Article

THE CARIS ENGINEERING ANALYSIS MODULE ASSISTING IN THE MANAGEMENT OF QUEENSLAND'S WATERWAYS

By Owen CANTRILL **(Maritime Safety Queensland - Australia)**
& Daniel KRUIMEL **(Caris Asia Pacific - Australia)**

Abstract

Maritime Safety Queensland (MSQ) is responsible for protecting Queensland's waterways and the people who use them providing safer, cleaner seas. MSQ first incorporated CARIS products into their workflow in 2009 with HIPS and SIPS and BASE Editor and in 2012 are looking to utilize the new functionality of the Engineering Analysis module to assist them in the management of their ports and waterways throughout Queensland. This paper will look into how BASE Editor and the Engineering Analysis Module are being utilized in the Ports and Waterways environment, with a focussed case study on the application with MSQ. Included in this will be a detailed comparison of techniques for volume computation (such as end area volumes, hyperbolic and TIN volumes), a summary of the results that can be achieved and the associated advantages/disadvantages with each method.

Résumé

La sécurité maritime du Queensland (MSQ) est chargée de la protection des voies navigables du Queensland et des personnes qui les utilisent en leur procurant des eaux plus sûres et plus propres. La MSQ a d'abord incorporé des produits CARIS dans son plan de travail en 2009 avec HIPS et SIPS et BASE Editor et, en 2012, elle a cherché à utiliser la nouvelle fonctionnalité du module d'analyse bathymétrique afin d'aider à la gestion de ses ports et de ses voies navigables à travers le Queensland. Cet article examine la manière dont BASE Editor et le module d'analyse bathymétrique sont utilisés à l'intérieur des ports et des voies navigables avec une étude de cas consacrée aux applications à la MSQ. Il comprend une comparaison détaillée des techniques de calculs de volumes (tels que les volumes finis, les volumes hyperboliques et TIN), un résumé des résultats qui peuvent être obtenus et des avantages/inconvénients de chaque méthode.

Resumen

La Autoridad de la Seguridad Marítima de Queensland (MSQ) es responsable de la protección de las vías navegables de Queensland y de las personas que las utilizan, proporcionando mares más seguros y más limpios. La MSQ incluyó los productos CARIS por primera vez en su proceso de trabajo en el 2009, con HIPS y SIPS y el Editor BASE y en el 2012 esperaban utilizar la nueva funcionalidad del Módulo de Análisis de Ingeniería, como ayuda para la gestión de sus puertos y vías navegables en la totalidad del Queensland. Este artículo profundizará sobre cómo el Editor BASE y el Módulo de Análisis de Ingeniería están siendo utilizados en el entorno de los Puertos y las Vías Navegables, con el estudio de un caso centrado en la aplicación de la MSQ. En dicho estudio se incluirá una comparación detallada de técnicas para el cálculo de volumen (tales como los volúmenes finales de áreas los volúmenes hiperbólicos y TIN) y un resumen de los resultados que pueden obtenerse y las ventajas/desventajas asociadas a cada método.

INTRODUCTION

Maritime Safety Queensland (MSQ) is a division of the Department of Transport and Main Roads within the Queensland State Government. MSQ's role is to protect Queensland's waterways and the people who use them - providing safer and cleaner seas. Within the corporate structure of MSQ, the Hydrographic Services section carries out hydrographic surveys on behalf of clients. Current clients include North Queensland Bulk Ports (Ports of Hay Point, Weipa, Abbot Point and Mackay), Ports North (Cape Flattery, Thursday Island), Gladstone Ports Corporation and Boating Infrastructure and Waterways Management (recreational boating facilities). These various sites are spread over 1700Nm of coastline.

OVERVIEW OF OPERATIONS

MSQ utilize a variety of survey equipment, such as a Kongsberg Simrad EM 3002D multi-beam echo sounder, Klein 3000 Sidescan, Starfish 452f sidescan, SEA Swath plus 234 kHz interferometry system, Echotrak MK III dual frequenciy single beam, Deso 300 single beam, Applanix POS MV 320, Applanix POS MV Wavemasters and Lecia RTK DGPS. Surveys range from boat ramps that integrate land survey and a small hydrographic component, through to high precision surveys for Under Keel Clearance systems.

A permanent installation of the EM3002D exists on the vessel QGNorfolk, with other mobile systems deployed on vessels of opportunity, such as the QG Bellara used during rapid response surveys in the 2011 Brisbane floods.

MSQ ensures a high quality of work through the use of experienced and competent personnel. There are six surveyors certified at Level 1 by the Australasian Hydrographic Surveyors Certification Panel (AHSCP) and five surveyors (including graduates) that work under direct supervision.

In an effort to improve acquisition to processing ratios, MSQ first incorporated CARIS Ping-to-Chart products into their workflow early in 2009, turning to HIPS and SIPS for processing their bathymetric data. Later that year, BASE Editor was also brought on board to assist in bathymetric data compilation and QC. Staff from MSQ have stayed well versed in the latest functionality for the software packages through participation in open training courses held in the region by the CARIS Asia Pacific office. After attending a training course on the new Engineering Analysis Module (compatible with BASE Editor) in August of 2011, MSQ sought to expand on their current functionality and utilize the new module to assist them in the management of their ports and waterways throughout Queensland.

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.

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, multi-beam, 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.

<u>End Area Volumes</u>

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.

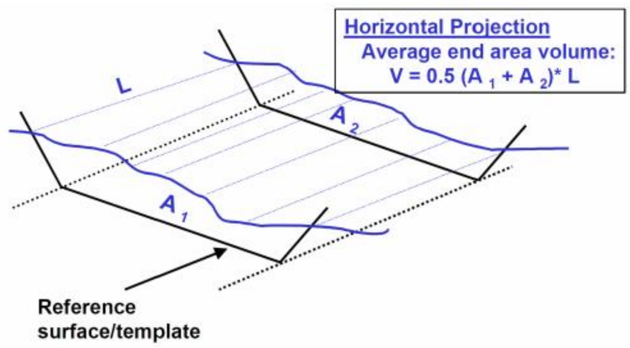


***Figure 1**: Calculation of End Area Volumes (USACE, 2001).*

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.

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.

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.

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.

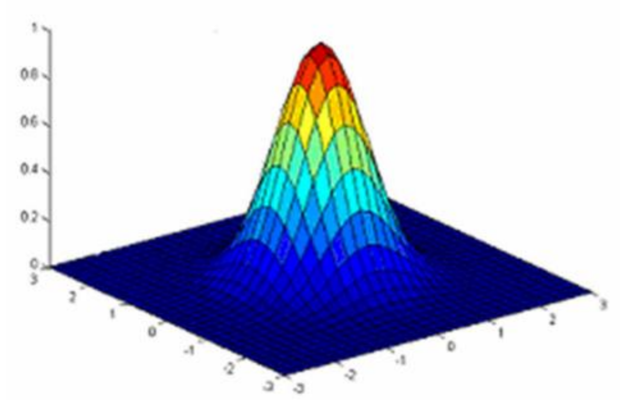


***Figure 2**: Representation of the hyperbolic paraboloid volume method*

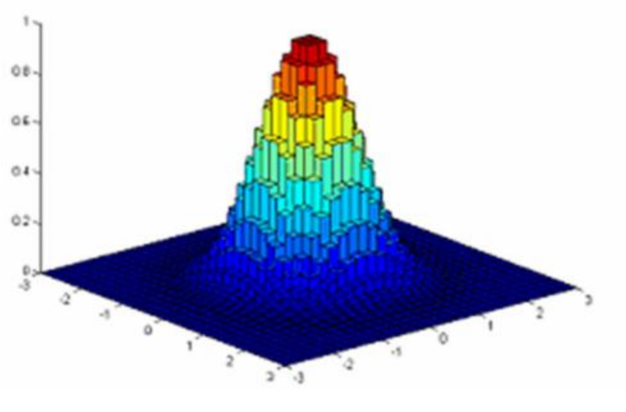


***Figure 3**: Representation* of the rectangular volume method

VOLUME COMPARISONS

As previously outlined, there are a number of different methods available to the hydrographer for volume determination. So this leads to the next question - which method should be used? This will largely be dependent on what technology is available to conduct the survey. 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 which is 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.

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 had already been binned at 1m. A reference model for the Port of Weipa was also used in the calculations. The test area used is a section of channel located just to the east of beacons 7 and 8 in 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 *(Note: this is just 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 multi-beam bathymetry at intervals of 25m, 50m and 100m. The results can be seen in ***Table 1***. *(Note: In this case, 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 zero error in the hyperbolic volume result).*

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.

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

METHOD	VOLUME (m³)	DIFFERENCE (m³)	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

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.

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 was found by Dunbar J.A and Estep H of the Baylor University

Department of Geology (BU) in Texas, USA. The project undertaken by BU was to study the hydrographic surveying methods utilized by the Texas Water Development Board (TWDB) in determining water and sediment volume in reservoirs throughout Texas. Whilst the project also investigated sub bottom profiling and sediment surveys, the volume comparison was carried out in Lake Lyndon Baines Johnson (LBJ), 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 LBJ. In order to evaluate the influence of survey profile spacing on volume accuracy:

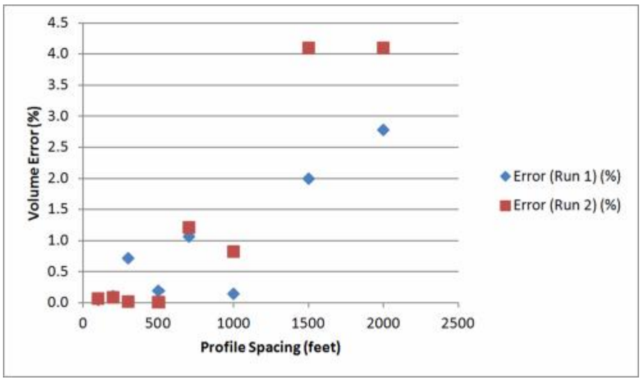
> *"BU extracted simulated profiles at spacing's ranging from 100 to 2000 ft from a high-density multi-beam survey collected by an independent contractor. Volume calculations based on the extracted profile sets were compared to the volume based on the full multi-beam survey. " (Dunbar, J.A, Estep, H, 2009)*

The results produced in the study by BU can be seen in ***Table 2***. They are also shown graphically in ***Figure 4***. When extracting the profile sets to produce simulated volumes, BU 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 multi-beam bathymetry.

By undertaking a statistical analysis of the BU 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.

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



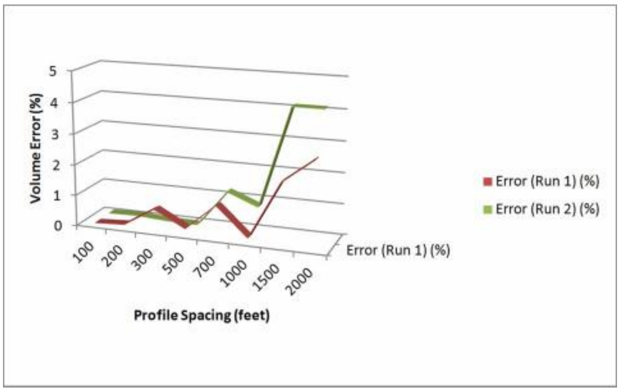


Figure 4: *Scatter plot and 3D line graph of BU volumes comparisons.*

From these results, a conclusion can be drawn that when increasing the population size of our sample dataset, the error values do display a tendency for 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 BU 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)*

VOLUME COMPUTATIONS AT MSQ

MSQ have traditionally used the TIN method to compute volumes for their hydrographic surveys. As part of an evaluation for the Engineering Analysis Module in 2011, MSQ ran a comparison of TIN volume computations using the module against their existing capability. 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 (which the existing capability was not able to achieve).

***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

CONCLUSION

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 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.

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. The ability to increase the data sets reduces the trade off historically required between precise volumes (e.g. 0.5m spaced data) with practical processing limits. (Data generalised to 2.5m)

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BIOGRAPHIES

Owen Cantrill is a Level 1 Certified Hydrographic Surveyor having gained certification in 2000. He gained a Bachelor of Surveying with honours from the University of Melbourne in 1989. He is currently employed as the manager of the Hydrographic Services section of Maritime Safety Queensland (MSQ). owen.j.cantrill@msq.qld.gov.au

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. At the start of 2011, Daniel took up a role with CARIS Asia Pacific as a Technical Solutions Provider. daniel.kruimel@caris.com

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