A project funded by the United Nations Development Programme/Global Environment Facility (UNDP/GEF) and executed by the United Nations Office for Project Services (UNOPS)

Special Study on Sediment Discharge and Its Consequences (SedSS)

Summary of findings

G. Patterson

2000

Pollution Control and Other Measures to Protect Biodiversity in Lake Tanganyika (RAF/92/G32)

Lutte contre la pollution et autres mesures visant à protéger la biodiversité du Lac Tanganyika (RAF/92/G32)

Le Projet sur la diversité biologique du lac Tanganyika a été formulé pour aider les quatre Etats riverains (Burundi, Congo, Tanzanie et Zambie) à élaborer un système efficace et durable pour gérer et conserver la diversité biologique du lac Tanganyika dans un avenir prévisible. Il est financé par le GEF (Fonds pour l'environnement mondial) par le biais du Programme des Nations Unies pour le développement (PNUD)"	The Lake Tanganyika Biodiversity Project has been formulated to help the four riparian states (Burundi, Congo, Tanzania and Zambia) produce an effective and sustainable system for managing and conserving the biodiversity of Lake Tanganyika into the foreseeable future. It is funded by the Global Environmental Facility through the United Nations Development Programme.

Burundi: Institut National pour Environnement et Conservation de la Nature
D R Congo: Ministrie Environnement et Conservation de la Nature
Tanzania: Vice President's Office, Division of Environment
Zambia: Environmental Council of Zambia

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Sedimentation Special Study (SedSS) - summary of findings

1. INTRODUCTION

This document aims to summarise the SedSS and to define the threat of suspended sediments on Lake Tanganyika. The key questions relate to how do suspended sediments impact on biodiversity and is this in equilibrium or is there an additional threat related to increased human activity in the catchment of the lake. It also addresses other key factors that relate to sediment input including hydrology of the catchment, nutrients associated with sediments and the upstream factors which cause this sedimentary material to be mobilised. The document further suggests a prioritised set of monitoring and research activities to be undertaken in the future.

1.1 Sediment Discharge into Lake Tanganyika and its Consequences - study proposals

At the commencement of the Lake Tanganyika Biodiversity Project (1 August, 1995) the principal aims of this study were identified as:

- Investigation of deforestation within the lake catchment area and the effect of land use changes on the rate of sediment inflow to the lake.

- Quantification of the sediments currently entering the lake with indication of seasonal variations

- Tracing the fate of particles entering the lake (vertical and horizontal transport).

- An investigation of the nature of sediment particles and a consideration of the effect of catchment geology, climate and vegetation on the nature of the sediment input.

- Analysing the impact of sediments on the water column, including the effect of sediments on important limnological parameters which may influence the planktonic communities. This will include impact of sediments directly on these organisms as well as reaching an understanding as to how planktonic communities are impacted.

- Analysing the impact of sediments on the benthic environment. The effect on benthic processes as well as the benthic organisms. This will include taking short cores of sediment to establish historical timing, background fluctuation and rates of reductions in biodiversity.

- To consider long term effects of current (and possibly increasing) rates of sediment input to the lake and to consider its likely impact.

The first objective of the SedSS was the production of the Baseline Review which was examined at the project Inception meeting and the objectives further refined and more precisely defined as the following:

- To give a broad view (by use of low resolution remote sensing) of vegetation changes within the catchment of Lake Tanganyika and their likely effects on rate of sediment input to the lake.

- To produce high resolution imagery of areas of special significance (identified during the preliminary studies of riverine inputs) for time series analysis.

- Upgrading and/or introducing river gauging in a number of specific areas in order to understand amount and seasonality of sediment input.

- Consideration of the near shore hydrology to understand the fate of sediments entering the lake.

- Analysis of sediment physico-chemical nature (which may vary in time or between catchments).

- To consider the limnological processes (nutrient fluxes and light) near shore and the effect of high sediment loads on these processes.

- To perform a whole lake (rapid assessment) survey of sediment (shallow coring). This will derive maps of sediment types, estimations of rate of change of sediment input, a measure of the extent of influence from major river inputs and maps of diversity of benthic organisms.

- To consider the role of important wetlands of the catchment in an attempt to predict the impact of their possible destruction on the sediment load of inflowing rivers.

- To understand the effect of high sediment loads on the trophic structure of the littoral environment. This will included effects on production (including primary production of algae and bacteria), populations of organisms as well as impacts on behaviour, feeding and breeding of these organisms. This will allow and understanding of how increased sediment input affects the ecosystem and, therefore, the biological diversity.

1.2 The Transboundary Diagnostic Analysis

A preliminary part of the development of this Strategic Action Programme was the LTBP Transboundary Diagnostic Analysis (TDA) meeting which was held in November 1998. From this meeting a regional consensus was reached which ranked the threats to the biodiversity of Lake Tanganyika. This ranking not only depended on level of impact but also on whether there were appropriate management interventions which could modify the impact and whether there was any additional benefits from management interventions. These findings are summarised in Table 1 though only limited findings of the SedSS were available to the delegates at this meeting due to many of the studies being incomplete at that stage.

Table 1 Prioritisation of Problems - Control of Sedimentation

Specific Problem	Ranking
Erosion from inappropriate farming practices	High
Deforestation	High
Human settlements badly designed or uncontrolled	Medium
Sand extraction and other activities in river banks	Medium
Overgrazing in plains	Medium
Bad installation or management of mines and quarries	Medium
Unsatisfactory designing or construction of roads	Medium
Erosion from uncontrolled bush fires	Low
Potential mines and quarries	Low

Those specific problems that are scored with a 'High' ranking in the TDA were further elaborated in Tables 2 and 3.

Table 2 Reduction/Control of erosion from inappropriate farming practices

Management Action	Comments
Severity of problem:	*the problem is believed to be serious because the cumulative impact of poor agricultural practices forms the major erosion source, including those which release sediments into the fragile lake ecosystems.*
Feasibility of solutions	*the problem is not easy to solve, because of its scale, the large number of concerned farmers and the constraints they are confronted with. However technical solutions are well known and efforts are underway and intervention strategies are improving on the basis of previous experiences. Despite the scale of the problem, interventions can be concentrated according to the two criteria of agriculture viability and lake protection.*
Additional benefits	*social and economic benefits from a sustainable agricultural development, reduced loss of fertility and associated reduced need for fertilisers.*

Table 3 Reduction/Control of deforestation

Management Action	Comments
Severity of problem	*deforestation, including diffuse deforestation, largely associated with agricultural expansion, is a primary cause of accelerated erosion. The problem is considered to be particularly serious in forest reserves gazetted as protection forests, on the basis of their catchment protection value. The problem covers agricultural clearing, woodland destruction through burning, wood exploitation (particularly for charcoal and, in Tanzania, for tobacco curing).*
Feasibility of solutions	*the problem is hard to solve, but multiple responses are known, and are locally implemented. A favourable social climate exists in at least one part of the region and despite the scale of the problem, it is possible to focus efforts on the most critical areas.*
Additional benefits	*a control of deforestation and actions in favour of agroforestry would lead to obvious benefits in terms of production of wood and other products, land conservation, water control and conservation of forest biodiversity (including regional endemic species).*

2. METHODOLOGY FOR SedSS

2.1 Introduction

The methodology chosen to conduct the SedSS relied on identifying teams to conduct aspects of the work based on their particular expertise and in some cases institutional responsibility. The work carried out, and the principal personnel involved are listed below in Appendix 1. This strategy was agreed at the Project Inception meeting where gaps in knowledge were discussed and the researchable gaps were identified. This resulted, however, in different activities taking place in different places to some extent and the SedSS has to rely on communicating these findings throughout the region and assessing how well findings in one area are transferable to another.

One of the clear issues raised through the study Baseline Review and the Inception meeting was the dearth of long-term monitoring data on the linkages between the lake and the catchment (principally river flow and suspended load). These data, if they had been available, would have provided indications of the impact of sedimentation on the lake and whether the situation that currently exists has already been affected by human-induced changes (distinguishing natural and man-made impacts). These measurements are clearly needed to assess whether the threat currently exists as well as to forecast the future impacts.

Therefore one key activity that was initiated by the SedSS was the establishment or restoration of river gauging stations in a number of key locations in the catchment and these were intended, not only to provide data for the project itself, but had also been identified (early in the project) as one of the key areas where future monitoring activities would be required. The findings of the SedSS have not caused us to change this view but rather to reinforce it (see section on monitoring below).

2.2 Reporting and the questionnaire

The principal output of the SedSS was a series of technical reports. These form the background documents, along with the baseline review, which support the technical findings of the SedSS. The findings reported in this document are partially a synthesis of those technical documents; additionally a questionnaire was sent to all participants in the SedSS which specifically guided them to consider their findings in light of the priorities established by the SAP document (see above). The results of these are summarised below and are intended to form a consensus of the expertise drawn together to conduct this Special Study. A list of all participants in the SedSS is given in Appendix 2.

3. KEY FINDINGS OF THE SedSS

The key findings of the SedSS are included in the following series (Table 4) of technical reports available on the internet at web address http://www.ltbp.org/PDD5.HTM. They are also included on the final project CD. A summary of these reports is given in Appendix 1.

Table 4 SedSS reports

Report number	Authors and date of production	Title	No. of pages & file size
1	O'Reilly, C. 1998.	Impact of sedimentation on primary production.	21p. - [492K]
2	Cohen, A. S., M. R. Palacios-Fest Dettman, D, Msaky, E, Livingstone, D. and McKee, B. 1999.	Paleo-limnological investigations.	165p. - [2.1Mb]
3	Duck, R. W. and S. F. K. Wewetzer. 1998.	Side-scan sonar and echo-sounding surveys of the southern end of Lake Tanganyika.	24p. - [992K]
4	Sichingabula, H. 1999.	Analysis and results of discharge and sediment monitoring activities in the southern Lake Tanganyika basin, Zambia.	105p. - [1.7Mb]
5	Drake, N., M. Wooster, E. Symeonakis, and X. Zhang. 1999.	Soil erosion modelling in the Lake Tanganyika catchment.	67p. - [8.4Mb]
6	Eggermont, H. 2000.	Impact of sediments on the larval chironomid fauna of river deltas.	4p. - [164K]
7	Brion, N., E. Nzeyimana, L. Goeyens, D. Nahimana, and W. Baeyens. 1999.	Nitrogen dynamics in northern Lake Tanganyika.	12p. - [520K]
8	Sebahene, M., M. Nduwayo, T. Songore, G. Ntungumburanye. 1999.	Travaux Hydrologique et d'echantillonnage sédimentologique du Bassin du Lac Tanganyika (Burundi).	74p. - [1.63Mb]
9	Irvine, K., I. Donahue, E. Verheyen, R. Sinyinza, and M. Taylor. 2000.	Impact of sedimentation on biota.	80p. - [320K]

Table 4 continued

10	Kakogozo, B., N. Kahindo, B. Mwenyemaile, and O. Drieu (ed.). 2000.	Etude Hydrologique du Bassin Nord-Ouest du Lac Tanganyika (R. D. Congo).	44p. - [1.3Mb]
11	Nkotagu, H., and Mwambo, K. 2000.	Hydrology of selected watersheds along the Lake Tanganyika shoreline.	111p. - [711K]
12	Swarzenski, P.	Riverine delivery of contaminants and nutrients in impacted vs. non-impacted sites[1].	
13	Duck, R. W. 1998.	Kigoma Master Water Plan. [Report on the volumes of the plan held by LTBP].	9p. - [25K]
14	Bryant, A. 1999.	Monitoring and explanation of sediment plumes in Lake Tanganyika (M.Sc. Dissertation).	92p. - [4.6Mb]
15	Irvine, K. and I. Donohue. 1999.	Review of taxonomic knowledge of the benthic invertebrates of Lake Tanganyika.	38p. - [76K]
	Huttula, T. (ed.). 1997.	Flow, thermal regime, and sediment transport: Studies in Lake Tanganyika. Kuopio University Publications C. Natural and Environmental Sciences[2]	73. 173 p. - [4.3Mb]
	Patterson, G. 2000.	Sediment Discharge and Its Consequences Special Study (SedSS) - Advice to the Strategic Action Programme.	22p. - [136K]
	Patterson, G. 2000.	Sediment Discharge and Its Consequences Special Study (SedSS) - Summary of findings (**i.e. this document**)	22p. - [151K]

The findings listed of the individual groups listed in Table 4 and Appendix 1 are complex and require careful interpretation.

3.1 Severity of impact

In summary, the severity (threat to biodiversity) of the problem of input of suspended solids to the lake is regarded as high and this has probably already resulted in some recent loss of diversity in parts of the lake. This is the consensus of those participating in the special study as well as that of the technical panel gathered at the TDA. It may proved difficult to rank whether increased sediments or increased nutrients form the greater single long-term threat to the lake, but since these are so closely linked they cannot and should not necessarily be isolated. The Pollution Special Study (PSS) has confirmed that eutrophication, caused by increased nutrient inflow, is not an immediate threat therefore the impact of suspended solids is a principal and current threat to the lake's biodiversity.

Even without the evidence presented here (using the precautionary principal) it would seem clear that efforts should be made to reduced input of sediments to the lake. Lake Victoria stands as an example of how a large lake can change rapidly - Lake Tanganyika with its larger volume and lower riparian populations may not yet have seen dramatic change, though clearly the balance between the lake and the catchment has shifted over the last 50 years or so with an increase in dissolved and suspended runoff threatening the pristine nature of the lake.

The participants of the Sedimentation Special Study agree that land use changes and the increase in inflow of suspended matter (and the concurrent increase in inflow of major plant nutrients) is a very real threat to both the biodiversity of the lake and the sustainability of livelihoods which depend on the production of the lake.

To reduce the transport of sediment and nutrients to the lake has another clear benefit since their increased inflow to the lake represents an important loss of both soil material and fertility from the agricultural systems of the catchment. In this sense, what happens in the lake may reflect a much

[1] Work not carried out under the project and not completed to date (31 July2000)

[2] This work was carried out for LTBP under the Interagency Agreement between UNOPS and FAO

greater human catastrophe as agricultural production in the lake's catchment is compromised. Management of the lake therefore has a double benefit as it is the ultimate recipient of these terrestrial losses and therefore not only does it assess the threat to its unique biodiversity but it also acts as useful indicator of catchment activities.

In addition the same factors which cause increases in sedimentation also may result in increased flooding during the rains which could cause major damage in high density population areas (due to the lower capacity of the catchment to retain rainwater) and this could be another key management issue.

3.2 Summary findings of the SedSS

This summary combines the findings of all the SedSS participants (see Appendix 1)

- There is strong evidence of large increases of suspended solids entering the lake compared to historical rates of input

- It is clear that this is due to a combination of woodland clearances and agricultural practices carried out in the catchment

- There is strong evidence that the increase in sediment input is correlated with an increase in nutrient and organic matter input to the lake though signs of eutrophication are, as yet, limited

- There are some complex factors which affect the distribution and therefore impact of sediment within the lake. The evidence suggests that medium-sized catchments are particularly responsible for changing the ecology, and therefore the biodiversity, adjacent to their river mouth (catchments of approx. 50 km_-4000 km_). These factors therefore have a strong regional component

- The distance that sediments are transported are influenced by the season and the topography of the lakeshore close to the river mouth. Sediment can be transported in significant quantities at least 10 km from source. and impact is most likely where rivers discharge onto relatively gently-sloping lake floors

- There is a dearth of long-term monitoring data which could have been used to monitor changes of the dynamics of suspended sediments. Recent measurements have quantified suspended sediment input for a number of rivers and it is felt essential that this monitoring should continue as part of the routine function of the appropriate national institution in all four countries

- The current rate of influx of sediment is well above historical levels and is likely to increase (or at least stay high) if deforestation is not controlled and/or more efficient soil conservation measures are not initiated.

- Work of this project and work described in the literature suggest that diversity in a particular inshore region of the lake is negatively correlated with sediment input and it has therefore had a role in dictating the distribution of organisms over a long period.

- It is clear that recent increases in suspended sediment loads have led to a reduction in the distribution of the most diverse habitats (rocky surface) as well as directly reducing diversity.

3.3 Linking with other LTBP Special Studies

This report principally summarises the findings of the SedSS though there is much written here on the other dimensions of the whole project and the overlap with the other special studies. All Special Studies within this project are directed towards conservation, with the priority of maintenance of diversity (with special value placed on endemic species) within the lake system. As is pointed out by the Biodiversity Special Study (BioSS) the principal threat is therefore to the narrow littoral band around the lake where the majority of species reside. Further it is the rocky habitats that hold the greatest diversity and therefore take the highest priority in regard to conservation. The Fishing Practices Special Study (FPSS) suggests that it is unlikely that these areas are threatened by overfishing (or damaging fishing practices) and it would seem the principal threat is increased sedimentation causing damage to the organisms present as well as the loss of habitat with siltation causing previously hard substrate to be lost. BioSS recommend a 'coastal zone management' approach to conservation with the zoning of coastal habitats with respect to both their conservation value and the degree of threat. It must be stressed that the principal threat may be a point source of suspended matter (a river mouth) some kilometres away from the site of interest and the cause may be at a much greater distance, higher in the catchment, where changing land-use practices are resulting in increased erosion. As stated here, catchment size and underwater topography are important issues regarding the distribution of sediments once they enter the lake - horizontal sediment transport within the lake is one of the less well understood facets of the work carried out, as it is affected by a complex range of dynamic factors (such as physical characteristics of material, bottom topography, wind, water density etc.). It has been shown by the lake circulation work (Table 4) that sediments can be transported up to 10 km from the mouth of the Lufubu and the Malagarasi.

In regard to some form of coastal zoning the SedSS concludes the following.

Littoral sites within 10 km of the point of discharge of a catchment of the medium size range (50-4000 km_) would appear to be most threatened by any changes in erosion rate within that catchment (most likely caused by deforestation or change in farming practices). In addition change in catchments that originate in the areas demarcated in Figure 1 of the SedSS report 'Advice to the Strategic Action Programme' (Table 4) are particularly vulnerable and should be regarded as a key threat to littoral areas close to the point of discharge from these areas. Littoral areas adjacent to smaller catchments of < 50 km_ (particularly if the lakeshore is steeply shelving as is usually the case in these areas) will be less affected by catchment activity and those close to larger catchments (>4000 km_) are unlikely to be affected in light of their long history of input of suspended matter.

4. RECOMMENDED MONITORING AND FUTURE RESEARCH

The difference between research and monitoring is simply that monitoring work should be carried out indefinitely and therefore these programmes must distinguish of priorities in light of the limitations of recurrent budget. Research indicates the necessity to establish important answers that are required to reach a greater understanding of the complex linkages between sediment input to the lake and other physical and biological factors. Obviously some overlap between the two exist and the level of priority given below is a consensus from all participants in the project and are a compromise between the different participants who see priorities differently. Some of the site specific comments have been removed since there is a great deal of overlap throughout the study they often apply more widely than in the specific locations of which the respondent may be more familiar.

4.1 Monitoring

High priority

Most comments in this section refer to the continuation (and addition to) the river monitoring network set up by the project. Most participants see the value of routine river monitoring and recognise the inadequacy of the data that was available prior to the project. The network established by the project (19 gauging stations) can be considered as a minimum and most recognise that a much more widespread system of river monitoring would be appropriate in gaining an understanding of hydrological issues in the catchment of the lake as well as gaining a deeper insight into soil erosion (causes and extent) affecting the catchment. This monitoring programme is the key to establishing long-term trends. Other comments within this section note the key requirement of maintaining the infrastructure to deal with this monitoring programme (and all associated research activities).

- Continue to measure discharge and water levels on studied rivers and lake - this should be carried out by the appropriate government institution and the network reviewed and probably expanded

- Determination of suspended sediment concentration of selected studied stations

- Determination of dissolved solids of selected studied stations including key nutrients which indicate fertility (N, P and Si)

- Identification and classification of high, medium, and low – risk shorelines (with respect to sediment input potential - links with BioSS recommendations on coastal zone management) around the lake. This should also break down the land use patterns into relatively discrete uses so that management can be more effective (i.e. deforestation, agriculture, centres for fishing activity, etc.)

- Efforts should be made to harmonise methodologies for all future monitoring work to improve the ability of different teams to compare results

- The Lake Tanganyika Authority (as defined in the SAP) should assess periodically (1-3 yearly) involvement and capacity of local institutions to carry out monitoring programmes and instigate a programme to improve this capacity where/when it is required.

- Continued training of key personnel in methodologies

- Maintenance of infrastructure (e.g. boat and basic lab facilities) to permit monitoring and research activities. The use of other institutions (schools etc.) in the monitoring work should be explored.

- The key water balance figures for the lake as a whole are not available. More detailed monitoring of rainfall, evaporation, water level, inflows and outflows would improve this situation (some of these have been initiated by the project). When security permits the establishment of a gauging station at the single outflow from the lake (the Lukuga River in DRC) should be a high priority

Medium priority

- Atmospheric SS-load, it is suggested that two monitoring stations, one in north and one in south for assessing atmospheric load (of dust particles and key nutrients) be established

- Mapping of sediment plumes and sediment extent near river mouths. This could be via remote sensing and echo-signals. This would usefully be done pre and post rains.

- Application of the erosion model and its routine use (see below for further research requirements for this work)

- Establish a sediment trap monitoring system as part of the ongoing monitoring program of sediment discharge at selected stations (this could be included as research as it is unlikely a long-term programme would be achievable with limited resources)

Low priority

- Ecological studies on animal biota and their response to increasing sediment loads. This could involve both field and laboratory studies of “model” organisms (work already initiated by the project).

- The routine measurement of benthic primary productivity, suspended and settled sediments, and algal biomass at the sites of different impact levels.

- Plume Detection - estimating lake sediment inputs by directly detecting sediment plumes in the lake using satellite imagery. Our investigations indicate that this has significant potential but further research is necessary (see below).

- Initiate one or a number of fixed stations to make vertical profiles to assess vertical variability and therefore improve on models of circulation within the lake

4.2 Research

High priority

- Obtain detailed sedimentation rate information across a small number of target deltas, to allow for meaningful modelling efforts to link lake sedimentation rate and hydrologic sediment flux data sets.

- Undertake botanical surveys and surficial pollen samples in the target catchments to fully interpret the palynological data we have acquired.

- Further investigate the complex chemistry by which suspended sediment acts as carriers of pollutants and nutrients (particularly N & P) in the lake. This may allow for surrogate data for nutrient inputs to be obtained from monitoring of total suspended solids in rivers

- Initiate a programme of mineralogical and chemical (including isotopic analysis) studies of the sediments to understand their source, behaviour and possible impacts. This may be a powerful tool for discriminating proportionate fluxes of muds from various river sources.

Medium priority

- Continued development of the erosion model leading to its routine application. This would involve validation of the erosion and routing model results against existing discharge and sediment yield data and improvements in for example the routing model and the rainfall estimation. Because of the limitations provided by the coarse resolution of the model, it would be most effectively used if it formed part of a more complex, multi-scale modelling package. An initial multi-scale investigation of an area identified as significantly eroding is the first stage in developing this process and one that we recommend

- Establish a water quality numerical model for the lake, focussed on nutrients and pollutant mass balance hydrodynamics

- Improve knowledge on the bathymetry of the lake, particularly in deltaic regions, in order to better understand the patterns of sediment transport and dispersal from influents

- Begin gradient analyses of sediments and benthic invertebrate distributions across the target deltas to clarify the extent to which the accumulation of these indicators reflects original distribution or transport and develop transfer functions to relate impacts with subsequent biotic responses

- Further investigate the climate trigger-soil erosion hypothesis advanced in this study by looking at other river systems for a 1961 (see findings of the paleolimnolgical group in Appendix 1) event. This may also be advanced by analysis of repeat photographs of well-located delta sites, and the secondary analysis of core material with higher precision geochronologic tracers than ^{210}Pb.

- Monitor to what extent the neighbouring wetland areas act as a sink of both sediments and pollutant

- Research to allow direct identification of the conditions giving rise to plume sinking/floating and for converting of satellite images to estimates of actual suspended sediment concentration within the plume. A combination of *in situ* and satellite data collection and cross-calibration will be required

- Investigate the mobilisation of deep sediments under extreme conditions

Low priority

- Examine the complexation of sedimentary constituents with iron oxides; pore waters can be very high in reduced iron. Also to investigate how this complexation affects the delivery and availability of such nutrients as PO_4 to benthic organisms

- Carry out an ecological study of benthic diatoms, since more data from more sites may allow for the identification of benthic community assemblages that indicate a decline in the health of the aquatic ecosystem

- Investigate the distribution of fires in the catchment and to understand to what extent does fire outbreak enhance sedimentation rates

5. MANAGEMENT ACTIONS

5.1 General

The questionnaire (Section 2.2) asked all participants in the SedSS to consider what outputs of their study could inform management actions. The output of the TDA regarding sedimentation issues was offered to assist this (i.e. Tables 1, 2 and 3). Encouragement was given to consider any other management issues. This section considers the general problems and then considers specific options for amelioration. Again it should be stressed that this is a **win-win** situation where loss of soil and fertility is a major threat to agriculture as well as causing downstream damage to the lake.

As a management action it is clear that more viable agricultural practices be implemented where possible. High erosion seems to occur primarily due to land clearing for cultivation. The erosion may be so severe as to expose bedrock in some cases. Some of the methods for reducing erosion from farmed areas are listed below.

Deforestation is closely associated with the agricultural problem. Benefits of tree planting can be numerous, including water, nutrient and soil retention. Apart from reducing erosion the planting of trees has also many additional benefits long recognised by agronomists including sustainable wood supply (mainly for firewood and building materials), shade, fruit production and the use of leguminous tree species which can act as an alternative to fertilisers (which would ultimately add to the nutrient burden of the lake). Tree planting programs could focus on shade and fruit trees in areas around houses. Native trees could be planted on the more severe slopes and these areas possibly designated as forestry reserves. A further threat created by the removal of vegetation is the increased potential for flash floods and soil slips which form a danger to life and property.

Other issues to address include increased inputs from population centres. This involves sediment erosion from areas cleared for building, river bank denudation, etc., but also is concerned with nutrient inputs. These may be in the form of terrestrial organic matter, the decay of which can reduce oxygen concentrations. Some of this organic material may be due to increased erosion of soil organic matter, but evidence suggests that some of it is in the form of sewage (see additional research note below). The development of sanitary waste disposal would be of great benefit both to the local communities and to the lake. The use of community compost heaps may be practical for both deposing of organic food wastes and as a soil fertiliser, particularly in areas of high population density.

Burning is another issue that contributes to deforestation and increased erosion. Occasionally, burning of grasslands may occur solely for the purpose of maintaining a monopoly in grass production (for roof thatching) or pest control. More work needs to be done to determine the reasons for much of the burning that occurs and education and alternatives need to be provided.

Measures to control the rate of erosion and deforestation clearly need to be applied. The modelling study (see Appendix 1) have tentatively identified five broad regions where these control measures appear to be particularly warranted. Area 1 - north-western Burundi (extending into Rwanda), Area 2 - north western lakeshore region in DR Congo, Area 3 - close to the Burundi shoreline near the Tanzanian border, Area 4 - western Tanzania (highland area east of Mahale) and Area 5 - DR Congo (these are highlighted in Figure 1 of the SedSS report 'Advice to the Strategic Action Programme': Table 4). Deltas draining from some of these same areas have been shown by the paleolimnological work (Report 2, Appendix 1) to areas of combined high sedimentation risk (currently unimpacted or lightly impacted catchments, with large area and low offshore slopes) and are particularly likely to show rapid degradation following future impacts and are probably more easily regulated by sound catchment management practices than are areas that have already been severely degraded. Some are also shown to drain into areas of high biodiversity (such as Mahale national park) and would prove attractive test areas for the establishment of erosion control measures prior to their excessive exploitation.

Participants in the SedSS therefore **basically agree** with the Table formulated by the TDA prioritising the threats caused by enhanced sedimentation and the areas in which management should operate. Obviously most participants in the special study have expertise in understanding the dynamics of sedimentation and its impacts on the lake rather than have management responsibilities. However there is a general understanding of what specific methods would be appropriate to reduce erosion, and the increased input of sediments to the lake, and these are listed here. It is generally agreed that the over-arching management action is **environmental education**. Having identified the problems and prioritised them, nothing can improve unless these practices are stopped, minimised or undertaken in a controlled way (e.g. development of human settlements). The message of environmental education must get passed down from management to the local people who potentially do not realise the consequences of their actions with respect to sedimentation.

5.2 Specific management practices

Specific management practices that should be considered. These are approximately in order of importance dictated by the stress given by the questionnaire respondents (Section 2.2).

- To limit as much as possible tree cutting and initiate a programme of reforestation. This should be undertaken and concentrated in the upstream section of the catchment where maximum erosion normally occurs and using appropriate tree species that do not result in the depletion of groundwater resources that sustain surface water flows during the dry season.

- To practise terraced farming on sloping lands

- To find out the best use of the available soil, which means the necessity of selecting the most suitable farming practices according to climate, soil and the needs for the human beings.

- To reduce or prevent stream bank cultivation where erosion can be severe

- To require industrial activity (such as extraction of sand and other activities in the river beds) to conduct an environmental impact assessment (EIA) and apply appropriate measures if potential damage is envisaged

- To legislate for a required programme of reforestation during and after industrial development

- To find alternatives to charcoal production which is a major cause of deforestation in some areas

- To more carefully manage bush burning in the region

- To protect land owners and offer them suitable compensation if the management measures required cause them to have less land under cultivation

- To construct sediment retention dams during road construction or in other locations where erosion threatens

- To impose stricter building regulations designed to reduce erosion

- To limit off-track driving

All the above are considered sensible guidelines. Clearly the application of these management methods require either rules or legislation and enforcement of these by either agreement or by fair and even policing. All respondents were aware that the protection of livelihoods of those people dependant on the land was a key priority.

Regarding the situation of underwater reserves the respondents were cautious about making specific recommendations, particularly without the results of thorough lakewide habitat and biodiversity surveys, but made the point that adjacent catchment protection was a key to protection of near-shore environments.

6. CONCLUSIONS

The general consensus of the SedSS participants is that the problems of excess sedimentation is a major threat to the biodiversity of Lake Tanganyika and further also indicates a problem of soil and nutrient loss in the catchment. Littoral sites within 10 km of the point of discharge of a catchment of the medium size range (50-4000 km_) would appear to be most threatened by any changes in erosion rate within that catchment. In general the SedSS participants reinforced the view that the priority threats and management outlined by the TDA in Table 1 of the are accurate. They have also suggested monitoring priorities and researchable questions which would greatly benefit future natural resources management of both the lake and the catchment.

This document marks the conclusion of the first phase of the GEF Lake Tanganyika Biodiversity Project. This study has set the framework for future work and it is hoped that the recommendations given here will be taken forward by further phases of the project in order to protect the integrity of this great lake.

G. Patterson 31 July 2000

APPENDIX 1 Sub-components of the SedSS (as listed in Table 4) - Individual reports, objectives and key results

Title and number of Report	Principal Participants	Main Objectives of study	Main findings of study
Report 1 Impact of Sedimentation on Primary production	O'Reilly	· To compare the following in impacted and forested catchments: net primary productivity, respiration, algal biomass, light availability, inorganic material settled on rock surface · To examine seasonal variation in benthic primary productivity. · To examine to effect of upwelling on benthic primary productivity.	· Benthic net productivity does not differ significantly between the forested and deforested catchment. · Benthic respiration is significantly higher at the impacted catchment. · There are significantly greater amounts of inorganic material on the rocks at the impacted site. · Algal biomass is significantly higher at the impacted site. · There is significantly less oxygen in the water at the impacted site. · Seasonal variation in net productivity and respiration is not significant in the Kigoma area sites but are significant at the Mpulungu site.
Report 2 Paleo-limnological Investigations	Cohen, Palacios-Fest, Dettman, Msaky, Livingstone and McKee	· Document patterns of historical change in sedimentation rates and their relationship to possible changes in catchment forest cover and/or agricultural practices through paleolimnological investigation of lake sediments at the study sites. · Determine the inception of significant changes in sedimentation and indicators of catchment condition in regions of Lake Tanganyika with varying modern human population, and relate these paleolimnologically-recorded changes, where possible, to historical records. · Understand the interplay between climatic factors and anthropogenic-driven changes in sedimentation style and rate, particularly during intervals of rapid change. · Identify possible relationships between changes in sedimentation rate or quality of sediment input and lake ecological change over the study period, again using paleolimnological methods. · Identify regions or catchment types whose deltaic regions have been particularly sensitive to deforestation-related changes in sediment loading over the past few centuries.	· Many cores show increases in tree pollen and fern spores at the expense of grass pollen over the past few centuries. We interpret this surprising finding as the probable result of conversion of low elevation landscapes from mixed grassland/woodland to subsistence agricultural land use. · Increased sedimentation rates at several of our study sites (3x increases in rate at some Tanzanian sites and up to 9x in northern Burundi) and correlated changes in the bulk composition and stable isotopic signature of sediments and is most likely a result of increased hydrologic discharge and erosion rates on a progressively deforested landscape. · These changes are evidenced in the northern parts of the lake prior to the 20th century, although a major acceleration of change dates to 1961 or thereabouts linked to high rainfall triggering an increase in erosion · Invertebrate communities (especially ostracode crustaceans) and their fossil record in Lake Tanganyika have responded to these catchment changes in complex ways. Under regimes where disturbance is very high and total sediment input is increasing, diversity is invariably low, and communities are dominated by species tolerant of sediment loading. · Taken as a whole, the results suggest that the susceptibility of coastal (littoral, sublittoral and profundal) ecosystems of Lake Tanganyika to direct sedimentation impacts varies, depending on the nature of the hinterland catchment and underwater slope conditions. Larger catchments**,** particularly those discharging onto relatively gently-sloping lake floors, e.g. those studied in northern Burundi, are at greatest risk.

Report 3 Side-scan sonar and echo-sounding surveys of the southern end of Lake Tanganyika	Duck, Wewetzer, Sinyinza and Syapila	· Side-scan sonar survey of Musende Bay between the LTBP Station and Kasakalawe Point, together with a programme of bottom sediment sampling to aid the interpretation of sonographs. · Bathymetric survey of Musende bay to augment the side-scan sonar survey. · Bathymetric survey of the delta of the Lunzua River, together with a programme of bottom sediment sampling.	· The relative simplicity of the bathymetry of Musende Bay on the large scale but its complexity on a small scale. · The discovery, using side-scan sonar, of a suite of shore parallel terraces underwater that may be linked with former, dated low stands of the lake. · The possible existence of microhabitats within the ‘treads’ and ‘risers’ of the near-shore terraces. · The acoustic imaging of the patchy zonation of sediment types, the zonation typically indicative of variations in the shell content of living and dead molluscs. This concurs with the general findings of Coulter who reported that gastropods and bivalves in the lake tend to be localised in optimal habitats and their distribution tends to be ‘patchy’ · The observation of near shore sets of interfering wave ripples indicative of the movement of mobile sands by winds blowing dominantly from the north-east and subordinately from the north-west. · The bathymetric map produced of the Lunzua delta reveals that it has a simple morphology characterised mainly by slopes of less than 0.5°. The broad flat shelf is indicative of a large zone of sediment accumulation. · The absence of distributary channels in the Lunzua Delta.
Report 4 Analysis and results of discharge and sediment monitoring activities in the southern lake Tanganyika basin, Zambia	Sichingabula	· To establish six new stations for discharge and water level and sediment monitoring in the southern Lake Tanganyika basin · To determine the physical and chemical characteristics of the streams draining in to the lake · To determine particle size distribution of bed material sediment near river mouths of five study catchments · To assess local people's capacity to contribute positively to the project and be involved in the programme · To assess the impact of human activities on the hydrological regimes and other related aspects of the study streams	· Mean flow discharges n study rivers were found to range from 1.43 m_ s-_ on Izi River to 98.6 m_ s-_ on Lufubu River · Mean 'annual' clastic suspended sediment deposited into Lake Tanganyika by study rivers was found to range from 1.25 tonnes on Izi River to 208.8 tonnes on Lufubu River · Total volume of discharge draining into Lake Tanganyika by study rivers in the study period was found to range from 31.4 million m_ yr-_ for Izi River to 2.2 billion m_ yr-_ for Lufubu River · The total volume of suspended sediment deposited into Lake Tanganyika by the study rivers was found to rang from 318.2 tonnes yr-_ for the Izi River to 53,818 tonnes yr-_ from the Lufubu River · Water levels in Lake Tanganyika varied 2.0 m over the study period and 11.0 m over the period 1957-1992 for which archival data are available

Report 5 Soil erosion modelling in the lake Tanganyika catchment	Drake, Wooster, Symeonakis and Zhang	· To implement a regional scale soil erosion model of the Lake Tanganyika catchment and the surrounding area on a daily to dekadal time step in order to assist study of erosion in the catchment. The model should have a 1-8 km pixel size, and be driven by a combination of remote sensing, GIS and meteorological data inputs. · Using this soil erosion model to perform a retrospective study for the 1996 wet season in order to assess feasibility of using the model for long term monitoring. · Determine the optimal methods for incorporating spatial estimates of rainfall into the soil erosion model, concentrating on a comparison of interpolated rain gauge data and remote sensing derived rainfall estimates. · Investigate erosion to assist estimation of actual sediment inputs to the lake. · Define areas within the catchment that are most sensitive to erosion by predicting likely increases in erosion rates based on scenarios of extreme rainfall events, land degradation and deforestation. · Develop a demonstrator for real-time erosion prediction using data from the real-time (LARST) AVHRR receiving station, currently based in Kigoma, Tanzania	· The soil erosion model, implemented with remotely sensed estimates of vegetation cover, GIS-based estimates of soil erodability and topography, and remote sensing or meteorological estimates of rainfall provides a tool for the delineation and investigation of source areas of erosion in the catchment. The model is very sensitive to rainfall and satellite-estimates appear to be the best as they are spatially explicit (rainfall measurements being sparse in many areas). · Previous spatial studies of lake sediment inputs have simply assessed forest cover to determine those catchments most likely to provide increased sedimentation due to deforestation. Our model provides a more direct method for estimating sediment affected areas of the lake, supplies source-area maps, and thus provides a significant improvement understanding of the pollutant that provides the most immediate and significant threat to the lake ecosystem. · The results of the retrospective feasibility study and the real time demonstrator show that linking the regional scale erosion model to a routing algorithm can provide broad-band estimates of the quantity of sediment transported into the lake, which in most cases appears to support the existing interpretation of sediment delivery (i.e. most sediment enters at the northern end of the Lake). However the current routing algorithm appears to break down in regions of low topography (e.g. parts of the Malagarasi river) · Within the Lake Tanganyika catchment there is only one large area in western Burundi that appears to be actually subject to very severe erosion (because it always appears to have low vegetation cover). However, many catchment areas were susceptible to erosion during 1996 (having very low vegetation cover on steep slopes at certain times of year). At these locations severe erosion would occur if rainfall was also significant at these times. If forests were to be removed from western Tanzania then erosion would also be most severe here. · Results show that operational implementation of the model could provide the riparian nations with up to date information on erosion and sediment yield that could be used to target research and co-ordinate remediation.
Report 6 Impact of sediments on the larval chironomid fauna of river deltas	Eggermont	· to investigate the impact of sedimentation on the chironomid fauna of the Lake by comparing species assemblages from river deltas from undisturbed catchment areas (Gombe, Lubulungu, and Kabesi) with five highly disturbed areas (Mwamgongo, Gatorongoro, Nyamuseni, Karonge/Kirasa & Luiche)	· Results suggest that does not have a dominant impact on the diversity and species composition of chironomid faunas in Lake Tanganyika. · The high specificity of the fauna in each river delta emphasises the importance of a conservational strategy that covers the largest possible length of Lake Tanganyika shoreline

Report 7 Nitrogen dynamics in northern Lake Tanganyika	Brion, Nzeyimana, Goeyens, Nahimana and Baeyens	· to determine the importance of rivers (study conducted in Burundi) as nutrient sources for the water column in the northern part of the lake including the determination of seasonal variations of the nitrogen load resulting from the most important affluents; · to determine the seasonal distribution of nitrogen in the surface waters of the lake; · to contribute to the determination of internal nitrogen fluxes in the surface waters of the lake by measuring seasonal variations of nitrogen uptake by phytoplankton.	· The annual dissolved inorganic nitrogen (DIN) load discharged into the lake represents 477 T of N with most of it the oxidised NO_2 & NO_3 form. · The most important contributor is the Rusizi River with 450 T of nitrogen mainly under the oxidised forms. The Mutimbuzi only represents 11 T of N, mainly nitrite and nitrate, and the Ntahangwa 16 T of N with here an important proportion of ammonium (7 T): that is easily understandable since we know that this river passes through the city of Bujumbura where it receives domestic wastewater. · During the wet season the nitrite and nitrate concentrations were almost always below the detection limit (0.05 µM) and ammonium was the most abundant N source, however, with concentrations never exceeding 0.2 µM. During the dry season, DIN concentrations increased up to 18 µM with nitrite and nitrate being the most abundant. · Data on phytoplankton uptake results are not all available with only the wet season data analysed. Results were extremely variable with specific rates ranging from 0.0002 to 0.02 h^{-} _ with ammonium and nitrate being the dominant N forms being taken up, showing a variable N uptake regime of phytoplankton. We see that even with very low ambient nutrient concentrations (nitrate and nitrite were at the detection limit), the nitrogen uptake rates are quite important suggesting a very rapid N-cycling: nutrients are taken up at the same rate as they are produced or supplied.
Report 8 Travaux Hydrologique et d'echantillonnage sédimentologique du Bassin du Lac Tanganyika (Burundi).	Sebahene, Ntungumburanye, Songore and Nduwayo	· To evaluate the volume of sediments which enter the lake as suspended materials by monitoring six rivers in the Northern and North-Eastern part of the Burundian shore of the Lake Tanganyika basin, · To determine particle size and mineralogical distributions of bed material sediments · To determine the physical and chemical characteristics of water in these six rivers. · To evaluate the impact on the biodiversity of the Lake Tanganyika of the excessive sediments inputs due to human activities. · To evaluate the impact of human activities on the hydraulic regimes of the rivers (in conjunction with Socio-Economic Special Study).	· Evaluation of the quantity of sediments currently entering the lake, including seasonal variations · River gauging in some specific areas in order to estimate the quantity of sediments and the seasonal variations of the sediments into the Lake. · Evaluation of the physical characteristics of the sediments entering the Lake. · For the Gatorongoro area the volume of sediments directly discharged into the lake during the past year was estimated to be 11,000 tons, a large part of it was discharged during the rainy season (from January to April 1999).
Report 9 Impact of sedimentation on biota	Irvine, Donahue, Verheyen, Sinyinza & Taylor.	· The monitoring of the Lunzua, Kalambo and other (e.g. Lufubu) river mouths in relation to patterns of sediment distribution. · Field experiment to establish recolonisation of rocky substrata following disturbance by sediment · Establishment of aquarium facilities and measurement of invertebrate life history traits when subjected to varying sediment loads.	· Monthly monitoring off the mouths of the Kalambo and Lunzua rivers has been ongoing since Jan. 1999 and intensive sampling of the Lunzua, Kalambo and Lufubu have been done in March and September 1999. · Overall there is a decrease of both number of taxa and overall densities of animals in the wet compared with the dry season. · In sediment-addition field experiments on rocky habitats a negative impact of sediment on gastropod populations was demonstrated. interpretation of results for fish populations are not yet complete. · An aquarium facility has been installed and at the Mpulungu Fisheries station. This will provide capability for a range of experimental work.

Report 10 Etude Hydrologique du Bassin Nord-Ouest du Lac Tanganyika (R. D. Congo).	Kakogozo, Kahindo and Mwenyemali	· Quantification of the sediments which currently enter the lake including the seasonal variations · Vertical and horizontal distributions of the suspended matters along the lakeshore · To initiate the gauging of rivers in some specific zones in order to estimate the quantity of sediments inputs into the lake and the seasonal variations · Find out the types of sediment transport and sedimentation processes in the river mouths · Find out the flow distributions in the streams and the variability with time	· The average value of the contributions Kalimabenge: 1,772 m_ s-_, Mulongwe: 2,187 m_ s-_, Kavimvira: 0,580 m_ s-_. · The average of the concentrations of the suspended matter from the rivers is higher during the rainy season and varies much from a river to another. The values range from 65 mg l-_ to 3197.5 mg l-_. · The total quantity of the suspended matters discharged into the lake is very significant during the rainy season. Kalimabenge: 25.299 tons / year, Mulongwe: 21.311 tons /year-_, Kavimvira: 18.761 tons year-_. · Though the volume of water discharged by these rivers is negligible compared to the total volume of water of the lake, the volume of the solid matters they release in the lake is very significant.
Report 11 Hydrology of selected watersheds along the Lake Tanganyika shoreline.	Nkotagu, and Mwambo	· To quantify the current sedimentation rates from both impacted and pristine Gombe catchments · To characterise the chemistry of natural waters and identify levels of pollutants and nutrients as delivered into the lake from both impacted and pristine Gombe catchments. · To establish the mode of nutrient and pollutant transport into the lake · To compute the water balance of the Gombe catchments · Derive a conceptual model for the management of the lake Tanganyika	· The impacted catchment has an order of magnitude higher than the pristine environment in the current sedimentation rates · Groundwater forms about 70% of the total stream inflow to the lake. · Low levels of nutrients and chemical pollutants are currently observed to be carried by the streams flowing into the Lake · Groundwater plays a dominant role in the mode of nutrient and chemical pollutant transport into the Lake on long term bases. · Significant nutrients are also transported during high flows. · Natural factors seem to play a decisive role in determining the chemical character of natural water in both catchments. · Sediments may be considered as the major pollutant and possibly carrier of pollutants that threatens the bio - diversity of the Lake
Report 12 Riverine delivery of contaminants and nutrients in impacted *vs*. non impacted sites.	Swarzenski	· to study riverine delivery of contaminants and nutrients in impacted vs. non impacted river-lake systems.	· still in progress (not part of the LTBP but will provide important additional data on the effect of catchment activity on nutrient mobilisation)
Report 13 Kigoma Master Water Plan.	Duck	· Report on the volumes of the plan held by LTBP	· Reviews the nine volumes of the final report of the “Kigoma Water Master Plan” (NORAD, 1982) are held by the Lake Tanganyika Biodiversity Project

Report 14 Monitoring and Explanation of Sediment Plumes in Lake Tanganyika (M.Sc. Dissertation)	Bryant	· to assess the possibility and identify the procedures for the detection , explanation and monitoring of possible near-surface sediment plumes in Lake Tanganyika, through the use of satellite remote sensing imager, contemporary image processing techniques and field data analysis	· Results indicated that detection is possible in many situations, but that at certain times of year and at certain river inputs the plumes rapidly sink below the surface (due to their greater density). With further study it is likely that for floating plumes relatively accurate measurements of suspended sediment concentration and distribution could be made. A combination of this direct detection, coupled with the routing of modelled erosion (see above), holds promise for holistic monitoring of lake sediment inputs.
Lake circulation study Flow, Thermal Regime and Sediment transport Studies in lake Tanganyika	Timo Huttula (as editor - many involved) *NB. this work was carried out under Inter Agency Agreement between UNOPS and FAO*	· to study the wind driven water circulation · to study the major upwelling phenomena in the southern lake basin and their role in vertical transport of hypolimnetic waters · to study the secondary upwellings and spreading of these waters along eastern and western shore of the lake · to study the periodic oscillations in the lake · to study the horizontal dispersion and transport of suspended matter in the lake, especially near the main river inlets	· The upwelling in the south end of the lake was observed in 1996 and 1997, although it was not as extensive as in the year 1993. · The water temperature data revealed tilting of thermocline along the main axis of the lake · The current measurements revealed high speeds and the variation of the surface currents (down to 20 - 40 m) due to local winds. · The barotropic flow models were used to calculate the circulation patterns and their evolution with time. High spatial resolution of the regional models (from 0.4 km to 5 km) made it possible to describe in detail the dynamics of the flow regime and its effect on transport of suspended matter. · In the dry season the discharge of the river waters and suspended particulate matter concentration in river waters is low. The simulations with regional sediment transport models showed that in this time the dilution and the advection of river waters happens in the vicinity of the river mouths. Because of the high hydraulic friction the effect of river plumes on currents is negligibly small. Gravitational settling, advective transport by wind-induced currents and turbulent diffusion are the main governing factors generating the zones of higher SPM concentration mainly in shallow areas near river and creek outlets. The great depth of the lake reduces considerably the probability of erosion and resuspension of already settled solid particles to these narrow areas along the lake shore. · Currents directed N - NW near the River Malagarasi mouth determine the prevailing spreading of suspended matter in the same direction. The river plume is attenuated in longitudinal direction. During the wet season the spatial gradients are higher than during the dry season. This is result of a higher incoming SPM concentration and inflow velocities. But due to the similar wind-induced flow patterns in this region the calculated plume has similar elongated shape during both seasons. · The SPM plume from the River Lufubu is spreading to a more limited area than from the River Malagarasi. This is due to the deeper bathymetry and expected lower SPM concentration of river waters. · The PC version of the particle tracking model (TANGPATH) was developed in addition to the mainframe models. The model incorporates pre-calculated surface and depth-averaged flow fields of the lake wide and regional model. It gives a user the possibility to study the transport of buoyant and settling particles under the different meteorological conditions of the wet and dry seasons.

APPENDIX 2 - SedSS participants

Regional Staff

Person	**Institutional affiliation (or project direct employee)**
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Mr Gerva Shayo	Tanzanian Met. Dept.
Mr William Chilambo	Tanzanian Met. Dept.
Mr Medard Madula	Tanzanian Met. Dept.
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Mr J C Chama	Zambian Water Affairs Dept.
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Mr Labson Mpepo	Gauge reader – Project (Zambia)
Mr Daniel Paka Matebele	Gauge reader – Project (Zambia)
Mr Edward Chifunda	Gauge reader – Project (Zambia)
Mr Alfred Mpondela	Gauge reader – Project (Zambia)
Mr Abram Mbao	Gauge reader – Project (Zambia)
Mr. Robert Sinyinza	Zambian Fisheries Dept.
Mr. Mutanga Syapila	Zambian Fisheries Dept.
Mr Whiteford Chomba	Zambian Fisheries Dept.
Mr Kennedy Kaoma	Zambian Fisheries Dept.
Mr Gideon Zulu	Zambian Fisheries Dept.

* indicates national co-ordinator of study

APPENDIX 2 - continued

International staff

Person	**Institutional affiliation**	**Other non-regional support to these institutions (not listed above)**
Dr G. Patterson	NRI	SS co-ordinator
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Dr Robert Duck	Department of Geography, University of Dundee.	Dr S Wewetzer
Dr Ken Irvine	Department of Zoology, Trinity College, Dublin	Mr Ian Donahue, Dr P. Tierney, Dr E Verhayen
Dr Leo Goeyens	Department of Chemistry, Vrije Universiteit Brussel.	Dr N. Brion, Dr W Baeyens
Dr Martin Wooster	Department of Geography, Kings College London.	Dr N Drake, Dr Elias Symeonakis, Mr Xiaoyang Zhang, Mr Ross Bryant, Mr R. Loftie, Dr V. Copley