

A Review of Various Algorithms for Volume Estimation of Water Reservoir

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Abstract— According to Sciortino J.A. (2011) "Accurate volume estimates are important for the choice of dredging plant, production estimates and ultimately project costs." Volume estimation must be free from error because they play an important role in supporting the local economies. This paper investigates the existing volume estimation algorithms used in water reservoirs around the globe.

I. INTRODUCTION

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). 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.

II. VOLUME ESTIMATION ALGORITHMS

A. 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 Fig.1). The key components in computing the volume are 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 be just an approximation.

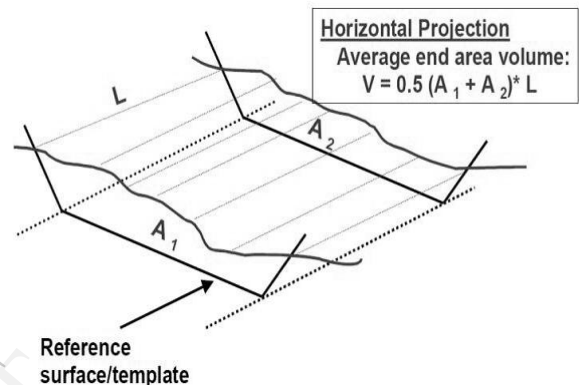


Fig.1. Calculation of End Area Volumes (USACE, 2001)

Volume calculation equation:

$$v = 0.5(a1+a2) * l$$

Where

$a1$ = area of reservoir within the outer depth contour being considered

$a2$ = area of reservoir within the inner contour line under consideration

l = difference in depth between two successive depth contour

B. 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.

TIN's offer several advantages over the average-end-area method, which is traditionally used to calculate dredge volumes. TIN's offer greater flexibility in the collection of survey data, since the data need not be aligned along pre-determined cross-section or profile lines. Dredge volumes from irregular sections, such as corners or turning basins, can be calculated easier from TIN's than from the average-end-area method.

It can compute volume quantities either from sections across channels or from surface models (TIN MODEL). The CROSS SECTIONS AND VOLUMES program quickly computes volume quantities for cross sectional profile lines compared to the channel design template and channel over depth template for each line. The program is the de facto standard for volume computations by several national survey agencies. Over 20 methods are available to compute the area and volume of material for each profile segment (left slope, main channel, and right slope), it can compute quantities for a single survey versus the design template, or for a pre-dredge versus an after-dredge comparison. CROSS SECTION AND VOLUMES can read hundreds of sections, compute the volumes and send all of the sections to the printer/plotter in a matter of seconds. The latest capability added is support of beach volumes for beach replenishment projects. The TIN MODEL program can be used to compute several types of volume quantities. Input data can be from single beam, multibeam or multiple transducer surveys.

An example of what is happening is shown in the Fig.2. Point B, at the very top of the side slope can be used for hundreds of triangles. Since Point B is usually very shallow, it influences the surface in any triangle which has it as a vertex. Next, take a look at the triangle vertex A-A'. The TIN MODEL has the depth at Point A and Point A' and assumes a straight-line interpolation along the line. The result is the dashed line (See Fig.2.), where reality is actually the black line. The TIN MODEL has created material that does not exist!

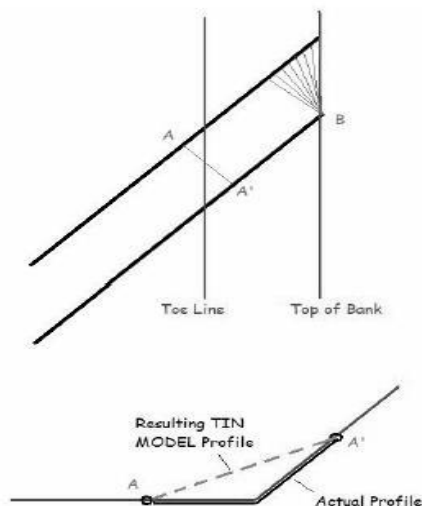


Fig.2. TIN Model Example

C. Hyperbolic volumes

For this method, a hyperbolic cell is created from the centers 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). This gives a smooth approximation of the surface and good volume results, but is processing intensive and can be time consuming.

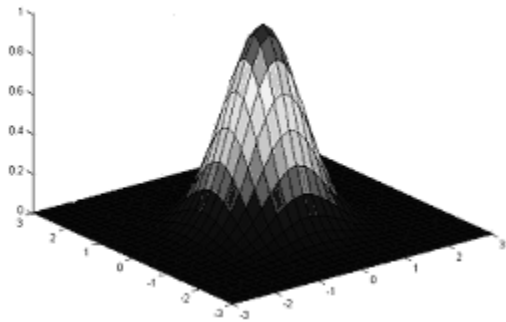


Fig.3. Representation of the hyperbolic paraboloid volume method

D. 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.

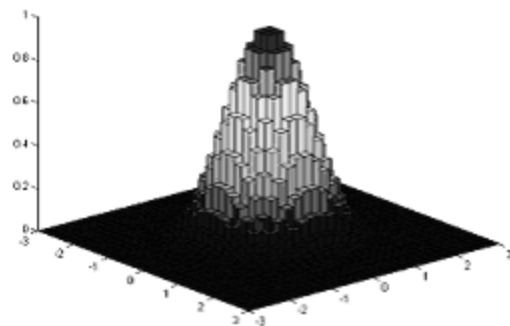


Fig.4. Representation of the rectangular volume method

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.

III. 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 produce 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.

IV. STUDY OF VOLUME COMPARISON

In order to test the results produced by the various methods of volume calculation, a study was carried out by Daniel Kruiemel, Andrew Hoggarth and Gordon Johnston using the data provided by MSQ at the port of Weipa in October 2011. The data provided was in ASCIIXYZ format. The test area was a section of south channel of port of weipa.

Table 1. Volume comparison

Method	Volume (m ³)	Difference (m ³)	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 error percentage in rectangular volume is maximum. The error percentage in hyperbolic is zero hence it

is most suitable. The results displayed 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 centerline clear of siltation.

V. CONCLUSION

The Engineering Analysis Module is able to greatly assist users in managing Ports and Water ways 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. The ability to increase the data sets reduces the tradeoff historically required between precise volumes (e.g. 0.5m spaced data) with practical processing limits. (Data generalized to 2.5m).

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