Assessment of Sedimentation Capacity in Rantambe Reservoir using Acoustic Methods

Yasanga S.K., Udara H.M.D., Dilantha M.G.A., Rupasinghe M.G.A.R., *Premasiri H.M.R. and Ratnayake N.P.

Department of Earth Resources Engineering, University of Moratuwa, Sri Lanka

*Corresponding author - hmranjith@yahoo.com

Abstract

Reservoir sedimentation is a major problem for dam safety, water security and productivity. So, regular monitoring and assessment of sedimentation rate performances are paramount. Rantambe reservoir with an initial gross capacity of 21 MCM, constructed under Mahaweli Development Scheme is a multipurpose reservoir used for power generation (52 MW) and flood controlling. However, due to excess sedimentation through Uma Oya, the capacity of the reservoir is affected and therefore compromised the dam safety and water security. In this study, the sedimentation characteristics were assessed using acoustic methods for identifying the performance of reservoir sediment management measures. Hence, Sub-bottom profiler with 10 kHz and 3.5 kHz transducers were used as the main acoustic instrument to determine the height of the water column, the layering of the reservoir bed and the sedimentation pattern. Results show 1.93 MCM as the reservoir's existing volume and due to excessive sedimentation in the mouth of Uma Oya exceeding the dead storage level at the dam thus significantly decreasing the water depth limiting the reservoir capacity.

Keywords: Acoustic, Rantambe Reservoir, Reservoir Sedimentation, Sub bottom profiling, Sediment Thickness

1 Introduction

Due to rapid growth of population and the development throughout the last century there is a huge demand for energy and fresh water. Only about 0.003 % of the world's fresh water is available for human consumption [1]. One of the major solutions for this issue is building of reservoirs. Type of the reservoir will vary with the purpose which is expecting from the reservoir. So, the reservoir technology exists from the past but with the development of the technology it comes to a whole next level. A reservoir can be constructed by building a dam across a valley or by using natural or manmade depression [2]. When building a reservoir there should be a considerable capacity to store fresh water and considerable useful lifetime.

So, building a reservoir leads to many disturbing consequences like, river line erosion, reservoir induced landslides and earthquakes, temperature variation in the surrounding area, disaster and reservoir sedimentation. Among all of them, reservoir sedimentation takes the important place because the annual cost caused by reservoir sedimentation in the world is US$ 15 billion [3].

Reservoir sedimentation is mainly because of stagnation due to dam construction [4] and natural and manmade activities in upper catchment area. This reservoir sedimentation threatens the dam safety and water security.

Providing a "Dead Storage" is the main solution that can usually give with the initial reservoir design to mitigate the effects of reservoir sedimentation [5]. Other than that, sediment management techniques such as sediment traps, dam heightening, sluicing, flushing, hydraulic dredging, catchment management, erosion control and, sediment modelling can be used [6]. Improper management of reservoir sedimentation may lead to loss of capacity and therefore useful lifetime of the reservoir.

Sri Lanka as a tropical country with a significant elevation difference has many reservoirs for managing water resources and hydropower production. Rantambe Reservoir is one of the reservoirs developed under the Mahaweli River Multipurpose Development Scheme, mainly to produce hydroelectricity and to control flooding. Rantambe Reservoir has a gross capacity of 21 MCM and receives water mainly from the outflow of Randenigala power plant and the Uma Oya tributary. Uma Oya river tributary brings the excess amount of muddy sediments to Rantambe reservoir [7] and sedimentation could have reduced the reservoir capacity as well as the dam safety. In the present study, investigations of the reservoir sedimentation were done by using sub-bottom profiling and bathymetric surveying. Such acoustic studies were used elsewhere to identify sedimentation in both natural and manmade water bodies [8], [9].

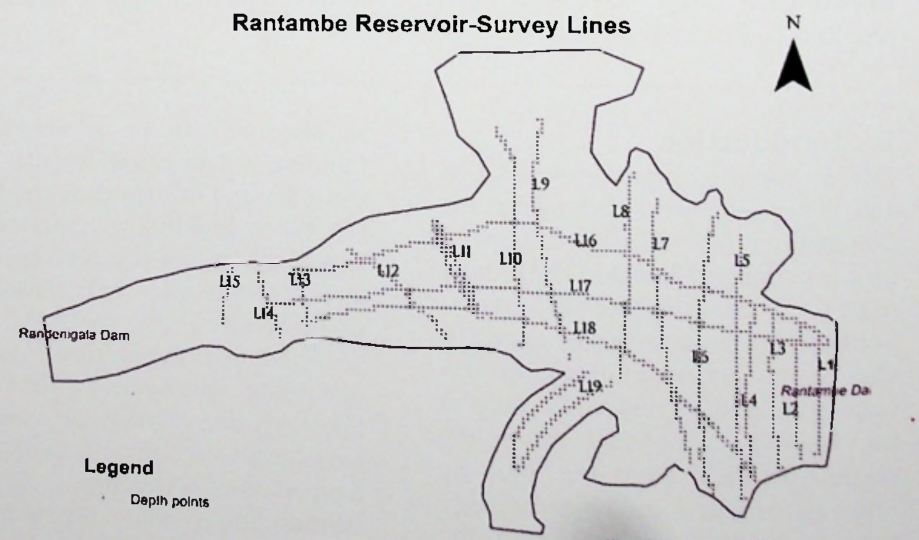

Figure 1: Sub-bottom and Bathymetric Survey Lines Carried at the Rantambe Reservoir.

2 Methodology

2.1 Site Selection

Rantambe reservoir was selected because it is the most affected reservoir from sedimentation issue in Mahaweli reservoir complex and it is relatively small with compared to the other reservoirs in the Mahaweli Reservoir complex.

2.2 Materials and Methods

2.2.1 Surveying

Sub-bottom profile and bathymetric Survey were carried to cover the whole reservoir as per Figure 1. Strata Box-HD 3510 sub-bottom profiler with 10 kHz and 3.5 kHz transducers were used for surveying. Spot depth Echo Sounder (Hondex PS-07) was used for spot depth measurements for precision and accuracy.

The navigation is carried out using a GPS system of Hemisphere A42TM Antenna an R330TM GNSS Receiver with an accuracy of 4 cm. Field data acquisition was done by using StrataBox HD software and from collected data from the sub-bottom profiler was post-processed in SonarWiz and ArcGIS platforms. The survey was carried out on November 7th, 2018, when the water level of the reservoir reached its spilling level.

3 Data Processing and Results

Through, bottom tracking with optimizing the gain setting, the reservoir floor surface was identified, and bathymetry of the reservoir was generated as CSV (Comma Separated Values) files using SonarWiz software (Figure 2, Figure 6).

CSV files generated from the post-processing of SonarWiz were imported into the "Surfer" and "ArcGIS" to develop a 3D model (Figure 3), and a bathymetric map (Figure 4).

3.1 Reservoir Capacity Calculation and Sedimentation Patterns

Reservoir capacity was calculated with respect to the maximum dam height of 152 m level using the present

Figure 2: Survey Line after Changing the Gain Settings and Bottom Tracking.

bathymetric maps. Sedimentation pattern of the reservoir bed was identified using ArcMap (Figure 4).

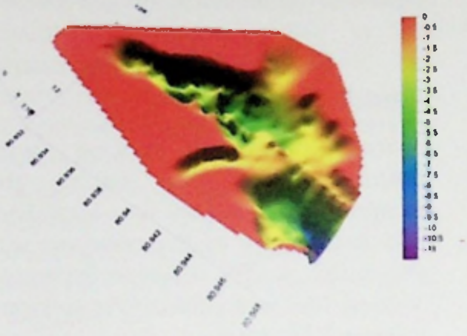

Figure 3: A 3D Map Generated by Surfer.

Figure 4 shows the current Rantambe reservoir divided into two sub-basins with the maximum depth in the range of 8 to 10 m near the dam side basin while 6-7 m in the western sub-basin (Figure 4).

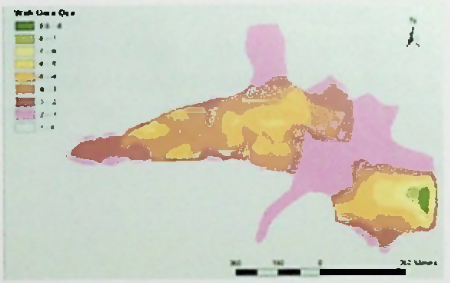

Figure 4: Raster File Created Using Survey Data.

The gradual depth reduction along the reservoir bank is clearly shown in the maps (Figure 3) while near to the Uma Oya river inlet, a clear depth reduction is visible separating the whole reservoir into two sub-basins.
A 3.5 kHz transducer was sufficient to penetrate sound waves into sub-bottom strata, and could identify a 1 to 1.5 m thick sediment substrata in the L13 survey line located in the western end of the reservoir located away from the dam structure.
Based on the current depth model, calculated reservoir volume with respect to the spill level (152 m) was approximated as 1.93 MCM.

Table 1: Calculated Reservoir Capacity in 152 M Surface Level.

Water surface elevation (m)	Storage up to the elevation (MCM)
152	≈1.93

The reservoir capacity at 152 m level in 1990 and 2013 was gathered from the Mahaweli Authority and regarding those results how the reservoir capacity variation happens over the years are given in Figure 5.

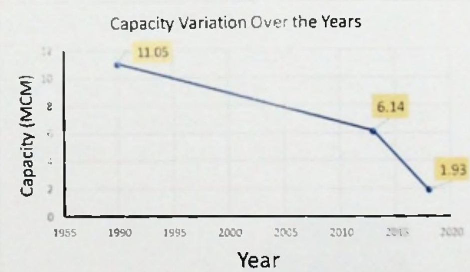

Figure 5: Reservoir Capacity Variation over the Years.

4 Discussion

Uma Oya, a sub-catchment of upper Mahaweli catchment, is the worst, reporting the highest sediment yield measured for any catchment in Sri Lanka [7]. So significant excess amount of sediment yield accumulates through the Uma Oya tributary, into Rantambe reservoir. Previous studies show how much of wash load and total load coming through Uma Oya.

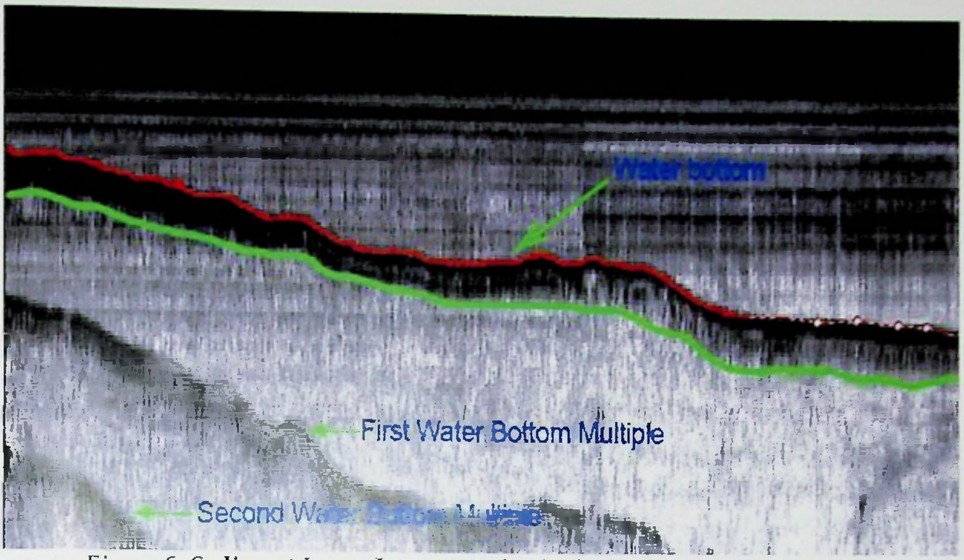

Figure 6: Sediment Layer Interpretation Using 3.5 Khz Transducer Data.

In 1993/1994 the wash load was 293,142 tonnes and the total load was 375,938 tones. However, over the years the amount of this wash load and total load were reduced but the sediment accumulation did not terminate by any mitigation process. So, the sediment accumulation process is still ongoing continuously.

Observed division of the Rantambe reservoir into two sub-basins in front of the Uma Oya river outlet is due to continuous siltation of the sediment load coming through Uma Oya tributary.

As the main objectives of this study, determination of sediment pattern and reservoir capacity and assessing the sediment layering in the reservoir bed Sub Bottom Profiler is the best acoustic instrument to achieve all these goals from single attempt.

From the data which was collected from the first attempt gives the depth measurements along the survey lines.

However, the expected penetration did not achieve, due to the unexpected weather conditions and sudden water level variations experienced in the reservoir environment.

Due to this unexpected weather conditions many noises were generated and because of those noises (turbidity variation, underwater flow currents due to spilling and power turbines, water flowing speed, water temperature variation) results were not in the expected range. Too much reflections were there in the first attempt when 10 kHz transducer was used. Determination of sediment layering cannot be done with those errors. However, determination of sediment pattern and calculation of reservoir capacity was done using those results.

In the second attempt, 3.5 kHz transducer was used, and better bottom penetration results were observed.

From both generated 3D map and raster map it can be seen that how the depth variation happen in the reservoir bed due to sedimentation.

Whole reservoir was not able to cover because of shallow depths near the reservoir banks and because of the spilling of Randenigala reservoir at the time of survey.

5 Conclusion

According to this study, the sediments of the reservoir mainly comes from Uma Oya.

For a proper bottom tracking and penetration gain values should be altered correctly and range values should be given accordingly.

Only the mud gate opening was done as a mitigation process to reduce reservoir in filling from sediments and that is not enough to remove the sediment accumulated in the reservoir.

To reduce the capacity loss of the reservoir, it is necessary to take some mitigationary measures for the upper catchment area of Uma Oya.

6 Future Directions

Sub bottom profiling should be done with minimum noise (accurate data can be obtained if survey is carried out in dry season where spilling won't happen, and survey should be done when no hydroelectricity is generating so, turbulence currents will be very low).

Sub bottom profiling is not so suitable for shallow, muddy conditions.

Identified sediments in the reservoir can be dredged out and used for construction industry, tile making industry, fertilizer etc. Since reservoir is in a reserved area, proper legal and environmental procedures should be followed before implanting a dredging program.

Acknowledgement

The authors are grateful to the following personnel who helped us in various ways to complete this research project;

The research project coordinator, Dr. G.V.I. Samaradivakara, for the guidance and immense support, Mahaweli Authority, Sri Lanka, for their logistical support and for providing necessary guidance concerning project, and to Sgd. Eng. S.R.K. Aruppola, Director HAO&M Division and Eng. Thissa Rajarathna Engineer in charge (Randenigala and Rantambe), Eng. Anushika Senarathna and all the other staff who is working in Rantambe reservoir for the immense support which they have given for us.

References

[1] Vijaya, R. (2015) Surface Water Resource Management Using Remote Sensing and GIS Techniques - A Case Study of Sirumalai Hill Environs, Tamil Nadu, India, National Conference conducted by School of Earth and Atmospheric Sciences, Madurai Kamaraj University, Madurai, Tamil Nadu, India on December – 17 & 18, 2015. ISBN: 9789384193614.

[2] Votruba, L. and Broža, V. (1989) 'a Reservoir Function and Basic Tools 1 Basic Function of Water Reservoirs'. doi: 10.4236/jss.2015.35013.

[3] Water Resources Department DHI (2012) 'Reservoir sedimentation management: Cost-efficient and sustainable solutions for the dam industry', Dhi.

[4] Annandale, G. (1987). Reservoir sedimentation. Amsterdam: Elsevier.

[5] Walker, W. and Bridgeman, P. (1985) 'Water Resources Engineering Education', Journal of Water Resources Planning and Management, 111(3), pp. 338–345. doi: 10.1061/(ASCE)0733-9496(1985)111:3(338).

[6] Giri, S. (2018) 'Handbook for Assessing and Managing Reservoir Sedimentation', (June).

[7] Diyabalanage, S. et al. (2017) 'Impact of soil and water conservation measures on soil erosion rate and sediment yields in a tropical watershed in the Central Highlands of Sri Lanka', Applied Geography. Elsevier Ltd, 79, pp. 103-114. doi: 10.1016/j.apgeog.2016.12.004.

[8] Ratnayake, A., Dushyantha, N., DE Silva, N, Somasiri, H.P., Jayasekara, N.N., Weththasinghe, S., Samaradivakara, G.V.I., Vijitha, A.V.P., Ratnayake, N. (2017). Sediment and Physicochemical Characteristics in Madu-Ganga Estuary, Southwest Sri Lanka. Journal of Geological Society of Sri Lanka. 18. 43-52.

[9] Weththasinghe, S., Ratnayake, A., Dushyantha, N., Ratnayake, N., Samaradivakara, G. and Vijitha, A. (2018). Sub-Bottom Features and Physical Properties of Water of The Tangalle Bay, Sri Lanka. Journal of Geological Society of Sri Lanka, 19-2 (2018), pp.17-27.