LIMITATIONS OF HYDRODYNAMICAL MODELS WITH LIMITED DATA AVAILABLE
CASE STUDY: SONDU RIVER BASIN (KENYA)

BY

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ABSTRACT

The Surface Water Modeling System (SMS) model has been incorporated in the Sediment Transport and Watershed Management Component of the FRIEND/NILE project as a research tool for presenting practical solutions for sediment transport problems. In order to predict sediment transport and deposition in selected river sections within the Nile river basin, the SMS model is being tested for its suitability for hydrodynamic modeling in rivers and reservoirs. The paper therefore discusses the use of SMS to predict water depth, stream velocity, sediment loadings and bed elevation changes in the Sondu Miriu River in Kenya. In addition the paper also discusses the problems experienced with SMS in modeling meandering rivers with low volumes of discharge as well as limited cross-sectional data regarding the river channel width, and water level data corresponding with the discharges at specified times, and discusses how the limited data availability affects the quality of the results obtained by SMS. The paper discusses the possible measures that were taken to resolve the problem of data gaps. Comparing the results from the model run with field data provided some validation; this shows that the dryness of the channel that is predicted by the model is also observed in the field. The paper also gives recommendations on the workability of the SMS model on various rivers.

INTRODUCTION

UNESCO under the auspices of the International Water Decade launched at MarDelplata some decades ago through its Cairo office (Friend/Nile Project) joined in by establishing the Sediment Transport and Watershed Management component among other components, to supplement the on going research efforts in the Nile River Basin by the Nile Basin Initiative.

The FRIEND/NILE also will act as forum which will bring together Professionals from Nile Basin to exchange experiences, ideas and or expertise and to foster mutual understanding and cooperation. As one family such forum will enable the scientists to acquire and regenerate data required for the development of sediment models (Surface water modeling system) that will eventually be used to estimate and predict the sediment load/deposition for monitoring the sediment problems within River Sondu and other rivers in the region and to enhance the regional research capacity on topics related to sediment transport and watershed Management.

Sediments produced by erosion of the land surface by rain and other man-made activities into the stream channels are the major agents for pollutants in the surface and subsurface water resources. For this reason some models have been developed in the recent past to try and solve or to come up with a multi-purpose solution to the problems of sedimentation. Such models are for examples. The Universal Soil Loss Equation (USLE) by Wischmeier and Smith (1978), Modified Universal Soil Loss Equation (MUSLE) by Williams (1975).

The Revised Universal Soil Loss Equation (RUSLE) by USDA-Agricultural Research Services (ARS) and USJJA- Natural Resources Conservation Service (NRCS), PSIAC by PSIAC (1968), Flaxman, delivery ration by ASCE (1975), ARS (1975), Negev by Negev (1967) CSU by Simons et al (1975) ANSWERS by Beasley (1977) and SCREAMS model by Knisell (1980a) are in use in various countries.

Among other rivers in East Africa Sondu River basin in Kenya was selected as one of the research areas under the STWM component of the UNESCO/FRIEND project with an aim to testify and validate the suitability of the SMS as a module in different environmental geographical conditions. The research aims at testing and the calibration of the SMS as new surface water modeling software if it can be used as a tool for the prediction and the estimation of the sediment transported by the rivers within the Lake Victoria drainage systems. The sediment transport and watershed management program in the Sondu River Basin is to initiate an integrative programme of research that explores the proper management of the basin and the quantification of the amount of sediments deposited into Lake Victoria annually from the river Sondu catchment area and the problem caused by such deposition. Besides other functions the SMS as a river model allows for the prediction of water depth, velocity, compute sediment loadings and bed elevation changes in complex waterways and river reaches. The purpose of the research for the watershed is therefore to integrate the existing information (data) on sediment transport and watershed management into a larger working model which will investigate the interdependency and feedback among the ecological, social and economic factors influencing the land use pattern within the basin to raise the level of awareness of policy makers, stakeholders and the public at large on various problems related to sediment transport and socio-economic problems.

STUDY AREA

The Sondu /Miriu is one of the main river in Nyanza Province draining the slopes of Mau Escarpment into the great Lake Victoria (Kenya portion) and is located in the Western Flank of the Gregory Rift (Kenya). The elevation in the Sondu River Basin ranges between 1000 m. a.s.l. and –2000 m a.s.l., and is situated between $35^{o}\ 45^{'}$- $34^{o}\ 45^{'}$

longitude and -$0^{o}\ 15^{'}$ to $1^{o}\ 00^{'}$ latitude and has a total area of approximately 5,180 km^2. Yurith River which originates within the slopes of Mau Escarpment is one of the main tributaries which drain parts of Kericho, Bomet and part of Kisii districts respectively joins the Kipsonoi River which drains parts of Kisii and Rachuonyo district at Ikonge where they form the

Sondu River down stream from the confluence. River Sondu flows through narrow, hilly gorges, bypassing the Nyakach Escarpment then meanders into the Odino Falls with a steep drop at Fotobiro hills before entering the flood plains of Nyakwere and eventually drains into the Winam Gulf of Lake Victoria at Osodo Bay approximately 22 km South East of Kisumu City (see the map below).

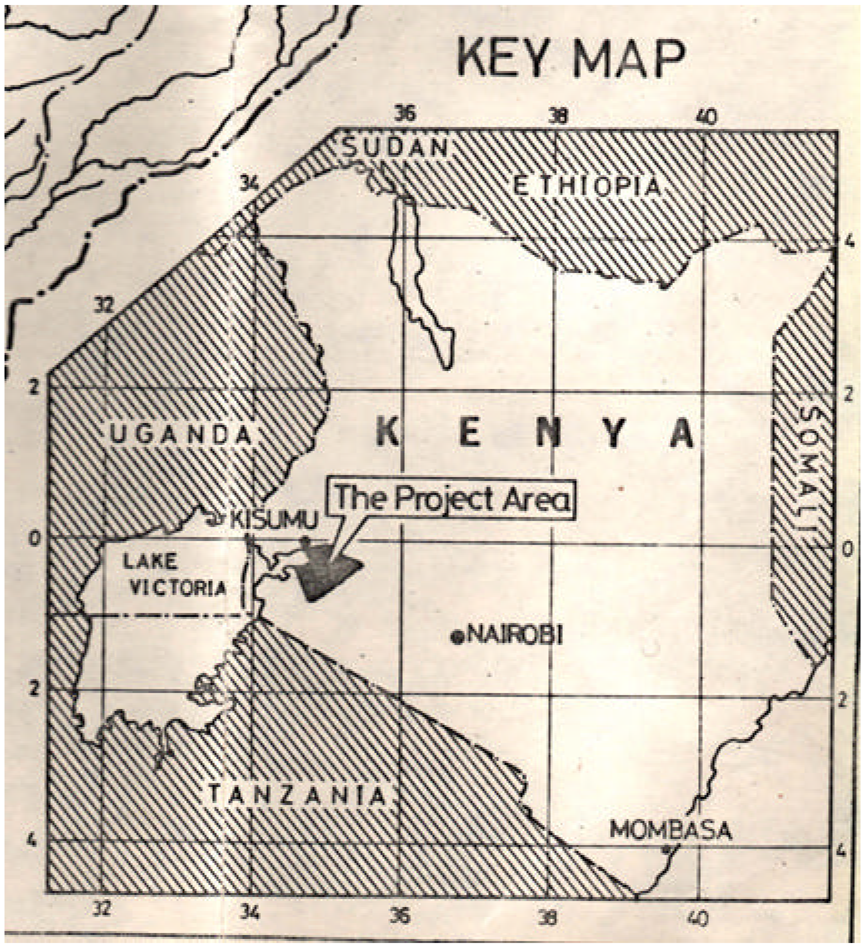

Fig. 1 Map of Kenya showing the project area

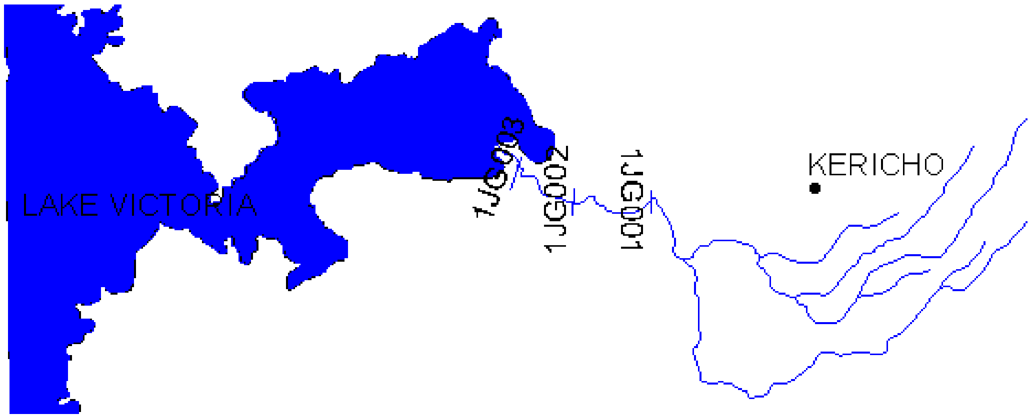

Fig. 2 The gauging stations on river Sondu used in the SMS model

The Sondu River catchment can be divided into two major climatic regions considering its temperature and rainfall characteristics. The rainfall is in two main seasons with the mean annual rainfall of approximately 1,000mm. The long rainy season is between April, May and June whereas the short rains fall around October, November and December. However this seasonality is much clearer in the lower region compared to the highland regions. The highland region receives a total amount of annual rainfall of approximately 1,835 mm annually, and decreases to about 1,500mm.towards the lowlands. The lowlands have an average annual temperature of 26^0C. The mean annual maximum temperature is about 30^0C and the mean annual minimum temperature is 18^0 C. The relative humidity is about 62% for most of the year. The geology of the catchment is characterized by three main geological units being volcanic rocks, the Bukoban system and alluvium. The Bukoban system, which is approximated to be 670 million years old, may be further divided into andesites, rhyolites, basalts and the volcanic rocks, which include phonolites, trachites and tuffs. These are believed to have been formed in the middle Miocene age. The widespread occurrence of tuffs indicates that lava ash showers were characteristics of the eruptions (Ojany and Ogendo, 1973).

The soil typology follows closely the underlying geology. The soils that are appearing in the volcanic foot ridges in the upper reaches as well as in the upper middle level uplands include (i) humic NITOSOLS; which are well drained, extremely deep, dark reddish brown, friable clay with acid top soil on the interfluves; (ii) humic NITOSOLS; of which the characteristics are the same as the humic NITOSOLS with the exception that they contain volcanic ash; (iii) mollic ANDOSOLS developed on recent volcanic ashes and pyroclastic rocks. In the plateau areas bearing quartzite exist Humic FERRALSOLS. The soils are well-drained, deep, reddish brown, friable clays with acid humic top soil. On the lower level uplands RANKERS with LITHOSOLS and rock outcrops occur which are excessively drained, shallow, dark brown, very friable, rocky, sandy loam to clay loam with acid humic topsoil. On the lower middle uplands, eutric CAMBISOLS occur. And the foot slopes have developed colluviums from undifferentiated basement system rocks. This complex has well drained, deep to very deep, dark, reddish brown to dark yellowish brown soils of varying consistence and texture. In some places, these soils are gravelly and stratified and referred to as ferralic ARENOSOLS, and in other places orthic LUVISOLS.

METHODOLOGY

The study consisted of three main parts. Part one of the study involved reference work. The necessary and relevant information and data were collected by literature reviews from the Lake Basin Development Authority documentary center, the Ministry of Water Resources and irrigation library, the Institute of Development Studies at the University of Nairobi, the Department of Meteorology at Dagoretti and Internet searches. Part two involved the acquisition of hydrologic and topographic data such as river discharge data, water level data, cross-sectional data and topographic data of the study area. Based on the available data in terms of water level and discharge data, the two gauging stations were chosen and these are - 1JG02 and 1JG03 because of the available data on the water levels for 1980 and 1984

Table: 1. Water level data for 1980 and 1984.

Station ID	Station Name	Date	Water Levels	Discharge
1JG 03	Miriu	19/05/80	232	57
1JG 03	Miriu	24/06/80	187	44
1JG 03	Miriu	19/07/80	225	54
1JG 03	Miriu	20/11/80	70	16
1JG 03	Miriu	22/09/84	182	25
1JG 03	Miriu	05/10/84	169	19
1JG 03	Miriu	16/11/80	137	17
1JG 03	Miriu	23/11/84	118	13

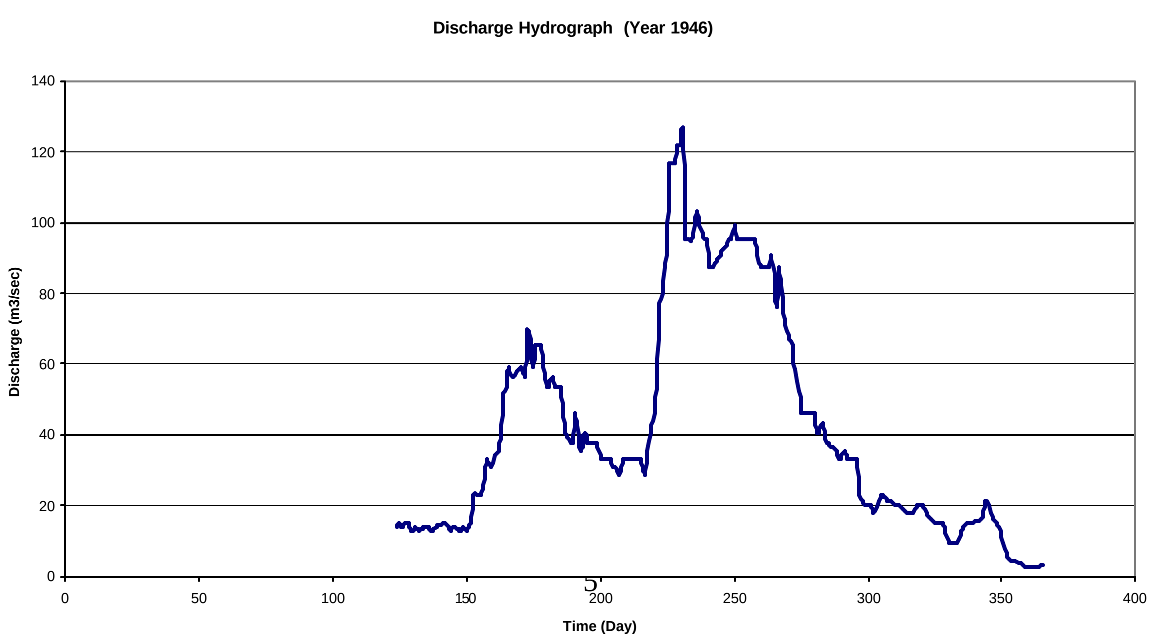

Fig. 3 Discharge hydrograph for the year 1946

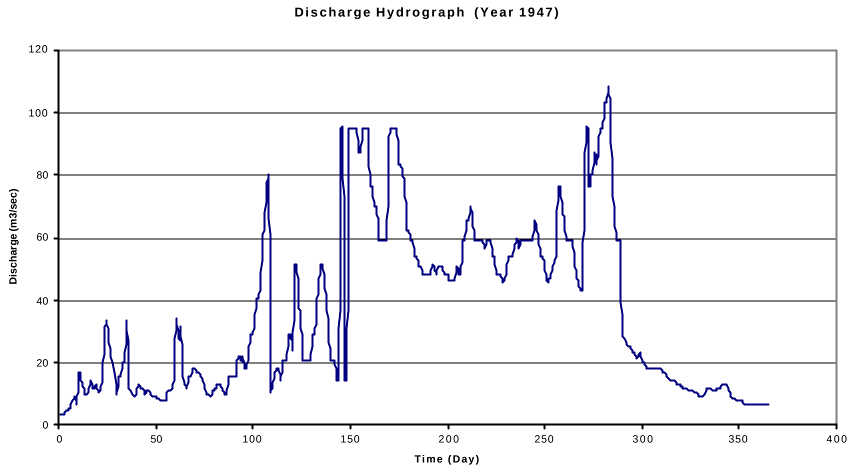

Fig. 4 Discharge hydrograph for the year 1947

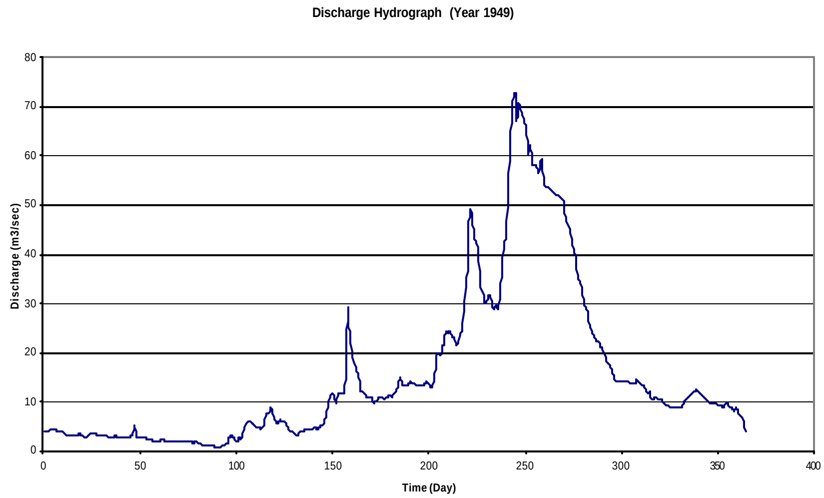

Fig. 5 Discharge hydrograph for the year 1949

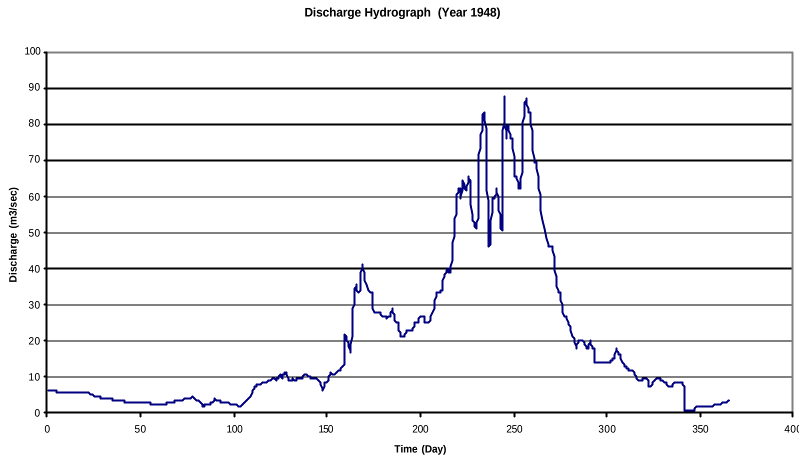

Fig. 6 Discharge hydrograph for the year 1948

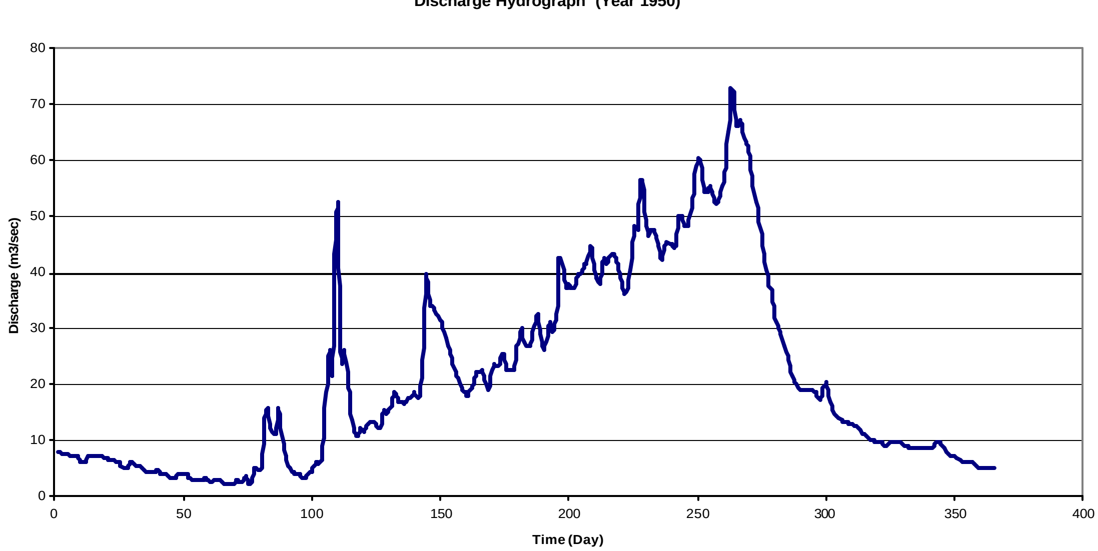

Fig. 7 Discharge hydrograph for the year 1950

Part three of the study involved the calibration of the hydrodynamic and sediment transport model. The Surface Water Modeling System (SMS) model was selected in the Sediment Transport and Watershed Management Component of the FRIEND/NILE project as a research tool for the simulation of flow of water and sediment in river channels. In this study, the following two models were used in SMS: (i) RMA2, hydrodynamic models which have the ability to compute the velocity of water surface elevation and shear stress in two-dimensional planes, (ii) SED2D, a sediment transport numerical model that computes the suspended sediment concentration and bed elevation changes when supplied with a hydrodynamic solution computed by RMA2. During the steady state and dynamic state, the hydrodynamic model was run using RMA2 so as to calculate water surface elevations and flow velocities for the entire reach. SED2D was then used to compute sediment loads and bed elevation changes. The detailed topographical maps of Nyakach and Belgut was scanned and saved as a tiff image and the portion of the river channel used for calculation is shown below.

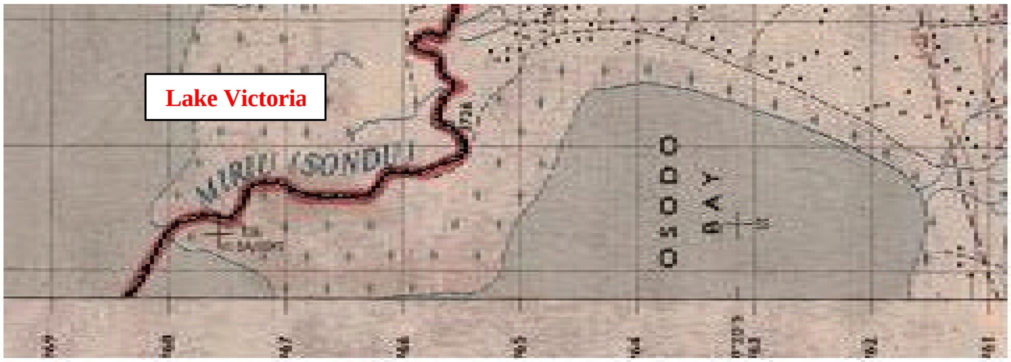

Fig. 8 The digitized topographical map of the project area

On River Sondu at the upper reach where the first gauging station **1JG 01** is situated was the only cross section available where the **Auto CAD** was used for the generation of other cross sections along the river down stream after the geo-referencing then digitized the channel and saved it as a project file before being transferred to the SMS. This proved to be useful to realize one of the conditions of using the SMS model. We also went to the field so as to see if it could be possible to establish some cross sections along the entire channel which could help us to collect more data.

1,150. m.a.s.l

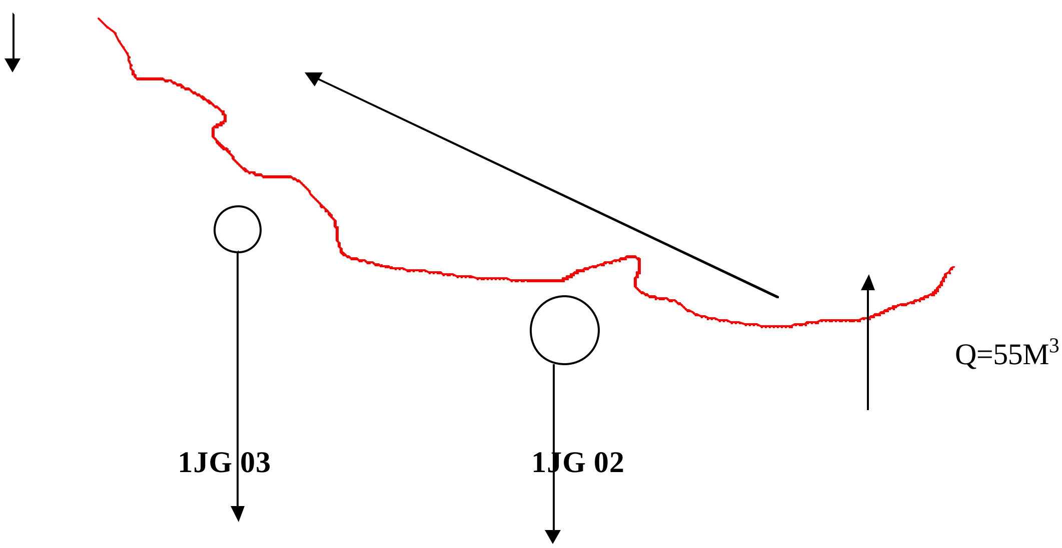

Fig. 9 Digitized channel of Sondu River between 1JG 01 to the lakeshore.

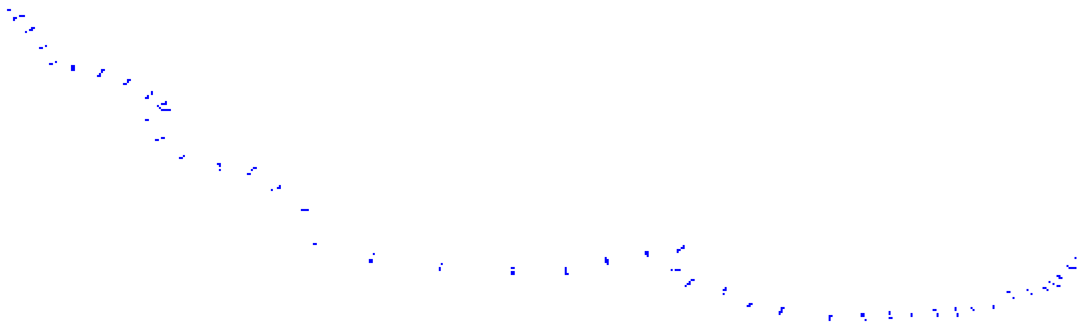

Fig. 10 Digitized channel of Sondu River between 1JG 01 to the lakeshore.

The Sondu River basin as is seen in the photo below cuts across the mountains and thick forest, which makes it difficult to establish a reasonable hydrographic network in a short time. The river channel is long with a lot of meanderings and waterfalls thus causing a lot of complications to obtain a reasonable data suitable for the calibration of the SMS software. However, after some consultations with other researchers using the same software in different regions of Africa, it was discovered that SMS model does not work well on the mountainous rivers with steep slopes, non perennial rivers with the discharge less than $2m^3$/sec, where geo-informatics and properly formatted hydrologic data is not available.

During the calibration it was also realized that the SMS works well only on rivers with big discharge. Consequently, on Sondu River this cannot work well because here the discharge at times is in tens of cumecs or less, and coupled with little data, the results from the SMS software were not satisfactory.

Fig: 11 Meanders on Sondu River

Fig: 12 Odino Falls on Sondu River

RESULTS

Using the little real and regenerated data available to us during research period, the hydrodynamic model was first run in steady state. The sampling da ta of April, 10th 1985 at 1JG 02 and 1JG 03 were chosen as boundary conditions with the water level of 1150m.a.s.l., a discharge of 55 m^3/sec and water depth of 340 cm. The results from the calculation using the software were as shown below:

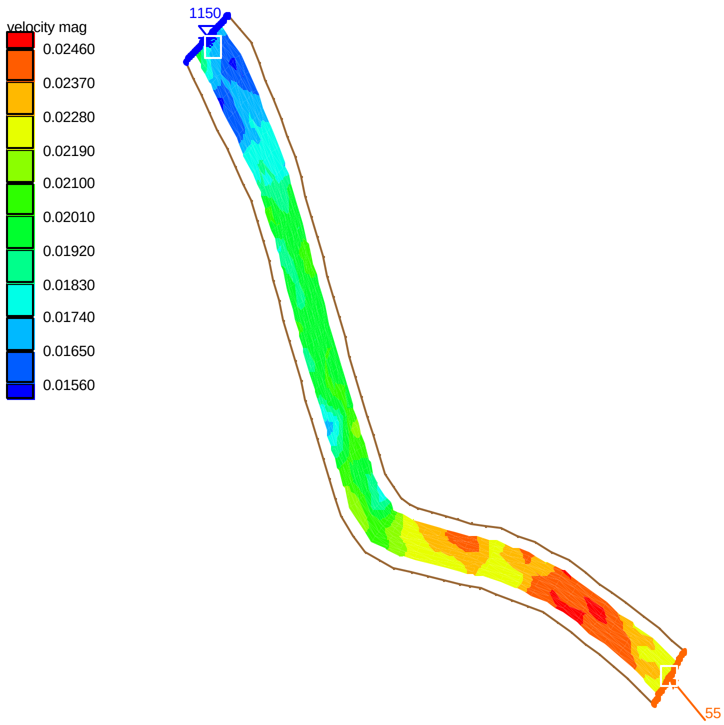

Fig. 13 Results of Water velocity for the 5Km. Stretch.

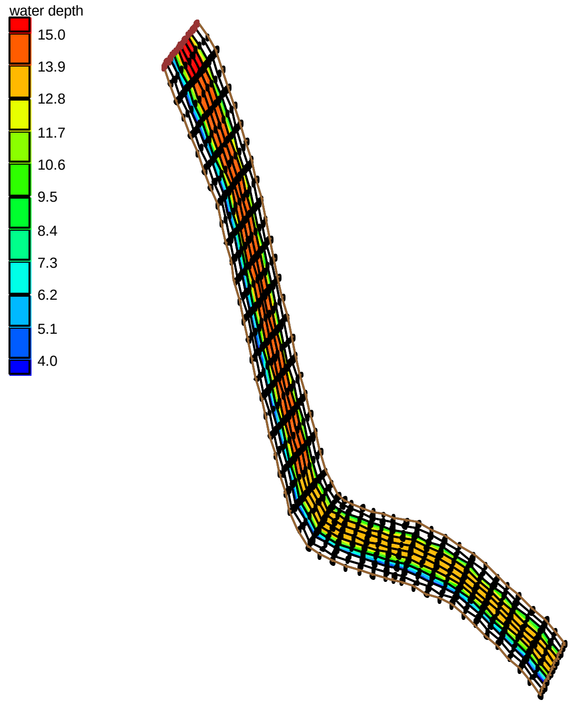

Fig. 14 Results of the Water depth at 5 km. stretch

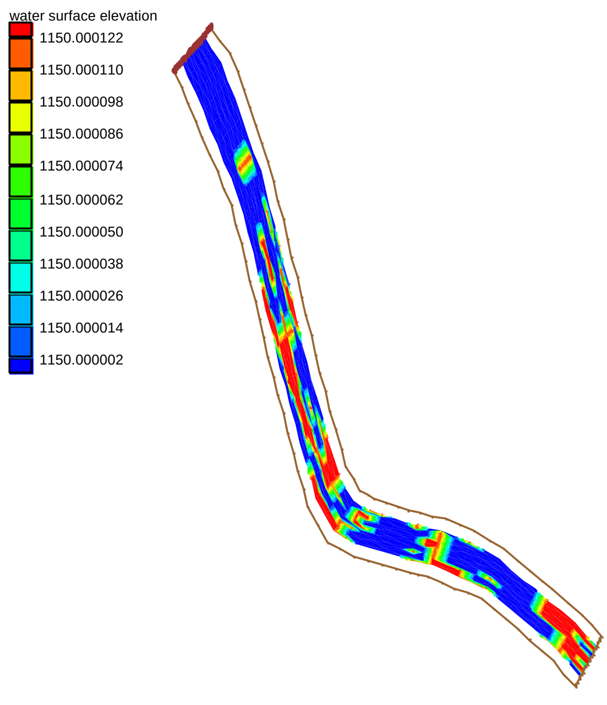

Fig. 15 Results of the water surface elevation

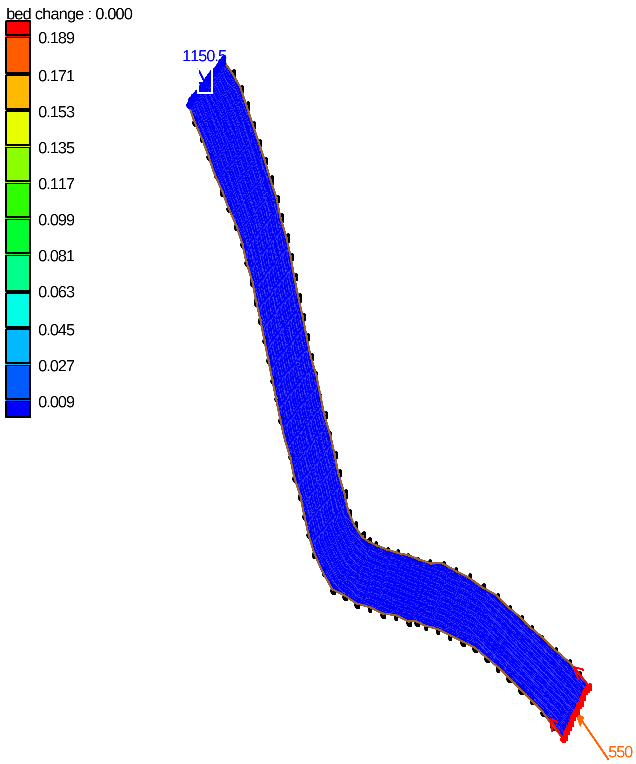

Fig. 16 Results of bed change at t=0

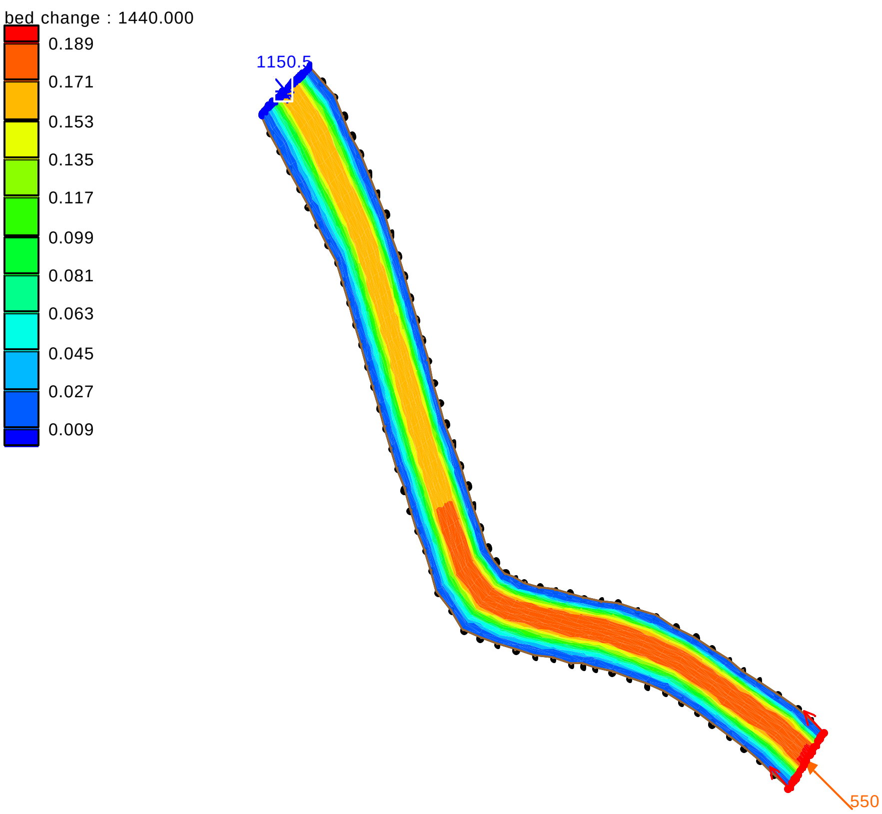

Fig. 17 Results of bed change at t=1440

With the help of the results obtained from the created mesh a graph of water level and sediment concentration were plotted for the down stream and this graph (***elevation vs. time***) and (***concentration vs. time***) were used to produce the results for the dynamic run in RMA2.

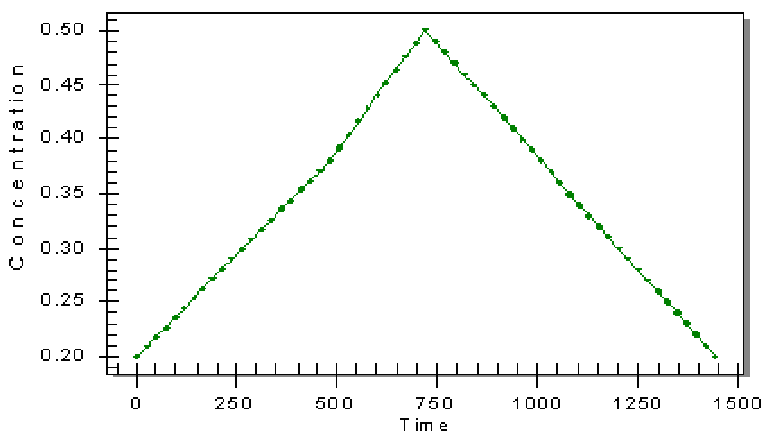

Fig. 18: Sediment Up Stream Boundary Condition

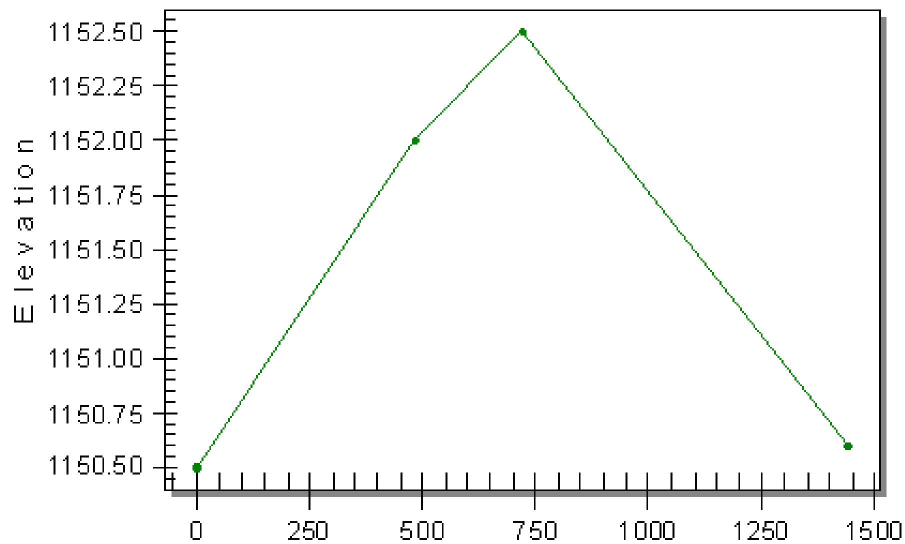

Fig. 19: Water Level Down Stream Boundary Condition

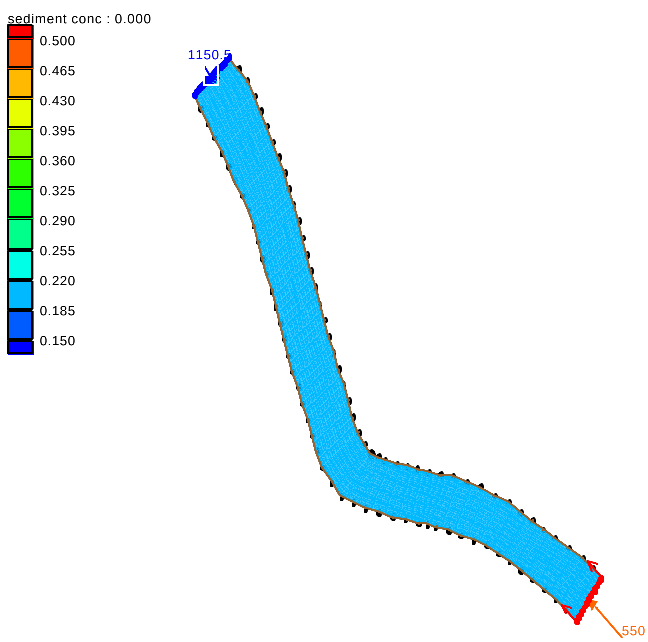

Fig. 20 Results of sediment concentration at t=0

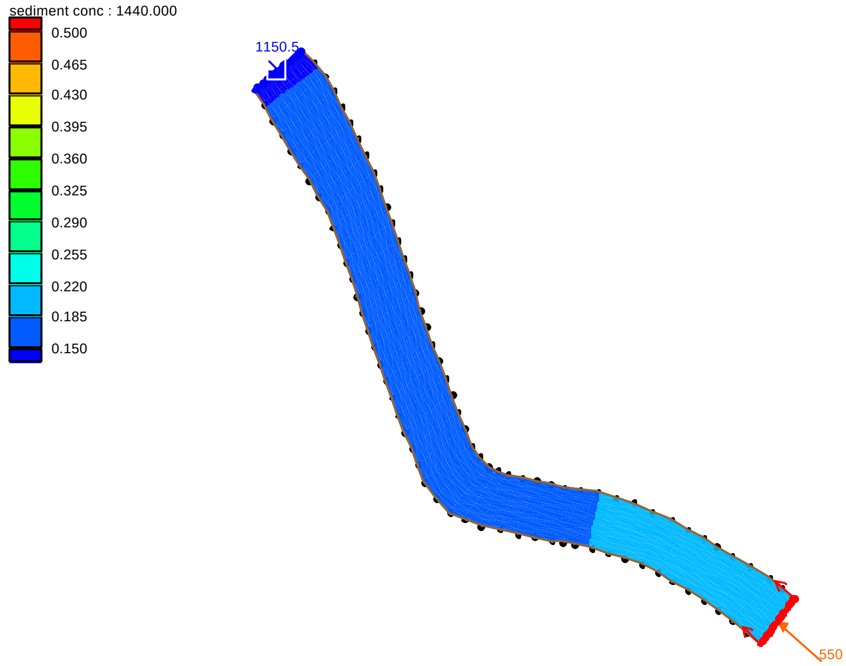

Fig. 21 Results of sediment concentration at t=1440

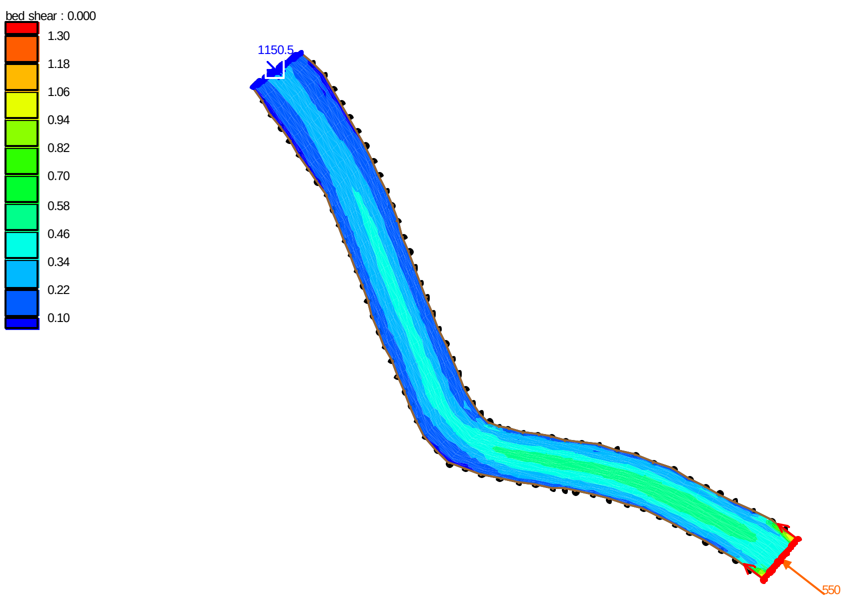

Fig. 22 Results of bed shear at (t=0)

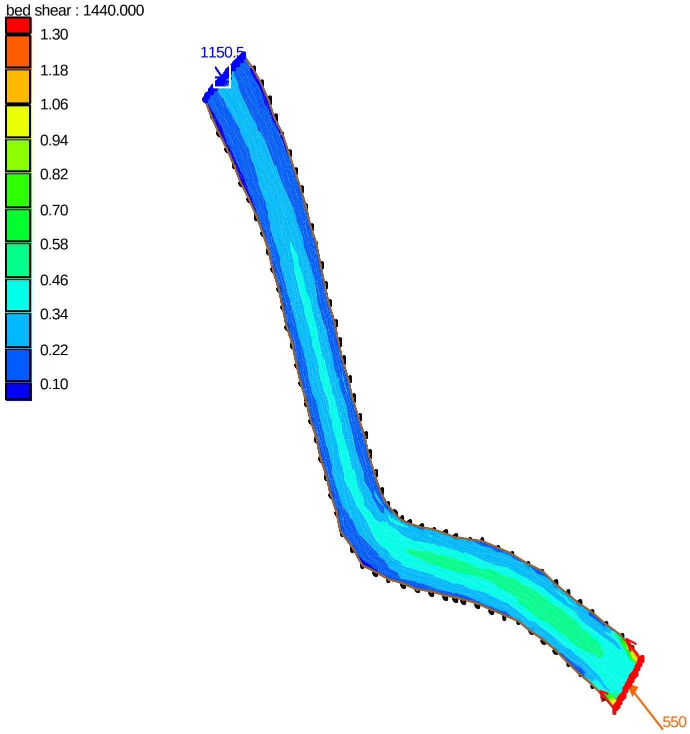

Fig. 23 Results of bed shear at (t=1440)

The pictures below show the condition of water level gauging staff at the station 1JG2 as the research assistant checking the washed away staff level during our field visit at the station when the river was at its lowest level with the depth of only 25 centimeter deep

Fig. 24 Water level gauging station at JG 02

Fig. 25 River bed during dry seasons within the five kilometer stretch

Discussion

About the SMS

Surface Water Modeling System (SMS) model has been incorporated in the Sediment Transport and Watershed Management Component as a research tool for the possible viable research findings by comparing other models in existence to date, and the calibration of the SMS model for eventual validation of its contribution in the solution of the Sediment transport problems.

SMS is such an easy-to-use and accurate modeling system owing to its powerful mesh/grid creation tools, coupled with GIS software, including points, arcs, and polygons that are built in it. The numeric models supported in SMS compute a variety of the information applicable to surface-water modeling. Primary applications of the models include calculation of water surface elevations and flow velocities for shallow water flow problems for both steady-state or dynamic conditions. Additional applications include the modeling of contaminant migration, salinity intrusion, sediment transport (scour and deposition), wave energy dispersion, wave properties (directions, magnitudes and amplitudes) etc. In addition to the hydrodynamics, researchers will often need to analyze pollutant and/or sediment transport in the waterway system. There are two soft wares built in the SMS model that adds to its capability to do other operations. The two models are:

- SED2D - A sediment transport numerical model that has the ability to compute sediment loadings and bed elevation changes when supplied with a hydrodynamic solution computed by RMA2.
- RMA4 - A constituent migration modeling code that has the ability to compute constituent concentrations and dispersion when supplied with a hydrodynamic solution computed by RMA2.

Difficulties and problems with the SMS

A hydrodynamic water and sediment flow model was applied to the Sondu river basin, located in Kenya. The application of the SMS software in this case study was limited mainly because of the lack of the processed and the appropriate input data format required by the SMS module. The few cross-sectional data which were available for the creation of a finite element mesh to calculate the flow of water and sediment in the river channel were not in the format required by the module. The few hydrologic data available for river Sondu are of long term nature (i.e. approximately 60 years), but the problem is that such gauging stations are only two with un-planned hydrological network coverage in the Sondu river basin. Secondly - the Sondu River has a steep channel gradient, including several waterfalls, which renders the application of the existing hydrodynamic flow models available in commercial software (such as SMS) difficult. Third, the River has a very irregular flow regime, and the riverbed happens to be dry during the dry season. The latter causes instability problems when running the models for larger time periods.

The cross-sectional data measured at one gauging station were extrapolated for the entire reach. Thereby, the river channel was given a uniform width of about 1000m. while at some places the width of the river is approximately 40m. or so. The results of the runs were therefore not realistic. There is a clear need to establish more cross-sections for the data collection on Sondu Miriu river channel for the calculation using the SMS model. Both models implemented in SMS need relatively deep rivers with large volumes of discharge. Even though the primary applications of the model include the calculation of the water surface elevations and flow velocities for shallow water flow, it has become evident that the model does not work well for small rivers, which do not have big volumes of annual discharge. In the case of the Sondu river basin, the riverbed happens to be dry during the dry season (see pictures). In these cases of occasional zero flow, the flow and sediment models do not run properly.

CONCLUSIONS AND RECOMMENDATION:

Even though some training has been conducted, some problems in the application of the SMS model are still being encountered by most of the Sediment Transport and Watershed Management (STWM) theme researchers in the participating countries especially those with meandering and mountainous rivers where the application of the SMS seems to be problematic. For this reason more practical training and or practical experience is still needed to overcome the difficulties and make the SMS model results that would give a reasonable scientific contribution for the research on Sediment Transport.

Since the introduction of the SMS software for modeling of the sedimentation problems to the participating countries, a lot of achievement and or progress have been realized with the help of the Egyptians counterparts who might have lived longer with the SMS model.
In the Kenyan situation given that most of our river gauging were not designed for research purposes, but for the domestic and industrial water supply with the provision of Irrigation and hydropower to some extent, the suitability of the present hydrographic network will hardly certify the conditions and the detailed data requirement of most models i.e. SMS.
The following observations have been recorded from the short time hand practice on the SMS model.

- That the SMS model needs to be used on the large and deep rivers with mean discharges not less 50 m^3/sec.
- Low land rivers with less meandering and moderately low gradient profiles
- Perennial rivers with the water depth not less than one meter.
- Well designed river cross sections with a predetermined intervals
- Longer period of observed data.

- Besides research in sediment transport, it is necessary to look into gully erosion, which has not been well studied as this contributes to the rapid transfer of sediment to catchment outlet;
- River Sondu as a mountainous river with meandering profile is not suitable for the SMS model but we have yet to use proper data to prove our hypotheses.

With the hand held GPS for geo-reference, we have established another two more cross sections which we have used for practice with the SMS model.

- One cross section was established at the Osodo Bay (1JG3) at a distant of 5 km. from the lake with the elevation of 1134 msl.
- Nyakwere (1JG2) – distant from the lake is 15 km. with the elevation of 1135 msl.
- Sondu diversion (1JG1) – distant from the lake is 53 km. with the elevation of 1535 msl.
- Sondu Bridge – distant from the lake is 56 km. with the elevation of 1537 msl.

Data for the last station was extrapolated from the data of the 1JG1 with the longest observed records. It has also been observed that the case-study on Sondu river shows that the application of hydrodynamic flow and sediment transport models not only requires high quality input data, but also requires advanced practical and theoretical experience of the researchers involved in the modeling. Especially in mountainous rivers, the modeling of water flow and sediment transport in the channel is complex, and requires advanced training and capacity building for the implementation of the SMS

In conclusion, there is a need for:

- An evaluation of the economic impact of the soil erosion and sediment transport in all reservoirs built or planned to be built in any drainage basin taking into account the environmental implications.
- Regular and uniform sediment monitoring should be enforced.
- There is also a need for training and support of large number of Kenyans in all aspects of water and soil management in related fields such as agriculture, forestry and water resources management and conservation.
- It is also worth noting that the future sedimentation problems cannot be adequately assessed merely by measuring the sediment in the river channel at the site planned for reservoir
- There must be also a realistic evaluation based on a thorough understanding of hydrologic and geomorphic processes as they relate to the land use on the entire catchment

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