km upstream experience the deposition phenomenon and somewhat has limited the increase in erosion depth at the outer arc curves in this area. Also at the beginning of this range Zahak deflecting dam has led the output stream directly to from severe erosion at the right edge of the Sistan River which is already protected by a Gabion wall. Sistan dam to dam have led to experience the phenomenon of sedimentation. Sistan Dam has led the upstream to experience the phenomenon of sedimentation. This phenomenon is exacerbated in the internal arc curves (Sistan River Flood Control Studies. 2008). Ahmari et al. (2001) analyzed the state of sedimentation in Sistan River using HEC-6 software and concluded that the river was unable to discharge more than 600 cubic meters per second. Farshadi and Bajestan (2010) using HEC-RAS software calculated the input sedimentation into the Gotvand dam reservoir. They did calculations using 24 upstream points of the dam and on the Karun River and did the sediment calculations using Yang sediment transport equation. Haghyabi and ZareDehdasht (2012) evaluated the- HEC-RAS software in predicting erosion and sediment transport. In this research they used the HEC-RAS software (V4) to analyze the riverbed. Analytical results obtained from running the sediment model had good agreement with the actual conditions of river. Then a comparison between the results of the software HEC-RAS and MIKE11 was conducted in which HEC-RAS model prediction was much more accurate than MIKE11. Goodarzi and Mousavi (2000) reviewed erosion and sedimentation in major branches of the Zayanderood River using a computer model HEC-6 and concluded that the overall deposition rate estimated by the program HEC-6 compared with sample values taken, shows a meaningful correlation of 95%. Peyrov et al. (2012) analyzed the rivers sedimentation and found that the inner edge of the river screws is suitable for the material removal because the river when crossing bights bends towards the outer edge of the bight sedimenting in the inner edge instead. They also concluded that the removal of sand causes suspended sediments. HEC-RAS model was used in this study. The Zahak dam operation in the river has caused the outflow of it to expose severe erosion in Sistan River it the right edge directly and the existence of Zahak dam on Sistan River led the 5 km upstream experience sedimentation (Consulting Engineers Tehran Sahab. 1990). Hssanpour (2008) conducted a study to examine the impact of hydraulic structures of Kohak, Zahak and Sistan on the deposition Sistan of riverbed, the results indicated that increased levels of the riverbed was due to the inappropriate utilization of Zahak Dam in 17 km upstream during the years 1954 _1990, which is about 2.5 meter. Regarding geometrical average point width of 130 m (based on 19 upstream cross sections of the Zahak

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dam removed in 1993), the volume of deposited sediment would be over 5.5 million cubic meters. Hssanpour started to analyze the critical sedimentation points and defining optimal dredging intervals using mathematical models and concluded that considering the high volume of the sediments brought by the river and its low slope in the scope under consideration, dredging is very important. In this study, HEC-6 software was used. Curran and Wilcock (2005) reported that choosing special type of sedimentation equation is really effective in the transfer rate of sediments in the rivers. To select the best equation, in addition to draw river bed sediment gradation curve, he applied field observations of the river and its surroundings. Gibson et al. (2006) reported that the ability of sediment transport have been added to the HEC-RAS program. It has the capability of computing the moving floor. The initial version of the sediment model contains all extensive hydraulic calculations capabilities in HEC-RAS. All features of HEC-6 such as transfer, erosion, sedimentation, movement of the substrate, changes in cross section etc. calculations has been added to HEC-RAS. Lyn (1987) presented Non-linear solutions for sedimentation and deposition which had better adaptation with experimental data than linear solutions. Gibson et al. (2010) considering the moving riverbed, started modelling of the Kollwitz River in HEC-RAS. He used the Laursen-Copeland equation in his calculations because it includes grading of very fine sand to large rubbles. They also stated that the possibility of adding a bed particle size in 20 different classes is added to HEC-RAS model (V1.4). Because of the difficulty of direct measurements of sediment deposited in reservoirs and rivers and its high costs and also the lack of precision in of experimental techniques for all dams and rivers mathematical and computer models have been widely used as useful and efficient tools. In this context one of the models is HEC-RAS 4 which is launched by the engineering office of American Army, the last edition of which is able to analyze erosion and quality. Since this model has great potential to analyze hydraulic flow, in this study it is used to investigate the effects of utilization of the Zahak and Sistan deflecting dams on sedimentation and erosion through Sistan River.

MATERIAL AND METHODS

Location of the study area

All the irrigated and irrigable Iranian parts of Helmand River delta are called Dashte Sistan (Sistan Plain) which is located in Sistan and Baluchistan province. The whole plain area is about 8117 square kilometers. The eastern and northern part meets Afghanistan and the southern part approaches Nosratabad city of Sistan and Baluchistan province and the western part is surrounded by Nehbandan in and Lut Desert. Around 150,000 hectares of the field have agricultural potential and could be used in crop production cycle. It is 480 meters above sea level and this plain on both sides of the Sistan River is about 14000 meter length and 473 meter height. The Plain weather is dry with hot summer's ¬ (35 to 45 ° C) and cold winters (zero to 10 ¬ ° C) with an average of 40 to 50 mm rainfall and surface evaporation of 4 meters annually (Consulting Engineers Tehran Sahab, 1990). Helmand River in Afghanistan travels about 1,100 kilometers in Afghan land and in the border of Iran and Afghanistan it branches into Priyan and Sistan. Sistan River is the main source of water in the plain and after traveling about 70 km from the Sistan plain it flows into the Helmand River. This river with the general slope of 0.00002 to 0.00006 from the level of 489 m gets to the 75.474 m level in Hamun of Helmand (Ahmari et al, 2001). Figure 1 shows an overview of the position of Sistan and Sistan River.

Mode of operation of the Zahak diversion dam

In order to minimize damages to agricultural lands in downstream of Zahak dam caused by flood, depending on the flow of the river during floods the size of gate's openings are in Table 1. Maneuver ability of the dam during the flood is in such a way that a huge part of flood is transmitted through Niatak; also a part of flood is removed through city and Taheri channels.

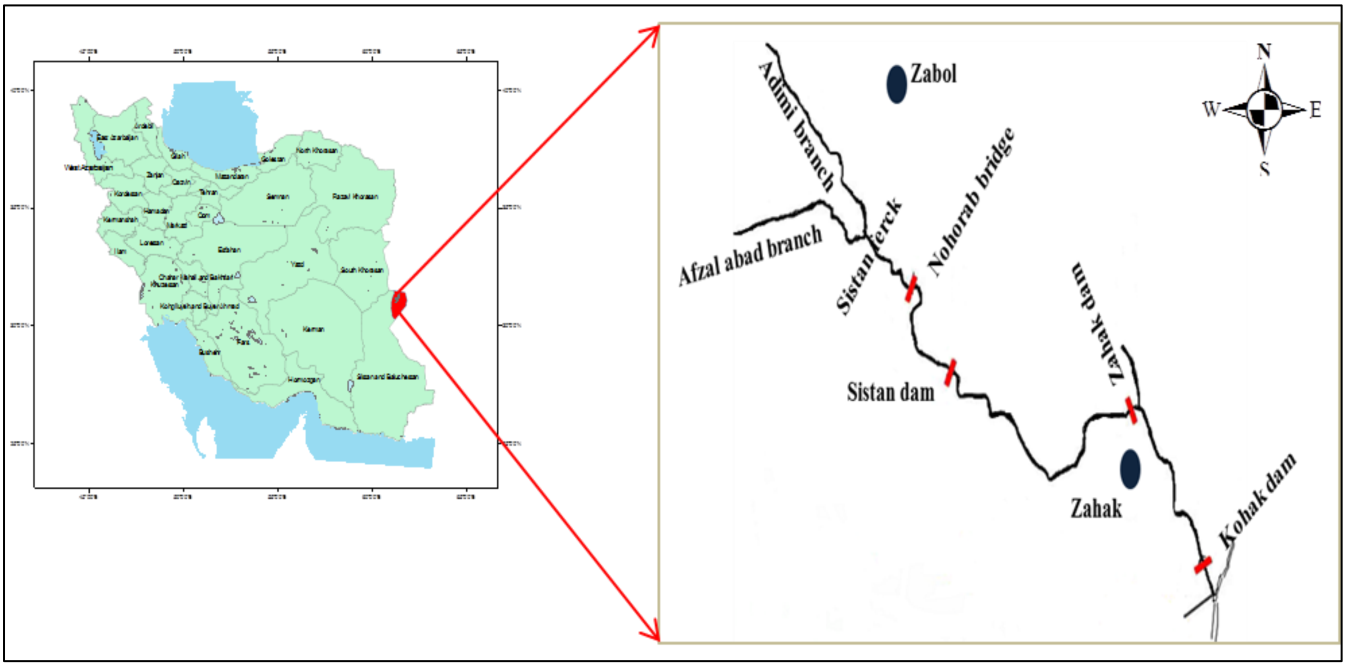

Figure 1. Position of Sistan region and plan of Sistan River

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Table 1. How to maneuver the gates of Zahak dam in various discharges

Inlet flow (m^3/s)	Gate's openings (cm)							
	Gate#1	Gate#2	Gate#3	Gate#4	Gate#5	Gate#6	Gate#7	Gate#8
0 -10	10	10	10	10	0	0	0	0
10 -20	10	10	10	10	10	10	10	10
20 - 40	10	10	10	10	20	20	20	20
40 - 60	25	25	25	25	25	25	25	25
60 - 80	30	30	30	30	30	30	30	30
80 -100	30	30	30	30	35	35	35	35
100 -150	40	40	40	40	40	40	40	40
150 - 200	50	50	50	50	50	50	50	50
200 - 300	65	65	65	65	60	60	60	60
300 - 350	65	65	65	65	65	65	65	65
350 - 400	70	70	70	70	70	70	70	70
400 - 600	80	80	80	80	80	80	80	80

HEC-RAS Model

The completed version of the HEC-2 is HEC-RAS program which is running under the Windows operating system. This software package is of hydraulic analysis program series, where the user communicates with the system via a graphical user interface (GUI). HEC-RAS software is designed to perform one dimensional hydraulic calculation for a full network of natural and synthetic channels. The part of sediment transport of this model is introduced to simulate one dimensional deposition of sediments or erosion and scour of the seabed in 2006 as version 4. This section is able to analyze, calculate and distribute water and sediment movement and hydraulic parameters of deposition at open tracts. Another feature of this version is the ability to separate the sediment due to the bed load and suspended load, and grading the kernels to classify them separately in 20 classes, from the fine clay particles to gravel. Executive Overview of This model has graphic mode and Degradation and Aggradation in the river section is well recognized (HEC-RAS. 2010).

In order to use this model to simulate the flow and sedimentation, the required data are entered into the model:

- **The geometric data:** In the geometry section, the general plan along with the cross sections of the river gathered in 2006, are introduced to the model. In order to do this 88 cross sections were used. The existing Structures on the river include Zahak dam, Sistan Dam and Nohurab Bridge and side structures along the river are Niatak floodgate, Taheri and city channels, shibab and poshtab channels introduced to the model.
- **Hydraulic data (quasi flow):** To enter hydraulic data (like the non-permanent) of the flood hydrograph flow rate of the years 2006-2007 was used, which at the peak of the flood has the flow of 509/547 cubic meters per second.
- **Sedimentary data:** In Sedimentary data section, suspended sediment evaluation curves obtained from Kohak Hydrometric station, were used as inputs. In order to enter the data related to river sediments grading, the results of tests of samples from the river bed levels and the obtained graded particles by the investigator were used and the riverbed particle grading was performed at each cross section.

The coordinates of the moving bed and the width erosion prone district of all the area were introduced to the model. By" moving bed" we mean actually a part of the river where there is possibility of erosion or sediments. The depth of the river bottom sediments by which a thick layer of riverbed erosion that is possible, introduced to the model according to the field studies. For border conditions in this part of the sediment rating Kohak Hydrometric curves located at the beginning of the interval were used.

Calibration of HEC-RAS model

- **Hydraulic Calibration:** To calibrate the flow in discharge data model – the scale of the desired station were obtained and the model was performed in different discharges changing the Manning roughness coefficient and the output data of the water surface in the model was compared with reality. The optimal Manning roughness coefficient of the main channel was 0.02 and in the plain flood was 0.035 respectively. RMSE error value is also 13.24 cm which represents high accuracy calibration.
- **Sediment Calibration:** The HEC-RAS software had the ability to remodel the flow of sediment through sediment transport equations and four ways to calculate the fall velocity. In order to calibrate the sediment model, a combination of 28-state relations of fall velocity of sediment and transport equations were evaluated in the software and among the equations on sediment transport, equation of Toffaleti and among the equations of fall velocity the equations Toffaleti had the closest match with natural conditions of the area.

RESULTS AND DISCUSSION

The results of simulations in full utilization of Niatak spillway

IN full utilization of Niatak floodgate conditions out of 88 simulated districts, 41 districts were erosion prone and 47 were prone to sedimentation; The highest sedimentation happen at 33,659.83, 125 cm height because of Zahak dam's existence and the low slope in this section and maximum erosion is in section section 31728.27 with 89 cm depth immediately after Zahak dam which happen as a result of the bottleneck in the section caused by the dam. The longitudinal profile of Sistan River before and after the floods is in Figure 1.

The cumulative weight of input and output sediment at various sections at the end of the floods is presented in Figure.3.which shows different levels of erosion and sedimentation. The total input precipitation during the entire simulation is less than total output deposits at the end of simulation showing the difference of 9176410 tons; this indicates that during floods the river has been erosion prone.

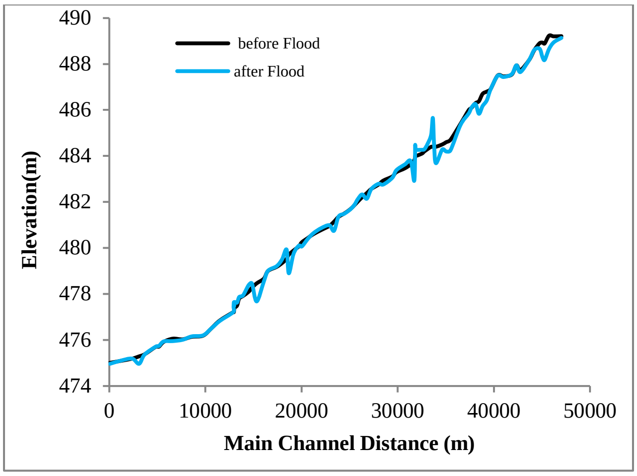

Figure 2. Sistan River's longitudinal profile

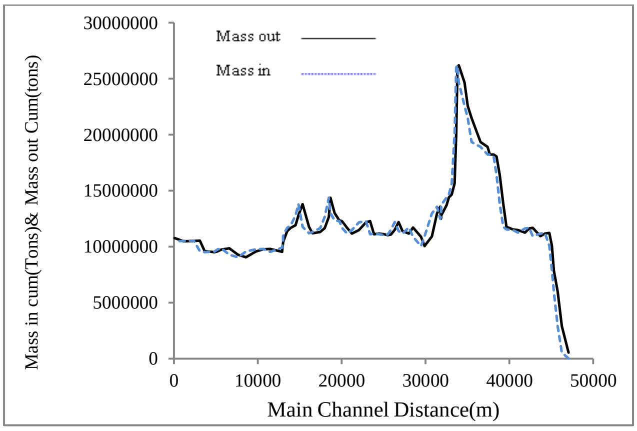

Figure 3. the accumulative weight of inflow and outflow sediments in various sections at the end of floodwater

Figure 4 shows the Status of the riverbed and the level of water stillness in upstream and downstream of the Zahak dam. In this figure the state of Erosion and sedimentation are well presented around the Niatak floodgate and Zahak dam. The length of this sediment prone interval is approximately 2 kilometres.

Deposition has happened approximately 2 km upstream of Sistan dam with the maximum height of 45 cm and 4446498 tons volume, which precipitated due to the dam structure. Figure 5 shows sedimentation in upstream of Sistan dam.

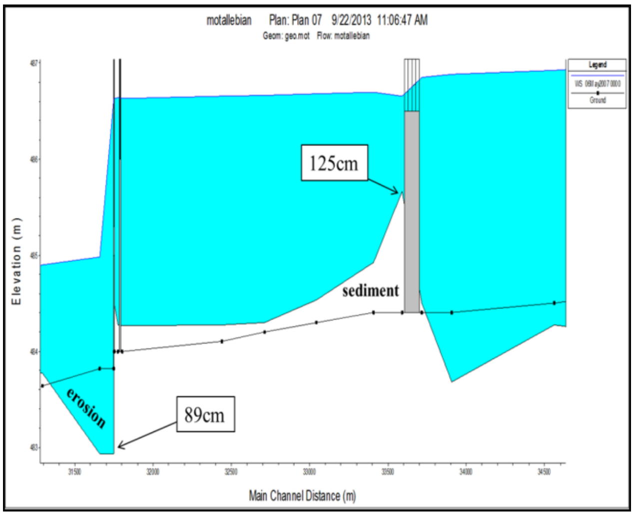

Figure 4. Sedimentation between the Niatak spillway and Zahak dam

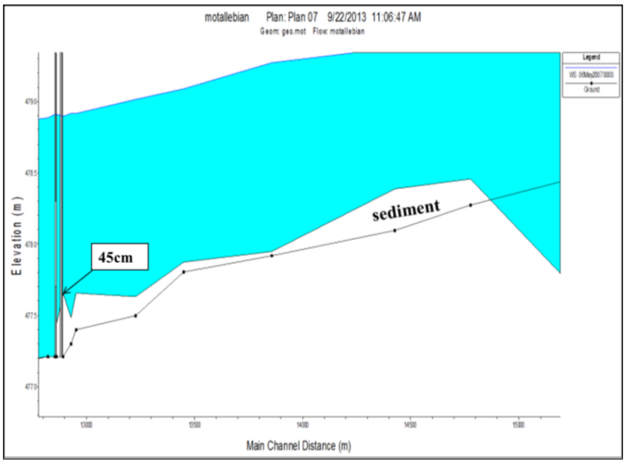

Figure 5. Sedimentation in upstream of Sistan dam

The results of simulation model in situation of full utilization of Niatak spillway

This is a hypothetical case that simulates the impact of openness of gates in Zahak dam during flooding. If the gates of the Zahak and Sistan are widely open, from 88 simulated sections, 52 sections are erosion prone and 36 sections are sedimentation prone The most sedimentation of which has happened in section 33659.83 with 38 cm height due to Zahak dam and low slope of this section and the most erosion has happened in section 31728027 immediately after Zahak damn with 69 cm depth which is due to Zahak dam. Figure 6 shows the longitudinal profile of Sistan River before and after the Flood.

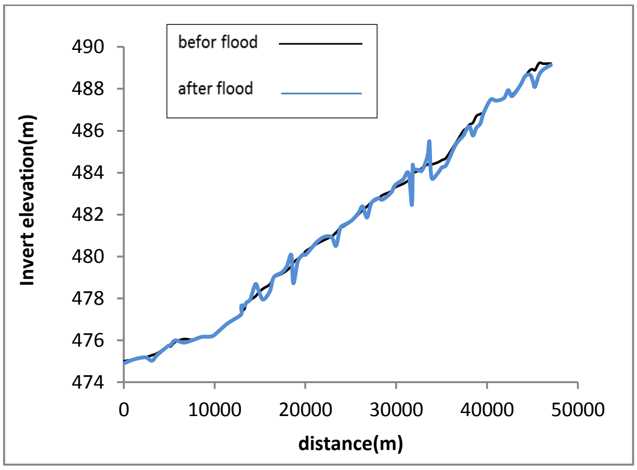

Fig.6. Sistan River's longitudinal profile

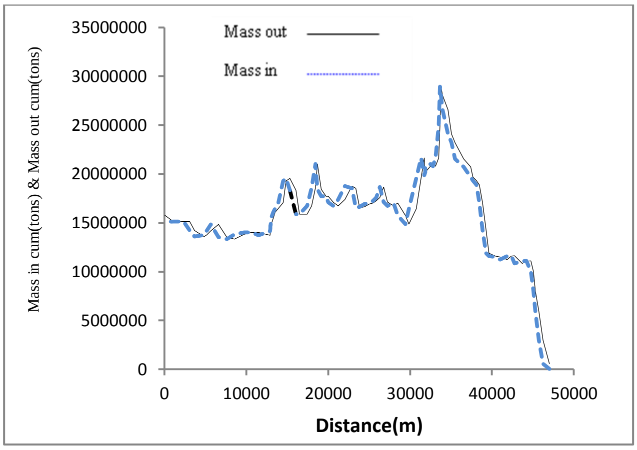

Figure 7. the accumulative weight of inflow and outflow sediments in various sections at the end of floodwater

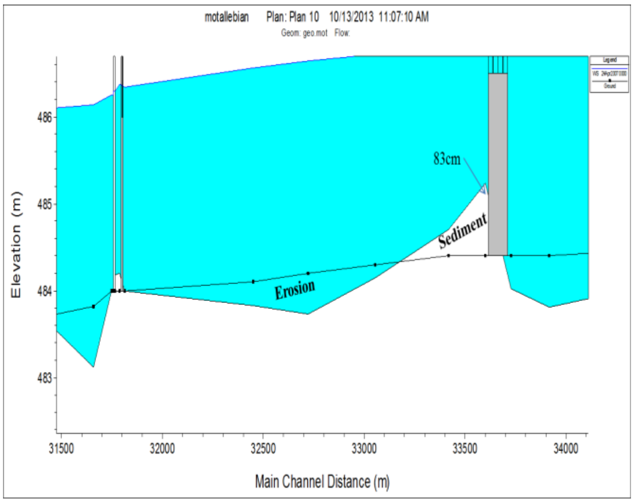

Figure 8. Sedimentation between the Niatak spillway and Zahak dam

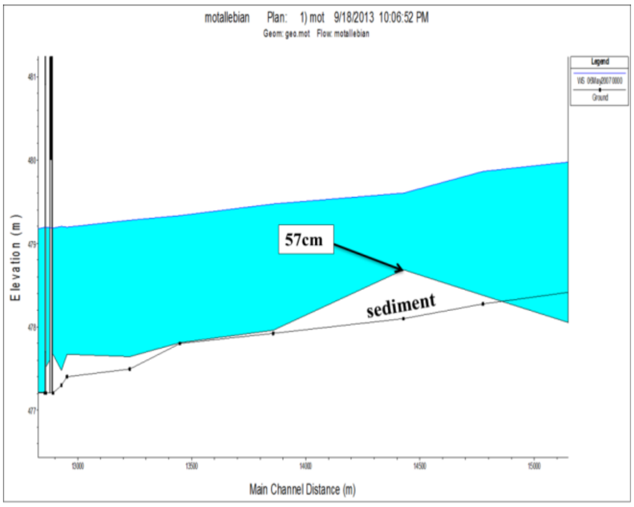

Figure 9. Sedimentation upstream of Sistan dam

CONCLUSION

Maximum sedimentation happens between the Niatak spillway and Zahak dam when the gates are widely open or closed. The weight of accumulated sediment at in full mode utilization of Niatak spillway is 13486202 tons about 45% of the whole accumulated sediment in this mode. And the Weight of accumulated sediment in the interval when the gates are wide open ¬ equals 6750372 tons which is 20% of total of accumulated sediment in the river. In closed gate conditions of Sistan and Zahak out of 88 simulated sections, 41 sections were erosion prone and 47 were prone to sedimentation; the highest sedimentation happen at 33,659.83, 125 cm height because of Zahak dam's and low slope in this section and maximum erosion is in section 31728.27 with 89 cm depth immediately after Zahak dam which happen as a result of the bottleneck in the section and the resulting velocity. In open gate conditions of Sistan and Zahak dams out of 88 simulated districts, 52 districts were erosion prone and 36 were prone to sedimentation; The highest sedimentation happen at 33,659.83, 83 cm height because of Zahak dam's existence and the low slope in this area. In both open and closed gate conditions the Sistan River has been prone to erosion along this flood path.

The results may suggest that in times of flooding the gates of Zahak dam to be fully open to prevent sedimentation behind the dam.

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