Assisting in the Management of Waterways

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SUMMARY

Maritime Safety Authorities – usually a division of the Ministry of Transport or the Ministry of Commerce are given responsibility for protecting a nation's or region's waterways and the people who use them providing sustainable resources from safer, cleaner seas. Within these Maritime Safety Authorities, a Hydrographic Services section may exist to carry out hydrographic surveys on behalf of clients. Alternatively these projects may be assigned to other government departments. Often clients include local Ports, Boat building Infrastructure, waterways management (for recreational boating) and fishing and farming.
Initially a Maritime Safety Authority would incorporate into their workflow computer based systems to process their bathymetric data. For some this has developed into management of the data that extends capability beyond the bathymetric data compilation and QC.
An example of this development of technology is new functionality in modules that are designed to support new demands through Engineering and Analysis with tools such as sophisticated and fast volume computations and advanced 3D visualization of bathymetry and reference models.

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1. INTRODUCTION

Maritime Safety Authorities often are empowered to protect a nation's or region's waterways and the people who use them - providing safer and cleaner seas. Within the varied and often large structure of a Maritime Authority, the Hydrographic Department will oversee or even undertake Hydrographic surveys on behalf of the authority and other clients and stakeholders. These may include river authorities, ports and harbours, coastal areas and islands under local administration, boating and leisure craft infrastructure as well as architectural or environmental organisations.

2. OVERVIEW OF OPERATIONS

Waterways are managed by authorities that use a variety of survey equipment on permanent installations onboard the survey launches. These may often be supported with other mobile systems deployed on vessels of opportunity, such when used during rapid response surveys. Equipment used includes multi beam echo sounders, Sidescan sonars, Swath interferometric system, single beam echosounders supported by peripheral devices to compensate for motion, attitude, heading. For positioning satellite based solutions, typically RTK or DGNSS. Surveys range from boat ramps that integrate land survey data with only a small Hydrographic component, through to large high precision surveys for Under Keel Clearance systems.

The nature and importance of the Hydrographic survey work requires that the waterways authorities ensure that their survey personnel are of a high quality and have relevant experience and competencies. For example in Australia the Maritime Safety Queensland authority have surveyors certified at Level 1 by the Australasian Hydrographic Surveyors Certification Panel (AHSCP) supported by additional surveyors (including graduates) that work under direct supervision.

In an effort to improve acquisition to processing ratios, waterway authorities had to identify and source suitable technical solutions including integrated processing software. The solution was to incorporate the CARIS Ping-to-Chart products into the workflow and to adopt the CARIS HIPS and SIPS products for processing bathymetric data. These off the shelf software packages provide a considerable level of user quality control and checking as well as visualisation. However a further package, BASE Editor, can also be used either on board the survey launch or back in the Hydrographic office to assist in bathymetric data compilation and QC. A significant development relating to the CARIS products is the Engineering Analysis Module (compatible with BASE Editor). Its functionality enables the user to improve their management of the ports and waterways.

3. THE ENGINEERING ANALYSIS MODULE

The Engineering Analysis Module features under the 'Analysis' pillar of the Ping-to-Chart workflow, as part of the Bathy DataBASE suite of products. Recognising the fact that different users have different requirements, Bathy DataBASE is a scalable solution.

In order to provide more functionality for users in the ports and waterways environment, the Engineering Analysis module was introduced to the Bathy DataBASE product suite. The module works with either BASE Editor or BASE Manager, and includes many functions migrated from an existing CARIS application (BEAMS - Bathymetry and Engineering Management System). These functions include volume computations, shoal management, conformance analysis and reference model creation and maintenance.

4. VOLUME CALCULATION METHODS FOR HYDROGRAPHIC SURVEYING

The calculation of volumes in hydrographic surveying is frequently used in dredging applications and reservoir analysis (for example, sedimentation). A number of different methods can be utilized in determining a volume. The 'best' method to use is determined by factors such as the technique of sounding for the data (single beam, multibeam, LiDAR etc.) and also the nature of the material (smooth, sandy bottom is quite different to an undulating, rocky terrain).

"Accurate volume estimates are important for the choice of dredging plant, production estimates and ultimately project costs. " (Sciortino J.A., 2011)

In addition to the volume of material, the type of material is another important factor. The cost of dredging rock will be much higher compared to the same amount of material in sand.

4.1 End Area Volumes

End Area volumes have been derived from land-based methods used in railroad and roadway construction. They involve calculating the volume from cross sections of a channel, surveyed at regular intervals (see Figure 1). The key components in computing the volume are the cross sectional area (an average is taken of the two areas) and the length between the cross sections. This method assumes that the cross sectional area is relatively constant between two successive cross sections. If this assumption is not true, the volume produced will realistically just be an approximation.

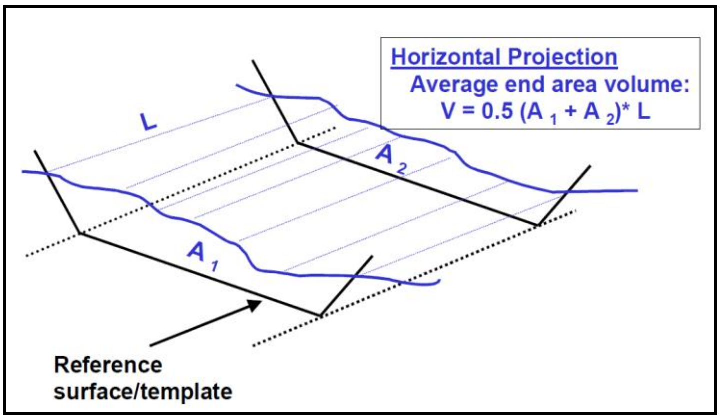

Figure 1: Calculation of End Area Volumes *(USACE, 2001).*

4.2 TIN Volumes

Triangulated Irregular Network (TIN) Volumes are based on the true positions of depths to calculate the volume of a surface. This calculation involves modelling the surface as a collection of small planes. TIN's can either be derived from a gridded bathymetry source (i.e. surface) or from a point cloud. One advantage in using the TIN method (particularly for point data) is that the true position of the source depths will be utilized in the volume calculation. This is the historically preferred method for most dredging type applications where volume is critical.

4.3 Hyperbolic Volumes

For this method, a hyperbolic cell is created from the centres of every four adjacent grid cells. The depths from the grid cells are used as the depths for the corners of the hyperbolic cell. For this calculation, the surface is modelled as a collection of hyperbolic paraboloid sections, with a hyperbolic paraboloid created to smoothly pass through the points of each hyperbolic cell (see Figure 2). This gives a smooth approximation of the surface and good volume results, but is processing intensive and can be time consuming.

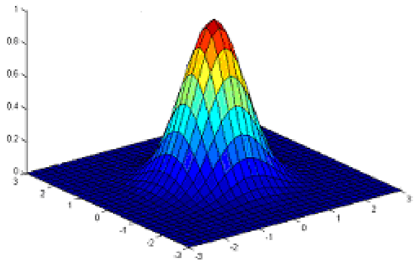

Figure 2: Representation of the hyperbolic paraboloid volume method

4.4 Rectangular Volumes

In this method, a single depth value from each cell (or bin) in the surface is used to calculate the volume. The surface is modelled as a collection of disjointed rectangular prisms, with the depth for each grid cell becoming the depth of the prism (see Figure 3). In comparison to the previous hyperbolic method, this results in a much more 'simple' volume calculation which is processed much faster, however the accuracy of the computed volume may not be as reliable.

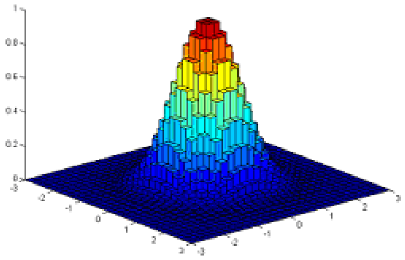

Figure 3: Representation of the rectangular volume method

One limitation on the rectangular volume method is the inability to perform a volume calculation against a sloped or non-horizontal surface in a reference model (for example the bank of a channel). This is because by definition, a rectangular prism cannot have a sloped edge, so only horizontal reference surfaces are supported.

5. VOLUME COMPARISONS

As previously outlined, there are a number of different methods available to the Hydrographic Surveyor or Engineer for volume determination. Depending on the technology available to conduct the survey, different methods may be adopted to calculate and derive the volumes but one approach may produces a more realistic solution. If the user only has access to a single beam echo sounder, they will be limited to end area volumes and TIN volumes. For a full density multibeam survey, rectangular and hyperbolic volumes can also be taken into consideration.

The nature of the seafloor (or riverbed/reservoir) could be another factor in determining the most suitable volume method to be used. If the bottom topography is smooth (such as with sand), hyperbolic volumes, which produce a smooth estimate of the terrain using constructed hyperbolic paraboloids could yield the best results. For a harsher, rocky terrain, TIN volumes utilizing the true positions of each depth may be the most robust answer.

It’s necessary to test and validate the possible solutions on a number of data sets to assess their merit. In order to test the results produced by the various methods of volume calculation Maritime Safety Queensland (MSQ) undertook a case study of data they had collected.

5.1 Case Study in Weipa

In order to test the results produced by the various methods of volume calculation, a case study was carried out using survey data collected by MSQ at the Port of Weipa in October, 2011. The data was provided as an ASCII XYZ file that was binned at a 1metre resolution. A reference model for the Port of Weipa was also used in the calculations. The test area used is a section of the south channel.

Volumes were calculated in the test area to determine the amount of material that would need to be removed to bring the channel down to a declared depth of 16m *(an arbitrary value chosen for testing purposes).* The methods used for comparison were hyperbolic, rectangular and TIN volumes. Simulated end area volumes were also calculated by extracting profiles from the multibeam bathymetry at intervals of 25m, 50m and 100m. The results can be seen in Table 1. where the hyperbolic volume has been used as the benchmark for determining volume difference and error for other methods. This does not mean that there is a zero error in the hyperbolic volume result.

Table 1: Comparison of volume results for the test area in Weipa

METHOD	**VOLUME (m^3)**	**DIFFERENCE (m^3)**	**VOLUME ERROR (%)**
Hyperbolic Volume	794,912.5	0	0
Rectangular Volume	805,090.2	10,177.7	1.280
TIN Volume	798,654.4	3,741.9	0.471
End Area (25m Interval)	803,019.1	8,106.5	1.020
End Area (50m Interval)	802,755.3	7,842.7	0.987
End Area (100m Interval)	802,022.8	7,110.2	0.894

The results displayed in Table 1 yield some interesting results. As could be expected, the two volumes closest to each other are the hyperbolic and TIN volumes. What is probably most surprising are the results achieved through the use of end area volumes. One would generally assume that profile spacing would be inversely proportional to the volume difference/error (i.e. the lesser distance between profiles, the greater the accuracy of the computed volume). This is not reflected in these results, where the error actually decreases as the interval increases. This may be due to the nature of the seabed. The data used was a pre dredge data set following the wet season. The channel is typically smooth and shaped in a reasonably consistent V shape due to the amount of siltation and the effect of significant shipping movements which assist in keeping the centreline clear of siltation.

5.2 Validation of Case Study

As the results produced in the Weipa case study did not reflect expected results, an additional independent case study was sought out. One such research project was by the Baylor University Department of Geology (BUDG) in Texas, USA. The project undertaken by Dunbar J.A and Estep H of the BUDG was to study the hydrographic surveying methods utilized by the Texas Water Development Board (TWDB) in determining water and sediment volume in their Texas reservoirs. Whilst the project also investigated sub bottom profiling and sediment surveys, the volume comparison was carried out in Lake Lyndon B. Johnson, a Highland Lake on the Texas Colorado River.

As part of the project, Hydrographic Consultants Inc. collected and processed a multi-beam survey in Lake Lyndon B Johnson. In order to evaluate the influence of survey profile spacing on volume accuracy, BUDG extracted simulated profiles at spacing's ranging from 100 to 2000 ft from a high-density multi-beam survey. Volume calculations based on the extracted profile sets were compared to the volume based on the full multi-beam survey. (Dunbar, J.A, Estep, H, 2009)

Table 2: Results of BU Volume Comparisons *(Dunbar, J.A, Estep, H, 2009)*

Simulated Profile Spacing	Run 1 Volume (acre-ft)	Run 1 Volume Error (%)	Run 2 Volume (acre-ft)	Run 2 Volume Error (%)
Full Multi-Beam	51,701.5	0.0	51,701.5	0.0
100 ft	51,726.6	0.048	52,020.9	0.062
200 ft	51,646.9	0.106	51,746.4	0.087
300 ft	52,072.8	0.718	51,712.7	0.022
500 ft	51,803.2	0.196	51,703.9	0.005
700 ft	52,247.2	1.06	51,076.0	1.21
1000 ft	51,775.6	0.14	51,277.4	0.82
1500 ft	52,712.5	2.00	49,581.3	4.10
2000 ft	53,141.1	2.78	49,584.5	4.10

The results produced in the study by BUDG can be seen in Table 2. They are also shown graphically in Figure 4. When extracting the profile sets to produce simulated volumes, BUDG did this in two runs (Run 1 and Run 2). This meant, that for each simulated profile spacing, two independent sets of profiles were extracted from the bathymetry data sets.

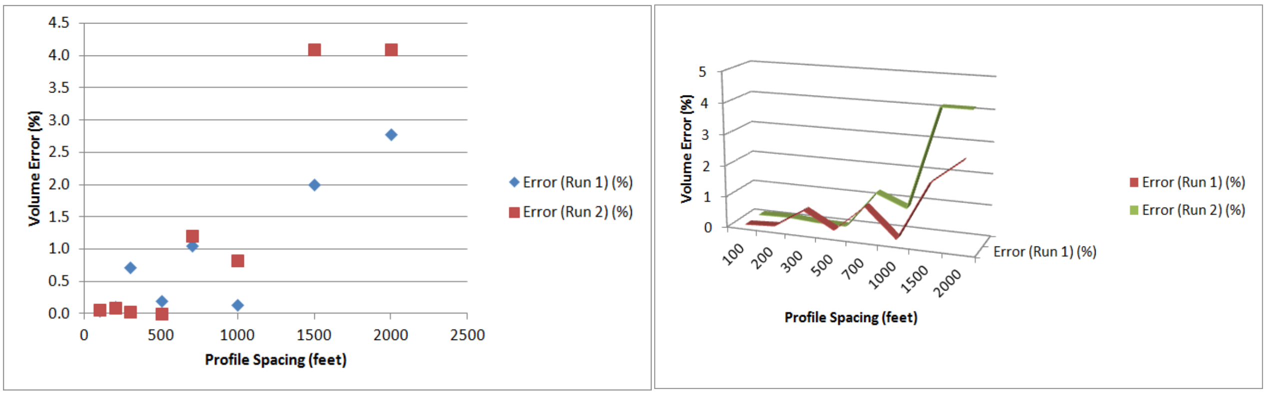

Figure 4: Scatter plot and 3D line graph of BUDG volume comparisons.

By undertaking a statistical analysis of the BUDG Volume comparison results, values from Run 1 have a coefficient of correlation of 0.884 and 0.936 for Run 2. This indicates a strong positive correlation between profile spacing and volume error, which is what we would generally expect. However despite the strong correlation, there are inconsistencies in the data. Such as the very low value of 0.14 % for 1000 ft profile spacing in Run 1, and a difference of 0.696% in Run 1 and Run 2 error for 300 ft profile spacing. This is because the Volume Error of 0.718% for 300 ft profile spacing in Run 1 is higher than expected in contrast to other results.

From these results, a conclusion can be drawn that when increasing the population size of our sample dataset, the error values display a tendency for a strong positive correlation. In the Weipa Case Study, the population size was only three (25m, 50m and 100m spacing) so these results were not apparent. If further intervals were added and multiple runs as in the BUDG example, perhaps we could expect to see similar results.

It could therefore be argued that while there is a trend for volume error to increase with profile spacing, for any given dataset based on one set of profiles, i.e. a single beam survey, the accuracy of the volume is essentially down to luck. In their report, Dunbar J.A and Estep H state that "Reducing the profile spacing to less than 500 ft does not guarantee improved volume accuracy." (Dunbar, J.A, Estep, H, 2009)

6. VOLUME COMPUTATIONS

As part the evaluation for the CARIS Engineering Analysis Module, MSQ ran a comparison of TIN volume computations using the module against their existing capability. MSQ traditionally used the TIN method when required to compute volumes for their Hydrographic surveys and the results from the comparison can be seen in Table 3. The Engineering Analysis Module produced the same TIN volume results, in less time across all cases, as well as having the ability to compute a volume for the entire channel.

Table 3: Volume results and processing times at MSQ

	CARIS Engineering Analysis Module		**Existing capability**	
Area	Time to Process (hh:mm:ss)	Volume to Dredge (m³)	Time to Process (hh:mm:ss)	Volume to Dredge (m³)
Whole Channel	0:47:00	116,724	Not enough memory to compute	Not enough memory to compute
BN16 - BN18	0:01:57	2,234	0:03:14	2,233.8
BN6 - BN 8	0:05:50	31,015	0:19:34	31,016.2
BN 8 - CH15500	0:02:00	19,049	0:02:45	19,048.8
BN2 - BN4	0:05:52	10,492	> 1 hr	9867

7. CONCLUSION

Waterway Authorities have various survey requirements imposed on them for a whole variety of stakeholders and users. The Engineering Analysis Module is able to greatly assist users in managing ports and waterways through the use of conformance analysis, sophisticated volume computations, shoal detection/management and the creation, editing and maintenance of reference models. When computing volumes, users should consider what type of volume will deliver the most accurate results. While End Area volumes have traditionally been quite widely used, this paper presents evidence that TIN volumes and hyperbolic volumes should be taken into consideration as they are capable of producing volume results that are reliable and repeatable.

As computing, IT and data management systems develop and improve so the demands made of them often increase. New implementations still require to be thoroughly tested and validated, in order to improve the users' experiences. The Engineering Analysis Module has provided MSQ with the ability to compute volumes faster and on much larger data sets than their existing capability, along with new functionality for advanced visualization techniques. Hydrographic surveys continue to gather and add volumes of data to the databases and stores but the ability to increase the data sets reduces the historical trade off required between precise volumes of 0.5 metre spaced data, with practical processing limits that would previously be limited to data generalised at the 2.5 metre level of density.

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BIOGRAPHICAL NOTES

Daniel Kruimel is an active member of the Spatial Industry and is currently a member on the SSSI Regional Committee of South Australia, as well as the Hydrography Commission National Committee. Daniel is with CARIS Asia Pacific as a Technical Solutions Provider.

Andrew Hoggarth is the head of Sales for CARIS, based in Canada. Educated in England. After spending a number of years, on a variety of offshore survey projects, he moved to Canada where he is the global sales manager for CARIS.

Gordon Johnston BSc(Hons), MRICS, FRIN is a consultant to private companies, NGOs and government agencies relating to Geodetics, Hydrography and Data Management.

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