

Sediment Transport within the Reservoir of Mandali Dam

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ABSTRACT

Mandali Dam is one of the small dams in Iraq; it is located on Haran Wadi, Gangir, just 3km north-east Mandali City. Mandali dam consists of four main parts, the dam body, the intake structure, the spillway, and the bottom outlet. The dam body is zoned earth filled with a central core. The main purposes of the dam are to maintain flow of Wadi Haran, supplying irrigation and drinking water to Mandali City, and recharging the groundwater. Over a period of seven years of operation, the dam lost its ability to store water due to accumulated sediments within its reservoir. The accumulated sediment is about 2.25million m^3 . The average annual rate of reduction during this period is about 0.321million m^3 . This is form an annual reduction in the original capacity of the dam by 14.26%. This paper attempts to study the hydraulic characteristics and the characteristics of sediment process including the velocity patterns, the distribution concentration, and bed change of sediment within the reservoir of Mandali Dam. The main conclusions of the study that, the velocity is very high in the upstream of the reservoir, due to the relatively narrow section of the wadi and high elevations of the bottom reservoir at this part and the velocities tend to decrease gradually toward the middle part of the reservoir. High concentration in the reservoir is located at the upstream of the reservoir, due to high flow velocities at the upstream and decrease gradually toward the reservoir outlet from spillway. The thickness of deposited sediment is very high in the middle part of the reservoir due to immediate drop in the velocity of water at this part lead to high deposition of sediment.

Keywords: Wadi Haran, Mandali Dam, Sediment Transport.

نقل الرواسب في خزان سد مندلي

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الخلاصة

سد مندلي هو احد السدود الصغيرة في العراق والذي يقع على وادي حران كنعير على مسافة 3كم شمال شرق مدينة مندلي. يتكون السد من أربعة أجزاء رئيسية جسم السد ومأخذ القناة والمسيل المائي والمخرج السفلي. يتكون جسم السد من الاملائيات

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الترابية مع قلب مركزي. وهو يتألف من مواد نفاذة وغير نفاذة حيث استخدمت المواد غير النفاذة في مركز السد والنفاذة في القشرة. تتمثل الاغراض الرئيسية للسد في الحفاظ على تدفق وادي حران وتوفير مياه الري والشرب لمدينة مندلي وكذلك تغذية المياه الجوفية. على مدى فترة سبع سنوات من التشغيل فقد السد قدرته على تخزين المياه للاغراض التي صمم من أجلها بسبب الرواسب المتراكمة في خزانه. وتبلغ كمية الرواسب المتراكمة 2.25 مليون متر مكعب حيث بلغ متوسط المعدل السنوي للترسيب خلال هذه الفترة حوالي 0.321 مليون متر مكعب وهذا يمثل انخفاضا سنويا بنسبة 14.26% من السعة التخزينية الاصلية للسد. لذلك فان هذه الدراسة تهدف لفهم الخصائص الهيدروليكية وخصائص توزيع الرسوبيات بما في ذلك أنماط السرعة وتوزيع التراكيز وتغير طبقة السطح. الاستنتاجات الرئيسية للدراسة تبين ان السرعة عالية جدا في أعلى الخزان وذلك بسبب ضيق مقطع الوادي وأرتفاع مناسب قاع البحيرة في هذه المنطقة ثم تبدأ السرعة بالتناقص بشكل تدريجي باتجاه منتصف الخزان. تكون التراكيز عالية في أعلى الخزان نتيجة السرعة العالية في أعلى الخزان ثم تبدأ بالتناقص بشكل تدريجي من مخرج المسيل المائي. سمك الرواسب المودعة يكون مرتفع جدا في منتصف الخزان بسبب الانخفاض المباشر في سرعة الماء في هذا الجزء مما يؤدي الى ترسيب عالي للرواسب.

الكلمات الرئيسية: وادي حران، سد مندلي، نقل الرواسب.

1. INTRODUCTION

Mandali Dam is a small dam located on Haran Wadi, Gangir. This Wadi originates in Iran and crosses the Iraqi borders northeast of Mandali City. The dam is located just few kilometers from the border. It is an earth-fill dam with a spillway at its central part and is provided by an irrigation outlet. It has a normal storage of $3.62 \text{ million } m^3$. After a few years of operating the dam, the dam is seriously affected by the accumulation of sediment and lost its ability to store water. The elevation of sediments reached just two-meter below the crest of its spillway, which is about eight meters of sediment accumulation.

The trend of recent researches in the field of sedimentation within dams reservoir is focused on the estimation of sediments and how to reduce its amount, routing of sediments, and reducing and removing of accumulated sediments with the aim of developing sustainable dams reservoir capacity. In general, this study aims at investigating the hydraulic performance and sediment distribution within Mandali Reservoir. This investigation will be helpful in understanding the patterns of the flow velocity, circulation regions, water depth, the bed change variation, sediment concentration.

2. DESCRIPTION OF THE STUDY AREA

Mandali Dam is located just 3 km northeast Mandali City, $E=554920$, $N=3738376'$. **Fig.1** shows layout location of Haran Wadi. The main purposes of the dam are to maintain flow within Wadi Haran for irrigation and drinking water to the Mandali City and recharging the groundwater storage. (General Directorate of Engineering Design, Ministry of Water Resources, 2004), presented the following paragraphs summarize the details of Mandali Dam.

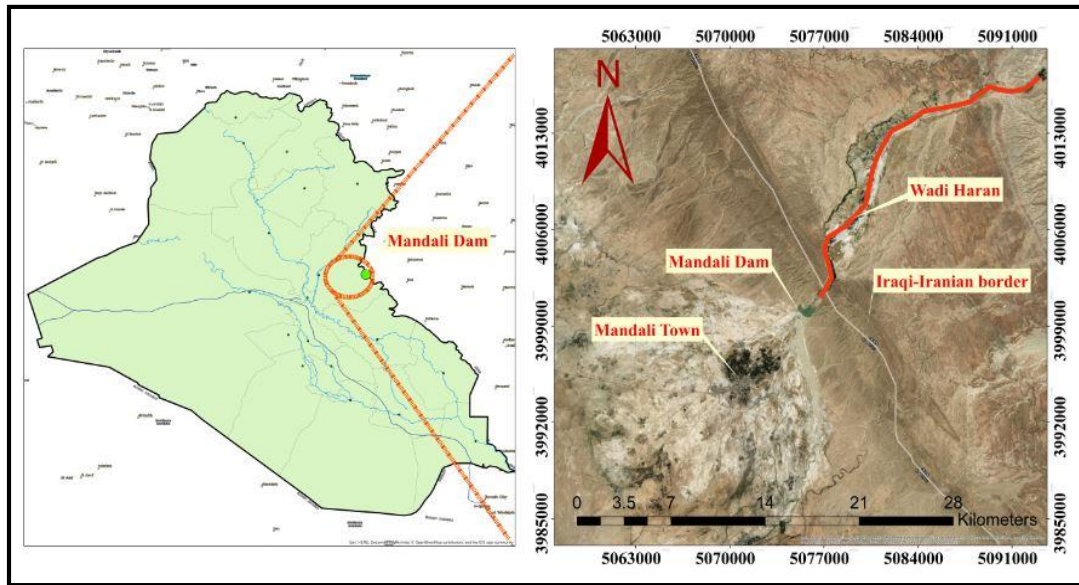


Figure 1. The general layout of Haran Wadi, *Google Maps*.

Mandali dam consists of four main parts, the dam body, the intake structure, the spillway and the bottom outlet as showing in Fig.2. The dam body is zoned earth fill with a central core. Fig.3 shows cross-section of Mandali Dam, it consists of combined sections of pervious and impervious material. Impervious materials used for the core and pervious materials for the dam shell.

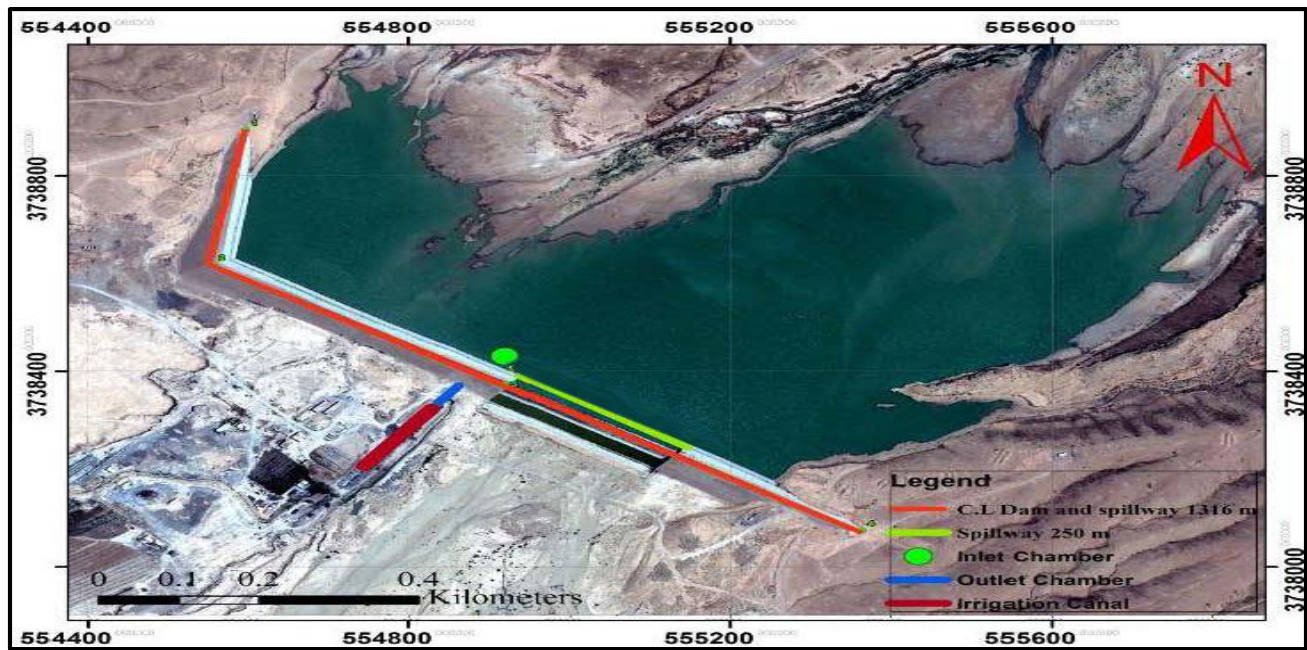


Figure 2. Satellite image showing Mandali Dam, *Google Maps*.

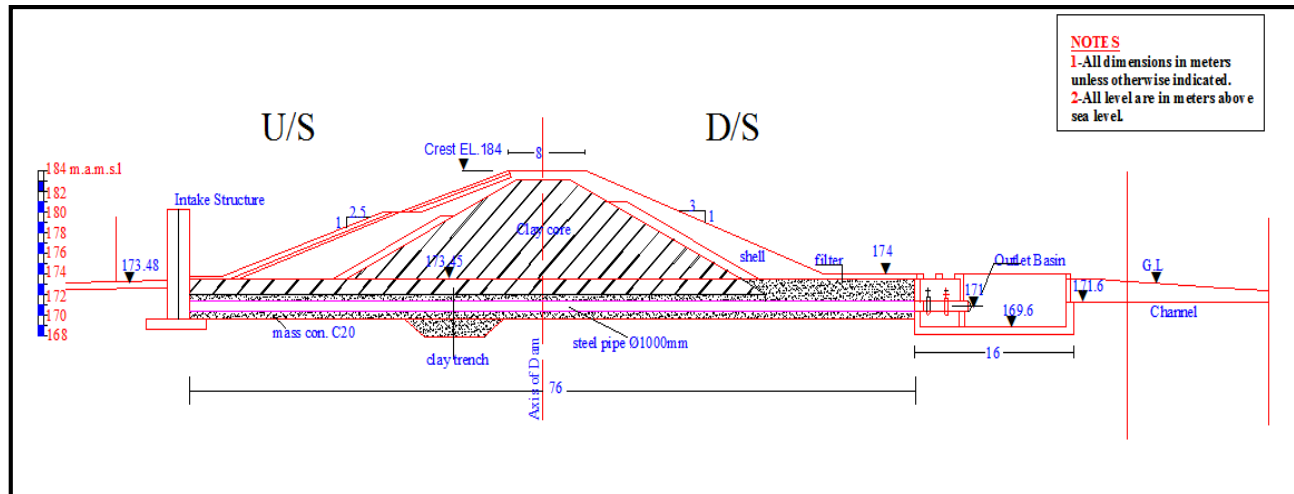


Figure 3. Cross-section of Mandali Dam, *Mandali Dam Design Report, 2004.*

The maximum reservoir capacity of the dam is 6.21 million m^3 and normal storage is 3.62 million m^3 . The reservoir has a normal and maximum water level of 180 m a.s.l. and 182.5 m a.s.l., respectively, and a bed is at elevation 170 m a.s.l. The dam has a height of 14 m and a length of 1316 m of which is 250 m spillway length. The dam has ungated ogee spillway located at a distance of 300 m of the left side of the dam, **Fig.4**. The spillway has a crest level of 180 m a.s.l. a max head of 2.5 m over its crest, and a design discharge of 1725 m^3/s . The rating curve of the spillway is shown in **Fig.5**. Mandali dam has a bottom outlet consists of the intake structure, the conduit, and the outlet control valve chamber. The intake consists of a square concrete tower with three rectangular openings facing the reservoir. The sill of the lowest opening is at the elevation of intake channel bed at 173 m a.s.l. The three openings are of 1.6 m * 1.6 m and are protected by steel trash screen.

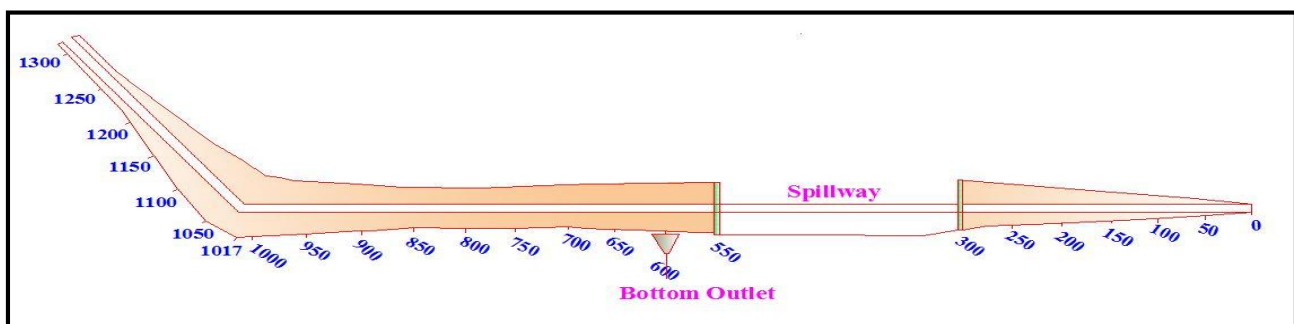


Figure 4. Top view of the dam showing the location of the spillway, *Mandali Dam Design Report, 2004.*

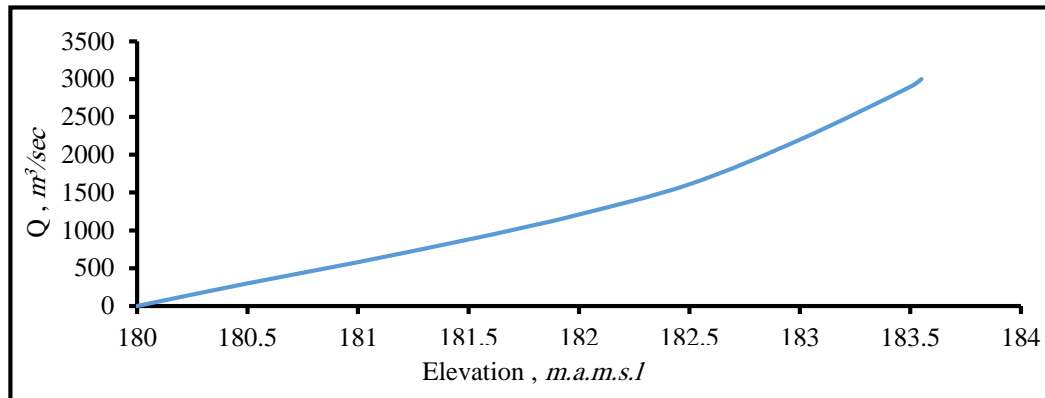


Figure 5. The spillway Rating Curve, *Mandali Dam Design Report, 2004*.

3. DESIGN OF MODELS RUNS

Different well-known software was used to generate the digital contour map, the hydraulic characteristic of the flow, and the variation of concentration of sediments and the change in the bed of the reservoir of Mandali Dam. These used software are the GIS, SMS-RAM2, the parameters presented in (Donnell, 2009) and SMS-SED, (Coastal and Hydraulic Laboratory, 2000, User Guide to SED2D).

There is a lack of field records, including the incoming discharges, the concentration of incoming sediment, and the records of the bed change after the operation of the dam. To understand the characteristic of the variation of concentration of sediments within Mandali Dam Reservoir and its bed change, different values were assumed and examined for the flow discharge and its load of sediment at the upstream boundary of the reservoir of Mandali Dam and the corresponding water level as the downstream boundary. The head over spillway was calculated according to equation of ogee spillway of Mandali Dam. Table 1 shows the discharge upstream and the water level downstream boundaries used in the SMS-RAM2 model. The SMS-SED2D used to estimate the amount of sediment at different sites of the reservoir, and it was useful for both deposition and erosion studies. Both sand and clay beds can be analyzed, but single effective grain size is considered by the model during each run. Therefore, a separate model run is required for each effective grain size. (Ackers-White 1973), adopted a formula that is performed satisfactorily to be used in the SMS-SED2D model for sand bed. (Krone 1962), started the investigation of cohesive sediment transport adopted formula for clay transport, deposition rates of clay beds. Detailed input parameters for sand and clay beds are presented in Table 2. According to the hydrometer analysis the bed material can be described the range of upper limit sand particle of diameter 0.1mm and lower limit clay particle of diameter 0.001mm . The value of dispersion coefficient was adopted according to velocity patterns that were used from previous application.

To understand the characteristic of the sediment accumulation within the reservoir of the dam, the variation of the sediments was investigated by using the SED2D model. The incoming concentration of suspended sediment within the incoming discharge at the upper boundary of the reservoir was assumed. This assumed concentration of suspended sediment within the incoming discharge is 8kg/m^3 . This concentration represents the highest possible value of concentration of sediments. It was estimated depending on the catchment type and mean annual sediment concentration, (HR



Wallingford Guidelines for Predicting and Minimising Sedimentation in Small Dam, DFID, 2004). This high assumed value amplifies the sedimentation process values to get precise results in a short time of model runs.

. **Table 1.** The upstream and downstream boundaries used in the RMA2 model.

Run number	Discharge at upstream, m^3/sec	Water level at downstream, $m.a.m.s.l.$
1	200	180.6
2	1725	182.5

Table 2. SED2D model input parameters.

Sand Bed		Clay Bed	
Input Parameter	Value	Input Parameter	Value
Concentration	$8kg/m^3$	Concentration	$8kg/m^3$
Dispersion coefficient (xx)	$10m^2/sec$	Dispersion coefficient (xx)	$10m^2/sec$
Dispersion coefficient (yy)	$10m^2/sec$	Dispersion coefficient (yy)	$10m^2/sec$
Particle fall velocity	$0.004m/sec$	Particle fall velocity	$0.0001m/sec$
Specific gravity	2.65	Density	$450kg/m^3$
Gravity	$9.81m^2/sec$	Gravity	$9.81m^2/sec$
Grain shape factor	0.7	Consolidation	$256kg/m^3$
Grain size	$0.1mm$	Grain size	$0.001mm$
Simulation time	$1hr$	Simulation time	$1hr$
Grain roughness	0.075	Critical deposition shear stress	$0.078N/m^2$

4. LOCATION OF BED MATERIAL SAMPLING

Samples from the river bed were taken in order to specify the type, size distribution. The amounts of sediment reaching the reservoir have also been classified into three types, sand, silt and clay. The amount each of these types was estimated at different sites in the reservoir by used hydrometer analysis. Three deep boreholes were taken from different points and at deep $1m$, which are called boreholes P1, P2and P3 as showing from **Fig 6**.



Figure 6. Location of the sites of sediment sampling.

4.1 Laboratory Tests of Bed Sediment

The sediment samples from boreholes were analyzed for grain size distribution three sampling points. The sieve analysis showed that all the partials of these samples were smaller than No. 200. A hydrometer analysis was conducted to determine grain size distribution. **Fig.7** shows the average composition of bed material for all sections undertaken. It can be seen that the bed material can be described the range of upper limit sand particle of diameter 0.1mm and lower limit clay particle of diameter 0.001mm .

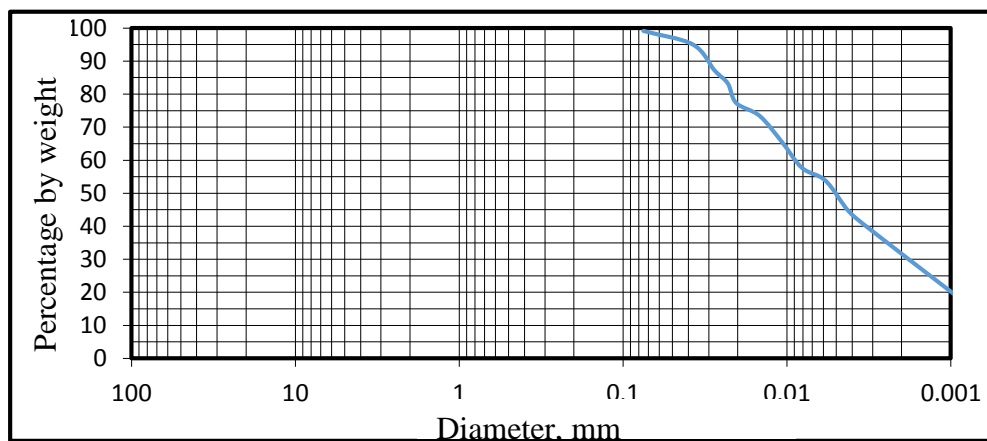


Figure 7. Grain size distribution curve of the soil samples.

5. RESULTS AND ANALYSIS

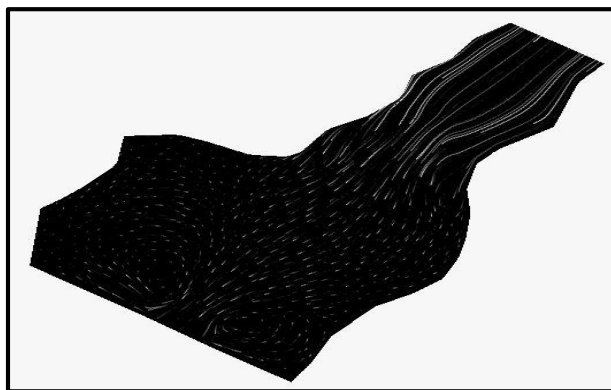
This section presents the analysis of the hydrodynamic and sediment distribution results of the simulation models under two cases of discharge and an incoming concentration for each of sand and clay bed.

5.1 Velocity Pattern within the Reservoir

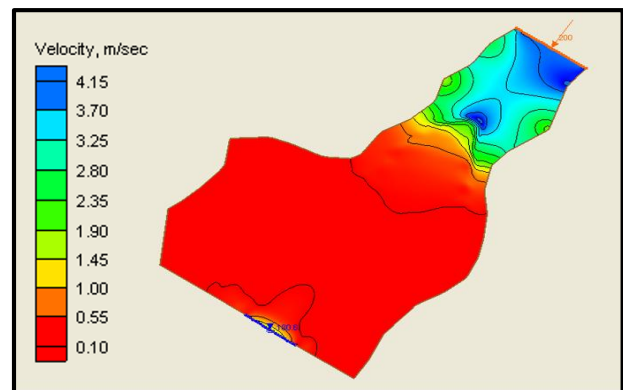
The velocity of water is the most important factor that affects sediment transport in the reservoir. The drop in the velocity of water causes settling of large parts of the suspended sediment in the reservoir. The remaining fractions are settled across the area of the reservoir according to the velocity pattern in the two directions.

Generally, velocity pattern and circulation in the reservoir are affected by the geometry of the reservoir the value of the incoming discharge and water surface elevation in the reservoir. **Fig. 8** and **Fig.9** show the results of the pattern and a snapshot of a films loop of velocities within the reservoir of Mandali Dam for different values of incoming discharges.

The obtained velocities are very high in the upstream part of the reservoir, due to the relatively narrow section of the wadi and high elevations of the bottom reservoir. The velocities tend to decrease gradually towards the middle part of the reservoir. The results show that the velocity across the area of the reservoir is approximately constant with low values, except the velocities in the upstream of the reservoir and outlet of the spillway. Generally, the velocities are almost very low in the western part of the reservoir. Mean velocity of about 0.64m/sec and a maximum of 4.2m/sec were obtained within the reservoir when the discharge is $200\text{m}^3/\text{sec}$, and the water surface elevation at the spillway is 180.6m.a.m.s.l. At an incoming discharge is $1725\text{m}^3/\text{sec}$ the elevation at the spillway is 182.5m.a.m.s.l. , these velocities are 3.5m/sec and 36m/sec , respectively.

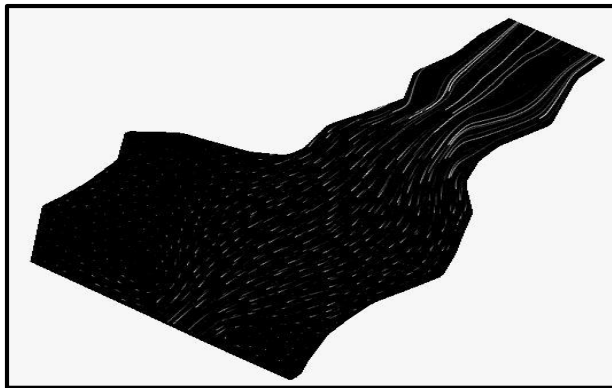


a- Snapshot of the velocity.

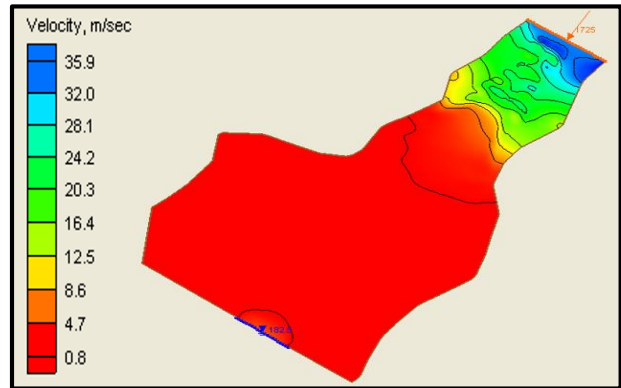


b- Velocity pattern.

Figure 8. Water velocity profile for a discharge of $200\text{m}^3/\text{sec}$ and water surface elevation 180.6m.a.m.s.l.



a- Snapshot of the velocity.



b- Velocity pattern.

Figure 9. Water velocity profile for a discharge of $1725\text{m}^3/\text{sec}$ and water surface elevation 182.5m.a.m.s.l.

5.2 Water Depth Variation within the Reservoir

Fig.10 and Fig.11 show the results of water depth variation within the reservoir computed for different values of incoming discharges. The depth is shallow at the upstream part of the reservoir due to the high elevation bottom of the reservoir in this part and increases gradually toward downstream part of the reservoir. Generally, the water depths are almost very high near the dam part of the reservoir due to low elevation bottom of the reservoir at this part. A mean water depth of about 2.8m within the reservoir and a maximum water depth of 10.6m were obtained when the discharge is $200\text{m}^3/\text{sec}$ at a water surface elevation of 180.6m.a.m.s.l at the spillway. At an incoming discharge is $1725\text{m}^3/\text{sec}$ the elevation at the spillway is 182.5m.a.m.s.l and these water depths are 4.2m and 12.6m , respectively.

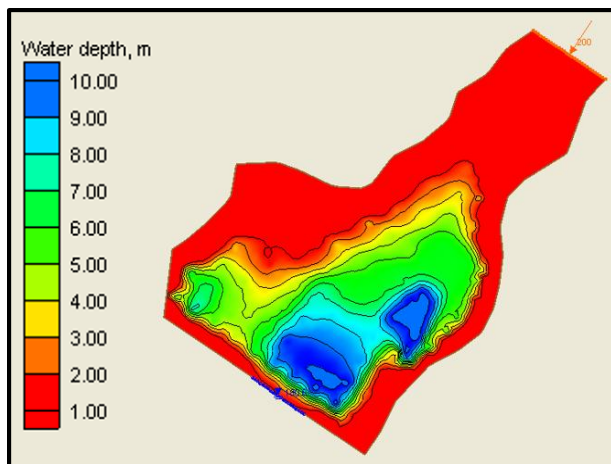


Figure 10. Water depth, $Q=200\text{m}^3/\text{s.}$

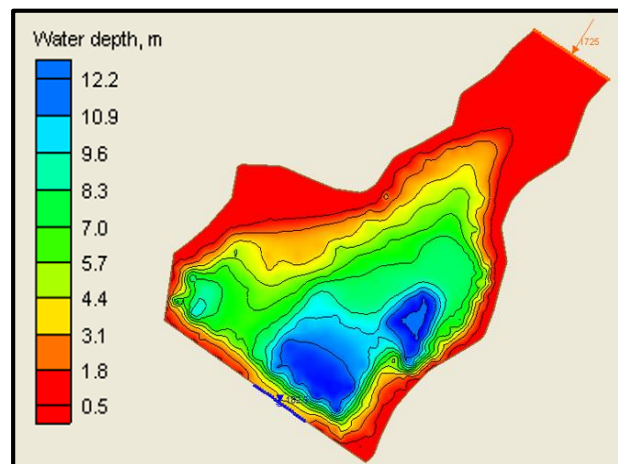
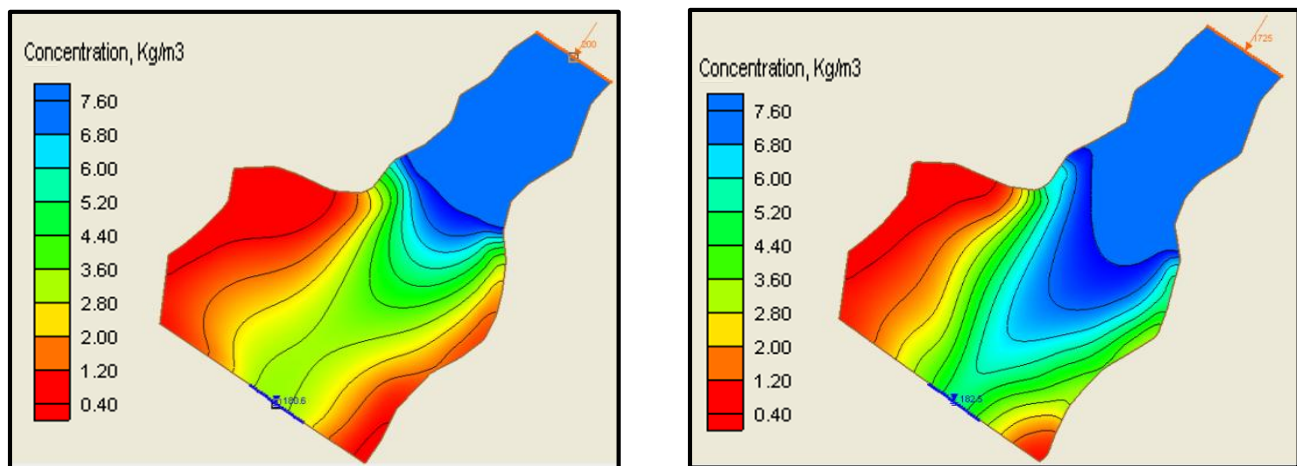


Figure 11. Water depth, $Q=1725\text{m}^3/\text{s.}$

5.3 Distribution of Suspended Sediment under Sand Bed

Fig. 12 shows the variation of concentration within the reservoir for an incoming discharge and concentration. Generally, the results show that the concentration of suspended sediments decreases gradually towards the reservoir outlet. The decrease in the concentration of suspended sediment is related to the velocity of water in the reservoir. A high concentration of the suspended sediment was found at upstream part of the reservoir due to the high velocity of water. It can be noticed that an increase in the discharge leads to relatively high concentration within the reservoir and at the outlet of spillway.

At a water surface elevation of $180.6m.a.m.s.l$, a discharge of $200m^3/sec$, the concentration outflow from the reservoir spillway is $2.3kg/m^3$. The volume of sediment out the reservoir at this incoming concentration is $624m^3$. The high concentration is located at the upper northern part of the reservoir and decreases gradually toward the reservoir spillway outlet. For the same condition but with a discharge of $1725m^3/sec$ and water surface elevation $182.5m.a.m.s.l$, the concentrations out of the spillway is $4.1kg/m^3$, and the percentage of outlet is 51.25%. It can be noticed that the concentration within the reservoir and at the outlet of spillway are higher than that when incoming discharge is $200m^3/sec$. Also, the volumes of sediment out the reservoir are higher due to high flow velocity.



a- Incoming discharge $200m^3/sec$.

b- Incoming discharge $1725m^3/sec$.

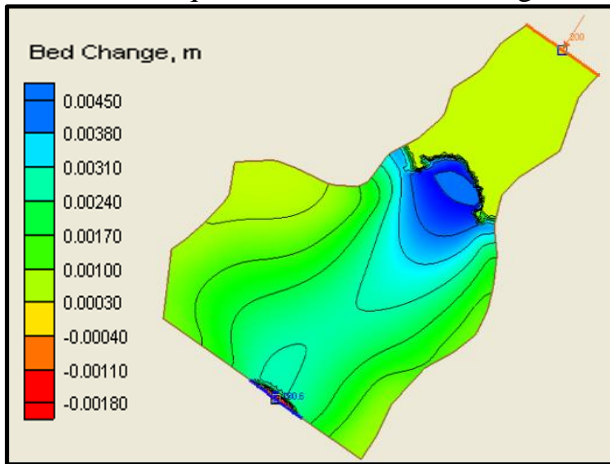
Figure 12. Variation of concentration for sand bed.

5.4 Reservoir Bed Change under Sand Bed

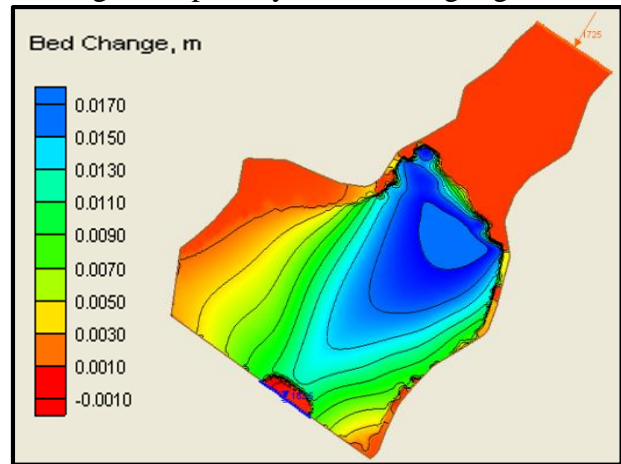
Fig.13 shows the variation of bed change within the reservoir of Mandali Dam. The thickness of sediment within the reservoir is very high in the middle part of the reservoir due to an immediate drop in the velocity of water in this part. The immediate drop in the velocity of water causes settling of large parts of the suspended sediment within this part. At a water surface elevation of $180.6m.a.m.s.l$, a discharge of $200m^3/sec$ the high bed thickness is located at the middle part of the reservoir due to the immediate drop in the velocity of water causes settling of large parts of the suspended sediment in the reservoir. The volume of sediment accumulated in the reservoir is $1594m^3$, and the percentage of sediment deposition in the reservoir is 73.3% at the incoming concentration of $8kg/m^3$. For the same condition but with a discharge of $1725m^3/sec$ and at water surface elevation of $182.5m.a.m.s.l$, the percentage volume of sediment deposition in reservoir is



reduced and equal is 48% due to flushing of sediment through the spillway outlet during high flow.



a- Incoming discharge $200m^3/sec$.



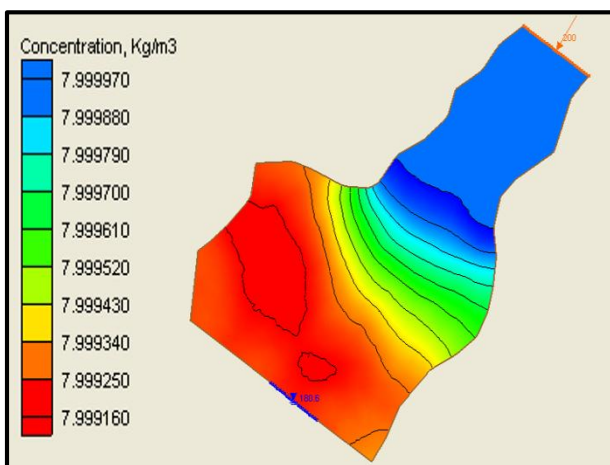
b- Incoming discharge $1725m^3/sec$.

Figure 13. Variation of bed change for sand bed.

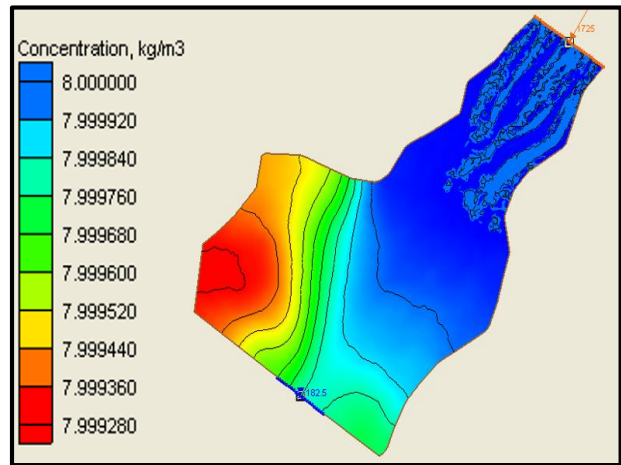
5. Distribution of Suspended Sediment under Clay Bed

The result of the variation of concentration under clay bed for different incoming discharge shows that relatively very slight changes with concentration. The sediment bed samples were taken in the reservoir show that the bed material can be described as clay bed, this is an indication that the incoming discharge stays within the reservoir and deposited in the reservoir.

Fig.14 shows the variation of the concentration of clay sediment within the reservoir of Mandali Dam. At water surface elevation of $180.6m.a.s.l$, a discharge of $200m^3/sec$, the high concentration of clay sediment within the reservoir is located at the stream of the wadi and decrease gradually at the northwest part of the reservoir due to the drop in the velocity of water. For the same condition but with a discharge of $1725m^3/sec$, the concentration over the reservoir and outlet have the same variation behavior as with an incoming discharge $200m^3/sec$, but with more extend value.



a- Incoming discharge $200m^3/sec$.

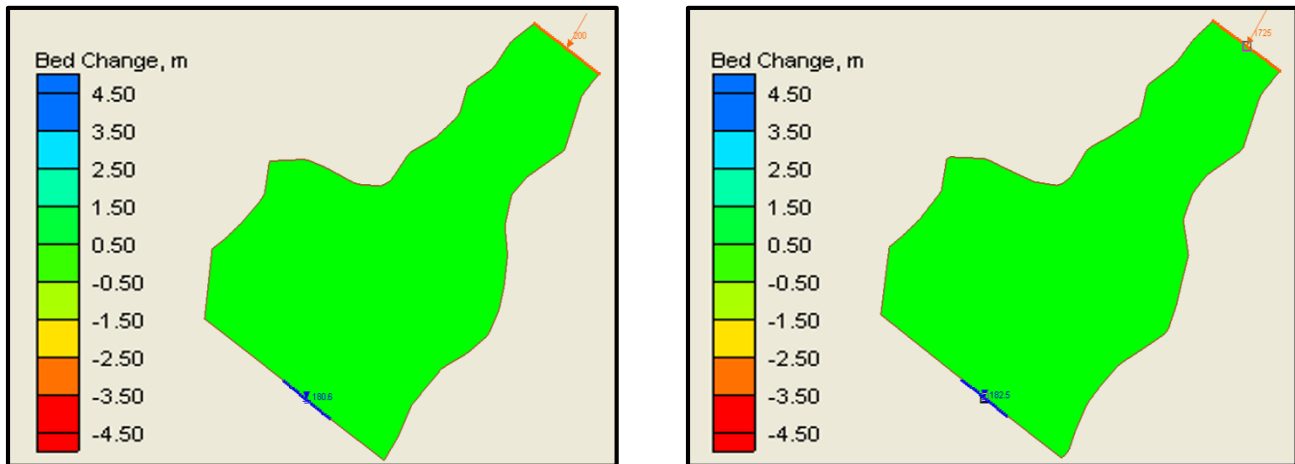


b- Incoming discharge $1725m^3/sec$.

Figure 14. Variation of concentration for clay bed.

5. Reservoir Bed Change under Clay Bed

Fig.15 shows the variation of bed change for clay sediment within the reservoir of Mandali Dam. A very slight or no changes in bed and is approximately equal zero within all parts of the reservoir due to effect by numerous factors effecting of sediment transport and deposition settling velocity, size particle, specific gravity, and shape. Moreover, the length of the reservoir is not long enough to allow the suspended sediment to settle.



a- Incoming discharge $200m^3/sec$.

b- Incoming discharge $1725m^3/sec$.

Figure 15. Variation of bed change for clay bed.

6. CONCLUSIONS

The following items summarize the main conclusions of this paper:

- 1- The velocity is very high in the upstream of the reservoir, due to the relatively narrow section of the wadi and high elevations of the bottom reservoir at this part and the velocities tend to decrease gradually toward the middle part of the reservoir.
- 2- The results show that the velocity across the area of the reservoir is approximately low, except the velocities in the upstream of the reservoir and outlet of the spillway. Generally, the velocities are almost very low in the western part of the reservoir.
- 3- The depth is very low in the upstream part of the reservoir due to the high elevation bottom of the reservoir in this part and increases gradually toward downstream part of the reservoir. Generally, the water depths are almost very high near the dam part of the reservoir due to low elevation bottom of the reservoir at this part.
- 4- High concentration in the reservoir is located at the upstream of the reservoir, due to high flow velocities at this part and decrease gradually toward the reservoir outlet from the spillway. The concentration out from spillway at incoming discharge is $200m^3/sec$ is 29% of the incoming concentration and at increase incoming discharge of $1725m^3/sec$ approximately is 50%.
- 5- The thickness of deposited sediment is very high in the middle part of the reservoir due to an immediate drop in the velocity of water at this part lead to high deposition of sediment. The deposition of sediment at the incoming discharge of $200m^3/sec$ approximately is 70% of the incoming concentration, and when increasing discharge to $1725m^3/sec$ this percentage is



47%.

- 6- Generally, high deposition of sediment occurs in the reservoir when incoming low discharge and low deposition of sediment when incoming high discharge, due to high velocity it leads to flush of sediment through the spillway outlet of the reservoir.
- 7- The variation of concentration under clay bed for different incoming discharge shows that relatively very slight changes with concentration, due to affected by numerous factors effecting of sediment transport and deposition settling velocity, size particle, specific gravity, and shape.
- 8- The variation of bed change under clay bed shows that a very slight or no changes within the reservoir and equal zero at all the reservoir, due to this distance of the reservoir is not long enough to allow the suspended sediment to settle in the reservoir bed.

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