Hydrological Sciences Journal

Publication details, including instructions for authors and subscription information:
<http://www.tandfonline.com/loi/thsj20>

Sedimentation and new operational curves for Mosul Dam, Iraq

Issa E. Issa^a, Nadhir Al-Ansari^a & Sven Knutsson^a

^a Luleå University of Technology, SE-971 87, Luleå, Sweden

Accepted author version posted online: 25 Mar 2013. Published online: 13 Sep 2013.

To cite this article: Issa E. Issa, Nadhir Al-Ansari & Sven Knutsson, Hydrological Sciences Journal (2013): Sedimentation and new operational curves for Mosul Dam, Iraq, Hydrological Sciences Journal, DOI: 10.1080/02626667.2013.789138

To link to this article: <http://dx.doi.org/10.1080/02626667.2013.789138>

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at <http://www.tandfonline.com/page/terms-and-conditions>

Sedimentation and new operational curves for Mosul Dam, Iraq

Issa E. Issa, Nadhir Al-Ansari and Sven Knutsson

Luleå University of Technology, SE-971 87 Luleå, Sweden
issa.elias@ltu.se; nadhir.alansari@ltu.se; sven.knutsson@ltu.se

Received 27 August 2012; accepted 12 February 2013; open for discussion until 1 April 2014

Editor D. Koutsoyiannis

Citation Issa, E.I., Al-Ansari, N., and Knutsson, S., 2013. Sedimentation and new operational curves for Mosul Dam, Iraq. *Hydrological Sciences Journal*, 58 (7), 1–11.

Abstract Mosul Dam is one of the biggest hydraulic structures in Iraq. Its storage capacity is $11.11 \times 10^9 \text{ m}^3$ at a maximum operation level of 330 m a.s.l. The dam became operational in 1986 and no survey has been conducted to determine its storage capacity and establish new operational curves since this date. A topographic map of scale 1:50 000 dated 1983 was converted into triangulated irregular network (TIN) format using the ArcGIS program to evaluate the operational curves. Then the reservoir was surveyed in 2011 to establish the reduction in its storage capacity and to develop new operational curves. The results indicated that the reduction in the storage capacity of the reservoir was 14.73%. This implies that the rate of sedimentation within the reservoir was $45.72 \times 10^6 \text{ m}^3 \text{ year}^{-1}$. These results indicate that most of the sediment was deposited within the upper zone of the reservoir where the River Tigris enters the reservoir.

Key words bathymetric survey; dam operational curves; reservoir sedimentation; Mosul Dam, Iraq

Sédimentation et nouvelles courbes d'exploitation pour le barrage de Mossoul en Irak

Résumé Le barrage de Mossoul est l'un des plus grands ouvrages hydrauliques de l'Irak. Sa capacité de stockage est de $11,11 \times 10^9 \text{ m}^3$ au niveau maximum d'exploitation (330 m au dessus du nmm). Le barrage a été mis en service en 1986 et aucune enquête n'avait été menée depuis pour déterminer sa capacité de stockage et établir de nouvelles courbes d'exploitation. Une carte topographique à l'échelle du 1/50 000 établie en 1983 a été traduite au format de réseau irrégulier triangulé en utilisant le programme ArcGIS pour évaluer les courbes d'exploitation. Le réservoir a alors été étudié en 2011 pour mesurer la réduction de sa capacité de stockage et établir de nouvelles courbes d'exploitation. Les résultats ont indiqué que la capacité de stockage du réservoir avait été réduite de 14,73%, ce qui implique que le taux de sédimentation dans le réservoir avait été de $45,72 \times 10^6 \text{ m}^3 \text{ an}^{-1}$. Les résultats indiquent que la majeure partie des sédiments a été déposée dans la zone située à l'amont du réservoir, à l'embouchure du Tigre.

Mots clefs levé bathymétrique; courbes d'exploitation du barrage; sédimentation du réservoir; barrage de Mossoul, Irak

INTRODUCTION

Scarcity of water resources in the Middle East is an extremely important factor in the political stability of the region, and an integral element in its economic development and prosperity (Naff 1993, Al-Ansari 1998, 2005). Future predictions suggest more severe shortages of water and a reduction in water security (Bazzaz 1993, Al-Ansari *et al.* 1999). Until the 1970s, Iraq was considered an exception relative to its water-stressed neighbouring countries due to the

presence of the Tigris and Euphrates rivers (Al-Ansari and Knutsson 2011).

The idea of building dams in Iraq started in the first half of the twentieth century. Primarily this was to protect Baghdad, the capital, and other major cities from flooding. The first big dam (Dokan) was constructed in 1959 on the Lesser Zab River. Later, dams were constructed for irrigation and power generation purposes (Iraqi Parliament 2009). The total water withdrawal in Iraq in 1990 was about $42.8 \text{ km}^3 \text{ year}^{-1}$ ($1357 \text{ m}^3 \text{ s}^{-1}$), which was used for agricultural

(90%), domestic (4%) and industrial (6%) purposes (Sadik and Barghouti 1993, Al-Ansari 1998, 2005). According to the most recent estimates, 85% of the water withdrawal is used for agricultural purposes (Al-Ansari 1998, Al-Ansari and Knutsson 2011). It should be mentioned, however, that safe water quality supplies reach 100% of the urban areas and only 54% of rural areas. The purification and distribution of municipal water supplies had deteriorated after the Gulf War for both water and sanitation sectors (Al-Ansari and Knutsson 2011). In 1977, the Turkish Government started to utilize the water of the Tigris and Euphrates rivers through the South-eastern Anatolia Project (GAP). The project includes 22 multipurpose dams and 19 hydraulic power plants, which are to irrigate 17 103 km² of land, with a total storage capacity of 100 km³—three times more than the overall capacity of Iraqi and Syrian reservoirs (Al-Ansari and Knutsson 2011). Eight of these dams are to be constructed on the River Tigris, only three have been built to date (two in 1997 and one in 1998).

Iraq receives 20.9 km³ year⁻¹ of water from the Tigris River and, once the Ilisu Dam is constructed, this is likely to drop to 9.7 km³ year⁻¹, which means that 47% of the river flow will be depleted (Al-Alaf 2009). This means that 6961 km² of agricultural land will be abandoned due to water scarcity (Al-Ansari and Knutsson 2011). The Iraqi Government realized the process of building dams should be speeded up due to the huge increase of water demand and the threat of reducing water flows in the Tigris and Euphrates by Turkey and Syria. The process stopped in the 1990s due to the second Gulf War and UN sanctions and none of the dams were filled to their maximum storage capacity until the year 2012. The reduction of flow in the Tigris and Euphrates rivers in Iraq is considered to be a national crisis, and will have severe negative consequences on health as well as on environmental, industrial and economic development (Al-Ansari and Knutsson 2011).

In view of the situation described above, it is imperative to manage national water resources prudently. The Iraqi Government is forced now to adopt speedy and effective procedures to overcome the water shortages (Al-Ansari and Knutsson 2011). Among these procedures is the evaluation of the actual storage capacities of reservoirs. Despite the importance of the evaluation of the actual capacity of the existing reservoirs, very little work had been executed in this context. In Iraq, the only existing work was carried out in 1987 (Al-Ansari 1987). Similar work was carried out in Jordan after

2003 (Al-Ansari and Al-Alalami 2003, Al-Ansari and Knutsson 2012). In this research, a pre-construction topographic map of scale 1: 50 000, dated 1983, was converted into a digital map in a triangulated irregular network (TIN) format using ArcGIS. The TIN map was used to compute the area–storage capacity curves before the dam operation, in order to evaluate the adopted operating curves that were proposed by Imatran Voima Osakeyhtio, Consulting Engineers, Finland (IVO 1968). Then, Mosul Reservoir was surveyed in 2011 to evaluate its existing storage capacity and to establish new operational curves. It should be mentioned, however, that the maximum water level in the reservoir is 330 m a.s.l., while the survey was conducted when the level was 320 m a.s.l. The difference in the capacity of the reservoir obtained by the adopted operating curves and the new survey conducted in 2011 represent the sediment accumulated within the reservoir between 1986 and 2011. The two surveys were used to determine the sediment distribution within the reservoir.

SITE DESCRIPTION

Mosul Dam, which has been built on the Tigris River in northern Iraq, is one of the biggest hydraulic structures in Iraq. The dam is located approximately 60 km northwest of Mosul city and 80 km from the Syrian and Turkish borders, as shown in Fig. 1. The main dam is 113 m high, 3650 m long (including its spillway), has a 10 m top width and crest level of 341 m a.s.l (Iraqi Ministry of Water Resources 2012). Mosul Dam was operating on 24 July 1986. It is a multipurpose project for irrigation, flood control and hydropower generation. The majority of the water entering the reservoir flows from the River Tigris. The water surface area of the reservoir at the beginning of the dam operation was 380 km² with a storage capacity of 11.11×10^9 m³ at the maximum operation level of 330 m a.s.l., including 8.16×10^9 m³ live storage and 2.95×10^9 m³ dead storage (Iraqi Ministry of Water Resources 2012). The length of the reservoir is about 45 km and its width ranges from 2 to 14 km at the same operation level. There are 10 main valleys feeding the reservoir, seven on the left bank and three on the right bank (Muhammad and Mohamed 2005, Mohammed *et al.* 2012). The soils in the bed of the valleys are mainly silty loam, silty clay loam and clay (Mohammed *et al.* 2012). The estimated catchment area of the River Tigris upstream of Mosul Reservoir is about 54 900 km², shared by Turkey, Syria and Iraq

Fig. 1 Location of Mosul Dam.

Fig. 2 Monthly inflows of Tigris River into the reservoir averaged over the years 1931–2011.

(Swiss Consultants 1979, Saleh 2010), and the catchment area of the valleys surrounding the reservoir is about 1375 km² (Muhammad and Mohamed 2005, Mohammed *et al.* 2012).

The highest mean monthly discharge occurs during April and the driest month is generally September (Fig. 2). The maximum and minimum monthly discharges of the River Tigris, recorded since 1931, were 3514 m³ s⁻¹ in April 1954 and 87.7 m³ s⁻¹ in September 1986, respectively (Engineering Consulting Bureau 2010). Impounding of the reservoir started in June 1984, with initial reservoir filling during the spring of 1985, while the actual operation of the dam started in 1986. Figure 3 illustrates the inflow–outflow operation in the period 1986–2011.

TOPOGRAPHIC SURVEY OF 1983

A pre-impoundment (1983) 1: 50 000-scale topographic map, obtained from the Remote Sensing Centre

at Mosul University, Iraq, was used to evaluate the adopted operating curves and for comparison with the 2011 bathymetric survey. The topographic map was projected onto a satellite image and georeferenced to the Universal Transverse Mercator (UTM) projection, “WGS-1984, Zone 38N” in the ArcInfo program of ArcGIS version 9.3 (Environmental Systems Research Institute, Inc. 2012) (Fig. 4). To check the accuracy of work done, the map was superimposed on the satellite image. It can be seen that the course of River Tigris and side valleys coincide (Fig. 4).

Contour lines and spot locations of elevation (benchmarks and high-water marks) within the reservoir area on the map were manually digitized to compute x , y and z coordinates. Furthermore, stream path lines representing the River Tigris within the reservoir area were also digitized using water surface slope and contour lines. The water surface slope of the River Tigris within the reservoir area at that time was 0.65 m km⁻¹ (Swiss Consultants 1979, Najib

Fig. 3 Mean inflow and outflow of Mosul Reservoir (1986–2011).

Fig. 4 Projection of the 1983 Mosul Reservoir topographic map onto the 2009 satellite image.

1980). The total number of digitized points within the reservoir area was 6029 (Fig. 5).

A reservoir Polygon Shapefile (hard clip) around the reservoir boundary was created from the satellite image using the ArcMap program in ArcGIS (Fig. 6). This image, representing the reservoir at 320 m a.s.l., was obtained from the Remote Sensing Centre at Mosul University. The polygon was used in a TIN development to prevent the interpolation outside the enclosed area.

All digitized point files from the 1983 map and the reservoir Polygon Shapefile were used to develop a TIN for the reservoir area before the construction of the dam (Fig. 7). The “WGS-1984, Zone 38N” projection information, linear unit of metre for interpolation, and a 0.9996 scale factor were used in this process.

In addition, the longitudinal bed profile of the River Tigris within the reservoir area before impounding was plotted from the topographic map and the TIN of the 1983 survey using the ArcGIS software (Fig. 8). When comparing the resulting slope (0.667 m km^{-1}), its value was found to be very close to that calculated before the dam was constructed on the Tigris River (0.65 m km^{-1}) (Swiss Consultants 1979, Najib 1980).

The TIN of the 1983 survey was used to construct area–storage capacity curves of Mosul Reservoir for the pre-impoundment period (Fig. 9). These were compared with existing operational curves proposed by IVO. It was found that the percentage difference was 4.0% for the stage–storage capacity curve and 7.7% for the stage–water surface area curve. This difference is due to the fact that the operation curves

Fig. 5 Location of digitized points on Mosul Reservoir topographic map.

Fig. 6 Mosul Reservoir polygon (hard clip) at 320 m a.s.l. elevation generated using ArcMap.

Fig. 7 Mosul Reservoir TIN surface model generated from 1983 survey using ArcMap.

Fig. 8 Bed profile of Tigris River from 1983 survey.

Fig. 9 Area-capacity curves for Mosul Reservoir, pre-impoundment.

proposed for the dam by IVO were constructed using topographic maps dated before 1968, while the map used in this work was made in 1983.

BATHYMETRIC SURVEY OF MOSUL DAM RESERVOIR

The methodology and data-processing methods that were used in the bathymetric survey for Mosul Reservoir conducted in May 2011 to develop new area-storage capacity curves and determine the sediment distribution within the reservoir using echo sounder sonar viewer and ArcGIS software are as follows.

Field work

The bathymetric survey of the Mosul Reservoir was conducted in May 2011 using an echo sounder with accessories, a Jet Ski boat, a 12v DC echo-sounding power unit, and a variety of auxiliary equipment.

The data were collected using a 200-kHz single-beam echo sounder viewer (Sea Charter 480DF; Eagle Electronics 2003) linked to a real-time kinematic global positioning system (RTK-GPS) to define the absolute coordinates (x, y, z) of the reservoir bottom during the traverses. The bathymetric survey system software records the (x, y, z) coordinates data in a sonar chart (*.slg file format) (Eagle Electronics 2003).

The Mosul Reservoir bathymetric survey was conducted over 12 days from 15 May to 3 June 2011. The survey was conducted according to US Army Corps of Engineers standards for distances between transverse sections, boat types and calibration (US Army Corps of Engineers 2004). Before the bathymetric survey could be carried out, installation and calibration of the echo sounder were performed. The calibration was performed by a marked rod over the side of the boat in calm water, according to the methods described by Eagle Electronics (2003) and Ferrari and Collins (2006). The error values of water depth measurements were ± 4 cm, depending on the

water depth within the reservoir. The water temperature during the survey was taken by sea chart echo sounding. The temperature range was 28–30°C during the whole survey period. Since the temperature was almost constant, the effect of temperature was ignored. Transducer face depth (draft) during the survey was 0.35 m below the water surface. The draft depth was used to correct the water depth that was recorded by an echo sounder. The bathymetric survey was performed in calm water to avoid errors in water depth measurement due to waves. The water surface elevations during the survey were recorded at the hydropower generation station at the dam site, and at the pumping station of North Al-Jazeera Irrigation Project in the upper zone of Mosul Reservoir. The elevation readings of between 319.75 and 319.96 m a.s.l. were used to convert the acoustic depth measurements to reservoir bottom elevations during data processing. Figure 10 shows the details of the transect lines during the bathymetric survey.

Data processing

Depth and boat position data obtained from the echo sounding survey were in (*.slg) format. Each (*.slg) file was converted to (x,y,z) coordinates (*.csv) MS Excel file format by Sonar Log Viewer 2.1.2 (Lowrance 2012). The water depth values in *.csv were adjusted with respect to transducer depth (draft = 0.35 m). The value of bed-elevation = water surface elevation – adjusted depth. It should be mentioned, however, that, as the survey was conducted during a calm period, the heights of waves were less than 10 cm. For this reason, the effect of waves was neglected. The water surface elevation for each survey

date was used for each data set collected on that date. A water surface boundary of the reservoir was manually digitized from satellite image and saved in *.csv to determine the boundary of the reservoir. The *.csv Excel files and Polygon Shapefile were then used to develop the TIN of the 2011 survey using the same method as described in Section 3 (Fig. 11).

RESULTS AND DISCUSSION

To ensure prudent operation of Mosul Dam, new operational curves were established based on the survey conducted in 2011. The TIN for the 2011 bathymetric survey (Fig. 11) and operational curves (Fig. 9) were used to update the area–storage capacity curves for Mosul Reservoir using ArcGIS (Fig. 12). The new operation curves of the Mosul Reservoir (based on the 2011 survey) were compared with those proposed by IVO. It is evident that there is a shift between the curves. This is due to the changes in the storage capacity and water surface area of the reservoir due to sediment deposition during the operational period of the dam.

The storage capacity of Mosul Reservoir at pool elevation of 320 m a.s.l was $7.749 \times 10^9 \text{ m}^3$ for the original operation curve and $6.606 \times 10^9 \text{ m}^3$ for the 2011 survey, giving a difference in storage capacities of $1.143 \times 10^9 \text{ m}^3$. This represents the total storage loss due to sediment deposition throughout the operational period, and represents 14.73% of total storage. This implies that the annual sedimentation rate is 0.59%, which is less than both the worldwide rate of 1% proposed by Mahmood (1987) and that of the Middle East of 1.02% (Basson 2008). In view of the above, the annual sedimentation rate for Mosul

Fig. 10 Mosul Reservoir bathymetric survey data points.

Fig. 11 Mosul Reservoir TIN surface model generated from 2011 bathymetric survey using ArcMap.

Fig. 12 New area–capacity curves for Mosul Reservoir.

Reservoir during 1986–2011 is calculated as $45.72 \times 10^6 \text{ m}^3 \text{ year}^{-1}$. This suggests that the reservoir will be filled completely within 169 years.

Furthermore, using Fig. 12, the live storage capacity of the reservoir was derived as $4.797 \times 10^9 \text{ m}^3$ in 1986 and $4.234 \times 10^9 \text{ m}^3$ in 2011. These results show that the sediment deposited within the live storage was $0.5657 \times 10^9 \text{ m}^3$, which represents 49.5% of total sediment deposited within the reservoir. This implies that the live storage capacity was reduced by 11.8% over the period 1986–2011.

To show the sediment distribution within the reservoir area, the reservoir was divided into three zones: upper, middle and lower, using ArcMap (Fig. 13). The divisions were based on the shape of the reservoir: there are two bends within the general shape of the reservoir, and these were used to

designate the borders between these zones. The volume and percentage of accumulated sediment in the three reservoir zones were computed by 3D-analyst tools and are presented in Table 1.

It can be seen from Table 1 that the overall reduction in the capacity of the reservoir was 14.73% between the two surveys. The upper zone of the reservoir showed the highest reduction in storage capacity (39%) compared to the middle (10.5%) and lower (7.17%) zones. This is shown in Fig. 14, and is due to the fact that the River Tigris enters the reservoir from the north. Such a sequence is very logical in reservoirs (Fan and Morris 1992).

It is assumed that the overall capacity of the reservoir that had been evaluated from 1983 topographic maps would be exactly the same value as given by the designed operation curve of the dam when the

Fig. 13 Zones of the Mosul Reservoir polygon at 320 m a.s.l. elevation.

Table 1 Storage capacity of Mosul Reservoir at 320 m a.s.l. for the two surveys..

Location	Storage capacity ($\text{m}^3 \times 10^{-9}$)		Accumulated sediment ($\text{m}^3 \times 10^{-9}$)	Storage reduction (%)
	1983	2011		
Upper zone	1.538	0.938	0.600	39
Middle zone	2.85	2.55	0.300	10.5
Lower zone	3.361	3.12	0.241	7.17
Total	7.749	6.606	1.143	14.73

water level is at 320 m a.s.l. (Fig. 9). However, it should be mentioned, that, at lower water levels, there was a slight deviation of not more than 4%. For the 2011 survey, the readings of the echo sounder

showed very small deviation from actual depth values (± 4 cm) and the water temperature was more or less the same during the survey. In addition, the field survey was conducted during very stable weather conditions when the height of the waves was less than 10 cm due to calm wind.

The results imply that the average rate of sediment yield in the catchment area upstream of the Mosul Dam is $780 \text{ t km}^{-2} \text{ year}^{-1}$. This rate is lower than the erosion rates in the region ($875 \text{ t km}^{-2} \text{ year}^{-1}$) given by Walling and Webb (1996) and Walling (2009). It is assumed that the construction of dams in the upper parts of the River Tigris will trap some of the bed and suspended loads. As a consequence the life span of the Mosul Dam will be increased.

Fig. 14 Three-dimensional profiles of Mosul Reservoir: 2011 and 1983.

CONCLUSIONS

Two TIN maps were constructed for Mosul Reservoir using ArcGIS 9.3 software. The first represents the year 1983 (before the impounding of the reservoir), based on the topographic map (printed in 1983) and the second, the year 2011, based on the bathymetric survey conducted in 2011 (after 25 years of operation). The 1983 map was used to evaluate the adopted operational curves. The results, when comparing the adopted designed operation curves with that obtained from the 1983 topographic map, showed that the maximum percentage difference was 4.0% for the stage-storage capacity curve and 7.7% for the stage-water surface area curve.

New operation curves were established from the 2011 survey. The results showed that the reduction in the storage capacity of the reservoir was 14.73% ($1.143 \times 10^9 \text{ m}^3$). This indicates that the annual rate of sedimentation within the reservoir was 0.59% ($45.72 \times 10^6 \text{ m}^3 \text{ year}^{-1}$), which is less than the depositional rates worldwide and in the Middle East. This implies that the estimated operational age of the dam is about 169 years. This age will be increased due to the upstream sediment trapping once all the dams of the GAP project are constructed. The results showed that the sediment deposited within the live storage part of the reservoir was $0.5657 \times 10^9 \text{ m}^3$. This amount represents 49.5% of total sediment delivered from the catchment area to the reservoir. This implies that the reduction in live storage capacity was 11.8%. Most of the sediment was deposited within the upper zone of the reservoir ($0.6 \times 10^9 \text{ m}^3$) where the River Tigris enters the reservoir, and the amount decreases towards the dam site.

Acknowledgements The authors would like to express their deep thanks and gratitude to Professor Ian Foster for reading the manuscripts and giving very fruitful suggestions and comments. Thanks to the Remote Sensing Centre at Mosul University, Iraq, for providing the topographic maps and aerial photos. The Mosul Dam Project helped the authors to conduct the survey.

REFERENCES

- Al-Alaf, I., 2009. *Ilisu dam and its effect on man and environment in Iraq and Turkey* [online]. Batnaya. Available from: <http://www.batnaya.net/forum/showthread.php?s=9bd97aa8bfae0b9b35554d8ce6c2787e&p=151263#post151263> [Accessed 14 May 2012].
- Al-Ansari, N.A., 1987. Hemrin Reservoir: geological and hydrological investigation. *Journal of Water Research*, Special Publication No. 2.
- Al-Ansari, N.A., 1998. Water resources in the Arab countries: problems and possible solutions. *UNESCO international conference—water: a looming crisis*, 3–6 June 1998, Paris, 367–376.
- Al-Ansari, N.A., 2005. *Applied surface hydrology*. Mafraq: Al al-Bayt University publication.
- Al-Ansari, N.A. and Al-Alalami, H., 2003. Reduction of water storage capacity of the Wadi Arab Dam (Jordan) due to reservoir sedimentation. *Al Manara Journal for Scientific Studies and Research*, 9 (2), 155–168.
- Al-Ansari, N.A. and Knutsson, S., 2011. Toward prudent management of water resources in Iraq. *Journal of Advance Science and Engineering Research*, 1, 53–67.
- Al-Ansari, N.A. and Knutsson, S., 2012. Reduction of storage capacity of two small reservoirs in Jordan. *Journal of Earth Science and Geotechnical Engineering*, 2 (1), 17–37.
- Al-Ansari, N.A., Salameh, E., and Al-Omari, I., 1999. *Analysis of rainfall in the Badia region, Jordan*. Mafraq: Al al-Bayt University Research Paper, No.1.
- Basson, G., 2008. Reservoir sedimentation—an overview of global sedimentation rates, sediment yield and sediment deposition prediction [online]. *International workshop on erosion, transport and deposition of sediment*, 28–30 April 2008, Berne. Available from: http://www.chr-khr.org/files/u8/Bern_Basson.pdf [Accessed 20 July 2012].
- Bazzaz, F., 1993. Global climatic changes and its consequences for water availability in the Arab World. In: R. Roger and P. Lydon, eds. *Water in the Arab world: perspectives and prognoses*. Cambridge, MA: Harvard University Press, 243–252.
- Eagle Electronics, 2003. *Installation and operation instructions*. Publication 988-0143-731 [online]. Available from: http://www.eaglenav.com/upload/Eagle/Documents/Manuals/sea Charter480df_0143-731_121903.pdf [Accessed 10 January 2011].
- Engineering Consulting Bureau, 2010. *Sedimentation study at the intake of North Al-Jazira Irrigation Project*. Mosul: Mosul University, College of Engineering, Contract No. 20, Final Report.
- ESRI, 2012. Available from: <http://www.esri.com> [Accessed 5 April 2012].
- Fan, J., and Morris, G.L., 1992. Reservoir sedimentation. I: Delta and density current deposits. *Journal of Hydraulic Engineering of the American Society of Civil Engineers*, 118 (3), 354–369.
- Ferrari, R.L. and Collins, K., 2006. Reservoir survey and data analysis. In: *Erosion and sedimentation manual* [online]. Denver, CO: Bureau of Reclamation, Sedimentation and River Hydraulics Group. Available from: www.usbr.gov/pmts/sediment [Accessed 15 March 2011].
- Iraqi Ministry of Water Resources, 2012. *Water resources, Mosul Dam* [online]. Available from: <http://www.mowr.gov.iq:81/arabi/> [Accessed 11 July 2012].
- Iraqi Parliament, 2009. *Dams of Iraq. Official site of the Iraqi Parliament* [online]. Available from: <http://www.iqparliament.com/vb/showthread.php?t=30387> [Accessed 14 May 2012].
- IVO, 1968. *Hydrological and reservoir information*. Republic of Iraq: Ministry of Agrarian Reform No. RU3ML0166.
- Lowrance, 2012. *Sonar Log Viewer* [online]. Available from: <http://www.lowrance.co.it/Download/Sonar-Log-Viewer-SLV/> [Accessed 10 February 2012].
- Mahmood, K., 1987. Reservoir sedimentation: impact, extent, mitigation. Washington, DC: World Bank Technical Report No. 71.
- Mohammad, M.E., Al-Ansari, N.A., and Knutsson, S., 2012. Sediment delivery from right bank valleys to Mosul Reservoir Iraq. *Journal of Ecology and Environmental Sciences*, 3 (1), 50–53.
- Muhammad, A.M. and Mohamed, Y.T., 2005. Estimating water yield from all wadis that flow to eastern bank of Mosul Dam Reservoir. *Al-Rafidain Engineering Journal*, 11 (2), 46–56.

- Naff, T., 1993. Conflict and water use in the Middle East. In: R. Roger and P. Lydon, eds. *Water in the Arab world: perspectives and prognoses*, Cambridge, MA: Harvard University Press, 253–284.
- Najib, Y.E., 1980. *Characteristics of Tigris River at Mosul*. Thesis (MSc), College of Engineering, Mosul University.
- Sadik, A. and Barghouti, S., 1993. The water problems of the Arab world: management of scarce resources. In: R. Roger and P. Lydon, eds. *Water in the Arab world: perspectives and prognoses*, Cambridge, MA: Harvard University Press, 1–38.
- Saleh, D.K., 2010. Stream gage descriptions and stream flow statistics for sites in the Tigris River and Euphrates River basins, Iraq. Basins: US Geological Survey, Data series 540.
- Swiss Consultants, 1979. *Mosul Dam Project-planning report. State organization of dams*. Republic of Iraq: Ministry of Irrigation, vol. 1.
- US Army Corps of Engineers, 2004. *Engineering and design hydrographic surveying*. Washington, DC: Department of US Army, Em1110-2-1003/toc.htm.
- Walling, D.E., 2009. The impact of global change on erosion and sediment transport by rivers: current progress and future challenges. *The UN World Water Assessment Programme* [online], 26. Available from: <http://unesdoc.unesco.org/images/0018/001850/185078e.pdf> [Accessed 11 July 2012].
- Walling, D.E. and Webb, B.W., eds., 1996. Erosion and sediment yield: a global overview. In: *Erosion and sediment yield: global and regional perspectives* (Proceedings of the Exeter Symposium). Wallingford: IAHS Press, IAHS Publ. 236, 3–19.