JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 17 2009

USING SATELLITE DATA WITH COMPUTER MODELS TO ESTIMATE THE SEDIMENT YIELD TO RESERVOIRS: MOSUL LAKE, IRAQ

Adil A. Bilal Al-Hamdani
Anass M.M. Rasheed

Dams and Water Resources Research Centre
University of Mosul
Mosul, Iraq

The aim of this research is to estimate surface runoff and sediment yield for all ungaged wadi inflows to Mosul Lake, the regulating lake of the Mosul dam, Iraq. These processes, which affect the live storage of the lake, are estimated using a combination of three computer methods. The first is to convert physical basin maps to digital maps by using GIS methods with satellite images and remote sensing information. The second method delineates the basin boundaries and morphological characteristics and simulates runoff for basins using the Watershed Modeling System. The third method is to estimate the sediment yield using the assumptions of the modified universal soil loss equation under single storm rainfall by applying spatial programs together with programming. The field work consisted of soil tests and surveying cross sections along the lake to compare with the initial cross sections when the reservoir was filled. Sediment yield and accumulation affect the operation of the power station and also the regulation of the releases to the Tigris river. They also determine the life of the project as dead storage diminishes over time.

INTRODUCTION

Sediment yield estimation in the watershed areas of rivers and water surface bodies is considered an important issue in the hydraulic and sediment models design of control canals against floods, sediment estimation in reservoirs, and navigation canals.

It is an important parameter in the evaluation of the sediment effects on the projects and activities occurring due to land use. Estimation of annual sediment yield produced from a single rainfall event requires applying many approaches to get acceptable and valid results. These approaches were classified as a single event approach and an average annual approach, knowing that the most project designs require quantitative estimation of the transported sediment volumes resulting from a single rainfall event.

A commonly used method is the modified universal soil loss equation (MUSLE) developed by Williams and Berndt (1977). This equation estimates the sediment yield produced from a single rainfall event and represents an alternative to the earlier equation universal soil loss equation (USLE) developed by Wischmeier and Smith (1978). The USLE does not define the hydrological processes like rainfall, infiltration, runoff and the main erosion processes like detachment of soil particles as a result of rainfall drop power and sediment transport. It also neglects gully and bank erosion.

A main consideration of hydrology is the rainfall-runoff relationship of a watershed. The response of a watershed to rainfall is observed as the runoff at the basin outlet. For gauged basins this is recorded as a hydrograph (discharge vs. time graph). The unit hydrograph of a basins is the surface runoff caused by a unit of excess rainfall distributed uniformly over the area, and its determination is significant in hydrology. For gauged basins, unit hydrographs are determined from observed storm data, hyetographs and corresponding hydrographs. For ungaged basins there are several techniques for derivation of synthetic unit hydrographs. The SCS (1986) unit hydrograph method is one of these techniques. Different form other techniques, the flexibility of the SCS methodology enables it to be adapted to new technologies such as digital elevation models (DEMs) in Geographic Information Systems (GIS) (Garbrecht et al., 2001; Ogden et al., 2001). It has been widely used in the water resources field. The hydrograph and drainage information derived from DEMs (surface drainage, channel networks, drainage divides, and other hydrographic data) are used with automated methods that are faster and provide more precise and reproducible measurements than traditional manual techniques applied to topographic maps.

The objective of this research is to develop a conceptual model which can mathematically simulate overland flow and erosion-sediment routing, and estimate the sediment yield at the outlet of a watershed. The importance of studying sediment yield in the regulation of Mosul lake is due to the effect of these sediments on the operation of the power station and the regulation of releases to the Tigris river, as well as the overall life of the project.

LITERATURE REVIEW AND ANALYSIS OF RELATED WORK

There are few studies about this area of study, and they are focused mainly on water quality and general ideas about the morphological aspects and bank erosion of the lake. Al-Hamdani (1997) found severe erosion behind Mosul dam is due to jet impact from the bottom outlets. The increase of the rate of erosion within the lake is mainly due the daily fluctuation of the water level as a result of electric power generation. Al-Taiee and Rasheed (2004) explain the morphological characteristics of the Fayda and AL-Baqaq wadies selected as case studies in the eastern area of

Mosul lake to estimate the average sediment yield resulted from the erosion processes during rainfall and predicting a unit sediment hydrograph entering Mosul lake. The study included computer topographical and morphological simulation using the Watershed Modeling System (WMS5.0, 1997) and feeding this model with hydrological and physical data about the site with the aid of commonly used approaches for the estimation of sediment yield in the drainage basins. This is a useful tool to evaluate the future influence of these sediments on Mosul lake and many treatments to reduce these sediments such as check dams may be suggested. The present project will discuss in detail the bathymetric characteristics and annual sediment yield in addition to today's dead storage in comparison with the design storage.

STUDY AREA

The current study area is located upstream of the main Mosul Dam and it represents the watershed area of Mosul lake. The area is 205 km^2 with a maximum elevation of 600 m and minimum elevation of 260 m at the dam. The distance between study area to Mosul city is 50 km. Figure 1 shows the location of the study area in Iraq. Mosul lake has 14 million m^3 of storage and is about 40 km long with an average width of about 2000 m. The main aim of the lake is to regulate the flow to the Tigris river. The minimum design discharge is 330 m^3/sec. The second aim of the lake is to maintain relevant water levels for the proper operation of the intake of the pump storage at the Mosul Dam. To keep the storage volume constant, it is essential to minimize the sediment load transported from the lake catchment area.

Sedimentation is considered one of the biggest problems at the lake and is an important issue in the evaluation of the actual status of the lake to explain and understand the processes that affect the design dead storage of the lake.

Climatology of the Study Area

The study area is classified climatologically according to Koppen classification (Pidwirny, 1999) as mid-latitude (Mediterranean climate) summer dry. Climatological data were collected from the climatological station in the Mosul dam project for the years 1994 to 2006.

The data are maximum and minimum daily temperature, daily pan evaporation, daily maximum and minimum relative humidity daily wind direction and speed, and rainfall depths. Figures 2 and 3 show the average maximum and minimum air temperature for the years 1994 to 2006. The temperature is presented by percentage groups from greater than 10 ^oC and less than 50 ^oC for the maximum temperature, and from greater than 10 ^oC and less than 40 ^oC for the minimum. The measured maximum percentage for the maximum air temperature during the year is 29% for temperatures between 20 ^oC and 30 ^oC.

Figure 4 shows the average maximum relative humidity. The maximum measured relative humidity is 48% for a range of to 80-90% relative humidity. The daily pan evaporation in the study area is shown in Figure 5 in which 43% of the year represents an evaporation less than 5 mm/day and 23% of the year the recorded evaporation depth ranges between 15 to 20 mm/day. The average lake evaporation may be calculated by multiplying the pan evaporation depth by 0.75 as a pan coefficient (Al-Taiee and Hachum, 1988).

The average measured daily wind direction is shown in Figure 6, in which the northeast direction represents the maximum percentage during the year while Figure 7 shows that 44% of the wind velocity is less than or equal to 5 km/hr.

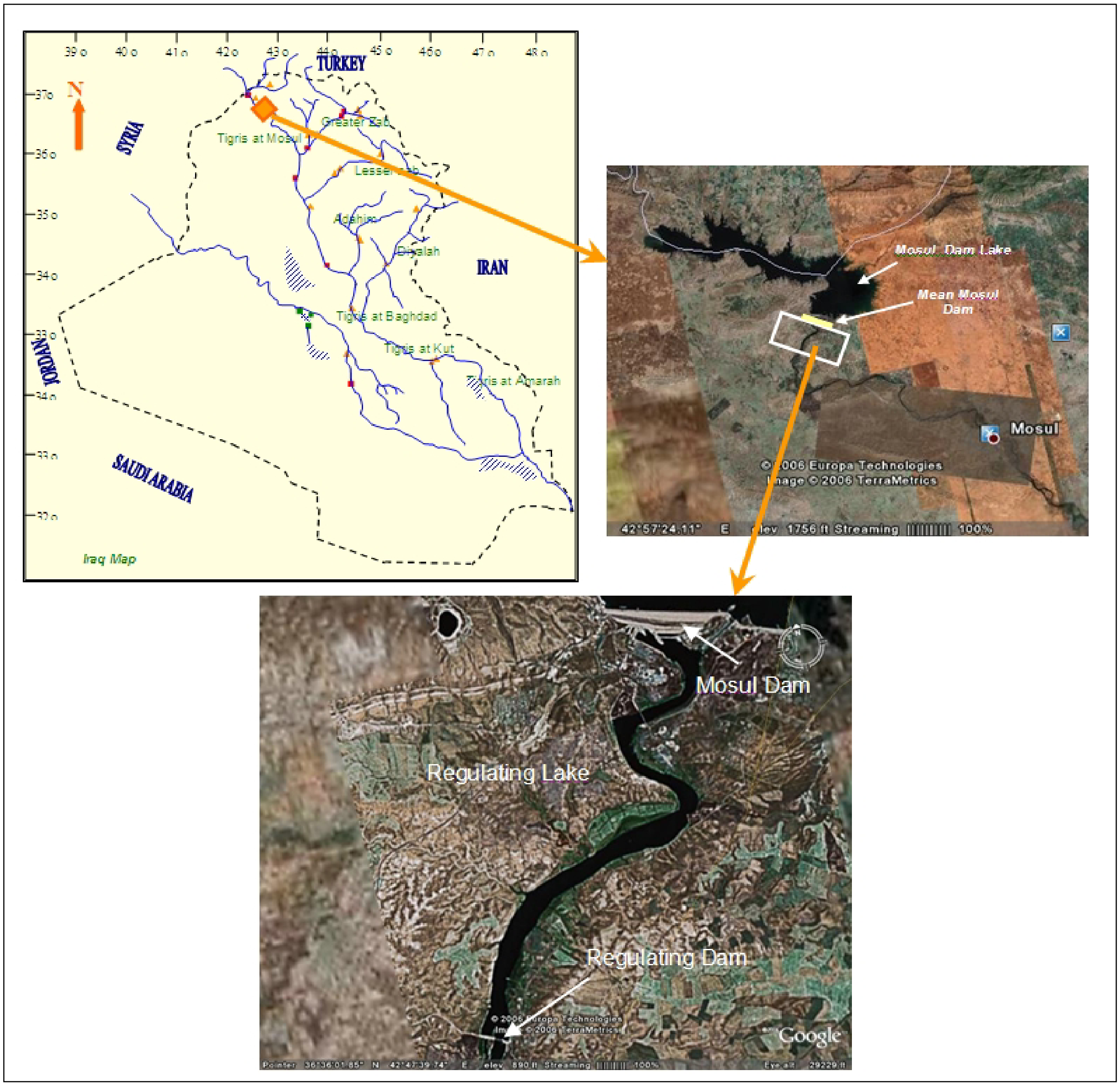

Figure 1. Location map of study area.

Figure 8 shows that 10% of the year consists of rainy days. Figure 9 shows that 26% of the rain days produced runoff (i.e., more than 12 mm depth of rain).

MORPHOLOGICAL CHARACTERISTICS OF LAKE DRAINAGE BASINS

Morphological characteristics like drainage density, watershed length and width, channel length, and channel slope of the watershed are important in understanding the hydrology of the watershed. Runoff response is different for different slopes, shapes, lengths, widths and areas. Computation of watershed morphological characteristics is a prerequisite to further detailed hydrological analysis of the watershed. Hydrologists have attempted to relate the hydrologic response of watersheds to watershed morphologic characteristics. Presently these characteristics are determined manually from the topographic and stream network maps of the watershed. Manual computation in order to generate these characteristics is not only tedious and error prone but also time consuming.

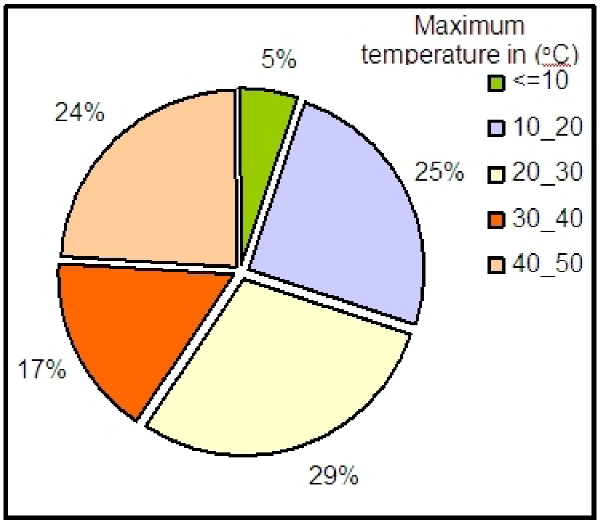

Figure 2. Average groups for the maximum

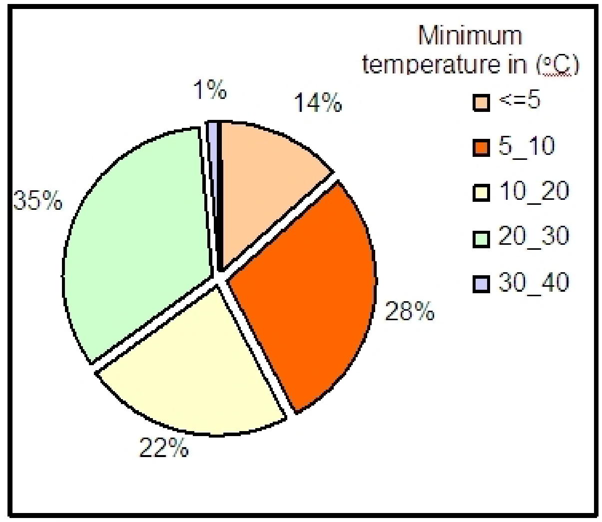

Figure 3. Average groups for the minimum daily

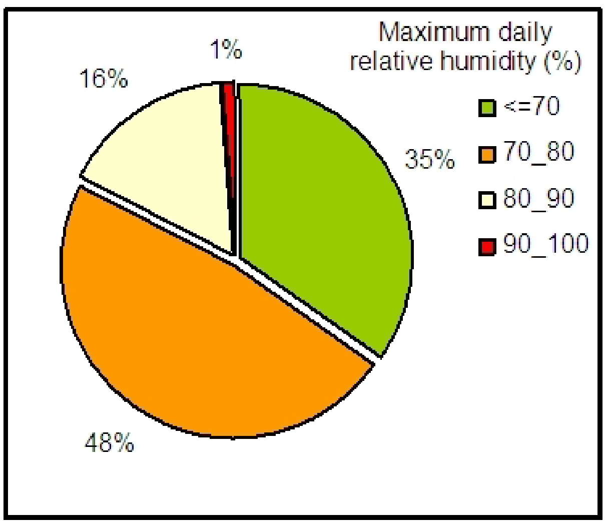

Figure 4. Average groups for the maximum daily

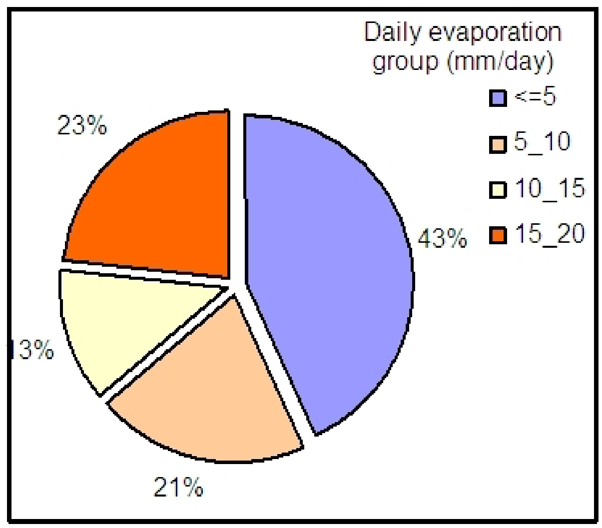

Figure 5. Average percentage for daily

Technologies like Geographic Information Systems (GISs) (Klong, 2000) have gained significant importance over the last decade in their application to distributed hydrologic modeling. GIS is suitable for analysis of spatially referenced data. Nowadays GIS is widely used for resources planning in watersheds. GIS can be used for the computation of the morphological characteristics of a watershed.

The combination of Watershed Modeling Systems (WMS5.0, 1997) with Arc/Info GIS was used to compute the important morphological characteristics of the watershed. Important watershed characteristics included are the area of watershed, perimeter, elongation ratio, circular ratio, form factor, drainage density, average slope of watershed, main stream and channel slope. The model uses watershed boundary maps, drainage network maps and contour maps for computation of the morphological characteristics.

The morphological characteristics for all watersheds that flow to Mosul lake are shown in Figure 10 and explained in Table 1.

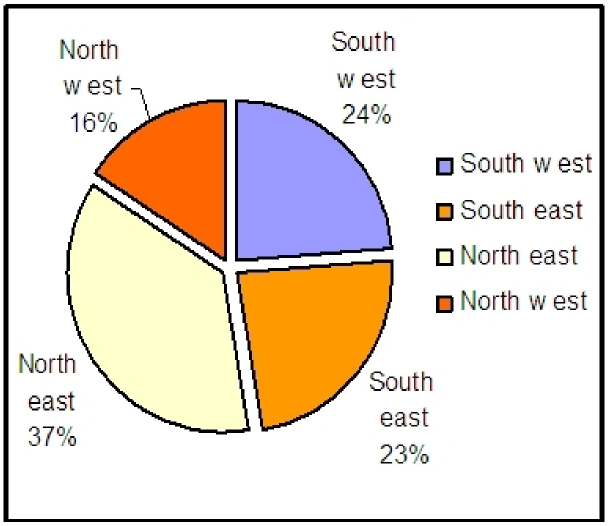

Figure 6. Average wind directions percentage during the years 1994-2006.

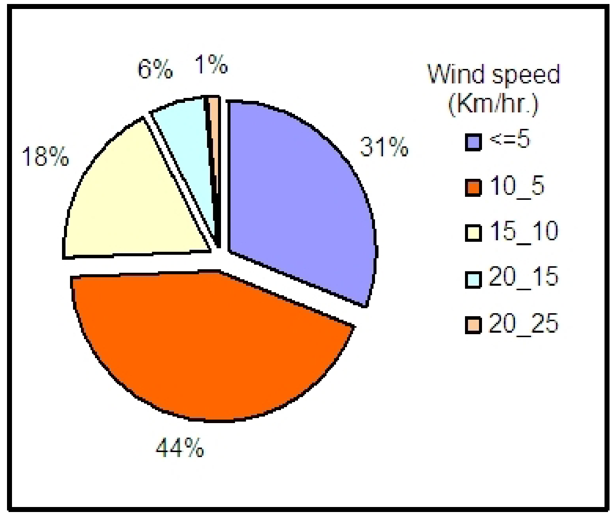

Figure 7. Average wind velocity percentage during the years 1994-2006.

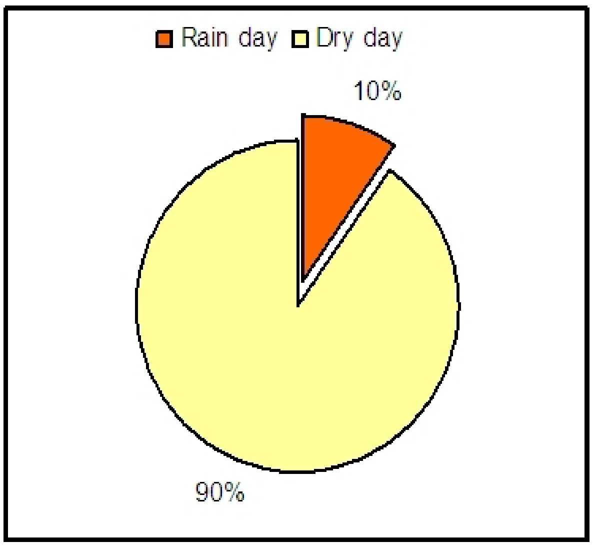

Figure 8. Average percentage of the rain and dry days during the years 1994-2006.

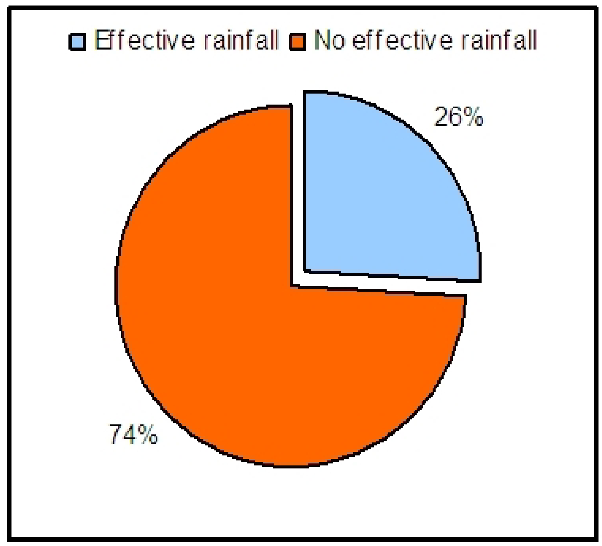

Figure 9. Average percentage for the effective rainfall percent from the total of rain days in the year.

COMPUTER MODEL

Methodology

The aim of a watershed predictive model is to reach a best understanding of the watershed performance. In addition to a being a suitable tool to use specific data to predict flows. The simulation process in the model is considered an alternative to carrying out continuous detailed field studies and experiments which are often costly and difficult to verify. In this study, a conceptual model for the study site was used. The conceptual model is a simple representation for the study site watershed borders and the surface runoff movement over the basin for the main streams in the valleys, in addition to the topography of the basin and soil types. A number of assumptions and simplifications to get the conceptual model were adopted. The watershed area was divided into many parts based on non-homogeneity in the physical characteristics. These

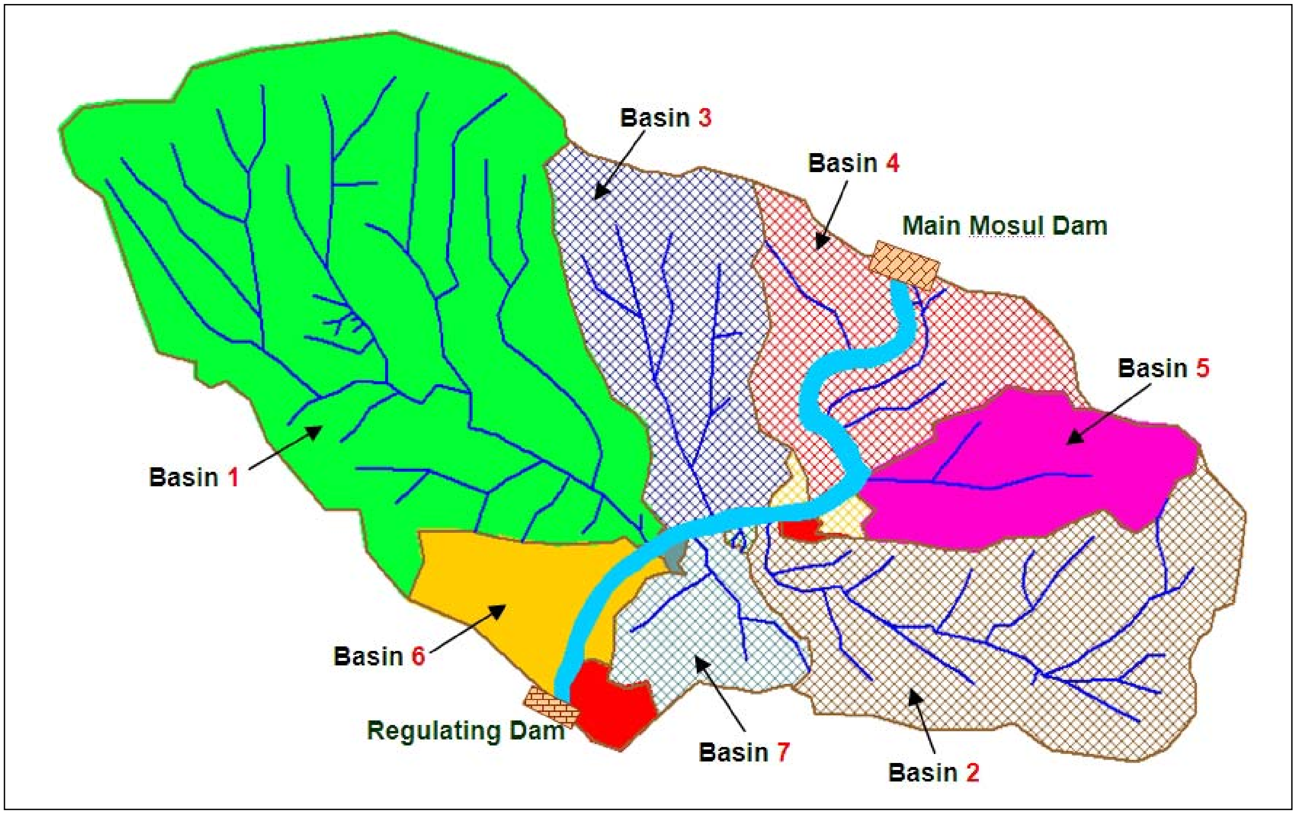

Figure 10. Location map of the study area showing all watersheds that flow to the regulating dam.

characteristics can be represented using some specified symbols such as points, curves, and polygons to illustrate all the information which defines the conceptual model, including boundary conditions. These characteristics can be converted to digital maps using GIS. These data are provided to the watershed modeling program to simulate the morphological characteristics of the study watershed area and surface runoff over the basin, producing the surface runoff hydrograph at watershed outlet.

Sediment yield modeling is more complicated due to the detailed information required about the amount and type of precipitation, runoff, and velocity of water. The objective of this study is to develop a conceptual model which can mathematically simulate overland flow, erosion-sediment routing and estimate the sediment yield of the outlet of watershed.

MODEL COMPUTATION

Runoff

Owing to simplicity and compatibility with remote sensing and GIS, the runoff component was estimated using the SCS curve number method (Soil Conservation Service, 1986) as follows:

$$R = 0 \text{ if } P < (0.2 * S) \quad (1)$$

where, R = Runoff (mm), P = Precipitation (mm).

$$S = (25400 / CN) - 254 \quad (2)$$

where, CN = Curve number

The curve numbers can be derived from information on land use, land cover and hydrological soil groups. The curve numbers are provided for moderate antecedent soil moisture conditions

Table 1. Morphological characteristics for all basins in Figure 5.

Morphological Characteristics	Basin 1	Basin 2	Basin 3	Basin 4	Basin 5	Basin 6	Basin 7
Area (Km^2)	82.050	36.600	24.540	22.440	14.820	10.040	8.960
Basin Slope (m/m)	0.025	0.014	0.035	0.020	0.018	0.032	0.010
Average Overland Flow	0.580	0.550	0.600	0.550	0.610	1.010	0.480
Percent Facing North (%)	0.220	0.510	0.170	0.340	0.540	0.370	0.880
Percent Facing South (%)	0.780	0.490	0.830	0.660	0.460	0.630	0.120
Max Flow Distance (Km)	16.60	13.480	9.340	8.230	7.640	6.050	4.730
Max Flow Slope (m/m)	0.006	0.007	0.011	0.009	0.006	0.022	0.009
Centroid From Centroid to Stream (Km)	1.920	0.600	0.690	0.600	0.230	0.300	0.080
Centroid Stream Distance (Km)	7.600	6.630	5.060	3.220	3.180	3.080	2.950
Centroid Stream Slope (m/m)	0.005	0.005	0.006	0.004	0.015	0.017	0.002
Max Stream Length (Km)	15.72	12.52	7.020	6.490	4.700	3.860	4.070
Max Stream Slope (m/m)	0.012	0.005	0.016	0.009	0.013	0.006	0.008
Basin Length (Kilometer)	14.70	9.55	8.26	6.40	6.89	3.66	3.78
Basin Perimeter (Km)	40.65	30.23	23.52	23.23	17.68	15.20	13.83
Basin Shape Factor	2.632	2.494	2.778	1.828	3.203	1.334	1.597
Basin Sinuosity Factor	1.070	1.311	0.850	1.014	0.683	1.055	1.076
Basin Average Elevation (m.a.s.l)	381.1	328.9	339.3	307.3	330.7	311.4	297.7
Drainage Density	0.862	0.909	0.833	0.909	0.820	0.495	1.042
Circularity ratio	1.266	1.410	1.339	1.384	1.296	1.354	1.304
Circularity ration	0.624	0.503	0.557	0.522	0.595	0.546	0.588
Elongation Ration	0.096	0.160	0.234	0.261	0.333	0.455	0.544
Area Relations	19.705	12.140	9.551	9.052	7.057	5.587	5.218

(ASM-II), to convert into ASM-I and ASM-III conditions, regression equations are developed from the data available in the Handbook of Hydrology using curve fit software.

$$\text{CN-I} = 0.3358 * 1.009^{\text{CN-II}} * \text{CN-II}^{1.038} \quad (3)$$

$$\text{CN-III} = 3.5610 * 0.9961^{\text{CN-II}} * \text{CN-II}^{0.8101} \quad (4)$$

where, CN-I, -II, -III represent curve numbers for antecedent moisture conditions I, II and III respectively. ASM = Antecedent Soil Moisture.

To compute the total runoff over a grid cell, in m^3,

$$V = (R / 1000) * \text{grid cell area (in } m^2) \quad (5)$$

Peak runoff rate

The peak runoff rate (Qp) can be computed as suggested in EPIC (Erosion Productivity Impact Calculator) model:

$$Q_p = 3.97 * A^{0.7} * S^{0.16} * \left(\frac{R}{25.4}\right)^{0.903 * A^{0.017}} * LW^{-0.19} \quad (6)$$

where, A = area of the cell (km^2), S = length of the cell along slope (m/km), R = runoff depth (mm), LW = length to width ratio of the cell.

All the grid cells in the present study are square cells having length to width ratio of 1.0.

Erosion

The erosion component was divided into detachment, transport capacity and net detachment. Details are given below.

Detachment (D)

To compute detachment of soil particles the Universal Soil Loss Equation (USLE) or its variants were often used with a modification in energy component. We have assumed that the surface runoff is the major component that governs the soil detachment and its transport. Hence we retained the basic structure of Revised Universal Soil Loss Equation (RUSLE) as:

D = ë * K * LS * C * PP (7)

where, D = soil loss, ë = erosive energy component, K = soil erodibility factor, LS = slope length factor, C = cover factor, PP = erosion control practice factor.

The ë ?component could be explained by modifications as suggested by various authors as (from Erosion Productivity Impact Calculator (EPIC) model documentation for MUSS (small watershed version of (MUSLE))

ë = 0.79 * (V * Qp) $^{0.65}$ * $A^{0.009}$ (8)

where, V = storm runoff volume (m^3) , Qp = peak runoff rate (m^3/sec), A = area of the grid cell (ha).

The other parameters like K, C, LS, and P factors were computed as defined in the RUSLE manual, and converted to the digital map (DEM grid file) representing the distribution of these characteristics in the study area.

The K factor

Soil Erodibility is the function of physical characteristics of soil and its management, including both land and crop management. The erodibility index was calculated for each soil series in this study, using the following equation:

K = (2.1 $M^{1.4}$) 10^{-4} (12-a) + 3.25 (b-2) + 2.5 (c-3) (9)

- where M = particle size parameter (% silt + % very fine sand) or (100 - % clay)
- a = % organic matter
- b = soil structure class (1 for very fine granular; 2 for fine granular; 3 for medium to coarse granular; and 4 for blocky, platy or massive);

· c = soil permeability class (1 for rapid; 2 for moderate to rapid; 3 for moderate; 4 for slow to moderate; 5 for slow; and 6 for very slow)

All M, a, b and c values were extracted from soil reports of individual soil series.

According to this equation, the K value is calculated on the basis of the organic matter content, the type of soil structure, the soil permeability and the soil texture. Figure 11 shows the distribution of soil erodibility coefficient in the study area.

The LS factor

In this study, the slope length for different types of land use was determined, using information from the field survey. Data on aspect, land use and slope maps were overlaid to map the slope length. L and S were treated as a combined factor to find the LS index. The LS factor was computed for slope gradients of less than 8%, using the following equation.

$$LS = (1/22.13)^{n}\ (0.0065 + 0.045\ s + 0.0065\ s^{2}) \quad (10)$$

where, LS = slope length in meters, s = slope gradient in % , and n is slope length exponent. Table 2 shows values of n.

When the slope had a gradient of more than 8%, the following equation was used.

$$LS = \{(1/22.13)^{0.5}\}\ \{(0.17\ s) - 0.55\} \quad (11)$$

The C factor

The cover factor (**C**) is defined as the ratio of vegetation cover to bare soil. This value ranges between 0.2 to 0.25 for the present study area.

The PP factor

The erosion control factor (PP) is considered a function of land use and is often used in agricultural lands (Haan et al., 1994). The PP value depends on the gradation of the surface topography, slope, cultivation method, and roughness of land. Its value is usually 1 where data are not available about the land use. No agricultural activities were found in the watershed of Mosul lake, and the PP value is taken to be 1.

Slope of Land Element

A slope map can be produced using the slope operation in GIS. According to the GIS user manual, slope of cell at location x,y is calculated as an average. Rainis (2004) classified this method as a quadratic surface method. Equations 12 and 13 are used to calculate the average change in elevation for each unit distant in x and y directions. Figure 12 shows the simple grid file and the procedure below explains how Equations 12 and 13 to calculate the slope of grid (Z5) in Figure 12.

$$Sx = \frac{(Z3 + Z6 + Z9) - (Z1 + Z4 + Z7)}{3} * Cx \quad (12)$$

$$Sy = \frac{(Z1 + Z2 + Z3) - (Z7 + Z8 + Z9)}{3} * Cy \quad (13)$$

where

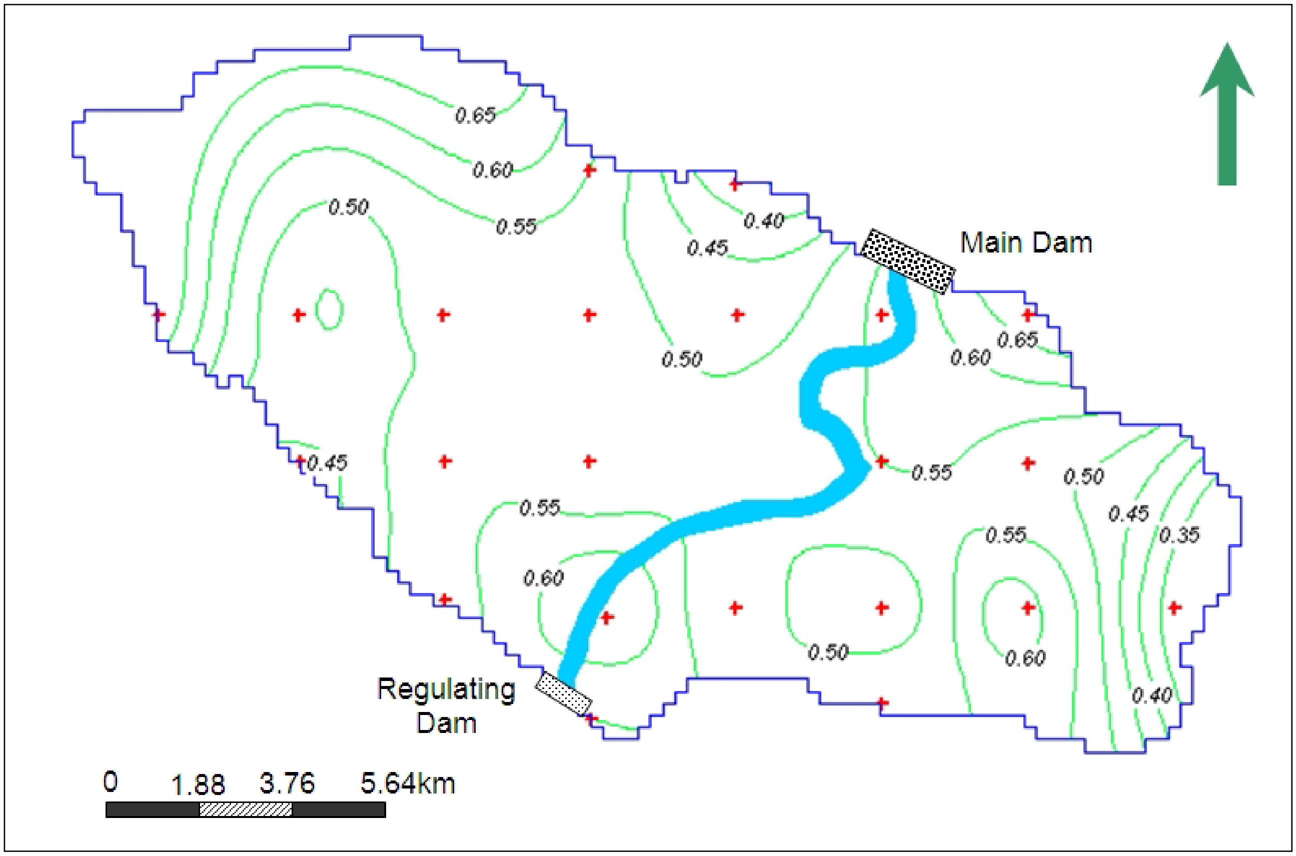

Figure 11. Distribution of soil erodibility coefficient.

Table 2. Values of n.

Slope	< 1%	(1-3) %	(3-5) %	> 5 %
n	0.2	0.3	0.4	0.5

Z1..Z9 = Elevation in 3*3 window in Figure 12

Cx = Pixel size in x direction,

Cy = Pixel size in y direction.

Calculate the slope for x,y as follows,

$$S = \frac{\sqrt{(Sx)^2 + (Sy)^2}}{2} \tag{14}$$

If S =< 1, slope percent = 100 * S otherwise slope percent = 200 – 100/S

Slope degree is calculated as in Equation 15 below.

$$Slope\_degree = \tan^{-1}(S) * \frac{180}{\pi} \tag{15}$$

Transport Capacity (T)

It is a well known phenomenon that all the detached sediment will not be transported to the mouth of the watershed. It depends on the transport capacity of the flow. The transport capacity equation given by Kandrika (2006) was used as it accounts for surface cover variations.

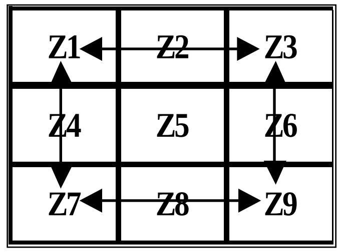

Figure 12. Basic approach to calculating slope.

$$T = Q^D * C * Sin(S) * 10^{-6} * A \quad (16)$$

where, T = transport capacity of the flow (tons), Q = runoff (mm), C = cover factor (dimensionless), S = slope of the land element (%), A = area of the cell (m^2).

Net Detachment (N)

It is true that all the sediment detached will not be transported down the stream. The transport capacity of the cell limits the net detachment and the detachment excess of transport capacity will be deposited in the cell under consideration. As the transportation of sediment detached (D) is limited to the transporting capacity, the net detachment (N) from the cell will be:

$N = D$ if $(D < T)$ or $N = T$ if $(D > T)$

Sediment Transport from Grids to Streams

The variables, D and L are required to route the gross eroded sediment in each cell to the closest adjacent stream. A soil transport model was derived from field measurements (Raleigh, 1990).

$$N_d = N * (l-0.97\ Le/L) \quad (17)$$

where: N_d = mass moved from each cell to the closest stream network, Le = the least-cost distance from a cell to the nearest stream network, L = the maximum distance that sediment with mass M may travel (m). This variable was calculated by the equation detailed in Raleigh (1990).

$$L = 5.1 + 1.79 * M \quad (18)$$

SURVEYING MOSUL LAKE

Mosul lake has an active storage capacity of 14 million cubic meters. The main aim of the lake is to ensure continuous minimum discharge of 330 m^3/sec into the Tigris river and to maintain a certain water level for the operation of the pump storage scheme. One of the main aims of the present study is to evaluate the real status of the storage by comparison between the volume storage of the lake after five years of the operation of the dam in 1991 with the present storage volume in 2007. The volume difference between the two periods will be related to the sediment yield in the watershed which will be estimated and simulated using the Watershed Modeling System (WMS5.0, 1997). Figure 13A shows the layout of the regulating lake with the fixed surveyed cross-sections during 1991 and 2007. Eight lake cross-sections were selected to survey during 2007 based on the geomorphological and geographical features of the sections to cover almost all the lake.

The surveying process was conducted using an echo-sounder instrument and some surveying instrument fixed on a steam boat. The cross sections were surveyed beginning from the left side to the right side looking downstream. Using WMS, two dimensional contour maps for the lake depth in the selected surveying periods 1991 and 2007 are shown in Figure 13.

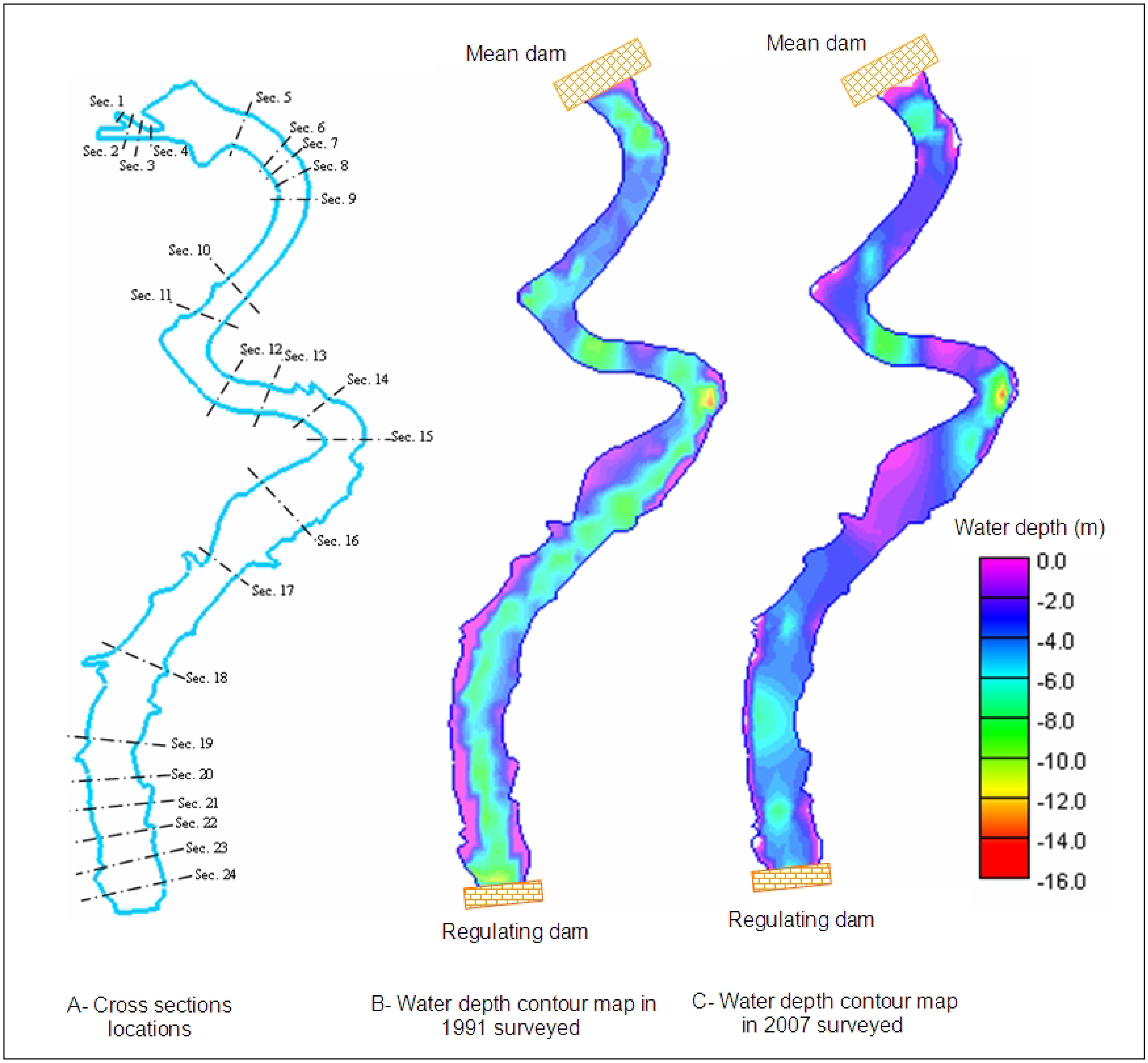

Figure 13. Location of cross sections surveyed and contour maps for the regulating lake surveyed during 1991 and 2007.

RESULTS AND DISCUSSION

The assumption of the US Soil Conservation Service (SCS) which defines the curve number was adopted to simulate the runoff and predict the conceptual model for the study site using the WMS. The model was fed by all the hydrological soil types in the basin represented by maps describing the distribution of soils in the basin (SCS, 1986). Soil tests in the basin showed sand loam and silt loam which are classified as type C. The agricultural processes and activities were considered as type SR. This information was fed to the computer model using maps to describe these characteristics. The value of curve number CN was found to be 85 for all the basins of the study area. This means any rainfall less than 11 mm will not produce runoff.

Analysis of the rainfall records for the Meteorological station of Mosul dam showed 73 effective rainfall storms during 1993 – 2006 which were simulated by the computer program. Table 3 explains the results of predicting sediment yield the by simulation model in the Universal Soil Loss Equation (USLE).

Table 3. Some of the results of sediment yield predication model.

Day	Month	Year	P (mm)	Basin 1 (tons)	Basin 2 (tons)	Basin 3 (tons)	Basin 4 (tons)	Basin 5 (tons)	Basin 6 (tons)	Basin 7 (tons)	All Basins (tons)
4	12	1993	25	2050	915	613	561	370	251	20	4780
18	12	1993	18	701	313	210	192	127	86	7	1633
23	12	1993	23	1639	731	490	448	296	201	16	3822
30	12	1993	23	1639	731	490	448	296	201	16	3822
16	2	1994	16	361	161	108	99	65	44	4	841
3	3	1994	24	1842	822	551	504	333	225	18	4295
21	3	1994	14	42	19	12	11	8	5	0	97
3	4	1994	41	6075	2710	1817	1661	1097	743	59	14163
3	11	1994	16	361	161	108	99	65	44	4	841
17	12	1994	17	528	236	158	144	95	65	5	1231
30	12	1994	20	1061	473	317	290	192	130	10	2473
21	1	1995	35	4413	1968	1320	1207	797	540	43	10287
29	1	1995	21	1248	557	373	341	226	153	12	2911
5	2	1995	30	3168	1413	947	866	572	388	31	7385
15	3	1995	18	701	313	210	192	127	86	7	1633
25	3	1995	18	701	313	210	192	127	86	7	1633
4	1	1996	20	1061	473	317	290	192	130	10	2473
5	1	1996	14	42	19	12	11	8	5	0	97
6	1	1996	18	701	313	210	192	127	86	7	1633
19	1	1996	17	528	236	158	144	95	65	5	1231
29	1	1996	14	42	19	12	11	8	5	0	97
11	2	1996	51.5	9426	4205	2819	2578	1703	1153	92	21975
25	3	1996	20	1061	473	317	290	192	130	10	2473
6	12	1996	30.5	3286	1466	983	899	594	402	32	7662
9	12	1996	38	5221	2329	1561	1428	943	639	51	12172
29	12	1996	30	3168	1413	947	866	572	388	31	7385
16	1	1997	22	1441	643	431	394	260	176	14	3360
26	2	1997	18	701	313	210	192	127	86	7	1633
29	10	1997	18	701	313	210	192	127	86	7	1633

Table 3 shows that the amount of total sediment yield into Mosul lake is 317,952 tons during 1993 – 2006. The sediment yield calculated by the USLE includes only one type of sediment yield (sheet and rill Erosion. To calculate all types of erosion, the Dendy and Bolton (1976) Equations 19 and 20 were used. These equations include all types of sediment yield (sheet and rill Erosion, gully Erosion, channel Bed and bank erosion and mass movement). Table 4 shows sediment yield during 1993 – 2006. The total sediment yield to the lake increased to 1,079,807 tons during this period.

$$Ys = 1280\ Q^{0.46}\ [1.43-0.26\ \text{LOG}\ (A)] \qquad (19)$$

$$Ys = 1958\ e^{-0.055Q}\ [1.43-0.26\ \text{LOG}\ (A)] \qquad (20)$$

where, Q = yearly total runoff (inch) and A = drainage area (mile^2)

The two values of the predicted sediment yield represent the results of the simulation programs. To check these results with the actual sediment yield during the same period, the lake was surveyed bathymetrically two times in 1991 and in 2007. The difference between the two surveys represents the volume of sediment yield to the lake. This volume was calculated using the Surfer 8 package. Actual measured volume of sediment is 1,014,241 tons. This value represents all types of which entered the lake.

The comparison between the predicted and measured sediment quantities shows good agreement. The percentage of error between predicted and observed is only 6%. Sheet and rill erosion represents 32% of the total while 68% consists of gully erosion, channel bed and bank erosion and mass movement. Some empirical equations predicted the sediment yield in the study area. These equations may be used in the future without any need to operate the simulation model as shown in Table 5.

Table 4. Results of predicted sediment yield by Dendy and Bolton (1976).

Year	P (mm)	Sediment Yield (tons/km^2/year)	Sediment Yield (tons)
1993-1994	453	305	62528
1994-1995	474.5	292	59767
1995-1996	332	393	80617
1996-1997	332	393	80617
1997-1998	337	389	79775
1998-1999	142	586	120146
1999-2000	265	453	92796
2000-2001	334	392	80279
2001-2002	308	414	84784
2002-2003	330	395	80956
2003-2004	311	411	84252
2004-2005	280	439	89919
2005-2006	316	407	83372
	Total sediment yield		1079807

Table 5. Empirical equations.

Basin name	Empirical equations for to predicting sediment yield (tons)	Type of the eroded sediment yield	R^2
Basin 1	$Ys = 2.5518P^2 + 83.108P – 1622.1$	Sheet and Rill Erosion	1
Basin 2	$Ys = 1.1383P^2 + 37.072P – 723.58$	Sheet and Rill Erosion	1
Basin 3	$Ys = 0.7632P^2 + 24.857P – 485.16$	Sheet and Rill Erosion	1
Basin 4	$Ys = 0.6979P^2 + 22.729P – 443.64$	Sheet and Rill Erosion	1
Basin 5	$Ys = 0.4609P^2 + 15.011P – 292.99$	Sheet and Rill Erosion	1
Basin 6	$Ys = 0.3122P^2 + 10.17P – 198.49$	Sheet and Rill Erosion	1
Basin 7	$Ys = 2.2077P^2 – 32.865$	Sheet and Rill Erosion	0.98
All Basins	$Ys = 5.9491P^2 + 193.76P – 3781.8$	Sheet and Rill Erosion	1
All Basins	Ys = 789.7 e-0.0021PP	Sheet and Rill Erosion, Gully Erosion, Channel Bed and Bank Erosion and Mass Movement	0.96

p = rainfall depth for single event (mm), PP = yearly rainfall depth (mm), Ys = sediment yield (tons).

CONCLUSIONS

According to the conceptual model the amount of total sediment yield from sheet and rill erosion which entered the lake was 317,952 tons during 1993-2006. The total amount of sediment from all sources for the same period was 1,079,807 tons. This number represents sheet, rill, gully, channel and bank erosion when derived using the Dendy and Bolton equations. This amount agrees with the actual measured volume from 1991 to 2007 of 1,014,241 tons.

A comparison between the predicted results and the actual sediment accumulation shows good agreement. Sheet and rill erosion represents 32% of the total.

Finally, by using statistical analysis some empirical equations are proposed for the sediment yield in the study area which can be used in the future without any need to operate the model. They are listed in Table 5.

RECOMMENDATIONS

Recommendations concerning reduction of sediment yield to Mosul lake include:

1. Planning for the effective management of the watershed area of the regulating lake using methods such as check dams, vegetation cover, and proper plowing of the soil surface across the main slope of the land.

2. Bathymetric survey of the lake every 2-3 years to evaluate the real status of storage volume.

3. Flushing the lake every 3 years by drawing down the water level to eject sediment from the lake.

4. Design engineering treatments for the banks of the lake to prevent scouring due to the fluctuation of the water level.

REFERENCES

Al-Taiee, T.M., and A.M.M. Rasheed. 2004. Predicting flowing sediment hydrograph in Fayda and AL-Baqaq wadies. Al-Rafidain Engineering Journal. Vol. 12(3), pp.32-44.

Al-hamdani, A.B. 1997. Development of the Tigris river reach between Mosul dam in Mosul city. Unpub. Phd Thesis College of Science University of Baghdad, Iraq.

Al-Taiee, T.M., and A.Y. Hachum. 1988. Climatological estimates for evaporation from Mosul dam. Confidential research. Research center for dams and water resources, Mosul University.

Dendy, F.E., and G.C. Bolton. 1976. Sediment yield runoff-drainage area relationship in the United States, J. of Soil and Water Conservation.

Garbrecht, J., F.L. Ogden, P.A. DeBarry, and D.R. Maidment. 2001. GIS and distributed watershed models. I: Data coverages and sources. Journal of Hydrologic Engineering., ASCE, Vol.6(6), pp. 506-514.

Haan, C.T., B.J. Barfield, and J.C. Hayes. 1994. Design hydrology and sedimentology for small catchment. Academic press.

Klong, L. 2000. Integration of geographic information systems (GIS) and satellite remote sensing (SRS) for watershed management. Apisit Eiumnoh School of Environment, Resources and Development Asian Institute of Technology, Thailand.

Kandrika, S., and L. Venkataaratnam. 2006. A spatially distributed event-based module to predicated sediment yield. Journal of Spatial Hydrology. USA. Vol. 5(1), pp. 1-19.

Ogden, F.L., J. Garbrecht, P.A. DeBarry, and L.E. Johnson. 2001. GIS and distributed watershed models. II: modules, interfaces, and models. Journal of Hydrologic Engineering., ASCE, Vol. 6(6), pp. 515-523.

Pidwirny, M. 1999. Climate regimes of the world climatology. The geographic study of the atmosphere, International to physical geography II. Department of Geography, Okanogan University College.

Rainis, R. 2004. The effects of slope information from different GIS software. Journal of Spatial Hydrology. USA. Vol. 4(2), pp. 1-20.

Raleigh, N. 1990. Modeling soil erosion transport on forest landscape. Southern Global Change Program USDA Forest Service, USA.

SCS. 1986. Urban hydrology for small watershed. Technical releases 55, 2nd Ed., Soil Conservation Service, U.S. Dept. of Agriculture, Washington D.C.

Williams, J.R., and H.D. Berndt. 1977. Sediment yield prediction based on watershed hydrology. Trans. ASAE 20(6):1 100-1104.

Wischmeier, W.H., and Smith, D.D. 1978. Predicting rainfall erosion losses-a guide to conservation planning, Agriculture Handbook No. 537. U.S. Department of Agriculture, Washington, D.C.

WMS5.0. 1997. Watershed modeling system. engineering computer graphics laboratory. Brigham Young University, USA.

ADDRESS FOR CORRESPONDENCE
A.B. Al-Hamdani
Dams and Water Resources Research Centre
University of Mosul
Mosul, Iraq

Email: hamdani_adil@yahoo.com