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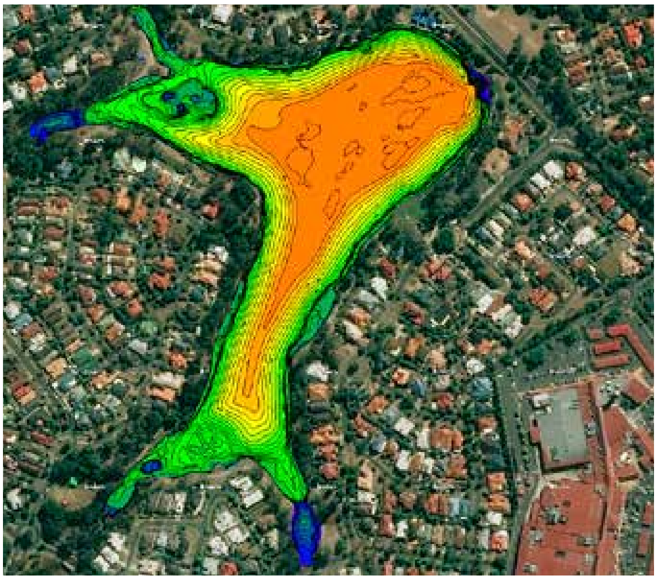
Determining Total Volume of Sediment in Recreational Lakes

By Daniel Wagenaar, Application Specialist

I. INTRODUCTION

A survey was performed of a recreational lake within Forest Lake, Brisbane to determine the total volume of sediment deposited in the lake. The survey comprised of the main water body and four inlets discharging into the lake. The survey methods applied during the bathymetry survey varied from bathymetric survey using unmanned surface vehicle and dual frequency echo sounder to topographic survey of the banks and inlets using survey rod and data collector.



This technical note gives a broad overview of the equipment and surveying techniques used during the survey process, as well as the methodology followed in developing surface elevation models and calculating total volume of sediment in the lake.

II. SURVEY CONTROL

A. Survey Equipment

The equipment chosen for the surveys consisted of two Global Navigation Satellite System (GNSS) receivers, CEE HydroSystems CEESCOPE with dual frequency echo sounder and rQPOD with autonomous navigation. The survey software utilized during the surveys consisted of HYPACK® Hydrographic Survey and Carlson SurvCE software respectively.

GNSS

Base Station: Hemisphere S321 Smart Antenna was setup precisely over a known survey marker using tripod and tribrach shown in Figure 1. The coordinates and elevation of the survey marker and height of GPS Antenna was entered into the SurvCE software to reference the survey against known datum.

Rover: Hemisphere S321 Smart Antenna was setup on either rQPOD or survey pole with the exact height of the GPS antenna entered into the survey software.

Fig. 1. Hemisphere S321 Smart Antenna

Fig. 2. CEESCOPE & M195 Dual Frequency Echo Sounder

Echo Sounder
CEESCOPE and M195 Dual Frequency echo sounder from CEE HydroSystems shown in Figure 2 was mounted on unmanned surface vehicle (USV) for the bathymetric component of the survey. The data was transmitted from the CEESCOPE to land based HYPACK® Hydrographic Survey software using CEE-LINK™ shore radio module.

Autonomous rQPOD was used for the USV for the bathymetric component shown in Figure 3. A special mounting was designed for the M195 echo sounder to fit into the existing instrument wet-well.

The line plan developed in HYPACK® Hydrographic Survey software was uploaded onto rQPOD. This enabled rQPOD track the lines autonomously during the bathymetric survey ensuring much higher efficiency in performing the surveys.

Fig. 3. Autonomous rQPOD

B. Survey Control Design
The horizontal and vertical survey control for the bathymetry survey at Forest Lake was based on four survey markers shown in Figure 4. The position of the survey markers was selected based on Real Time Kinematic (RTK), Network RTK and Theodolite survey requirements.

Fig. 4. Location of Survey Markers

C. Horizontal and Vertical Control
The four survey markers were established using Static GNSS survey technique, collecting more than 2 hours of raw satellite data at each survey marker. The raw satellite data was collected using Hemisphere S321 (multi-GNSS, multi frequency) Smart Antenna. The data collected during the static surveys were converted to RINEX format from where it was uploaded to the AUSPOS post processing facility on the Geoscience Australia website.

The Real Time Kinematic (RTK) and Network RTK surveys were verified against the established horizontal and vertical control during the Forest Lake survey to ensure that high level of accuracy is achieved.

D. Survey Localization
The results obtained from Geoscience Australia of the static surveys performed at the survey markers showed a higher accuracy in position and elevation at survey marker SM1. Based on the higher accuracy survey marker SM1 position and elevation was used to localize the entire survey.

III. BATHYMETRY SURVEY

A. Survey Procedure
The survey procedure at Forest Lake comprised of two components, a topographic and bathymetric component.

The topographic survey consisted of surveying the lake boundary and the four inlets. The top and bottom bank elevation of the boundary was surveyed at every 5th step shown in Figure 5.

The inlets topographic survey comprised of surveying the surface elevation of the sediment and channel bed. Special circular foot was mounted at the bottom of the survey rod to prevent the survey rod from penetrating the sediment during the sediment survey.

Fig. 5. Top and Bottom Bank Survey

Fig. 6. rQPOD Platform

The topographic and bathymetric surveys was based on RTK survey technique, using Hemisphere S321 Smart Antenna's.

The bathymetric survey was performed using CEE HydroSystem with dual echo sounder and HYPACK® Hydrographic Survey software. The survey vessel consisted of rQPOD remote control platform with autonomous feature shown in Figure 6.

The bathymetric survey area was defined by a boundary based on actual measurements from where a line plan was developed at 10m intervals perpendicular to the channel topography as shown in Figure 7.

Figure 7: Border and Line Plan

B. Data Collection

Figure 8: Bathymetric Survey

The line plan develop for the main water body of Forest Lake was uploaded autonomous rQPOD.
Individual measurement files containing all the raw data from the Hemisphere S321 and CEEHydroSystems echo sounder were created in Hypack for each of the planned lines.

The actual ship track of the autonomous rQPOD is shown in Figure 8.

Position and elevation of each point during the topographic survey was recorded using Hemisphere data collector and SurvCE software.

The individual points surveyed during the topographic survey at Inlet 1 is shown in Figure 9.

Figure 9: Topographic Survey

C. Water Elevation

The water elevation was relatively constant during the bathymetric survey of Forest Lake. Water elevation was surveyed each day before and after the completion of bathymetric surveys, summarized in Table 1.

Pressure sensor was also installed at the lake to monitor the water level trend during the bathymetric surveys. Water elevation of 36.292 mAHD was used to translate the depth measurements from echo sounder to elevation in mAHD. The elevation is based on average of surveyed water levels over the three days.

Table 1: Water Elevation

Date	Time	Elevation (mAHD)
1st Oct	14:39	36.287
2nd Oct	10:01	36.3266
	10:03	36.2977
	15:42	36.2932
	15:43	36.3106
3rd Oct	09:19	36.289
	09:20	36.271
	14:03	36.287
	14:04	36.283

D. Survey Statistics

Survey statics calculated from the raw data collected during both the bathymetric and topographic surveys preformed are summarized in Table 2.

Table 2: Survey Statistics

Variable	Description	Value
Line Plan	Total number of survey lines	94
	Total length of survey lines	9,130m
Soundings	Number of soundings using echo sounder	141,612
	Number of soundings using survey pole	2,446
Perimiter	Distance of lake perimeter including four inlets	2,697.3m
	Area of lake perimeter including four inlets	108,318.1m^2
Elevation	Highest surveyed elevation	38.45m AHD
	Lowest surveyed elevation	32.63m AHD

IV. MODEL DEVELOPMENT

A. TIN Model

TIN Model was developed based on the sediment surface and channel bed surface elevation in Hypack bathymetric software package illustrated in Figure 10. The models were developed from XYZ soundings of both the bathymetric (dual frequency echo sounder) and topographic surveys (survey rod).
The XYZ soundings from both the bathymetric and topographic surveys were combined with the bottom of bank surveys. A grid of 1m x 1m was developed from the XYZ soundings in Hypack. The top of bank soundings were combined with the 1m x 1m grid for the final TIN model.

Figure 10: Forest Lake TIN Model

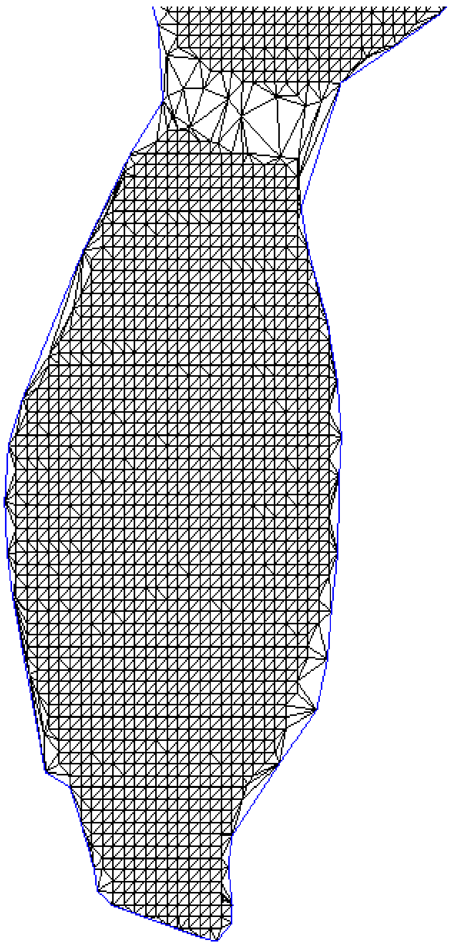


Figure 11: Inlet 1 TIN Model

The final TIN model of Inlet 1 is illustrated in Figure 11. The TIN models developed for sediment surface and channel bed surface elevation was used for all outputs generated in Hypack.

B. Sediment Surface Elevation

Sediment surface elevation was developed from the developed TIN Model for Forest Lake shown in Figure 12.

Elevation color scheme range of 32.70 – 38.40m AHD was adopted for Forest Lake survey. This clearly shows the change in elevation of the four inlets to the main water body.

3D Sediment surface elevation of Forest Lake is shown in Figure 13. The surface elevation of the main water body does not change significantly across the lake.

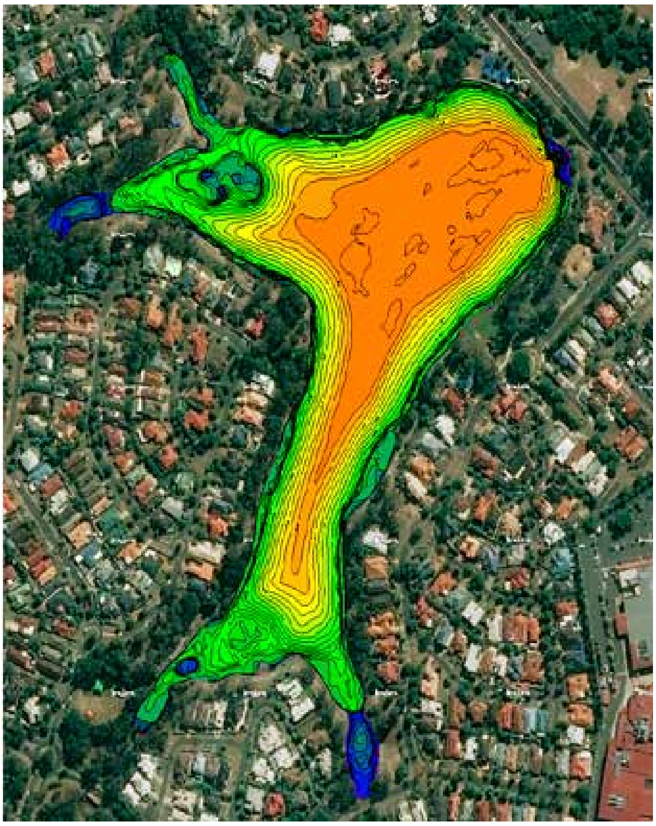


Figure 12 Sediment Surface Elevation

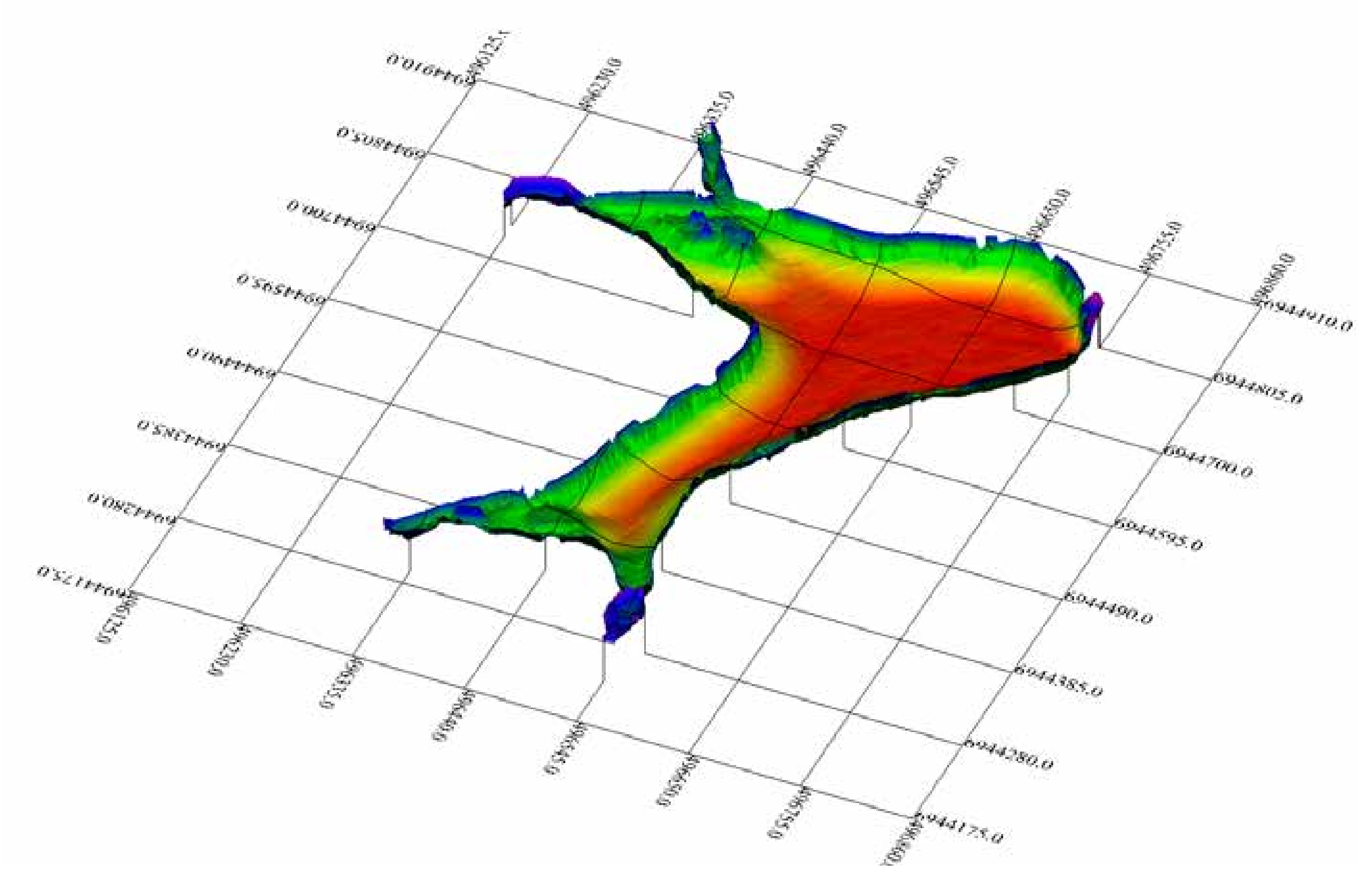


Figure 13: 3D Surface Elevation

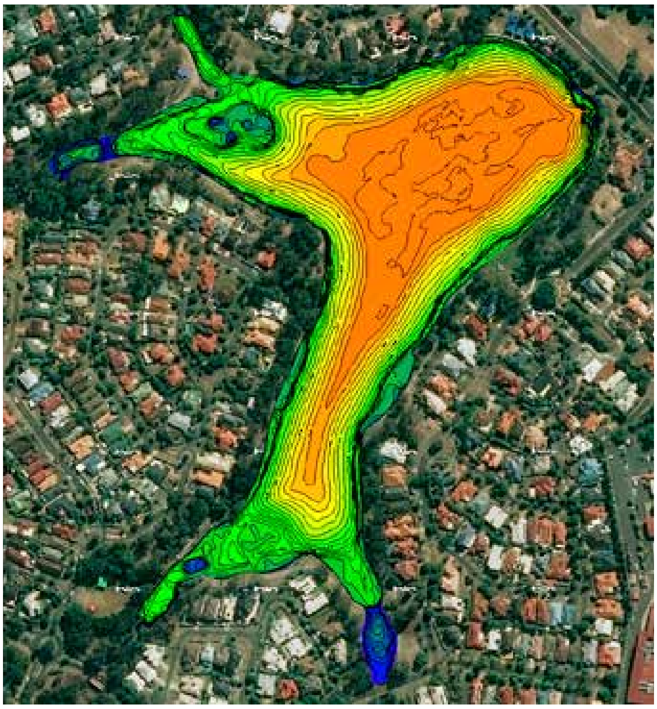


Figure 14 Channel Bed Surface Elevation

C. Channel Bed Surface Elevation

Channel Bed surface elevation was developed from the developed TIN Model for Forest Lake shown in Figure 14.

Elevation color scheme range of 32.70 – 38.40m AHD was adopted for Forest Lake survey. This clearly shows the change in elevation of the four inlets to the main water body.

D. Sediment Thickness

The sediment thickness was determined by developing a surface elevation model for Sediment surface and the Channel Bed.

The difference in elevation between the two models resulted in the total thickness of the sediment within Forest Lake shown in Figure 15.

Figure 15: Sediment Thickness

E. Sludge Volume

Volume and Area calculation was performed between the difference of the Sediment and Channel Bed Surface Elevation models of Forest Lake. The volume and area of total sediment calculated in Forest Lake is summarized in Table 5.

The volume and area above is the total amount of sediment above the channel bed supplied in Table 5. The volume and area below is the total volume below the channel bed.

Table 5: Sediment Volume and Area Calculation

Volume Above (m^3)	Area Above (m^2)	Volume Below (m^3)	Area Below (m^2)
3435.2	106361.7	113.3	26365.4

V. CONCLUSION

The survey approach and data processing is unique to each project even though the survey equipment and techniques are similar. There are aspects that are similar between different projects, but it is unlikely that you could apply the same approach entirely on a new project.

What I have found over the years that if you comply with the following key principles, the likelihood in achieving accurate survey results are very high,

1) Segment surveying, is a key component in overall survey design. Depending on the size of the project, it is difficult to perform the entire survey in one operation. The following process was followed for Forest Lake,

   a. Establish horizontal and vertical control
      i. Visibility to sky is crucial for GPS surveying,
      ii. Line of sight is essential for Theodolite (Total Station) surveying. Areas with dense vegetation and or buildings will need a different survey technique.
   b. Survey top and bottom of bank of entire lake
   c. Survey each individual inlet
   d. Perform bathymetric survey of main lake

2) Systematic approach with both the survey and data processing,

3) Establishing control for surveying and water elevation measurements. Existing survey markers and water level instrumentation can be used, but operator must verify the accuracy.

4) Verification process for surveying and water level measurements. It is important to verify the position, elevation and water level accuracy during the entire survey against a reference (survey markers, water level sensor, staff gauge, etc.).

5) Segment data processing. Depending on the size of the project, it is impossible to process all the raw data at once. In certain cases only a part of the data can be processed at a time from where the different segments are combined. Forest Lake process followed,

   a. Echo sounder data was processed separately,
   b. Combine bottom of bank with echo sounder soundings,
   c. Generate 1m x 1m XYZ grid,
   d. Clip XYZ file (1m x 1m grid) with top of bank border file,
   e. Combine XYZ (top of bank) with clipped XYZ (1m x 1m grid) file,
   f. Develop TIN model.

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Xylem Analytics Asia Pacific
analytics.asia-pacific@xyleminc.com
www.xylem-analytics.asia

Xylem Analytics Australia
salesAus@xyleminc.com
www.xylem-analytics.com.au

Xylem Analytics South Asia
analytics.india@xyleminc.com
www.xylem-analytics.in

Xylem Analytics Japan
ysijapan.support@xyleminc.com
www.xylem-analytics.jp

Xylem Analytics Korea
junjae.won@xyleminc.com
www.xylemanalytics.kr

Xylem Analytics Vietnam
analytics.vietnam@xyleminc.com
www.xylem-analytics.vn