International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org Volume 3 Issue 5‖ May 2014 ‖ PP.20-27

Bathymetry Generation of Umiam Reservoir Using SONAR and GIS Techniques

Jeffrey Denzil K. Marak[1], E. Venkata Rathnam[2], Ng. Romeji Singh[3] and S. Sudhakar[4]

[1](*M. Tech Student, Water Resources Engineering, National Institute of Technology, Warangal, India)*
[2](*Associate Professor, Department of Civil Engineering, National Institute of Technology, Warangal, India)*
[3](*Scientist 'SD', North Eastern Space Applications Centre, Umiam, Meghalaya, India)*
[4](*Director, North Eastern Space Applications Centre, Umiam, Meghalaya, India)*

***ABSTRACT*: *Umiam reservoir is located in the border region of East Khasi Hills and Ribhoi districts, about 15 km to the north of Shillong in the state of Meghalaya, India. The catchment area of the reservoir spreads for over 220 km^2. The Umiam reservoir serves as the major source of hydroelectric power to the region. In recent years, it is reported that there is an increase in rate of catchment erosion and reservoir sedimentation leading to reduction of storage capacity and power generation. This study aims to obtain the bathymetric information on Umiam reservoir to examine the changes in storage capacity, changes in reservoir areal spread, depth, etc. The bathymetric survey was carried out using a single frequency echo sounder and Global Positioning System (GPS) device to generate XYZ coordinates. The physical parameters including, depth, volume, area, width and length were derived. The maximum depth was 52.61 m located near the dam site. A contour map and a three dimensional map of the reservoir were produced. Elevation-storage curve and elevation-area curve are developed for Umiam reservoir. The findings of this study will be helpful to the reservoir authorities.*

KEYWORDS **:** *Bathymetry, Catchment, GIS, SONAR, Umiam Reservoir*

I. INTRODUCTION

The state of Meghalaya in the north-eastern part of India is bestowed with numerous rivers and waterfalls making it highly potential for hydroelectric power generation. The region receives highest amount of rainfall in the world with an average annual rainfall of 11,872 mm [1]. The drainage basin of Umiam reservoir extends over an area of 220 km^2 and lies entirely in the East Khasi Hills District of the State of Meghalaya. The area comprises mainly of forests and agricultural land with a fragile ecosystem [2]. The capital city of Shillong, the most important urban centre, is located in the heart of the basin. Shillong urban agglomerate at the head of the Umiam reservoir drains an area of about 25.4 km^2 of the Greater Shillong city. The important tributaries of the Umiam river are the Wah Umkhrah and the Umshyrpi, which flow through the city of Shillong from East-South towards West-North directions and join together below the city limits to form the Wah Roro river before joining the Umiam river further downstream, feeding the Umiam reservoir. The Umiam River ultimately joins the Brahmaputra River. The first survey of the Umiam reservoir after impoundment in 1965 was carried out by Water and Power Consultancy Services (WAPCOS) in 1990. As per the report, the gross capacity of the reservoir has reduced from 179.757 MCM at FRL (Full Reservoir Level) 981.456 m to 167.069 MCM over a period of 25 years (1965 – 1990) indicating an average rate of sedimentation of 0.50752 MCM per year. Second Hydrographic and Topographic surveys of the reservoir were carried out in April 2004 by Tojo-Vikas International (P) Limited (TVIPL) using the state-of-the-art high-tech instruments of Differential Global Positioning System (DGPS), Digital Echosounder and Electronic Total Station supplemented by Analogue echo sounder. The silt samples and water samples were collected using grab sampler and Nelson bottle sampler respectively, covering the entire reservoir area [3].

Fifty years after the construction of dam, a series of additional stages to the project have been added further downhill. Despite the increased generating capacity, the Umiam Hydroelectric Power project has not been able to keep up with the increasing demand. At times of peak power demand, particularly in the summer months, the Meghalaya state electric utility must selectively cut power. These scheduled blackouts have become a fact of life in areas served by power from Umiam Dam. The project provided power to an under-served part of India, but it could not keep up with increased demand due to population and industrial growth. The Umiam reservoir has not received much attention from the state authorities and continues its own fate of degradation due to pollution and sedimentation [2].

Therefore, the objectives of this study were intended to study the bathymetry using modern techniques incorporating Echosounder and GIS. Secondly, this study aims to compare the capacity of the reservoir from the time it was first built and the present capacity and also to provide updated area capacity curves. The findings of this study will be of great use to the authorities in efficient maintenance of the reservoir.

II. MATERIALS AND METHODS

2.1 Description of the study area

The Umiam Reservoir (Storage Reservoir of Umiam Stage I Hydro Electric Project) is located between coordinates 25.629 N, 91.853 E and 25.673 N, 91.904 E at an elevation of 1004.878 m above sea level (Fig. 1). This project is the first stage in the series of cascade development planned on the rivers Umiam, Umtru and Khri, designed and constructed as a Hydro electric project to provide benefits of hydropower and drinking water supply. The five hydropower projects built by MeSEB, with Umiam stage I as the precursor, provide 185.2 MW of hydroelectric power to the state of Meghalaya [3].The main dam of Umiam Stage - I comprises a concrete structure of 195 m in length and 73.2 m in height above the deepest foundation with a spillway (two bays each of 12.2 m length) with crest level at 969.5 m controlled by two gates of size 12.2 m X 12.2 m designed to discharge a design flood of 1840 cumecs [3]. The main earth dam is 463.4 m in length and 37.2 m in height above the deepest foundation. There is also a road dyke that is 167.7 m in length and 17.4 m in height above the deepest foundation level. For diversion of water into the powerhouse through a 2057.4 m long tunnel (horse shoe shape - diameter 3.05 m), an intake tunnel (a circular shaft of 3.05 m diameter and height 28.5 m) is provided with intake gates of 3.05 m x 3.05 m. The surface power house at Sumer at the end of the tunnel, surge shaft and penstocks, houses four turbo generating units of 9 MW capacities each (Total installed capacity 36 MW). The tailrace channel is 137.2 m in length leads the water for Stage II development at Um Sumer Power station [3].

2.2 Materials

Hydroacoustic SONAR (Sound Navigation and Ranging) technology is a popular method for preparing bathymetric maps. It is used by creating a link to the Global Positioning Systems (GPS) device [4]. Echo Sounder is a type of SONAR which determines the depth of water by transmitting sound pulses into water. The time interval between emission and return of a pulse is recorded, which is used to determine the depth of water along with the speed of sound in water at that time. This information is then typically used for navigation purposes or in order to obtain depths for charting purposes.

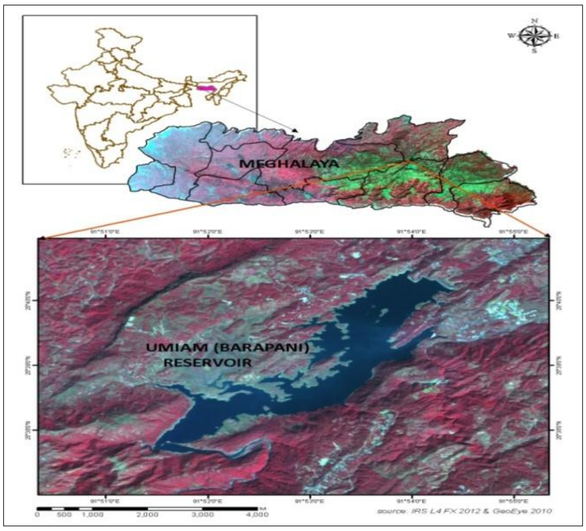


Figure 1: Location of Umiam Reservoir

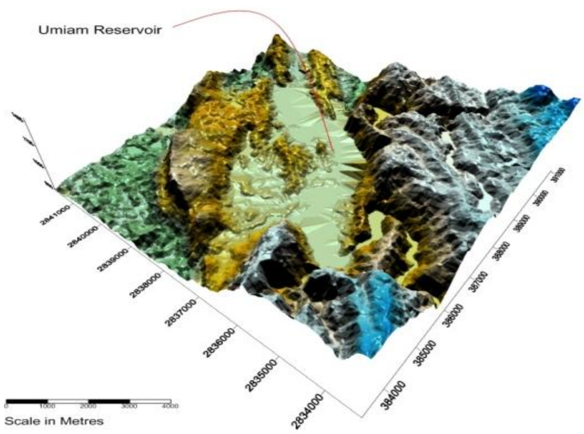


Figure 2: 3D View of Umiam Reservoir

In this study, a portable echo sounder was used as it provides good results in real time, requires less time and labour and is cost effective [4]. Moreover the Echo sounder instrument was readily available at North Eastern Space Applications Centre, Umiam. The Echo Sounder used in the present study was portable South SDE-28 Single Frequency Digital Echosounder (Fig. 3). SDE-28 has a depth range of 0.39 to 220 m at resolution of 1cm and a frequency of 220 kHz. It comes with a 12.1 inch LCD touch screen computer and SDE-

28S software running on built in Windows XP to process the signal from the transducer. It also has USB ports to connect to input devices like GPS device, a mouse or a keyboard. In this study GARMIN Colorado 300 GPS (Fig. 3) was connected to the SDE-28 using standard data cable in order to record GPS readings in conjunction with echo sounding functions to create full XYZ hydrographic data.

Figure 3: Echo Sounder and GPS Instrument Used

2.2.1 Data

In this study, multitemporal satellite imagery as IRS P6 L4 MX, L3 MX (2000 - 2012), high resolution GeoEye-1 image, CARTOSAT-1 Stereo data, etc were used to extract the spatial features as lake spread area of Umiam reservoir [7]. Ancillary data as discharge, reservoir levels, etc., were also used to interpolate and draw area-capacity curves.

2.3 Methodology

The reservoir area was studied and travel paths for the survey were carefully planned. The planned map was prepared using ArcGIS 10.1 (Fig. 5) and printed out in order to cover a maximum area during the stipulated time. The survey was carried out for two days, on October 29th and 30th 2013 on a clear weather. Before beginning the survey, the transducer was connected to the echo sounder and fixed on the middle of the boat's side in order to reduce the influence and interference of the traffic surge to the transducer. About 0.5 m of the transducer pole was immersed into the water. The face of the transducer was kept parallel to the water surface at all times so that reflected signals are well received. When the speed of the surveying boat is fast, then the junction pole connected with the transducer must be tilted slightly backwards, which has to be kept adjusted by increasing the reinforcement of the forward rope and the backward rope, considering the drag force from the flow and the gesture of the driving boat.

Figure 4: Instrument Setup for hydrographic survey

The water level on 29th and 30th October 2013, were noted from MeECL water level display board and was found to be 977.66 m and 977.878 m respectively. Thus average water level was taken as 977.74 m. It was cross checked with the GPS reading and found to be correct. The UTM projection and WGS-84(World Geodetic System) datum was used in GPS settings for the survey [5]. The motor boat was the started and a test run was performed on known depth profiles. The display on the LCD monitor showed that the instrument was functioning well and the survey was started. Some parts of the reservoir had to be avoided as there were fish breeding spots by the locals of the area. However, every possible attempt had been made in order to cover the entire water surface. A continuous record of floor topography was measured at boat speed of 5-6 km/h along predefined traverse lines along length and width of the reservoir. The shoreline coordinates and zero depths were also taken on the same dates using a handheld GPS. At the end of survey the data recorded by the echo sounder was transferred to a desktop computer for further processing.

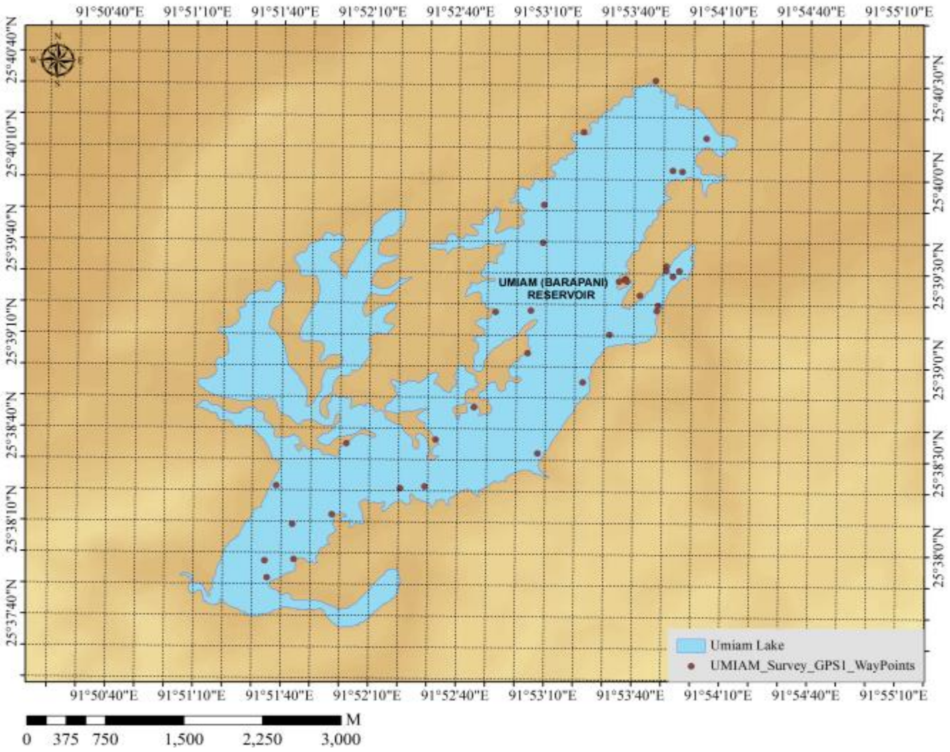


Figure 5: Hydrographic survey plan (grids and GPS start-end points)

2.4 Data processing

The data from the echo sounder was analyzed for inconsistency and suitable corrections were made by linear interpolation method using MS Excel 2007. The corrected data was then used in ArcGIS 10.1 to create shape files of the travel paths and the corresponding XYZ values. The travel path shapefile was selected and points were constructed along this line using construct points option in the editor menu in ArcMap to get the required observation points. A total of 1604 observation points were sorted out with their respective coordinates and depth values. The data was then entered into Surfer 11 worksheet under the column names X, Y and Z respectively. The Z values were preceded by a minus (-) sign. This was done as water surface was taken as the reference level and if minus sign was not given, Surfer would calculate Z values as elevations instead of depth.

Creating the BLN File: The first step is to obtain or create a boundary file in BLN format defining the boundary of the lake (the lake edge) as a polygon. This was done by importing the satellite image of the reservoir and digitizing its boundary using digitize option in Surfer. The digitized coordinates are automatically added as a text file in a pop up window. This file was saved in .bln format.Gridding the data: After creating a .bln file, it was used to create a grid file of the bathymetric data. In the Grid Data dialog, Kriging gridding method was selected. A number of gridding methods support breakline files, but Kriging generally produces a grid that creates a nice, smooth map [6] (Fig. 6).Blanking a grid file: Blanking is done to limit the XY extent of the volume calculation to a confined boundary. The BLN file of the reservoir boundary was opened in the Surfer worksheet and confirmed that cell B1 has the appropriate number (a “1” if area inside the boundary is to be blanked or a “0” if area outside the boundary is to be blanked), “0” in this case (Fig. 7).

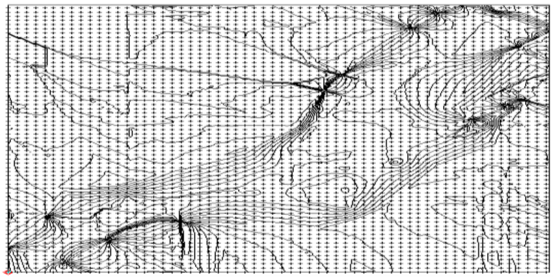


Figure 6: Unblanked Grid File

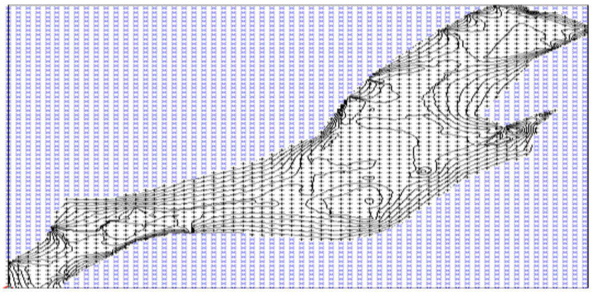


Figure 7: Blanked Grid File

2.5 Volume Calculation

The areas outside the reservoir boundary were blanked out and volume was calculated for the blanked grid file containing the bathymetric data. In volume calculation process, the water surface was taken as the upper surface and the depth was defined by negative Z values. The accuracy of volume and area calculations was done using three numerical integration algorithms.

i) Trapezoidal Rule

$$V_T \approx \frac{y}{2}\left[A_1 + 2A_2 + 2A_3 + \ldots\ldots + 2A_{n-1} + A_n\right] \quad (1)$$

ii) Simpson's Rule

$$V_S \approx \frac{y}{3}\left[A_1 + 4A_2 + 2A_3 + 4A_3 \ldots\ldots + 2A_{n-1} + A_n\right] \quad (2)$$

iii) Simpson's 3/8 Rule

$$V_{S\frac{3}{8}} \approx \frac{3y}{8}\left[A_1 + 3A_2 + 3A_3 + 2A_3 \ldots\ldots + 2A_{n-1} + A_n\right] \quad (3)$$

Where, y = the grid row spacing, A = grid area, n= No. of grids and V_T , VS and $V_{S\frac{3}{8}}$ are total volumes obtained by trapezoidal rule, Simpson’s rule and Simpsons 3/8 rule respectively.

III. RESULTS AND DISCUSSIONS

3.1 Maps and Contours

A contour map of the reservoir was generated from the grid file. The contour interval was taken as 5 m (Fig. 8). A three-dimensional (3D) meshed surface map was generated in Surfer based on the bathymetric grid data (Fig. 9). The red colour in the scale represents the reservoir surface and the blue colour represents the lower elevations in the bottom of the reservoir.

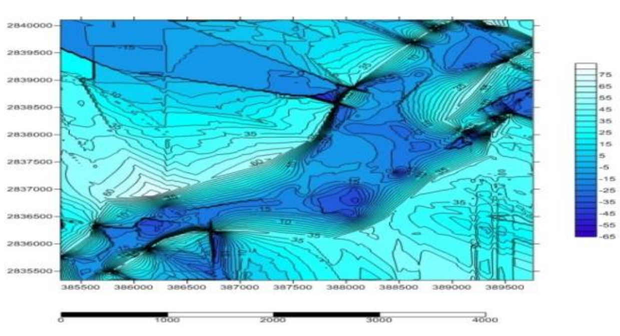


Figure 8: Contour Map

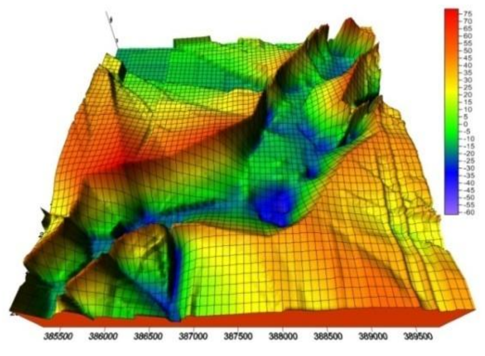


Figure 9: Meshed Three Dimensional Surface Map

3.2 Physical and Storage Characteristics

The volume and surface area of the reservoir was calculated using Surfer 11 (Golden Software). The reservoir storage volume during the study period was found to be 135 MCM (Table I), which shows that its capacity has decreased from its original capacity of 180 MCM at the time of construction in 1965 by 45 MCM. This reduction in the capacity is due to massive sedimentation taking place in the reservoir. According to MeSEB the sedimentation rate in the reservoir takes place at around 26.1 ha m/100 km^2/year [3]. However the findings of this study shows that 45 MCM of sediment has been deposited since the reservoir began operating in 1965. Thus, it is evident that 0.9375 MCM of sediment is deposited every year into the Umiam reservoir. The surface area of the reservoir has also decreased from 10 Km^2 to 6.65 Km^2. The perimeter of the reservoir was found to extend over 56 Km.The reservoir has maximum length in the North-West Direction covering a distance of 6.604 Km and maximum width of 1.95 Km in the East-West direction. Area-elevation-capacity curves are of the most important physical characteristics of dam reservoirs. These curves are used for reservoir flood routing, reservoir operation, prediction of sediment distribution in reservoirs, etc. They also enable us to study the seasonal variations in storage in the reservoir [9]. In this study the stage and capacity curves were drawn with respect to the reference water level 977.74 m i.e. the water level on the day the survey was conducted (Fig.10). The volume and area were determined following at 5 m intervals by changing the Z values as -5, -10, -15,-20,..., -60, instead of water surface level at Z= 0 at 977.74 m. From the elevation capacity curve (Fig. 10) and area elevation curve (Fig.11) it can be seen that both capacity and the area of the reservoir has positive relationship with the elevation and their values increase with the increase in elevation.

Table I: Morphometric Parameters of Umiam Reservoir

Reservoir Parameters		Magnitude
Area		6.651 Sq. Km
Perimeter		56 Km
Max Depth		52.6 m
Mean depth		18.158 m
Max Length (North West)		6.604 Km
Max Width(East-West)		1.947 Km
Volume	By Trapezoidal Rule	135 MCM
	By Simpson's Rule	134.929 MCM
	By Simpson's 3/8 Rule	135.048 MCM

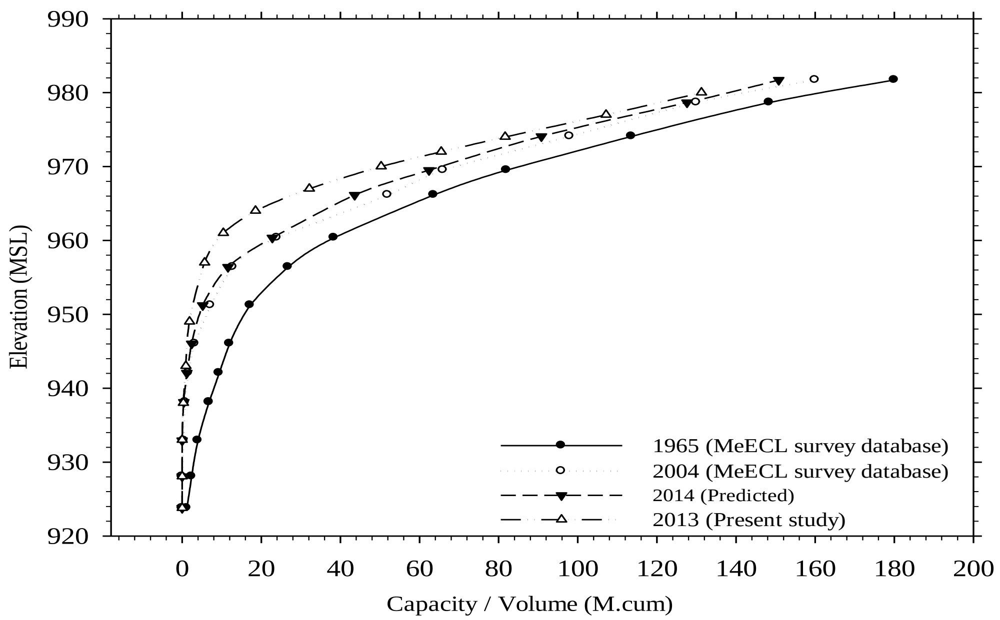


Figure 10: Comparison of Elevation Capacity Curves for Umiam Reservoir

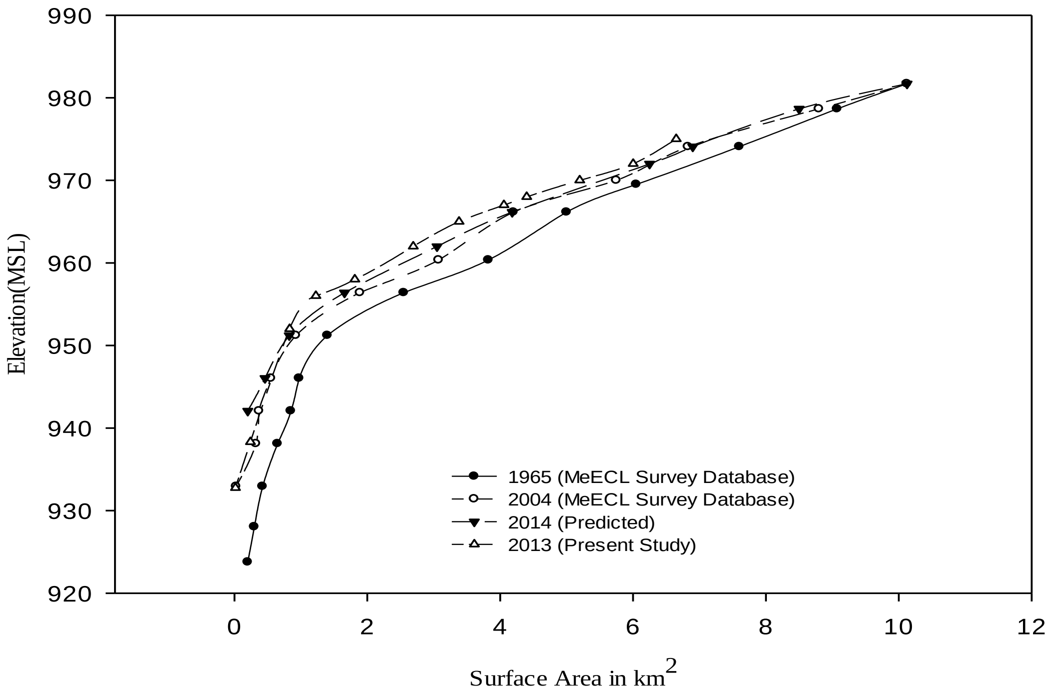
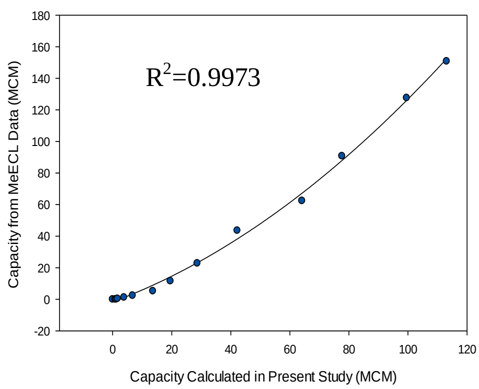


Figure 11: Comparison of Elevation Capacity Curves for Umiam Reservoir

When compared to the data provided by MeECL form previous surveys, the curve obtained from the present survey data showed a good relationship in both elevation-capacity curve and elevation-area curve. It is observed that the curves obtained in the present study are very closely related to the curves predicted by MeECL for the year 2014. A regression analysis was carried out in order to determine the correlation between the data obtained from MeECL and present study. The elevation capacity curve of MeECL for the year 2014 showed good correlation with the results of this study with R^2 value of 0.9973 (Fig. 12) Similarly, the elevation-area curves were analyzed for the data of the same year group and showed good correlation with an R^2 value of 0.978 (Fig. 13).



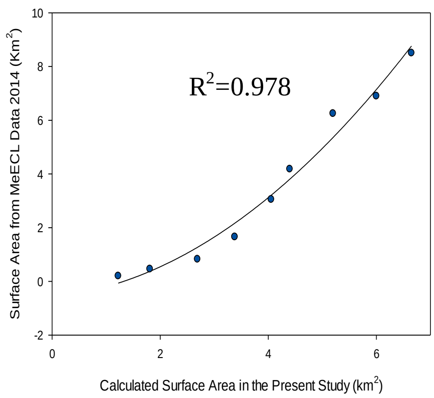


Figure 12: Regression Plots of Reservoir Capacities   Figure 13: Regression Plots of Reservoir Surface Area

IV. CONCLUSIONS

Bathymetric plots and Elevation-storage curves of the reservoir were generated using SONAR (Echosounder data) and GIS techniques (GPS data). It was found that the reservoir capacity has decreased more than the predicted or expected rate. The maximum and mean depths were computed in the range of 52.6 m and 18.158 m respectively during the dry season. The surface area was found to be reduced to 6.65 km^2 in 2013 from 10.125 km^2 in 1965. The alarming siltation rate may be attributed to the massive entry of pollutants flowing through the Wahumkhrah River from Shillong urban, along with the catchment erosion. Other reasons might be reduction in the flow of water from the Umiam River into the reservoir due to watershed degradation and environmental changes. In order to have a clear idea of the factors affecting the reservoir water quantity and quality it is required to study the landuse landcover, soil erosion and climate change aspects in the watershed. Also, a water balance analysis of the reservoir is necessary in order to effectively utilize the reservoir water and to monitor the seasonal variations in its storage. These studies will be helpful in planning and managing its resources for sustainable use.

Acknowledgements

The author(s) are indebted to the North Eastern Space Applications Centre (NESAC) for providing the necessary facilities and instruments for the hydrographic survey along with geospatial data processing. We would also like to thank the Meghalaya Energy Corporation Limited (MeECL), especially Director (Generation) and Mr. Jain for providing the valuable data on Umiam reservoir and consent to carry out the survey. We would also like to express our gratitude to Meghalaya Tourism Development Corporation (MTDC), Government of Meghalaya, for providing the water boat to carry out the survey. We extend our gratitude to Water and Environment Division, Department of Civil Engineering, NIT Warangal for encouragement and giving the permission to carry out the study in NESAC. We are also thankful to Sangyal, Zigmi and Suranjana for rendering their help during the entire survey.

REFERENCES

[1] D. T. Zimba, *Geography of Meghalaya*, University of California, 1978.

[2] Nongbri and Syiem, Analysis of heavy metal accumulation in water and fish (Cyprinus carpio) meat from Umiam Lake in Meghalaya, India. *International Multidisciplinary Research Journal, 2(2),* (2012), 73-76.

[3] MeSEB, Demistifying Umiam Lake Degradation, *India Water Portal*, 2009.

[4] Hassen M Yesuf, Tena Alamirew, Assefa M. Melesse and Mohammed Assen. Bathymetric Mapping for Lake Hardibo in Northeast Ethiopia Using Sonar. *International Journal of Water Sciences. 1(1)*, 2012, 1-9.

[5] US Army Corps of Engineers, Engineering Design and Hydrographic Surveying Manual No. 1110-2-1003, Department of the Army Washington, DC, 2001.

[6] José Fernandes Bezerra-Neto, Ludmila Silva Briguenti and Ricardo Motta Pinto-Coelho, A new morphometric study of Carioca Lake, Parque Estadual do Rio Doce (PERD), Minas Gerais State, Brazil, *Acta Limnologica Brasiliensia, 20(2),* 2008,161-167.

[7] Special Projects Operations Team Data Acquisition and Processing Report. *Hydrographic Systems Readiness Review Memo, SPOT (s3004)*, Portsmouth, VA, USA, 2007.

[8] Encyclopaedia Britannica Bathymetry. *Encyclopaedia Britannica Inc. Online*, 2014. (www.britannica.com/EBchecked/topic/55994/bathymetry).

[9] S. Lu N. Ouyang, B. Wu, Y. Wei, and Z. Tesemma, Lake water volume calculation with time series remote-sensing images. *International Journal of Remote Sensing, 34 (21−22)*, 2013, 7962 −7973.