Nile Basin Capacity Building Network 'NBCBN'

River Morphology
Research Cluster

GROUP I

ASSESSMENT OF THE CURRENT STATE OF THE NILE BASIN RESERVOIR SEDIMENTATION PROBLEMS

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STATEMENT OF THE PROBLEM

Reservoir sedimentation and the consequent loss of valuable water storage is becoming increasingly important in the Nile Basin. There are evidences of steady rise in soil erosion in some parts of the Basin that endangered reservoir projects and caused doubts about the viability of existing and future schemes. The impoundment of water for potable and irrigation supplies, hydropower, and flood control is a necessary step towards socio-economic development of the Basin countries. Untimely sedimentation may reduce the benefits and, if it is ignored, remedial measures may become either prohibitively expensive or technically unfeasible. In fact reservoir sedimentation is considered as a priority area of research for the River Engineering Research Cluster of the NBCBN-RE.

RESEARCH OBJECTIVES

For such wide and outreaching topic such as reservoir sedimentation, it is important to defined accurately objectives that can be realistically achieved within the given budgetary and time constrains and considering the scope of work of the other two groups in the river morphology research cluster viz. River Bank Erosion and Protection (Group II) and Watershed Erosion and Sediment Transport (Group III), the overall objective of Reservoir Sedimentation (Group I) is: to manage sustainably, efficiently and economically reservoir sedimentation in the Nile basin. More specific objectives are:

i) Collect, collate and synthesize readily available data in order to have an overview of reservoir sedimentation in the Nile basin and data base
ii) Develop procedures to estimate reservoir sediment deposition rates and distribution
iii) Quantify impact of reservoir operation policies on sediment deposition within the reservoir
iv) Identify appropriate methods (economically and technically) for deposited sediment removal
v) Assess socio-economic impacts of reservoir sedimentation
vi) Identify cross-cutting themes for future joint research work between and among research groups/clusters
vii) Capacity building for the Nile Basin researchers in river engineering in general and reservoir sedimentation in particular.

RESEARCH METHODOLOGY AND APPROACH

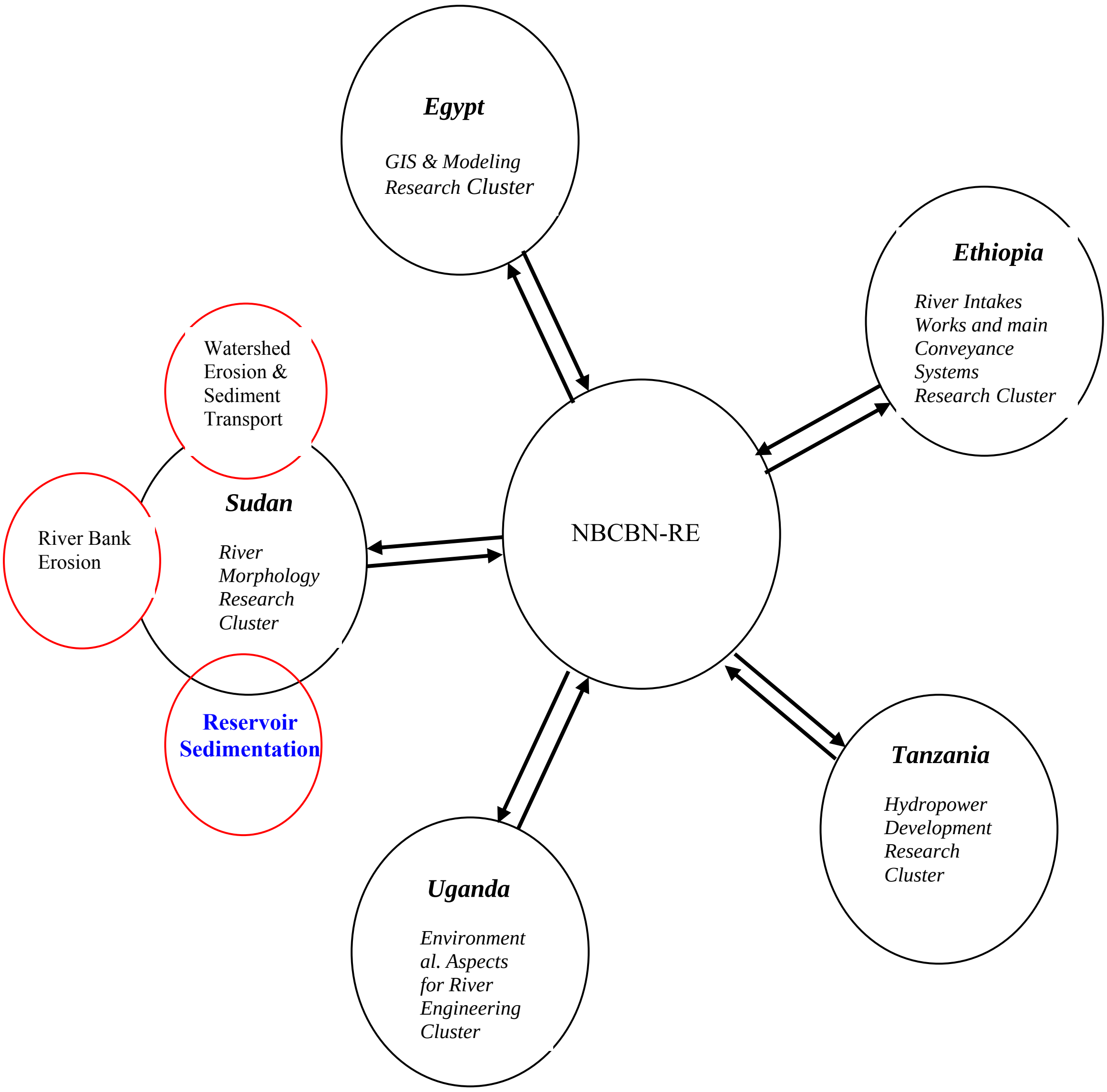
By considering case-study approach, reservoir sediment deposition, rates of capacity loss, Distribution of deposited sediment, delta formation and development are assessed using carefully selected cases from the Nile Basin. Practices used to control/mitigate reservoir sedimentation in these cases will be fully delineated, critically examined and compared.

RESEARCH OUTPUT

- Advancement and dissemination of knowledge through high quality research
- Recommendations for appropriate/best management practices
- Data base establishment within NBCBN platform.

FUTURE PLAN

- Complete the already set plan and
- Examine the feasibility and effectiveness of using numerical models as a management tool for reservoir sedimentation.



Regional placement of the Research study

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1.1 STATEMENT OF THE PROBLEM

Global fresh water distribution is neither uniform in space nor in time. Some parts of the world are endowed with too much water while many others are facing scarcity in this life-giving natural resource. Likewise, the temporal distribution of water is erratic and unreliable. Since the dawn of history, mankind tried to harness the available surface water resources by building dams that impound water at the time of plenty for later use at the time of scarcity. Even for parts of the world where water is plentiful, dams were built to alleviate flood risks.

Dams with their concomitant reservoirs are perhaps the oldest and among the widest attempts of mankind intervention in nature. Control and regulation of natural surface water flows by dam reservoirs are significant. The quantity of global fresh water that is currently controlled by dam reservoirs by some estimates – is about 3400 km^3 while the potential quantity that can be controlled in the future varies between 9000 and 14000 km^3 annually. Thus reservoirs are key infrastructures for mankind survival and well being.

Reservoirs can be single or more usually multi-purpose. Traditionally, dam reservoirs have well known primary purposes such as water supply, irrigation, flood control, hydropower and navigation. Other purposes include, inter alia, flow regulation, fisheries, recreation and environmental management.

Despite the benefits realized, dam reservoirs are not without their drawbacks. Prominent among these are the interruption of the natural flow regimes and natural eco-systems, land inundation and required resettlement, water quality degradation, reservoir sedimentation and downstream river bed degradation. It goes without saying that it is vitally important to minimize these and other negative impacts in order to sustain benefits arising from dam reservoirs.

Reservoirs are often threatened by loss of capacity due to sedimentation. Causes of reservoir sedimentation are many. Watershed, sediment and river characteristics are among the main natural contributing factors. Other important ones are reservoir size, shape, and reservoir operation strategy. Manmade activities play also a significant role particularly land use pattern.

Rates of reservoir sedimentation differ considerably. Some reservoirs are filled up very rapidly, with an annual capacity loss rate of 1% or more, particularly in the tropics and sub-tropics, while others are hardly affected by sedimentation. Reservoir sedimentation rates depend on the sediment input and the trap efficiency of the reservoir. Both of these factors are variables, being themselves dependent on many other variables.

The range of problems caused by reservoir sedimentation is varied and wide. Apart from the already mentioned ones like loss of capacity, increased flood risks, interruption in hydropower generation and downstream bed river degradation; there are some other problems such as degradation of water quality, increased complexity in reservoir operation and maintenance and consequent increase in their associated costs.

To control and/or mitigate reservoir sedimentation, different methods are adopted to that effect. Among these are: i) reduction of sediment inflow by watershed management, ii) upstream trapping, iii) control of sediment deposition in the reservoir, and iv) removal of deposited sediment.

Although the number of dams built on the Nile and its tributaries is not large, nevertheless they play a significant role in the socio-economic development of the Nile basin riparian countries. Irrigation, hydropower generation and water supply are the most important functions for dam reservoirs on the Nile system. In the drier parts of the Nile basin particularly in Egypt and Sudan, dam reservoirs are indispensable for irrigation though their contribution in electric power generation has declined over the years because of the expansion of the thermal power generation.

Nile tributaries originating from the Ethiopian plateau carry large quantities of sediment estimated at about 180 Million tons annually. Most of this sediment is clay and silt carried in suspension during the rainy season. Reservoirs built on these tributaries are experiencing alarming loss in capacity due to sedimentation. In some reservoirs, the annual rate of capacity loss may approach 1%. Sedimentation has serious implications for reservoirs whose primary functions are irrigation, water supply and hydropower. For the former two functions, loss in capacity implies less stored water and for the later function implies hydropower generation interruption or curtailment. Khashm El Girba reservoir in Sudan for example lost so far 50% of its original capacity in less than 40 years with corresponding reduction in the area it used to irrigate. Roseires dam in Sudan generates a fraction of its hydropower potential during the rainy season because: (i) of the frequent blockage of the turbine intakes by sediment and (ii) the low head available due to a minimum operation level maintained in the reservoir during the rainy season to reduce reservoir sedimentation. For Angereb reservoir in Ethiopia whose primary function is water supply, the time to abandon the reservoir because of fast sedimentation rates is not far away!

This research work is focused on current state of reservoir sedimentation in the Nile basin. It is concerned with the range of problems encountered; estimates and assessment of reservoir sedimentation rates; socio-economic impact; control/mitigation measures adopted and lessons learned that can be appropriately applied to existing as well as proposed reservoirs within the Nile system.

1.2 RESEARCH OBJECTIVES

For such wide and outreaching topic such as reservoir sedimentation, it is important to defined accurately objectives that can be realistically achieved within the given budgetary and time constrains and considering the scope of work of the other two groups in the river morphology research cluster viz. River Bank Erosion and Protection (Group II) and Watershed Erosion and Sediment Transport (Group III), the overall objective of Reservoir Sedimentation (Group I) is: to manage sustainably, efficiently and economically reservoir sedimentation in the Nile basin. More specific objectives are:

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- xiii) Identify cross-cutting themes for future joint research work between and among research groups/clusters
- xiv) Capacity building for the Nile Basin researchers in river engineering in general and reservoir sedimentation in particular.

1.3 EXPECTED OUTPUT

This research work is of importance for a wide spectrum of stakeholders including dam owners and operators, recipients of benefits arising from and those who are negatively impacted by these dams, professional groups (researchers, designers, consultants ..etc), non-governmental organizations (NGO's) and the public at large. The expected output of this research work should, as far as possible, cater for such wide interest. It is planned that the output will include specifically the following:

- i) advancement of knowledge in reservoir sedimentation through high quality research work
- ii) knowledge dissemination (research reports, papers, manuals, best management practices, ..etc.)

iii) data base establishment within NBCBN platform
iv) public awareness.

Hopefully the results of this research work will be formatted and produced in such a way that is useful for all those who are concerned.

1.4 RESEARCH METHODOLOGY

Reservoir sedimentation can be considered as a process where water and sediment inflows enter the reservoir, the water is regulated there and released downstream to satisfy certain requirements according to operation plans. In doing so, reservoir sedimentation takes place. Rates of sedimentation depend, inter alia, on characteristics of water-sediment inflow hydrographs, reservoir size and shape, and reservoir operation rules.

Sediment inflow is usually determined by either one or combination of (i) sediment yield from the watershed, (ii) reservoir re-survey data, and (iii) flow sediment sampling. Method (i) is outside the scope of this research work. Methods (ii) and (iii) will be used whenever data is readily available. However in case of data scarcity or non-availability, resort may be made to method (i) taking advantage of Group III research work.

Reservoir sediment deposition, rate of storage loss, trap efficiency, distribution of pattern of sediment deposition, delta formation and development will be assessed from available measured data augmented by carefully selected well proven and appropriate numerical modelling/empirical methods.

Problems arising from reservoir sedimentation and their adopted mitigation measures will be fully delineated, critically examined and compared to identify similarities and/or divergences. Recommendations for best management practices will be drawn accordingly.

In the process a data base for reservoirs in the Nile Basin will be established. The data base, naturally enough will start small and hopefully develop into a fully fledged one in the future.

Socio-economic impact, an often overlooked subject, will be dealt with in sufficient details thro' a case study.

1.5 RESEARCH APPROACH

It is believed that an appropriate approach for such research is by considering case studies. This is a well known research approach that has the following advantages:

i- enables changing over from general to specific considerations
ii- results from a carefully selected case study, can be generalized to other similar cases
iii- case studies represent reality with what all that entails, and
iv- enables comparative studies to be made.

However, given the multitude of likely case studies to choose from, criteria need to be established to characterize the case studies in order to set a framework for their rational selection; to assist in the analysis of the selected cases and to initiate data base establishment. It is to be pointed out that reservoirs, as defined for the purpose of this study are those which are man-made, purposely built within the Nile system, to impound unregulated water and sediment inflow for certain specific purpose(s). Accordingly the following criteria are formulated.

a) Country Interest

It goes without saying that country interest is pivotal for any meaningful cooperative research endeavor. Country interest is vital for trust building, strengthening inter-basin linkages and sharing of knowledge and information. It also reflects that specific country's willingness to participate in this joint effort.

b) Reservoir Size

Size of reservoirs differ considerably. It ranges from very large to small ones. There are different methods to assess a reservoir size. Among these are:

i) According to its volume
ii) According to the ratio of its capacity to the mean annual river discharge
iii) According to the ratio of its capacity to mean annual runoff per unit area of the drainage basin.

The first two are the most common. Variable arbitrary threshold values are sometimes specified to define the range of reservoir size. According to method (i), for example, reservoir sizes may be categorized as follows:

- less than 100 Mm^3 are considered small,
- between 100 Mm^3 and 1000 Mm^3 , medium
- between 1000 Mm^3 and 10,000 Mm^3 , large
- Larger than 10,000 Mm^3 , very large.

The case studies are selected to encompass, as far as possible, the four size ranges as defined herein.

c) Reservoir Purpose(s)

Reservoirs are built for a number of various reasons. These may be single or multi. Most reservoirs are multi-purpose in a combination of two or more of the following: irrigation, hydropower, water supply, flood control, navigation, fisheries, recreation and environmental requirements. The selection criterion here is to make reasonable balance between single and multi-purpose reservoirs. At least one of single-, twin-, and multi-(more than two) purpose reservoirs should be included in the selected list. This is important to reflect the impact of reservoir sedimentation on its purpose(s).

d) Representation

The selected reservoir should have typical range of problems usually encountered and should not have unique problems of its own such as complete emptying of the reservoir content, wind-transported sediment, industrial pollution and eutrophication.

e) Reservoir Inflow

The nature of inflow to the reservoir (particularly its hydrograph) has significant effect on its sedimentation characteristics and consequently on reservoir operation and sedimentation. The Nile system is characterized by its marked seasonality in its liquid and solid discharges which impact profoundly on almost all the reservoirs in the Nile basin. Therefore in order to include such an important factor, the inflow to the selected reservoir should be natural, continuous (non-ephemeral) and unregulated as far as possible. Sometimes, for a particular reservoir, the inflow is regulated by other upstream reservoir(s) that doesn't change materially the natural flow characteristics, in such case the inflow to that particular reservoir can be considered as unregulated as well.

f) Data Availability

Reservoirs that have reasonable, readily available and accessible data are definitely preferable. Small data, when shared, can go a long way.

The above criteria for the selection of the case-study reservoirs are by no means comprehensive nor exhaustive but are rather reasonable for an initial screening. Further criteria may be considered later if deemed necessary particularly when there is a large number of reservoirs to choose from which is an unlikely event at least at this stage.

g) Others

Other criteria may include reservoir geometry, for example in the Koka dam because of its peculiar shape is unfavorable for flushing.

Also the size of the sediment entering the reservoir, for example gravel and sand like in the Alpes is much easier to handle than cohesive silts and clays in the Nile.

1.6 SCOPE OF THE REPORT

The report describes the progress, analysis, recommendations and conclusions made so far in six Chapters. Beside the first introductory Chapter, the second one discusses state of sedimentation, estimation of sediment deposition and distribution and delta formation and development for some selected cases. Reservoir sedimentation socio-economic impacts are treated next in Chapter 3 where Roseires dam reservoir is considered as a typical example. In Chapter 4 an overview of reservoir sedimentation control measures, practices tried in the selected case studies, their successes and failures and best management practices are delineated. Chapter 5 describes the outlay, design and development of the Nile basin reservoir data base. Discussions, conclusion and recommendations appear in the sixth and last chapter of the report. The Report includes also a number of appendices.

2 ESIMATION OF SEDIMENT DEPOSITION AND DISTRIBUTION

2.1 INTRODUCTION

Reservoir sedimentation and the consequent loss of valuable water storage is becoming increasingly important in the Nile Basin. There are evidences of steady rise in soil erosion in some parts of the Basin that endangered reservoir projects and caused doubts about the viability of existing and future schemes. The impoundment of water for potable and irrigation supplies, hydropower, and flood control is a necessary step towards socio-economic development of the Basin countries. Untimely sedimentation may reduce the benefits and, if it is ignored, remedial measures may become either prohibitively expensive or technically unfeasible. In fact reservoir sedimentation is considered as a priority area of research for the River Engineering Research Cluster of the NBCBN-RE.

In this chapter estimates of sediment inflows, sedimentation rates and sediment deposition patterns are discussed by considering typical case studies of reservoirs in the Nile system.

2.2 OVERVIEW OF THE SELECTED RESERVOIRS

According to the criteria set before in Chapter 1, five reservoirs (Fig. 2.1) were chosen: two in Ethiopia (Angereb and Koka), two in Sudan (Roseires and Khashm El Girba) and one in Egypt (Aswan High Dam). The choice in the first place was made by the respective countries involved in the research work. The selection not only reflects national interests, but also it fits nicely with most of the criteria drawn up in the previous Chapter. Particulars of the selected reservoirs are summarized in the accompanying sheets and more details are given in the Appendix.

The selected reservoirs range in size from the very large (Aswan High Dam, AHD) to the very small (Angereb). The size range encompasses also the medium and the large sizes (Khashm El Girba and Roseires respectively). Thus the whole size range is represented.

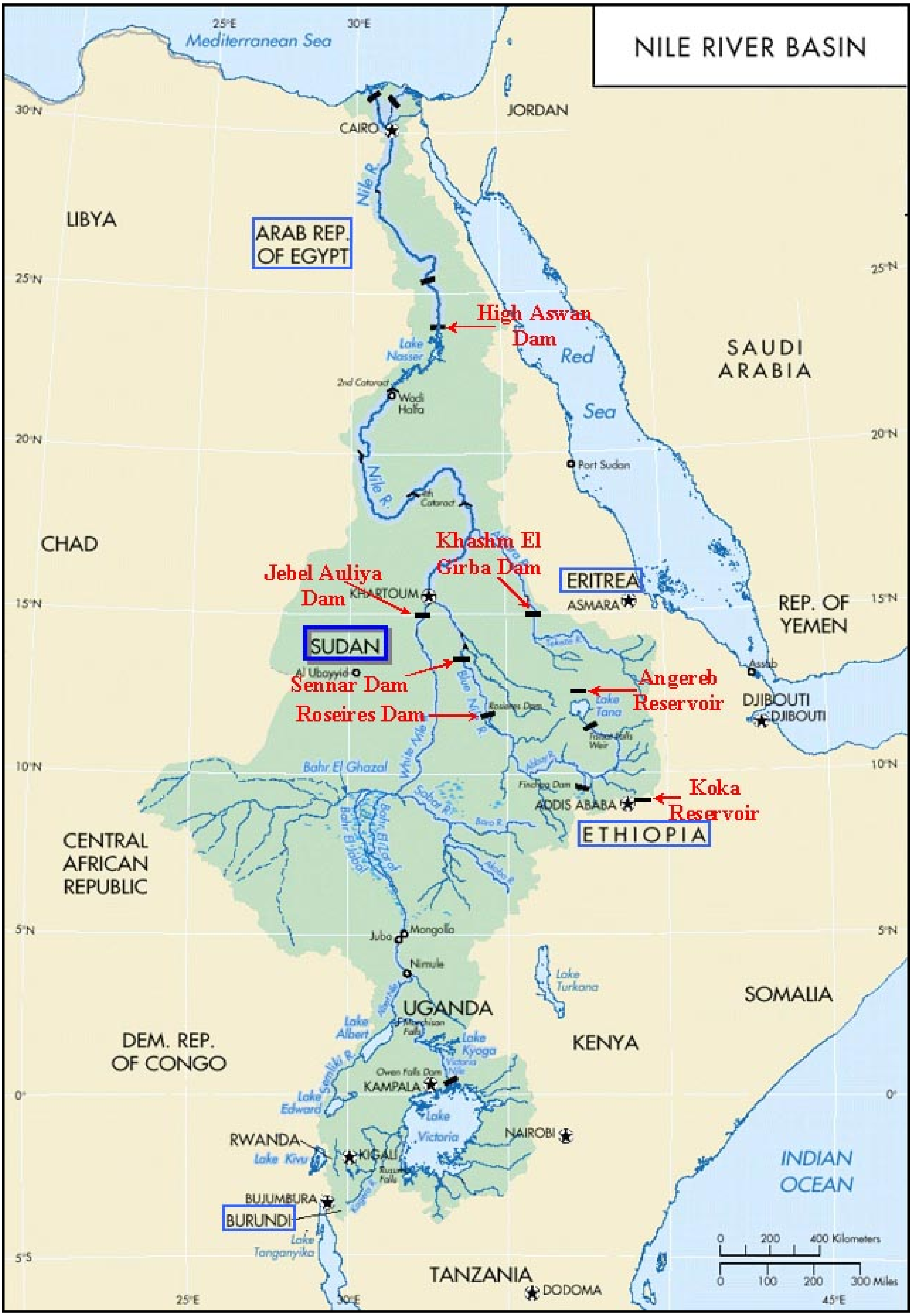

Figure 2-1 Location of Selected Reservoirs in Ethiopia, Sudan and Egypt.

From the selected case studies, there seem to be correlation between the reservoir size and its purposes. AHD is a multi-purpose reservoir with over-year storage for irrigation, hydropower, flood protection and navigation as its most important purposes. Roseires has twin-purpose function (irrigation and hydropower) while Khashm El Girba and Angereb are mainly single-purpose reservoirs; irrigation in the case of the former and domestic water supply in the later.

Loss in capacity is the most common problem facing the selected reservoirs though to a varying degree. AHD is the least affected due to its sheer size while the smaller reservoirs (Khashm El Girba and Angereb) witness significant reduction in their capacities (Khashm El Girba lost so far 60% of its capacity while Angereb lost about 15%). Roseires reservoir capacity decreased also by about 30% since its commissioning in 1966.

Another common problem is the relatively high sediment load particularly that carried in suspension during the flood. Measurements that are available have indicated that clay, silt and very fine sand dominate the materials transported in suspension in these reservoirs. This distribution has important implications for evaluating the trap efficiencies of these reservoirs.

Few meaningful assessments of bed load transport have been undertaken for the Nile System. Available data on the Blue Nile suggest that suspended sediment dominates the total sediment in transport and commonly account for approximately 90% of the total load.

Three out of the four selected reservoirs are commissioned in the 1960s, while the fourth (Angereb) is even more recently commissioned (1990s). This implies that sedimentation processes are still active in all of these reservoirs. Moreover long-term impacts such as changes in land use or climate on these reservoirs' sedimentation are not definitely known yet.

Draw-down, sediment sluicing during the rainy season and impounding only after the passage of the peak of the flood are the preferred methods to control sediment deposition in the Sudanese reservoirs. Both reservoirs are provided with low-level sluicing gates with discharge capacity comparable to river annual flood flows. In the case of hydropower generation in Roseires, low level sluices are intended to pass the bulk of the larger sediment particles which are present during the flood season to minimize abrasion of the runner blades of the turbines.

Ironically the largest and the smallest reservoirs in the group have no sediment sluicing facilities. This is understandable in the case of Aswan High Dam reservoir because its estimated half life runs into hundreds of years unlike Angereb reservoir whose half life is alarmingly about 21 years only!

Removal of the already deposited sediment is rather very limited for the selected case studies. Occasional flushing is made in Khashm El Girba reservoir. Sediment removal by dredging is regularly made in Roseires in front of the power house intakes before the following flood.

Reservoir surveys to determine the volume of deposited sediment and hence the loss in capacity by bathymetric survey and other means seem to be made often for larger than smaller size reservoirs. Aswan is the most frequently surveyed reservoir followed by Roseires and less so by Khashm El Girba. Angereb reservoir has not been surveyed so far.

Smaller reservoirs (Angereb and Khashm El Girba) are impacted more adversely by reservoir sedimentation than the larger ones (Roseires and Aswan) because the relative loss in capacity is much faster. This has much serious implications for both reservoirs. Khashm El Girba reservoir presently irrigates half the area it used to in the past, while the time to abandon Angereb reservoir and look for other water supply source is not far away.

Transient water quality degradation is common for all the selected reservoirs during the flood season because of the relatively high suspended sediment in transport and the high water turbidity. Aswan reservoir suffers from more persistent water quality degradation such as thermal stratification and non-oxygenation.

In the following sections of this Chapter, specific considerations will be given to each of the selected case studies in order to review how reservoir sedimentation is assessed and managed.

2.3 ROSEIRES RESERVOIR

Roseires reservoir, on the Blue Nile river, was completed in 1966, at a cost of 25 millions Sudanese Pounds, to serve the purposes of hydropower generation, irrigation, and flood retention. It has a width of 13.5 km at the dam site with a 1 km long section of concrete. The dam has 5 deep sluices, each measures 6m wide by 10.5m high at an invert level of 435.5m, which is the river bed level in the main channel. An overflow spillway is provided at a crest level of 463.7m with 10 radial gates, each measures 12m by 10m. Another special feature of the dam is that the hydropower station is located, away from the deep central channel, on the flood plain. The designed reservoir level is 481m and it has a length of 75 km giving a total volume of 3 Km^3 at crest level. The volume of the reservoir below the minimum operation level of 467m is 638 millions m^3 i.e. active volume of 2362 millions m^3. A typical operation program for a median year is shown in Fig. 2.2. The level of 467m has been adhered to since the commissioning of the first hydropower unit in 1971 (Tag Elsir and Osman 1986).

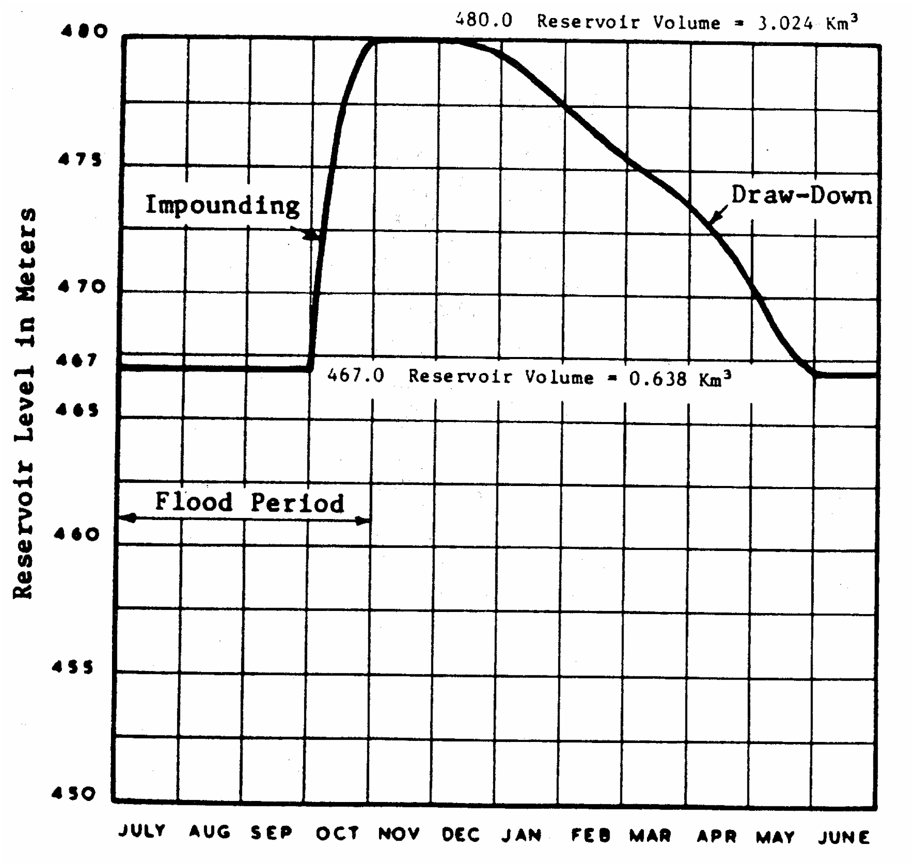

Figure 2-2 Typical operation program of Roseires reservoir.

Recently the earthwork of the second stage of dam design has already started. This will raise the dam by 10m (design level of 490 m) and increase the gross storage capacity to 7.4 Km^3.

Regarding the history of its sedimentation a total of five survey studies (four bathymetric surveys, in 1976, 1981, 1985, 1992 and one satellite imagery in 1995) were carried out by the consulting engineers Sir Alexander Gibb and Coyne et Bellier. The estimated progressive loss of the reservoir capacity is given in Fig. 2.3. The first intake blockage took place during the 1975 flood and again in 1983. By 1981, 83% of the storage below 467m level was silted up and by 1995 this figure reached 94% . The active storage lost was 5% by 1981 (15 years after operation) and 14% by 1995 (after 29 years of operation). In general the annual rate of siltation reduced non-linearly from 1.67% to 0.5% of the gross capacity in a span of 29 years. It was projected that the sedimentation rate will continue at a rate of 20 millions m^3 per year. However, with the anticipated heightening of the dam, the calculation showed that the rate would accelerate as the necessity to fill the reservoir dictates an earlier date of filling (Gibb and Coyne et Bellier report 1996).

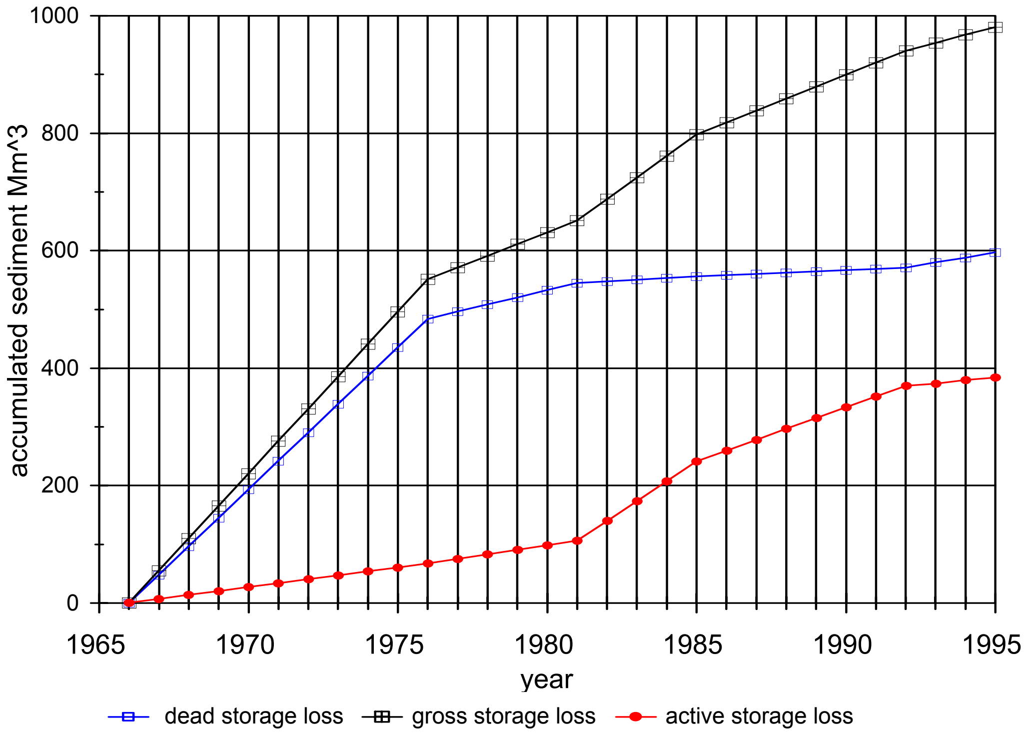

Figure 2-3 Storage loss of Roseires Reservoir (1966-1995).

The most important priority of the dam authority at present is to safeguard the hydropower intake from being overtaken by siltation. The presently applied sediment control measure is the removal of the deposited silt ahead of the intakes by dredging each year prior to the flood season. Fig. 2.4 shows a typical cycle of dredging and sedimentation in front of one of the power intakes, where an amount of more than 100000 m^3 of sediment is annually removed. At one time the cost of clearing the intake reached $20 per m^3 of sediment (Loman 1994).

On the other hand, sluicing of the rising limb of the flood, which is usually associated with very high concentration of sediment and filling of the reservoir after the flood peak has passed, is well observed. Tag Elsir and Osman (1986) pointed that sometimes forced filling occurs prior to the intended date because of the inadequate capacity of the bottom sluices to pass large flood flows. Mahmood (1987) mentioned that, this operational rule will save about 3.6 millions m^3 of storage from being silted, but nonetheless is not as efficient as that of Old Aswan reservoir due to geometrical differences between the two reservoirs.

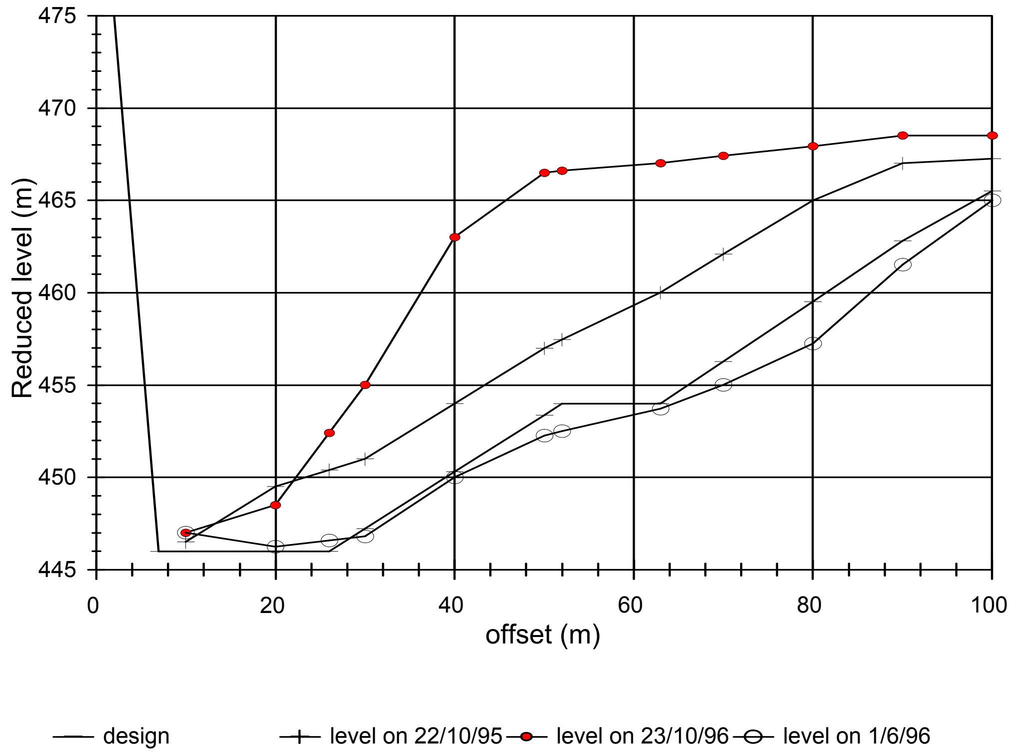

Figure 2-4 A typical annual cycle of dredging and sedimentation a head of Roseires hydropower intakes (intake 1)

2.3.1 Design of the Roseires Dam

The dam (fig 2.5) is a concrete buttress types about 1.000 meters long, flanked on either side by earth embankments, 8.5 kilometers long to west and 4 kilometers long to the east. The standard buttresses which make up nearly half of the total of 68 buttresses are spaced at 14.0 metre centers. The upstream water face has aslope of 3 in 10 and the water load is carried to the webs which are 3.0 meters thick down to RL 440 through the (T) heads with sloping haunches . The downstream face of the buttresses slopes at 6 in 10. The buttresses are built in trenches excavated to solid rock below the level of the weathered rock. Buttress web foundations for the future stage 2 dam have been constructed to above minimum tail water level or higher in the first stage. This is both for convenience and the safety of the structure and its equipment when the civil engineering works are recommenced for the final stage.

The deep sluice structure is sited in the main river channel and contains five sluice ways positioned as low as possible so that accumulations of silt in the reservoir can be kept to a minimum. Five radial gates 10.5 meters high by 6.0 meters wide control the discharge of water through the dam. An upstream emergency gate capable of closure under full flow condition is also provided.

To the west of the deep sluices is the surface spillway controlled by seven radial gates, each 12.0 meters wide. The spillway will augment the deep sluice flow when it becomes necessary to pass the peak of the flood. The maximum design flood of about 18 750 cumics can be passed, making due allowance for the effect of recorded flood over the past 60 years is sited in the diversion channel so that at maximum discharge the flow is dispersed over the full width of the natural trough in much the same manner as before construction commenced . A deflector bucket below the spillway throws the jet of water into a stilling basin clear of the dam. The stilling basin is an unlined excavation in the natural rock about 60 meters downstream of the spillway.

Immediately west of the Spillway structure, a small hydro electric service is contained between two buttress webs. This station provides power for the gates and for the township at Damazin. Further west, the buttress spacing increases from 14 m to 18 m to take the seven intakes for the main power station.

Figure 2-5 Roseires dam passing flood water in July 1966.

2.4 AHD RESERVOIR

The High Dam is a rock fill dam, completed in 1968, closing the Nile at a distance of 7km south of Aswan. Aswan High Dam Reservoir (fig. 2.6) extends for 500 km along the Nile River and covers an area of 6,000 km^2, of which northern two-thirds (known as Lake Nasser) is in Egypt and one-third (called Lake Nubia) in Sudan.

The storage capacity of the reservoir at the maximum allowable level (182m) is about 162 billion m^3. This amount is increased by 7 billion in case of raising the water level up to (183m). Table 2.1 shows the various storage capacities of the reservoir.

Table 2.1 Storage capacity of AHD reservoir

Storage	**From level (m)**	**To level (m)**	**Storage capacity billion m^3**
Dead storage		146	30.6
Live storage	146	175	90.7
Flood control storage	175	182	41
Emergency flood control storage	182	183	7
			168

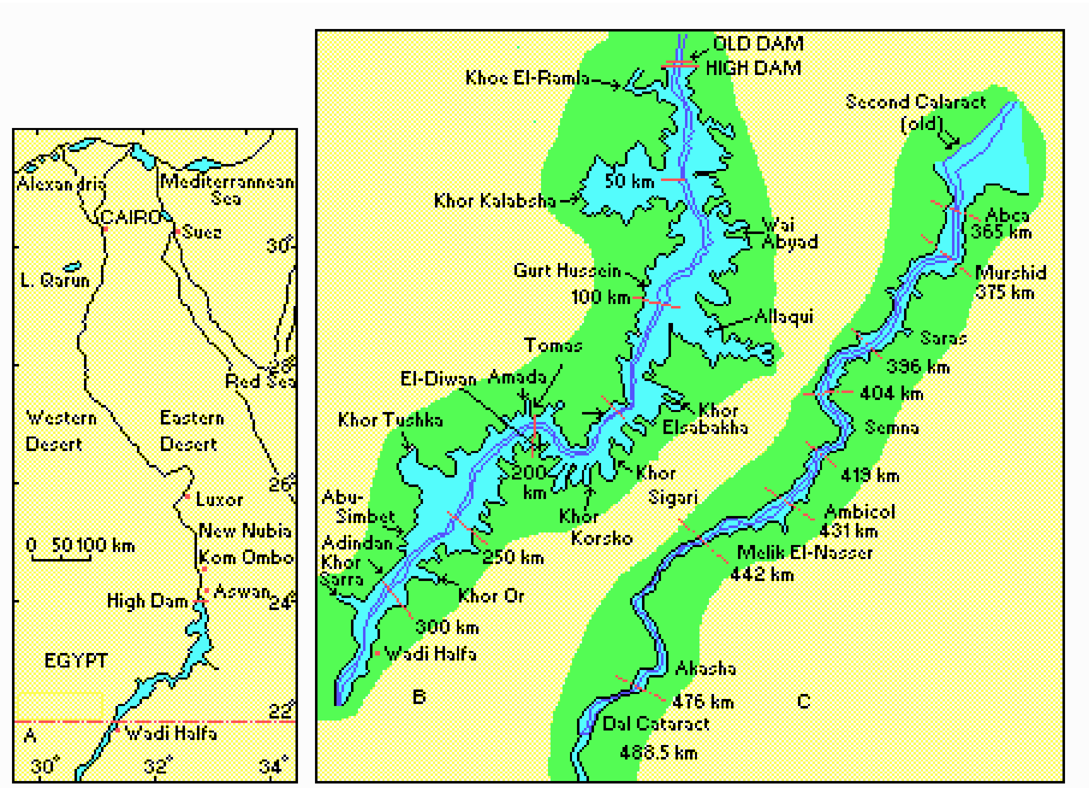

Figure 2-6 Location and extent of Aswan High Dam Reservoir

The mean annual discharge before and after the construction of Aswan High Dam is presented in figure. 2.7. and Figure. 2.8 shows the storage level of AHD and the corresponding reservoir content over years.

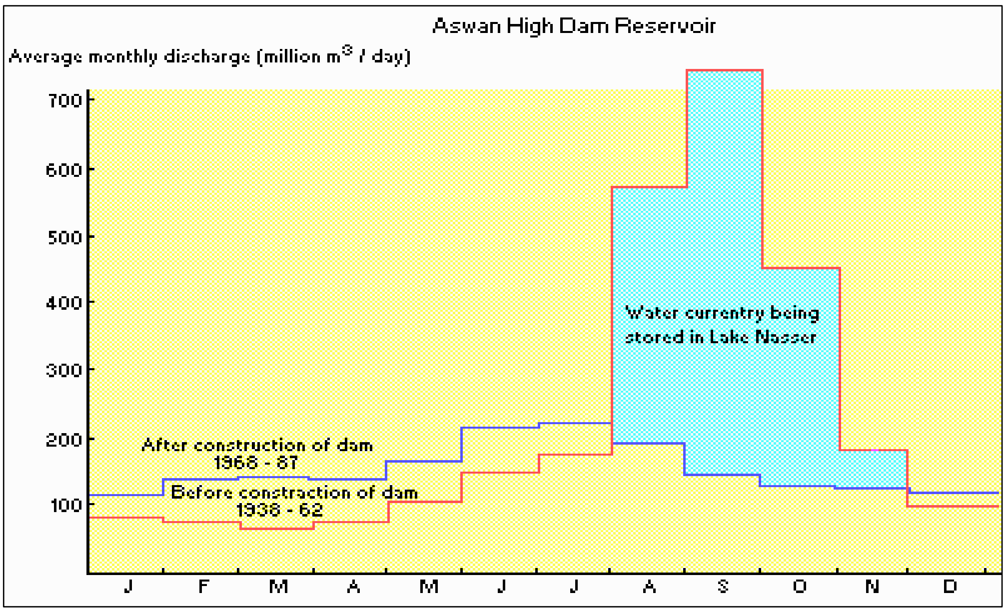

Figure 2-7 Average monthly discharges downstream the Reservoir before and after its construction

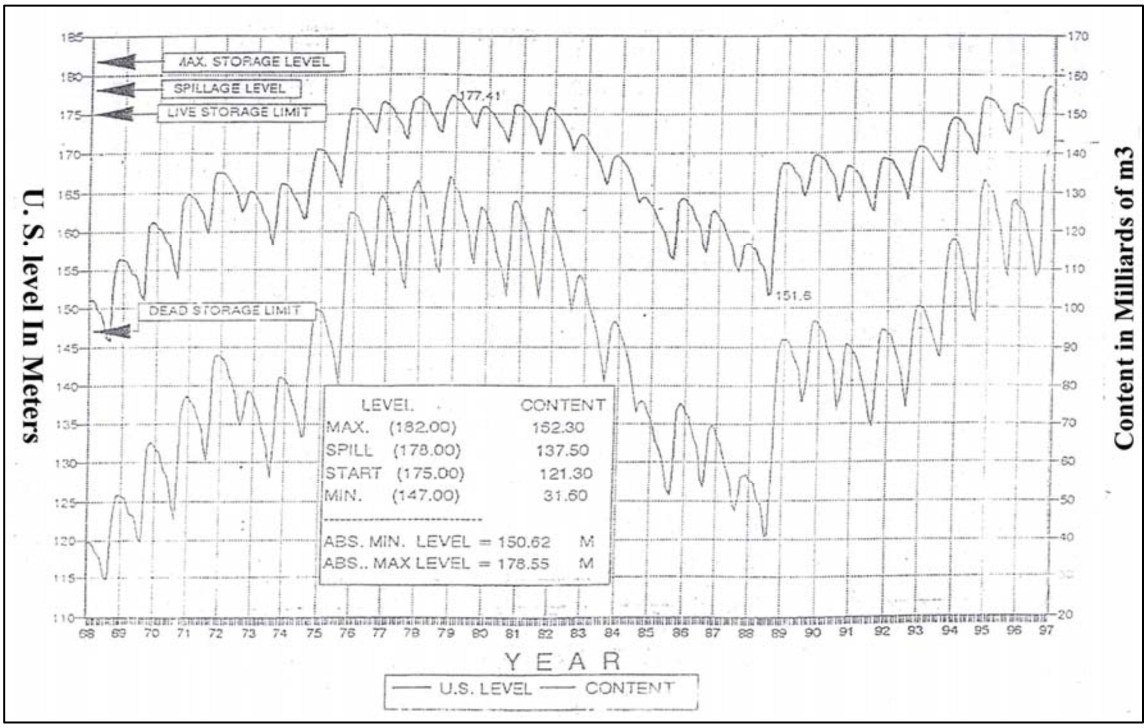

Figure 2-8 U/S Level and Content of High Aswan Dam.

The long-term average (1929-1959) of sediment load that enters the Old Aswan Reservoir at Wadi Halfa was estimated to be134 tons. Sediment distribution in AHD is investigated regularly along fixed 21 cross-sections (Figure 2.9). Extensive bathymetric survey is conducted along the fixed cross-sections resulting clear profiles of the reservoirs. Since 1973, investigations and analysis for sediment deposition both upstream and downstream AHD has been conducted.

Sediment investigations are carried out three times a year, before, during and after the flood period. The measurements cover a distance of about 220 km (Figure 2.9) at the tail zone of the backwater curve, behind which no sedimentation is observed. In this reach fixed measurement stations were selected. The types of records are velocity measurements, suspended sediment sampling, hydrographical survey, freshly deposited sedimentation samples, and chemical analysis of water samples. Figure 2.10 and fig. 2.11 show the longitudinal profile and suspended sediment distribution along AHD Reservoir respectively.

It has to be mentioned here that the total deposited sediment volume is 2477 million m3 in the time interval 1964-1995. However, compared to the other reservoirs AHD has experienced a unique sediment process with rather varying consequences.

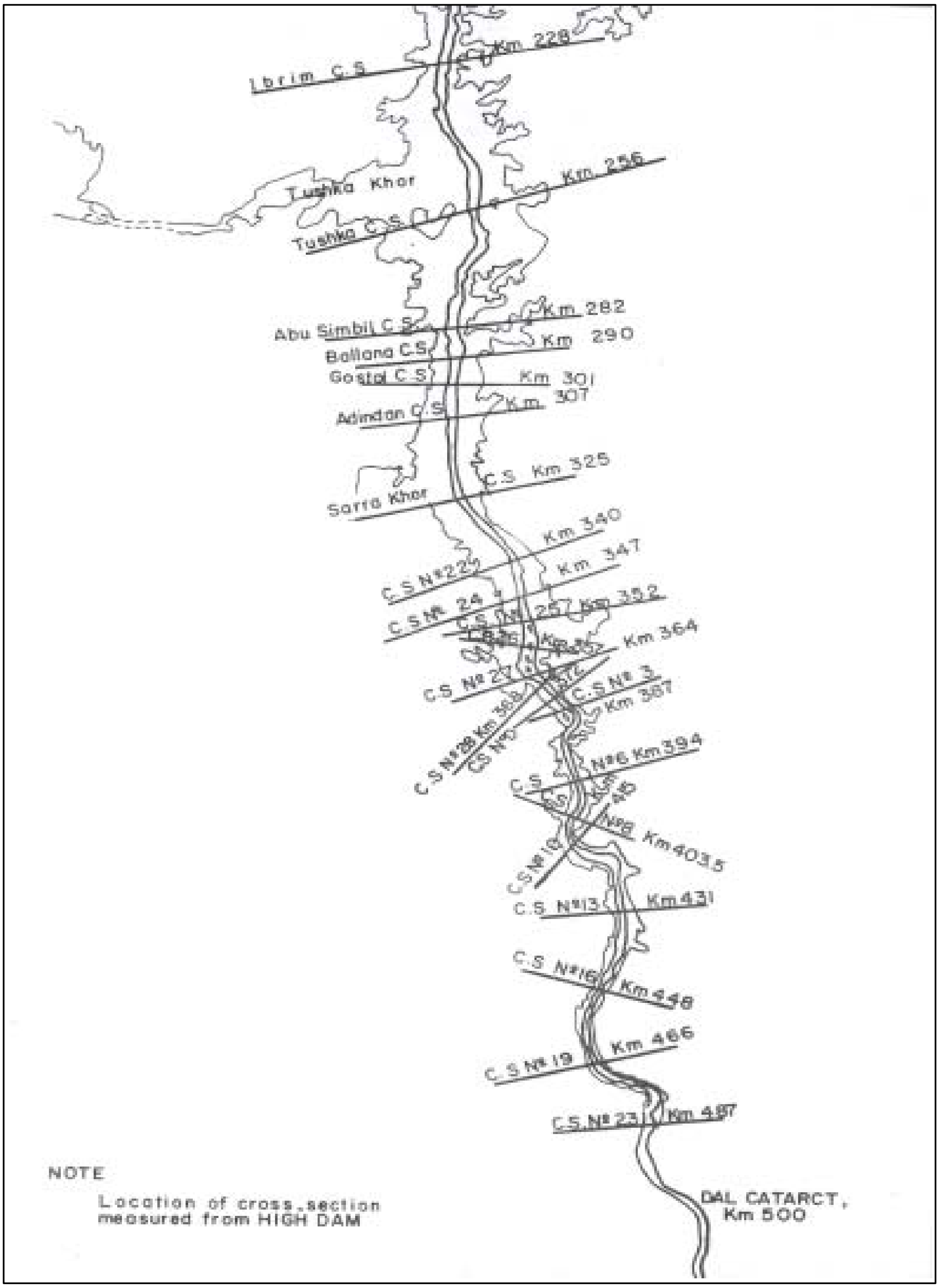

Figure 2-9 The Location of Cross Sections along Aswan High Dam Reservoir for Periodical Investigation.

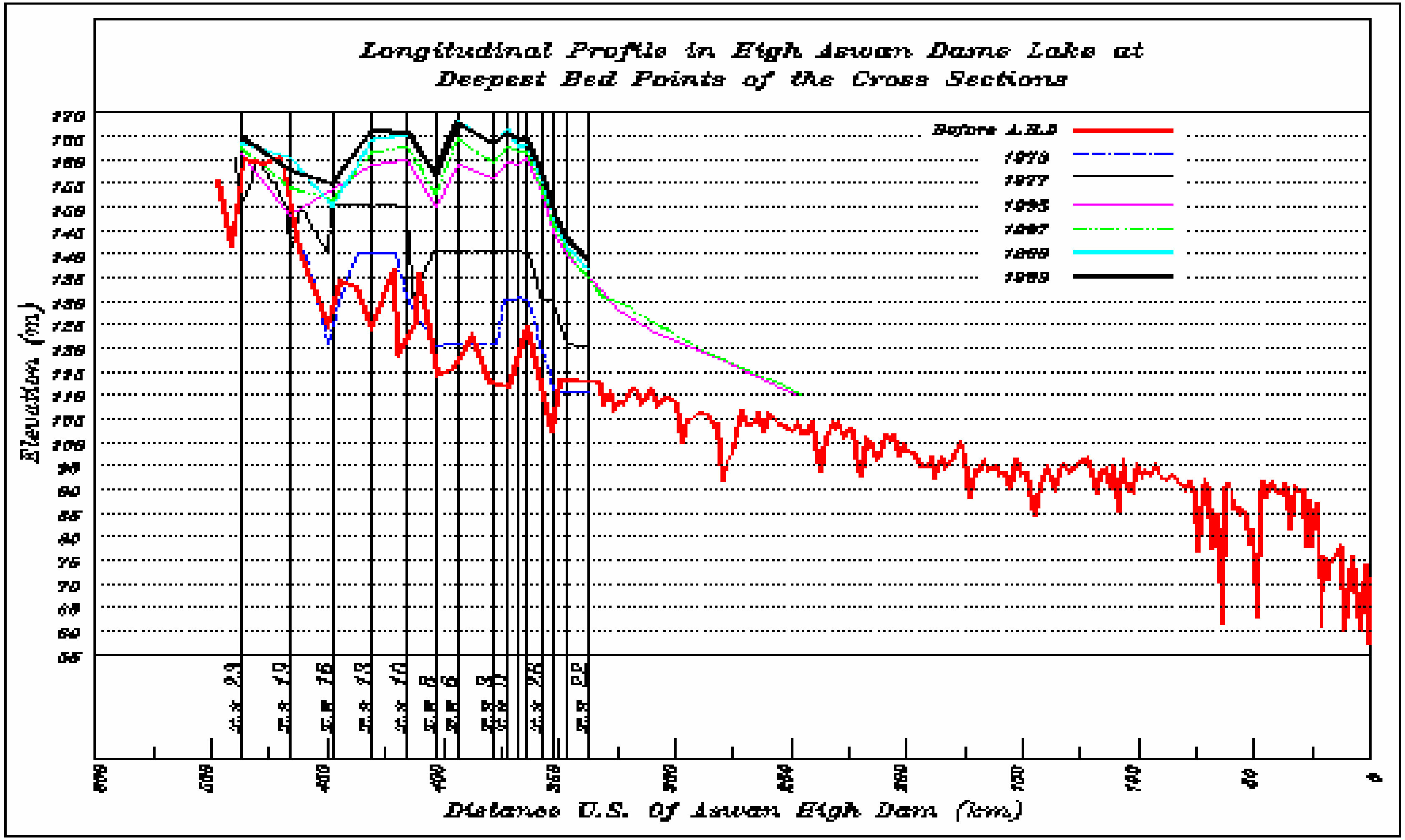

Figure 2-10 Longitudinal Profile in Lake Nasir showing Deposited Sediment Progress

During the reservoir filling process, the distribution of siltation used to cover wider areas depending on the size of the flood. More recently, siltation has been confined to the most southern part of the reservoir. This is clearly reflected by Fig. 2.11 which shows the decrease of suspended sediments towards the Dam. Particularly, heavy siltation occurs in the area between 360 km and 430 km south of the dam site. In this region, siltation beds have already emerged in the life storage zone as shown in Figure 2.10. Nevertheless, sediment transport phenomena tend to be in a northerly direction.

It can be noticed that sediment deposition started at the tail zone of the reservoir and steadily progresses northward along the river bed. It seems that sediment deposition will approach the dam after a pretty long period of time. The dead storage capacity was estimated to be sufficient for accumulation of suspended matter over 300-500 years (100-60 Mm^3/ year, or 150-90M tons/year).

Previous measurements/ studies have shown that a guaranteed sediment load of 130 tons/year (87 million m^3) coupled with a constant regulation rules of the High Dam (80-230 Mm^3/day) and the characteristics of rocky-narrow channel of the southern part of Lake Nubia worked to form a new delta on the sides of the lake with a significance seasonal (winter) agricultural potential.

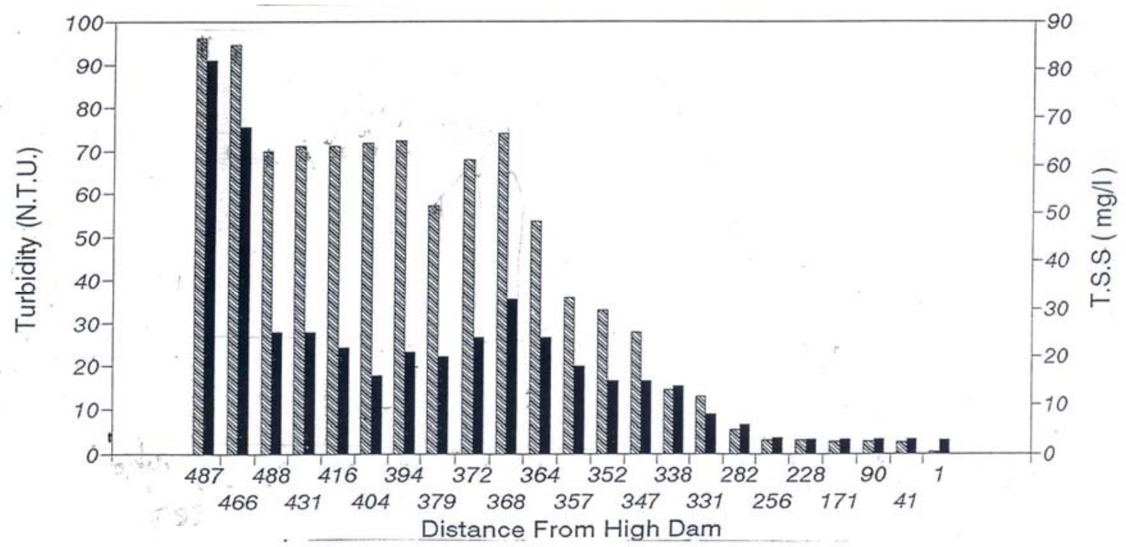

Figure 2-11Turbidity and Total Suspended solids along Nuba/ Nasir Reservoir.

2.5 ANGEREB RESERVOIR

Angereb dam (fig. 2.12) for water supply is constructed in 1986 on Angereb River, a tributary of the river Nile in the Ethiopian plateau. Angereb watershed is characterized by hilly topographic conditions, absence of vegetation cover, improper farming and soil management practices. Therefore, severe soil erosion in the Angereb catchment contributes to reservoir sedimentation and affects its water supply potential.

The mean annual flow of Angereb River at the gauging station is about 27 Mm^3 (fig 2.13). The trap efficiency of the reservoir estimated from the original capacity (5Mm^3) according to Brune median curve is 90.23%. Suspended sediment measurements at the Angereb gauging site show high variability. The mean annual suspended sediment discharge at the dam site in the period of 1983-1989 was estimated at 76,800 tons, with annual rate ranging from 7900 to 178,800 tons. The transport is heavily concentrated on the highest flood peaks in June-October. In dry season it is less than 300 ppm whereas in wet season it is above 2500 ppm.

The estimated mean annual sedimentation rate in Angereb reservoir is 1200 ton/ km^2/year. DEVECON and SHAWEL (1992) have shown that the reservoir half life would be alarmingly about 21 years. According to their prediction the reservoir would lose 15% of its volume in 2005 and about

30% in the year 2015. The water resources verification study (WASSA, 1993) revealed that by the end of 2010 there will be shortage of water in Gonder town because the reservoir capacity will be reduced by 50% (from 5Mm^3 to 2.5Mm^3) as a result of sedimentation. These conditions have impacted the operational level of the reservoir that has a direct effect on the people livelihood.

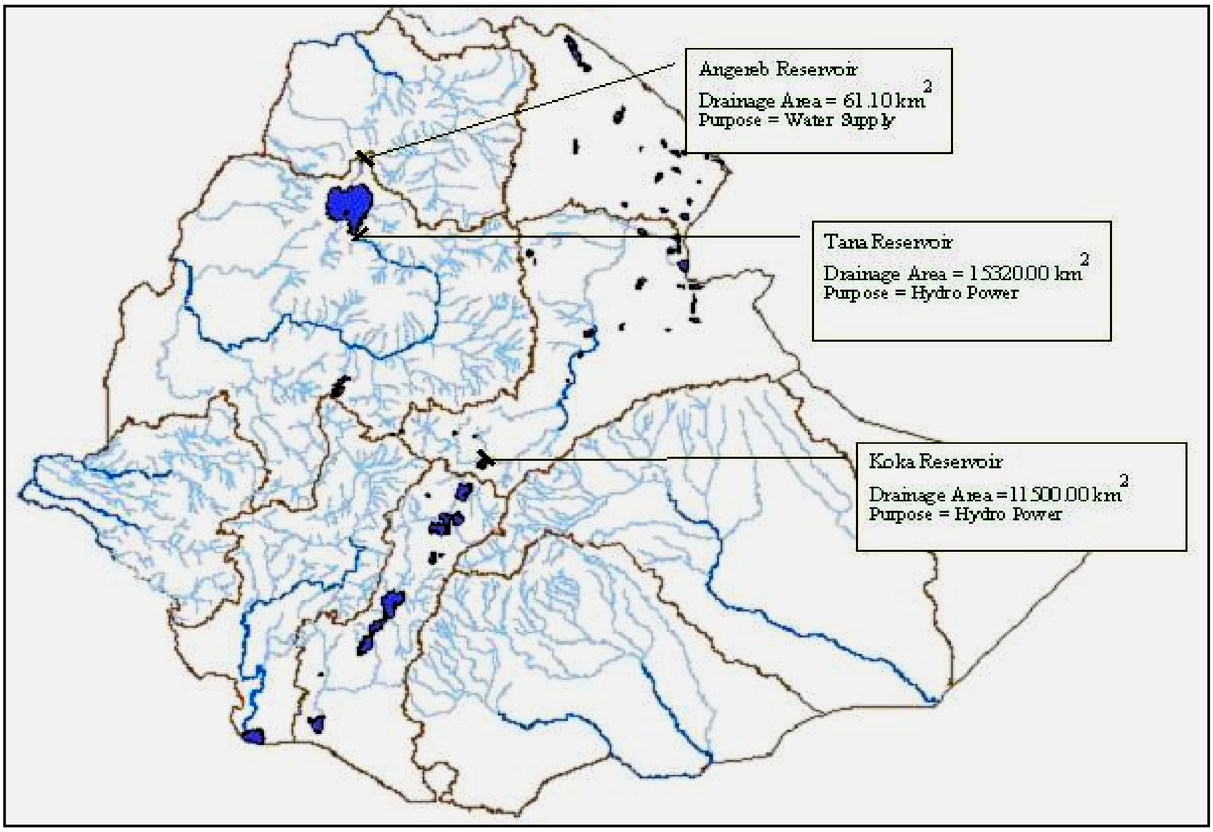

Figure 2-12 Location of Angereb Dam in Ethiopia.

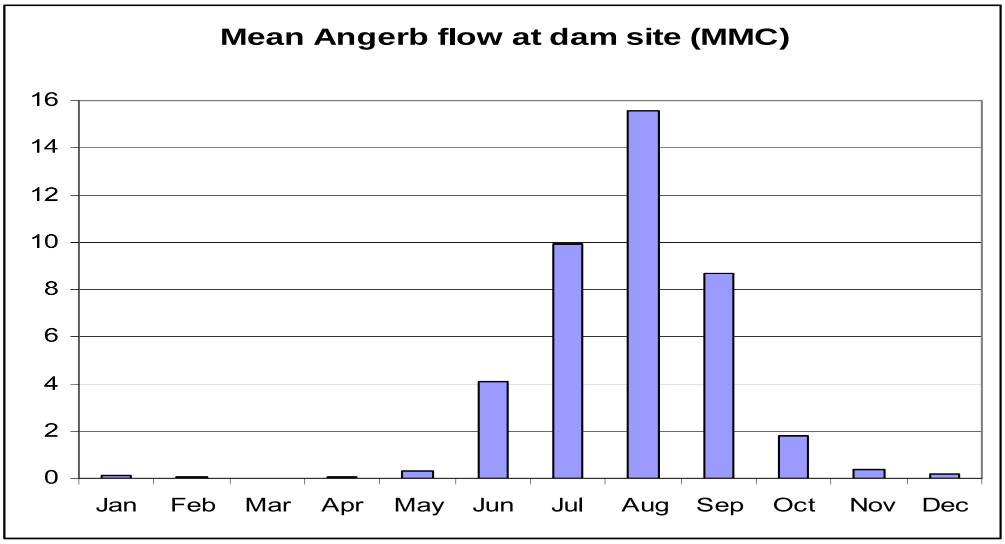

Figure 2-13 Mean Angereb Flow at Dam Site.

2.6 KOKA RESERVOIR

Koka dam (fig. 2.14) is constructed on Awash River, which originates from the high plateau some 150km west of Addis Ababa, at an altitude of about 3000m.

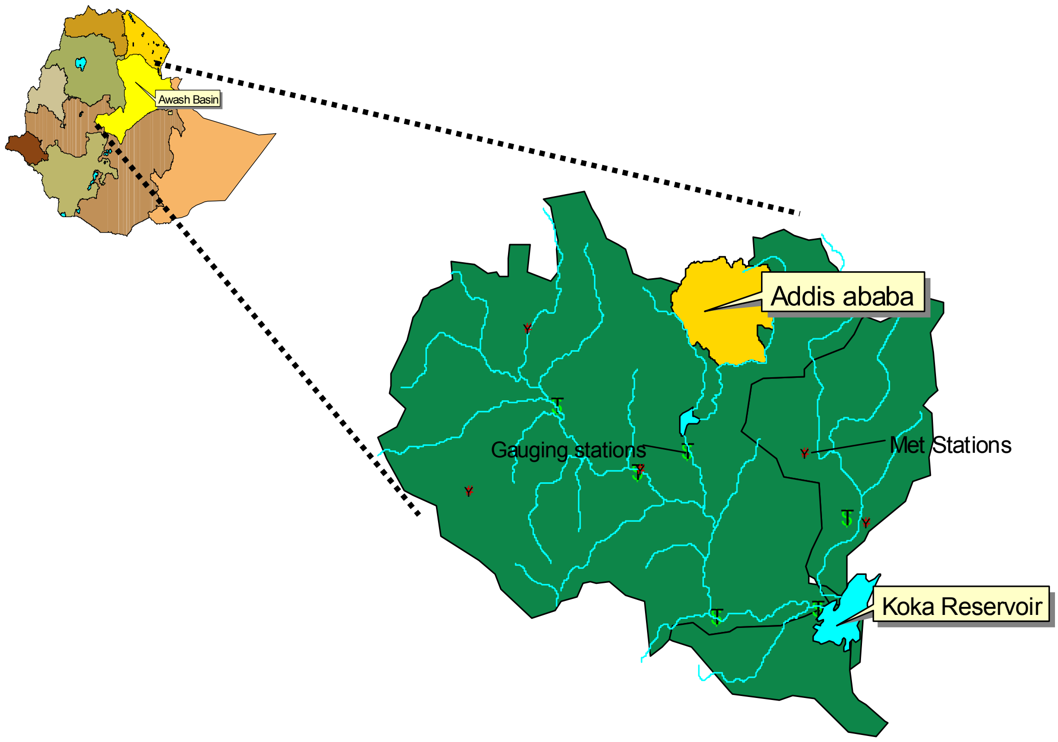

Figure 2-14 Location map of Koka Reservoir

Koka reservoir had an original storage capacity of 1650 Mm^3 at full reservoir level of 1590.7 m above sea level (or 110.m reduced level). Figure 2.15 shows the corresponding elevation capacity curve for Koka reservoir. When the dam was made operational in 1960 the capacity of the reservoir at 100.4m (minimum operating level) was 180Mm^3. At present only 8 Mm^3 of dead storage volume remains. This condition has impacted the operational level of the reservoir and has directly affected the uses of the reservoir. Koka dam incorporates a spillway comprising five sector gates, a bottom outlet with maintenance gate which were for a long time submerged by sediment and two fixed wheel bulkhead gates.

Koka reservoir sedimentation has been monitored by surveys made in 1959 (original ground without impoundment), 1981, 1988 and 1999, see figure 2.12. The mean rate of silt deposition in the reservoir is estimated at 13–20 Mm^3 per year (MWR, 1999), which is in the order of 1800 ton/km2/year. Using the original capacity of the reservoir and the mean annual inflow of Awash River upstream of Koka dam (29478 Mm^3 at Hombole station) the trap efficiency is estimated at 78.38%. However, the rate of silt deposition is expected to vary from year to year due to land cover/use changes in the catchment area and the variation in sediment trap efficiency due to storage changes.

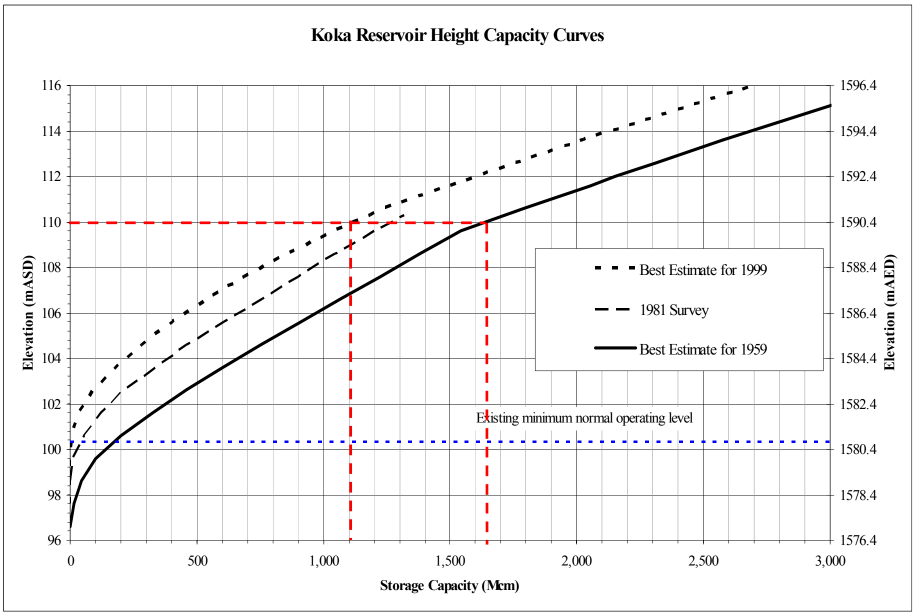

Figure 2-15 Koka reservoir Height Capacity Curve

2.7 KHASHM EL GIRBA RESERVOIR

Khash el Girba reservoir (Fig. 2.16) is located on the Atbara River approximately 200km downstream of the Ethiopian border and 75 km downstream the confluence of the Upper Abara and Setit rivers. Annually an average sediment load of 15000 ppm is carried by Atbara River and a maximum sediment concentration of 30000 is reached. (fig. 2.17). The mean annual inflow of Atbara River is 12 milliard measured at Kubur and Wad El Hiliew stations. Based on later figure and the original reservoir capacity (1300 Mm^3) the trap efficiency of the Girba reservoir reaches 86%.

Initially filled in 1964, Khashm el Girba had a capacity of 1.3 milliards at elevation 473 m in a reservoir length of 80 km length. By 1977, the capacity was reduced by sedimentation to 0.66 milliards, a loss of half of its capacity. Beside the natural phenomenon of heavy silt load Atbara River is characterized by steep slopes ranging from 5 m/km along 300 km from the catchment outlet to 25 cm/km for 500 km from Setit river confluence up to Atbara. This problem is further aggravated by the inappropriate operation policies of the reservoir.

Khashm el Girba dam was originally designed as a single purpose dam for irrigating New Halfa scheme and settlement of kassala & Shukria nomads. Use of turbines to simultaneously produce electricity and supply irrigation water when levels in the reservoir are high was considered. To supply domestic water reservoir, emptying is delayed to create command level for the pumping station at Showak town.

This change in operation (fig. 2.18) has contributed to silting up of the reservoir creating a set of negative impacts.

The loss of capacity caused severe water shortages during drought years resulting in decline of the area cultivated. The decline in storage has also caused hydropower generation to be limited to only the flood season. Located in the delta area of the reservoir, the headworks at El Showak are endangered of being drowned due to gradual rising of the delta already 12 m above the initial bed elevation. The sedimentation and floating debris problems at the turbine intakes are causing serious problems.

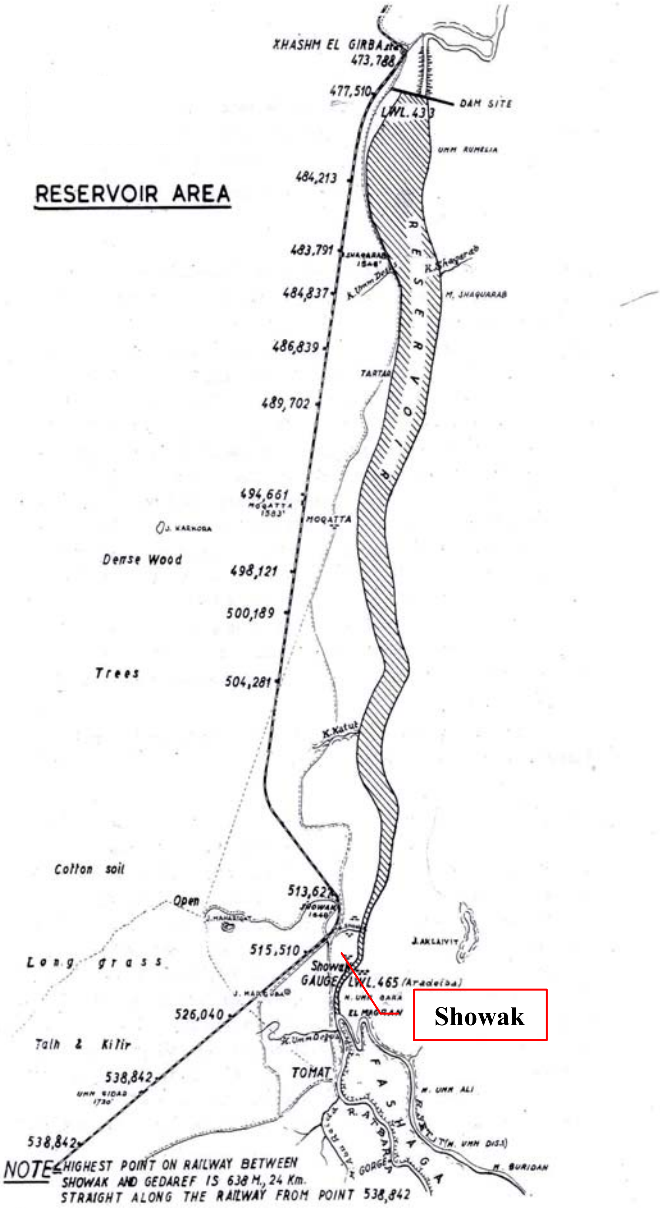

Figure 2-16.Khashm El-Girba Reservoir Area on Atbara River. Source: Bell, 1956.

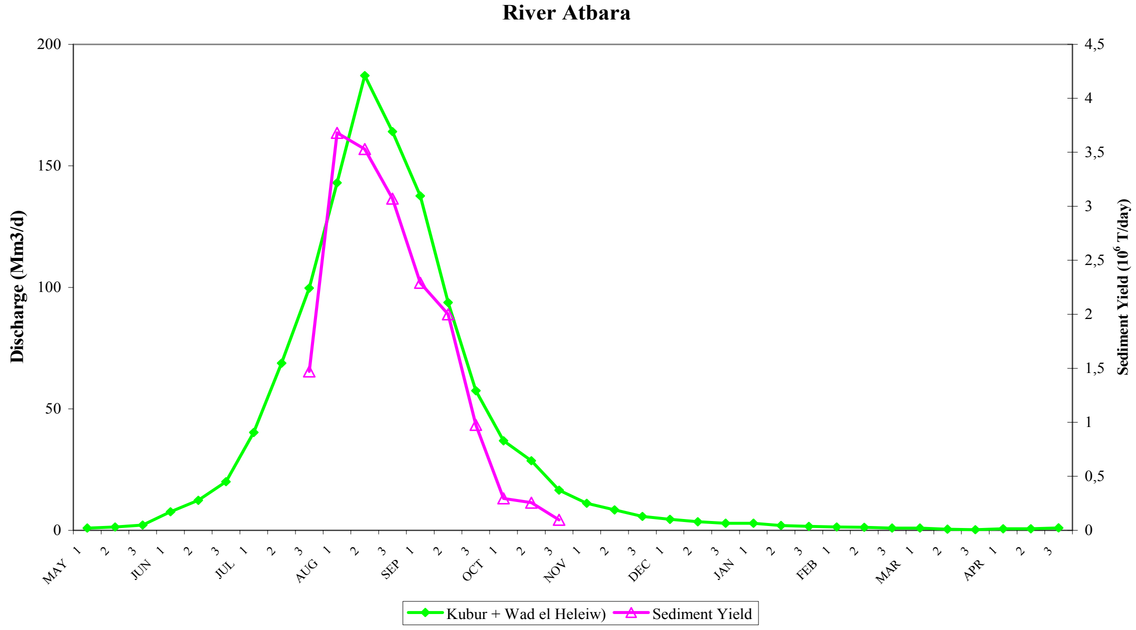

Figure 2-17 Average Inflow and sediment load upstream Khash el Girba reservoir.

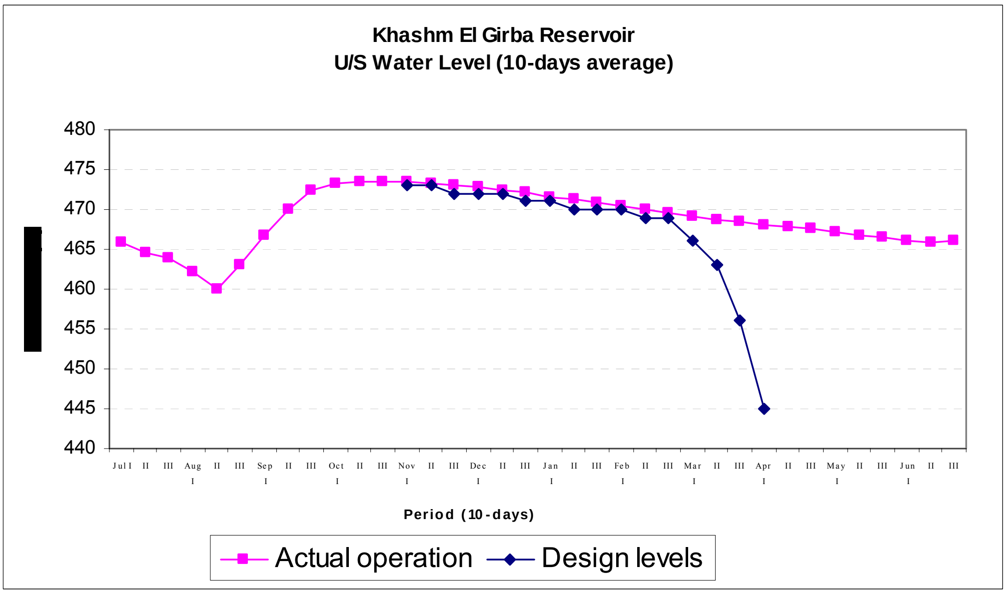

Figure 2-18 Actual vs Design Operation of Khashm El Girba Dam.

Based on data on the reservoir content and hydrographic surveys of the reservoir changes of Khashm El Girba Reservoir storage over the years and annual rate of storage loss at different levels is plotted in Figure. 2.19, 2.20 and 2.21 respectively.

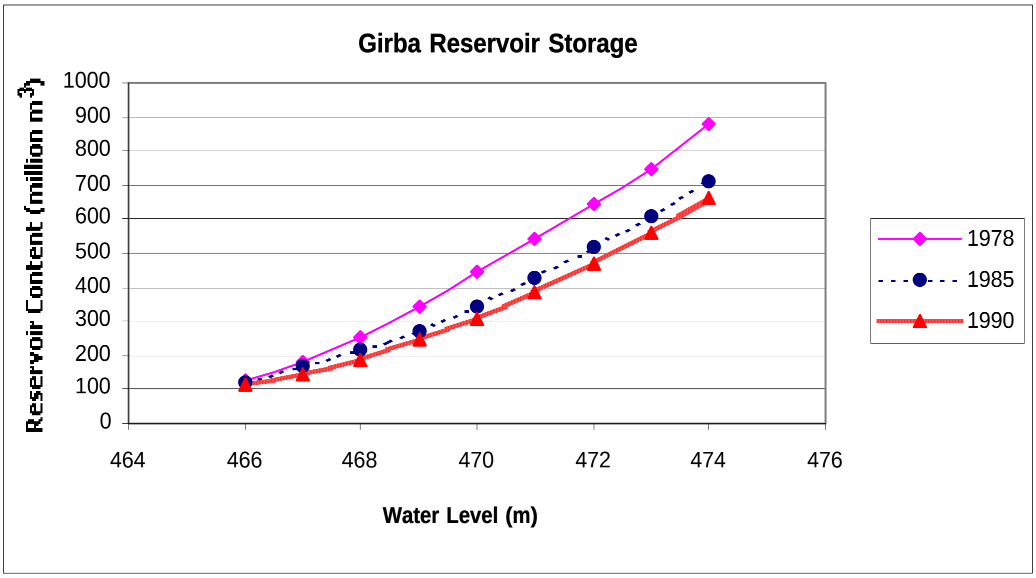

Figure 2-19 Khashm El Girba Reservoir Storage and its changes over the years

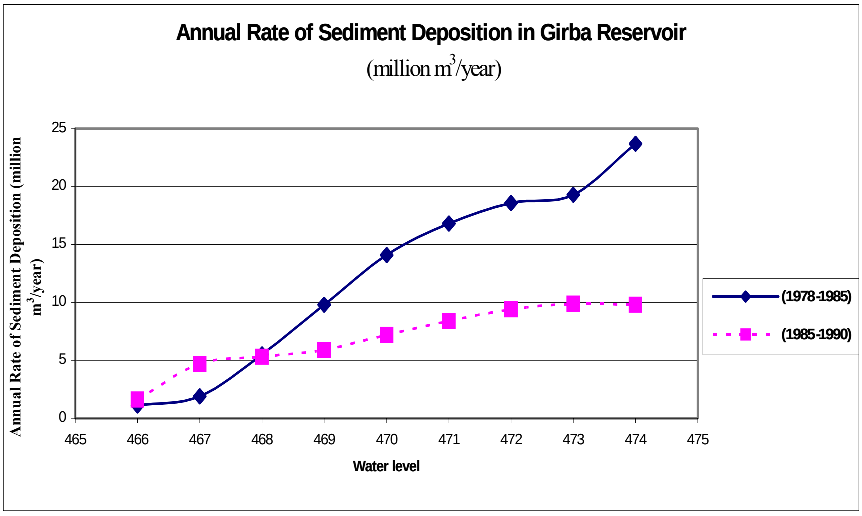

Figure 2-20 Rate of Sediment Deposition in Khashm El Girba Reservoir

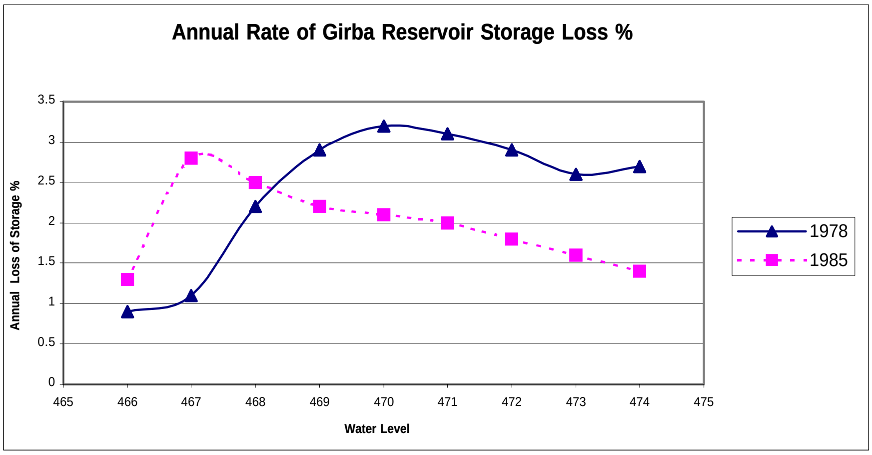

Figure 2-21 Rate of Storage Capacity loss in Khashm El Girba Reservoir.

Obviously, the existing sediment monitoring program is not sufficient to determine the amount of sediment entering the reservoir. Due to the severe sedimentation problem in the Girba reservoir, a sediment monitoring program is required to help assessing the extent of the problem. Establishment of monitoring stations at El Showak, Kashm el Girba dam and Atbara as priority locations is needed to investigate the operation rules and see if sediment deposition rates can be decreased. Also, obtaining appropriate sediment data acquisition equipment and training of technicians and engineers is recommended.

2.8 *COMPARISON OF TRAP EFFICIENCY IN THE SELECTED RESERVOIRS*

In the foregoing sections the state of sedimentation in five reservoirs in Ethiopia, Sudan and Egypt is presented based on Group 1 members' contributions (Appendices I, II, III). In table 2.2, an overview of the state of sedimentation in the selected cases is summarised. The Reservoirs under study are ordered according to the capacity/inflow ratio and the estimated trap efficiency (table 2.3). Comparison between the trap efficiency of the five reservoirs is made using Brune median curve. Plotting the capacity/inflow ratio on the horizontal axis (logarithmic scale) and the capacity itself on the vertical axis the range the range covered by the selected reservoirs is demonstrate in Figure 2.22. According to the empirical relationship (equation 1) developed by Brune trap efficiency a range between 78 to 98% is encountered. However, trap efficiency depends on a number of factors such as the age of the reservoir, shape of the reservoir basin, type of outlets, method of operation, size grading of the sediment and the behaviour of finer sediment fractions under various conditions (Mustafa, 2003).

$E = 100 \times 0.97{**}0.19{**} \log(C / I)$ Eq^n 1

$E = 100 \times (0.97^{0.19 \log C/I})$

Table 2.2 State of sedimentation in the selected reservoirs.

Reservoir	Year of Construction	Original Capacity (Mm^3)	Estimated loss %	Mean annual rate of sedimentation	Bottom Outlets/ sluices
Koka	1960	1650	32% (1999)	13–20 Mm^3/ yr,	?
Roseiris	1966	3000	40%	20 Mm^3 /yr	?
Girba	1964	1300	60%	49 Mm^3/yr	Seven
Angereb	1986	5.28	15%	1200 ton/ km^2/yr	One
Nasir-Nuba	1960 - 1970	162000		80 Mm^3/y	none

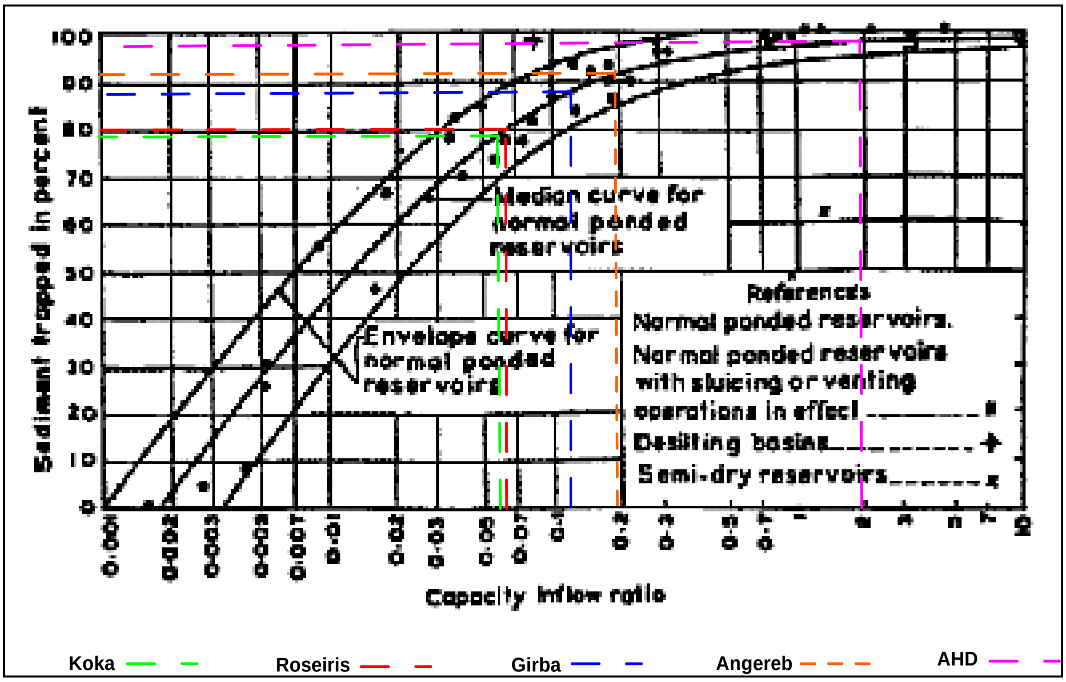

Figure 2-22 Trap Efficiency Curve by Brune.

Table 2.3 Trap efficiency Coefficients for different Nile Reservoirs estimated by Median Curve of Brune Method.

Reservoir	Capacity (C) (Mm^3)	Total Inflow (I) (Mm^3)	C/I	Brune Trap Efficiency %	Observed Trap Efficiency %	Location
Koka	1650	29478	0.0560	78.38	-	Awash River - Ethiopia
Roseiris	3000	48744	0.0615	79.64	45.5 (1976), 26.2 (1995)	Blue Nile - Sudan
Girba	1300	12000	0.1083	86.00	-	Atbara River - Sudan
Angerib	5.28	27	0.1852	90.23	-	Angereb River - Ethiopia
Nasir + Nuba	162000	84000	1.929	98.12	-	Main Nile – Egypt + Sudan

3 SEDIMENTATION IN ROSEIRES RESERVOIR

Herein analysis of sediment inflow rating curve, estimation of trap efficiency, deposited sediment and its distribution, remaining capacity, and prediction of future deposition rates and capacity loss will be made taking Roseires reservoir as a case study.

3.1 SEDIMENT INFLOW RATING CURVE

Reasonable data of suspended sediment concentration on daily basis for a number of years are available for El Deim gauging station which is located at the mouth of the reservoir.

El Deim gauging station is at Sudan-Ethiopia border. It was established in 1962 during the construction of the dam. The Station is sited in a deep rock gorge, which is believed to provide a very stable control, reliable and accurate flows.

Unlike water discharge measurements, sediment monitoring at El Deim is infrequent, unsystematic and incomplete. Good consistent sediment measurement data are scarce. The available paired data (solid and liquid) for a number of years are shown on Fig. 3.1. These are daily values of discharge and suspended sediment. The later was measured by bottle sampling taken once a day from the channel bank.

The scatter in the data is considerable despite the attempt of imposing some order by plotting data according to the time of the year. This is to be expected because sediment transport in the Blue Nile is a seasonal supply limited phenomenon resulting from rainfall-runoff in the catchment area. The suspended sediment is mostly fine material because weathering of the soils of the watershed during long, dry periods produces large transportable load of fine material.

From Fig. 3.1, for a given water flow, suspended sediment transport rate is higher during the rising (July-August) than the falling flood stage (September-October). This loop in the sediment transport – water discharge relationship (sediment rating curve) is common for many rivers.

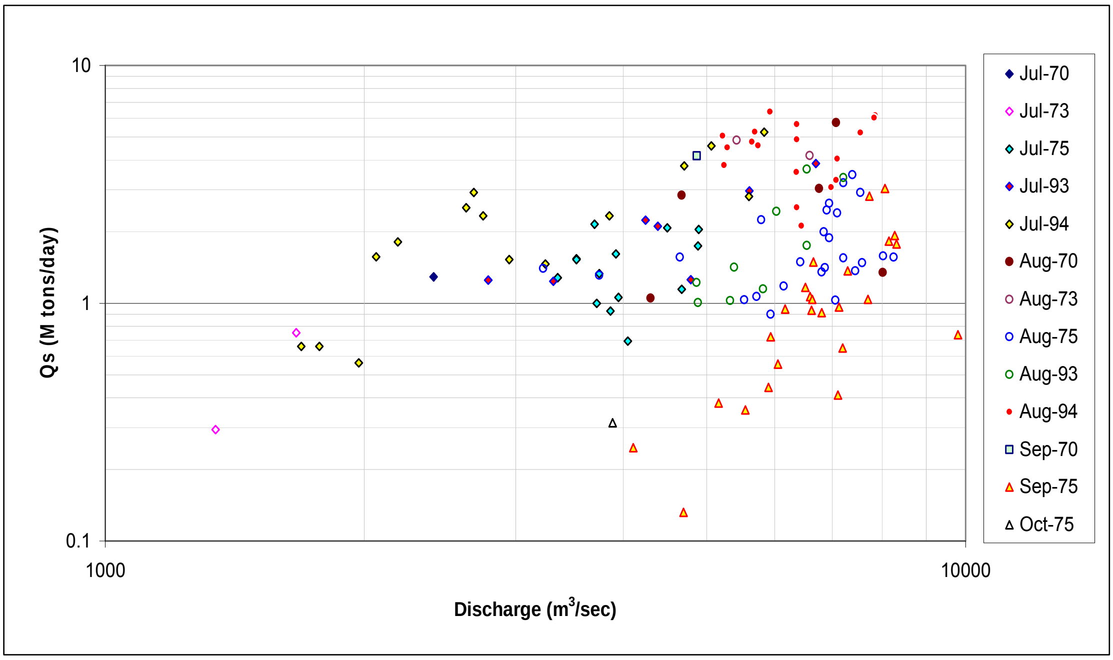

Figure 3-1 Daily Suspended Sediment - Water Discharge Relationship for El Deim Gauging Station at the Mouth of Roseires Reservoir

Segments of the sediment rating curve is usually approximated by a power relation of the form

$Q_s = m\ Q^n$ ……………………………………………………………………… (3.1)

In which

Q_s = suspended sediment transport (M tons/day)

Q = water discharge (m3/s)

m and **n** coefficient and exponent respectively.

The exponent n for many rivers varies little about a mean value of 2.0 (Garde, Ranga Raju 1985).

For clarity, Fig. 3.1 is separated into two: one for the rising flood stage (Fig. 3.2) and the other for the falling stage (Fig. 3.3). Observations indicate that for higher and higher flood discharges, the exponent n in Eq$^{\underline{n}}$. 3.1 will diminish and approach a value of unity (n = 1).

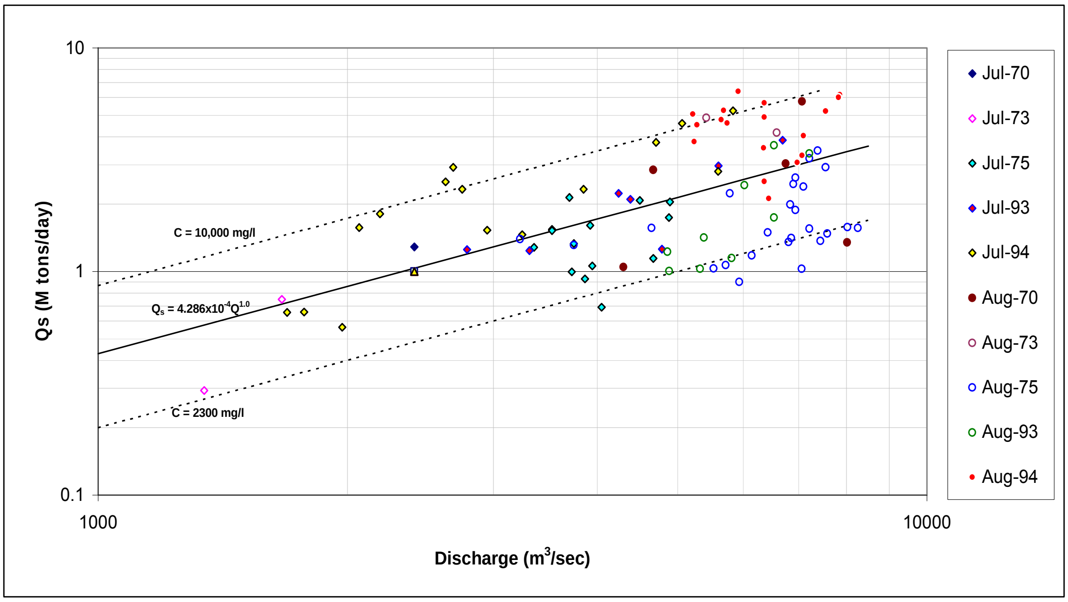

Figure 3-2 Suspended Sediment Rating Curve for El Deim Gauging Station - Rising Flood Stage

In such case, the sediment concentration is constant and independent of Q. The value of unity for n appears to be a common minimum value attained by many streams at high flood discharge (USDA, 1979). Indeed, the Blue Nile at El Deim follows this trend during the rising flood stage as it can be seen from Fig. 3.2. Shown in the Figure the upper and lower envelope lines (within which most of the data points fall) drawn to a slope of unity. The median line, drawn also to the same slope, represents the rating curve for the rising flood stage with an equation given by

$Q_s = 4.286\text{x}10^{-4}\ Q^{1.0}$……………………………………………………………… (3.2)

where all the terms are defined previously.

For the falling flood stage, the data points in Fig. 3.3 seem to follow approximately a trend having a slope of 2. As indicated by the upper, median and lower lines drawn in the figure to the same slope (n=2). The median line represents the rating curve for the falling stage with the following equation

$Q_s = 1.837\text{x}10^{-8}\ Q^2$……………………………………………………………… (3.3)

again the terms are defined as before.

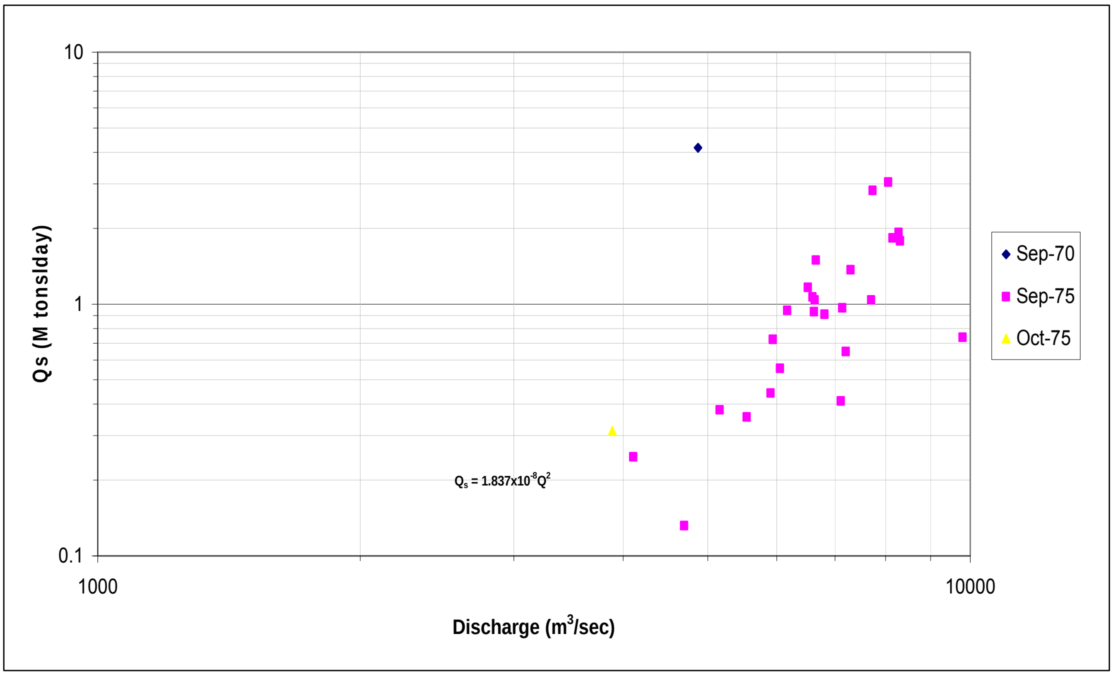

Figure 3-3 Suspended Sediment Rating Curve for El Deim Gauging Station - Falling Flood Stage

From the above analysis, $Q_s \sim Q^{1.0}$ for rising flood stage and $Q_s \sim Q^2$ for the falling stage. Thus one cannot expect a unique relationship between Q_s and Q to be valid for both stages.

It is to be noted that for both equations (3.2) and (3.3), linear least squares fit of the logarithms of the data points was not employed because of the considerable scatter that may give erroneous results. Instead, eye fitting was used.

3.1.1 Estimate of Sediment Inflow

Sediment rating curves are usually based on short-term data record unlike water discharge measurements. However, long-term sediment load estimates are required for reservoir sedimentation. Realizing this difficulty, Miller (1951) developed a method for finding the average sediment yield by combining short-term sediment rating curve with long-term flow-duration curve knows as Flow-Duration, Sediment-Rating Curve method. Flow-duration curve indicates the percentage of time a given discharge is equaled or exceeded in the available number of years of records. The discharge may be daily, weekly, monthly, yearly or any other time interval. The selection of the time interval depends on the purpose of the study.

Experience indicates that the flow-duration/sediment-rating curve method is most reliable when (i) the recording period is long, (ii) sufficient data at high flows are available, and (iii) the sediment-rating curve shows considerable scatter (Julien, 1995).

Because of its advantages, Miller's method is adopted in this study as it suits most the case under consideration. Flow-duration curves for 30 years (1966-1995) record of El Deim Gauging Station were developed for each 10-day period of the flood months (July-September). Typical flow duration curve is shown in Figure (3-4). The curve is divided into discrete values of time percent intervals. The discharge for each time percent interval midpoint is used to compute the suspended sediment rate from the appropriate sediment-rating curve (Fig. 3.2 or 3.3 or equations 3.2 or 3.3). This value is then multiplied by the time interval and summed over all the time intervals of the flow duration curve to give the mean sediment yield for the given period. The results following this procedure is given in the table 3.1.

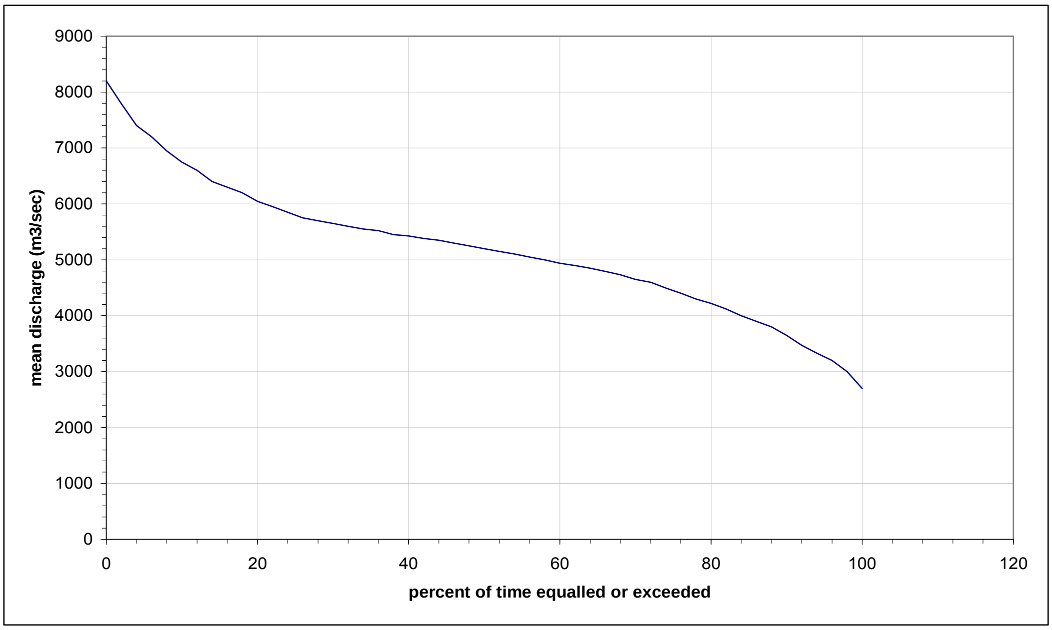

Figure 3-4 El Deim Flow Duration Curve for the first 10 days of August (1966 - 1995)

Table 3.1 Seasonal Long Term Mean Suspend Sediment Inflow at El Deim Gauging Station

Month	**July**			**August**			**September**			
Period	**1-10**	**11-20**	**21-31**	**1-10**	**11-20**	**21-31**	**1-10**	**11-20**	**21-31**	
Q_s M tons	**7**	**10**	**19**	**22**	**26**	**27**	**5**	**4**	**3**	
										123

In the absence of long-term record of suspended sediment data at El Deim gauging station, it is difficult to give judgment on the accuracy of the transport rate values given in the Table. Miller (1951) using this method for the San Juan river in U.S.A. found that the average annual computed sediment transport rate checked within 4% of the average value obtained from a 19-year record. In developing the suspended sediment rating curve(s) for El Deim gauging station, years where sediment data records were available were used (1970, 73, 75, 93 and 1994). For all these years, the mean annual water flows were equal to or greater than the long term mean which should produce results with a maximum error of 20% (Miller, 1951). Therefore it can be said that the estimates given in Table 3.1 appears to be sufficiently accurate for practical application.

This value of 122 M tons for long-term suspended sediment inflow at el Deim gauging station is equivalent to a suspended sediment yield of 480 t km^{-2} yr^{-1} for the Blue Nile catchment above El Deim. This can be compared with an average suspended sediment yield of 200-400 t km^{-2} yr^{-1} from the 275000 km^2 upper drainage basin of the Blue Nile and Tecazze rivers quoted by Walling (1984) from an earlier published work by McDougall et al. (1975). Walling (1984) presented a tentative and generalized map of the pattern of suspended sediment yields within the African continent. He suggested suspended sediment yield in the range 100-1000 t km^{-2} yr^{-1} for the Ethiopian highlands.

Although most of the sediments carried by the Blue Nile occur during the flood season (July – September) and are predominantly carried in suspension, some sediment is transported as bed load. Also some sediment quantities are transported after the flood season but these are usually insignificant because of the sharp drop in both water discharge and sediment supply. To cater for bed and post flood sediment transport quantities, the seasonal suspended sediment inflow was increased by 15% so that the total long-term annual sediment inflow is approximately **140 M tons.**

3.2 TRAP EFFICIENCY

Reservoir trap efficiency is defined as the ratio of deposited sediment to total sediment inflow for a given period within the reservoir economic life. Trap efficiency is influenced by many factors but primarily is dependent upon the sediment fall velocity, flow rate through the reservoir and reservoir operation. The relative influence of each of these factors on the trap efficiency has not been evaluated to the extent that quantitative values can be assigned to individual factors. The detention-storage time in respect to character of sediment appears to be the most significant controlling factor in most reservoirs (Gottschalk, 1964).

Trap efficiency estimates are empirically based upon measured sediment deposits in a large number of reservoirs mainly in U.S.A. Brune (1953) and Churchill (1948) methods are the best known ones. Brune presented a set of envelope curves for use with normal ponded reservoirs using the capacity-inflow relationship. While Churchill developed a relationship between the percent 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.

General guidelines for using these two methods were given by Murthy (1980). He recommended using the Brune method for large storage or normal ponded reservoirs and the Churchill method for settling basins, small reservoirs, flood retarding structures, semidry reservoirs or reservoirs that are continuously sluiced.

For a given reservoir experiencing sediment deposition, its trap efficiency decreases progressively with time due to the continued reduction in its capacity. Thus trap efficiency is related to the reservoir remaining capacity after a given elapsed time (usually considered from the reservoir commissioning date).

As trap efficiency is influenced by reservoir operation procedures, it is important to examine them closely in order to make judgment on their impact on the trap efficiently. There are four main operation periods for Roseires dam reservoir. During the rising flood, the reservoir is drawdown to RL 467 which is the lowest operating level. Over this operation period, minimum sediment deposition is expected despite the large quantities of sediment inflow which may reach 3 M tons/day. This is particularly true after many years of continuous operation of the reservoir where a well defined channel, capable of transporting almost the whole sediment inflow past the reservoir during the drawdown period, was developed naturally (Gibb et al 1987).

The reservoir filling period commences after the flood peak has passed. According to the reservoir operation rules, filling may start any time between the 1st and the 26th of September each year depending on the magnitude of the flow at El Deim. From past experience, filling normally starts within the first ten days of September when the suspended sediment concentration is still relatively high at about 2500 mg/l. The filling period usually lasts for nearly two months. Due to the gradually rising water level and the relatively high suspended sediment inflow, significant sediment deposition is expected during the filling operation period. In contrast, during the third and fourth operation stages (maintaining full retention level and reservoir emptying), sediment deposition is insignificant due to the exceedingly small sediment inflow quantities.

From the above description, only the operation filling period is of importance as far as reservoir sedimentation and trap efficiency are concerned in the case of Roseires reservoir. Therefore this is taken into consideration when estimating the trap efficiency using either Brune or Churchill method. Over the filling period, the water level in the reservoir is raised steadily from R.L. 467 m to R.L. 481 m. A mean reduced level at 474 m is considered for the computation. The reservoir content at this mean level is used together with an annual inflow of 50×10^9 m^3 to estimate the trap efficiency by both methods. The results are compared with measured values for the years when reservoir resurveys were made. The measured trap efficiency is computed from the following equation.

$$T.E(\%) = \frac{(V_o - V)\gamma}{T \times 140 \times 10^6} \times 100 \quad \textbf{(3.4)}$$

Where, T.E. = trap efficiency after T years of operation

V_o = original reservoir volume, m^3
V = volume remaining after T years of operation
γ = average specific weight of deposited sediment over T years (t/m^3)
γ is calculated from the following equation (Miller, 1953)

$$\gamma = \gamma_i + 0.434K[\frac{T}{T-1}(\ln T) - 1] \qquad \textbf{(3.5)}$$

where γ_i is the initial value of and γ is given by

$$\gamma_i = \gamma_{cl} \, P_{cl} + \gamma_{sl} \, P_{sl} + \gamma_{sa} \, P_{sa} \qquad \textbf{(3.6)}$$

where P_{cl}, P_{sl} and P_{sa} are fractions of clay, silt and sand respectively of the incoming sediment. γ_{cl}, γ_{sl} and γ_{sa} are coefficients of clay, silt and sand respectively which can be obtained from the Table 3.2 (USBR, 1982) for normally moderate to considerable reservoirs drawdown (Reservoir Operation 2) which is the case for Roseires reservoir.

Table 3.2 Coefficients for Clay, Silt and Sand (kg/m3)

Clay	Silt	Sand
561	1140	1550

The compaction coefficient K is found similarly from the table 3.3.

Table 3.3 K Values for Reservoir Operation 2 (USBR, 1982)

Clay	Silt	Sand
135	29	0

The composition of deposited sediment in Roseires reservoir differs widely. A reasonable approximate composition assumed in this study is given in the table 3.4 below.

Table 3.4 Assumed Composition of Deposited Sediment in Roseires Reservoir

Clay	Silt	Sand
25%	45%	30%

For theses assumed values, $\gamma_i = 1.118$ t/m^3 and K = 0.0468 t/m^3.

Comprehensive field measurement core sampling programme of deposited sediment in a number of major and minor canals in the Gezira Scheme was made in 1989 (HRL, 1990). The mean value of γ_i for a depth below bed level varying from 80 mm to 500 mm was 1.061 t/m^3 which is very close to the adopted value for Roseires reservoir considering that the Gezira Scheme draws its water from the Blue Nile.

Results of Roseires reservoir resurveys are summarized in Table 3.5.

The observed and computed trap efficiency values are given in the following table.

Table 3.5 Roseires Reservoir Volume Characteristics (1966-1995)

Reservoir Elevation (m)	Original Volume Curve (Mm^3)	Bathymetric Survey March 1976		Bathymetric Survey February 1981		Bathymetric Survey October 1985		Bathymetric Survey December 1992		Satellite Imagery Jan. to April 1995	
		Revised Volume Curve Bathy. (Mm^3)	Sediment Deposit Volume (Mm^3)	Revised Volume Curve Bathy. (Mm^3)	Sediment Deposit Volume (Mm^3)	Revised Volume Curve Bathy. (Mm^3)	Sediment Deposit Volume (Mm^3)	Revised Volume Curve Bathy. (Mm^3)	Sediment Deposit Volume (Mm^3)	Revised Volume Curve (1) Bathy. (Mm^3)	Sediment Deposit Volume (Mm^3)
467	636	152	484	91	545	80	556	65	571	39	597
(m.o.l.)	861									144	717
469	990	444	546	350	640	282	708	260	730	233	757
470	1131									353	778
471	1820	1271	549	1156	664			1050	770	980	840
475	3021	2470	551	2370	651	2224	797	2093	928	2122	900
480	3326	2775	551	2675	651	2530	796	2332	994	2415	911
481 (f.s.l.)											
			Total 551		**Total 651**		**Total 796**		**Total 994**		**Total 911**

(1) From bathymetric survey below E1.468.40 m
Source: Gibb, Coyne Et Bellier, July 1996

Table 3.6 Roseires Reservoir Trap Efficiency (%)

Year of re-survey T (years)	1976 10	1981 15	1985 20	1992 27	1995 29
Observed	45.5	36.0	33.2	28.0	26.2
Brune's Method (lower envelop)	51.0	49.0	46.0	45.0	45.0
Churchill's method	67.7	66.0	64.4	63.5	62.8

It is generally believed that the volume of deposited sediment from the 1992 resurvey as given in Table 3.5 was over estimated. Making use of the results of the later resurvey in 1995, it is expected that the trap efficiency in 1992 to be close but higher than its observed value in 1995 due to the relatively short time in between the two resurveys. A value between 1985 and 1995 values may be considered as well. Therefore a trap efficiency equals to 28% seems reasonable. Accordingly the cumulative volume of deposited sediment Vd between 1966 and 1992 i.e. 27 years of operation is computed from the following formula derived from Equation 3.4

$$\mathbf{Vd = (T.E./100) \times (140 \times 10^6 \times T)/\gamma \approx 907\ Mm^3}$$

which is the new revised volume of sediment deposition in 1992. This value will be discussed further in the following subsection.

From Table 3.6, both Brune's and churchill's methods overestimated the observed trap efficiency values. That was particularly so far Churchill's method. In the earlier years of the reservoir life, the rates of sediment deposition were high (reflected in the relatively high observed trap efficiency values). The deposition rates, however, decreased progressively with time as witnessed from the gradual drop in observed trap efficiency from 45.5% in 1976 to 26.2% in 1995. This trend was not reflected in the computed trap efficiency values using both Brune's and Churchill's methods which remained fairly constant over the years of observations.

Brune's method is certainly the most widely used one to estimate reservoirs trap efficiency. Siyam (2000) has shown that Brune's curve is a special case of a more general trap efficiency function given by the following equation:

T.E(%) = 100 exp(- β V/I) …………………………………………………….. (3.7)

Where, in addition to the already defined terms, β is a sedimentation parameter that reflects the reduction in the reservoir storage capacity due to the sedimentation process. Siyam (2000) demonstrated that Eq. (3.7) with values of β = 0.0055, 0.0079 and 0.015 describes well the upper, median and lower Brune's curves respectively as depicted in Fig. (3.5). Shown in the Figure Brune's data for semi-dry reservoirs (β=0.75), and in the case of a mixer tank where all the sediment is kept in suspension (β=1), Syam (2000). Shown also in the Figure Roseires Reservoir data fitted by Eq.(3.7) with β=0.056 which was the mean of the individual β values resulting from fitting the observed trap efficiency data with Eq. (3.7).

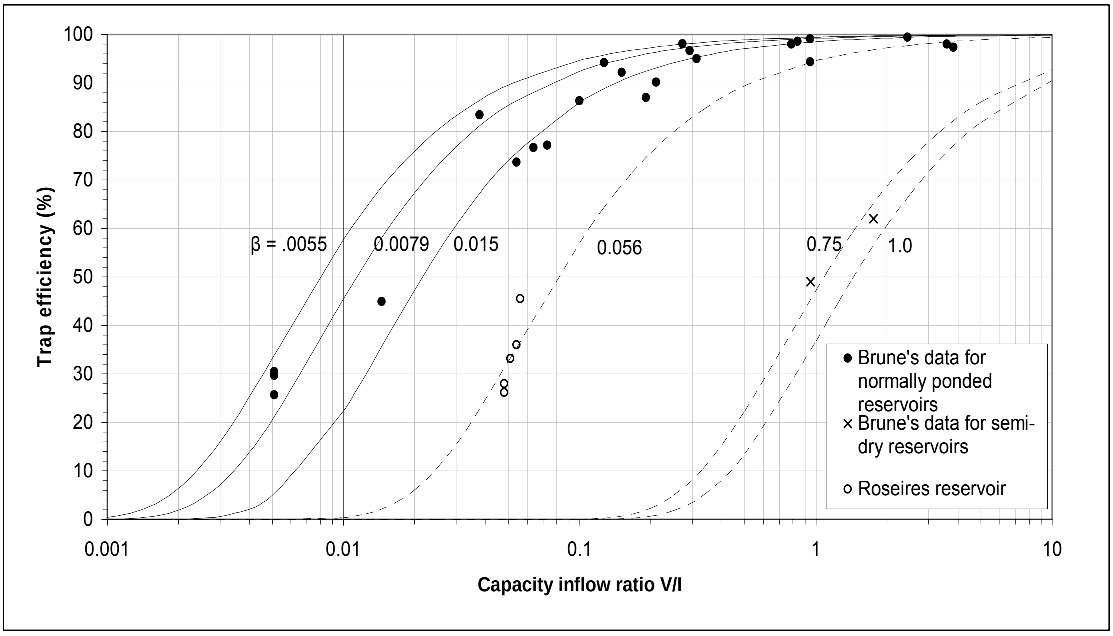

Figure 3-5 Comparison of Roseires Reservoir Trap Efficiency Data with that of Brune's

Figure 3.5 shows the success of the method to limit reservoir sedimentation via reduction of the reservoir level during flood. It is observed from Fig. 3.5 that Roseires reservoir data fall between Brune's data for normally ponded and semi-dry reservoirs. This is because Roseires reservoir belongs to neither type. According to Roseires reservoir operation rules, the reservoir is ponded at full retention level for about only 2 months in the year. Considerable drawdown precedes the pondage stage to reduce the reservoir sedimentation; while gradual drawdown follows the pondage stage in order to satisfy downstream requirements.

The relationship between observed trap efficiency and years of operation is shown in Fig. 3.6. The trend of the data points shows that

$$\mathbf{T.E \sim T^{-0.5}}$$

This Figure may be used to estimate subsequent trap efficiency of Roseires reservoir. From the Figure, the projected trap efficiency after 100 years of continuous operation will be about 14% if conditions remain the same in the mean time. However, when Roseires dam is heightened as planned, this relationship is going to change. Also it is not known at this stage what are the impacts of changes in the present operation rules on the reservoir trap efficiency

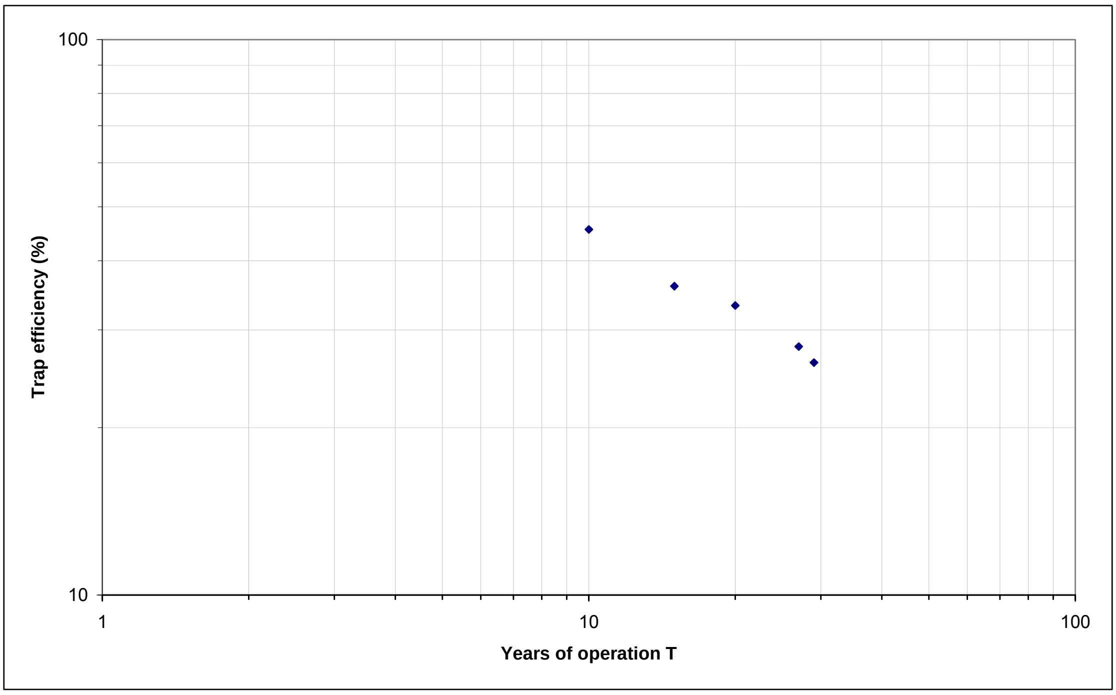

Figure 3-6 Relationship between observed trap efficiency and years of operation for Roseires Reservoir

4 STUDY OF THE ECONOMIC IMPACT OF RESERVOIR SEDIMENTATION: ROSEREIS RESERVOIR AS A STUDY CASE

4.1 INTRODUCTION

Recent research studies are focusing on developing new techniques to restore or prolong the life of the most threatened reservoirs. To justify the additional cost of a sediment control or storage recovery facility, an evaluation of the economic impact of siltation in existing reservoirs must be studied. Feasibility of many reservoirs were economically justified based on the criteria that the benefit/cost ratio (B/C) exceeds unity. This is not compatible with sustainability, which would have project life extended for more than 50 years. Because the present value (PV) of a benefit far into future is negligible, the result is that expense associated with features that would vastly extend the project life can not be economically justified (Hotchkiss (1994)). Hence making use of the available data on existing projects to evaluate the impact of siltation may assist in solving the question of how much investment should be devoted to a sediment control facility, at the design stage of a project, if an active storage capacity would be partially or fully preserved after certain period of time. This in turn will provide an economic justification for any sediment control facility meant to alleviate the siltation of an existing reservoir or as a feasible measure worth integrating in the design of a newly proposed reservoir project.

Basically in the computation of damages occasioned by sedimentation, any of the three standard methods may be used: 1) The annual cost method; 2) the present value (PV) method; or 3) the capitalised cost method which is a variation of the present value approach. In this research work the present value approach is selected, because the interest is in the estimate of PV of cost that can justifiably be allocated to a sediment control facility. Hence the economical loss is calculated based on the present value criteria and considered as a percentage of the total project cost

Available data relating to Rosaries Reservoir on the Blue Nile River in Sudan will be used (see Appendix . The intention is to estimate the extra cost that would have been justified for a sediment control facility which could reduce or eliminate the progressive loss of its active capacity. The maximum cost of the sediment control facility is calculated by assuming it equal to the benefit forgone due to active storage loss of the reservoir plus any other benefit lost due to the sedimentation. Both economic and financial analyses will be carried out. In Appendix all details of siltation characteristics of Roseires reservoir are given.

4.2 SOCIO- ECONOMICAL IMPACT OF RESERVOIR SEDIMENTATION

Reservoir siltation impose many socio-econnomical impacts. For the reservoirs under study the following are some of the negative impacts that have been experienced but not all can economically be assessed.

I) The upstream negative effects of reservoir sedimentation. For example the necessity of relocation or redesign of a water supply pump, as the case with El-Shwak pump station in Sudan where the bed level has risen by 12 m due to the sedimentation of Khashm El-Girba reservoir.
II) The downstream negative effects resulting from bed degradation or sediment deficiency.
III) The increase in damages due to the increase in flood peaks released downstream. This may be evaluated through operational scenarios especially if historical data are available.
IV) Reduction in efficiency of power generation due to sedimentation hazard during flood season.
V) The high cost of annual dredging in front of power intakes as this is not a permanent solution and nevertheless occasional blockage during flood period is not guaranteed
VI) The consequences of storage loss.

From a theoretical point of view, the total benefit that can be generated from a dam/reservoir project can be visualised as equivalent to the total benefit generated from the repeated use of the storage volume during the economic life of the reservoir. The merit of this visualisation is that, any reduction in storage can be transformed into a valued loss by using the well known discount rate formulae. The procedure is simple and direct for reservoirs with a capacity/inflow ratio greater than unity, i.e. which utilise the total annual inflow (over-year storage or ephemeral river reservoirs). For reservoirs with a capacity/inflow ratio less than unity, the procedure is not direct. In this case the reservoir needs to be operated according to a pre-defined rule to determine the annual inflow volume that might be utilised, by the beneficiary sectors, from an average hydrograh. For the case of Rosereis reservoir only some of the above impacts is going to be economically assessed.

4.3 FINANCIAL VERSUS ECONOMICAL ANALYSIS

The financial analysis considers a project from the view point of the investor, who expects a rewarding return to the investment made. Hence if the entities of the water users are separate, the issue of the water value for a consumptive use, as in irrigation, or non-consumptive use as the case with hydropower generation is the main concern. The financial loss due to siltation may be assumed to be the financial loss that would otherwise be gained from the revenues via the already defined water rates. On the other hand, the economical analysis considers a project from the view point of the national economy. Accordingly the impact of siltation will be seen in the national scale. As the necessity of the financial analysis stem from the view of ensuring the sustainability of the project, some light will be shed here on the water rates

4.4 WATER VALUES

Today water is indeed scarce in many parts of the world. The misunderstanding of water value or under pricing has caused serious misuse of water. The cost of recovery of lost capacity or controlling of siltation in a reservoir has never been thought of as one of the constituents that should be taken into account when defining water rates in water resources project. There are many definitions of water value and the valuation process requires a clear understanding of the type of value being estimated. In general water price are set by publicly owned supply agencies or regulated private utilities.
In agricultural schemes cost-recovery fees that ensure financial viability of water entities are more realistic, and evidence suggests that farmers are willing to pay for a reliable supply of water, but the complexity lies in the task of collecting the fees.

4.4.1 Water values in irrigated agriculture in the Sudan

In the irrigated sector in Sudan, the method of water pricing has passed through various stages. Only two of these methods are relevant to this study case. In both the primary objective was to cover the expenses of operating and maintaining the canal network and pump stations. Over 60% of these expenses were devoted to the annual deposited silt in canals during flood period.

In the first method, which is called the combined account (CA), the government of Sudan, the agricultural company and, the farmers share the net benefit from the sale of cotton in ratios of 2:1:2: respectively. The government takes the 40% from the net revenue in return for providing land and water to the farmers. The agricultural company takes 20% as management expenses and the remaining 40% goes to the farmers. The net revenue is calculated by deducting the total cost of production in all farms from the revenue of cotton sale. No other charge is taken from the farmers for the other main grown crops i.e. wheat, groundnuts and, sorghum. However, the farmers are obliged to follow a strict cropping pattern in which a certain area of cotton has to be cultivated every year.

The second method which is called the individual account (IA), was introduced in season 1980/81 following an advice given by the World Bank (Adam, 1997). As the name indicates in this method the farmers are treated individually with the intention to give them the incentive to increase their productivity. The disadvantage seen with CA is that unproductive farmers receive unworthy benefit as the production cost is shared among all farmers.

Further the water charge is also altered and calculated per fed. (1 fed. = 4200 m^3 = .42 hectare) of the irrigated area. The fee changes with the crop type to reflect the water consumption, and varies from year to year to accommodate change in prices. Between 1981 and 1995 the water rates for cotton varied between \$4.4 to \$21.8 with an average of \$ 13.2 per fed. For wheat it changed between \$3.4 and \$13.8 with \$9 per fed. being the average.

In practice there have been institutional obstacles regarding the full implementation of the systems, in the part of water fees collection, to achieve the objective goals. Recently, in July 1995, a separate institutional body was formed within the Ministry of Irrigation and Water Resources with the key objective of developing a method for pricing water, collecting water fees from the farmers, and carrying out the routine work of operating and maintaining the irrigation canal networks and pump stations. The recent direction in thinking of this body is to forge water charge in terms of cubic meter of water consumed. In Egypt for example the irrigation water is valued at \$6.1/1000m^3. This is equivalent to \$20 per fed. of wheat and \$31 per fed. of cotton according to the water consumption of wheat and cotton in Sudan. This simply reflects the under pricing of water in the irrigated sector in Sudan.

The misconception of not including operation and maintenance of the main infrastructure, i.e. dam/reservoir body, into water pricing still prevails. In fact there exists another department within the same Ministry, whose responsibility is just to operate the national dam and reservoirs bodies. The main infrastructures are seen to be owned by the national state which should operate and maintain. The result is that sedimentation of reservoirs with its huge impact is not directly seen as financial loss by any of the main users of the reservoir. This situation makes investment in sediment controlling facility financially not attractive if ever justifiable. Fig. 4.1 shows that canal siltation and reservoir siltation occurs at different times and hence water pricing for different crops to be determined based on account of maintaining canals or reservoir sedimentation can be practically distinguished. However, an annual cycle would be the most logical approach where all the costs of canal maintenance and lost reservoir capacity were reflected in the pricing.

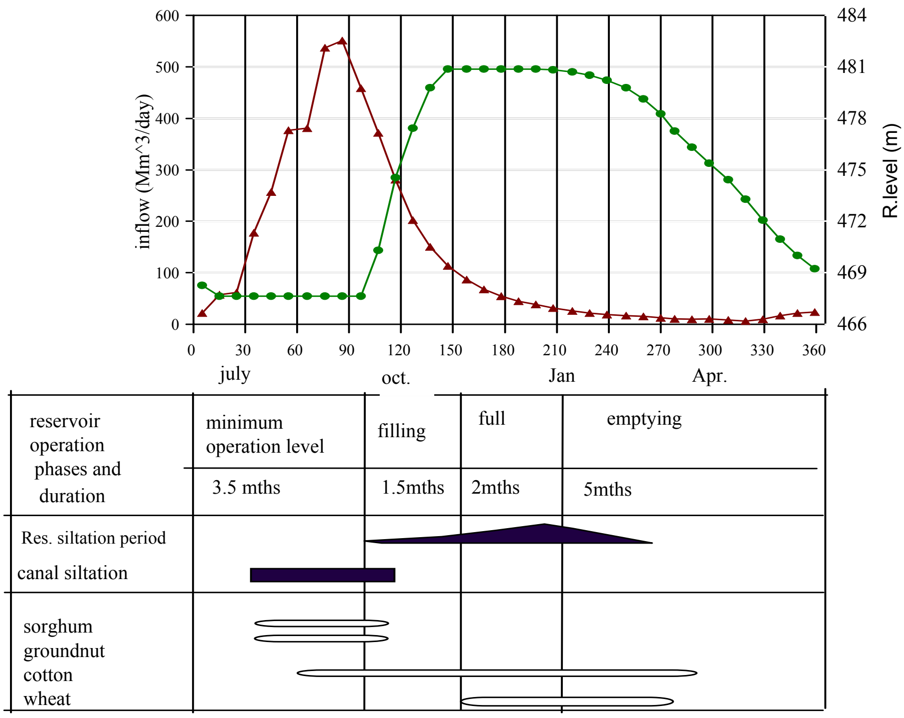

Figure 4-1 Roseires Reservoir operation curve and Plantation periods of the main irrigated crops.

4.4.2 Water values in energy sector in the Sudan:

The water value in the energy sector is regarded as the avoided cost of thermal or diesel generated energy that would be required due to shortage in hydropower energy production as a result of siltation. This shortage is equivalent to the energy that would be produced if a volume of water equal to silted volume would have been passed through the turbine. It was reported that the average cost of fuel/Kwh alone during 1980s and early 1990s was in the order of .065 US$ (Sharfi, 1993 and Final Kajbar report, 1997), while the energy tariff is in order of .084 US$/Kwh. Taking into consideration that the Sudan Government has never let the energy sector to the free market , the later value is assumed as a suitable representative water value in the energy sector to reflect the economical impact of siltation in the energy sector.

Like industrial water values, the water value in hydropower generation can be estimated by a least-cost alternative approach. In USA Gibbons(Bonnie and David 1987) examined the cost savings possible with hydroelectric power as compared to the alternative of coal-fired steam generating plants (the next least costly method). For the Colorado river hydroelectric system, the short run cost savings provided by hydropower compared to coal-fired steam generating plants are $31 per acre-foot and $76 per acre-foot when compared to gas-turbine electric plant based on 1986 dollar value. These are visualised as the additional cost of replacing lost hydropower production due to an acre-foot decrease in flow with a more expensive source of electricity, and can be thought of as short run marginal values. It must be noted that there are also reliability, facility longevity and environmental quality advantages of hydropower compared to other electricity producing methods. An additional allowance of 5-10 percent credit above cost savings to hydropower generation is usually added to account for its other advantages over other methods.

However, it may equally be argued, in the case of a storage lost due to reservoir siltation, that the value of the lost energy, that would be produced, may be regarded as the avoided cost of operating other expensive energy producing plants.

4.5 ECONOMIC EVALUATION OF SILTATION OF ROSEIRES RESERVOIR

The benefits from the Roseires reservoir are derived from its multi-purpose functions as the main provider for irrigation water, hydropower generation and flood detention. The reservoir also serves to augment low flows and to supply water for domestic use. Only the irrigation and energy sectors are thought of being seriously affected by reservoir siltation and hence the analysis will be restricted to these two sectors. Although the original flood detention capacity of 810 Mm^3 is reduced by 25%, the same capacity could be attained by adjusting the operational level, and therefore it is difficult to quantify that portion of flood-caused losses which could be attributed to siltation of the reservoir alone.

4.5.1 Determination of Irrigated crop revenues

Cotton, sorghum, wheat, and groundnut are the main crops produced by the irrigated sector in Sudan. Except for the wheat all the crops grown at the beginning of the rainy season June/July. Sorghum and groundnut are supposed to be harvested before the commencement of the dry period, while cotton continues to be irrigated until March. Wheat takes all its water during the dry period. Other crops sharing the dry season water are sugar canes, vegetables, forests, fodder and gardens. Here cotton and wheat are taken to be the two major crops which can reflect the economical impact of siltation in the agricultural sector. The water requirement for wheat is determined to be in the order of 3300m^3 per fed. and for cotton is 3800 m^3 per fed. during the dry season. Evaporation losses from open water surfaces in canals have been taken into account when calculating these figures. Water volume equivalent to the silted volume of Roseires reservoir has been assumed available for irrigation in each year. This volume is reduced by 6% to account for transmission losses in canals to conform with general practice of Sudanese irrigation managers.The remaining volume is assumed to be divided

between wheat and cotton based on equal area of plantation. This area is obtained by dividing the supposed volume by the combined water requirement for wheat and cotton during the dry season.
The cotton annual yield in kantar/ fed. (1 kantar = 100 lb), cost production and sale price (US $/kantar) are compiled for the period 1997/1996 from Sudan Cotton Co-operation (SCC), and Gezira Board (GB) and shown in Fig. 4.2 The SCC is responsible from selling the cotton collected by the agricultural company GB in the international market. The sale price is modified by 25% increase to allow for deduction usually taken by the SCC on behalf of the Sudan Government as taxes. The net annual economical revenue is generated by deducting the total annual cost of production from the total annual sale revenue. Average values of cotton yield, cost of production, and sale price for the period 1967/97 were assumed to prevail for the next 20 years of the economical life of the project , which is considered as 50 years.
Similarly the economical revenue from wheat is derived from data shown in Fig. 4.3. Average values were assumed for missing and future years, though the current trend in yield and price of wheat suggests higher values. The sale price of wheat are also modified to reflect the added benefit of local production. This added benefit, which in fact is the difference between local and imported wheat price fluctuates between 60 to 25% in favour of local production. However in some years negative benefits were experienced due to high cost of production. A value of 30% is considered to be justifiable for the added benefit due to local production of wheat. When there is no net benefit in any year the negative value is taken which must be compensated from other years. Different discount rates were assumed to assess the sensitivity of the economical evaluation

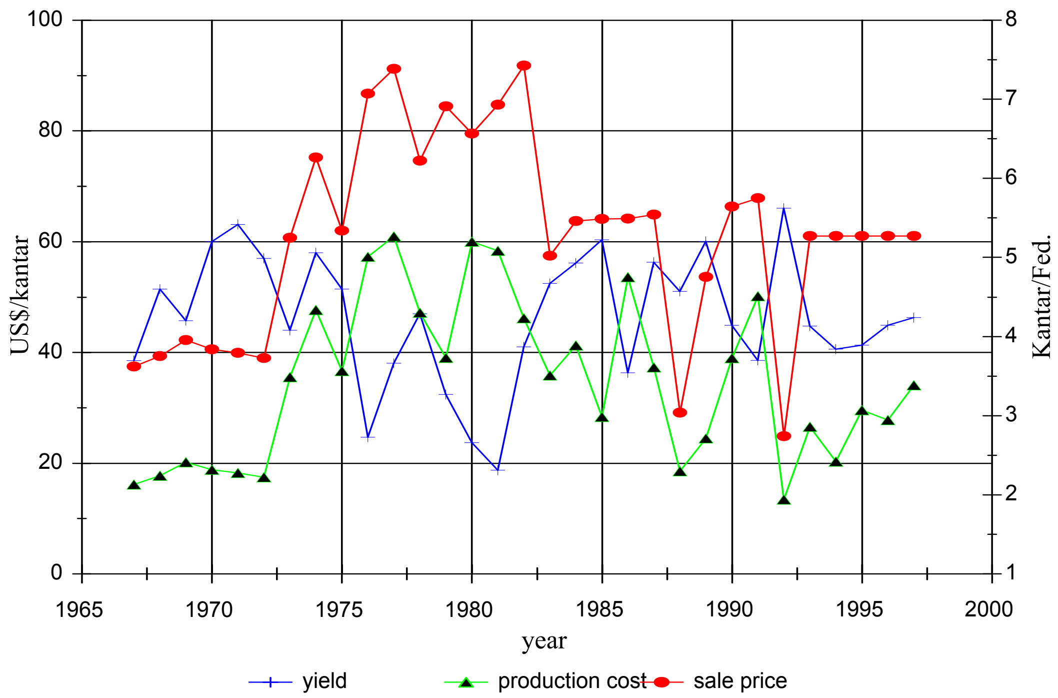

Figure 4-2 Yield, cost of production, and sale price of cotton for the period 1966-1997 (1 kantar = 100 lb).

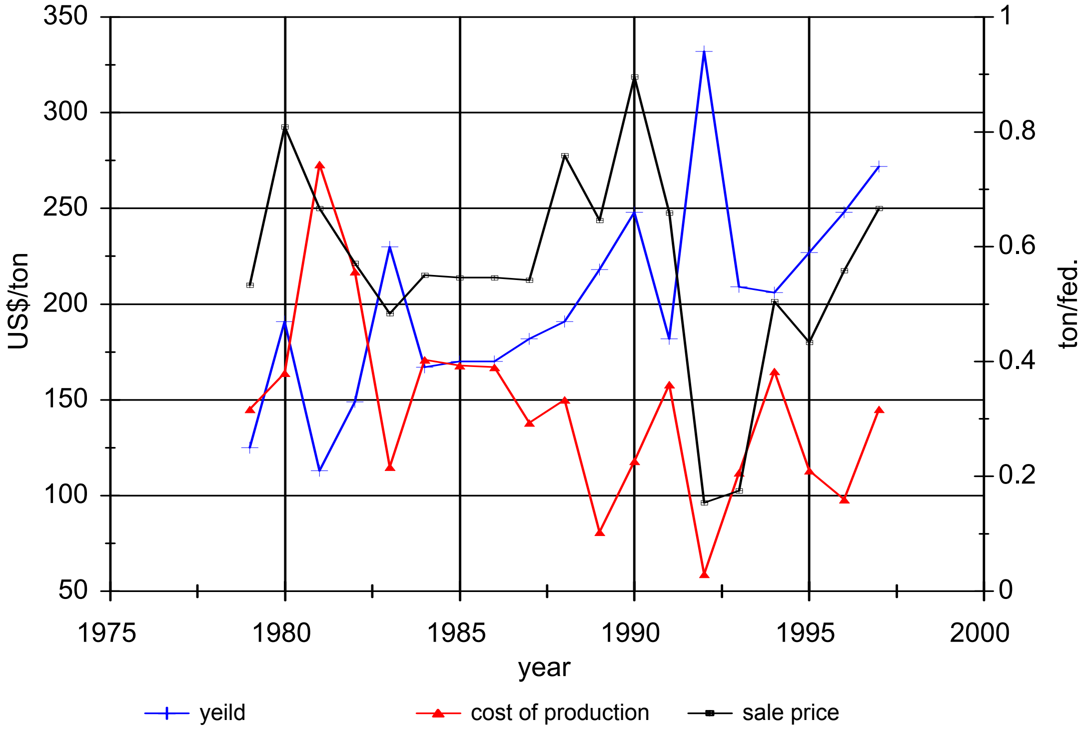

Figure 4-3 Yield, cost of production, and sale price of wheat for the period 1979-1997

4.5.2 Determination of Hydropower generation revenues:-

The progressive active storage losses, below specified levels, of the Roseires reservoir are obtained from the five bathymetric surveys carried in 1976, 1981, 1985, 1992 and 1995 (Coyne et Bellier and Gibb 1966) and drawn in Fig. 4.4. The volume of silted storage for the intermediate years are generated by linear interpolation between available data. As the energy that can be produced is a function of head, silted volume is descritised in intervals of one meter between the maximum and minimum operation level and then projected linearly into the future at a total rate of 20 million cubic meter per annum as suggested in a recent report (Coyne et Bellier and Gibb 1996).
The annual economical impact of the reservoir siltation can be regarded as the annual avoided cost of thermal or diesel generated energy that would be required due to shortage in hydropower energy production as a result of siltation. This shortage is equivalent to the energy that would be produced if a volume of water equal to the silted volume would have been passed through the turbine. Also the net economical revenue from sale of energy was calculated using discount rates varying between 5% and 12%.

One of the main assumptions in this analysis is that all the water volume, that would have been saved if the active storage was never silted up, would pass through the turbine and be available for irrigation usage afterwards. In fact this is not strictly true as by the end of March when cotton and wheat irrigation cease up, the reservoir level is usually kept high around 475m level (minimum operation level is at 467m) to cater for the critical period of shortage in energy during April and May. However, on the other hand, water usage is still in demand, for other purposes for example gardens, vegetables, sugar cane, and domestic use. It is believed that the economic benefit or water productivity in these beneficiaries far exceeds that in cotton or wheat. Hence it is concluded that the above assumption of utilising the whole water for wheat and cotton production to simplify the analysis yields a conservative evaluation.

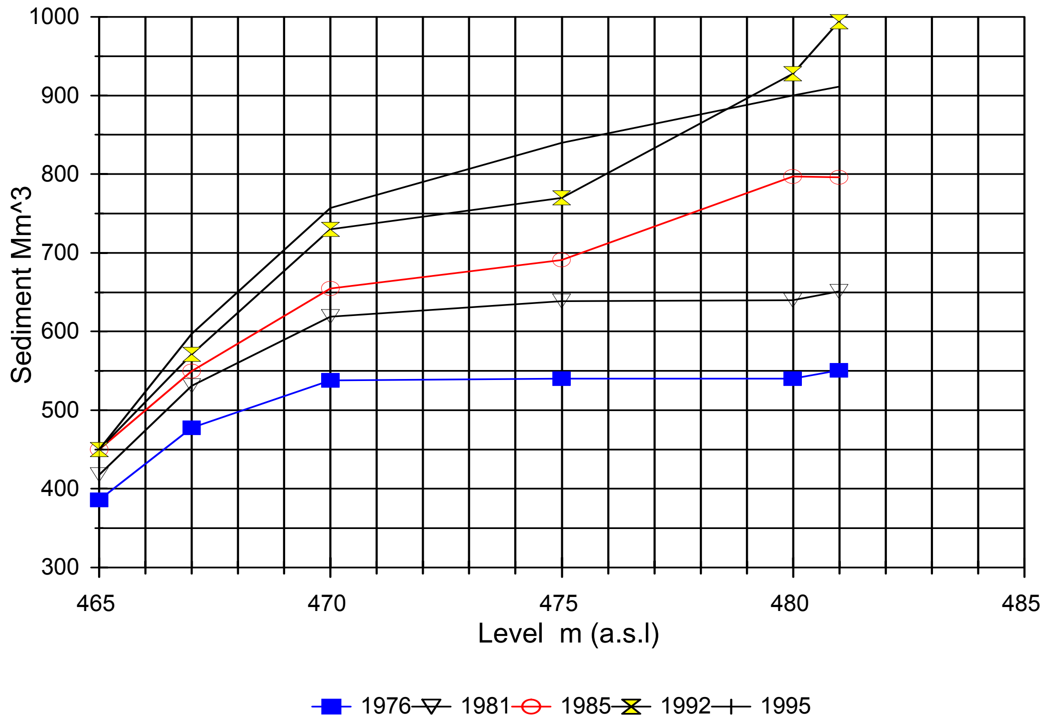

Figure 4-4 Sedimentation curves of Roseires reservoir.

4.5.3 Economical losses due to siltation of Roseires reservoir

The total net present value in 1966 of the economical revenues forgone due to siltation of the active storage of the Roseires reservoir is shown in Fig. 4.5 as a function of different discount rates. It is composed of the addition of the energy and the agricultural sectors revenues. The priority of irrigation over hydropower generation is clearly reflected in the amount of losses with the impact on the former being higher than the latter at all discount rates. Astonishingly the degree of impact from the economic point of view justifies the construction of another dam, similar in size to the Roseires dam, if the discount rate is in the range of 5 to 6%. In Fig. 4.6 the lost economic revenue is normalised by division by the original dam construction cost which is amount to 75 million US$ in year 1966. At higher discount rate, such as 12% the economical loss falls nonlinearly to 20% of the original dam cost. This indirectly tells the amount of investment that should be devoted to sediment controlling facility if it has the capability of securing the active storage of the reservoir. As a comparison with a recent proposed Merowe Multi-purpose hydroproject an amount of (88 million US$), 4.7% of the total cost has been allocated for the sediment sluicing facility. With the Kajbar the proposed proportion is less than 3%.

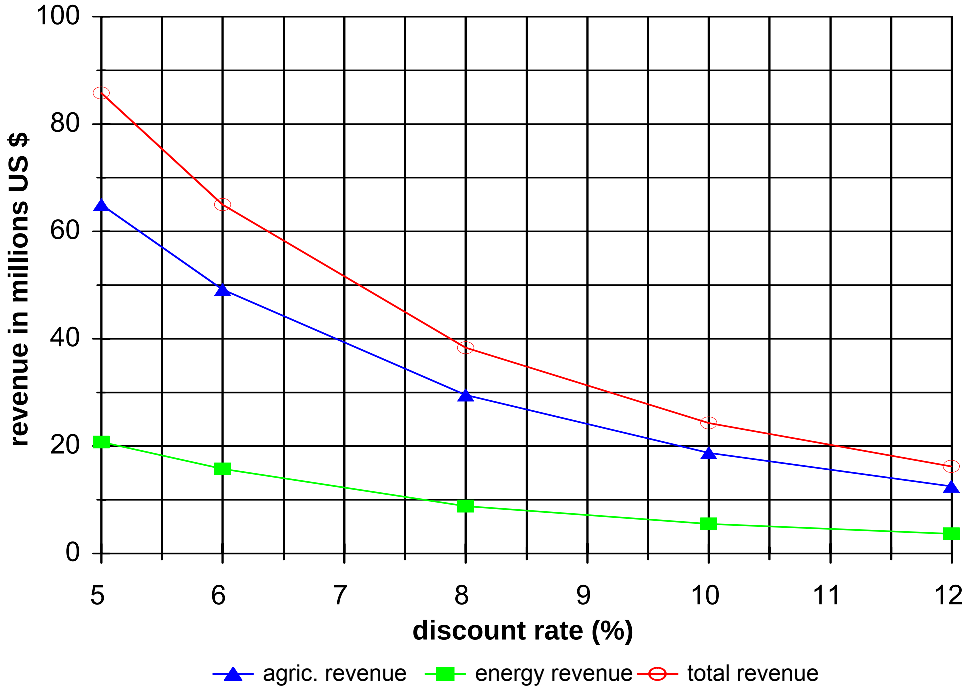

Figure 4-5 Economical revenues forgone in Agricultural and Energy sectors versus discount rate.

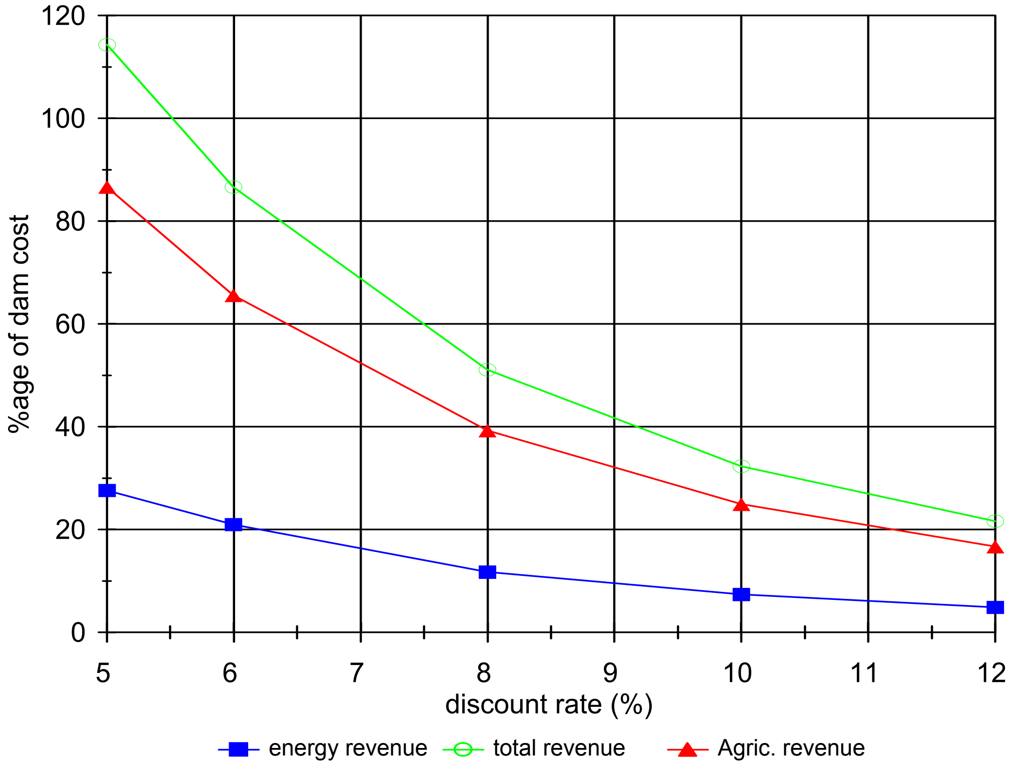

Figure 4-6 Economical revues forgone in Agricultural and energy sectors as a percentage of original dam cost versus discount rate

4.5.4 Financial losses due to siltation of Roseires reservoir

The NPV of the financial losses due to siltation is evaluated from the financial revenues forgone , and which could be attributed to the water value in agricultural and energy sectors. As described earlier in the agricultural sector two different methods were employed, one before 1981 and the other after 1981. Before 1981 the water rates are taken from net cotton revenue. From the 40%, which is the governmental share, 32% was assumed for the water value and 8% for the land fees. All the active storage lost was assumed to be utilised for cotton production.
After 1981, the financial losses are evaluated from the planted wheat and cotton area according to the historical rates of water fees per fed.. For the energy sector half of the economical revenues was assumed to be representative of the financial losses i.e. .042$ per Kwh produced.

Fig 4.7 shows the total financial losses due to siltation of Roseires reservoir as a function of the discount rate, and Fig 4.8 expresses the losses as a percentage of the original cost of the dam. The total financial losses varied non-linearly between 6% and 26% of the dam cost as the discount rate varied between 12% and 5% respectively. It also shows under the current assumption, that both energy and agricultural sectors have suffered equal financial losses due to siltation.

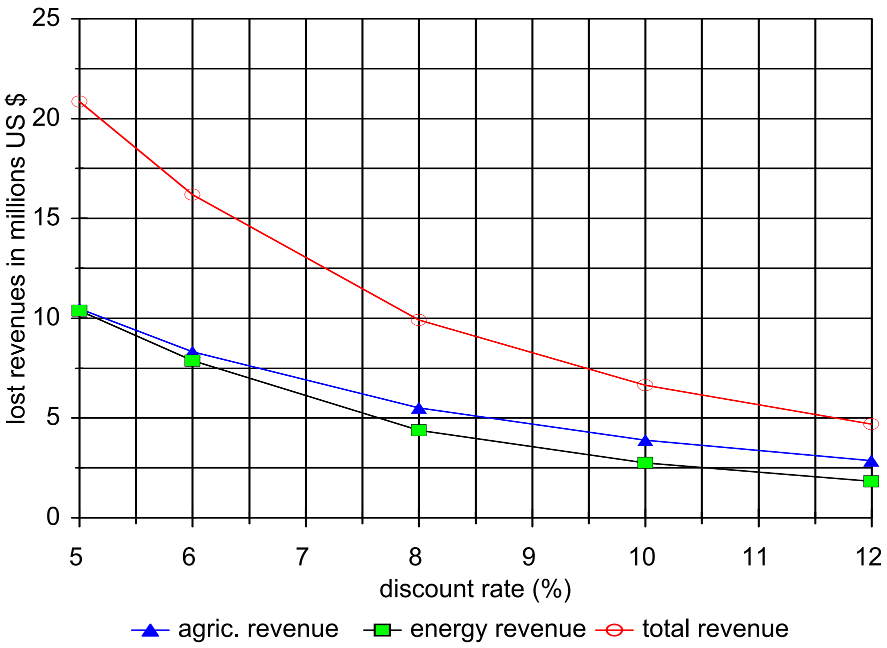

Figure 4-7 Financial losses versus discount rate.

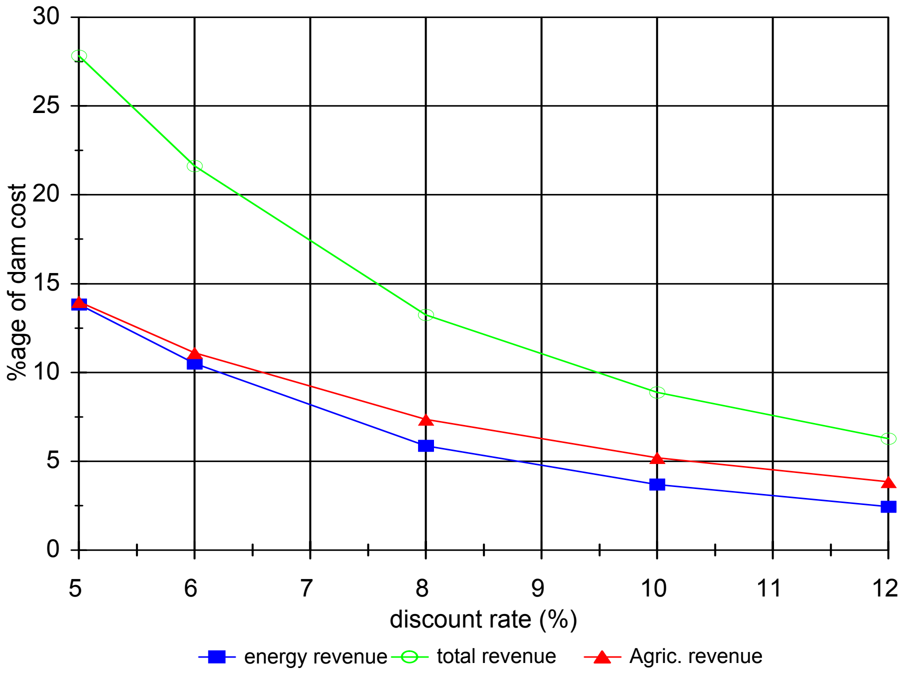

Figure 4-8 Financial losses as a percentage of original dam cost versus discount rate.

4.6 DISCUSSION

From the case study of the economical impact of sedimentation of the Roseires reservoir, it has been found that, a sediment control facility with capital cost as high as the cost of the total project would be economically justified if only the active storage of the reservoir would have been preserved. The total economical revenues forgone due to the active storage loss was found to vary non-linearly between 115% and 22% of the original dam cost when the discount rate varied between 5 and 12% respectively. When extra sediment- born losses were considered the percentage of revenues forgone has risen to 160% and 30% respectively. These losses were approximately shared equally between the two main users of the reservoir, the energy and the agricultural sectors.

The major portion of losses in the energy sector, which comprise over 25% of the total losses, were due to the cost of annual dredging in front of the hydropower intakes since 1981, and the reduced generation efficiency which is imposed since then due to the passage of high silt concentration during the flood period. In this evaluation only the operational cost ($1.5/$m^3$) of dredging was considered as data on the equipment were not available. To our knowledge the cost of dredging to clear the blocked intakes at one stage reached as high as $20/$m^3$ (Loman, 1994).

In the financial analysis the benefits forgone due to the siltation increased from 6.5% to 27% as the discount rate was varied from 12% to 5% respectively (see Figs. 4.8 and 4.9). Here the water rates, in the agricultural sector, were assumed to be equal to the water rates fixed by authorities responsible for irrigation canal maintenance, where removal of the annual deposited silt in these canals is the major problem. The financial benefits forgone in the energy sector have been assumed to be half of economic benefits forgone. The extra costs attributed to dredging and turbine efficiency reduction were not included in the financial analysis. The total financial losses were also found to be shared almost equally between the two sectors.

5 RESERVOIR SEDIMENTATION DATABASE

5.1 INTRODUCTION

Along the Nile basin a quite large number of dams were built for different purposes. Dams with its natural or man made lakes or reservoirs are subjected to reservoir sedimentation problem. Therefore, effective management of reservoir is needed for the purpose of planning and carrying out remedial actions to problems associated within the reservoir. Current trend towards a more efficient management of reservoir is the application of Information System specially the geographic information systems (GIS). Application of these information systems will create a system, which may be called a Reservoir Information System for gathering, storing, analyzing and displaying data regarding a particular reservoir. Database which contains all relevant information is core of the Reservoir Information System.

As one of the objectives of this joint research is to develop a Reservoir Information System for the reservoirs all over the Nile basin which will increase the ability of understanding the sedimentation problems in the different reservoirs and will enable the researcher to come up with common vision in better managing the reservoirs. And as the first phase of the joint research was concentrating on collecting data and information related to the sedimentation problem in some of the selected reservoirs in the Nile Basin, it was decided to limit the scope to the development of Nile Basin Reservoirs Database. Based on the developed database the development of Nile Basin Reservoir Information system could be achieved during the second phase of the research.

5.2 DATA AVAILABILITIES

For building the Nile Basin Reservoirs database, three reservoirs were considered to be the main core and source of data for this database. These are the High Aswan Dam reservoir (Lake Nasser) in Egypt; the Roseires Reservoir Lake in the Sudan and; the Angebra Reservoir Lake in Ethiopia. The design of the database will enable adding and updating information related to these reservoirs and also adds more reservoirs in different locations in the Nile Basin. The optimum goal is to include all reservoirs along the River Nile in the database.

5.3 DATABASE DESIGN CONCEPTS

The design of the Reservoirs database was based on the following concepts:

1. The Nile Basin is shared by 10 countries, which means country level in defining the reservoir location is essential.
2. The reservoir itself whether it is artificial or man made should be associated with a dam. This brings the dam to be the first object in defining the reservoir.
3. Data update and addition is a key factor in the dynamic nature of the database. Therefore, the database design should give the needed flexibility to add more features and update the existing information.
4. Easy and clear search module in the database will positively affect the use of the database in analysing the available data and define the gabs.
5. Possibility to link the dam/reservoir to all available types of files (documents, spread sheets, graphs, etc…) will facilitate enrich the data availability to the object.
6. The design should lead to the optimum goal of upgrading the database to be linked to an information system which will considerably enhance the possibilities of satisfying users need through the capabilities of data processing and analysis, automated data sources and data acquisition techniques that have been used in the development of the Nile Basin Reservoirs database.

5.4 DATABASE CONTENTS

Generally, the data that might be entered into database are of two types; spatial data and data associated with non-spatial attribute.

- Positional (Spatial) Data

The spatial data is that represent the geographic position of features. It contains a digital representation of the study area map. So far the developed database does not contain spatial data in forms of maps and satellite images, however this could be considered in the second phase of the research. In the developed database geographical information represent the exact location of the object (dam/reservoir) is stored. Some available photos describing the object are also stored.

- Attribute Data

  The non-spatial attribute data provide the descriptive information. Parts of the attribute data in this study were structured in tables form. The relational database was used. The attribute data would be fed later into the reservoir information system as polygons identifiers and establish the linking between the graphic and alphanumeric database. At the moment, the attribute data consist of all descriptive information of the dam and reservoir. The following list describe the information stored related to the dam and reservoir

  - Name of the dam/Reservoir
  - Location
  - Objectives
  - Dam characteristics
  - Reservoir characteristics (including river characteristics at the reservoir location)
  - Sedimentation
  - Problems associated with reservoir sedimentation

5.5 DATABASE NAVIGATION SYSTEM

Web based database programming was used to build the database interface. This will facilitate the database accessibility for the research group members in order to add/update the database records. Also this help in making the use of the database more users friendly and will also make very easy to link all the stored information to pictures and maps. The data stored are categorised first related to the country then the list of dams in the country. All available data associated with the dam can be viewed and accessed. The reservoir associated with this dam is appearing as a separate category which enables the user to go step further into all the data related to the reservoir. Links are also available to all types of information files that could be stored in the database.
The database include 2 main modules, the first is search module where the user can search for specific information related to a dam or a reservoir. Submitting the search criteria the results will appear in results window including the required information. The second module is the add/update module where the authorised users can add new records or edit his own added record. The design assign to each record the owner of it which means that the only user who can edit a certain record is the owner of it. This will prevent any accidentally data damage or change.

The following figures describe the different windows for using the database and how it is categorised.

5.6 FUTURE RESEARCH & CONCLUSION

This on-going research is to be continued with the second phase of the research, i.e., the development of Nile Basin Reservoir Information System (NBRIS). NBRIS will be used to plan, monitor and manage the reservoirs using the various analysis of spatial and non-spatial attribute overlaying, simulation and modeling, and integrated analysis of spatial and non-spatial attribute data. With the advent in Remote Sensing satellite data which provide 1-4m resolution, there could be also a plan to use this kind of data as one of the data sources for the Reservoirs database. This kind of data, coupled with centimetre level accuracy of GPS data, makes it possible to update the database with accurate, repeatable and useful data. The following information could be also added to the database

- Downstream Hazard potential of a Dam, which can identify the hazard to the downstream area resulting from failure or misoperation of the dam.

- Identification and review of the measures that can be taken to reduce sedimentation in reservoirs.
- Consideration of the options available for the removal of sediment from reservoirs and the associated environmental concerns.
- Consideration of the past and future consequences of reservoir storage loss.
- List of references to research or studies done for the sedimentation problems in the reservoir.

6 RESERVOIR SEDIMENTATION DATABASE

6.1 INTRODUCTION

Along the Nile basin a quite large number of dams were built for different purposes. Dams with its natural or man made lakes or reservoirs are subjected to reservoir sedimentation problem. Therefore, effective management of reservoir is needed for the purpose of planning and carrying out remedial actions to problems associated within the reservoir. Current trend towards a more efficient management of reservoir is the application of Information System specially the geographic information systems (GIS). Application of these information systems will create a system, which may be called a Reservoir Information System for gathering, storing, analyzing and displaying data regarding a particular reservoir. Database which contains all relevant information is core of the Reservoir Information System.

As one of the objectives of this joint research is to develop a Reservoir Information System for the reservoirs all over the Nile basin which will increase the ability of understanding the sedimentation problems in the different reservoirs and will enable the researcher to come up with common vision in better managing the reservoirs. And as the first phase of the joint research was concentrating on collecting data and information related to the sedimentation problem in some of the selected reservoirs in the Nile Basin, it was decided to limit the scope to the development of Nile Basin Reservoirs Database. Based on the developed database the development of Nile Basin Reservoir Information system could be achieved during the second phase of the research.

6.2 DATA AVAILABILITIES

For building the Nile Basin Reservoirs database, three reservoirs were considered to be the main core and source of data for this database. These are the High Aswan Dam reservoir (Lake Nasser) in Egypt; the Roseires Reservoir Lake in the Sudan and; the Angebra Reservoir Lake in Ethiopia. The design of the database will enable adding and updating information related to these reservoirs and also adds more reservoirs in different locations in the Nile Basin. The optimum goal is to include all reservoirs along the River Nile in the database.

6.3 DATABASE DESIGN CONCEPTS

The design of the Reservoirs database was based on the following concepts:

1. The Nile Basin is shared by 10 countries, which means country level in defining the reservoir location is essential.
2. The reservoir itself whether it is artificial or man made should be associated with a dam. This brings the dam to be the first object in defining the reservoir.
3. Data update and addition is a key factor in the dynamic nature of the database. Therefore, the database design should give the needed flexibility to add more features and update the existing information.
4. Easy and clear search module in the database will positively affect the use of the database in analysing the available data and define the gabs.
5. Possibility to link the dam/reservoir to all available types of files (documents, spread sheets, graphs, etc…) will facilitate enrich the data availability to the object.
6. The design should lead to the optimum goal of upgrading the database to be linked to an information system which will considerably enhance the possibilities of satisfying users need through the capabilities of data processing and analysis, automated data sources and data acquisition techniques that have been used in the development of the Nile Basin Reservoirs database.

6.4 DATABASE CONTENTS

Generally, the data that might be entered into database are of two types; spatial data and data associated with non-spatial attribute.

- Positional (Spatial) Data

  The spatial data is that represent the geographic position of features. It contains a digital representation of the study area map. So far the developed database does not contain spatial data in forms of maps and satellite images, however this could be considered in the second phase of the research. In the developed database geographical information represent the exact location of the object (dam/reservoir) is stored. Some available photos describing the object are also stored.

- Attribute Data

  The non-spatial attribute data provide the descriptive information. Parts of the attribute data in this study were structured in tables form. The relational database was used. The attribute data would be fed later into the reservoir information system as polygons identifiers and establish the linking between the graphic and alphanumeric database. At the moment, the attribute data consist of all descriptive information of the dam and reservoir. The following list describe the information stored related to the dam and reservoir

  - Name of the dam/Reservoir
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  - Problems associated with reservoir sedimentation

6.5 DATABASE NAVIGATION SYSTEM

Web based database programming was used to build the database interface. This will facilitate the database accessibility for the research group members in order to add/update the database records. Also this help in making the use of the database more users friendly and will also make very easy to link all the stored information to pictures and maps. The data stored are categorised first related to the country then the list of dams in the country. All available data associated with the dam can be viewed and accessed. The reservoir associated with this dam is appearing as a separate category which enables the user to go step further into all the data related to the reservoir. Links are also available to all types of information files that could be stored in the database.
The database include 2 main modules, the first is search module where the user can search for specific information related to a dam or a reservoir. Submitting the search criteria the results will appear in results window including the required information. The second module is the add/update module where the authorised users can add new records or edit his own added record. The design assign to each record the owner of it which means that the only user who can edit a certain record is the owner of it. This will prevent any accidentally data damage or change.

The following figures describe the different windows for using the database and how it is categorised.

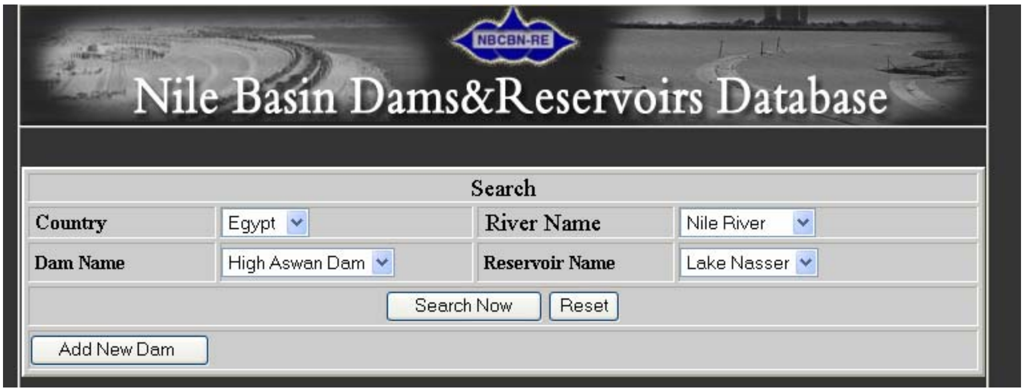


Figure 6-1 Database search Items

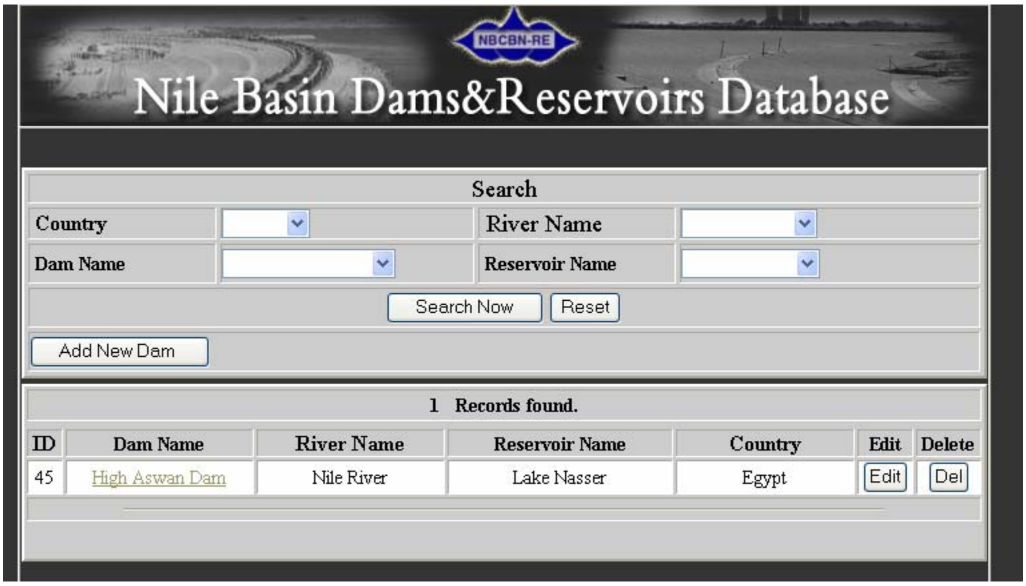
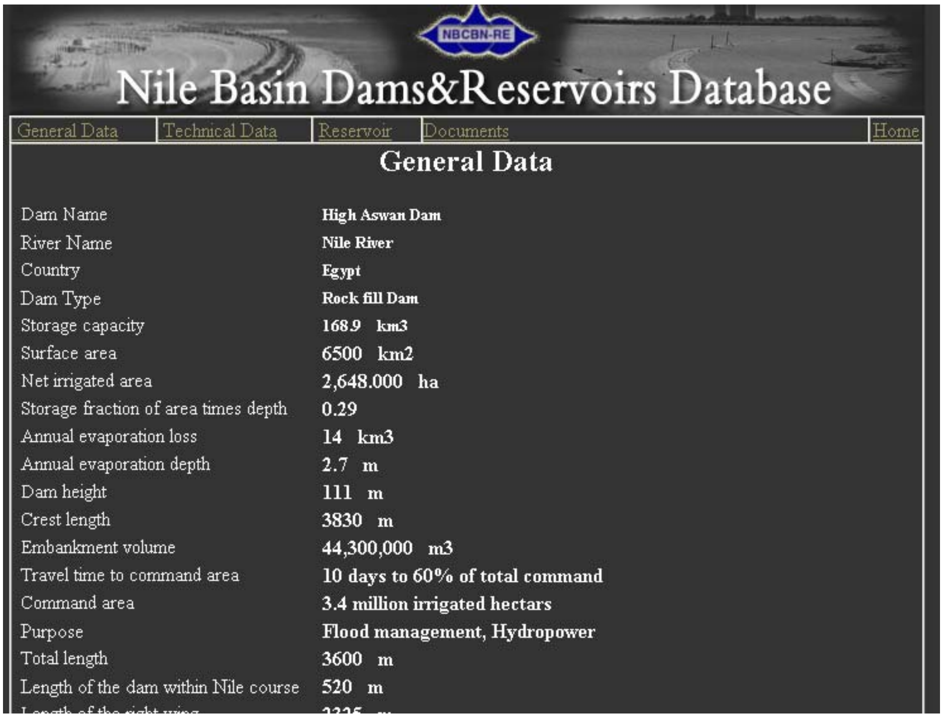


Figure 6-2 Database Search Results



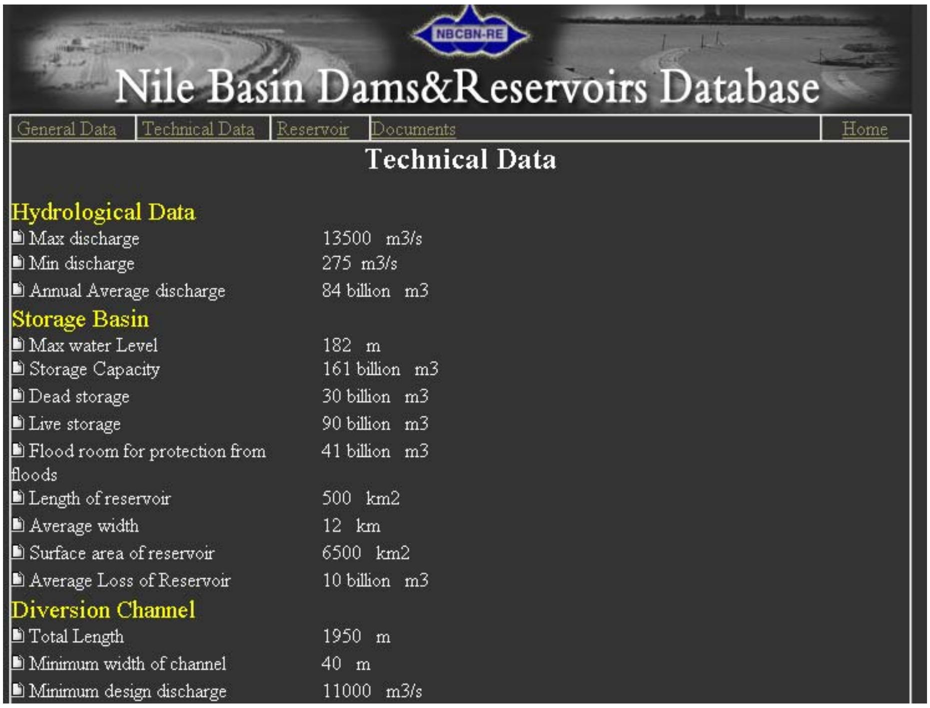
Nile Basin Dams&Reservoirs Database

General Data | Technical Data | Reservoir | Documents | Home

General Data

Dam Name	High Aswan Dam
River Name	Nile River
Country	Egypt
Dam Type	Rock fill Dam
Storage capacity	168.9 km3
Surface area	6500 km2
Net irrigated area	2,648.000 ha
Storage fraction of area times depth	0.29
Annual evaporation loss	14 km3
Annual evaporation depth	2.7 m
Dam height	111 m
Crest length	3830 m
Embankment volume	44,300,000 m3
Travel time to command area	10 days to 60% of total command
Command area	3.4 million irrigated hectars
Purpose	Flood management, Hydropower
Total length	3600 m
Length of the dam within Nile course	520 m

Figure 6-3 Dam General Data



Nile Basin Dams&Reservoirs Database

General Data | Technical Data | Reservoir | Documents | Home

Technical Data

Hydrological Data	
Max discharge	13500 m3/s
Min discharge	275 m3/s
Annual Average discharge	84 billion m3
Storage Basin	
Max water Level	182 m
Storage Capacity	161 billion m3
Dead storage	30 billion m3
Live storage	90 billion m3
Flood room for protection from floods	41 billion m3
Length of reservoir	500 km2
Average width	12 km
Surface area of reservoir	6500 km2
Average Loss of Reservoir	10 billion m3
Diversion Channel	
Total Length	1950 m
Minimum width of channel	40 m
Minimum design discharge	11000 m3/s

Figure 6-4 Dam Technical Data

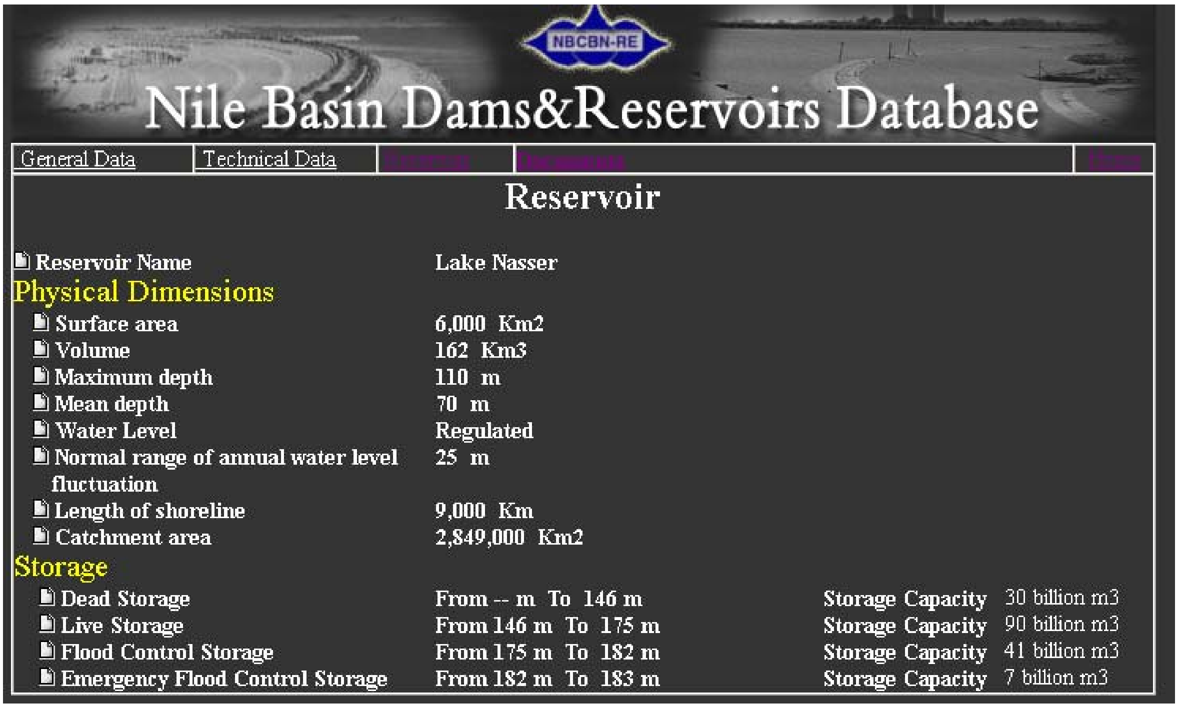


Figure 6-5 Reservoir Specific Data

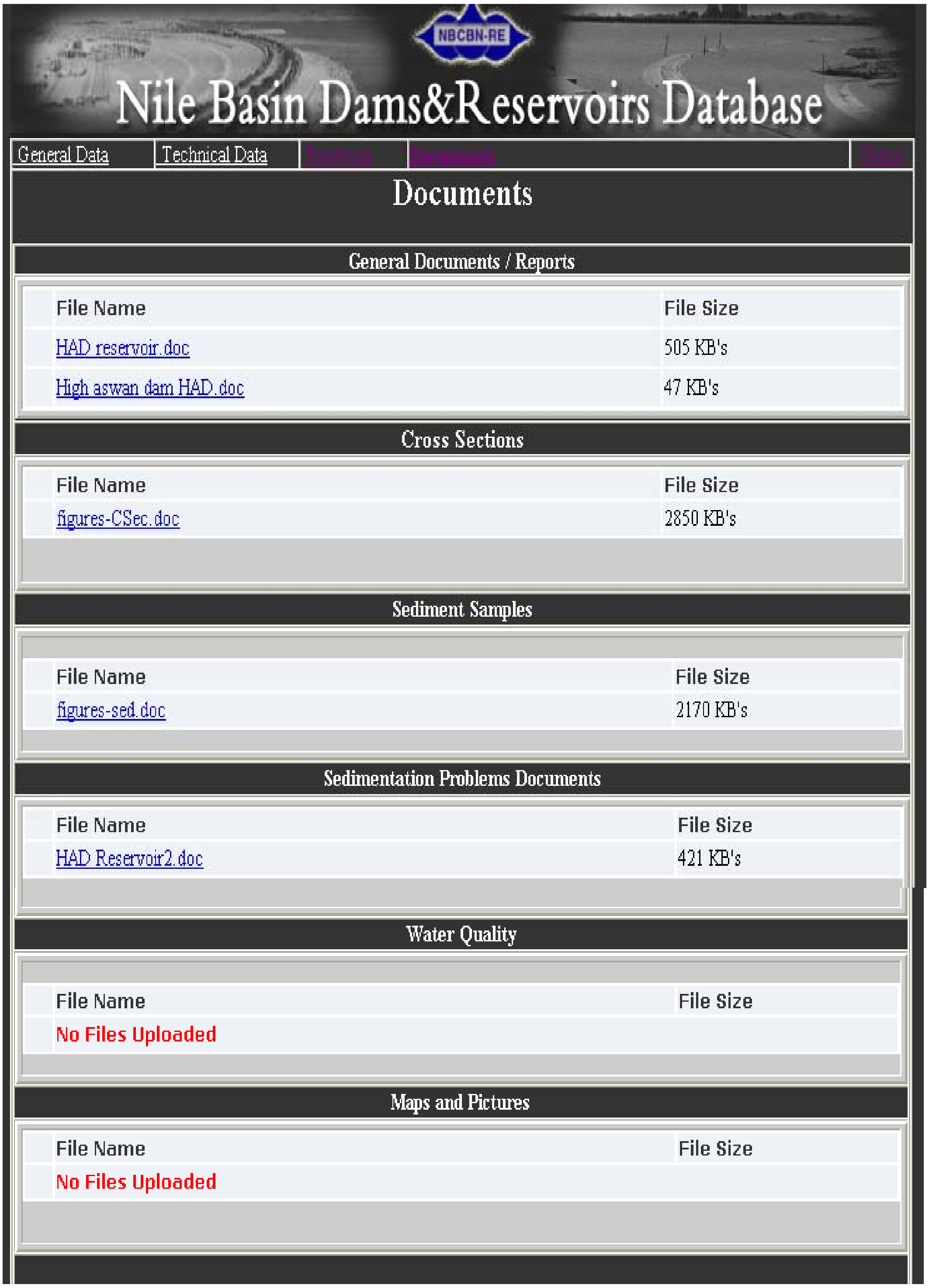


Figure 6-6 Documents Related to the Specific Dam and Reservoir Stored in the Database

6.6 FUTURE RESEARCH & CONCLUSION

This on-going research is to be continued with the second phase of the research, i.e., the development of Nile Basin Reservoir Information System (NBRIS). NBRIS will be used to plan, monitor and manage the reservoirs using the various analysis of spatial and non-spatial attribute overlaying, simulation and modeling, and integrated analysis of spatial and non-spatial attribute data. With the advent in Remote Sensing satellite data which provide 1-4m resolution, there could be also a plan to use this kind of data as one of the data sources for the Reservoirs database. This kind of data, coupled with centimetre level accuracy of GPS data, makes it possible to update the database with accurate, repeatable and useful data. The following information could be also added to the database

- Downstream Hazard potential of a Dam, which can identify the hazard to the downstream area resulting from failure or misoperation of the dam.
- Identification and review of the measures that can be taken to reduce sedimentation in reservoirs.
- Consideration of the options available for the removal of sediment from reservoirs and the associated environmental concerns.
- Consideration of the past and future consequences of reservoir storage loss.
- List of references to research or studies done for the sedimentation problems in the reservoir.

7 DISCUSSION, CONCLUSION AND RECOMMENDATIONS

7.1 DISCUSSION

The primary goal of this research study is to forge a collaborative research platform where water professionals and river engineers could exchange experience and develop common understanding to river engineering problems, that faces the water resources projects in the River Nile basin, and to enable devising a practical solutions.

During the past 18 months the group members of the reservoir sedimentation reearch topic have carried out an intensive collaborative research effort to produce this report. The previous chapters enumerate and reflect part of this effort

A solid base has been laid on for this research study in the sense that the problem of the reservoir sediment in the River Nile basin has been clearly stated. Research objectives, methodology and approach have been defined. The data collected on the individual selected reservoirs is far from being complete, but resemble acquisition, compilation and sorting of necessary information which is good enough for initiation of a multiphase research projects that can be followed by further detailed comparative studies.

Data pertaining to Roseries reservoir, Khasm El Girba Reservoir, High Aswan Dam, Koka Dam and Angrib Dam have been obtained. The data covers information on geometrical design and features of the dams, catchments characteristics, reservoir characteristics, trap efficiency, lost storage and successes and failures of some of the practiced sediment control measures.

It has been obvious that all of the above mentioned reservoirs have been seriously affected by sediment deposition at unexpected rates. This reached the extend that costly remedial measures have implemented on some of them to safe guard their functional purpose.

Further, decision on postponing the problem of sedimentation by heightening the dam, as in case of Roseires, has been taken and unresolved situation is waiting for others at planning, design or construction phases.

In accordance with the criterion set for selection of the case study during this phase of the research project Roseires Reservoir has received a great deal of attention and in depth analysis. A part from being a good and representative example for other reservoirs that suffer from sedimentation problems in the region, data availability and experience of participating members in the research group have also contributed.

The theory of the trap efficiency of reservoirs has been dealt with and the available methods of computation were applied for the selected Reservoir. For the case of Roseires reservoir a relationship between observed trap efficiency and years of operation has been found and in which the trap efficiency for the reservoir falls linearly with the square root of time. It is projected that its trap efficiency after 100 years will be in the order of 14%.

It has been sited that the Old Aswan Dam has zero percent trap efficiency while that for AHD is 100%. This resembles a range between a small reservoir where its sedimentation is controllable and a large reservoir where no feasible control measure is available. The situation for all other reservoirs lie within this range with varying degree of success for the applied control measures. The worst case is that of Khasm El Girba reservoir where almost 60% of its capacity has been lost. The flushing operation is reported to be carried twice a year in this reservoir and helped in alleviating the situation to some extend.

Further, a case study of socio-economic impact of sedimentation of the Roseires reservoir was carried out to assess the revenues forgone due sedimentation since had been commissioned in 1966. It has been found that, a sediment control facility with capital cost as high as the cost of the total project would be economically justified if only the active storage of the reservoir would have been preserved. The total economical revenues forgone due to the active storage loss was found to vary non-linearly between 115% and 22% of the original dam cost when the discount rate varied between 5 and 12% respectively. These losses were approximately shared equally between the two main users of the reservoir, the energy and the agricultural sectors.

Furthermore, another objective of this joint research has been realised through development, for the first time, a Reservoir Information System for the five selected reservoirs. The aim is to increase the ability of understanding the sedimentation problems in these different reservoirs and to enable the researcher to have common vision and there by suggesting ways and means for better managing these reservoirs.. Based on the developed database the development of Nile Basin Reservoir Information system could be achieved during the second phase of the research.

7.2 CONCLUSION

1. This pilot research project offered a nice opportunity to the group members to exchange experience and information on a crucial common regional problem as well as practicing capacity building.
2. Loss in capacity and active sedimentation processes are the most common problem facing the selected reservoirs though to a varying degree.
3. Reflection on extent of impact created by the problem of sedimentation, using existing data, represent a vital peace of information that enable dam planners, designers, owners and users to exert and joint efforts to combat this problem.
4. Apart from AHD, Draw-down, sediment sluicing during the rainy season and impounding only after the passage of the peak of the flood are seemed to be the preferred methods to control sediment deposition in the selected reservoirs.
5. An important objective of this joint research has been realised through development, for the first time, a Reservoir Information System for the five selected reservoirs.

7.3 RECOMMENDATIONS

1. During this phase of reservoir sedimentation research good deal of information relevant to the main artificial reservoirs have been collected. Further refinement and enlargement of the database, as well as evaluation of the collected data is deemed necessary.
2. Disseminating of the research findings, through publishing papers and guidelines should be done in the next phase of the research project.
3. Further detailed analysis of some selected case studies using computational programs and/or GIS-modeling tools should follow.
4. Development of guidelines on how to manage/operate reservoir optimally (considering the sedimentation as well), including flushing and sluicing.
5. Development of guidelines on how to assess the remaining reservoir capacity (sounding and remote sensing plus the accuracy which can be achieved)
6. Selection and if required improvement of reservoir sedimentation prediction methods and models.
7. Group training in GIS-modeling tools related to reservoir sedimentation
8. Preparation of joint research proposals with other cross-cutting research themes

8 REFERENCES

Adam, A. M., (1997), " Irrigation Funding Issues in Agricultural Schemes," (in Arabic), A Seminar on irrigation problems in the irrigated sector, Khartoum, Sudan, June, 1997.

Bommie Colb, S. and David, B. B., 1987, " Water markets in Theory and practice: Market transfers, Water values and Public Policy," Studies in Water Policy and Management, No. 12, Westview Press, Boulder and London, 1987.

Brune, G.M. (1953). "Trap Efficiency of Reservoirs." Transactions of American geophysical Union, Vol. 344, No.3.

Coyne et Bellier and Gibb Report (1996), "Physical Characteristics of Siltation of The Roseires Dam Reservoir," Ministry Irrigation and Water Resources, Sudan, July 1996.

Churchill, M.A. (1948). Discussion of " Analysis and Use of Reservoir Sedimentation Data," by L.C. Gottschalk, Proceedings, Federal Interagency Sedimentation Conference, Denver, Colorado.

Garde, R. J and Raju, K.G. (1985). "Mechanics of Sediment Transportation and Alluvial Stream Problems," Wiley Eastern Limited, 2nd edition.

Gibb, Coyne Et Bellier. (1996). "Physical Characteristics of Siltation of the Roseires Dam Reservoir." A report submitted to the Ministry of irrigation & Water Resources.

Gibb, Merz and Mclellan. (1987). " Updating of the Feasibility Study for the Heightening of Roseires Dam," Final Report submitted to the Ministry of Irrigation and Water Resources.

Gottschalk, L.C. (1964). "Reservoir Sedimentation," Section 17.1 in Handbook of Hydrology (V.T. Chow, Editor), McGraw Hill, New York.

Hotchkiss, R. H. and Xi Haung, (1994), " Reservoir Sediment removal: Hydrosuction Dredging," International Conference on Hydraulic Engineering, George V. Cotroneo, ed. and Ralph R. Rumer, ed., 1994.

Hydraulics Research Limited. (1990)."Research for Rehabilitation of Gezira Irrigation Scheme: Siltation Monitoring Study," Final Report EX 2244, Appendix C.

Julein, P.Y. (1995). "Erosion and Sedimentation," Cambridge University Press.

Loman, G., 1994, " Combat Reservoir Sedimentation by Dredging" paper presented in Feb. 1994 at IHE, Delft, the netherlands.

Sharfi, E. M. A. (1993), "Towards an Optimum Utilization of Water Resources in a Multipurpose Project," Sudan Enineering Society Journal, Vol. 40, No. 33, Dec. 1993, PP. 21-27.

Mohmood, K., 1987 ," Reservoir Sedimentation: Impact, Extent, and Mitigation," World Bank Technical report Number 71, The World bank, Washington, D.C.

McDougall, I., Morton, W.H., & Williams, M.A.J. (1975). "Age and Rates of Denudation of Trap Series Basalts at Blue nile Gorge, Ethiopia." Nature, London, 254, 207-209.

Ministry of Irrigation and Water Resources Report on Flushing operation of Khashm El Girba Reservoir, 2003

Miller, C.R. (1951). "Analysis of Flow-Duration, Sediment-Rating Curve Method of Computing Sediment Yield," United States Bureau of Reclamation (USBR).

Miller, C.R. (1953). "Determination of the Unit Weight of Sediment for Use in Sediment Volume Computations," Bureau of reclamation, Denver, Colorado.

Murthy, B.N. (1980). "Life of Reservoir," Technical Report No. 19, Central Board of Irrigation and Power, New Delhi.

Siyam, A.M. (2000). "Reservoir Sedimentation Control," Ph.D. Thesis, University of Bristol, England.

Tag-Elsir, A. Osman, E. H., 1986, " Sediment Transport in Relation to Reservoirs" International Conferrence on Water Resources Needs & Planning in Drought Prone Areas, Khartoum, Dec. 1986, PP 281.

USBR (1982). "Reservoir Sedimentation" Technical Guideline for Bureau of Reclamation, Bureau of Reclamation, Denver, Colorado.

United States Department of Agriculture (1979). "Field Manual for Research in Agricultural Hydrology," Agric. Handbook No. 224.

Walling, D.E. (1984). "The Sediment Yields of African Rivers," in "Challenges in African Hydrology and Water resources," edited by Walling, Foster and Wurzel, IAHS publication No. 144.

APPENDIX A

SUMMARY OF GENERAL RESERVOIRS FEATURES

GENERAL FEATURES OF ANGEREB RESERVOIR, ETHIOPIA

Summary Sheet

Location: Angereb river, a tributary of Megech river that flows into Lake Tana. The reservoir is located in Amhara Regional State near Gonder town, about 35 km North of Lake Tana, lat. 12° 36’ N and Long. 37° 12’ E. The dam construction started in 1990.

Purpose: Water supply

The Reservoir:

- design capacity at full reduced level is	5.286 Mm^3
- maximum retention level	*
- minimum	*
- normal range of annual regulated flow	*

Watershed:

- drainage area at the dam site: 68.1 km^2
- mean annual rainfall 1100 mm with 80% falling between June and September
- land topography is high mountains and steep slopes
- time of concentration is very short for heavy rains

Hydrology:

- Minimum mean flow:	0.04 m^3/s
- Peak mean flow for the period 1983-89:	6 m^3/s
- Mean annual flow	27 Mm^3

Design Capacity to mean annual inflow ratio = 0.20

Sediment Inflow:

- annual suspended sediment load over the period 1983-1989 varied between 7900 and 178,800 tons with a mean value of 76,800 tons
- practically all suspended sediment transport occurs in June-October.

Reservoir Resurvey: None

Operation Rules: *

--
*** missing data**

GENERAL FEATURES OF ROSEIRES RESERVOIR, SUDAN

Summary Sheet

Location:

Roseires dam first stage, commissioned in 1966, is on the Blue Nile at Roseires town some 500 km south of Khartoum. In the second stage, yet to be started, the dam is to be raised by 10 metres.

Purpose: Irrigation, hydropower

The Reservoir:

Design capacity at R.L. 480 m a.m.s.l.	3000 Mm^3	
Surface area	290 km^2	
Length	75 km	
Design capacity R.L. 490 m a.m.s.l.	7000 Mm^3	(after heightening)
Minimum retention level	467 a.m.s.l.	
Normal range of annual regulated water level	13 m	

Hydrology:

Blue Nile catchment area	254,230 km^2
Average peak flood discharge	6,300 m^3/s
Maximum recorded flood	10,800 m^3/s
Average low river flow	100 m^3/s
Total average annual flow at Roseires	50,000 M m^3

Design Capacity to mean annual inflow ratio = 0.06

Sediment Inflow:

Reasonable measured data for sediment transport are available. The measurements are mainly for suspended sediment transport during the rainy season. Rating curve for suspended sediment transport was developed from these measurements which indicated a peak transport rate of about 3 million metric tons per day.

Reservoir Resurveys: Made in 1976, 1981, 1985, 1992 and one satellite imagery in 1995

Main Problems: Loss in capacity, interruption in hydropower generation.

Reservoir Operation Rules:

- during the flood, the reservoir is drawn down to R.L. 467 m using the deep sluices. The spillway will augment the deep sluice flow when it becomes necessary to pas the flood peak.
- Impounding of the reservoir usually starts towards the end of September after the peak flood has passed and lasts for abut a month until top retention level is reached at R.L. 480 m. During the impoundment, the spillway gates are closed and the deep sluices control the flow past the dam until impoundment is completed.
- Outside the flood season, downstream releases are passed through the power station turbines
- Since 1981, the top retention level was increased by one metre to R.L. 481 m, while later the minimum drawdown level was increased to R.L. 467.6 m.

GENERAL FEATURES OF KHASHM EL GIRBA RESERVOIR, SUDAN

Summary Sheet

Location:

The dam is located at 16^o N and 36^o E on Atbara river, the last tributary of the Nile in its northward journey. The dam was commissioned in 1964.

Main Dam Components:

- a spillway with a total discharge capacity of 1000 m^3/s (at RL 473 m) intended primarily for discharge of floating debris
- low level flood gates with sill elevation at RL 432 m having a total discharge capacity of 7700 m^3/s (at RL 473 m)
- irrigation headworks
- a small power station

Purpose: Irrigation, water supply to Gedaref town

The Reservoir:

Design capacity at R.L. 473 m a.m.s.l.	1300 Mm^3
Surface area	125 km^2
length	80 km
maximum retention level	Rl 473 m
minimum retention level	RL 461 m
normal range of annual regulated water level	12 m

Hydrology: Atbara River is a seasonal river running dry in Summer

catchment area	112,400 km^2
Average peak flood discharge	2,500 m^3/s
Maximum recorded flood	5,020 m^3/s
Annual average discharge of Atbara River	12,000 Mm^3

Design Capacity to mean annual ratio = 0.11

Sediment Inflow:

Atbara river carries high concentration of suspended sediment and debris during the flood period resulting from the erosion of the upper catchment. Measured sediment inflow data are meager.

Reservoir Resurveys: *

Main Problems: Rapid Loss in capacity.

Reservoir Operation Rules:

- during the flood, the reservoir is drawn down to R.L. 461 m (using the low level flood gates) and irrigation diversion is made by pump lifting (turbines). But lately due to pump deterioration, a higher level viz. 463.5 is maintained during the flood.
- Flushing is made once or sometimes twice a year for a day or two over the period 10-15 August (peak of the flood). When flushing, reservoir level is maintained at RL 438 (using the low level flood gates).
- Reservoir filling starts after the peak of the flood has passed (usually between 25 Aug – 6 Sept.) Filling is usually completed in a month.

*** missing data**

GENERAL FEATURES OF ASWAN HIGH DAM RESERVOIR, EGYPT

Summary Sheet

Location:

The dam, completed in 1968, is on the river Nile at Aswan, Egypt. Its reservoir extends for 500 km, 350 km in Egypt (called Lake Nasir) and 150 Km in Sudan (called Lake Nubia)

Purpose: Multipurpose **(**Irrigation, hydropower, flood protection and navigation)

The Reservoir:

Located between lat. 20^o 27' – 23^o 58' N and long. 30^o 07' – 33^o 15' E, 183 m above sea level.

An over-year storage reservoir

Total reservoir design capacity	162 Km^3
Dead storage (85.147 to 146 m a.m.s.l).	31.6 km^3
live storage (146-175 m a.m.s.l.)	90.7 km^3
provision for flood protection 175-182 a.m.s.l.	41.0 km^3

Hydrological data:

Catchment area	2,849,000 km^2
Maximum discharge	13,500 m^3/s
Minimum discharge	275 m^3/s
Annual average discharge	84 Km^3
Annual evaporation losses	10 Km^3
Normal range of annual regulated water level	25 m

Design Capacity to mean annual inflow ratio= 1.93

Reservoir Resurveys: *

Main Problems: Delta formation and development, water quality degradation and high evaporation rates.

***missing data**

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