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BLUE NILE RIVER FROM THE ETHIOPIAN BORDER TO KHARTOUM

Final Report

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I. INTRODUCTION

Although the River Nile is one of the largest in the world it is not the best known river. Only few parts of the Nile system within the Sudan have been studied equally well while most of the studies carried out are rather incomplete. Unfortunately no detailed programme of chemical and biological studies on Sudanese rivers had been carried out before that could give sufficient knowledge of the ecology of our river which will help in pollution control. Determination of the biological effects and indicators of different types of pollution under Sudanese conditions are largely neglected.

During the past sixty years the Nile, particularly the Blue Nile, has undergone hydrological reconstruction causing a change in its regime. Sennar Dam was constructed in 1925, and Roseires Dam was built in 1966 across the Blue Nile. Gebel Aulia Dam was completed in 1937 across the White Nile. These dams no doubt have their influence upon the ecology and productivity of these rivers since they create reservoirs in which current velocity is much reduced and lake conditions are initiated. Moreover, the Nile is used over a large part of its length by towns, industry and agriculture. Therefore it seems beyond question that the best prospect of increasing the country's wealth lies in the further exploitation of the Nile waters (Map 1). Environmental scientists are increasingly alarmed by the fact that the Nile may suffer from contamination as a result of population growth and expansion in industry. The present writers agree with Hammerton (1976) that even a mild degree of eutrophication from industrial and agricultural development could have a serious effect

on the Nile because of the high temperature and high radiation inputs. Hence the control of population has to be a rigid practice. It is obvious that a detailed programme to determine indicators of environmental changes in the Nile need to be initiated.

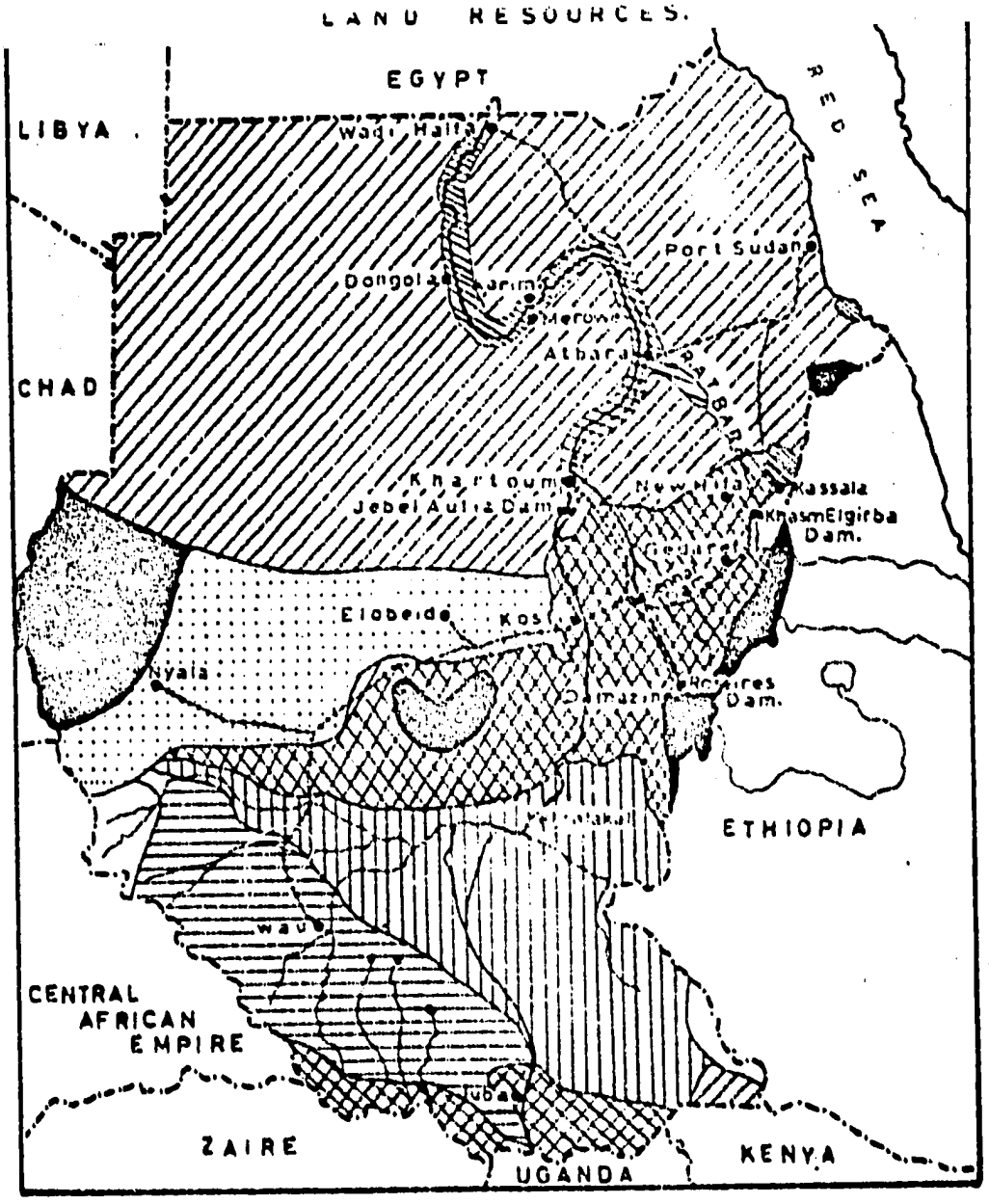
The present report describes the scope, nature and results of the research carried out on the Nile system within the Sudan since the turn of this century. Information reviewed in this report includes previously unpublished data, material contained in accepted theses and data extracted from published papers. These materials will serve as the baseline upon which the impact of any future effect can be assessed and also will provide some information on environmental changes which have occurred in recent times.

Since the River Nile system covers very large distances, the Blue Nile River was chosen to carry the studies of indicators of environmental changes. Along the Blue Nile the area most subject to changes (Khartoum-Sennar) was selected as the study area. Increase in population, impoundment of water dams, and location of factories along the Blue Nile together formed the criteria for selecting the study area.

The Nile Study Group is one of seven groups monitoring indicators of environmental changes in the Sudan. This monitoring is part of ETMA Programme (Environmental Training and Management in Africa) which is a collaborative project that works with African institutions to support environmental training and resource management. Once this study had been completed, further research on the Blue Nile area was removed out of the ETMA Programme and was

confined under a new independent project on the Blue Nile Watershed Management initiated by the Institute of Environmental Studies (IES), University of Khartoum.

LAND RESOURCES.



Arid & Semi arid Pediplain & Hill Soils.

'Qoz' Sands.

Central Clay Plain

Flood Plain Clays

Alluvium

II. SPATIAL AND TEMPORAL TRANSECTS

For the purpose of the present evaluation the Blue Nile is divided into six zones (Map 2) along its length within the Sudanese border, thus:

Zone I:
A zone of natural river flow not affected by the back water of Roseires dam. This zone extends from Sudanese border with Ethiopia to Roseires reservoir.

Zone II:
The Roseires reservoir with a back water affect extending 100 km upstream.

Zone III:
A zone of free river flow not affected by the back water of Sennar dam. It extends from Roseires dam to Sennar reservoir.

Zone IV:
The Sennar reservoir with a back water effect extending 140 km upstream.

Zone V:
A zone of free river flow extending from Sennar dam to a few kilometres south of Khartoum.

Zone VI:
Khartoum area

Hydrobiological investigations of the Nile began with casual observations some 80 years ago. For the purpose of this report this period of time can be divided into three "eras". Since dams have profound influence upon productivity and ecology of rivers the

three areas were marked by the construction of dams across the Blue Nile. Thus:

First era:

The period ending in 1925 before the completion of Sennar dam.

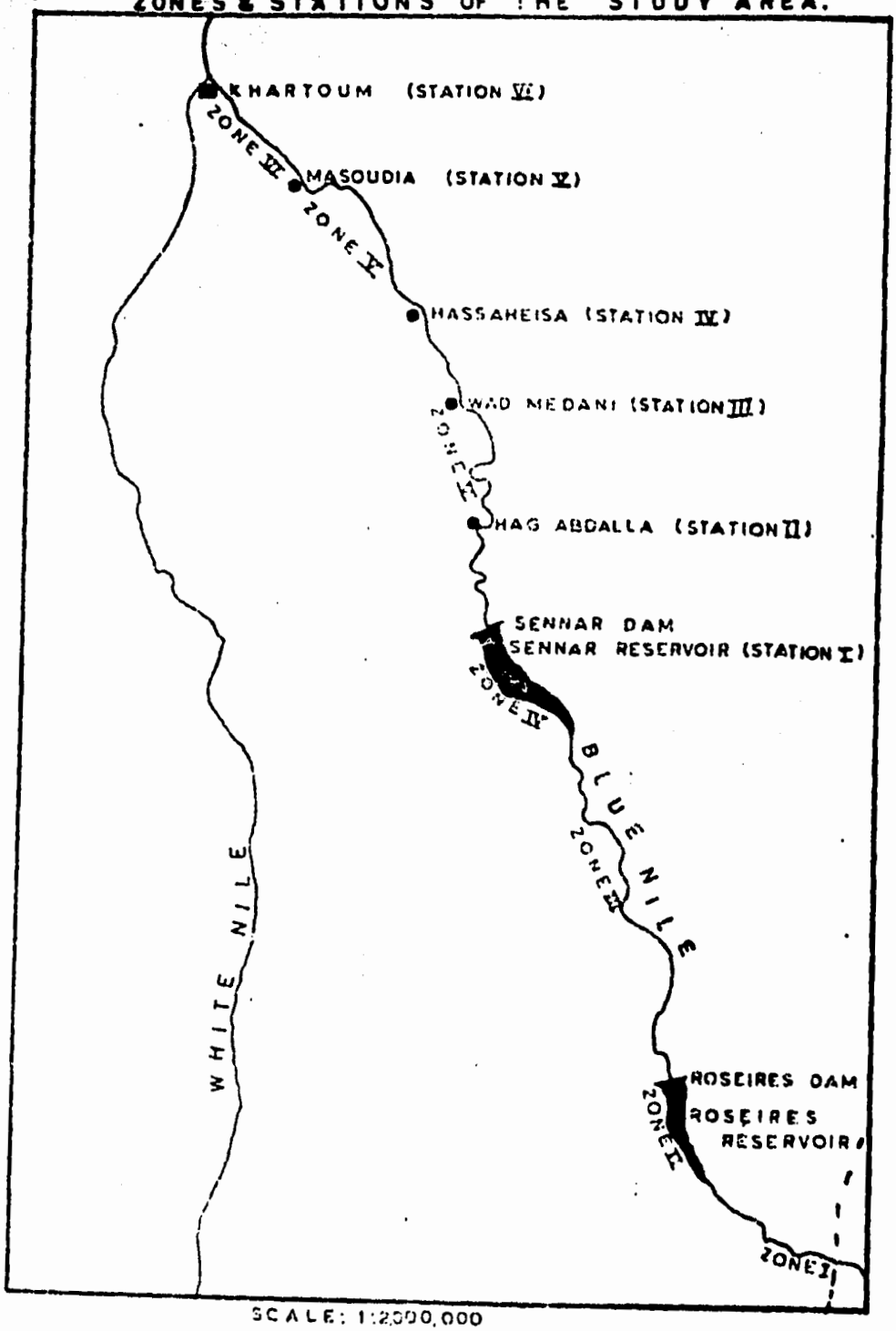
Second era:

The period beginning with the formation of Sennar reservoir in 1925 and ending in 1966 b before the completion of Roseires dam.

Third era:

The period beginning with the formation of Roseires reservoir in 1966 to present date.

ZONES & STATIONS OF THE STUDY AREA.



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III. THE STUDY AREA

Physical background of the Blue Nile system

The nile is the second longest river in the world flowing from its distant source at Lake Victoria (latitude 0° 30'N) on the C tral African Lake Plateau for about 5695 km to its mouth at the Mediterranean Sea (latitude 31°N.) The second source of the system is Lake Tana on the Abyssinian Plateau and which lies 4600 km away from its mouth. The Nile system consists of two main rivers: the White Nile which emerges from the former lake and the Blue Nile which comes out from the latter one. The two rivers meet at their confluence "Mogran" at Khartoum. From Khartoum the two Niles constitute jointly the Main Nile. The topography of the Nile have been extensively studied by Hurst (1950,1952), Hurst and Phillips (1932-1945) and Hurst et al. (1954). It is sufficient to recapitulate here.

The Blue Nile:

The Blue Nile flows out of Lake Tana (altitude 1800 m; area 3100 sqm) at latitude 12° 30'N over a series of rapids and quickly descends into a deep gorge until it enters the Sudan plain south of Roseires at latitude 12°N. Between Lake Tana and the Sudan plain the Blue Nile receives many tributaries of torrential nature, which supply most of the river. The annual discharge from Lake Tana is only 7% of the corresponding water reaching Khartoum. The flood occurring annually at Khartoum (late June-October) is mainly due to the torrential rains on the Abyssinian Plateau which drain into the course of the Blue Nile by these tributaries. The river is not navigable anywhere, except for short stretches, until well within the Sudanese boarder. In the lower part of its course

in the Sudan, the Blue Nile receives two tributaries: the Dinder and the Rahad Rivers, both flowing down the Abyssinian Plateau. The contribution of these two tributaries is little, their combined annual discharge barely exceeding 8% of that of the main river. The contribution of these tributaries is only noticeable during the rainy season on the Abyssinian Plateau. No other tributary drains into the river until it joins the White Nile (Map 3).

The Blue Nile has the characteristic of mountain streams. For instance its course is generally deeper and its banks are steeper than those of the White Nile. At the peak of its flood (August/September) the Blue Nile at Khartoum may rise to more than 5 m above its lowest level of May. Huge amounts of silt are carried annually by the Blue Nile, exclusively during the flood period (late June-October) transporting a total of 100-130 X 10^6 tons of silt annually.

The natural flow of the Blue Nile has been altered by artifical hydrological regimes within the Sudan. Two dams have been built across the Blue Nile: Sennar dam and Roseires dam.

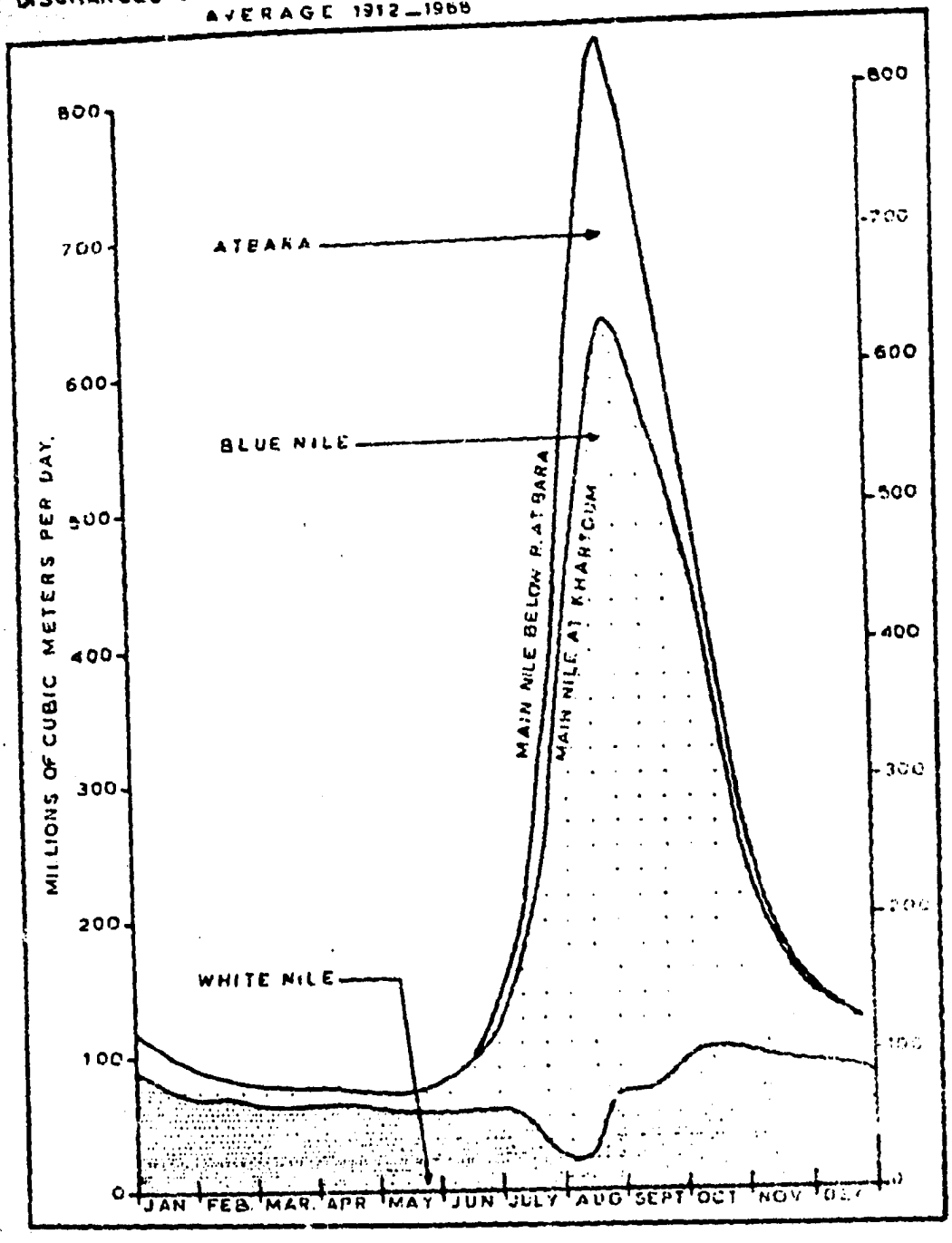
Sennar dam:

Sennar dam (360 km upstream Khartoum) was built in 1925. The dam holds 1 X 10^9 of water producing a backwater effect for 140 km. The reservoir has an area of 160 km^2, maximum depth 17 m and mean retention time of 32 days. Sennar dam was built to store water for irrigation from February to April.

Roseires dam:

This dam (650 km upstream Khartoum) was completed in October 1966. The dam holds 3 X 10^9 m^3 of water, producing a backwater effect for 100 km. The reservoir has an area of 290 km^2 and maximum depth of 45 m.

DISCHARGES OF THE NILE & ITS MAIN TRIBUTARIES.
AVERAGE 1912—1966



Since the Blue Nile is abundantly rich in silt during the flood, a special system is used when its water is stored. The filling of the reservoirs behind the two dams is carried out in two stages in order to avoid adverse silt desposition. An initial filling is carried out during the flood period (July-September) when most of the water passes through the dams. When the flood subsides the final filling of both reservoirs is completed. Usually by end of November the reservoirs reach their full capacities. The water in Sennar reservoir is gradually released for irrigation purposes until April-May when little remains and conditions of free river flow return. Roseires dam is utilized in regulating the level in Sennar reservoir.

Rainfall:

On the Abyssinian Plateau the rain is heavy although it varies with latitude and altitude. In general the average annual rainfall over the plateau is 1200 mm. There is a well marked rainy season on the Abyssinian Plateau from June-September with the maximum rainfall occurring at about the end of July. On the other hand the amount of rainfall at Khartoum district is much smaller with an annual average of about 148 mm, most of the rain falling with the period July-September.

IV. INDICATORS OF ENVIRONMENTAL CHANGE

Indicators of environmental change chosen in this work are grouped in 3 categories:

A. Physical indicators
B. Chemical indicators
C. Biological indicators

A. Physical indicators:

1. Current velocity/Discharge
2. Temperature
3. Transparency/Turbidity
4. Suspended matter

B. Chemical indicators:

5. Conductivity
6. p^H
7. Dissolved oxygen
8. Biological oxygen demand (B.O.D.)
9. Chemical oxygen demand (C.O.D.)
10. Plant nutrients
    a) Phosphate - Phosphorus, b) Nitrate - Nitrogen
    c) Ammonium - Nitrogen
11. Heavy Metals
    a) Copper, b) Iron, c) Lead, d) Zinc, e) Nickel
12. Major ions
    a) Calcium, b) Magnesium, c) Potassium, d) Sodium
13. Organic pollutants
    a) Herbicides, b) Fungicides, c) Insecticides

C. Biological indicators:

14. Macrophytes
15. Bacteria
16. Phytoplankton
17. Zooplankton

A. Characteristics of Physical Indicators

1. Current velocity/Discharge

$$D = V \times A$$

D = River discharge at a certain point.
V = Current velocity
A = Cross sectional area of certain point

The current or discharge in any river system plays a major role in determining the aquatic river habitat, which in turn determines the type of biota which live on it (Fig. 1).

2. Temperature

Temperatures of running waters are more variable than are those of standing bodies of water, but their absolute range is smaller. Seasonal variation as well as diurnal variations in temperatures of rivers and streams are two characteristics of all rivers. This variation is due to the many micro factors which operate to determine the value of temperature.

Direct and indirect activities of man interfere to change the temperatures of natural waters. Most obvious of these is thermal pollution, where water is used in cooling various industrial processes and operations in addition to being used for waste disposal. Fig. 2 summarizes the factors determining the temperatures of water bodies and the influence of temperature on other systems.

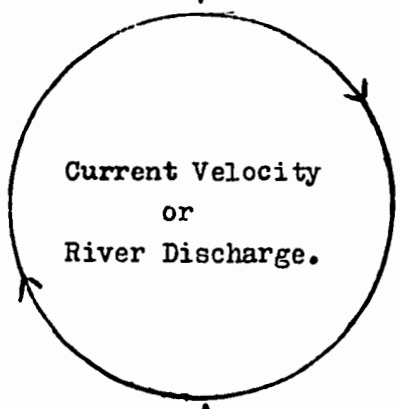
3. Transparency/Light penetration

The principal importance of light to aquatic ecosystems is that light serves as the energy source to support primary food production in surface waters. Often less than 1% of sunlight is changed into photosynthetic products (Fig. 3).

Fig. (1) Current Velocity or River Discharge - Indicator of Environmental Change

Factors Affecting Indicator → **Indicator of Environmental Change** → **Indicator's Effects Reflected on:**

1. Nature of gradient.
2. Surface of the bed.
3. Wind (in very large slow-flowing rivers).
4. Distance from waterfall.
5. Morphology of the channel.
6. Seasonality of rainfall



1. Distribution of living biota.
2. Silt transport.
3. Temperature mixing.
4. Suspended matter

Impacts of Man on Indicator:

1. Impoundments.
2. Water withdrawal.
3. Return water uses.
4. Flood control.

Fig. (2) **Factors Affecting Water Temperature in Rivers**

Factors Affecting Indicator	Indicator of Environmental Change	Indicators Effects Reflected on:
1. Presence of lakes. 2. Presence of impoundments along the course of the river. 3. Nature of the source of the river. 4. Presence/Absence of shading vegetation. 5. Latitude/Attitude of the river. 6. Thermal pollution. 7. Season/Climate.	Temperature	1. Thermal stratification. 2. Metabolic rates of aquatic life. 3. Acceleration of rates of synthesis and decomposition of organic matter. 4. Biotic and nutrient cycles. 5. Rate of growth, development and distribution of aquatic organisms. 6. Time and success of spawning. 7. Incidence of diseases.

Fig. (3) Transparency as Indicator of Environmental Change

Factors Affecting Indicator	→	Indicator of Environmental Change	→	Indicator's Effects Reflected on:
1. Absorption by water. 2. Absorption by dissolved or suspended material. 3. Scattering by particles.		Transparency Light Penetration		1. Source of energy. 2. Photoperiodic responses for: a) regulation of reproduction. b) migration patterns.

4. Suspended Matter

Inorganic particulates are materials held in suspension because of water turbulence, or, " rarely, unusual chemical conditions. Most important is the suspension of silt and clay. These are derived from transport into the ecosystem (Fig.4).

B. Chemical Indicators:

5. Conductivity

The electrolytic conductivity of a solution of electrolytes refers to the ability of the solution to carry an electric current. Since electricity is carried in the solution by migration of ions, the conductivity under standard conditions may be expected to bear some relationship to the total ion concentration.

The changes in river water quality brought about by modern civilization can be assessed by the changes in the natural quality of water as measured in this particular case by conductivity, e.g., changes in levels of total dissolved ions or conductivity.

On the other hand, since change in the river discharge (as a result of water impoundment caused by man) affect conductivity, conductivity can be used as an indicator of environmental changes in the river system (Fig.5).

6. p^H

p^H is the logarithm of the reciprocal of the hydrogen ion concentration. It is used to express how acid or how alkaline the water is. Most important when considering this parameter are the factors which produce the hydrogen ion concentration rather

Fig. (4) <u>Suspended Matter as an Indicator of Environmental Change</u>

Factors Affecting Indicator	→	Indicator of Environmental Change	→	Indicator's Effects Reflected on:
1. Water turbulence. 2. Unusual chemical conditions. 3. Current velocity. 4. Wave action by wind.		Suspended matter		1. On settlement load of the water body. 2. Scatter of sunlight. 3. Depth of light penetration.

Fig. (5) **Conductivity as an Indicator of Environmental Change**

Factors Affecting Indicator	→	Indicator of Environmental Change	→	Indicator's Effects Reflected on:
1. Geological nature of rivers 2. Rainfall 3. Discharge.		Conductivity		1. Degree of water salinity. 2. Quality of drinking water. 3. Distribution of animals and plants. 4. Fertility of water. 5. Level of ionic pollutant increase in conductivity indicates increase of ions in the source or discharged in the river.

its absolute value. Pure water is weakly dissociated and is neutral in reaction, i.e., H^+ and OH^- ions are present in equal proportions. If an acid, base or salt is added to this water, it dissociates and contributes H^+ or OH^- ions, thus altering their concentrations in the solution. Fig. 6 lists the different variable factors which cause changes in p^H value.

7. Dissolved oxygen

In aquatic environments oxygen is frequently a limiting factor of major importance. Dissolved oxygen enters and leaves fresh water through the photosynthetic or the respiratory activities (or both) of the biota. A litre of water in equilibrium with air at 20°C contains only 6.4 ml of oxygen. This initial scarcity of dissolved oxygen imposed by physical processes is often intensified by subsequent chemical events. This is particularly true of waters containing large amounts of organic matter (Bayly and Williams, 1973), Fig.7.

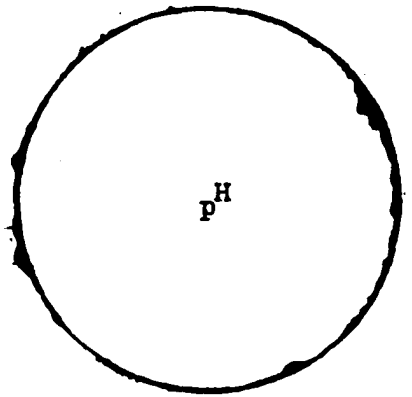
8. Biological Oxygen Demand (B.O.D.)

B.O.D. (mg/l) is an arbitrary measure of the amount of oxygen taken up by a sample of water incubated at 20°C for a given period (5 days). The amount of oxygen absorbed is dependent mainly on the amount of organic material present (the greater the amount, the larger the demand), but it should be stressed that numerous other factors are of significance. The basic mechanism of the test is similar to that causing deoxygenation in streams polluted by organic wastes: bacteria break down the complex organic materials into simpler substances and in the process remove oxygen from the water (Bayly and Williams, 1973).

Fig. (6) p^H as an Indicator of Environmental Change

Factors Affecting Indicator → Indicator of Environmental Change → Indicator's Effects Reflected on:

1. Addition of acids, bases or salts.
2. Temperature.
3. Rainfall.
4. Areas of limestone or other calcium-bearing rocks (bicarbonate amounts.
5. Free CO_2 in water.
6. Metabolic activity of the biota.



1. Extremes of p^H affect osmotic system of living organisms.
2. Very low p^H water often contains large amounts of dissolved organic matter and small amounts of clacium.
3. When the total alkalinity of a habitat is constant, p^H change is proportional to CO_2 change and is therefore a useful measure of the latter.

Fig. (7) Dissolved Oxygen as an Indicator of Environmental Change

Factors Affecting Indicator	→	Indicator of Environmental Change	→	Indicator's Effect Reflected on:
1. Current or Discharge. 2. Temperature. 3. Respiration of plants and animals. 4. Photosynthetic activity of plants. 5. Oxidation breakdown processes. 6. Atmospheric pressure/ altitude.		Dissolved Oxygen		1. Respiration. 2. Photosynthesis.

9. Chemical Oxygen Demand (C.O.D.)

Because the time required for completion of a B.O.D. analysis, which may be 5 days, is too great for the test to have application in many situations, the analysis of C.O.D., which requires 3 hr. or less, is often preferred.

The C.O.D. procedure is based on the fact that most organic compounds can be oxidized to carbon dioxide and water by strong oxidants under acid conditions.

Most samples contain a high percentage of material which can be chemically, but not biochemically, oxidized, such samples will have C.O.D. values greater than their B.O.D. values For example, textile, paper, mill and other wastes containing high concentrations of cellulose have a high C.O.D., but refinery wastes have a high B.O.D. and low C.O.D. (Caccio 1972).

10. Plant Nutrients

Nutrients discharged to a water course promote biological responses which may interfer with some desired uses of the water. Plankton blooms and excessive growths of attached algae such as Cladophera result from the over fertilization of lakes and rivers. The increase in the concentration of nutrients in a body of water is called eutrophication and is one of the most important pollution problems (Caccio 1972).

a. Phosphate - Phosphorus

Phospjorus is an important constituent of living organisms and often present in them in significant amounts, the quantities of phosphorus

occurring in most natural waters are very low. A large proportion of the phosphorus in surface waters originates from municipal waste effluents. A large proportion of this phosphorus comes from household detergents. Also runoff from manured land and urban runoff contribute a considerable amount of phosphorus to water bodies (Maitland, 1978).

b. Nitrate - Nitrogen

c. Ammonium - Nitrogen

In addition to dissolved nitrogen molecules, ammonia, nitrate, nitrite and organic compounds are the most abundant forms of nitrogen in natural waters.

Nitrogen is an important component of the cells of living organisms, and the amounts available in a water body, though often small, are of major significance to the nature of the ecosystem. In the majority of natural aerobic waters, most nitrogen occurs as nitrate. In eutrophic waters with large standing cropsof algae or macrophytes, almost all the nitrate present may have been taken up and incorporated in the plant cells. In anaerobic situations, nitrates are often broken down through nitrite and nitrous oxide, occasionally as far as nitrogen itself. In addition, in the absence of dissolved oxygen free amonia may occur as a result of protein breakdown (Maitland, 1978).

Nitrogen and phosphorus discharged to a water-course promote biological responses which may interfere with some desired uses of the water. Plankton blooms and excessive growths of attached algae such as Cladophera result from the over fertilization of lakes and rivers. The unaesthetic appearance and odor of plankton growths make water unfit for recreation and also for other purposes such as municipal and industrial water supply. The quantities of nitrogen and algae in water have been shown to limit algae populations. Both are common pollutants arising from municipal and industrial wastes and agricultural runoff.

Ammonia is favoured as the most reliable single parameter for measuring the quality of river water. Ammonia is present in sewage and some industrial wastes and the higher the degree of purification, the lower the ammonia concentration of the effluents, the ammonia being oxidized to nitrate.

11. Heavy Metals

Some heavy metals are among the most harmful of the elemental pollutants. These elements, which are in general the metals in the lower right hand corner of the periodic table, include essential elements like iron as well as toxic metals like lead, cadmium and mercury. Most of them have a tremendous affinity for sulfur and attack sulfur bonds in enzymes, thus immobilizing the enzyme (Manhan, 1979).

a. Copper

Copper is an essential trace element, not very toxic to animals, toxic to plants and algae at moderate levels. Its sources are:

- metal plating,
- industrial and domestic wastes,
- mining and mineral leaching.

b. Iron

Iron is an essential nutrient, a component of hemoglobin. It is not very toxic. However it can damage materials such as bathroom fixtures and clothing. Its sources are corroded metal, Industrial wastes and acid mine drainage.

c. Lead

Lead is a toxic substance. It can cause anemia, kidney disease, disorders of the nervous system and wildlife destruction. Its sources are industry, mining, plumbing, coal and gasoline.

d. Zinc

Zinc is an essential element in many metal-loenzymes and aids healing of wounds. However it can be toxic to plants at higher levels. Zinc can be a major component of sewage sludge limiting land disposal of sludge. Its sources are: industrial waste, metal plating and plumbing.

12. Major ions

a. Calcium, b. Magnesium, c. Potassium, d. Sodium

Although major ions are generally not considered indicators of pollution or environmental change, they are parameters of the ambient quality

of water and are therefore included in standard analysis procedures.

Calcium ion is a common constituent of natural waters, resulting from the dissolution of limestone, dolomite and gypsum. While not usually important from a physiological standpoint, calcium ion is unique in being desirable in moderate concentrations. Small concentrations are necessary to form a protective coating on the inside of steel pipes and boilers, but high concentrations result in harmful scale formation and waste of soap by precipitation of insoluble fatty acid salts (Ciacco, 1972).

Unlike calcium, which is physiologically without effect in moderate concentrations, magnesium ion in concentrations above 125 ppm can produce cathartic and diuretic effects. Like calcium, it causes scale formation in pipes and boilers.

Potassium ranks seventh, immediately below and approximately equal to sodium in relative abundance in the lithosphere, but its concentrations in natural waters generally are much lower than sodium ion concentration.

Sodium ion is found in most natural waters and varies in concentrations from 1 ppm or less to several hundred parts per million in surface and ground waters.

13. Organic pollutants

Almost all natural waters contain measurable concentrations of organic matter. The organic materials arise through the natural processes of

biological synthesis and degradation and through t the various activities of man. Most important of these are pesticides, herbicides, insecticides and fungicides. Large quantities of these compounds enter water either directly, in applications such as mosquito control, or indirectly, from the drainage of agricultural lands. Most of the water-pollutant pesticides belong to the major groups of chlorinated hydrocarbons and organic phosphate, of which the latter group is generally more biodegradable.

An example of harmful effects of pesticides upon human beings is the action of DDT. Like many insecticides, DDT acts upon the central nervous system, where it interferes with the transmission of nerve impulses; this might result in severe cases in killing of the target organism (Manham, 1979).

It can be summarized here that pesticides may be carcinogenic or toxic to human beings.

C. Biological Indicators

14. Macrophytes

Macrophytes consist principally of the aquatic flowering plants, but also include the aquatic mosses, liverworts and ferns. Three types of macrophytes can be identified: floating, submersed and emersed.

Macrophytes are distributed in various water bodies depending on the physical and chemical characteristics of the ecosystem. Current plays the most important role in distributing plants and it is a determining factor in plant establishment

process. The current affects the amount of water supply, the quantity and quality of light, reduces the daily variation between oxygen and carbon dioxide and minimizes temperature fluctuations. Most important of all, however, is its effect on the river bed, which is both the source of mineral nutrient and rooting substratum.

In recent years aquatic macrophytes have been used as indicators of pollution. Some macrophytes grow only in clean water; others only in polluted water and yet a third group is indifferent to the pollution (Desougi, 1980).

15. Bacteria

Bacteria are very small mostly unicellular organisms. Bacteria species are found in all parts of the world in marine, freshwater and terrestrial environments as free-living forms and inside the bodies of many plants and animals. Bacteria are responsible for a large number of plant and animal diseases, including many fatal to man. As such their presence in water can be used as an indicator of water quality, e.g., suitability for drinking or swimming, etc.

Methods to identify and quantify bacteria are many, but the most common test is the Standard Plate Count for the indirect measurement of viable number of bacteria in a water environment. Total Coliform Group Density Test, which indicates the degree of fecal pollution is a standard test of the sanitary quality of water.

16. The Phytoplankton

Phytoplankton may be regarded as one of the best biological indicators of environmental changes which may occur in bodies of water.

The chemical features of any body of water, as well as its optical properties, influence the biomass diversity, species composition and rates of production of the phytoplankton, Fig. 3.

In terms of biomass, bodies of water with high nutrient levels and high transparency support dense algal growth. Biomass is obviously the best index of eutrophication and hence of environmental change, since one of the prominent phenomena associated with eutrophication is excessive growth of algae. Algal biomass can be expressed as cell volume or cell carbon by conversion from cell numbers. Chlorophll a of waters has been demonstrated to correlate well with algal biomass expressed as total volume. Estimation of chlorophyll a is the simplest, most rapid and most widely used method in determining total algal biomass. In the Blue Nile, Rzoska, Brook & Prowse (1955), Talling & Rzoska (1967) and Sinada (1972) have all made some algal counts which can be converted to biomass. Unfortunately no records of chlorophyll a have been made.

The effect of increased nutrient input into a body of water is also reflected in the species diversity of plankton. Here by diversity is meant a measure of the number of species. A high diversity means that many kinds of algae are present. In low diversity there is a monotony of a few species. A

highly eutrophic body of water has a small number of genera and abundant population whereas a less eutrophic one has a population which consists of a wide range of genera and a small number of each genus. Brook (1954) and later Sinada (1972) presented comprehensive systematic accounts of the phytoplankton. Comparing their accounts to future similar accounts may throw light on changes in diversity.

In terms of species composition, increase in nutrient supply, change in optical properties of the water or the changing the regime of the river is usually accompanied by the appearance of new species which favour the new conditions and the disappearance of existing species which do not favour the new conditions. Different species of algae undoubtedly have different environmental requirements and it could be that a particular species dominates in a particular body of water because the prevailing conditions favour it. Therefore the appearance of new species of organisms and the disappearance of existing ones could perhaps be useful indices of environmental changes. The species list made by Sinada (1972) during 1968-1970, compared to that made by Brook (1954) during 1951-1953, shows that many species appeared and few disappeared from the Blue Nile. Such a change in the algal flora of the Blue Nile within the short period of time of about 15 years implies changes in the environment. Similar species lists made in the future will help to detect changes in the environment of phytoplankton.

V. TREND ANALYSIS AND BASE LINE DATA

1. Discharge:

The first era (1912-1926)

Discharge data collected from the Ministry of Irrigation and Hydroelectric Power is given in Table 1. The fluctuation in annual discharge ranged between 139 and 157 mm^3. Lowest mean value recorded (9.6 mm^3) was in April during the period 1917-1921.

Second era

This period followed the building of Sennar dam. Fluctuation on annual discharge passing Khartoum lies between 132-156. Lowest monthly mean (10.4 mm^3) recorded was again in April during two periods 1927-1931 and 1937-1941.

Third era

This era followed the building of Roseires dam. The maximum discharge of water recorded passing Khartoum is 139 mm^3. This approximately equals the lowest values recorded for the above mentioned two eras. Lowest annual record is 104 mm^3 for the period 1971-1976.

Most significant is the very low discharge value during 1982 which reached only 71 mm^3. On analysing the monthly discharge at Khartoum during the last 3 years (1980, 1981 and 1982) one notices that the lowest discharge values in the history of the Blue Nile River are recorded, e.g., 4 mm^3 in February 1980, 4.5 mm^3 in February 1981 and 4.5 mm^3 during March 1983.

The consequences of these lower discharge values are reflected in the appearance of aquatic weeds along the Blue Nile at Khartoum (refer to section on Macrophytes for more details). Also appearance of new islands on

Table 1

5 Years Average Monthly Mean Blue Nile Water Discharge in mm^3 at Khartoum (Soba Station)

Era	Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
First era	1912-16	40.6	19.0	15.3	14.2	16.8	43.2	147	515	471	296	131	77.7	149
	1917-21	37.5	25.6	16.5	9.6	13.1	26.8	146	485	478	261	119	55.7	139
	1922-26	38.3	24.5	16.9	10.8	13.7	30.2	187	487	562	326	124	62.5	157
Second era	1927-31	25.1	16.0	11.6	10.4	11.7	42.1	167	477	477	256	98.1	51.1	137
	1932-36	24.4	15.6	14.6	13.0	17.3	42.9	215	558	532	253	83.2	42.7	151
	1937-41	19.1	13.3	13.9	10.4	13.8	39.7	170	493	452	247	80.3	35.1	132
	1942-46	18.3	13.4	11.2	11.9	14.9	27.4	156	532	465	236	59.2	37.2	132
	1947-51	22.3	15.4	15.3	12.4	13.4	43.2	176	496	470	252	85.6	39.2	139
	1952-56	27.5	17.4	15.2	16.7	17.3	40.6	199	565	478	291	78.2	40.2	150
	1957-61	23.4	15.8	12.2	12.0	14.7	33.8	174	535	529	287	67.0	45.7	146
	1962-66	19.9	14.8	11.0	13.7	18.0	27.5	136	624	605	349	56.2	33.8	156
Third era	1967-71	19.6	16.3	12.8	16.6	12.0	16.8	165	634	498	241	40.3	22.6	139
	1972-76	14.2	9.3	7.7	12.2	15.6	14.3	40.2	515	372	203	36.2	11.5	104
	1980	6.00	4.0	5.0	6.5	14.5	10.5	112	637	394	670	21.0	9.0	107
	1981	6.00	4.5	5.0	6.0	10.0	10.5	51.5	545	521	103	21.0	6.0	106
	1982	9.00	6.0	4.5	13.5	6.0	9.0	44.0	392	205	138	17.5	8.0	71

Source: Ministry of Irrigation and Hydro-Electric Power.

the course of the river is another indicator of environmental change caused by the human interference with the natural regime of the river.

2. Temperature:

First, second and third eras

Water temperature in the Blue Nile was found always to be below the air temperature. The value reached depends upon the season of the year and on the time of the day, e.g., Desougi (1980) recorded a 10°C difference between air (30°C) and water (20°C) temperature at (4:40 pm) in January 1979 at Sennar reservoir.

Moghraby (1972) recorded temperature ranges along the Blue Nile from Khartoum to the Ethiopian border to be between 17°C and 30°C during the period 1965-1970.

Thermal stratification is absent over most of the Nile. However, stratification is recorded in dam reservoirs, e.g., Roseires reservoir (Hammerton 1972 b and 1972 c). Clear variations along the Blue Nile in temperature are noticed only between the Sudanese plains and Lake Tana in the Ethiopian Plateau.

Diurnal changes in temperature were recorded by Ali (1982) at Khartoum ranging between 23-28°C, with the highest value at 4 pm and the lowest at 6 am (29 April 1982).

Thermal pollution is possible in the Blue Nile, because the Gunied Sugar Factory uses Blue Nile water in its cooling process.

3. Transparency/light penetration:

First era

No transparency data on the Blue Nile is available in this period.

Second era

During this period transparency measurement of 1.1 meters was recorded at Lake Tana on 12 March 1964 (Talling and Rzoska 1967). Gradual changes from flood to low water conditions caused the depth of transparency to increase from 0 to 0.5 m and more (Hammerton, 1976). This observation on seasonal changes in transparency was also recorded at Khartoum by Talling and Rzoska (1967), where transparency during flood season (July-September) was nil but gradually started to increase as the flood passes.

Third era

Hammerton (1972) noted that transparency (Secchi disc) increased from 0.5 to 2.8 in the reservoir of the new Roseires dam with values of 1.8 m at Sennar and 0.6 m at Khartoum. After the dam started functioning, silt began to settle down above the dam; this increased depth of the euphotic zone 670 km downstream to Khartoum.

4. Suspended matter:

First era

Beam (1906) recorded suspended matter in the Blue Nile water at Khartoum to be in the range of 4.1 ppm (in February 1905) and 993.5 ppm August 1905). It should be stressed here that information concerning the sediment load of the Nile is limited compared to the wealth of available river discharge data.

Second era

Measurements were taken on the Blue Nile (1954 and 1955) as part of the studies for Roseires dam by the Ministry of Irrigation. The average annual suspended sediment (million tons) was found to be 134; composed of 62 million tons of sand and 72 silt and clay. Maximum sediment concentration, in mg/l, measured was 10,530 and the maximum was 170.00.

Third era

Studies on transport of sediment in the Blue Nile River were carried out by El Bedri (1969/1970) during his Ph.D. work. El Bedri calculated that in the 1969 flood period, 69 million tons of sediment were transported past Khartoum, of which 40 million tons were sand-silt and the remainder was fine clay particles. These figures compared with a total of 36 million tons in 1968, composed of 22 million tons of sand and silt and 14 million tons of clay.

The above values are much lower than those obtained in the 1959-60-61 seasons by the hydrologists of the Ministry of Irrigation and H.E.P. It is thought that deposition of silt in the new Roseires reservoir is largely responsible for the lower quantity now transported past Khartoum.

5. Conductivity:

First era

Salinity measured as solids in solution in ppm was found higher during the low water flow than high flow (Beam 1906).

Second era

Seasonal changes in conductivity at Khartoum were investigated by Talling and Rzoska (1967) during 1954-1956 and were found to be less than two hundred with a few high values (conductivity 200 umho/cm). In September, March and April samples from 1956, 1963 and 1964 the values recorded were, respectively, 145, 228 and 238.

Hammerton (1972 d) gave a range of 140-390 umho/cm for values recorded at Khartoum in the period 1965-67.

Moghraby (1972) during 1965-1970 showed the conductivity of the Blue Nile to be in the range of 120-350 umho/cm. This indicates a moderate amount of solutes in solution. The minimum values of conductivity were found during the flood and in October and November. These were followed by an increase towards January and values shot up to a maximum during April-June. Moghraby worked on eleven stations along the Blue Nile. It should be noted here that (1) data between the same month from year to year vary greatly, e.g., during January 1969 conductivity was 230 umho/cm and in January 1970 it was 160 umho/cm and (2) no measurements have been made during flood periods, except at Khartoum station.

Desougi (1980) measured the conductivity at Sennar reservoir in November 1978; he found it to be 145 umho/cm. Ali (1982) gave the value of 235 umho/cm at Khartoum during April.

6. p^H:

First era

No data from this period are available.

Second era

According to Talling and Rzoska (1967), the values of alkalinity indicate that at equilibrium with atmospheric carbon dioxide, p^H values of 8.1-8.3 would be expected, (e.g. Talling and Talling 1965). Appreciably lower values, below 8.0, were found only in silt-laden water and probably correspond to increased concentrations of carbon dioxide resulting from organic decomposition. Much higher p^H values, around 9.0, were reached from the photosynthetic consumption of carbon dioxide during the two seasonal maxima of phytoplankton (January-March and May-June). The highest p^H value recorded in the Blue

Nile, 9.2, was found in January (16.1 1954, 31.1 1955) during the first Anabaena maximum.

Third era

Several researchers have measured the p^H value in the Blue Nile water during this period. Their results were as follows:

Hammerton (1976) 7.9-9.1 p^H during 1965-67 at Khartoum.

Sinada (1972) 7.5-9.3 p^H during 1968-70 at Khartoum.

Moghraby (1972) 7.4-9.4 p^H during 1966-70 at Khartoum.

at eleven stations from Khartoum to the Ethiopian border.

Desougi (1980) 8.8 November 1978 Sennar reservoir.

Ali (1982) 7.9-8.7 diurnal variation during April/82 at Khartoum, maximum at 7:00 and 8:00 am and lowest at 12 midnight till 2:00 am.

7. Dissolved Oxygen:

First era

No data are recorded for this period.

Second era

Talling and Rzoska (1967) showed that during 1953-55 in the Blue Nile at Khartoum the seasonal trend for surface water indicates a moderate degree of sub-saturation during the phase of flood water, and a slight super-saturation during the two maxima of phytoplankton. A pronounced oxygen deficiency, e.g., below 50% of saturation, was never found. This oxygen seasonality is accompanied with seasonal variation in temperature of the surface water.

Hammerton (1976) while studying the limnology of the Blue Nile, before building Roseires dam, recorded that the percentage saturation of oxygen in surface

water varied with occasional super-saturation in January-February (Cyanophycean bloom); absolute concentrations were lower during the flood period.

Third [illegible]

Moghraby during his Ph.D. studies (1966-1970) stated that in the Blue Nile the surface waters are usually in a state of slight supersaturation (6.0 mg/Litre = 75% saturation). During the flood, however, moderate degree of sub-saturation is sometimes found. One incidence of oxygen deficiency below 50% saturation was recorded at Khartoum during the flood of 1968.

Hammerton (1972 a,b and 1976) reported that periods of variable deoxygenation have occurred in the Roseires reservoir, including an episode of complete deoxygenation soon after its first filling.

Diurnal variations in dissolved oxygen in the Roseires reservoir were studied by Moghraby (1965-70). He found a maximum value of 10.4 mg/L O_2 during the period of high photosynthetic activity at 12:00 noon and lowest value of 6.5 mg/L O_2 at 18:00 hours.

Ali (1982) found diurnal variations between 7.8 mg/L and 8.2 mg/L during April 1982. The lowest concentration was recorded at 3:00 am and the highest one at 3:00 pm afternoon. From the above data clear day and night variations in dissolved oxygen values can be seen. Oxygen surface-supersaturation was recorded by Talling and Rzoska (1967) during the period of annual phytoplankton maximum.

8-9. B.O.D./C.O.D.:

To date no studies for the B.O.D. and C.O.D. parameters have been made.

10. Plant Nutrients:

a) Phosphate-Phosphorus

First era

No data are available for this period.

Second era

According to Talling (1976) concentrations of soluble orthophosphate were about 100 ug PO_4-P/L in the Blue Nile before the main period of phytoplankton development (Prowse and Talling 1958; Talling and Rzoska 1967; Hammerton 1972 d), but declined thereafter to 10 ug PO_4-P/L. The first part of the decline may be influenced by hydrological changes upstream, such as the continued decline of flood-water in the Blue Nile. This phase included the initial growth of the major diatom Melosira granulata in the Blue Nile river which occurred in a relatively phosphate rich medium.

Hammerton (1972 b) measured a decline in phosphate and nitrate in the Roseires reservoir for the 1967-68 inter flood season, these nutrients also decreased along a longitudinal section towards the dam.

The latter part of the phosphate decline observed by Talling at Khartoum was due to uptake associated with dense phytoplankton which included abundant blue-green algae - especially Anabaena flos-aquae f.spiroides.

Desougi (1980) measured values between 64 and 70 ug/l PO_4-P in eleven of the Gezira irrigation canals between Medani and Khartoum in January 1979. The canals receive their water from Sennar reservoir.

Ali (1982) detected diurnal phosphate concentrations at the Blue Nile at Khartoum in April 1982 to be in the

range of 6-18 ug/L with no obvious changes recorded between day and night.

Sinada (1972) reported a range of phosphate concentration at Khartoum to be between 14.0 ug/L and 300 ug/L during 1968-1970.

b) Nitrate-Nitrogen:

First era

Beam (1906) measured the nitrate-nitrogen for one year between November 1904 and October 1905. Maximum values of 0.054 ppm were recorded in June while the minimum value of 0.015 ppm in January. There are no data available for the annual flood period (July, August and September).

Second era

Talling and Rzoska (1967) showed that large seasonal changes in nitrate-nitrogen take place. During 1954-56 period the flood water contained large amounts of nitrate-nitrogen occasionally exceeding 500 ug/L. A decline to levels below 20 ug/L occurred in November/December during the first maximum bloom of the diatom *Melosira granulata* and low concentrations were maintained throughout the following maximum bloom of *Anabaena flos-aquae f.spiroides.* However in absence of adequate analysis of upstream water, it is not possible to separate the consequences of subsiding flood water and uptake by phytoplankton.

Third era

Moghraby (1972) stated that during the flood the nitrate-nitrogen had a concentration of 0.08-0.1 mg/L. This rapidly decreased to 0.002 mg/L or less at the end of December-January.

Sinada (1972) showed the range of nitrate concentrations at Khartoum to be between 80 ug/L and 200 ug/L.

Hammerton (1972) indicated that the nitrate-nitrogen levels at Khartoum ranged between 1 and 100 ug/L. At Roseires reservoir he recorded the following concentrations 55 ug/L in November 1967 and 2 ug/L NO_3-N in May 1968 (1972 b).

Desougi measured NO_3-N in the Gezira irrigation canals to be in the range of 0.52 and 1.00 mg/L during January 1979.

Ali (1982) stated that at Khartoum, the Blue Nile water performs diurnal changes in nitrate-nitrogen content between 0 and 25 ug/L.

c) Ammonium-Nitrogen:

First era

Beam (1906) measured ammonium-nitrogen to be in the range of trace (in December 1904) to 0.032 ppm (in June 1905); no data are recorded for the annual flood period (July, August, September) at Khartoum.

Second & Third eras

The range of values recorded was always below 0.05 ug/L N, Talling and Rzoska (1967).

To date there have been no studies done on ammonium-nitrogen.

11. Heavy Metals a) Cu, b) Fe, c) Pb, d) Zn.

No studies have been conducted to study the heavy metals in the Blue Nile River.

12. Major ions (Ca, Mg, K, Na):

First era

Beam (1906) recorded maximum values for the major ions in June 1905 and lower values in December 1904 as follows: Calcium 25.53 and 18.4, Magnesium 5.89 and 4.34, Potassium 1.90 and 1.4, and Sodium 7.81 and 5.57 ppm.

Second era

Green and Snow (1939) measured the major ions in the Blue Nile (at Medani 1936-37) to be in the follows: Calcium 20.5-23.4 mg/L, Magnesium 4.8-5.3 mg/l and Potassium 8.4-8.9 mg/L.

Talling and Rzoska (1967) stated that the major ions measured from Khartoum to Singa (Blue Nile) in December 1955 were as follows: Calcium 1.5, Magnesium 0.72, Potassium 0.06 and Sodium .47 mg/L.

Hammerton (1961/1963) found the major ions at Khartoum to be Calcium 29.2, Magnesium 4.9, Potassium 3.7 and Sodium 3.7 mg/L.

Sinada (1972) gave a range of values for the season 1968-1970 as follows: Calcium 18-34.7 mg/L, Magnasium 3.5-9.0 mg/L, Potassium 1.3-3.3, and Sodium 5.0-15.0 mg/L.

Moghraby (1972) summarized his work along the Blue Nile during the period 1966-1970 in this way: "The major ions were always found in fairly high concentrations (Calcium 12.8-28 mg/L, Magnesium 3.6-7.8, Potassium 1.2-2.8 mg/L and Sodium 4.1-9.5 mg/L".

Desougi (1980) gave the following values for Sennar reservoir during November 1978: Calcium 18.44, Magnesium 5.10, Potassium 0.94 mg/L and Sodium 6.90 mg/L.

Ali (1982) showed that there are no diurnal changes in the values of the major ions at Khartoum during April where he recorded the following: Calcium 20.0-23.0 mg/L, Magnesium 9.6-11.6 mg/L, Potassium 1.8-2.1 mg/L, and Sodium 8.7-11.2 mg/L.

13. Organic pollutants:

To date there have been no studies done on organic pollutants in the Blue Nile.

C. Biological Indicators

14. Macrophytes:

Macrophytes were not abundant in the Blue Nile, they were assumed to be less important primary producers than phytoplankton. According to Desougi (1980) the following species were recorded in the lakes as well as in the Sudanese plains:

- Ceratophyllum demersum
- Echinochloa stagnina
- Nymphaea caerula
- Nymphaea lotus
- Pistia stratiotes
- Typha domigensis

Desougi also noted the absence of the Potamogeton species (P. crispus, P. nodosus, P. pectinatus and P. perfoliatus) which are very common in the Gezira irrigation canals. Potamogeton species are also absent from the water pools "mayas" of the Dinder National Park and Sennar reservoir.

Andrews (1945) and Desougi (1980) recorded the prevalent plant species in the Sennar reservoir (See Table 2). The absence of Potamogeton species

Table 2

Plant Species Recorded by Andrews (1945) and Desougi (1980) in Sennar Reservoir

	Andrews 1945	Desougi 1978
Ceratophyllum demersum	+	+
" submersum	-	+
Chara globularis	+	+
Cynodon dactylon	-	+
Cyperus alopecuroides	+	+
Cyperus rotundus	+	+
Echinochloa stagnina	+	+
Ipomea reptans	+	+
Najas marina	-	+
Najas pectinata	+	+
Najas schweinfurthii	-	+
Nitella batrachosperma	+	+
Nymphaea caerulea	+	+
Nymphaea lotus	-	+
Ottelia alismoides	+	-
Ottelia ulvifolia	+	-
Panicum meyeranium	+	+
Panicum repens	-	+
Pistia stratiotes	+	+
Polygonum glabrum	+	+
Polygonum lanigerum	+	-
Spirogyra Sp.	-	+
Utricularia inflexa	+	+
Utricularia stellaris	+	+
Utricularia thonnigii	+	-
Vossia cuspidata	+	+

+ present - not present

in both records is noticeable. However the later author recorded the presence of Potamogeton crispus in April (1981) in the Blue Nile at Khartoum and along the Main Nile up to the surveyed 20 km. The appearance of Potamogeton is attributed to the reduced current velocity. The plant is also recorded 80 km south of Khartoum at El Massodia.

15. Periphyton, benthos and bacteria:

Although the scientific and economic importance of the Nile have long been recognized, many aspects of its biology have been largely neglected and some biocenoses especially benthos and periphyton have not been examined.

Surprisingly, bacteria have not been studied at all. Most of the biological studies have concentrated on the phytoplankton and zooplankton.

16. The Phytoplankton:

First era (1831-1925)

Hydrolbiological studies were not carried out on the Blue Nile before the construction of Sennar dam in 1925. Indeed most of the work which has contributed greatly to our knowledge of the ecology of the Nile within Sudan has been carried out long afterwards by members of and collaborators with the Hydrobiological Research Unit which was established in the University of Khartoum in 1953. Prior to the formation of the Sennar reservoir, ecological research was largely neglected in the Sudan. The only material pertaining to the Nile consisted of some occasional notes by passing biologists. These include notes on algae and freshwater fauna by Ehrenburg and Hemprich (1831),

Schweinfurth (1862), Grunow (1870), Ekman (1903), Daday (1910), Gurney (1911) and Chappim (1922) Beam (1906) indicated that the plankton was scanty and mixed with detritus and adventitious forms, a finding which is in conformity with our present speculations.

Second era (1925-1966)

All of the work which has contributed significantly to our knowledge of the biology of the Nile began in the early 1950's long after the construction of Sennar dam. Most of this work, however, was carried out within the vicinity of Khartoum.

Ethiopian headwaters:

Due to the topography and the nature of the river on the Abyssinian Plateau, it is expected that the Ethiopian headwaters do not contribute significantly to the plankton of the Nile. Talling and Rzoska (1967) sampling the Ethiopian headwaters during March 1964 found only a sparse and rudimentary plankton population.

Zone I, Zone II and Zone III:

Hammerton (1970 a,b; 1971 a) in three different surveys carried out during February 1964, February 1965 and February 1966 found an extremely sparse plankton population in 400 km section of the river upstream of Sennar dam. The diatom *Melosira granulata* and the bluegreen alga *Anabaena flos-aquae* - two principal components of the Blue Nile north of the Sennar reservoir were present in very small numbers around 20 cells ml^{-1} within this stretch of the Nile. All the samples collected

during 1964-1966 contained visible quantities of silt and fine sand and some organic detritus with a Secchi disc visibility less than 50 cm. Therefore poor light penetration, coupled with relatively high current velocity seems to be the sole factor checking the development of phytoplankton within this stretch of the Blue Nile, before the construction of Roseires dam.

Zone IV (Sennar reservoir):

As mentioned before no hydrobiological studies were carried out within this zone prior to the construction of Sennar dam.

Hammerton (1970 a,b; 1971 a) confirming the findings of Talling and Rzoska (1967) found that as the water entered the dam basin most of the silt settled out. The Secchi disc visibility increased considerably resulting in a dense phytoplankton development within the reservoir. *Melosira granulata* increased from around 20 cells ml^{-1} to 2140 cells ml^{-1} in the reservoir. There was a similar increase in the numbers of *Anabaena flos-aquae*. Unfortunately no work was carried out after 1970.

Zone V:

Talling and Rzoska (1967) made the first longitudinal survey of its kind along the Blue Nile during December 1955. They observed that densities of *Melosira* increased appreciably in the first 150 km stretch below the dam but not further downstream. Increase in *Anabaena* population was much more pronounced in the lower river stretch below the dam. Talling and Rzoska (1967) concluded that most of the phytoplankton biomass reaching Khartoum is produced in true river conditions below Sennar reservoir.

Hammerton (1970 a,b; 1971 a) in his three different longitudinal surveys confirmed the views of Talling and Rzoska (1967) that the plankton population which was brought to full development in Sennar dam basin persisted as a true river plankton throughout zone V over 350 km downstream with little loss in numbers.

Zone VI (Khartoum):

This zone has been thoroughly and better studied than other stretches of the Nile.

Brook (1954) presented systematic account of the phytoplankton of the Blue Nile from samples collected at Khartoum between 1949-1952. Over 90 algal taxa were identified. This detailed study was not repeated until after the completion of Roseires dam when Sinada (1972, unpublished) presented a similar systematic account (See below).

Of the 90 taxa reported by Brook (1954) only a few contributed significantly to the total phytoplankton biomass. Rzoska, Brook and Prowse (1955) and Talling and Rzoska (1967), from records made during 1951-1953 and 1954-1956, respectively, have shown that the dominant species in the Blue Nile were Melasira granulata and its variety angustissima, Anabaena flos-aquae f. spiroides and Lyngbya limentica. These findings are summarised below.

The concentration of plankton was very low during flood period of July-October when adverse conditions of rapid flow and high turbidity existed. As the current subsided in November diatoms were the first group to appear in numbers particularly Melosira granulata which was favoured by the post-flood relatively high concentrations of nitrate-nitrogen and phosphate-phosphorus. The former nutrient reduce to 10-20 ugl^{-1} was responsible for

the primary check to the increase of Molosira which was surpassed by Anabaena flos-aquae. The latter alga produced higher population densities in January-February and were probably responsible for the depletion of phosphorus. A decline of phytoplankton occurred between March-April after which a second maximum developed during May/early June before the entire plankton was washed out by late June. The components of the second maximum were Melosira granulata, Anabaenopsis cunningtonii, A. tanganyikae, Anabaena sceremetievi, Raphidiopsis curvata and Synedra acus. Lyngbya limnetica was a minor component of the maximum of May-June 1956 (Talling and Rzoska, 1967), although a major one in 1953 (Rzoska et al. 1955).

No further seasonal studies on the phytoplankton of the Blue Nile were carried out between 1956 and 1962. However the Hydrobiological Research Unit, University of Khartoum launched a long-term study in 1963 to determine the impact of the Roseires dam on the biological conditions of the Blue Nile. Hemmerton (1970 a,b; 1971 a) sampling the Blue Nile at Khartoum during 1963-1966 observed seasonal cycles and succession of phytoplankton which were remarkably predictable and similar to those recorded by previous workers without changes in the species composition of the plankton.

Third era (1966-1983):

Man-made lakes have profound influences on the biological productivity and ecology of rivers. With this in mind the Hydrobiological Research Unit (University of Khartoum) made plans in 1963, three years before the completion of Roseires dam, to carry a long-term study of the whole 740 km length of the Blue Nile to determine the impact of Roseires dam on the biological conditions of the river. A survey was carried out on conditions

before and after the dam was put into use. The valuable studies carried out by Brook (1954), Rzoska et al. (1955), Talling and Rzoska (1967) and Hammerton (1970 a,b; 1971 a) have provided much of the baseline data for comparison with conditions in the newly formed reservoir and in the river after the filling of the reservoir.

Zone I:

This zone is not affected by the formation of Roseires reservoir. Within this zone normal river conditions existed with large detritus suspension and few adventitious organisms (Moghraby, 1972).

Zone II (The Roseires Reservoir):

The reservoir of the Roseires dam was first filled in October 1966. Shortly after that, Hammerton (1971 b) observed a moderately rich plankton in the reservoir, with Microcystis flos-aquae and Phormidium mucicola as important components. Microcystis became rapidly dominant and in December 1966 the surface of the lake was bright green. It was interesting to note that Microcystis had never previously been a major component of the Blue Nile (Brook, 1954). Melosira granulata, always an important component of the Blue Nile plankton, was present throughout the sampling season with peak growths in November 1966, March and May 1967. The other important component of the Blue Nile Anabaena flos-aquae did not appear until January 1967 and reached a peak growth in February 1967.

The following season - November 1967 - May 1968 - the phytoplankton of Roseires reservoir showed considerably heavier growth than during 1966-67 with the dominant algae being the same, namely Melosira granulata, Microcystis flos-aquae and Anabaena flos-aquae (Hammerton, 1971 c). Many other algae were present including Pediastrum spp.

which were particularly prominent. Melosira granulata was already abundant in November 1967 and increased through December to a peak of 4150 cells ml^{-1} in January 1968. During February 1968 there was a sharp decrease, recording only 44 cells ml^{-1} in March but increased again to 5220 cells ml^{-1} in May 1968. Microcystis flos-aquae and Anabaena flos-aquae were present in November 1967 but formed dense surface blooms during December-February 1968. In March 1968 Pediastrum spp. became dominant while Microcystis reappeared in enormous numbers in May 1968.

During 1969-1970 season the Roseires reservoir showed further differences from the "usual" seasonal cycle though Melosira granulata produced a heavy growth in November (Hammerton, 1972 c). Unexpectedly Volvox aureus dominated the phytoplankton in December 1969 but this disappeared in January 1970 to be replaced by a large growth of Pediastrum simplex var. duodenarium which continued throughout February 1970. It was surprising that only trace amounts of Anabaena and Microcystis were found during that season - the first time that blue-green algae failed to be a major component of the phytoplankton of the Blue Nile.

It is apparent that the reservoir during the first three years of its filling (1966-1970) had not stabilized biologically. The seasonal cycles and succession of phytoplankton as described above differed from year to year. Unfortunately, as far as we are aware, no further studies were undertaken after 1970 and it is not possible to point out if and when the biological regime of the reservoir and thorogughly stabilized. However it can be safely stated that the formation of the Roseires reservoir had brought about changes in the species composition and seasonal cycles of the plankton in the Blue Nile.

Zone III:

The phytoplankton within this stretch has not been studied. However Hammerton (1971 c) reported that phytoplankton densities were reduced to 40% of that of Roseires reservoir.

Zone IV (The Sennar Reservoir):

The phytoplankton in Sennar reservoir had not been studied on a seasonal basis before the construction of Roseires dam in 1966. However Hmmerton (1971 c, d. 1972 b) followed the seasonal cycles of the phytoplankton in the Sennar reservoir for three consecutive seasons, thus: November 1967-May 1968, November 1968-May 1969 and November 1969-May 1970. His findings are summarised below:

Melosira granulata was dominant in the reservoir during the whole season of 1967-1968 increasing from 3145 cells ml^{-1} in November 1967 to a large peak of 11770 cells ml^{-1} in January 1968, then decreasing to 1530 cells ml^{-1} in March before rising to a second smaller peak of 5000 cells ml^{-1} in May 1968. Anabaena flos-aquae, co-dominant throughout much of the season, also showed peak growths in January and May 1968 of 4900 and 3610 coil-turns ml^{-1}, respectively. It is interesting that total population densities in Sennar reservoir were higher than those in Roseires and still higher than any previous records in the Blue Nile. It is striking that Hammerton (1971 c) did not mention Microcystis flos-aquae in Sennar reservoir although it was a co-dominant member of the phytoplankton of Roseires reservoir.

During 1968-1969 two periods of phytoplankton growth were noted in Sennar reservoir. The first period started from October 1968 to February 1969 with Melosira granulata being dominant; the second period extended from April-June 1969 with Microcystis being the dominant alga and Melosira

was co-dominant. However, similar to conditions in Roseires reservoir, Anabaena flos-aquae was not reported to constitute any phase in the plankton of Sennar reservoir during that season.

Similarly during 1969-1970 season, two periods of maximum algal growth were observed: a shorter period during October-December 1969 with a dense growth of Melosira in November, and a second period from March to June 1970. During the latter period Melosira peaked in April, to be followed by Microcystis which dominated the plankton in May 1970.

It is interesting to note that Anabaena flos-aquae, an alga prominent for so many years in the Blue Nile, became less important during November 1968-May 1970. Further studies were not carried out after 1970 to ascertain the role played by Anabaena flos-aquae in Sennar reservoir after the construction of Roseires dam. The fluctuations in the densities of Melosira, Microcystis and Anabaena within the Sennar reservoir during 1968-1970 closely reflected the seasonal changes of the numbers of these algae in Roseires reservoir. This indicates that the formation of the Roseires reservoir greatly influenced the phytoplankton composition and density within the Sennar reservoir.

Zone V:

The only available longitudinal survey carried out along this stretch of the Blue Nile during the third "era" indicated that the seasonal variations in species composition and densities of the phytoplankton closely reflected the changes in Sennar reservoir. However there was a decrease in the densities of the major components of the phytoplankton downstream of the Sennar dam, with a slight increase near Khartoum (Hammerton, 1971 d). The populations near Khartoum were less healthy than at Sennar.

Zone VI (Khartoum):

Sinada (1972) studied the phytoplankton of the Blue Nile during the period August 1968-December 1970. The principal components of the phytoplankton during this period were *Melosira granulata*, *M. distans*, *Synedra acus*, *Microcystis flos-aquae*. *Anabaena flos-aquae* was prominent only during January-February 1969 (800-2800 coil-turns ml^{-1}). It was surprising that this blue-green alga remained in very low numbers during the rest of the period of the above mentioned study as found in Roseires reservoir by Hammerton (1971 c,d. 1972 b). *Melosira granulata* in this zone showed a definite and regular seasonal cycle. It appears in September/October and quickly establishes a peak in November/December after which it decreases sharply to lower numbers which are maintained until May. In late May/early June a sudden summer peak occurs before being washed out in late June (Sinada 1972). This seasonal cycle of *Melosira* reported during 1968-1970 is reminiscent of that reported by Rzoska *et al.* (1955) and Talling and Rzoska (1967) fourteen years earlier.

The maximum development of *Melosira distans* in the Blue Nile at Khartoum during 1968-1970 always occurred in November-December although it was likely that this period might extend until February (Sinada 1972). It is interesting to note that this diatom was not reported in the Blue Nile before 1968.

Microcystis flos-aquae attains its maximum development during February-May although the magnitude may vary considerably from year to year. The period July-October is obviously unfavourable for the growth of all algae. Significant increase in numbers of *Microcystis* occurs in November-December (Sinada 1972).

Synedra acus showed definite recurrent peaks during November-December and May-early June.

Sinada (1972) showed that the annual flood of the Blue Nile is the most important factor limiting numbers of phytoplankton. The scarcity of planktonic algae during the flood, despite of high nutrient concentrations is attributable to the high silt content (>4 gl^{-1} suspended matter). The Secchi disc visibility during the flood season is in the very low range of 0-5 cm. In addition the current velocity may be as high as 1.8 m sec^{-1} compared to <0.09 m sec^{-1} during May/early June when the second maximum of algal growth occurs. The increase in algal densities begins in late October/early November when the current subsides (velocity <0.35 m sec^{-1}) and most of the silt settles out (Secchi disc visibility 20 cm). Therefore poor light penetration coupled with high current velocity is the sole factor checking the development of phytoplankton in the Blue Nile during the flood season (Sinada 1972). These conditions reported in the Blue Nile during the annual phase of the flood during 1968-1979 were no different from those reported before the construction of Roseires dam by earlier workers.

Sinada (1972) listed over 150 algal species belonging to 74 genera of the various algal classes. Comparing his list with that of Brook (1954) made over fourteen years earlier it is obvious that there was an increase in diversity of species. Many algae appeared though in very small numbers in the Blue Nile at Khartoum during 1968-1970 and a few others disappeared (See Tables). Of the important species which appeared during 1968-1970 were Melosira distans and Attheya zachariasi which contributed significantly to the total algal biomass of the Blue Nile at one time or another. Likewise, one species, namely Microcystis flos-aquae which had been reported by Brook (1954) in 1951-1953 as being an

an unimportant component of the phytoplankton of the Blue Nile, preponderated shortly after the construction of the Roseires dam and continued to constitute an important phase in the phytoplankton of the Blue Nile throughout 1968-1970. Occasional samples taken from the Blue Nile at Khartoum during 1977-1983 have shown that Microcystis as well as Melosira distans, have established themselves (Sinada, unpublished). On the other hand certain blue-green algae like Anabaenopsis spp which were recorded by Rzoska et al, (1955) and Talling and Rzoska (1967) as important members of the plankton of the Blue Nile during 1951-1956 were rarely observed during 1968-1970 by Sinada. Similarly Lyngbya limnetica which constituted an important component of the Blue Nile in the early 1950's (Rzoska et al., 1955) disappeared from the Blue Nile during 1968-1970 (Sinada, 1972).

It is obvious that the algal flora of the Blue Nile has undergone a considerable change within a short period of time between 1956 and 1968. This change in the algal flora of the Blue Nile may be attributed to the construction of the Roseires dam across the Blue Nile in 1966.

17. The Zooplankton:

Little work has been carried out on zooplankton and no study worth mentioning was undertaken during the first era.

Second era (1925-1966):

As far as we are aware the only studies carried out were those of Rzoska et al.(1955) and Talling and Rzoska (1967) and few casual observations made by Hammerton (1970-a,b).

Zone I, II and III:

The only available data were the outcome of a preliminary survey carried out during December 1955 by Talling and Rzoska (1967) and during February 1964 and February 1965 by Hammerton (1970 a,b). They showed that the zooplankton was very scanty within this stretch of the Blue Nile before the construction of Roseires dam. The quantities of the zooplankton were not assessable, with few *Moina dubia* and *Thermocyclops* species. However, adventitious forms were numerous in the detritus-rich waters. This finding is not surprising considering the topography of the area within this stretch of the Nile.

Zone IV (Sennar reservoir):

As the water supproached the Sennar reservoir, the zooplankton built up, chiefly within the last 100 km above the dam (Talling and Rzoska 1967). Near the dam a moderately rich and varied zooplankton was presented in the middle of the reservoir. The principal components were *Ceriodaphnia cornuta*, *C. dubia* and *Moina dubia*.

Zone V:

No record of the zooplankton within this stretch of Nile was available before 1966.

Zone VI (Khartoum):

The only available records were those of Rzoska *et al.* (1955) and Talling and Rzoska (1967) who were engaged in studying the Nile at Khartoum during 1951-1953. The zooplankton during that period followed the same pattern as the phytoplankton with two peaks. There was no plankton discernible in the silt-laden waters of July-October except for

few Moina dubia and adventitious forms. Plankton began to appear in November rising sharply in numbers to peak in February before a drop in March or April. A second rise followed in May-early June before the plankton is washed out in late June. During the first period of maximum growth two species of Ceriodaphnia were most numerous with C. cornuta. The second maximum of May/June appeared to be more variable in composition with Diaphansoma excisum and C. cornuta being dominant in 1952 and Cyclopoids in 1953.

Third era (1966-1983):

Moghraby (1972) started a four-year extensive investigation of the zooplankton of the Blue Nile just after the first filling of Roseires reservoir in November 1966. His valuable study remains the only available record of the zooplankton of the Blue Nile after the completion of Roseires dam.

Zone I:

Moghraby (1972) noted that within this zone normal river conditions existed, with large amounts of detritus suspension and few organisms most of which are adventitious forms. This finding was in conformity with previous findings obtained during 1955 by Talling and Rzoska (1967) indicating that this zone is not affected by the formation of Roseires reservoir. No further records were available after 1970.

Zone II (Roseires reservoir):

Moghraby (1972) pointed out that the formation of the Roseires reservoir resulted in a dense community of zooplankton with an increase up to

316 times more than in the river upstream from the reservoir within zone I. Rotifeors which were particularly absent within zone I were fairly well represented in the reservoir. The zooplankton in Roseires reservoir, typical of that of a tropical reservoir, was characterised by larger numbers of Crustacea than Rotifers; Cladocera were more numerous than Copepoda. The plankton community within the reservoir showed a maximum in November and another during February-April.

No further records were made after 1970 to follow up the impact of Roseires dam on the zooplankton community.

Zone III:

Moghraby (1972) observed that the zooplankton downstream from the dam exhibited a seasonal cycle similar to that in Roseires reservoir although the densities decreased in conditions of free river flow below the dam. No further studies were undertaken after 1970 within this stretch of the Blue Nile.

Zone IV (Sennar reservoir):

Mograby (1972) noted that the densities of the zooplankton in Sennar reservoir were greater than in the river above and even greater than in the Roseires reservoir. The greater concentration at Sennar were attributed to the greater inoculum flowing into the Sennar basin from Roseires reservoir. Comparing the results obtained by Moghraby (1972) with those of Talling and Rzoska (1967) obtained over a decade previously, it is interesting to note that the presumably biologically-

stable Sennar reservoir showed higher densities of zooplankton during 1966-1970 than during the period preceding the construction of Roseires dam.

The seasonal cycle of zooplankton at Sennar reservoir was similar to that at Roseires, with a maximum in November, a pulse in January or February and a peak during March-April (Moghraby, 1972).

Zone V:

Moghraby (1972) recorded a decrease in zooplankton densities at Wad Medani and Hassaheisa (See Map 1). However, the densities of the zooplankton within this stretch were generally higher than those recorded during 1951-1953 by Talling and Rzoska (1967). The seasonal cycles of zooplankton at Wad Medani and Hassaheisa were similar to those at Sennar although the succession and dominance of species differed especially among Crustacea (Moghraby, 1972). Unfortunately no further studies were undertaken after 1970.

Zone VI (Khartoum):

Moghraby (1972) observed that in late October the density and number of species of zooplankton increase abruptly at Khartoum with a peak in February followed by a second peak in May-early June before being washed out in late June. Only Cyclopoids and *Moina dubia* remain in the silt-laden waters of July-October with few adventitious forms. This indicates that the annual cycles of zooplankton at Khartoum during the period 1966-1970 remained remarkably similar to those reported by Talling and Rzoska (1967) some fourteen years previously. However, Moghraby (1972) noted that

Caldocera were more numerous than Copepoda and Diaptomidae were fewer than Cyclopida, thus following the upstream trend.

Ceriodsphnia dubia, C. cornuta and Diaphonosema excisum became less dominant than during 1951-1953. Thermodiaptomus galobi became a prominent member of the zooplankton replacing Thermocyclops neglectus (Moghraby, 1972). Similarly Keratella tropica, K. cochlearis and Filinia longiseta became less numerous in the Blue Nile while Daphnia lumboltzi and D. barbata became more prominent than previously recorded. These changes in the densities of the plankton may be attributed to the influence of the Roseires reservoir.

Table 3

Algae of Blue Nile Water at Khartoum collected during 1951-1953 by Brook (1954) but did not appear during 1968 - 1970

Gonium pectorale
Volvox globator
Pediastrum boryanum var. granulatum
P. boryanum var. longicorne
Sorastrum americanum
Micratinium radiatum
Tetraedron enorme
T. limneticum
T. bifurcatum
Polyedriopsis quadrispina
Westella botryoides
Dimorphococcus lunatus
Cruciginia quadrata
Scenedesmus bijugatus
S. opoliensis
Coelastrum microsporum
C. proboscideum
Ophiocytium capitatum
Euglena granulata
Lyngbya limnetica

Table 4

Algae of Blue Nile Water at Khartoum ollected during 1968-1970 by Sinada (1972) but were not present during 1951-1953

Phacotus lenticularis	T. lacustris
Phacotus sp.	T. dybowski
Pteromonas aculeata	T. pulchella
Golenkinia paucispina	Trachelomonas spp.
Errerella bronhemiensis	Glenodinium sp.
Pediastrum obtusum	G. quadridens
Echinosphaerella limnetica	Stipitococcus sp.
Treubaris triappendiculata	Mallomonas sp.
Lagerheimia spp.	Melosira distans
Selenastrum westii	M. argus
Tetraedron spp.	Atteya zachariasi
Polyedriopsis spinulosa	Synedra capitata
Scenedesmus bijuga	Pinnularia gibba
Scenedesmus incrassatulus var mononas	Epithemia turgida
	Rhopalodia gibba
Staurastrum spp.	Cymatopeura solea
Penium margaritaceum	Surirella capronii
Closterium aciculare	S. robusta var splendida
C. parvulum	S. linearis var constricta
Euglena aous	
E. proxima	S. tenera
Trachelomonas superba	Oscillatoria limnetica
T. volvocina	Oscillatoria spp.

VI. CONCLUSION

The ecology of the Blue Nile River is controlled by the natural regime of rainfall of the watershed area of the river in the Ethiopian plateau. This phenomenon is the major factor causing seasonal variations in current velocity, water discharge, amount of silt delivered downstream of the river and degree of turbidity or suspended matter or transparency. These physical factors by their turn generate changes in the chemical and biological constituents of the Blue Nile River ecosystem. The broad outline of the changes either in time (since 1900) or in region (from the Sudanese border to Khartoum) are pointed out below.

Construction of 2 dams (Sennar 1925 and Roseires 1966) across the Blue Nile River channel brought changes in the discharged water passing Khartoum especially during the low flow season. In the last 3 years (1980-1983) reduction of more than 60 to 70% in the discharge was recorded in comparison of the mean values before the construction of Roseires dam. These new conditions made the river habitat appropriate - during the low flood season - for the appearance and growth of aquatic weeds on the Blue Nile.

Changes in water temperature due to the construction of the dams were recorded, specially in the reservoir zone. Thermal stratification during some times of the year was observed. This took place because of the creation of large masses of water.

Industrial cooling processes are potential sources of thermal water pollution along the Blue Nile. Incidents were recorded where the river water is under use for that purpose.

Changes in transparency and suspended matter in the Blue Nile water were also directly correlated with the Sennar and Roseires dams. Where transparency and silt precipitation in the dams' reservoirs increased, lower values were recorded at Khartoum.

The chemical characteristics of the Blue Nile are unfortunately not fully studied. Basic information on the following is lacking: Biological Oxygen Demand (B.O.D.); Chemical Oxygen Demand (C.O.D.); the heavy metals, copper, zinc, iron, nickel, lead; herbicides, fungicides and insecticides. The scarce available data on the rest of the chosen chemical indicators are summarized in the following:

The conductivity of the Blue Nile water varies with season and from year to year. The range recorded was found between 120-350 umho/cm.

The p^H values recorded showed the same trend of variation between seasons. But the p^H values fluctuated around 8 with lower values reaching 7.4 and higher values up to 9.4.

The surface water of the Blue Nile is in a state of slight oxygen super-saturation (6.0 mg/l). However, incidences of oxygen deficiency below 50% were recorded. In the Roseires reservoir oxygen concentration was found to be a function of depth where with increase of depth decrease of oxygen concentration was recorded. It is to be noted here

that temperature governs the solubility of oxygen gas in water. Diurnal variations in oxygen concentration were stated by many workers.

Phosphate-phosphorus was found to be up to 100 ug/l, but declines with the development of phytoplankton to reach values of 6 ug/l.

High nitrate-nitrogen values recorded reached up to 1000 ug NO_3-N/L during the flood water of the Blue Nile at Khartoum. These values, however, vary with the season and depends upon the development of phytoplankton.

Ammonium-nitrogen was always found to be below 0.50 ug/l.

The major ions were found ranging between 18-34.7 mg/l calcium, 3.5-9.0 mg/l magnesuim, 1.3-3.3 mg/l potassium and 5-15.0 mg/l sodium. These again vary with variations in season.

It is to be concluded here that the literature review and trend analysis showed beyond doubt that the data available in the physical and chemical indicators are scarce, scattered in a large period of time and unified methods for analysis were used. Moreover, the studies were not carried out on the same specific locations/ stations to ensure systematic procedure. For some indicators complete ignorance has been recorded. It is therefore highly recommended that continuous monitoring of the Nile system should be carried out. This can only be done by creating an environmental agency for protection of the environment. The limited resources of the University of Khartoum allow only occasional studies on detection of the changes which are taking place in the environment.

Phytoplankton productivity is a function of nutrients and light. Light does limit the aquatic production in waters which have large amounts of suspended solids that increase turbidity. The Blue Nile in its upper reaches has always had waters with large quantities of silt and detritus. Such conditions affect the plankton growth adversely and the concentrations of phytoplankton and zooplankton in the upper stretches of the Blue Nile are always very low.

In rivers water storage and low current flow favour the increase in number of plankton. Therefore the construction of dams like Sennar dam and Roseires dam initiates lake-like conditions in which the silt settles out, resulting in clearer waters which favour the growth of the phytoplankton and zooplankton.

It has been demonstrated by Hammerton (1972 a), Moghraby (1972) and Sinada (1972) that the construction of Roseires dam in 1966 has exerted profound influence on the biological conditions of the Blue Nile at Roseires as well as downstream at Khartoum. Unfortunately no hydrobiological studies were carried out on the Blue Nile before the construction of Sennar dam in 1925. The effect of the formation of Sennar reservoir on the ecology of the Blue Nile remains largely speculative.

The formation of Roseries reservoir in 1966 has brought noticeable changes in the species composition and densities of the phytoplanton and zooplankton (Hammerton, 1972 a; Moghraby, 1972; Sinada, 1972). Presumably, the Roseires reservoir has become biologically stable by now. Any future

changes in algal flora or zooplankton may result from changes in the chemical and physical features of the Nile. The chemical features of any body of water influence the biomass, diversity and species composition.

Therefore it is recommended to monitor:

i) Total algal biomass by chlorophyll a.

ii) Densities of major components of the zooplankton and phytoplankton communities.

iii) Diversity and species composition of the plankton by making exhaustive species lists of zooplankton and phytoplankton of the Blue Nile.

Previous workers have shown that the concentrations of plankton were very low in the Blue Nile during the annual phase of high flood water between late June-October inclusive. There is no reason to assume whatsoever that these flood conditions will change in the future. Therefore it is not worth the effort to sample the Blue Nile during this period.

Different workers have established that recurrent growth peaks of plankton along the Blue Nile occur during November-December, January-March and in May-early June.

Therefore it is recommended to sample the Blue Nile regularly thrice a year during December, February and early June. For this purpose six stations were carefully selected along the Blue Nile within the constraint of time and facilities (See p.2).

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