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Hydrological Criterion of Sedimentation Processes in the Iraqi Dams

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☐ ABSTRACT ☐

Six dam sites on Tigris river and its tributaries (the Greater and the Lesser zab rivers) were chosen as a case study to predict the hydrological criterion of sedimentation processes in their reservoirs such as trap efficiency, sedimentation index and their impact on the annual storage loss according the predicted sediment yield. The studied reservoirs were classified hydrologically and topographically according to the classification of reservoirs predicted by many scientists interested in dams engineering. Hydrologically, the studied reservoirs were classified either seasonal or hold over storage reservoirs in which almost all the studied reservoirs were classified as seasonal storage reservoirs. Topographically they were classified either gorge or hill or flood plain foothill types. The research work concluded that the trap efficiency values of the studied Iraqi dams ranged between 0.6 to 0.84. It increased in accordance with the increase of sedimentation index, the capacity inflow ratio and the retention period. Moreover, there is a strong relation between the trap efficiency values and the narrowness and depths of the reservoirs. Finally the annual storage loss due to the sedimentation in the studied dams was predicted to be in a range of (0.1 to 0.84) percentages.

Key Words: Trap efficiency, Reservoirs, Sedimentation processes**,** Dams.

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المعايير الهيدرولوجية لعمليات الترسيب في السدود العراقية

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□ الملخّص □

اختيرت ستة خزانات للسدود المنشاة على نهر دجلة وروافده كحالة دراسية لتعيين المعايير الهيدرولوجية لعمليات الترسيب مثل كفاءة الترسيب، دليل الترسيب وتأثيرها في فقدان السعة الخزنية السنوية استنادا إلى الإنتاج الرسوبي المخمن. صنفت الخزانات قيد الدراسة هيدرولوجيا وطوبوغرافيا حيث تم تصنيفها هيدرولوجبا إلى خزانات موسمية وخزانات ذات خزن طويل الأمد، كما صنفت طوبوغرافيا إلى ثلاثة أنواع وهي الوادي الضيق والهضاب وأقدام السهول الفيضية.

خلص البحث إلى أن قيمة كفاءة الترسيب في السدود العراقية قيد الدراسة تراوحت بين (0.6 إلى 0.98) وتزداد هذه القيمة مع زيادة دليل الترسيب وبزيادة النسبة بين السعة الخزنية ومعدل الجريان الداخل السنوي وكذلك مع زيادة زمن الاحتجاز وإن هنالك علاقة كبيرة بين كفاءة الترسيب مع تضيق شكل الخزان وعمقه. كما تراوحت قيمة المتنبأ بها للفقدان السنوي لحجم الخزان بسبب الترسيب في هذه الخزانات مابين (0.1 إلى 0.84) %. كما تراوحت النسبة بين زمن الاحتجاز ومعدل سرعة الجريان في الخزان ما بين($1.6*10^{8}$ إلى $8*10^{8}$) متر$^{-1}$.

الكلمات المفتاحية: كفاءة الترسيب، خزانات، عمليات الترسيب، سدود.

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Introduction:

Reservoirs interrupt the flow of water and therefore sediment. It causes a change in the upstream hydraulic depth of flow and velocity by forcing the energy gradient to approach zero. The result is a loss of transport capacity with the resulting sediment deposition in the reservoir. The primary reservoir problem is the deposition of sediment in the reservoir. The determination of the sediment accumulation over the life of the project is the basis for the sediment reservoir. The reservoir sedimentation study should forecast sediment accumulation and distribution over the life of the project. The ultimate destiny of all reservoirs is to filled with sediment, (Linsley,et.al.,1992). The above consequence of sediment deposits is depletion in reservoir storage capacity. Figure(1) illustrates components of sediment deposition in a deep reservoir. The volume of sediment material in the delta and the main reservoir depends on the inflowing water and sediment, reservoir geometry, project operation and life among other things. The delta will continue to develop with time and the reservoir will eventually fill with sediment.

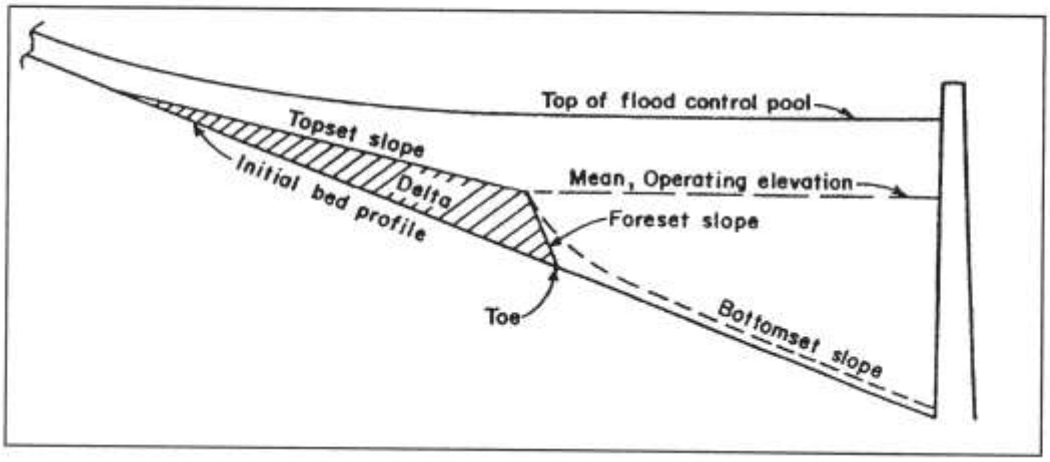

Figure (1) : Conceptual deposition in deep reservoirs

Trap Efficiency:

Trap efficiency is the percent of inflowing sediment that remains in the reservoir. Some proportion of the inflowing sediment leaves the reservoir through the outlet works. The proportion remaining in the reservoir is typically estimated based on the trap efficiency. This efficiency is primarily dependent on the detention time with deposition increasing as the time in storage increases.

Trap efficiency is of a particular importance when determining the annual sedimentation rate or capacity loss.

Reservoir deposition is not synonymous with sediment yield. Some amount of inflowing sediment leaves the reservoir through the outlets and is not deposited within the pool. Although studies by Brune,1953 and others showed that reservoirs generally trap sediment greater than 80% of the inflow that should not be considered a rule of thumb. Trap efficiency is calculated by knowing the flow velocity through the reservoir and the gradation of the inflowing sediment load. It is reasonable to assume the trap efficiency of inflowing sands (particles sizes greater than 0.125mm to be 100%. Silts and clays are more difficult to settle but pool with ratio as 0.1 and more of the reservoir capacity to average annual inflow settle 80-95% of all sediments.

Factors Affecting Trap Efficiency:

There are two types of factors: the first type is the hydraulic characteristics of the reservoir such as capacity inflow ratio (C/I) (which is a measure of retention time), reservoir shape, type of outlets, reservoir operation. The second type is sediment characteristics of inflowing sediment such as particle size distribution of sediment load, particle shape, behavior of sediment under varying temperature, concentration, water chemical, secondary currents and turbulence.

Sediment Diameters:

The diameter of sediment particles commonly transported by stream ranges over five log cycles. Generally the coarse material will settle first in the outer reaches of the reservoir followed by progressively finer fractions farther down towards the reservoir dam. Based on this depositional pattern, the reservoir is divided into three district regions top-set, fore-set and bottom set beds. Top set bed is located in the upper part of the reservoir and is largely composed of coarse material or bed load. While it may have small effect on the reservoir storage capacity, it could increase upstream stages. The fore-set region represents the live storage capacity of the reservoir and comprises the wash load. The bottom set region is located immediately upstream the dam and is primarily composed of suspended sediments brought from upstream by density currents. The region is called reservoir dead storage and does not affect the storage capacity of the reservoir (Figure 1).

Reservoir Shape:

Reservoir shape is an important factor in calculating deposition profile capacity, but the path of the expanding flow does not necessarily follow reservoir boundaries. On the other hand, entering narrow reservoir has a more uniform distribution across the section resulting in hydraulic conditions that are better approximated by one dimensional hydraulic theory, (www.EM 1110-2-1420.)

Aim of the Study:

The aim of the research work is to predict and estimate the main hydrological criterion of the sedimentation process in some Iraqi reservoirs such as sediment trap efficiency, sedimentation index and the annual storage loss of the reservoirs as a result of sedimentation processes.

Description of the Study Site:

Few large dams had been constructed on the Tigris and Euphrates rivers in Iraq. Some of them started in operation since the end of the sixties of the last century such as Dokan dam, others dams in the mid of the eighties such as Mosul dam on Tigris river and Haditha dam on Euphrates river. Some dams had been started in construction and stopped due to some technical and political reasons such as Bekhma dam on the Greater zab river and Badoosh dam and Makhool dam on Tigris river. Some other dams had been planned and designed and have not started in construction yet, such as Quair dam on the Greater zab river. Figure (2) shows the location map of the present mentioned case study dams on Tigris river in Iraq.

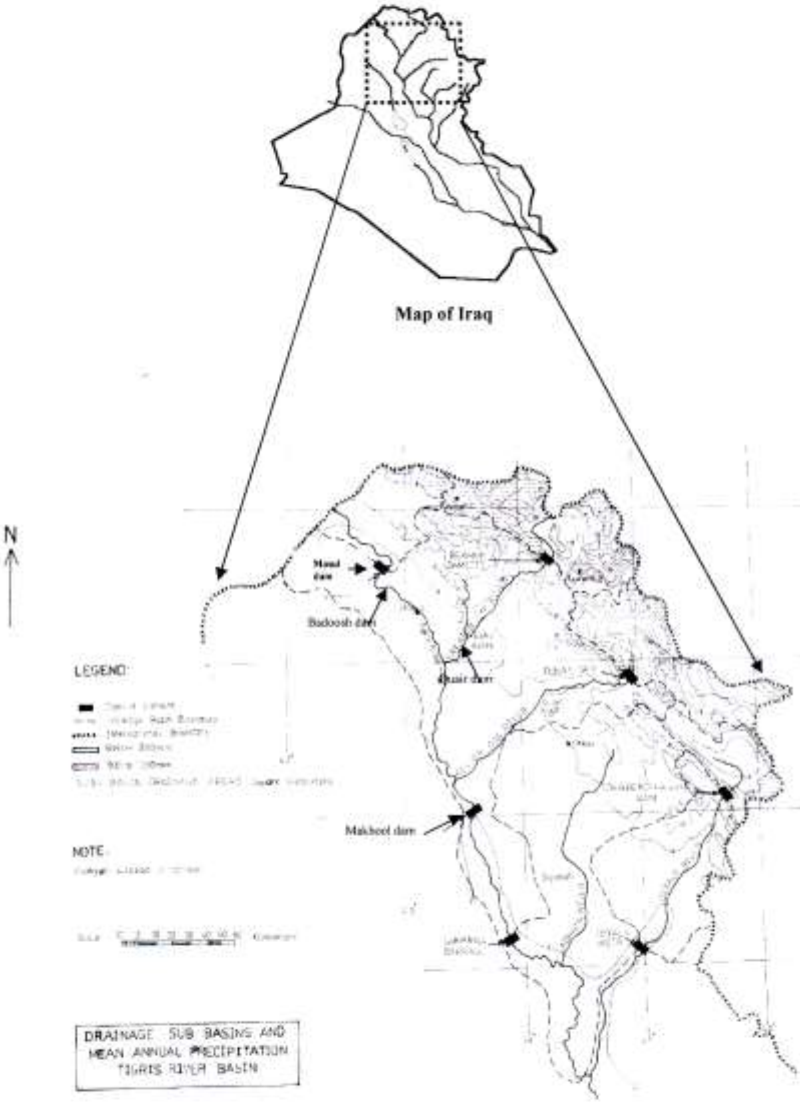

Figure (2) Location Map of the Studied Dams in Iraq

Classification of Reservoirs:

Borland and Miller (1958) classified the reservoirs in four standard types. They found a definite relationship between the reservoirs shape and the percentage of sediment deposited at various depths throughout the reservoir. The shape is defined by the depth to capacity relationship. The classification criterion is given in Table (1).

Table (1)

m	Reservoir Type	Standard Classification
1-1.5	Gorge	4
1.5-2.5	Hill	3

2.5-3.5	Flood plain foothill lake	2
3.5-4.5	Lake	1

m; the reciprocal of the slope of the line obtained by plotting reservoir depth as ordinate and reservoir capacity as the abscissa on log-log paper

The table shows that at lower elevation, Type 1 (lake type) reservoir has lower percentage of silt deposition than type 4 (Gorge type). This is because a gorge type reservoir offers little opportunity for sediment grains to deposit at higher elevation than lake type reservoir.

As mentioned before Mosul, Badoosh, Dokan, Bekhma, Quair and Makhool reservoirs dams in Iraq were selected in the research work to analyze hydrologically. All the selected dams were located either on the main Tigris river or on its tributaries such as the Greater zab and the Smaller zab as shown in Figure (1). Table (2) shows some hydrological characteristics of those reservoirs.

Table (2)

Dam	Capacity million(m^3)	Average annual inflow discharge (m^3/sec)	Watershed Area (km^2)	Average annual rainfall (mm)
Mosul	11.1	570	54900	750
Bekhma	14	630	17000	1000
Badoosh	0.25	420	5000	350
Quair	5.5	450	24000	700
Makhool	4.8	1350	10700	400
Dokan	6.9	240	15000	800

The selected case study reservoirs were classified according to Table(1) to be as follows:

Dam	Mosul	Badoosh	Bekhma	Quair	Makhool	Dokan
Classification type	Gorge-Hill	Hill-Flood plain foothill	Gorge	Hill	Flood plain foothill	Gorge

The above classification related directly with the reservoir topography (reservoir shape), and Figure (3) and (4) show the depth storage relationship for all the studied reservoirs. It is obvious that Bekhma and Dokan dams were located in a gorge narrow deep valley, by contrast, Makhool dam was located on wide flood plain shallow valley.

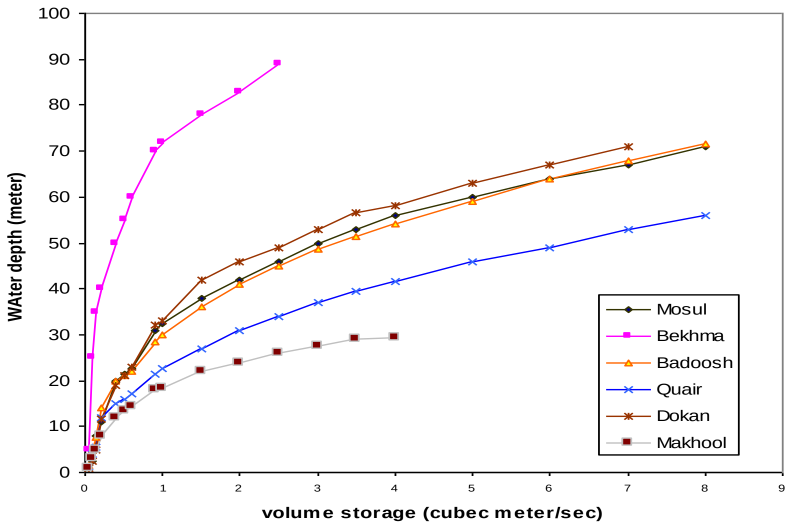

Figure (3) Water depth storage volume relation for the studied dams in iraq

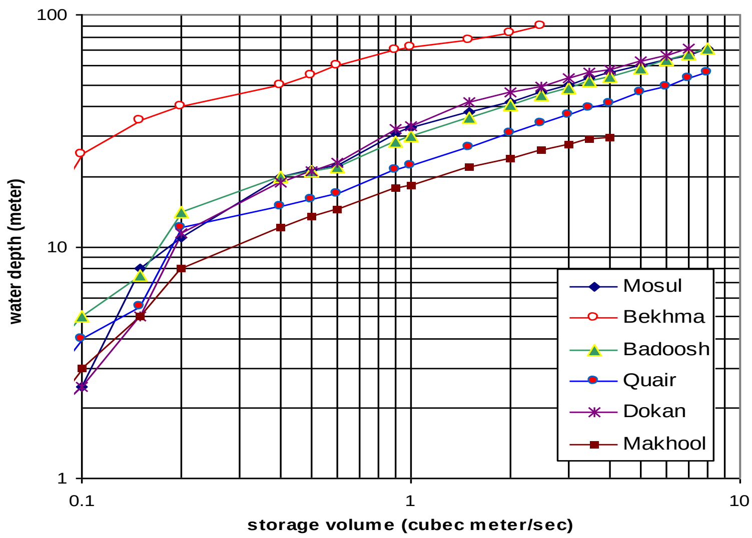

Figure (4) Log –log relationship of the water depth –storage volume for the studied dams.

Trap Efficiency Estimation:

The trap efficiency of a reservoir can be defined as the percentage of the total inflowing sediment that is retained in the reservoir. It is of a particular importance when determining the annual sedimentation rate or capacity loss. As sediment is trapped, the reservoir storage capacity is decreased and in turn, the trap efficiency decreases. If storage depletion is rapid, the trap efficiency should be updated at time increments with an adjustment of the original reservoir capacity. The main depended relationship for trap efficiency (T.E) was developed by Brune (1953), which relates the trap efficiency with the ratio of the reservoir capacity to mean inflow (C/I), while Churchil,1948 presented a relationship relating sedimentation index (S.I) and trap efficiency. The sedimentation index of a reservoir is the period of retention (R.P) (capacity of reservoir divided by daily inflow discharge) divided by reservoir mean velocity. Table (3) shows the estimated trap efficiency, retention period and sedimentation index of the studied reservoirs in Iraq.

Table (3)

Dam	C/I	R.P (day)	T.E	S.I (m^{-1})
Mosul	0.62	195	0.95	$1.6*10^8$
Badoosh	0.02	4	0.6	$8*10^5$
Bekhma	1.07	386	0.98	$5*10^8$
Quair	0.39	141	0.92	$7*10^7$
Makhool	0.11	41	0.87	$3*10^7$
Dokan	0.92	331	0.96	$2*10^8$

Table (3) shows an ascending order relation between the capacity inflow ratio with the sedimentation index, trap efficiency and the retention period. A simple viewing of the trap efficiency values of the reservoirs with the reservoirs shape shows a strong positive relation between the two factors in which the deeper narrow reservoir shape, the greater is th trap efficiency value.

Hydrologically, the reservoirs can be classified according to the capacity inflow ratio in which those reservoirs have C/I less than 1.0 are called the seasonal storage reservoirs, while those having C/I more than 1.0 are called hold over storage reservoir. From the above table it is clear that almost all the studied reservoirs in Iraq are classified as seasonal storage reservoirs.

The retention period (residence time) in the reservoirs depends on the capacity inflow ratio, shape of the reservoir and the type of the outlet and operation schedule. Reservoirs can be classified according to the operation basis (Borland and Miller,1958) as follows:

Reservoir Type	Reservoir operation
1	Sediment always submerged or nearly
2	Normally moderate to considerable reservoir draw down
3	Reservoir normally empty
4	River bed sediment

All the studied reservoirs can be classified and rolled within the first and second type on the above table (i.e.; sediment always or nearly submerged or normally moderate to considerable reservoir draw down).

An annual sedimentation rate or capacity loss can be estimated depending on the trap efficiency value and can be expressed by the equation (WWW.EM 1110-2-4000):

$C_1 = E\, Y_s / C$;

C_1 = annual sedimentation rate or annual storage loss in percent.

E = trap efficiency, in percent

Y_s = annual net sediment yield from the drainage area.

C = original reservoir storage capacity in same unite as Y_s

The sediment yield from a basin is that portion of the eroded soil which leaves the basin. Two main methods of sediment yield estimation can be categoried: methods based on direct measurement and mathematical methods. The most accurate historical sediment yield is that calculated from a long term sediment gage record. An empirical equation to predict sediment yield from some catchment areas in the north of Iraq which was predicted by Al-Taiee and Rashid (2003) was used in this research work to estimate sediment yield from the watershed areas of the present studied Iraqi dams. This equation was predicted and modified from the famous common universal equations used by Dendy and Bolton (1976) and Langbein and Schumm (1958). The equation is as follows:

$Y_s = -0.0004 P^2 - 0.171P + 426.2$; Y_s in ton /km^2/year , P annual rainfall in (mm)

Applying the above equation, the annual sedimentation rate can be calculated from the studied dams as shown in Table (4)

Table (4)

Dam	Y_s (m^3/km^2/year)	Annual storage loss in reservoir %
Mosul	520	0.3
Badoosh	415	0.4
Bekhma	655	0.1
Quair	501	0.28
Makhool	422	0.84
Dokan	545	0.13

Conclusions:

From the hydrological analysis of the collected data concerning the selected Iraqi dams, it was concluded that almost all the studied dams reservoirs were classified as seasonal storage reservoirs. Topographically, they were classified as either gorge or hill or flood plain foothill types. The trap efficiency values of the reservoirs ranged between 0.6 to 0.98. Trap efficiency increased as the sedimentation index , capacity inflow ratio and the retention period increased too. There is a strong relation between trap efficiency values with the depth and the narrowness of the reservoirs. Finally , the annual loss due to sedimentation in the Iraqi dams was predicted to be in the range of (0.1 to 0.84) percentage.

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