بسم الله الرحمن الرحيم

University Of Khartoum
جامعة الخرطوم

Faculty of Engineering
Civil Engineering Department

The Effect of the Sediment Accumulation in Reservoirs:

Case of the Roseires

Thesis Submitted in Partial Fulfillment of M.Sc degree in Water Resources Engineering

Prepared by: Eltayeb Ahmed Khalifa Jaroot

Supervisor: Dr. Kamal ELdin Bashar

January 2009

بسم الله الرحمن الرحيم

{أَوَلَمْ يَرَ الَّذِينَ كَفَرُوا أَنَّ السَّمَاوَاتِ وَالْأَرْضَ كَانَتَا رَتْقاً فَفَتَقْنَاهُمَا وَجَعَلْنَا مِنَ الْمَاء كُلَّ شَيْءٍ حَيٍّ أَفَلَا يُؤْمِنُونَ}

صدق الله العظيم

سورة الأنبياء

الآية (30)

DEDICATION

To my father.

To my mother.

To my brothers.

&

to all my friends,

with love and respect

ACKNOWLEDGEMENT

I wish to express my sincerest thanks to those who have helped in executing this work. This includes my family, colleagues and friends.

My profound gratitude is expressed to my supervisor: Dr. Kamal eldin Bashar; special thanks for guidance, supervision, support and advice.

Thanks also go to the staff of the Roseires Dam, Hydraulic Research Station in Wad Medani, Ministry of Irrigation and Water Resources and Ministry of Agriculture in Blue Nile State.

Abstract

This study is especially about the effect of sediment accumulation in Roseires dam reservoir. It is situated along the Blue Nile reach between the dam site and the Ethiopian border. The dam is located in the vicinity of the Damazin city, approximately 500 km south of Khartoum, with drainage area 290 km^2, length 75 km, volume 3.024×10^9 m^3 at top water level 480 m and 7.4×10^9 m^3 at level 490 m after dam heightening.

The main objective of this study is to assess the sediment accumulation rate in the Roseires dam reservoir. The historical data and information of the previous bathymetric surveys carried at Roseires dam reservoir, which include those carried in years 1976, 1981, 1985, 1992, 2005 and 2007 were used. Comparison of accumulated silt volumes deposited among the different surveys was\ obtained.

The case study revealed that the sediment deposition in the Dam Reservoir reduced its capacity (from 3.024 milliard m^3 to 1.92089 milliard m^3 after fourty one years of operation (1966-2007)). It was clearly depicted during the 41 years that there is increase in the silt deposit with time at all reduced levels and decrease in siltation rate with time at all reduced levels.

مستخلــــــص

هذه الدراسة خاصة بتأثير الطمي المتراكم في بحيرة خزان الروصيرص التي تقع علي النيل الأزرق وعلي بعد 500 كيلو متر جنوب الخرطوم وتمتد من جسم السد حتى الحدود الأثيوبية بطول 75 كيلو متر، مساحة قدرها 290 كم مربع ، سعتها 3.024 مليار متر مكعب عند ارتفاع 480 متر و 7.4 مليار متر مكعب عند ارتفاع 490 م بعد التعلية.

الهدف الأساسي من هذه الدراسة حساب معدل الطمي المتراكم و تاثيرة علي بحيرة خزان الروصيرص وذلك باستخدام بيانات عمليات المسح المائي التي تمت في البحيرة لعدة سنوات سابقة (Bathymetric surveys in 1976, 1981, 1985, 1992, 2002 and 2007) ومقارنتها مع بعضها البعض.

أظهرت الدراسة أن الاطماء في بحيرة الخزان أحدثت نقصا واضحا قي السعه التخزينية حيث أصبحت 1.92 مليار متر مكعب بدلا من السعة التصميمية 3.024 مليار متر مكعب في فترة تشغيلية قدرها 41 سنة من سنة 1966 وحتى 2007 م. كما أنة ظهر جليا أن تراكم الطمي يزداد مع الزمن علي كل المستويات التخزينية وان معدل الاطماء يتناقص مع الزمن.

TABLE OF CONTENTS

Contents **Page. No**

Chapter One Introduction

Chapter Two Literature review

Chapter Three the Study Area

Chapter Four Methodology

Chapter Five Analysis, Results and Discussions

Chapter Six Conclusion and Recommendations

LIST OF SYMBOLS

S_{topset}	Top-set slope of the delta deposit	[-]
S_{river}	Ole river slope	[-]
$S_{frontset}$	Front-set slop of the delta deposit	[-]
A	Reservoir surface area	[m^2]
T.E	Trap efficiency after T years of operation	[-]
V_d	Accumulative volume of deposited sediment	[m^3]
V_0	Original reservoir volume	[m^3]
T	Years of operation	[year]
V	Volume remaining after T year of operation	[m^3]
γ	Average specific weight of deposited sediment over T years	[t/m^3]
γ_i	the initial value	[t/m^3]
K	Constant depends on reservoir	[-]
P_{cl}	Fractions of clay	[-]
P_{sl}	Fractions of silt	[-]
P_{sa}	Fractions of sand	[-]
γ_{cl}	Coefficients of clay	[-]
γ_{sl}	Coefficients of silt	[-]
γ_{sa}	Coefficients of sand	[-]
USBR	United State Bureau of Reclamation	[-]
R.L	Reduce level	[m]
MOI	Ministry of irrigation	[-]
ß	Factor of difference in diffusion of fluid and discrete sediment particle	[-]
SI	sedimentation index	[m^3]

LIST OF FIGURES

Contents **Page No.**

LIST OF TABLES

Contents **Page. No.**

Chapter One

1.0 Introduction

Sedimentation is the major problem which endangers and threatens the performance and sustainability of reservoirs. It reduces the effective flood control volume, presents hazards to navigation, changes water stage and affects operation of low-level outlet gates and valves and reduces stability, water quality, and recreational benefits.

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 inland use pattern (Nazr, 2006).

Sedimentation is a complex hydro-morphological process which is difficult to predict. It has been underestimated in the past and perceived as a minor problem which can be controlled by sacrificing certain volume of the reservoir for accumulation of the sediment (dead storage). However, to days experience revealed that it is of paramount importance to take design and implementation of sediment control measures into consideration in the planning, design, operation, and maintenance phases, of the reservoirs (Siyam, 2005).

Considering Reservoir sediment problem, surveys are necessary to get more realistic estimated data regarding the rate of siltation to provide reliable criteria for studying the implication of annual loss of storage over a definite period of time. This loss should be associated with particular reference of intended benefits in the form of irrigation potential, hydropower, flood absorption capacity and water supply for domestic and industrial uses including periodic reallocation of available storage for various pool levels. It will also help in proper estimation of loss of storage at the planning stage itself besides evaluating the effectiveness of soil conservation measures carried out in the catchments area of Blue Nile River (K.K. Agarwal, 2000). Since the major cause of storage capacity change is sediment deposition the monitoring program can determine:

- depletion caused by sediment deposition since closure of storage dam
- annual sediment yield rates
- current location of sediment deposition
- sediment densities
- lateral and longitudinal distribution of deposited sediment
- reservoir trap efficiencies

It is generally recommended to continue carrying out bathymetric surveys of reservoirs, so that the quantity of sedimentation taking place can be assessed and timely remedial measures taken.

1.1 Study Area

The selected case for this study is Roseires reservoir, which is located in Sudan. This reservoir is situated along the Blue Nile reach between the dam site and the Ethiopian border. The dam is located in the vicinity of the formerly Damazin Rapids, approximately 6 km upstream the Roseires and some 500 km south of Khartoum. This reservoir was built in the year 1966 at the Blue Nile River. The dam is multi-propose irrigation, fisheries and hydropower see figure (1.1) (Gibb, 1996).

The watershed of the Roseires reservoir is located between longitudinal lines (11°--14°) north and longitude lines (33°--35°) east. The soil properties of the study area are clay layers covered with hilly forest at Eldeim then surround by poor Savanna in Roseires and Damazin**.**

The climate is hot in summer with rains but is cold in winter. The temperature is between (27°—46°c). The annual average rain fall is 700 mm and usually falls between June to October in Damazin and 1500 mm in Eldeim. Rainfall increases gradually upon going South and decreases towards the North till it is almost dry. Figure (1-1) shows the location of the reservoir within the Blue Nile System. (Ministry of agriculture in Blue Nile State, 2008).

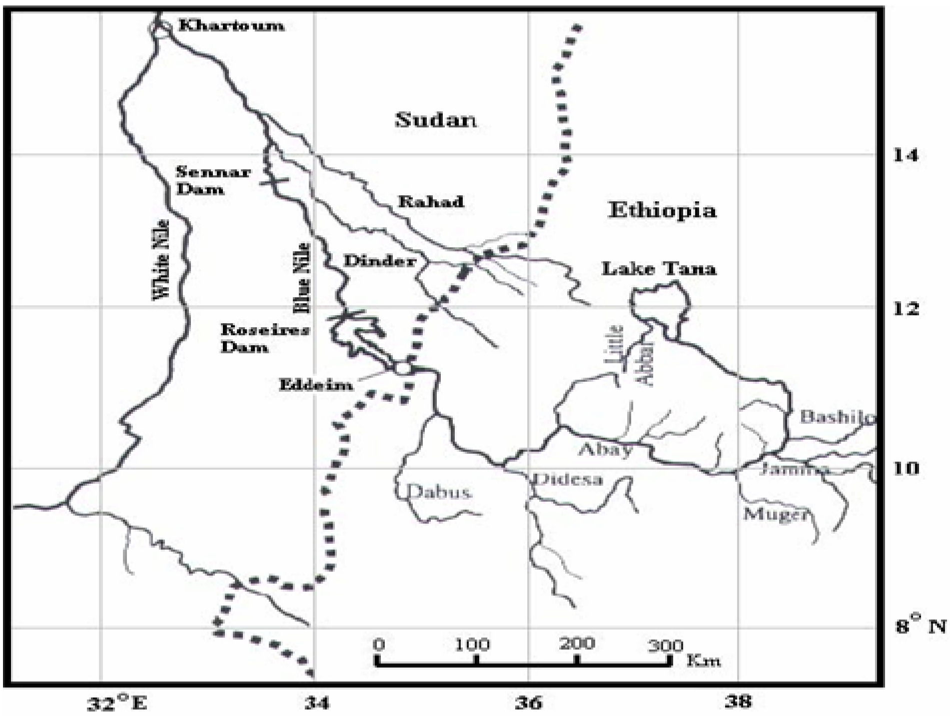


Figure (1-1) Location of Roseires Dam and the Eldeim station in Ethiopia and Sudan.

1.2 Statement Of The Problems

The primary reservoir sediment problem is the deposition of sediment in the reservoir witch leads to;

- Reduction in storage capacity.
- Blockage of hydropower intakes and power outage as a consequence.
- Increased flood risks due to upstream propagation of the deposited sediment deltas.
- River bed degradation and river bank erosion downstream of dam.
- Interruption in hydropower generation associated with degradation of water quality, as well as increased complexity in reservoir operation and maintenance.

The determination of the sediment accumulation over the life of the project is important to control the operation of dam.

1.3 Objectives

The main objective of this study is to assess the sediment accumulation rate in the Roseires reservoir.

The specific objectives are to:

- Collect, collate and synthesize readily available data in order to have an overview of reservoir sedimentation in the Roseires reservoir.
- Identify the magnitude of sedimentation rate and sediment distribution patterns in Roseires reservoir.
- Study different kind of sedimentation that occurs in Roseires reservoir.

1.4 Layout of thesis

The thesis is composed of several chapters namely, chapter one, which is the introduction, stating the objectives and statement of the problems statement of the problems. Literature review and previous study of Roseires reservoir are found in chapter two. In chapter three, the background about study is presented and the main data and information available about the Blue Nile River, and the property of the reservoir is described. Chapter four describes the methods, and equipments used to estimate sediment deposited and siltation rate. Chapter five shows the analysis of the data collected and discussion of the results. Chapter six gives the conclusion and recommendations based on the discussion of the results as well as some recommendations for future works, References used and Appendix are listed at the end of the Thesis.

Chapter Two
Literature review

2.0 General

Reservoir sedimentation consists of complex processes. These processes happen in stages namely: 1. Erosion, 2. Entrainment (drawing of particles into a fluid), 3. Transportation, 4. Deposition, 5. Compaction.

The detachment of particles in the erosion process occurs through the kinetic energy of raindrop impact, or by flowing water. Once a particle has been detached, it must be entrained before it can be transported away. Both entrainment and transport depends heavily upon the weight, shape, size, and the forces exerted on the particle by the flow. Deposition occurs when the forces are diminished enough seeing a reduction or cessation of transport (Eltahir, 2000).

Sedimentation starts after damming a natural river and storing water in the reservoir behind the dam. Due to increased flow geometry of a river when it enters to the reservoir, the water flow velocity is reduced and sediment carrying capacity will diminish which cause dumping most of the sediment load carried by a river into the reservoir. Two different types of sedimentation occur in the reservoir, one due to normal deposition of the sediment load at the front u/s beginning of the reservoir, and the other due to formation of density current which brings more sediment to middle and downstream end of a reservoir.

The knowledge about the rate and the pattern of sediment deposition is one of the important requirements for understanding the sedimentation and morphological processes in the reservoir. It is also important to have a good insight about the different reservoir sedimentation behavior and their consequences on the reservoir storage volume, water quality as well as its impacts on the morphological change at the downstream reach of the reservoir (Nazr, 2006).

For better understanding of the reservoir sedimentation behavior, it is important to use a tool to explore the different sedimentation processes that happen in the reservoir.

Sedimentation happens in every reservoir in the world, and the sensitivity of such phenomena is determined by the normal reservoir size, hydrological size as well as the morphological behavior of the river system.

From the water resources point of view, due to limitation of the natural resources and the global changes that happened in the latest century, the reservoir sedimentation has become a serious problem. This is especially noticed when it affects the availability of water resources in some areas and maximizing the risks coming from the excessive floods due to weather changes in others. Due to the increased sedimentation in the reservoir and the global increased number of reservoirs, the annual storage loss by sedimentation is roughly estimated at 1%, which is corresponding to about 50 km^3 of water in the world (Mahmood, 1978). In some other reservoirs more than this figure, was observed e.g. the Sanmenxia Reservoir in China loses about 1.7% yearly, Sefid-Rud reservoir in Iran about 2% and the Welbedacht reservoir in South Africa loses about 5 % of its capacity.

From economic point of view, sedimentation is a serious problem. This is clearly felt by the aggradations of the reservoir as a result of reduction of available water as well as the cost required for removing the accumulated sediment, estimated as 6.109 US$ per m^3 yearly (Sloff, 1997).

The sustainability of reservoirs is another issue which associated with prolonging the reservoir life time and increases the reservoir water storage. Several techniques have been used for this purpose based on the local suitability for the reservoir. Flushing is a most familiar method, which is used to remove sediment from the reservoir and it is successfully done in several reservoirs in the world. Cachi reservoir is one of those reservoirs, which almost every year apply flushing process to remove the accumulated sediment. Several other methods are also available for prolonging reservoir lifetime (Nazr, 2006).

2.1 Blue Nile Hydrology

The Blue Nile flow out of the Tana Lake, in Ethiopian highland at an altitude of 850 m, and then passes through gorges until it reaches the Sudan plains at an elevation of 500 m. Then it flows in northern westerly direction to its confluence with the White Nile at Khartoum. Between Sennar and Khartoum the two tributaries Dinder and Rahad drain in to Blue Nile. The most upstream gauging of the Blue Nile is at Eldeim near the Ethiopian boarder, while the most downstream gauging station is at Khartoum.

The Blue Nile contributes by about 60% of the annual discharge of the main River Nile. The length of the Blue Nile reach in the Sudan is a bout 500 miles. The Blue Nile is highly variable, during the flood the discharge may rise to 60 times as that of the lower river discharge, in some years the discharge may approach 300-400 times as mach. Due to its high erosive force the Blue Nile has the ability to carry great amount of solids during the flood season.

The Blue Nile normally begins to feel the effect of rains on the Ethiopian plateau in about the mid May and starts to rise bringing the first red silt down to Khartoum in about 20^{th} of June. It then continues with an irregular flow, forming it peak level to wards the end of August at Khartoum. Late in September it begins to fall rabidly. In this period the river appears to be red in color due to presence of red silt. To make use of this river, two dams were constructed, the upstream one is located at Roseires and the other one is at Sennar (Paul J., 2007).

2.2 Dams in Sudan

In the Sudan there are five dams namely Sennar dam which was constructed on the Blue Nile and was completed in 1925. Jabbel Awlia dam; constructed on the White Nile between (1932-1937). Khasm-elgirba dam; constructed on Atbra River between (1959-1964). Roseires dam; constructed on Blue Nile and was completed in 1966. Merowe dam; which is now under construction since 2003, and expected to be completed in 2009.

Water in the Sudan is available either as surface water (river, wadies, precipitation, etc) or subsurface water (aquifers).

The aims of constructing dams in the Sudan are Irrigation water requirement and Hydro-electric power generation.

2.3 Reservoir Sediment Transportation and Deposition

The reservoir sedimentation involves entrainment, transport and deposition. They originate from the catchments area, river system and settled in the reservoir. As a river enters the reservoir, its cross section of inflow is enlarged due to the effect of the backwater curve. Thus it causes a decrease in the water flow velocity; subsequently the sediment carrying capacity of water is reduced too. The major part, or all, of the sediment transported will deposit in the u/s part of the reservoir influenced by the back water curve.

Reservoir sedimentation undergoes different processes of transportation and settling of sediment. This cusses the reservoir to possess different kinds of deposition at different positions. These differences are controlled by the effects of the sediment particle size, hydraulic condition and sediment transportation methods in the reservoir.

Due to different behaviour of sediment particles in transportation and deposition, they have different impacts on the reservoir sedimentation pattern and storage losses. Thus, it is important to treat each type separately, so as to understand how they are deposited and transported in the reservoir. This is hardly needed in analyzing the reservoir sedimentation problem and providing the best measures.

2.4 Types of Reservoir Sedimentation

The river flow usually carries a wide range of the sediment particle sizes and they are transported either as a bed load or as a suspended load. In general, the bed load material (coarse sediment particles) move near the bed and start to deposit in the beginning of the reservoir entrance in the form of the delta as shown in figure (2-1). The suspended sediments (fine sediment particle with lower settling velocities) are transported deeper into the reservoir either by non stratified flow forming a uniform deposition at the middle of reservoir, or by stratified flow depositing at lower part of the reservoir forming a muddy lake. Generally the suspended load is divided in two parts; one comes from the bed of the river, and the other load from the catchments area as wash load.

Batuca and Jordaan (2000) have classified the reservoir sedimentation based on the location of deposition into three categories, with inclusion of the sedimentation in backwater reach as a part of the reservoir sedimentation. The position of each type of reservoir sedimentation can be seen in the longitudinal profile of the reservoir shown in figure (2-1) which is classified as Back water deposition, Delta deposition and Bottom set deposition.

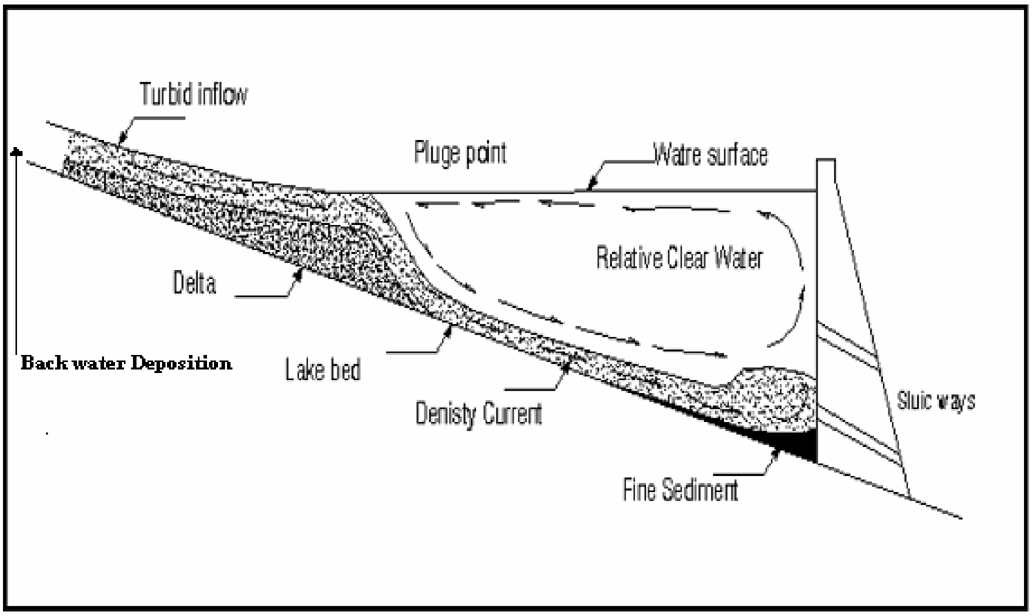


Figure (2-1) longitudinal cross section of reservoir sedimentation

2.4.1 Back water Deposition

This type of deposition occurs in the river reach before entering the reservoir. After changing the water level in the river by the effect of back water curve, the velocity of water will be reduced. Subsequently a small part of the coarse sediment will deposit in this region till it reaches the reservoir delta deposition. It is considered as a transition between the original river bed and delta formation as shown in figure (2-1). In theory, the backwater deposit should grow progressively, into upward and downward direction of the river, because it extends with changes of bed forms. However this growth is limited, because the stream adjusts its channel by eliminating meanders, forming a channel having an optimum width-depth ratio or varying bed form roughness. These factors make the stream transports its sediment load through the reach with evolution done in one direction (Nzar, 2006).

The backwater deposition is not fixed, but it is fluctuated and advanced toward the reservoir and delta. As a result of the variation of the reservoir water surface and water flow velocity, the backwater sediment is re-eroded, transported toward the reservoir and contributes in the formation of the delta.

2.4.2 Delta formation

Delta formation is caused by rivers that enter a reservoir, lake, or sea. The process involves deposition of sediment of large sand sizes (bed load) due to the reduction of stream sediment holding capacity.

Mainly, the change of the water level and the expansion of the inflow cross section in the reservoir are considered to be the most important reasons to diminish the water velocity and continuity of sediment movement in the stream at the delta reach. Therefore the deposition happens in this place at the beginning. The deltaic deposition takes place along and across the reservoir and its basin (in the main river reach and over the flood plain as well) (Betuca and Jordaan, 2000).

From the observation of the reservoir sedimentation, the delta formation may contribute the majority of the sedimentation in the hydrologic ally small reservoir. While for the large reservoir the delta constitutes only a small part of sedimentation (Fan and Morris, 1997).

Due to the small volume of shallow part at head of reservoir, the deposition and formation of delta even with small volume will be problematic from the standpoint of upstream aggradations. The longitudinal cross section of the delta can be divided in two zones, the top-set bed and front-set bed which are different in surface slope and deposition texture as given in figure (2-1). According to the US Bureau of Reclamation (1986) the slope of top-set of the delta is in the range from 100% to 20% of the original bed slope, which was found to be based on observation of 31 reservoirs in the United States.

For design purposes 50% slope is acceptable.

Hence: -

$$S_{topset} = 0.5 S_{river} ------------------------------------(2.1)$$

Based on the same survey data done by US Bureau of Reclamation (1986) the slope of front set can be have the relation:-

$$S_{frontset} = 6.5 S_{topset} ------------------------------------(2.2)$$

In some cases the delta formation takes the major part of the reservoir sedimentation. For example in Glenmore reservoir at Canada, about 10 percent of its total water capacity was lost in the year 1968, with about 70 percent of the deposits that occurred in the delta area (Fan and Morris, 1997).

The advancing shapes of the delta formation toward the reservoir are different. They are affected by hydraulics and geometric shape of the reservoir inlet. This results in different advancing speed in delta propagation, subsequently having different impacts on reservoir sedimentation. Sloff (1991) has indicated that the parameters which affect the shape of delta formation are namely, Slope of the valley, length and shape of the valley, sediment particle size and its distribution, and Reservoir operation and capacity of inflow ratio. According to the empirical criterion which was developed by Zhang and Qian (1985), there are two major type of delta formation. The 1st are the Wedge-shape deposits; in which the front reaches to the dam wall and sediment site are uniformly distributed in the basin. The second are the delta-shape deposits; in which the front does not reach to the dam wall and sediment site are non-uniformly distributed in the basin.

According to the experimental investigation made by Chang (1982) in the laboratory, the delta formation starts with the deposition of the bed load at the channel mouth. The suspended load is deposited rather uniformly over reservoir bottom (Nzar, 2006).

2.4.3 Bottom-set bed depositions

Bottom deposition of the reservoir is formed by transporting and depositing the fine sediment, which is carried by the water to the middle and end of the reservoir in suspension stage. This type of deposition is mainly composed of clay and silt fraction, which are transported in the reservoir water body either by the turbulent suspension or by turbidity currents. Its deposition starts beyond the delta up stream the dam wall site.

The shape and configuration of the deposit is affected by the process of transporting and depositing of suspended material. There are two main ways of transporting fine sediment into the reservoir body. First one is by suspension action of the sediment particle. In this case they travel beyond the delta toward the reservoir body either by the action of electro-magnetic of small particles or by turbulence action of flowing water. The second way is by gravity action on the sediment-laden water which enters to the bottom of the reservoir in the form of turbidity current.

2.4.4 Sediment transport and Deposited in reservoir

The rate of the reservoir sedimentation and form of the deposition is affected by the rate of sediment transport and the method of its deposition in reservoir. Sediment particles are transported by different mechanism depending on the sediment size and the water sediment holding capacity.

Due to existence of different kinds of sediment particle in the stream inflow, several transporting and depositing kinds occur in the reservoir. In general, the river sediment is divided in two major parts; bed-load and suspended load. They exist in the stream inflow at different ranges and different quantity with respect to the time and space.

The increase or decrease of any type of sediment has direct reflection on the deposition pattern in the reservoir (Nzar, 2006).

2.5 Depress flow

Woods and light material that comes with flow cause many troubles and interruption during dams operation. They are quite dangerous to gates and especially to running turbines when the protecting screens are broken under the heavy pressure of the accumulated materials. The best method to get red of depress is to direct these floating materials towards the spillways to pass downstream. However, since the depress (wood) come from the upper catchments then it would be better to treat the problem there by improving and protecting the environment of the wood source. For more information on this topic consult the reference (Nzar, 2006).

2.6 Regulation Rules

At present the Blue Nile system, including the Sennar and Roseires reservoirs are operated in accordance with the document (Regulation Rules for the working of the reservoirs) prepared by the Ministry of Irrigation and Water Resources in 1968. The aims of the Rules are to use natural river flow for irrigation, distribute stored water and grantee the required minimum flows at Khartoum. There is provision for flow at Roseires dam and Sennar dam for power generation but this provision is governed as restricted by irrigation demands.

The following rules are provided for the regulation of the reservoir of Roseires dam and Sennar dam. These working arrangement are for the control of flows of the Blue Nile:

a- The hydrological year will be reckoned as beginning on first of June and ending at end of May.

b- The working of the two reservoirs must be always closely coordinated in order to restrict the deposit of sediment in the reservoirs during the period of high flood. At this period no water is kept in Roseires and Sennar reservoirs more than that necessary for main reservoirs purposes.

c- If at any time difficulty should arise, or appear likely to arise, in meeting the full prospective requirements of irrigation due to power generation requirements, irrigation, shall in general have priority over the requirements for the power generation.

d- The date of the beginning of the period of low flow in the Blue Nile, during which the requirements of water exceeds the natural flows in the river at Eldeim gauging station varies considerably in different years. At the end of low flow period the natural flow of the river at Eldeim gauging station rises indicating high flood flows.

2.7 Operation of Roseires and Sennar Dams

The system of operation works through four main stages:

1- The Flood begins from early June and the filling starts in September to wards the end of the flood. The aim of operation in this stage is to maintain the level of reservoir at minimum water level 467.6 m and 417.2 m in Roseires and Sennar dams respectively to reduce silt as far as the discharge facilities allow. However, if the floods are above normal the levels in the reservoirs will be raised to the required levels to pass the flood discharges.

2- At the Filling program; to the level of 417.2 m in Sennar Reservoir all sluice gates and spillway are fully opened allowing the passage of a flow of about 11,000 m^3/sec. When the flow rate exceeds 11,000 m^3/s, the level in the reservoir will rise. At the maximum permissible level in the reservoir of 421.7m, it is believed a flow of about 17,000 m^3/sec can pass. At the level of 467.6 m in Roseires reservoir with all spillway and sluice gates fully opened a flow of about 6400 m^3/sec will pass. When the flow rate exceeds 6400 m^3/s, the level in the reservoir will rise. A maximum flood flow of 17,600 m^3/sec should pass safely without rising the level above 481 m. The Filling of the reservoir is carried out on the falling flood stage and the procedures are made difficult by the need to reduce siltation. The starting date of filling varies from year to year according to the rate of flow at Eldeim gauging station upstream Roseires reservoir. The starting date of filling extends from 1st September to 26th September and is completed within 45 days. Usually the filling of Roseires and Sennar reservoirs start on the same date. The filling operation can be affected according to the flow behaviour of Blue Nile River:

a- On first September if by that date the flow at Eldeim either have never risen above 350 million m3/day or have previously risen above that rate and has fallen bellow it.

b- On the date later than first September immediately following the day when the flow at Eldeim has fallen to 350 million m^3/day.

c- On September 26 at latest, even if the flow at Eldeim then is still greater than 350 million m^3/day.

3- After filling both reservoirs Roseires and Sennar they are both maintained at maximum W.L. Roseires reservoir attains 481 m, while Sennar attains 421.7 m. Both Roseires and Sennar continue keeping the maximum levels for periods depending on the amount of water from Eldeim gauging station and requirements of water downstream.

4- Emptying program (period of Emptying)

The period of emptying the reservoirs is the period during which the requirement of water for irrigation, power generation, transmission losses, reservoir evaporation, including the minimum flows to be passed to Khartoum, exceeds the natural flows in Blue Nile River at Eldeim gauging station. The date of emptying program varies considerably in different years. The period of emptying will end when the natural flow at Eldeim gauging station exceeds the requirements, as the rivers rises. The date at which the river rises also varies considerably in different years, and can not be forecasted much in advance of its actual occurrence. However it is usually taken as first 10 days period of June. The respective amounts of water to be drawn from either reservoir in any ten-day period may vary, the total requirements from storage are about 75% - 66.7%, should be drawn from Rosaries reservoir and 25% or 33.3% from Sennar reservoir. Allowances should be made for transmission losses (Regulation Rules, 1968).

2.8 Reservoirs in the Sudan

In the Sudan there are five reservoirs namely Khashm el-Girbar reservoir, Sennar reservoir, Roseires reservoir, Jabbel Awlia reservoir and Merowe reservoir. A reservoir is a man made water obstruction created in a river valley, which stores water during rainy season to be used or redistributed during summer time. During summer time the daily demand is greater than the daily inflow; therefore water has to be drawn from the reservoir to supplement the daily inflow to meet the daily demand. Releasing too much or too little may result in an economic loss, therefore water has to be released optionally to maximize the benefits from reservoirs on one hand and to meet the growing demands on the other. This growing demand is caused, in developing countries, by growing population, as well as continuous and rapid urbanization. In developing countries, the urbanization increases water demand in sectors like power generation and recreation. Although these sectors are not water consumptive, yet they may use water and may be in conflict with traditional largest water user in irrigation. To meet these growing demands, reservoir has to be operated optionally and water used efficiently by the rational water uses e.g. irrigation (Dafalla, 1999).

Reservoirs have mainly three zones. These are namely the full reservoir level which is the maximum storage level in reservoir. The dead storage level which is the minimum level of storage below which is silt accumulation. The live storage which is the active storage bounded between the reservoir full level and dead level.

2.8.1 Khashm el-Girba reservoir

The Khashm el-Girba reservoir is located on the Atbara River some 400 km south east of the river mouth at Atbara. The initial (1964) reservoir capacity was about 1.3 km^3 corresponding to water level 473.2 m R.L. Due to excessive sedimentation the reservoir capacity at the same level has dropped to slightly less than 0.6 km^3 by the year 1990. That is to say, the reservoir has lost 55% of its original capacity in 25 years see figure (2-2).

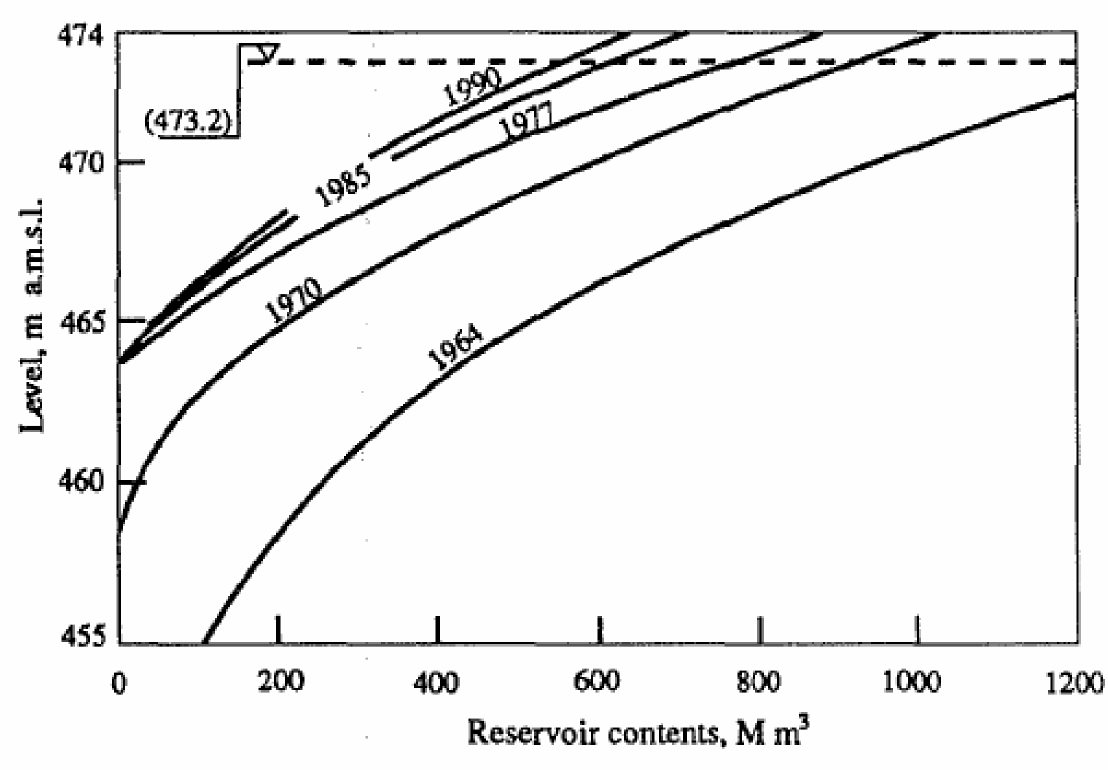


Figure (2-2) Decrease of live storage capacity of the Khashm el-Girba reservoir with time.

The first filling of the reservoir up to level 462 m R.L starts in the period 1-10 July each year. During this operation the lower sluices are kept open to let the silt laden water flow to the downstream. This goes on till the end of August or when the river discharge becomes about 1 270 m^3. The second part of the filling phase then begins and goes on till the beginning of October when the reservoir level reaches 473.2 m R.L. At present the possibilities of dredging the sediments out of the reservoir and/or implementing new operation rules are under investigation (LAHS, 1993).

2.8.2 The Sennar reservoir

The Sennar reservoir is under operation since 1925, shortly after the construction of the Sennar dam. It is located 350 km south east of Khartoum, on the Blue Nile.

The outflow from the reservoir exceeds the natural supply during the low-flow season of the river, from January to July. The difference represents the irrigation requirements of the Gezira land (area located between the White and the Blue Niles) during the same period. As such; the reservoir contents are gradually emptied as shown in figure (2-3). The first filling is accomplished in the second half of July so that on the first of August the level upstream the dam is raised to just 417.2 m R.L. to enable the canal to draw its full share from the river. Below this level the reservoir contents have nothing to do with live storage. The second filling starts around mid October when the Blue Nile water is sufficiently clear of suspended matter (concentration is about 200 ppm). The reservoir is considered completely full when its surface reaches the level of 421.7 m R.L., which coincides mostly with the beginning of December. The initial, 1925, live storage capacity of 0.93 km^3 has been reduced in the course of time to just 0.61 km^3 by the year 1986, i.e. to 65% of the original capacity after 62 years of operation. Extrapolation of these figures can show that 50% of the reservoir's initial capacity will be filled with sediments in no less than 100 years after the construction of the dam. This result reflects the efficiency of the operation rules of the reservoir (LAHS, 1993).

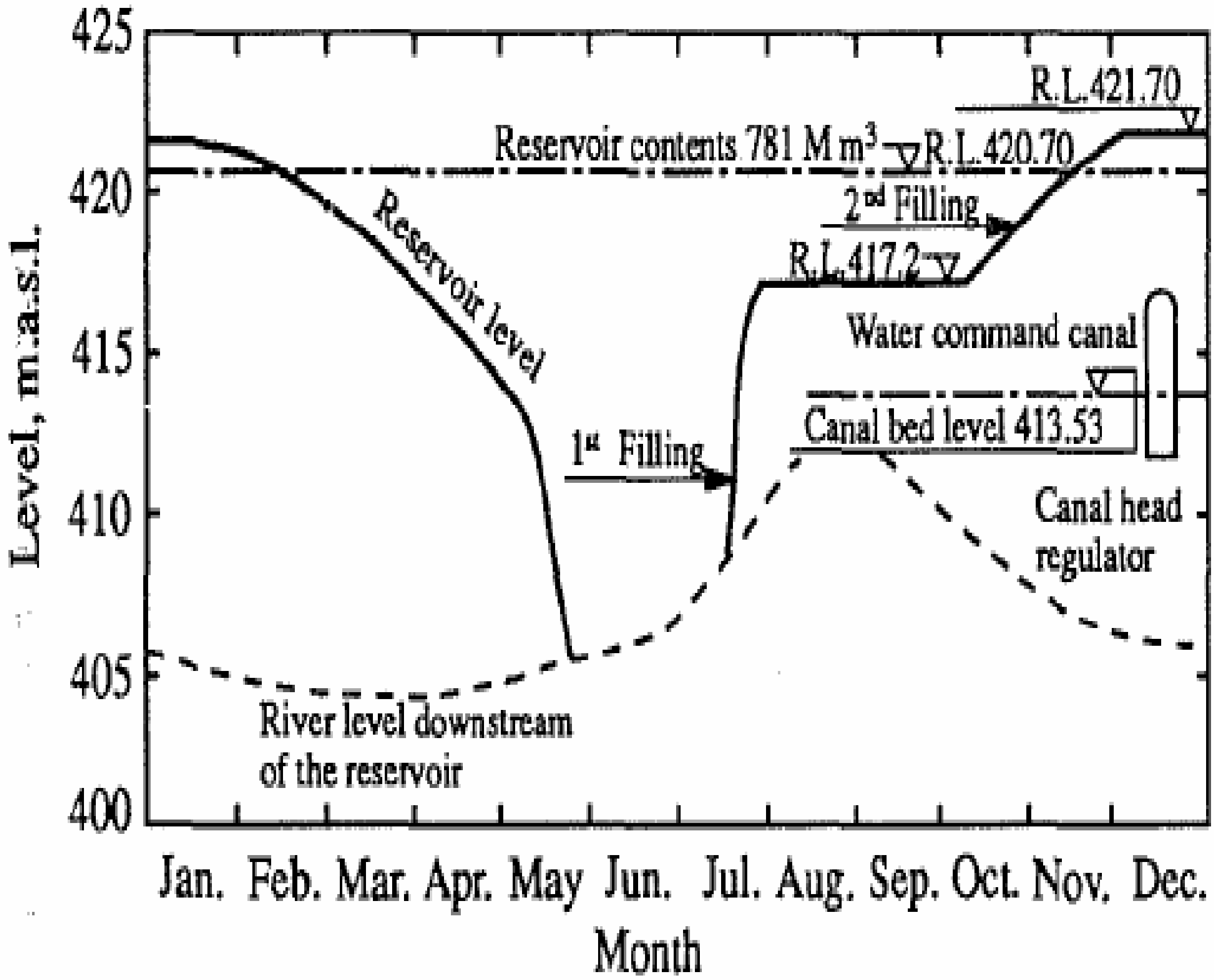


Figure (2-3) Operation rule curve of the Sennar reservoir (LAHS Publ, 1993)

2.8.3 The Roseires reservoir

The storage reservoir formed by the Roseires Dam was designed to retain water up to level 480 (481 as from 1984) m R.L in its first phase and up to 490 m R.L in its second phase. The corresponding storage capacities are 3.0 (later 3.024) and 6.8 km^3, respectively.

The Roseires reservoir is operated conjunctively with Sennar reservoir for irrigation and power generation. The filling of the former is delayed to the latest possible time during the falling flood. As such, the filling operation begins around mid September or some days later when the river flow is at or below 0.325 km^3. By the end of October the reservoir is full and remains so till the beginning of December, after which the reservoir storage is drawn down slowly till it reaches the minimum storage level by mid-June.

In spite of the deep sluices in the dam body to help flush the sediments deposited in the reservoir the problem is not entirely solved and the live storage at full reservoir level has been reduced by 20% in the period 1966-1981. The reduction of the storage contents at the different reservoir levels can be seen from figure (2-4).

In an attempt to increase the effective storage capacity, and increase the head for generating more hydroelectric power, the maximum storage level, as from 1984, has been raised by 1 m. Such a rise could be achieved by beginning the impoundment at an earlier date each year and by increasing the maximum discharge from 0.325 km^3 day to almost 0.5 km^3 days. This policy has led, unfortunately, to further sediment accumulation in the reservoir. The operation of this reservoir has recently been investigated with the aim of improving the silt flushing capacity of the deep sluices in the dam. In that investigation the operation of this Roseires reservoir, was performed as usual conjunctively with the Sennar reservoir.

Different policies have been suggested about hydropower generation and reservoir sedimentation, wherein the Roseires and the Sennar reservoirs are assumed to follow the same operation rules. In response to the system, basically the silt deposited and the energy generated, are determined. The operation curve in both dams has two parameters; date of beginning of filling and date of end of filling. Thirty-three operation scenarios were run a conceptual model in which the beginning of filling varied from 3 July to 3 September and the completion of filling from 1 September to 2 November. Each run simulated the conditions in the 20 year period, 1968-1987.

Consider the minimum sediment deposition scenario. Assuming that the sedimentation rate remains constant with time, the annual accumulation rate of sediments will drop from the presently 39.1 Mm^3 to 33.4 Mm^3.

This will lead to the filling of the reservoir in 85 years instead of 72 years, as with the historical operation rule. By full reservoir here is meant that the live storage at the maximum reservoir level drops down to 0.5 km^3 only (LAHS Pub, 1993).

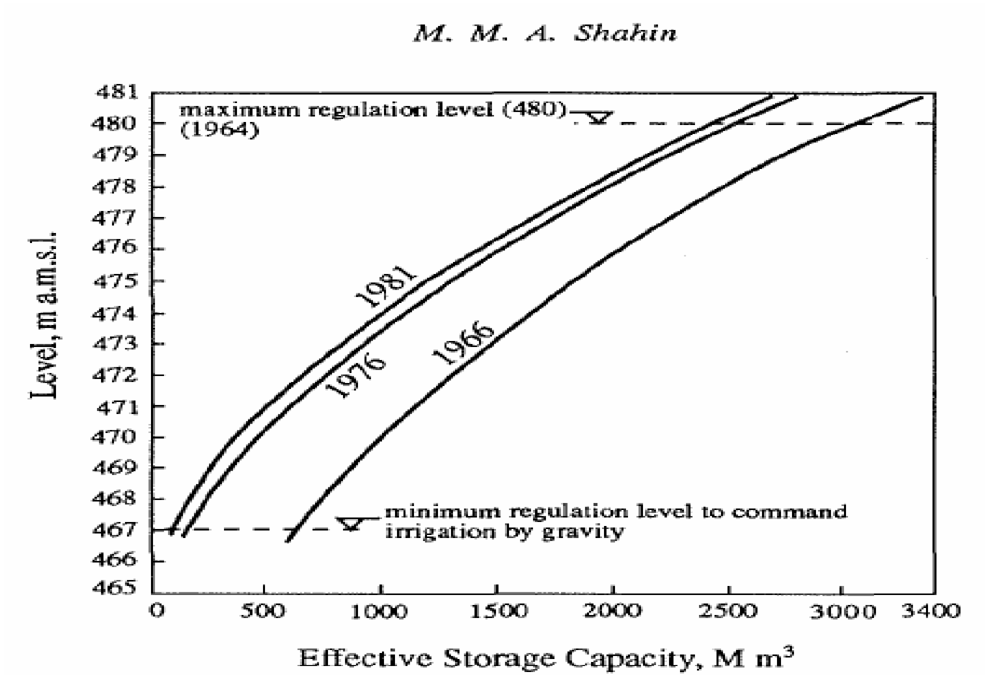


Figure (2-4) Decrease of live storage capacity of the Roseires reservoir from 1966 up to 1981 (LAHS Publ, 1993).

2.9 Sedimentation in Roseires reservoir

Regarding the history of its sedimentation a total of seven survey studies (Six bathymetric surveys, in 1976, 1981, 1985, 1992, 2005, 2007 and one satellite imagery in 1995) were carried out by the consulting engineers Sir Alexander Gibb and Coyne ET Belier.

The first intake blockage took place during the 1975 flood and again in 1983. In 1981, 83% of the storage below 467 m level was silted up, in 1995 this figure reached 94% and in 2007 reached 97.8%. The active storage lost was 5% in 1981 (15 years after operation) and 14% in 1995 (after 29 years of operation).

In general the annual rate of siltation was 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, 1996).

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. Figure (2-5) 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 (Siyam, 2005).

The 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 (Siyam, 2005).

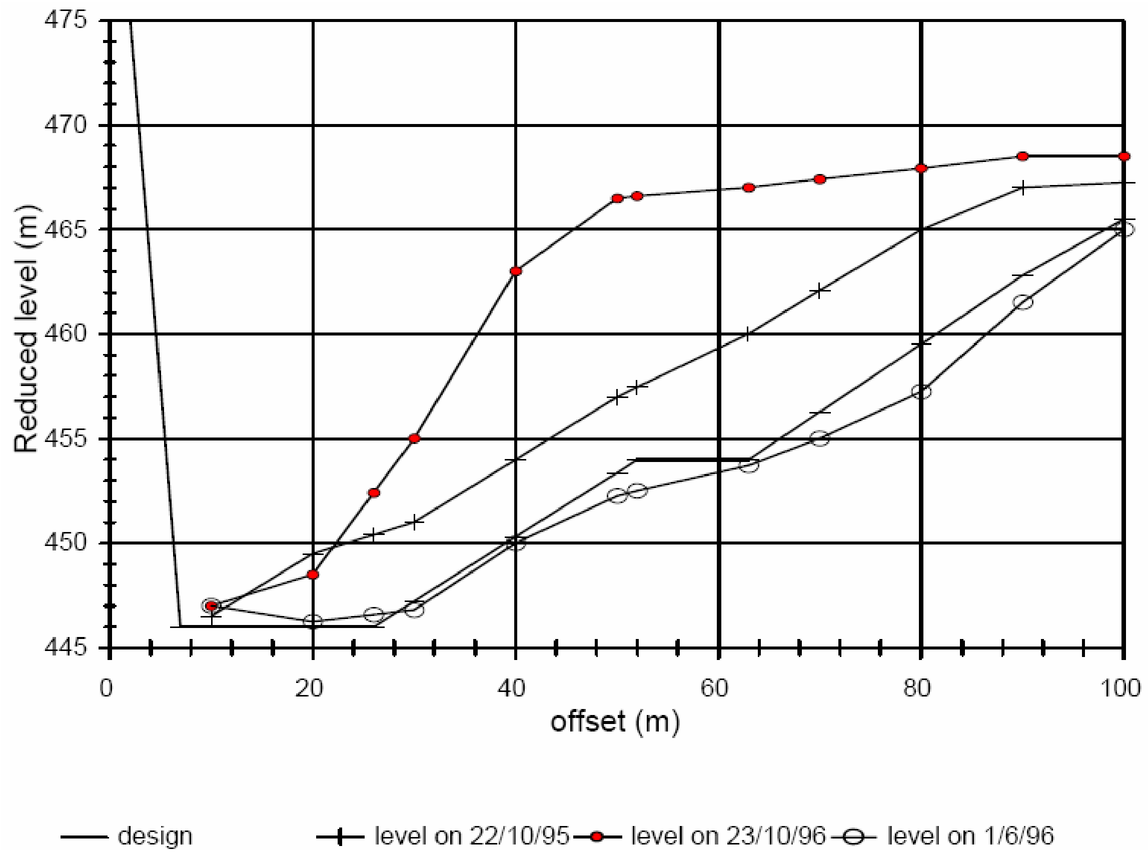


Figure (2-5) a typical annual of dredging and sedimentation a hand of Roseires hydropower intakes (intake 1**),** (Siyam, 2005).

Chapter Three
The Study Area

3.0 Introduction

No doubt that Roseires dam is most important dam in the Sudan and its successful completion in Dec. 1966 proved a significant event in the history of the Sudan. It has had a profound effect on the Gazira Scheme, N. W. Sennar (sugar), Elsuki, Elrahad, Abu Nuama, etc ….. It produces more than 90% of hydropower which is about 75% of the total power energy in Sudan.

This important dam faces many problems. The most important problems are the sedimentation and debris which cause operation problems to the Ministry of Irrigation (MOI) engineers and the National Electricity Corporation.

3.1 Geographical Location of Roseires Reservoir

The Roseires reservoir is situated along the Blue Nile reach between the dam site and the Ethiopian border. The dam is located in the vicinity of the formerly Damazin Rapids, approximately 6 km upstream the Roseires and some 500 km south of Khartoum. The lake of the Roseires reservoir is located between longitudinal lines (11°--14°) North and lantitude lines (33°--35°) East with drainage area of 290 km^2. Its length is 75 km, with a volume a of $3x10^9$ m^3 at top water level 480 m, volume $7.4x10^9$ m^3 at top water level 490 m after dam heightening.

The soil properties of the study area are clay layers covered with hilly forest at Eldeim, surround by poor savanna in Roseires and Damazin.

The rain water is collected and transported by several tributaries to the reservoir (Gibb, 1996). They are located both on the right and the left side of the watershed as shown in figure (3-1).

Figure (3-1) Water Shed of Roseires and the River Network (Google, 2008).

3.2 Reservoir and Roseires Dam property

The dam was originally designed and constructed for effective exploitation of the Blue Nile run-off for irrigation, hydropower and, fisheries. The design was prepared by Sir Alexander Gibb, Partners and Coyne ET Bellier, appointed by the Government of Sudan. The main contract for the constructional works was awarded in 1961 to the Italian consortium of Impresit-Lodigiani. The work started in 1961 and completed in 1966.

The dam (shown figure 3-2) is a concrete buttress types about 1.000 meters long, flanked on either side by earth embankments, 8.5 kilometers long to the west and 4.0 kilometers long to the east . The standard buttresses which make up nearly half of the total of 68 buttresses are spaced at 14.0 meter centers. The upstream water face has slope 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 slope at 6 in 10. The buttresses are built in trenches excavated to soil rock below the level of the weathered rock. Buttress web foundations for the future 2nd stage of the dam have been constructed above minimum tail water level. 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 the 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. (Gibb, 1966).

A deflector bucket bellow the spillway throws the jets of water into a stilling basin clear off 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 in buttress webs. This station provides power for the gates and for township at Damazin. Further west, the buttress spacing increases from 14 m to 18 m to take seven intakes for the main power station.

The main Hydrological features of the dam are:-

- Total average annual flow of the Blue Nile at Roseires is $50x10^9$ m^3/sec.
- Average peak flood discharge is 6,300 m^3/sec.
- Maximum discharge capacity at level 467.0 m is 6,400 m^3/sec.
- Maximum discharge capacity at level 480.0 m is 16,500 m^3/sec.
- Maximum recorded flood (60 years) is 10,800 m^3/sec.
- Average low River flow is 100 m^3/sec.

The Irrigation Potentials are:

Kenana canal headwork's	Maximum discharge	360 m^3/sec.
Dinder canal headwork's	Maximum discharge	360 m^3/sec.

The Hydro-electric potentials are:

Service Power House	2 turbines of 1 MW	Total 2 MW.
Main Power Station	7 turbines of 30 MW	Total 210 MW.

Figure (3-2) Roseires Dam passing flood water in July 1966.

3.3 Metrology of Roseires Water Shed

Average rain fall at Eldeim gauging station is 1500 mm. In this area the rain fall usually extends from April to November. In the study area of Damazin and Roseires it extends from May to October. According to the data of the period from 1999 to 2001, the average rainfall at the area near Roseires dam for the three stations (Damazin, Roro and Gouli) in the year 1999 is 785.83, 2000 is 684.73 and 2001 is 735.27 mm as shown in table (3.1) and figure (3-3).

Table (3.1) rainfall for different stations (Ministry of agriculture in Blue State)

Years	1999			2000			2001		
Months	Damazin	Roro	Gouli	Damazin	Roro	Gouli	Damazin	Roro	Gouli
May	75.7	6	28	58.8	31	67	97.9	91	99
Jun	165	59	34	91.2	74	43	121.6	101	30
Jul	230.7	116	144	232.2	167	169	195.9	126	211
Aug	129.8	282	348	182	127	159	232.2	190	201
Sep	213.1	127	158	46	71	96	89.3	86	82
Oct	62.2	89	90	32	82	66	37.9	37	77
Total	876.5	679	802	942.2	512	600	874.8	631	700

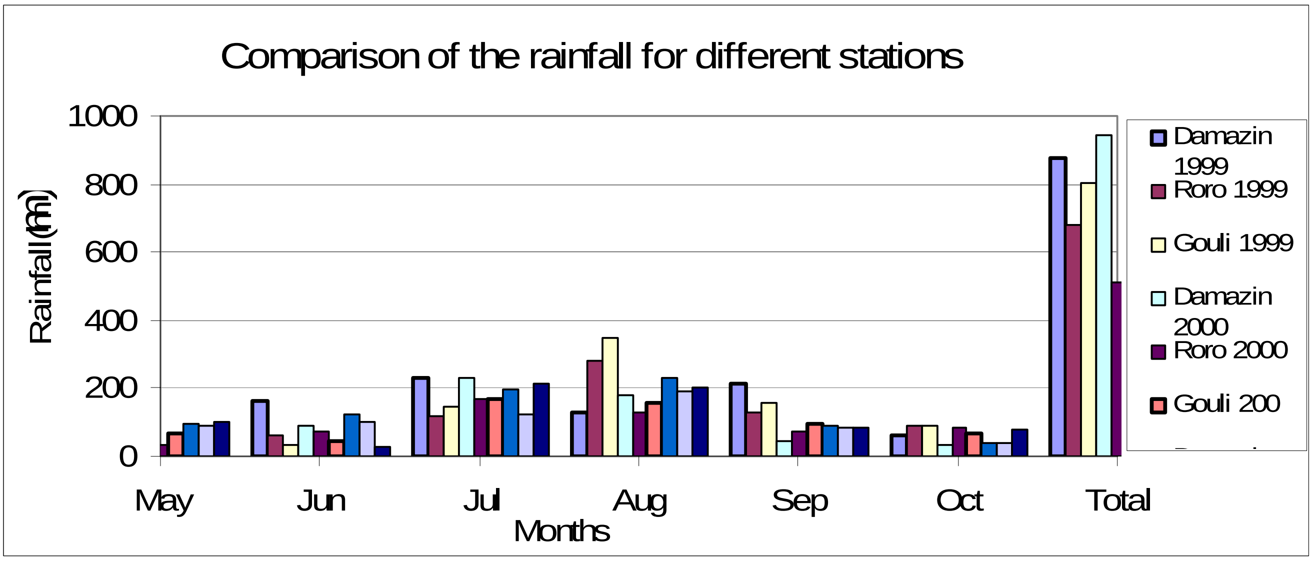


Figure (3-3) Rainfall for different stations

3.4 Sedimentation Studies for Roseires Reservoir

The Blue Nile has been known from earliest recorded times to bring down considerable amounts of silt in its flood time, renewing the fertility of intermittently flooded areas along its banks each year. The silt material originates mainly from heavy erosion in the upper catchment area in Ethiopia, where the slope of the river is steep. As a result of this high silt load, the reservoir operation is unavoidably accompanied with reservoir sedimentation. In order to up-date the level content relationship in Roseires reservoir lake cross-section surveys were carried out in different years. In this thesis bathymetric operations carried out on the Roseires in the years 1976, 1981, 1985, 1992, 2005 and 2007 are compared.

The reservoir is operated in accordance with the regulation Rules (1968). These rules are designed primarily to meet irrigation demands and provide a stipulated flow at Khartoum with production of hydro-electricity regarded as secondary to these requirements.

The system of operation divides the year into three main periods:-

(i) The flood before filling when the reservoir is held at a low level to reduce siltation as far as the discharge facilities allow,

(ii) The filling period, when the reservoir is filled according to detailed program.

(iii) The period of shortage when the storage within the reservoir is used to supplement the natural river flows to meet the requirements of irrigation and minimum flow to Khartoum.

The flood season starts from early June and the filling starts in September. The aim of the operation is to maintain the level of the reservoir at 467.0 m to maintain the required out put from the power station.

However, if the floods are above normal, the level in the reservoir will rise to the level required to pass the discharge. For the maximum recorded flood, Roseires reservoir was designed to attain 473.7 m R.L.

Filling is carried out on the falling flood and the rules are complicated by the need to delay filling as long as possible to reduce siltation, yet to ensure filling every year. The starting date for filling varies from year to year according to the flow at Ed Deim upstream of Roseires reservoir and then follows a day by day program.

The starting date for filling lie between 1st September and 26 September and filling is completed within 45 days.

The filling period begins on:-

(i) 1st September at the earliest

(ii) The day after the day when the flow at Ed Deim falls to 350 Mm / day, if between 1st and 26th September.

(iii) 26th September at the latest if the flow has not fallen sufficiently.

Filling then continues for 45 days. Details of the amount to be taken into storage are specified each day of the filling period.

After the reservoir is full there generally follows a period when the natural river flow is sufficient to meet the irrigation demands, a minimum flow at Khartoum, and all river and reservoir losses. During this period the reservoir is held at the retention level.

For control purposes the period of shortage is when there is insufficient natural river flow to supply the irrigation demands. This period is divided into 10 day periods and balancing operation is carried out for each period so that the requirements for irrigation, minimum level flow at Khartoum, evaporation from the reservoir and losses, should equal the natural river flow plus releases from storage. A schedule of releases is prepared to watch demands with expected flows at Khartoum to ensure that the storage is not exhausted before 10^{th} June. If demands cannot be met, priority is given to irrigation and flows at Khartoum are reduced to 3.5 million m^3 per day.

3.5 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, the detention-storage time, 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 could 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 (Siyam, 2005).

Trap efficiency estimates are empirically based upon measured sediment deposits in large number of reservoirs mainly in U.S.A. Brune (1953) and Churchill (1948) methods are the best known ones. Brune (1953) has presented a set of envelope curves for use with normal ponded reservoirs using the capacity –inflow relationship of reservoirs. These curves are reproduced in Figure (3.4). They are not recommended for use in computing T.E of desilting basins, flood retarding structures or semi-dry reservoirs. Churchill (1948) developed a trap efficiency curve of settling basins, small reservoirs, flood retarding structures, semi-dry reservoirs or reservoirs that are frequently sluiced. The essence of Churchill's method is contained in a graph relating the percentage of sediment that passes through a reservoir to a so-called sedimentation index SI.

The latter is defined as

$$SI = T/\bar{v} \text{--} (3.1)$$

$$T.E = 1 - SI \text{--} (3.2)$$

Where T = retention time and $\bar{v}$ = mean velocity of water flowing through the reservoir see figure (3.5). (A.Taher ,1999).

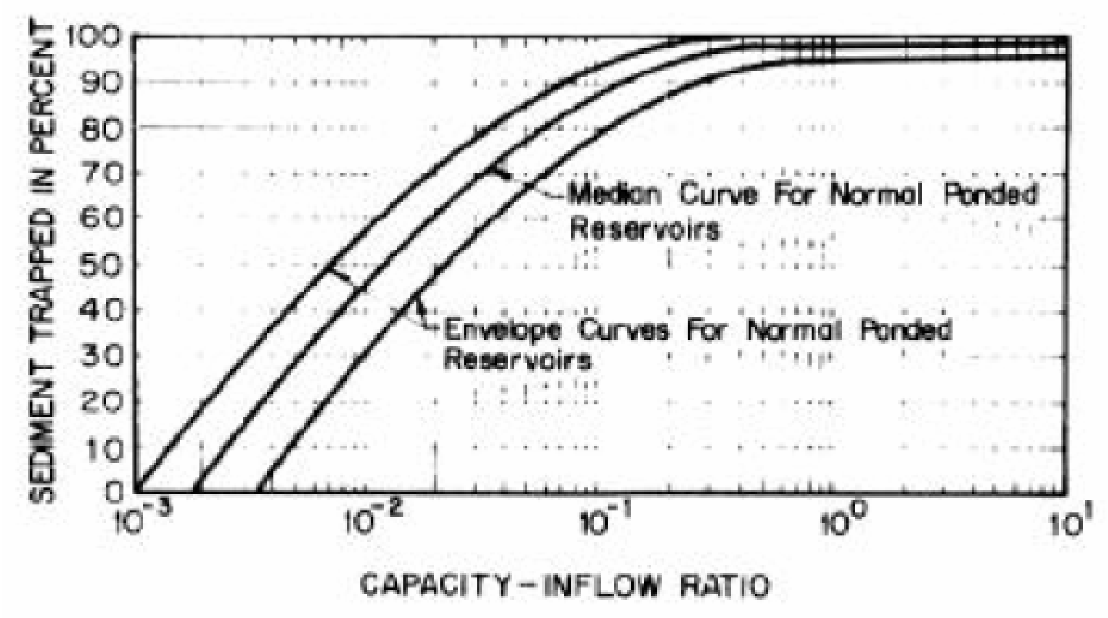


Figure (3-4) Trap efficiency curves due to Brune.

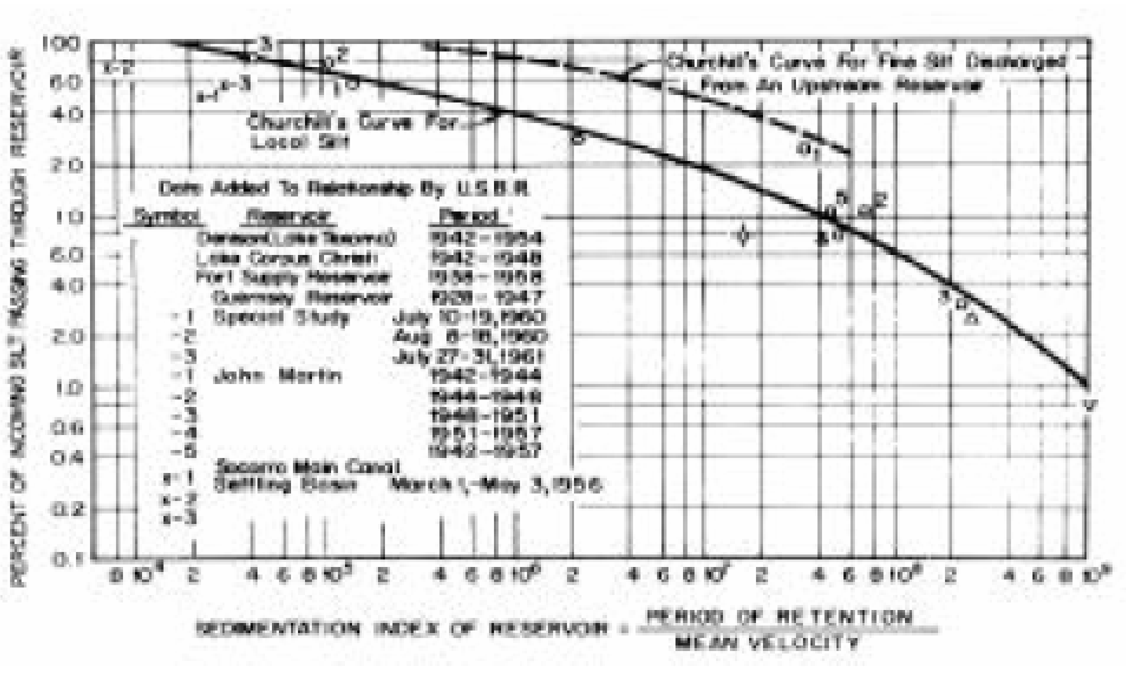


Figure (3-5) Trap efficiency curve for reservoirs, Churchill (1948).

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, and flood retarding structures, semidry reservoirs or reservoirs that are continuously sluiced (Churchill ,1948).

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, it is important to closely examine the reservoirs in order to make judgment on their impact on trap efficiency. There are four main operation periods for Roseires dam reservoir. During the rising flood, the reservoir drawdown attains the level of 467 R.L which is the lowest operating level. Over this operation period, minimum sediment deposition is expected despite the large quantities of sediment inflow which may approach 3 M ton/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 (Siyam, 2005).

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 on the flow at El Deim gauging station. 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 continues 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 and inflow quantities.

From the above description, only operation filling period is of importance as far as reservoir sedimentation and trap efficiency are concerned in Roseires reservoir. Therefore this is taken in consideration when estimating the trap efficiency using either Brune or Churchill method. Over the filling period, the water level at 474 m R.L is considered for the computation. The reservoir content at this mean level is used together with an annual inflow of $50x10^9$ m^3 to estimate the trap efficiency using both methods. The results are compared with measured values for the years when reservoir surveys were made. The measured trap efficiency is computed from the following equation.

$$T.E(\%) = ((v_0 - v)\gamma / (T x 140 \; x 10^6)) -------------(3.3)$$

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

v_0 = original reservoir volume, m^3

v = volume remaining after T year of operation

γ = average specific weight of deposited sediment over T years (t/m^3)

γ is calculated from the following equation (Miller, 1953)

$$\gamma = \gamma_i + 0.434\kappa[(T/(T-1))x(LnT)-1] -------------------------(3.4)$$

Where γ_i the initial value of and γ_i is given by

$$\gamma_i = \gamma_{cl} P_{cl} + \gamma_{sl} P_{sl} + \gamma_{sa} P_{sa} \text{ -------------------------------- } (3.5)$$

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), (USPR, 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/m^3)

Clay	Silt	Sand
561	1140	1550

The compaction Coefficient K is found similarly from the table (3.3).

Table (3.3) K Value for Reservoir Operation 2 (USPR, 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 γ_i = 1.118 t/m^3 and K = 0.0468 t/m^3.

Comprehensive field measurement core sampling programmer of deposited sediment in a number of major and minor canals in 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.

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 amore general trap efficiency function given by the following equation:

$$T.E(\%) = 100 \exp(-\beta v / I) ----------------------------------(3.6)$$

Where, in addition to the already defined terms, v is volume remaining after T year of operation, β is a sedimentation parameter that reflects the reduction in the reservoir storage capacity due to the sedimentation processes.

Siyam (2000) demonstrated that Eq.(3.6) 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 Figure (3-4). 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 (ß = 1). Shown also in the figure Roseires Reservoir data fitted by Eq (3.6) with β = 0.056 which was the mean of the individual ß values resulting from fitting the observed trap efficiency data with Eq. (3.6).

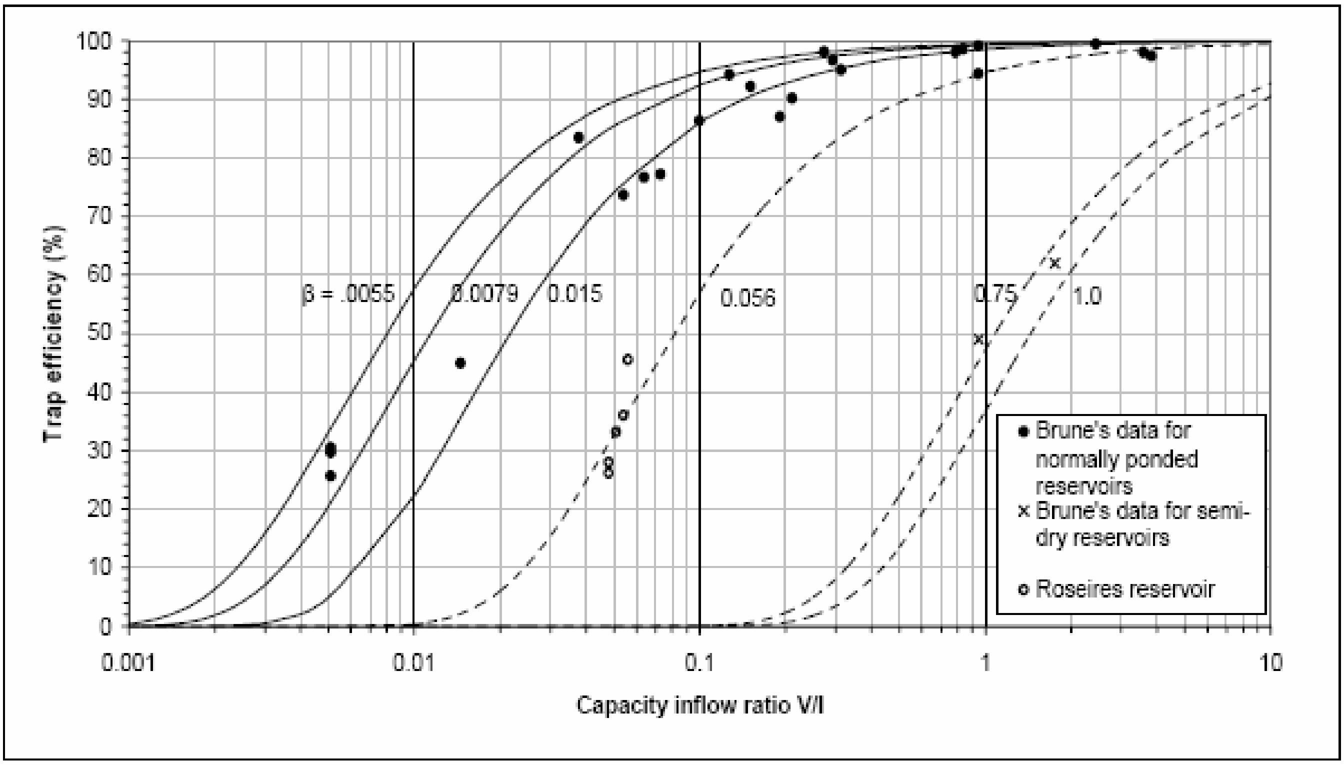


Figure (3-6) Comparison of Roseires Reservoir Trap Efficiency Data with that of Brune’s (Siyam, 2005).

Figure (3-6) shows the success of the method to limit reservoir sedimentation via reduction of the reservoir level during flood. It is observed from Figure (3-6) 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 rule, the reservoir is ponded at full retention level for about only 2 months in the years. 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 figure (3-7). The trend of the data points shows that

$$T.E \approx T^{-0.5} \quad \text{--------------------------------} (3.7)$$

This figure may be used to estimate subsequent trap efficiency of Roseiers reservoir.

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

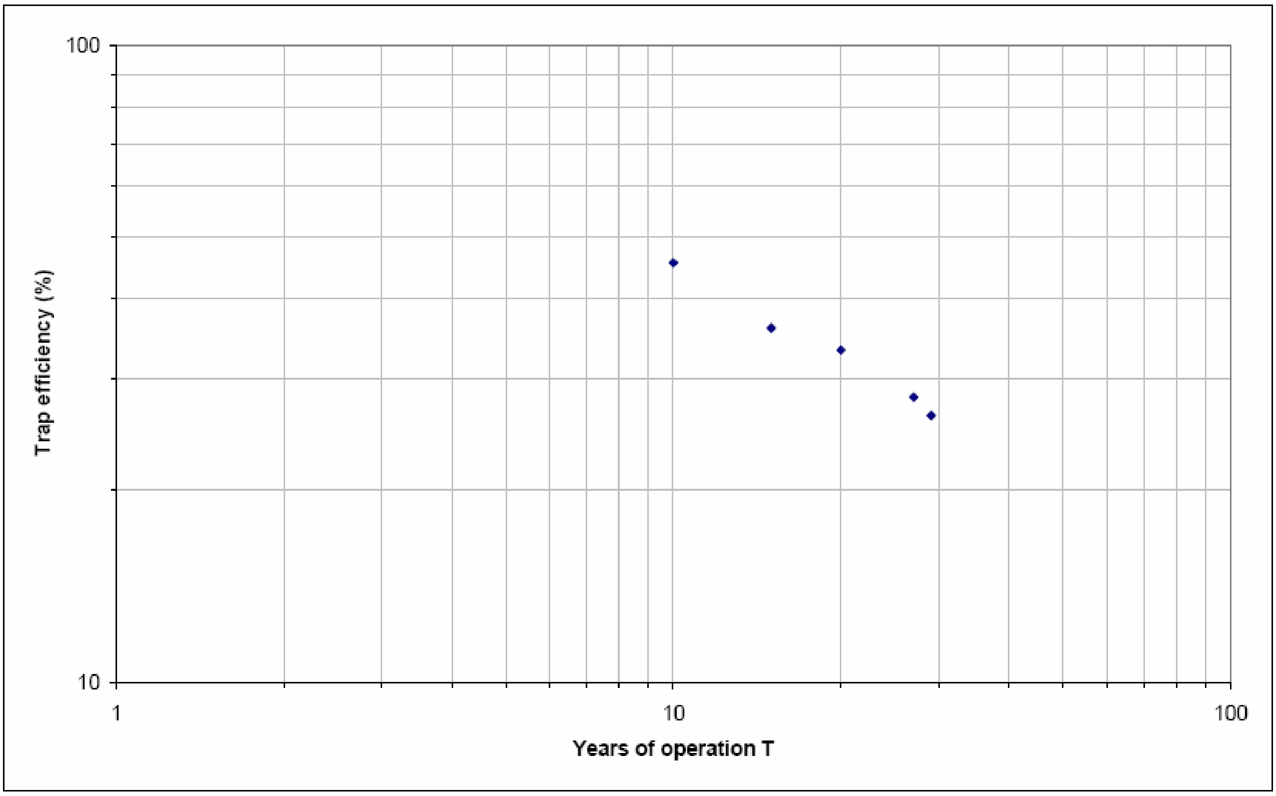


Figure (3-7) Relationship between observed trap efficiency and years of operation for Roseires Reservoir (Siyam, 2005).

Chapter Four

Methodology

4.0 Introduction

The previous chapters reviewed the literature and described the bathymetric survey done in the study area including reference to previous work. This chapter will describe and delineates the methods and materials used in this study. Overview of data collection and processing are shown in the next sections.

4.1 Data Collection

The previous bathymetric surveys carried at Roseires dam reservoir which include those carried in years 1976, 1981, 1985, 1992, 2005 and 2007 and annual rainfall from some locations near the Roseires reservoir were used. Some illustrative photos were also used. This data was collected from Roseires Dam, Hydraulic Research Station in Wad Medani, Ministry of irrigation and Water Resources and Ministry of agriculture in Blue Nile State.

4.2 Data processing

This section is concerned with data processing. Processing of the collected data was done by preparing it in spreadsheet formant. The spreadsheets format was analyzed for consistency. All the processed and analyzed proceeds were fed into excel spreadsheet to compute the area and volume for different reduced levels. The average silt deposit per year for the different reduced levels was calculated by dividing the sediment accumulated by the corresponding number of years of operation.

4.3 Method of calculation

4.3.1 Sediment accumulation

Sediment accumulation in the reservoir is calculated using the bathymetric survey data collected\from the Dams Directorate of the Ministry of Irrigation and Water Resources. The base line was taken as the design storage capacity of the reservoir at the different levels in 1966. The storage capacity in the different bathymetric surveys compared to that of 1966 at different level enables estimation of sediment accumulation rates. Thus, the comparison between accumulated silt volumes deposited between the different surveys is\ obtained. This work is done using spreadsheet analysis in excel.

The accumulative volume of deposited sediment v_d can also be calculated empirically from the following formula derived from Equation (3.3)

$$v_d = (\text{T.E}/100)x(140x10^6 xt)/\gamma ------------------------------(4.1)$$

Where, v_d = accumulative volume of deposited sediment, m^3

T.E = trap efficiency after T years of operation

T = years of operation

γ = average specific weight of deposited sediment over T years (t/m^3)

γ is calculated from the equation 3.2 (Miller, 1953).

4.3.2 Siltation rate

The average silt deposit per year for the different reduced levels is calculated by dividing the sediment accumulated by the corresponding number of years of operation.

The percentage of silt is obtained by the following calculation:

%age silt deposited per year = $v / A / d / N$ ------------ (4.2)

Where:

v : Volume of silt in the given range in m^3

A : Average surface area of the reservoir at the middle of given levels in m^2

d : difference between given levels in m.

N: number of years of operation.

Chapter Five

Analysis, Results and Discussions

5.0 Introduction

This chapter is dedicated for applying the methodology discussed in chapter 4, analyzing and discussing the results obtained. From the reservoir bathymetric surveys the different sediment accumulation rates at the different levels were obtained. The results were them critically examined. The outcome of the critical examination is expressed in the next sections covering bathymetric surveys, storage comparison and accumulation rate.

5.1 bathymetric surveys

The main purpose of a reservoir survey is to determine the storage capacity at the time of the survey, which, when compared to an earlier survey (usually the original survey), gives the sediment storage capacity. Bathymetric surveys were conducted in Roseires reservoir. Bathymetric survey is defined as underwater sounding below a specified datum range line. The main objective of that line is to compute change in storage volume between any two successive surveys giving comparison of changes at each range line.

5.2 Storage comparison

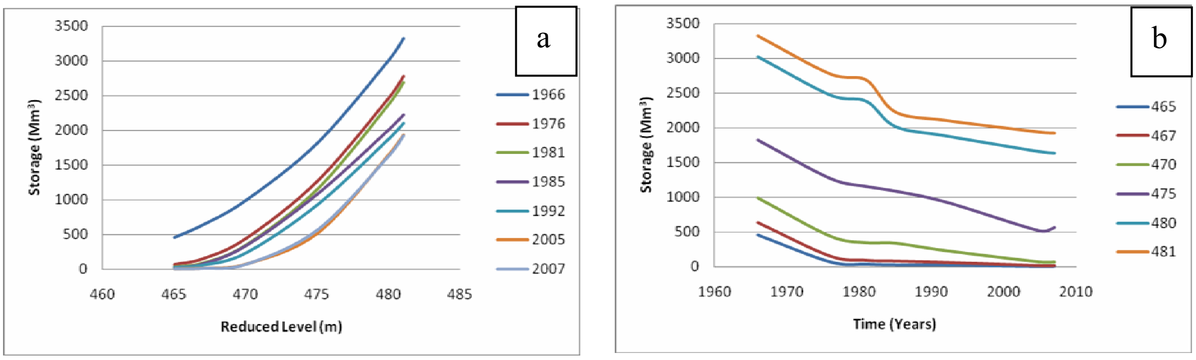
The following tables show the variations of the reservoir storage capacity and silt contents with elevations calculated from the bathymetric surveys of the years, 1976, 1981, 1985, 1992, 2005 and 2007. These surveys were carried out by the consultant engineers Sir Alexander Gibb and Coyne ET Bellier.

Table (5.1) Storage capacity

R.L	1966 (Mm^3)	1976 (Mm^3)	1981 (Mm^3)	1985 (Mm^3)	1992 (Mm^3)	2005 (Mm^3)	2007 (Mm^3)
465	454	68	36	26	23	4.5	6.21
467	638	152	91	80	60	13.71	13.98
470	992	444	350	342	235	72.46	72.38
475	1821	1271	1156	1088	932	517.46	566.85
480	3024	2474	2384	2020	1886	1658.38	1637.56
481	3329	2778	2689	2227	2104	1934.73	1920.89

The first columns in table (5.1) are the reduced levels for which the design storage capacities were calculated. The second column contains the design storage capacity of the reservoir at the different levels. The other columns contain the storage capacity in different bathymetric surveys.

In Table (5.1) above it is shown that there is decrease in the storage capacities with time at all reduce levels. Figures 5.1a and b show the variation of storage with reduce level in the specific survey years and the variation of the same with time at specific reduce level. It can be seen that after fourty one years of operation (1966-2007), the total capacity of the reservoir have been reduced to 1920.89 million cubic meters and 13.84 million cubic meters have been lost in the last two years (2005 – 2007). Figures 5-1 a and b depict variation of storage capacity with time and reservoir level.



Figures (5-1 a, b): Variation of storage with time and reservoir level

As the initial capacity below reduced level 467 was established to be 638 million cubic meters the loss of capacity below this level was 97.8% of the initial storage. The expected total capacity at design stage of the reservoir at level 490 m was 7.4 milliard m^3. However, due to the loss of capacity found now at level 481 m which amounted to 1.92 milliard m^3, the expected capacity after the heightening project implementation will be 5.48 Mm^3.

Table (5.2) Accumulated Silt volume deposit for different surveys

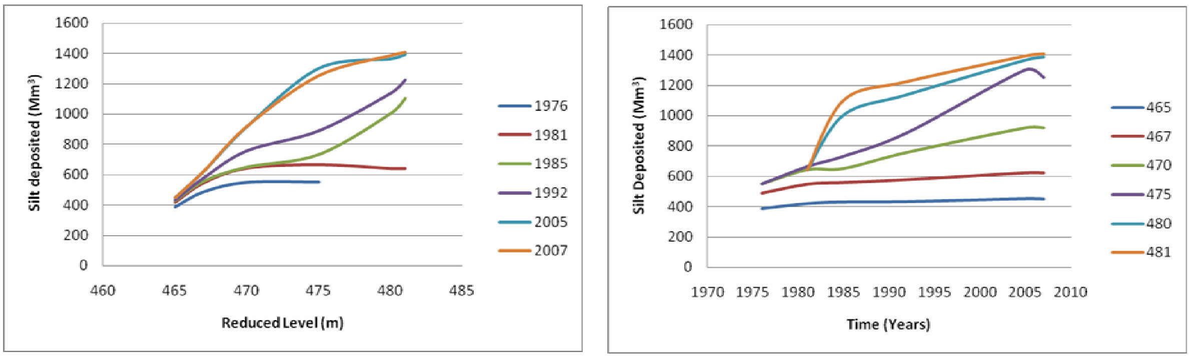
R.L	1976 (Mm^3)	1981 (Mm^3)	1985 (Mm^3)	1992 (Mm^3)	2005 (Mm^3)	2007 (Mm^3)
465	386	418	428	431	449.5	447.79
467	486	547	558	578	624.29	624.02
470	548	642	650	757	919.54	919.62
475	550	665	733	889	1303.5	1254.2
480		640	1004	1138	1365.6	1386.4
481		640	1102	1225	1394.3	1408.1

Table (5.2) Shows the accumulated silt deposited at the different reduced levels in the period from 1976 in the different years of survey. It can be seen that there is an increase in the silt deposit with time at all reduced levels. It also, shows that after fourty one years of operation (1966-2007), the accumulated silt volume deposit of the reservoir has amounted to

1408.1 million cubic meters. About 14 million cubic meters have been added in the last two years (2005 – 2007) i.e. about 1.1%.

Figures 5-2 a and b depict the variation of silt deposited with time and reduced level.

(a) (b)



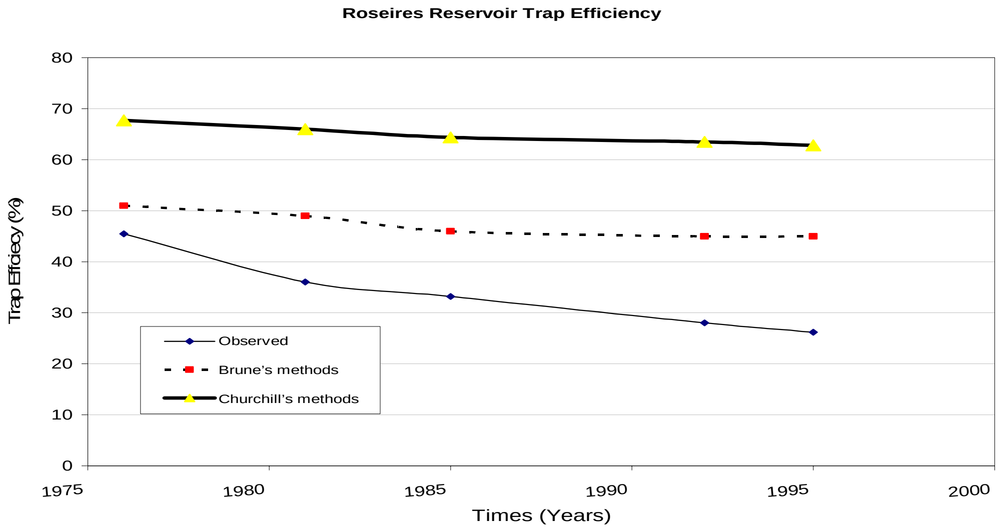
Figures (5-2 a, b): Variation of silt deposited with time and reservoir level

From Roseires reservoir resurveys are summarized above, the observed and computed trap efficiency values with Brune's and Churchill's methods are given in table (5.3). Figures 5-3 a and b show graphically the variation of the trap efficiency with time.

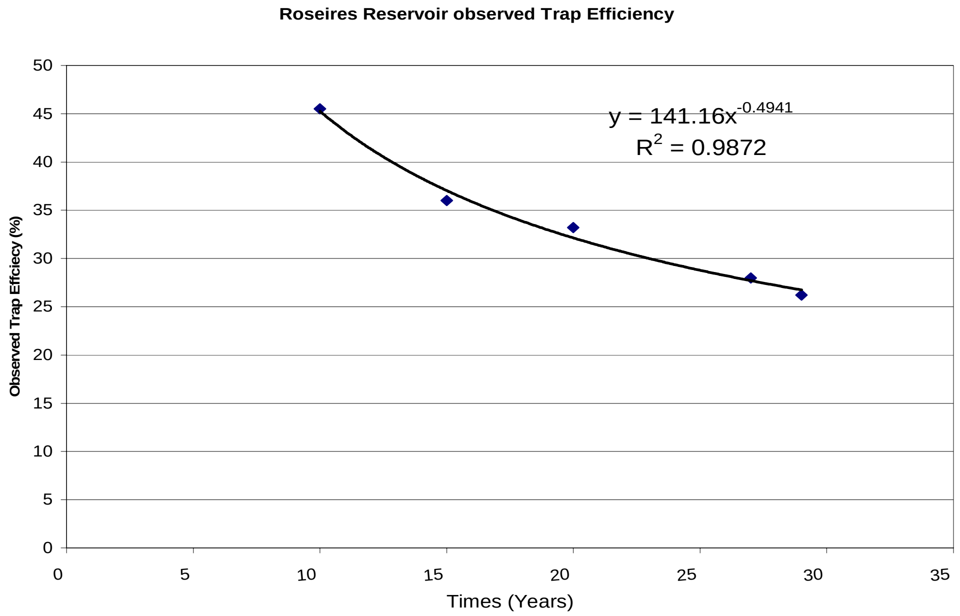
Table (5.3) Roseires Reservoir Trap efficiency %

Years of re-survey	1976	1981	1985	1992	1995
T (Years)	10	15	20	27	29
Observed	45.5	36	33.2	28	26.2
Brune's methods	51	49	46	45	45
Churchill's methods	67.7	66	64.4	63.5	62.8

(a)



(b)



Figures (5.3 a, b): Variation of trap efficiency of the reservoir with years of operation

From Figures (5.3 a, b) it can be seen that the observed trap effeceincy is invesely propotional to the square root of operation time. This figure may be used to estimate subsequent trap efficiency of Roseiers 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.

It is generally believed that the volume of deposited Sediment from the 1992 resurvey as given in Tables (5.1, 5. 2) 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.

From Table (5.3) both Brune's and Churchill's methods overestimated the trap efficiency values. The failure of these methods may be attributed to their structures as they consider only few factors. In the earlier years of the reservoir life, the rate of sediment deposited was high as reflected in the relatively high observed trap efficiency values. The deposition rate, 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.

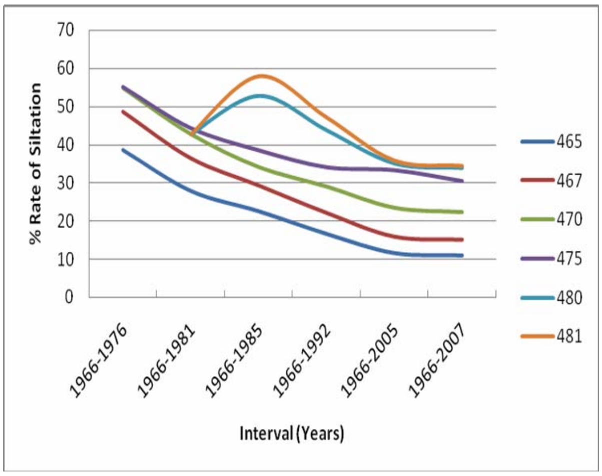
5.3 Accumulation rate

Table (5.4) contains the average silt deposited per year for the different reduced levels. As depicted in figures (5-4a, b) it can be seen that there is a decrease in siltation rate with time at all reduced levels. This phenomenon can be explained by the fact that as time passes a decrease in the reservoir storage capacity occurs; flow velocities for the same discharges are increased; the sediment carrying capacity of the flow being the limiting factor of sediment transport is in turn increased. The siltation rate has dropped from 16.01 million cubic meters per year to 15.22 million cubic meters per year at 467 reduce level and from 35.75 million cubic meters per year to 34.34 million cubic meters per year at 481 reduce levels.

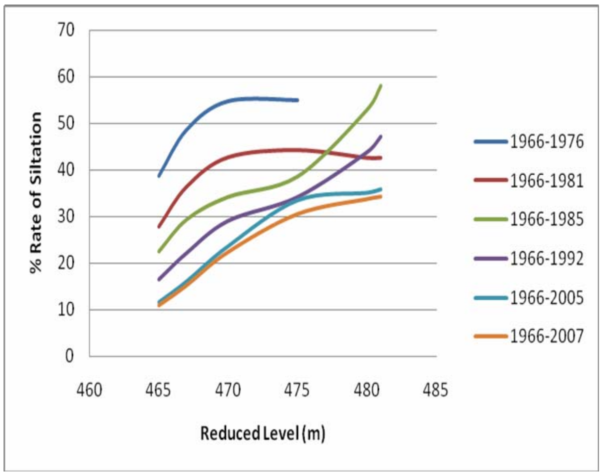
Table (5.4) Siltation Rate for different surveys (Mm^3/Year)

R.L (m)	1966-1976 (Mm^3/Year)	1966-1981 (Mm^3/Year)	1966-1985 (Mm^3/Year)	1966-1992 (Mm^3/Year)	1966-2005 (Mm^3/Year)	1966-2007 (Mm^3/Year)
Years	10	15	19	26	39	41
465	38.60	27.87	22.53	16.58	11.53	10.92
467	48.60	36.47	29.37	22.23	16.01	15.22
470	54.80	42.80	34.21	29.12	23.58	22.43
475	55.00	44.33	38.58	34.19	33.42	30.59
480	-	42.67	52.84	43.77	35.02	33.82
481	-	42.67	58.00	47.12	35.75	34.34

(a)



(b)



Figures (5-4a, b): Variation of % siltation rate with time and reservoir level.

The volume of silt deposited in the area impounded by the given reduced levels, the average surface area of the reservoir at a given reduced level and the corresponding estimate of % silt for years 2005 and 2007 are shown in table (5.5).

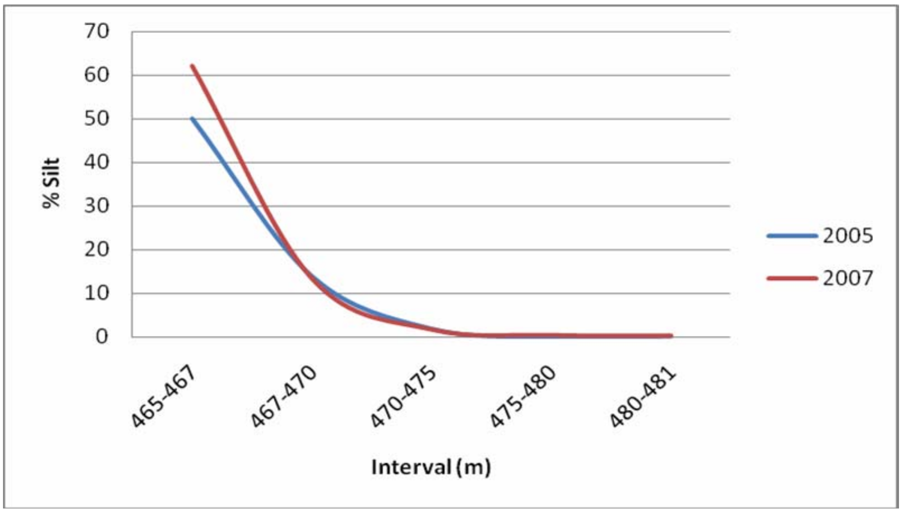
Table (5.5) Silt deposited per year as a percentage of storage capacity (2005, 2007)

Years		2005			2007	
Level (m)	Silt Vol. (Mm^3)	A($x10^6 m^2$)	%age of Silt	Silt Vol. (Mm^3)	A($x10^6 m^2$)Area	%age of Silt
465-467	175	4.5	50	176	3.46	62
467-470	295	17.6	14	296	18.11	13.3
470-475	384	84.1	2	335	102.9	1.6
475-480	62	236.1	0.1	132	216.14	0.3
480-481	29	273.4	0.3	22	281.62	0.2

The second and fifth columns in table (5.5) show volume of silt deposited in the area impounded by the given reduced levels in the first column. The third and the sixth columns represent the average surface area of the reservoir at the given reduced levels.

As expected, siltation rate is generally heavy below the minimum draw-down R.L maintained during the flood period which is 467. Siltation is small above this minimum draw-down level. There is no increase in the percentage Silt deposited in the ranges 475- 480. Figure (5.5) show the variation of the siltation rate for a given area in the reservoir in 2005 and 2007.

Siltation Rate for different surveys (%)



.

Figure (5.5): Variation of the siltation rate with area in 2005 and 2007.

Chapter Six

Conclusions and Recommendations

6.0 Conclusion

The reviewed case study leads to some principal conclusions. These are:

(i) About 30% of the reservoir storage capacity is silted up. The rate of siltation at all levels is continually decreasing with time which is an indicator of decrease in storage capacity.

(ii) Siltation rate below reduced level 467 dropped from 16 million m^3/year in the period 1966-2005, to 15.22 million m^3/year in the period 2005-2007. While below 481 R.L the siltation rate was dropped from 35.75 million m^3/year in the period 1966-2005 to 34.34 million m^3/year in the period 2005-2007. The present reservoir capacity at reduce level 481 is 1920.89 million m^3 of which 6.21 million m^3 is a dead storage below R.L 467.

(iii) The sediment deposition in the Dam Reservoir reduces its capacity and hence, negatively affects all the projects which depend on reservoir.

(iv) Loss in capacity and active sedimentation processes are the most common problem facing the Roseires reservoir.

(v) 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 square root of time. It is projected that its trap efficiency after 100 tears will be in the order of 14%.

6.1 Recommendations

The study recommendations are the followings:

1. It is recommended that a well-planned program for sediment data collection be established especially on the characteristics and movement of sediment in the reservoir, and Blue Nile near the Ethiopian border to monitor the effect of changes and interventions on the upstream site.

2. Regular bathymetric surveys, monitoring of sediment accumulation and reservoir trap efficiency is recommended to assess the effects of the interventions.

3. On implementation of dam heightening the use of Kenana and ELRahad canals may be used in combating of sediment accumulation in the reservoir.

4. More researches on sediment bathymetric methods and use modern techniques to increase the life time of the reservoir.

REFERENCES:-

Siyam. (2005). "Assessment of the current state of the Nile Basin reservoir sedimentation problems". Nile Basin Capacity Building Network (NBCBN), River morphology, Research Cluster, Group1 (Dr. Siyam, Dr.Muna, Eng. Saghyroon, Eng. Semunesh, Dr. Sherif).

K.K. Agarwal &K.C. Idiculla. (2000) "Reservoir sedimentation surveys using Global Positioning System". Central Water Commission, Ministry of Water Resources, R.K.Puram, New Delhi-110066.

Sloff, C.J (1997) "Sedimentation in reservoirs". Ph.D. thesis, Report no. 97-1,Communication on Hydraulic and Geotechnical Engineering, Delft University of Technology, faculty of civil engineering.

Nzar, A. R. (2006) "Exploratory Study of Reservoir Sedimentation by 2D and 3D Mathematical Modeling". MSc Thesis WSE-HERBD 06.11.

Anthony Makana. (2000) "Sediment logy of the Nile", Paris 1.096, Prof. Eltahir, 3.8.04.

LAHS Publ. (1993) "An overview of reservoir sedimentation in some African River basins".

Morris, .L. and Fan, J. (1997) "Reservoir sedimentation Handbook: Design and Management of Dams, Reservoir and Watersheds for Sustainable Use". McGraw-Hill, New York.

Sloff, C.J., Jagers, H.R.A. Kitamura, Y. (2004) "Study on the channel development in a wide reservoir". proc. 2nd Intern. Conf. on Fluvial hydraulics, River Flow 2004, Napoli, Italy.

Batuca, D. and Jordaan, J. (2000) "Silting and desilting of reservoir, Rotterdam, the Netherlands: A. A. Balkema.

Paul J. Block. (2007) "Integrated Management of the Blue Nile Basin in Ethiopia: Hydropower and Irrigation Modeling, University of Colorado, IFPRI Discussion Paper 00700, May 2007.

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

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

Churchill, M.A.(1948). "Discussion of Analysis and Use of Reservoir Sedimentation data," by L.C. Gottschalk, Denver, Colorado.

A.Taher Shamsi and M.R.M. Tabatabai. (1999) "Assessment of Reservoir Trap Efficiency Methods".

Gibb and Coyne ET Bellier, 1996:
Roseires Dam. By Ministry of Irrigation, Hydro- Electric power Republic of the Sudan and Gibb and Coyne ET Bellier, 1996.

Regulation Rules 1968:
For the working of the Reservoirs at Roseires and Sennar on the Blue Nile. By (Ministry of Irrigation and Hydro- Electric power).

Report 1981:
Report on the Removal and Disposal of Sediment and debris at Roseires Dam. Power plant Intake on the Blue Nile in Sudan. October 1981. By Sir Alexander Gibb and partners, Ministry of Irrigation (MOI) and Coyne ET Bellier.

Report 1985:
By Demas and Ministry of Irrigation (MOI), On Behalf of the Democtic Republic of the Sudan, Ministry of Irrigation and Hydropower, in October 1985.

Reports 1992, 2005, 2007:
Bathymetric survey of the Roseires Reservoir in years, 1992, 2005 and 2007 were carried out by the consulting engineers Sir Alexander Gibb and Coyne ET Bellier.

Appendix A

Roseires reservoir

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 meters.

Purpose:

Irrigation, hydropower

The Reservoir:

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

Hydrology:

Blue Nile catchments area	245,230 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 Mm^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, 2006 and 2007.

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.

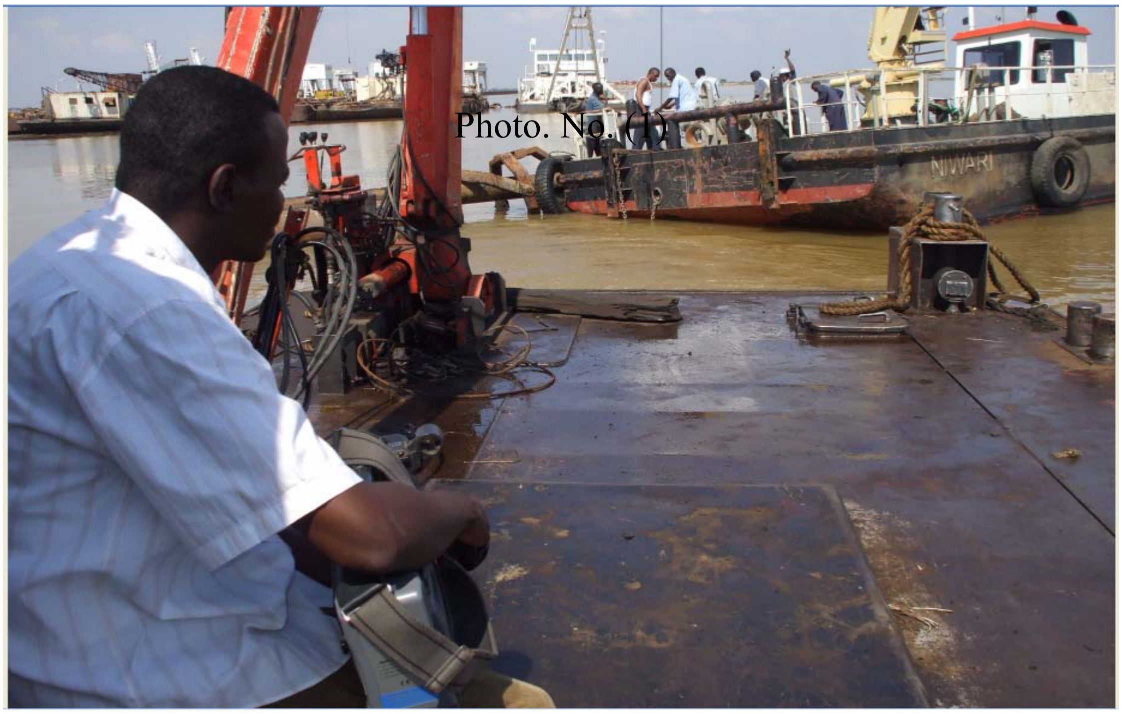
Impounding of the reservoir usually starts towards the end of September after a peak flood has passed and lasts for abut a month until top retention level is reached at R.L 480 m. During the impoundment, the spillway gates are closed and the deep sluices control the flow past the dam until impoundment 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 meter to R.L. 481 m, while later the minimum drawdown level was increased to R.L. 467 m.

Appendix B

Show Equipments for Debris Clearing and sediment Excavation



Photograph. No (1)

Photograph. No (2)
Shows woods comes with flow

Photo. No. (3) Debris deposits out front of power station

Photographs show Islands appeared after the dam construction

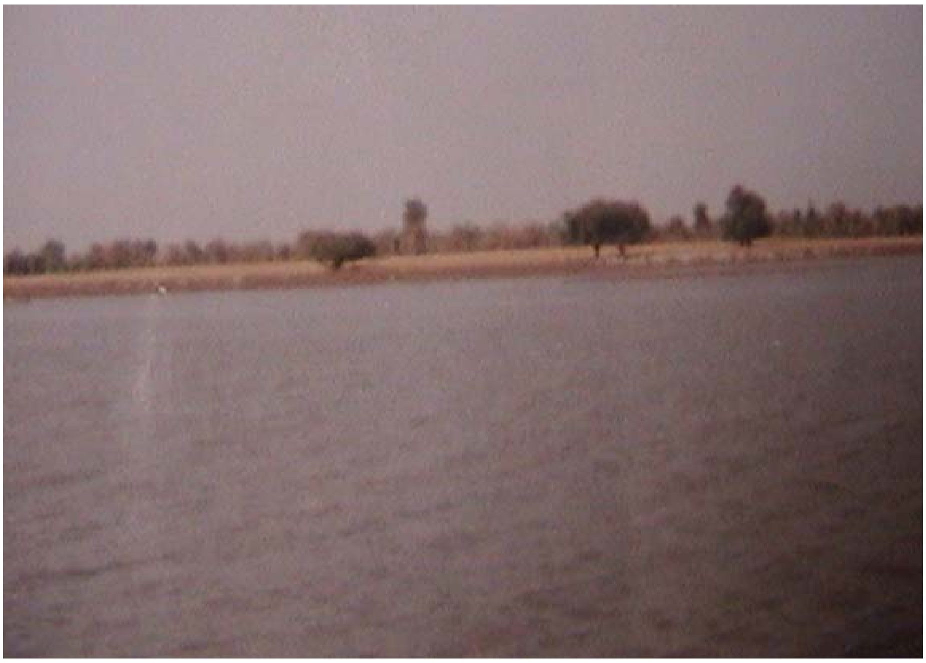


Photo. No. (4) Large Island 13 km long (start from 8 km of Dam)

Photo. No. (5) Large Island 26 km long (south to Kirma village)