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Sedimentation Problems In The Blue Nile Reservoirs And Gezira Scheme: A Review

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ABSTRACT:

The development in Sudan is basically dependent on the Blue Nile water. The high sediment load brought by the river during its flood has major influences on the design and operation of the reservoirs built across the river and the schemes irrigated from it. Sediment deposited in reservoirs reduces the useful life of the reservoirs as well as diminishes the benefits from the dam (irrigation and power genera(ion). Large operational costs are incurred every year in dredging the sediment from reservoirs and canal sediment clearance. The sediment monitoring programme launched in 1988 in Gezira Scheme and the Blue Nile, has revealed very important results and answered many vital questions regarding sedimentation in Gezira Scheme. On average 8.5 million tons of sediment enters Gezira scheme every year. More than 97% of this sediment is very fine; therefore, standard methods of sediment exclusion at the intakes will not offer a solution. More than 70% of the sediment can be excluded if the canals gates are closed during the period 20th July to 31st August.

This paper reviews the sedimentation problem in the Blue Nile and Gezira Scheme and its management options based on the outcomes of the monitoring programme.

Keywords: Sediment Blue Nile Gezira Scheme

INTRODUCTION

Large-scale gravity irrigation in Sudan started after the construction of Sennar Dam on the Blue Nile in 1925 and progressively expanded thereafter the construction of Roseires Dam on the Blue Nile in 1966. Now, the irrigated sub-sector; represents only 25% of the cultivated area; but contributes more than 50% of the value of the agricultural production of the whole country (Hamad, 1993). In addition to storing water for irrigation the two dams are used for hydropower generation. Hydropower generation capacities of 15 MW and 280 MW were install in Sennar and Roseires respectively. This represents 87% of Sudan hydropower before Merowe.

The Blue Nile originates from the Ethiopian highlands having an annual average flow of 52 billion cubic meters (Bm^3), most of this flow occurs during the flood season (July — October). During this flood season the river brings down considerable amount of sediment estimated as 140 million tons per year. The sediment material originates mainly from heavy erosion in the upper catchment area in Ethiopia. This high sediment load has major influences on the design and operation of the reservoirs build across the river and the irrigated schemes. Sennar and Roseires reservoirs have lost 60% and 34% of their storage capacities of 0.93 Bm^3 and 3.024 Bm^3 , respectively. The deposited sediment has reduced the water storage capacity of the reservoirs and the benefits from these reservoirs (irrigation & power generation), blockage of the power intakes and many other problems. The operation policy adopted for the two reservoirs is to pass the large annual flood volume through the dams during the flood period so as to minimize sediment deposition. During this period the reservoirs levels are kept at the minimum operating levels of 417.2 m and 467m for Sennar and Roseires, respectively. The incurred cost for deposited sediment and operation policy is very high. On the other hand sediment deposited in irrigation canals and control structures has resulted in reduced and interrupted irrigation water supply, increased height of canal banks, over topping and many other problems resulting in increased maintenance costs.

Since 1988 the Hydraulics Research Station of the Ministry of Irrigation and Water Resources (MOIWR) has started a sediment monitoring programme for the Blue Nile and Gezira Scheme which is continuously operating up to date. Large quantities of sediment data was collected in the 21 years, the life time of the programme. The collected data showed the spatial and temporal distribution of sediment, basic sediment characteristics and answered many vital questions.

The objective of this paper is to review the sedimentation problems in the Blue Nile reservoirs and the Gezira canal system and devise the promising sediment management and control measures based on the resultsof the sediment monitoring programme.

SEDIMENTATION PROBLEM

The Blue Nile brings considerable amounts of sediment during it flood season (July — October). This sediment material originates mainly from heavy erosion in the upper catchments in Ethiopia. It is noticed that there is an increase in the incoming sediment from the Ethiopian highlands since the seventies. This increase in sediment may be attributed to the successions of drought that hit the region and the accompanying excessive land use. A recent study has estimated the sediment yield of the Blue Nile upstream Ed Deim as 480 tons per square kilometer per year ($T/km^2/year$), (Hussein, 2006), resulting in average annual sediment load of 140 million tons at Ed Deim. The sediment concentration varies from year to year and has reached 2.6% by weight recorded at Roseires during the 1988 flood (Hussein, et al, 1994). This high sediment load has major influences on the design and operation of the reservoir built across the river and the irrigated schemes, which are not provided with sediment exclusion measures. At the design stage of these reservoirs, the sediment that will be deposited during their lifetime was accounted for in the dead storage. Also these reservoirs were operated according to rules that aim to minimize the sediment deposition during the flood rising stage. In spite of this the reservoirs, especially Roseires, has experienced severe sedimentation problems in 1975 and 1993 when the power intakes were completely blocked and energy output dropped from 88 MW to less than 15 MW (Mohamed et al, 2001). On the other hand, heavy sediment deposition in irrigation canals and control structures took place in the irrigated schemes. This sediment deposition has resulted in severe operational problems and interrupted irrigation supplies. It has reached its maximum in the Gezira Scheme which made MOIWR think, in 1988, of launching the sediment monitoring programme.

THE SEDIMENT MONITORING PROGRAMME

The Ministry of Irrigation and Water Resources has started an intensive sediment monitoring and management programme in the Gezira Agricultural Scheme in 1988. The programme was sponsored under the scheme Rehabilitation & Modernization fund. The programme has been implemented by the Hydraulic Research Station in collaboration with the Hydraulic Research (HR Ltd) Wallingford, The objectives of the programme were:

- ✓ Quantify the sediment entering some irrigation schemes, particularly Gezira scheme, and determine its distribution.
- ✓ Establish correlation between the rate of inflow and sediment concentration within the river Nile system and the irrigation schemes.
- ✓ Define the optimum filling dates of the Blue Nile reservoirs and to avoid unnecessary releases to the Gezira scheme in sediment peaks.

Accordingly data was collected from 52 locations scattered within the scheme on a daily basis for two seasons (1988/89 and 1989/90). From the season 1990/91 the sediment-monitoring programme was extended to cover different locations scattered along the Blue Nile in addition to the Gezira Scheme. These stations are Ed Deim, Roseires, Wad Alais and Sennar along the Blue Nile. The data was used to help in defining the optimum filling dates of Roseires and Sennar reservoirs. In the season 1996/1997 the programme was extended once again to cover the Rahad Scheme. Sediment data from other stations in the Main Nile, Dinder and Rahad River are available for 4, 4 and 10 seasons, respectively. For the Gash River, the sediment monitoring started in 1999 and continued up to date (Gismalla, 2009).

The collected field data comprises water samples, discharges and settling velocities measurements and surveys of some selected sites. The suspended sediment concentration is sampled on a daily basis for all stations during the flood season. The other measurements were occasional. Plastic bottles are used to collect and keep the water samples. Different sampling methods are used in collecting suspended sediment samples. Dip sampling is the common method used for sampling; whereby a suspended sediment sample is taken simply by dipping a bottle in the turbulent flow just downstream of the hydraulic structures in irrigation canals. This method was adopted based on the results of a research carried at HRS comparing different sampling methods. Other samplers used are the depth integrating samplers and point integration samplers.

The collected water samples are analyzed at the Hydraulic Research Station's soil laboratory at Wad Medani. The tests conducted in the laboratory include: the determination of sediment concentrations; and sediment grain size analysis and other properties. Sediment concentration in parts per million (ppm) by weight is obtained by dividing the weight of the dry sediment by the weight of the water-sediment mixture sample and multiplied by 106. The sediment load is the total amount of sediment to be carried by the flowing water and is obtained by multiplying the river or canal's flow by the sediment concentration in ppm.

SEDIMENT CHARACTERISTICS OF THE BLUE NILE

The transported sediment in the Blue Nile consists of significant quantities of very fine material composed of silt and clay with diameter less than 63 microns known as wash load which can be easily transported in suspension, and under certain hydraulic conditions it is ready to settle fast (Hussein et al, 1994). The sediment concentration varies throughout the flood season having its maximum concentration in the second period of July. Thus the maximum sediment concentration of the Blue Nile occurs about one month earlier than the peak discharge. The trend of monthly average sediment concentrations and annual sediment loads in the Blue Nile are increasing as depicted in Fig (l) and Fig (2). The historical sediment data, 1933 - 1938, shows that the mean sediment concentration entering Gezira main canal in August is 700 ppm (Mohamed, 2001), compared to 26,561 ppm recorded downstream Sennar on 18th July 2008 (Gismalla, 2009).

The plotted graphs of the sediment discharges versus the river flows at the different monitoring stations show a scatter. Very strong correlations are obtained from these scatter graphs for the rising and falling flood limbs. The correlation between river flows and the sediment discharges downstream Sennar for the period 2002 - 2008 are given by the following equations, depicted in Fig (3) (Gismalla, 2009).

<u>Rising Limb</u>

$Qs=O.517Q^{1.60}$ [R^2- 0.73]

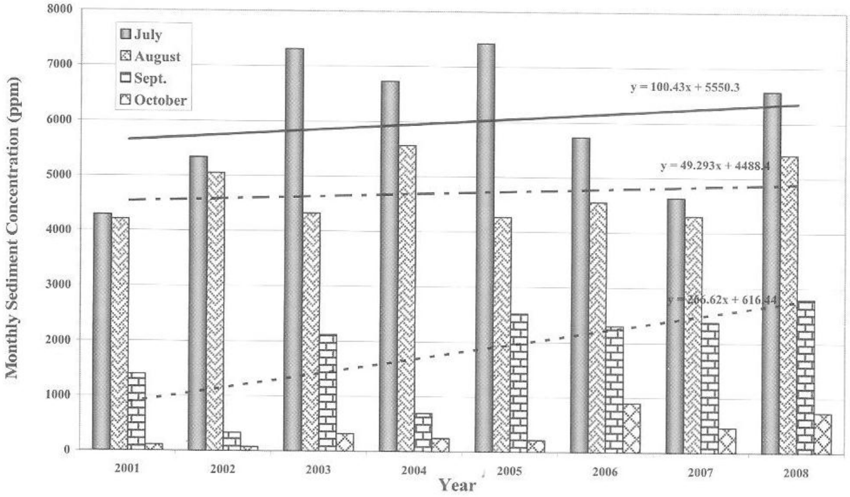

Fig (1): Monthly Average Sediment Concentrations in the Blue Nile downstream Sennar

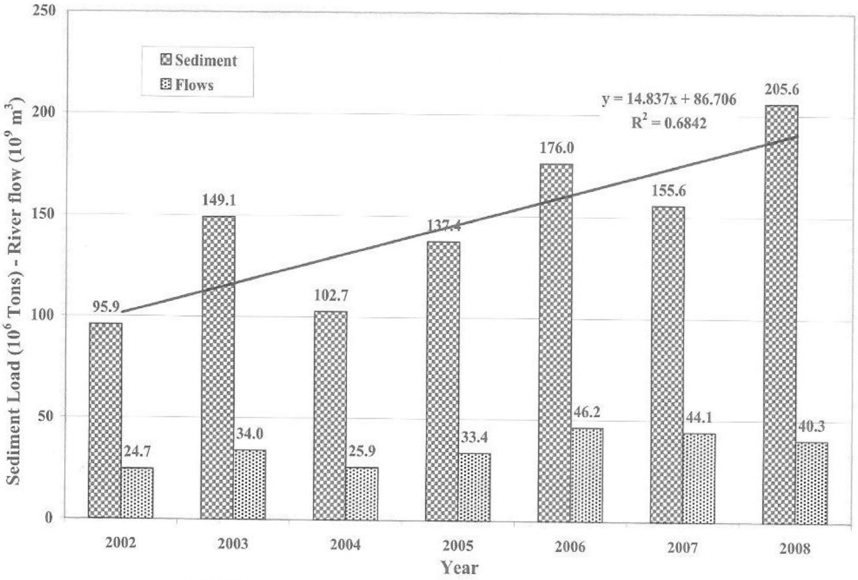

Fig (2):Blue Nile Flows & Sediment Load downstream Sennar Dam

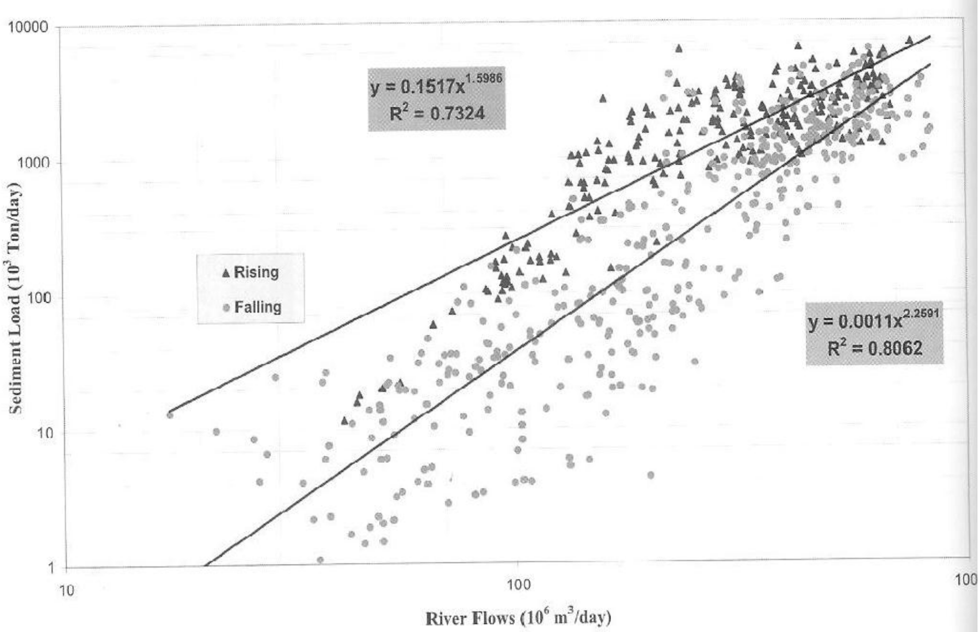

Fig (3): Sediment Load in the Blue Nile downstream Sennar (2002-2008)

Falling Limb

$Qs = 11x10^{-4}\ Q^{2.25}$ $[R^2 - 0.81]$

Where Q is the daily average river flow in 10^6 cubic meter per day ($10^6 m^3$/day) and Qs is the daily average sediment discharge in 10^3 Tons/day.

Other sediment characteristics revealed from the monitoring programme are:

- ✓ The concentration, grain size and density of the sediment decrease in the downstream direction.
- ✓ There is a clear time lag between different monitoring stations for a given event, e.g. maximum concentration.
- ✓ As the Blue Nile floods are highly variable its sediment data is also highly variable, this why sediment data collection is continued up to date to reflect the land use and climatic variations in the basin.

RESERVOIR SEDIMENTATION
INTRODUCTION

Sediment deposition in reservoirs is determined by the incoming sediment load or catchment yield and the reservoir's trap efficiency. The catchment yield is affected by many factors including the hydrology, catchment characteristics (soil and rock materials, vegetation cover, topography) and land use and human activities. Reservoir trap efficiency is the ratio of deposited sediment to total sediment inflow and is influenced by many factors but primarily is dependent upon the sediment fall velocity, flow rate through the reservoir and reservoir operation. Trap efficiency estimates are empirically based upon measured sediment deposits in a large number of reservoirs mainly in USA. Brune (1953) and Churchill (1948) methods are the best known ones. Brune calculates TE from the ratio of the original reservoir capacity to the average annual inflow (Capacity/Inflow, or C/I), while Churchill developed a relationship between the percentage of incoming sediment passing through a reservoir and a reservoir sedimentation index, which is defined as the ratio of the period of retention to the mean velocity through the reservoir. For any reservoir experiencing sediment deposition the trap efficiency decreases progressively with time due to the continued reduction in its capacity. Hussein et al (2005) computed the trap efficiency of Roseires reservoir using both methods mentioned above and compared them with the estimate trap efficiency of Roseires reservoir from bathymetric survey data. Hussein used an annual average inflow of the Blue Nile at Roseires as 50×10^9 m^3 and an annual sediment inflow of $140* \ 10^6$ tons. Table (l) gives the comparison of the sediment trap efficiency estimated from reservoir survey data and that computed using the two empirical methods.

Table (1): Roseires Reservoir Trap Efficiency (%)

Year of re-survey	1976	1981	1985	1992	1995
T(years)	10	15	19	26	29
Observed	45.5	36	33.2	28	26.2
Brune•s Method (lower envelop)	51	49	46	45	45
Churchil's Method	67.7	66	64.4	63.5	62.8

Ahmed (2003) reported that the rate of sedimentation of Sennar reservoir in the period (1925 - 1981) had never exceeded 1/2 % per year (4.6 million m3) with respect to the original capacity. In this period the river is left to flow naturally without any impoundment in the reservoir during the flood period (July — Sept.). The other reason behind this perfect performance is the excellent design of the dam where there are 80 deep sluices and 112 spillways gates (currently 2 spillway gates are operational) spreading across the river width, which enable the reservoir to get rid of the sediment during the flood period if that performance was continued in the same manner, the reservoir live time can go up to 200 years. On the contrary, the followed period (1981-1986) sedimentation increased drastically with a rate of 80 million m per year (91/2 %) i.e. a reduction of 400 million m3 (43%) in only 5 years. In addition to the increase of sediment load in general in the last two decades, however, the main reason behind the heavy sedimentation in the period (1981-1986) is the change of the operational rules to satisfy the irrigation requirements, for the agricultural schemes, upstream and downstream the dam. Now Sennar reservoir is no longer used to store a considerable amount of water, but to regulate the river flow and to generate hydropower. In the first period (1925-1981) Sennar dam represents the best example for the positive impact on sedimentation reduction in a reservoir using proper operation management. This proves that the operation rules are the best effective tool in saving the reservoir storage capacity and for its sustainability.

Impacts of reservoir sedimentation

Sediment deposited in reservoirs results in loss of storage capacity that reduces the useful life of the reservoir Table (2); as well as diminishing the benefit from the dam (irrigation, power, flood control...). Some of these impacts and their costs are listed below:

- Reduction in irrigated area and hydropower generated due to loss of storage. For example, the cost of hydroelectricity production forgone due to loss of storage in Khashm EIGirba is estimated as 0.1 million US$/year, and an area of 5850 Feddans of irrigated land in Halfa is lost every year due to sedimentation in Khashm EIGirba (ENTRO, 2007
- Blockage of power intakes resulting in stoppage of hydropower generation. In order to keep the power stations operative inRoseires, dredging of 100,000 to 350,000 m3 of sediment in frontof the power intakes is done annually which cost between 1.3 and 4.3 million US$. Similarly, the cost of sediment removal from the intakes of the two main canals in Sennar dam cost about 0.63 million US$ annually.

Table (2): Reduction in Storage Capacity of the Existing Dams due to Sedimentation

Name of Dam	Location	Year of Commission	Capacity (10^9 m^3)		%age Reduction
			Design	Present	
Sennar	Blue Nile	1925	0.93	0.37	60
Jebel Aulia	White Nile	1937	3.00	3.00	00
El Girba	Atbara River	1964	1.30	0.60	54
Roseires	Blue Nile	1966	3.35	2.20	34

The high sediment concentrations have destructive effects on turbines. Regular spare parts are needed and stoppages are common. The incurred spare parts replacement cost and sluice gates apron refurbishment cost are very high.

- During the high sediment concentrations reservoirs are operated at the minimum water levels, thus power generation is minimized. The average annual reduction in power generation in Roseires dulling August is 3.27 MWh which costs about 0.35 million IJS$, (ENTRO, 2007).

CANAL SEDIMENTATION

Design of stable canals in Sudan

Irrigation canals are man-made canals, which are designed taking into account aspects related to the irrigation criteria and sediment transport. On one side they should meet the irrigation requirements and on the other hand no deposition of the sediment entering into the system and no scour of the parent material should occur, Nester (1998). Four methods are used in designing stable canals, viz..

- Rational methods;
- permissible velocity;
- Tractive force method; and
- Regime method.

The design of stable canals in Sudan is based on the last method, the regime method. The regime concept uses data of canals in regime to establish the three independent equations required for determining the geometry of the canal viz. bed slope (S), bed width (B), and depth (D) for a given discharge. The regime hypothesis is a completely empirical approach, which does not incorporate physical explanation for its findings.
Three equations were developed which can be rearranged into a form that

Implies any one of the three parameters is a unique function of the discharge; these are:

Wetted perimeter $P = K_pQ^{l/2}$ ……………………………(1)
Hydraulic radius $R = K_RQ^{l/3}$ ……………………………(2)
Bed slope $S = K_sQ^{-1/6}$ ……………………………(3)

Where the proportionality constant depends on the nature and magnitude of the sediment transported as well as the materials forming the canal bed and banks.

Mathews (1952) carried out an investigation in the Gezira canalization system to study the applicability of Lacey's regime equations in the design of main and major canals of Gezira in the early 50's. He investigated the dimensions of 39 stable canal reaches in Gezira- These

Table (3): The different constants for the design of Stable Canals in Gezira

Formula	Constant	Main Canals 10 reaches	Major Canals 29 reaches	All Canals 39 reaches
$V=1/nR^{2/3}\,S^{1/2}$	n	0.021	0.017	0.018
$P=K_pQ^{l/2}$	K_P	4.55	5.51	5.26
$A=K_aQ^{5/6}$	K_a	2.75	2.60	264
$S=K_sQ^{-1/6}$	K_s	14.57	13.90	14.5

investigations were based on the assumption that the Lacey equations would apply and that the dimensions of stable canals would be developed from known stable canals. He concluded that Lacey's equations can be used for the design of stable canals in Gezira, and computed the different constants assuming a single value for Lacey's silt factor (f=0.63). Table (3) shows the different values of the constants given by Mathews for the design of stable canals in Gezira.

Based on Matthews's investigations the Ministry of Irrigation, through time, has established hydraulic design procedures for the standardized canals and hydraulic structures. These procedures are published in the "Design Sheet File". The main and branch canals are designed to have slopes between 7 and 10 cm/km. However, it is preferably that the slope of the reach under design is made as close as possible to Lacy slope for a silt factor of 0.63. Coefficient of roughness is taken as 0.025. Maximum permissible velocity of water for clay soils 0.6 - 0.9 m/s, and 0.3 — 0.6 m/s for sandy soils (Fadul, 2001).

Impacts of canal sedimentation

It is well known that canal sedimentation occurs whenever the rate at Which sediment enters the canal system exceeds the system's sediment transporting capacity. Aquatic weed growth increases silt deposition rates and aggravates the problem. The mechanical sediment clearance is effective in removing both the sediment and the aquatic weed. More a long term average of $16.5x10^6$ m of sediment is removed every year costing more than 10 million US$. This average is increased to $265x10^6$ m in the last decade due to the shift of management of minor canals from MOIWR to the agricultural administration of the scheme, Fig (4). The fact that sediment deposition problem is increasing monotonically and the unit cost of sediment clearance is escalating steadily necessitates testing other sediment control measures. Over the years, sediment removal efficiency dropped significantly to the extent that presently canals sedimentation is the main single factor causing irrigation water shortage. This inefficiency in the sediment removal is attributed to the type of machines used and lack of quality control over the resulting sections. Now more than 60% of the annual operation budget goes to sediment clearance. Sediment deposited in irrigation canals and control structures creates many problems, some of these problems are:

- Reduced and interrupted irrigation supplies
- Increased height of canal banks ,
- Over topping due to high water levels;
- Favors aquatic weed growth ,
- Reduced crop yields
- In-appropriate mechanical sediment removal has physical and hydraulic characteristics of the canals;

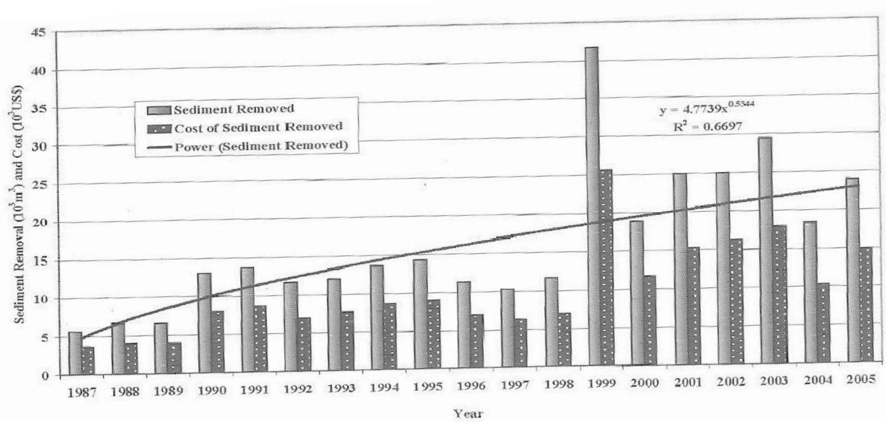

Fig (4) : Sediment Removed and Costs in Gezira Scheme

- The large amounts of sediment removed from canals have blocked access roads and raised the neighboring farms levels;
- Increases maintenance costs. Some phases of the sedimentation problem are beneficial to man

which should not be overlooked. The most important effect of sediment deposition is the maintenance of fertility of land inundated or irrigated by flood water. ENTRO (2007) showed that each ton of sediment passed to the fields is equivalent to 0.94 kg of urea fertilizer. Another benefit of sediment deposition is brick making manufacture practiced both at the river banks and canals banks.

Sediment monitoring in Gezira scheme

The sediment monitoring programme has revealed very important results and answered many Vital questions regarding sedimentation in Gezira Scheme, such as how sediment deposition is distributed in the canalization system. The programme has quantified the sediment entering the scheme and its distribution within the canal system. On average 8.5 million tons enters Gezira and Managil main canals at Sennar. The trend of the sediment load entering Gezira scheme shows an increasing rate (0.56 million ton per year Fig 5). All the sediment that enters the system is deposited as follows (Wallingford, 1989):

Main canals	4%
Major & branch canals	23%
Minor canals	35%
Passed to fields	38%

And, more than 80% of sediment is deposited in the first reach of the canals. Another result of the programme is that between 70% and 80% of the sediment entering the irrigation system did so during the period of mid July to the end of August Fig (6). Another important fact that emerged from the programme is that almost 97% of sediment entering the irrigation system is smaller than 63 microns. This has an important implication for sediment management, since many standard sediment control measures are inefficient in the silt and clay size range.

SEDIMENT MANAGEMENT AND CONTROL MEASURES:

The fact that sediment deposition problems are increasing monotonically and their costs are escalating steadily necessitates testing some sediment management and control measures. Selection of appropriate management and control measures depend on the particular and boundary conditions of the project and should be based on the knowledge of the sediment characteristics provided by the sediment monitoring programme and experience.

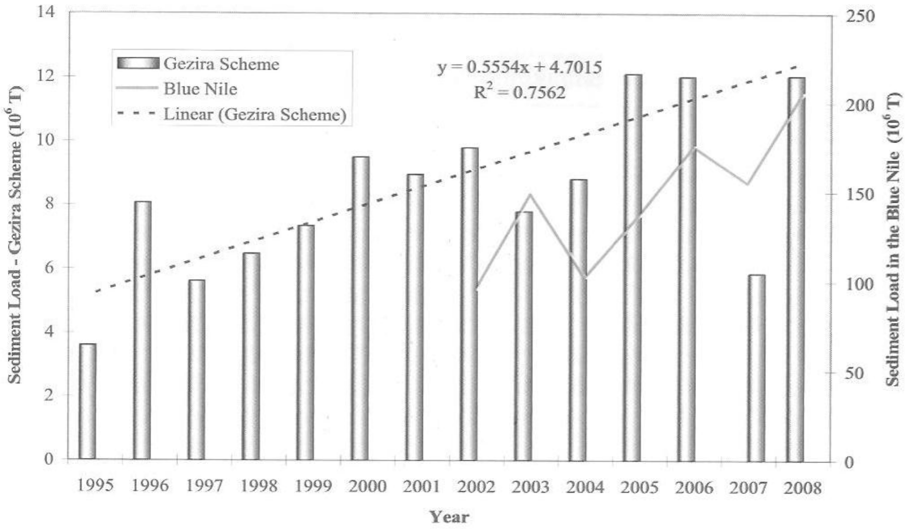

Fig (5): Sediment Load in Blue Nile and Entering Gezira Scheme at Sennar

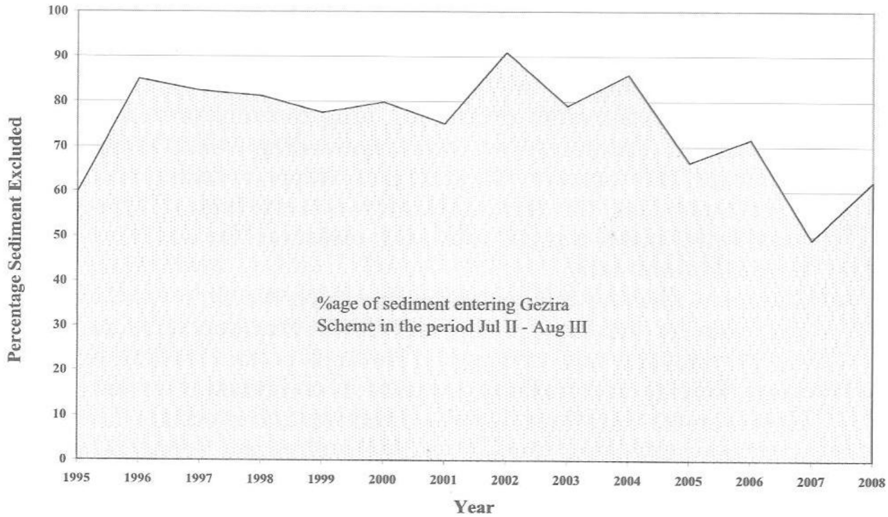

Fig (6):Percentage of Sediment Excluded if Canals Closed during Jul II - Aug IIII

Reservoir sedimentation control measures:

To control reservoir sedimentation interventions can be made at three different stages these are: minimize the incoming sediment load to the reservoir by watershed management, reduce sediment deposition within the reservoir by management procedures and removal of deposited sediment from the reservoir.

Catchment Control

This procedure, when possible, is the most effective. The basic principle is to arrest and prevent sediment movement at the source through arresting deforestation, improved vegetative cover, prevention of erosion etc.. (Mohamed, et al 2001). Most of the catchment area of the Blue Nile lies in Ethiopia, requiring high level of cooperation for effective catchment control measures. Fortunately a watershed management project for the Eastern Nile has been initiated under the Eastern Nile Subsidiary Action Program of the Nile Basin Initiative. Monitoring of the sediment of the Blue Nile at Ed Deim will reveal the effectiveness of the watershed project in Ethiopia.

Reservoir Management

- Reservoir operation plays an effective role as sediment control measures. The reservoir across the Blue Nile viz. Roseires and Sennar are operated in accordance with regulations rules that keep the reservoir water level at the minimum operation level during the flood season. As a consequence the sediment deposition is significantly reduced.
- At the beginning of impounding, early September the sediment concentration although decreasing progressively is still relatively appreciable. The policy is to start impounding as late as possible to minimize the amount of sediment trapped during filling the reservoirs when the trap efficiency is very high. The sediment monitoring plays a pivot role as it measures the sediment inflow concentrations daily.
- Sediment flushing is a technique in which the flow velocities in a reservoir are increased to such an extent that deposited sediments are remobilized and transported through bottom outlets. In many cases sluicing and flushing are used in combination or alternately. However the technique is only effective under certain favourable conditions and is not applicable for Roseires and Sennar (Gismalla, 2006).

Removal of deposited sediment

- Dredging was introduced in Roseires reservoir in 1984 with the sole purpose of alleviation of power station intakes blockage. A hydrographic survey for identifying and quantifying sediment deposited in pervious flood is carried out. Following the survey dredging is carried out by a fleet consisting of two floating cranes with buckets, dump barges and tug boat. The dredged sediment, between 100,000 and 350,000 m3, is dumped in the main channel in front of the deep sluice. This amount sustains the water supply to the power station. Anyhow, the running cost of dredging is high due to the expensive machine operation and maintenance

- Hydrosuction sediment-removal systems remove deposited or incoming sediments from reservoirs using the energy represented by the difference between water levels upstream and downstream from a dam. Hydro-Suction Sediment Removal is not practiced at the moment because of the incurred high cost, sophisticated equipment and human capacity required and the downstream implication of the removed sediment.

Use of monitoring data in managing reservoir sedimentation

The data collected in the sediment monitoring were used in defining the optimum date to start filling Roseires reservoir to optimize the power generated. This gives a better judgment in *trading-off between loss of storage volume by sedimentation and the benefits obtained from hydropower generation. The monitoring data was also used in calibrating a trap efficiency formula for Roseires reservoir as a function of retention time in the reservoir and the ratio of outflow/inflow discharge. Also, the correlations between sediment concentrations and river flows can be coupled with flood forecasting models to forecast future sediment loads for management and planning purposes.

Sediment management in irrigation canals:

Canal sedimentation management is done by either routing the sediment through the system or by deliberate removal of the sediment from the system. Sometimes a hybrid of the two may be more appropriate. Some of the sediment management options are listed below.

Changing the present irrigation practice by designing canals so that large proportions of the incoming fine sediment are conveyed to the fields. DEMAS has adopted this option and conducted an experiment in Abu Ushar subdivision. The main idea is to go for deep and narrow cross-sections for minor canals and to change the existing night storage canal system to a continuous one. The main drawbacks of this option are, the large capital investment to remodel over 8500 km of minor canals, scour degradations downstream controls structures and exerting extra operation burden especially on farmers due to shift to continuous system (Hamid, 2001).

- Changing the present clearance practices. Hussein et al. (1986) and Gismalla et al. (2006) discussed this option and questioned the current practice of restoring the design cross-section as the design sections are not the optimum ones as far as efficiency in suspended sediment is concerned. Gismalla et al (2006) introduced a new procedure for remodeling silted canals to maintain a more stable section based on the regime theory using the canal's maximum dominant discharge. The modelled sections are obtained by widening the existing canal sections without disturbing the canal bed. The new procedure cuts down the maintenance cost, reduces the time needed for excavation and provides a more stable canal section.

- Sediment exclusion by closing the main supply system. This option is based on the fact that about 70% of the sediment entering the irrigation system did so in six weeks period starting in July. Closing the canals gates in the period July II and August Ill would have excluded the proportions shown in Fig (6). This might suggest to strict or ban groundnut cultivation as it requires water as early as 15t June and continues demanding water during the high silt concentrations flood.
- Introducing settling basins in the irrigation system. The performance of settling basins for fine sediment has been studied intensively by Hussein et al. (1994) and the study of HRS-HRL joint study of the sediment management program. A number of possibilities exist, all based on encouraging sediment deposition at selected locations by forming enlarged canal sections or settling basins. Settling basins are proposed at different locations in the irrigation system of Gezira, at the intake, downstream the main canals off-takes and at the head reaches of the major canals. Using simulation models to assess the settling basins performance has shown that for the required trap efficiency the settling basins dimensions are very large which questions the practicality of de-silting such basins.

Use of monitoring data in managing canal sedimentation

- Data collected during the sediment monitoring study showed that sediments are well mixed in the incoming flow. Thus standard methods of sediment exclusion at the intakes will not offer a solution to Gezira sediment Problem
- Sediment could be excluded very effectively by closing the gates during the short period when the concentrations are high. Anyhow, canal closure for six weeks would completely disrupt the agricultural calendar, delaying planting dates and reducing yields. A detailed agro-economic study is required to determine the benefits of sediment related to gate closures of various durations in the context of present and future cropping patterns .
- Assessment of the settling basins performance was possible using simulation models. Two large settling basins options are promising. The first is to construct a large dredged settling basin of 5.74 km long, 574 m wide and 3m deep upstream the regulators of k57. It would

provide a 60% seasonal trap efficiency. The second option is to form a dredged settling area upstream the intake gates at Sennar.

- The long term average sediment concentrations obtained from the programme can be used to establish correlations between sediment deposited in canals and the released water. Such correlations can be used to estimate the deposited sediment in any canal knowing its flows during the flood season.

CONCLUSIONS

The following conclusions can be drawn:

8.1.Sudan can benefit from the Eastern Nile watershed management project in terms of sediment control.

8.2, The sediment monitoring programme launched by MOIWR in 1988 has quantified the sediment entering the Blue Nile and Gezira scheme and revealed its spatial and temporal distribution within the system.

8.3.Sediment data is highly variable thus long data records are needed to reflect the land use and climatic variations in the basin.

8.4. The characteristics of the Blue Nile sediment, 97% silt and clay, has limited the sediment management options in the canal networks.

8.5.Changing the present irrigation and clearance practices and sediment exclusion by introducing settling basins are among the sediment management option for Gezira Scheme.

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