Implications of the Navigation Surface Approach for Archiving and Charting Shallow Survey Data[1]

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SUMMARY

The Navigation Surface is a digital terrain model approach to managing, archiving, and creating multiple products from hydrographic survey data. Lieutenant Shep Smith, NOAA, proposed the Navigation Surface concept at the Shallow Survey 2001 Conference (Smith, 2001). Lt. Smith further developed the concept in his Masters of Science Degree thesis in 2003 (Smith, 2003). NOAA is adopting the Navigation Surface concept into its hydrographic survey and nautical charting process. In the Navigation Surface approach, survey data are archived as a certified digital terrain model rather than as a set of verified or certified soundings. The archived elevation model is saved at the highest resolution supported by the sounding data. The adoption of a digital terrain model as the officially archived hydrographic survey product has significant implications for both hydrographic survey practice and for the nautical charting process. Some of our oldest and most cherished hydrographic and nautical charting "rules" will no longer apply. In this paper we examine five of those rules. The increasing redundancy of depth measurement and the greatly improved confidence provided by swath sounding techniques provides us the opportunity to improve our products and reduce the manual effort required to create them. We should end our practice of shoe-horning high resolution surveys into lead line molds and adopt new approaches to our charting process.

[1] This paper was developed from a presentation by the authors at Shallow Survey 2003, the 3rd International Conference on High Resolution Surveys in Shallow Water, Sydney Australia, 17-20 November 2003

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1. INTRODUCTION

The Navigation Surface is a digital terrain or elevation model approach to managing, archiving, and creating multiple products from hydrographic survey data. Lt. Shep Smith, NOAA proposed the Navigation Surface concept at the Shallow Survey 2001 Conference (Smith, 2001). Lt. Smith further developed the concept in his Masters of Science Degree thesis in 2003 (Smith, 2003). NOAA is adopting the Navigation Surface concept into its hydrographic survey and nautical charting process. The underlying technology has been made freely available for technology transfer, and CARIS ™ has commercialized the concept by incorporating it into their hydrographic and charting software.

In the Navigation Surface approach, survey data are archived as a certified digital terrain model rather than as a set of verified or certified soundings. The archived elevation model is saved at the highest resolution supported by the sounding data. That is to say, that if the beam footprint on the seafloor of a full-coverage multibeam sonar survey is 0.5 meter, for example, the elevation model would be saved at a grid spacing of 0.5 meter. This practice has the advantage of preserving this high-resolution data for a variety of known and unknown future purposes, even if such resolution will never appear on a navigational or charting product. Charting products such as paper charts and electronic charts are created from scale-appropriate generalizations of the elevation model.

1.2 Implications

The adoption of a digital terrain model as the officially archived hydrographic survey product has significant implications for both hydrographic survey practice and for the nautical charting process. Some of our oldest and most cherished hydrographic and nautical charting "rules" will no longer apply. In this paper we examine five of those rules:

1. Surveys are conducted and recorded with a shoal bias.
2. A survey database is a representative collection of corrected soundings.
3. Charted soundings can be directly traced to a unique measured depth.
4. All survey depths are portrayed on a chart as equally valid.
5. Charts are compiled successively through the scales, from largest to smallest.

Surveys are conducted and recorded with a shoal bias— With multibeam and swath sonars, we will typically acquire multiple soundings in essentially the same location. At chart scales for example, soundings within 5 meters of one another are often considered as a group or bin (Figure 1). In deep water, the size of a bin may increase to tens of meters. In many hydrographic surveying organizations, a single depth is selected, after some cleaning process to remove outliers, from a bin as the representative depth. The selected depth could be the depth closest to the mean, it could be the median or the mode, but for safety of navigation purposes, it is usually the shoalest accepted depth from the cleaned data. This process creates a dataset of manageable size, but we thin the data once again to create our smooth or fair survey sheet. At survey scale, we can plot soundings at a spacing not much tighter than 5 mm., so for the same reason, we once again choose the shoalest sounding in the area.

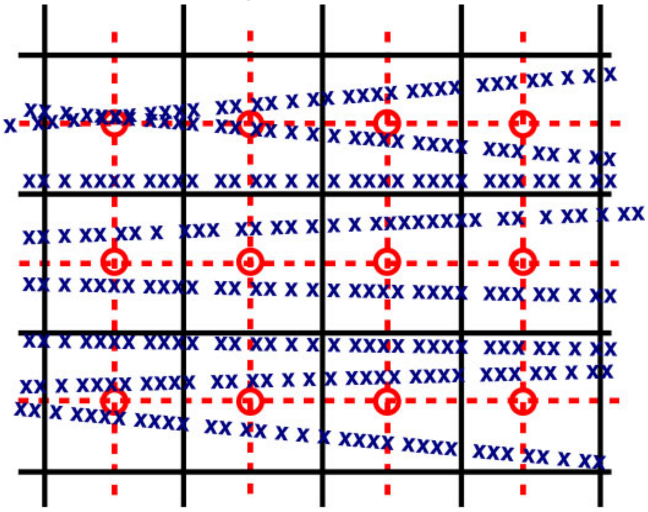

Figure 1. Multiple soundings in bins. (Courtesy deMoustier, C.)

Figure 2a portrays a set of multibeam soundings taken over a period of time from a stationary vessel. The data clearly show depths varying somewhat at the same position, with the range of variation increasing with increasing receive angle. This is precisely as we would expect. The red line shows the mean, which we would take to be the most likely depth. Figure 2b shows the computed uncertainty of depth vs. receive angle, with the uncertainty increasing as beam angle increases, and steeply at the outer beams. Now consider Figure 3, which shows a histogram by beam number of the selected depths that were portrayed on a recent NOAA hydrographic survey. The overwhelmingly greatest contribution of depths to the final archived survey was from the outermost (and most uncertain) beams. Note that the very outermost beams were not accepted, and that all soundings had passed through a careful cleaning process. Looking again at Figure 2a one can easily imagine the smooth sheet soundings as being from at or near the top of the swarm of soundings at the least accurate portion of the sonar swath. One can argue that the cleaning process should assure that no outliers are charted, but the inescapable conclusion is that our present practice leads to charting the noise, not the seafloor. With the Navigation Surface approach, we will create a survey product that most faithfully depicts the seafloor. This is the right thing to do. If a margin of safety is required for charting, that should be accomplished at the product level, not by imposing a bias in the database.

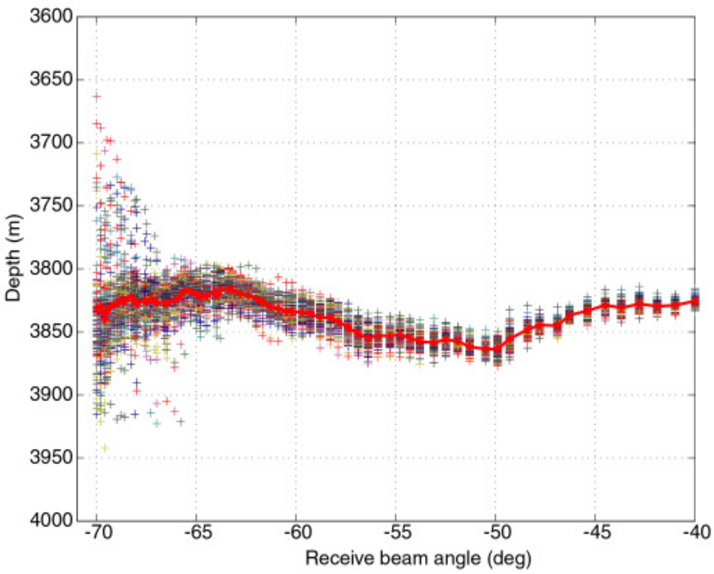

Figure 2a. Multibeam sounding distribution and variation with beam angle
(from deMoustier, C, in Oceans 2001 MTS/IEEE Conference Proceedings)

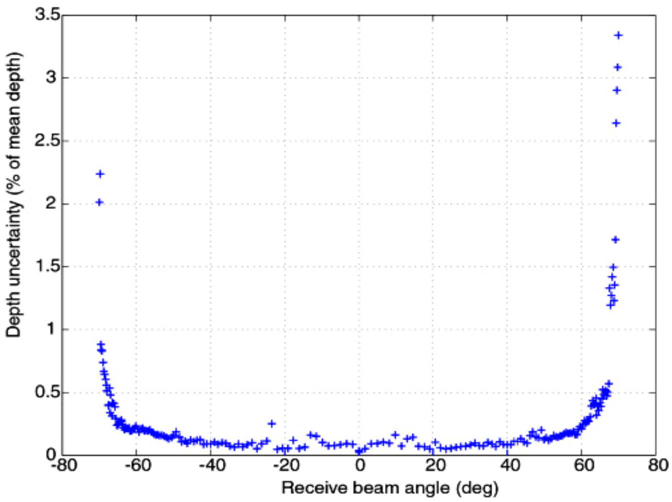

Figure 2b. Uncertainty of sounding accuracy by beam angle
(from deMoustier, C, in Oceans 2001 MTS/IEEE Conference Proceedings)

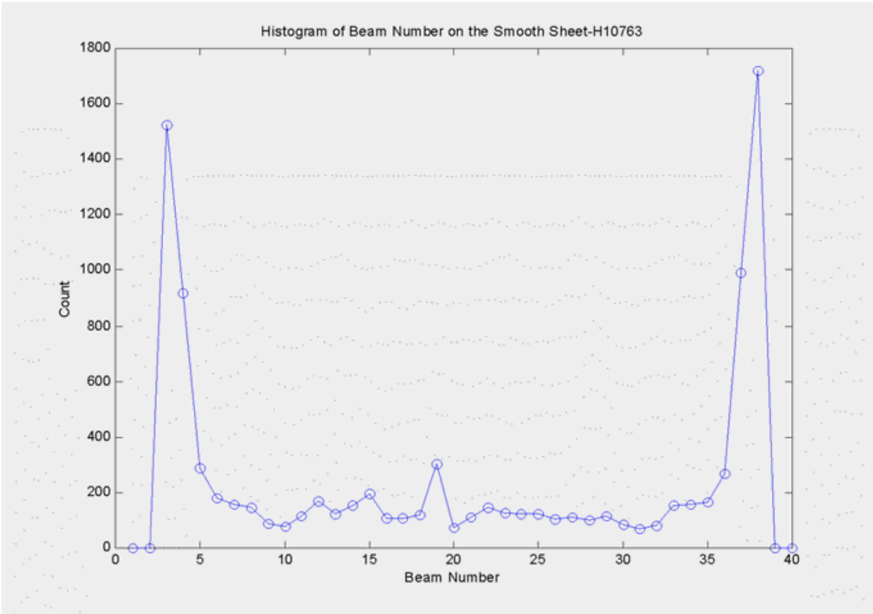

Figure 3. Smooth sheet selected soundings by beam number

A survey database is a representative collection of corrected soundings— A typical survey smooth sheet is shown in Figure 4. In most hydrographic offices, the smooth sheet is the archived survey product, and the smooth sheet soundings constitute the archived sounding database. Figure 5 is a TIN-model depiction of soundings from a smooth sheet. For paper charting purposes, this is probably an adequate representation of the seafloor. Figure 6 shows the same seafloor at the full resolution of the multibeam sonar survey. Clearly this depiction tells us much more about the seafloor, and this data would be far more useful for a variety of scientific and engineering uses beyond nautical charting.

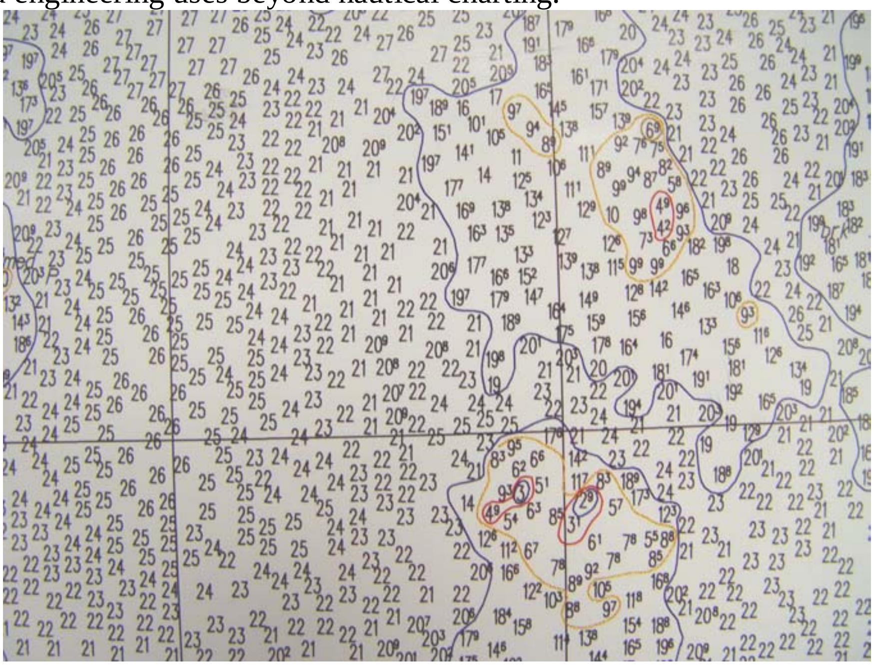

Figure 4. Portion of a NOAA Smooth Sheet

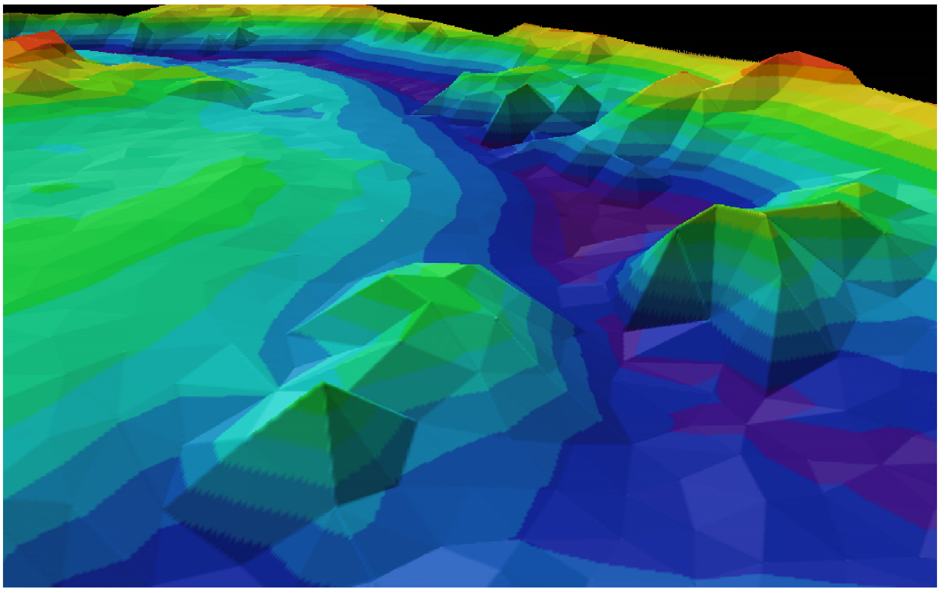

Figure 5. TIN-model at smooth sheet density

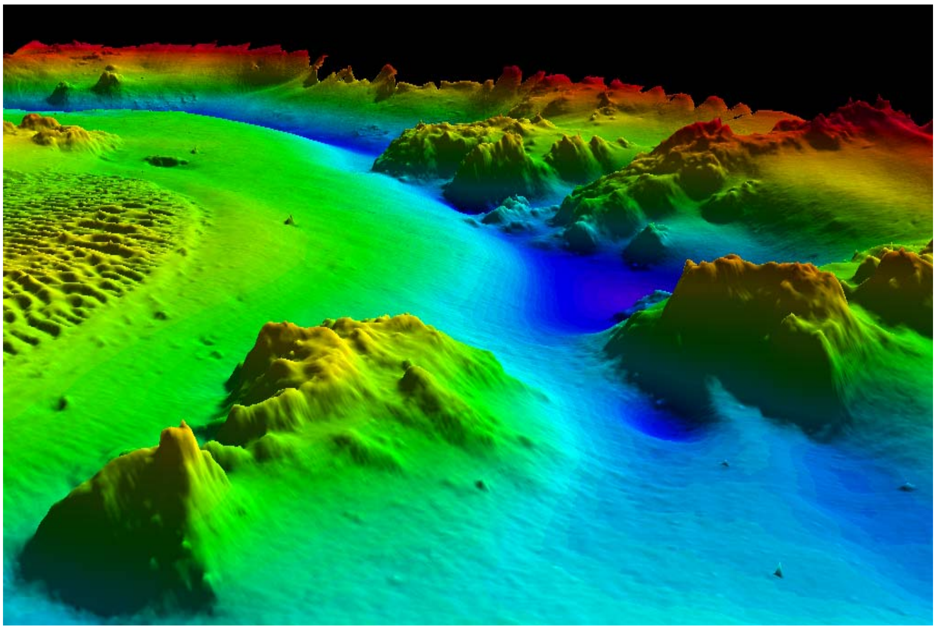

Figure 6. Grid model at original survey density

Particularly for high-resolution data, there are significant advantages to archiving a high-resolution grid model instead of soundings. Up until now, this idea has been something of an anathema to hydrographers. We have a strongly imbued sense that a discreet depth measurement is superior to an estimate—which is precisely what a grid implies. That prejudice comes from the fact that up until recently, our depth measurements were quite sparse. We long ago recognized in our geodetic surveying that the best results were obtained by meaning multiple observations, and in our positioning at sea, we happily record the output of multiple observations passing through Kalman filters for our GPS-derived positions. With today's multibeam and swath sonars, we now obtain many depth measurements at or near the same location. Each of these discreet measurements will differ from the others. There can be only one depth at a single position, so unless we wish to save a contradictory set of multiple depths for the same position, we must save some representative value. Just as in geodetic surveying and GPS positioning, we believe that a mean value is most likely to be closest to the truth, and that the most efficient and highest fidelity approach—for high-resolution data—is a regular grid. The Navigation Surface approach does, however, recognize that there are instances, for purposes of navigational safety, that a discreet measurement should be honored. An example would be an actual measurement on the shoalest point of a danger to navigation such as a rock or wreck.

Charted soundings can be directly traced to a unique measured depth— When we measured depth with a lead line, or even with a single-beam echo sounder, our set of measured depths was relatively sparse. Our smooth sheet reduces these surveys to even sparser levels. With multibeam sonars and traditional data cleaning and binning techniques, we are still working with measured depths, and our smooth sheet reduces these surveys to the same density as our single-beam surveys. Charts are created by automated, manual, or some combination of automated and manual selection of soundings from the survey. Figures 7a and 7b show a current edition of a NOAA nautical chart, and the 1954 vintage survey from which the charted soundings were selected. When we begin to archive our survey as a grid, we will, as noted above, be archiving not soundings, but estimated depths at regularly spaced grid nodes.

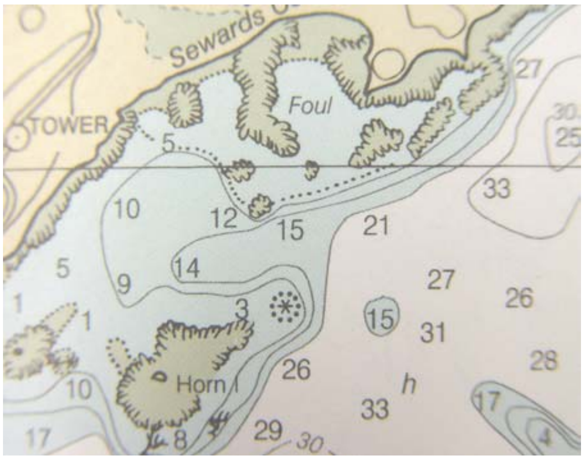

Figure 7a. Chart section

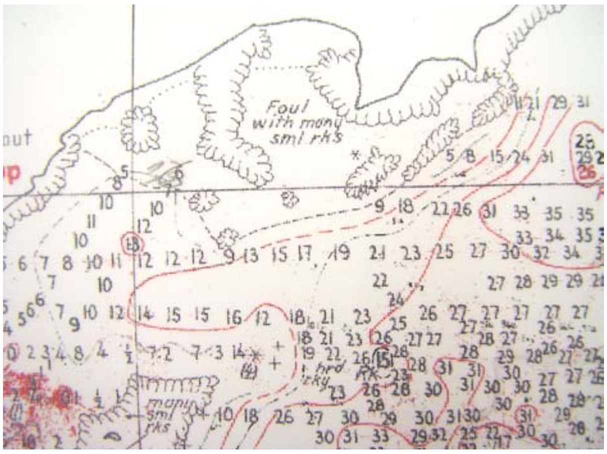

Figure 7b. Smooth sheet section

For each chart scale, we will create a suitably generalized product surface. If we choose to chart soundings, they will be depths plucked from the product surface. At any location we choose, we can select a depth. The depth will not be a measured survey sounding, however. It will be the DTM value of the product surface at that location. If we choose to chart contours, they will likewise be contours cut from the product surface. From a cartographic point of view, this will have the significant advantage that no sounding can inadvertently be selected from the wrong side of a generalized depth contour. Figure 8 shows a product surface (as a mesh) draped over the high-resolution survey surface from which it was derived. Figure 9 is a section of a trial chart created from a product surface. Although the extra features of color and sun-illuminated terrain model show beneath the depths and contours, the product is clearly equivalent in utility to a traditionally compiled chart.

All survey depths are portrayed on a chart as equally valid— Figure 10 is a section of the current edition of a NOAA chart covering the approaches to Portsmouth, New Hampshire. Three soundings are annotated in the figure with their survey source. One is from a lead line survey of 1909, one from a single-beam echo sounder survey of 1954, and one from a multibeam sonar survey of 1997. They are from very different sources, have very different positional accuracy (and subsequently different depth accuracy) and most importantly, represent a depth from surveys of very different sounding density. Yet they all look the same, and more importantly, the white space around them looks the same. To the mariner, they are the same, and the faithfulness with which they portray depth in the vicinity, is the same. To those of us who know the source, however, the lead line depth tells us nothing about the seabed nearby. In this area of rocky seafloor outcrops, an undetected rocky shoal could easily lie within meters of the lead line depth. In fact, the 1997 multibeam survey located several significantly shallower rocky depths between historical lead line depths.

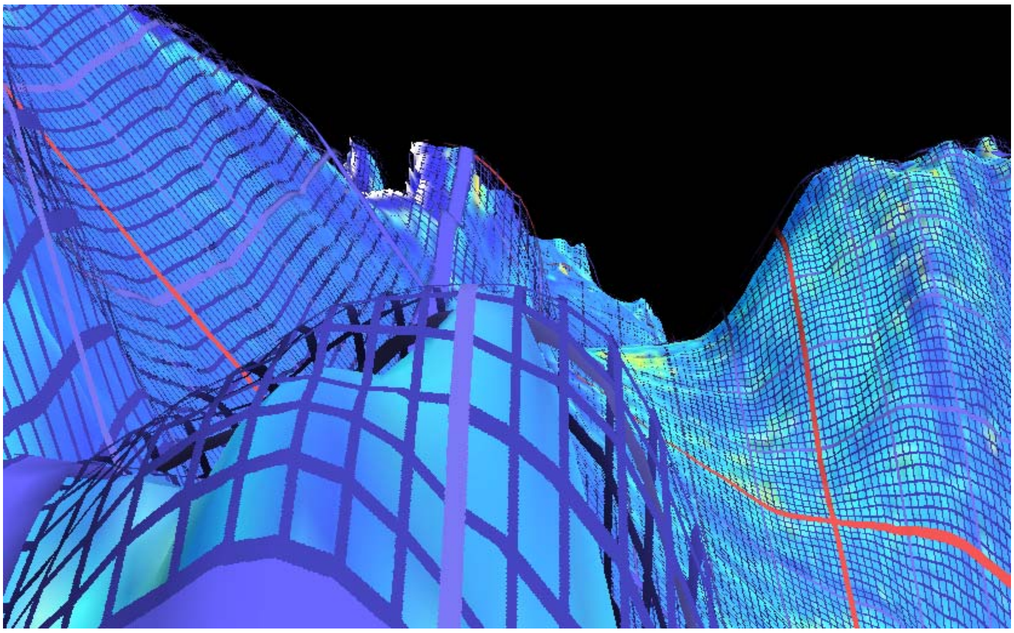

Figure 8. Product surface draped over high-resolution survey surface

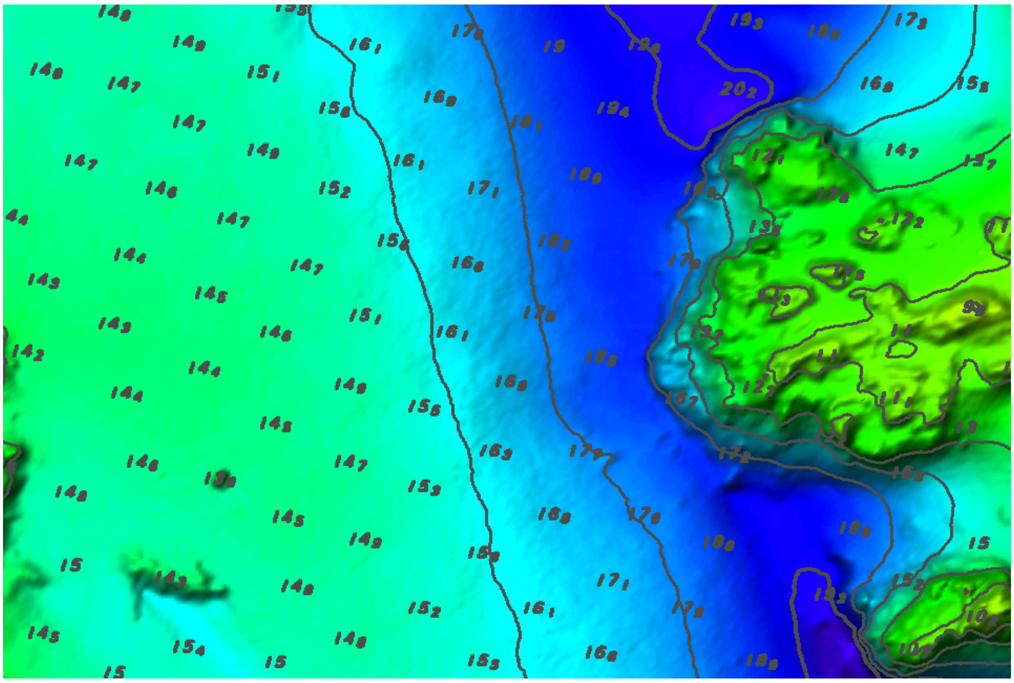

Figure 9. Trial chart section from product surface

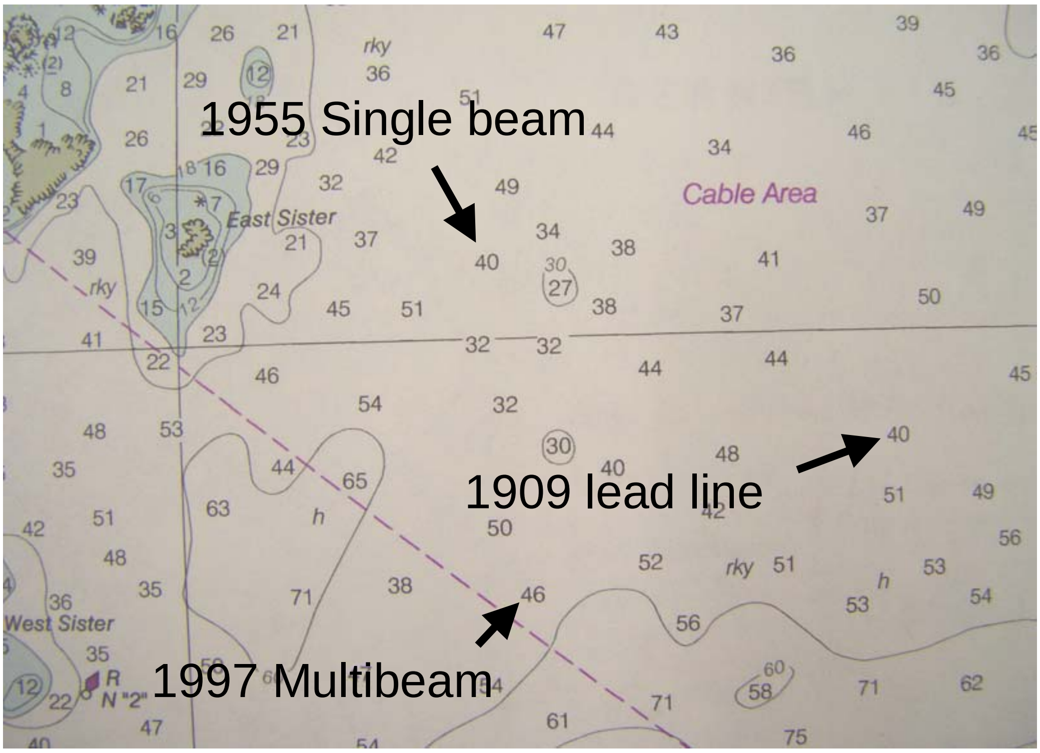

Figure 10. NOAA Chart with soundings from different sources marked.

(For hydrographers who remain opposed to charting digital terrain model depth estimates rather than measured soundings, what is the white space surrounding a lead line sounding and the depth curve enclosing lead line soundings if not a model?) The Navigation Surface will include, in addition to a depth model, an uncertainty model. Figure 11 shows the uncertainty model as color overlaying the sun-illuminated digital terrain model for the area from which the chart in Figure 10 is drawn. The green color is low uncertainty from the multibeam survey, orange is moderate uncertainty from the single-beam survey, and violet is high uncertainty from the lead line survey. How we should portray this uncertainty for the mariner or other user is unclear. That we should portray it somehow, seems clear.

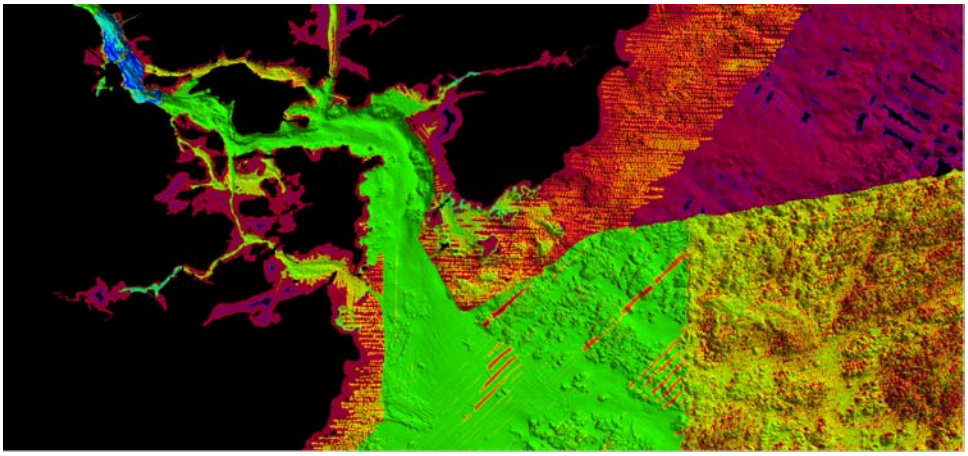

Figure 11. Uncertainty by color over digital terrain model in area shown in Figure 10.

Charts are compiled successively through the scales, in order from largest to smallest—This practice allow the nautical cartographer to successively generalize the survey data, selecting fewer and fewer soundings and smoothing the contours, masking finer and deeper detail on the chart. Figures 12a—c show the same piece of seafloor as it appears on successively larger scale charts. Several soundings are highlighted to demonstrate their appearance at each of the scales. This is an entirely rational and reasonable process, but one that will not be the same with the Navigation surface. The process will be much simpler and require much less manual cartographic effort. The generalization rules of the Navigation Surface will automatically result in more generalized product surfaces as the product scale decreases. However, there will be no need to do this in sequence, as the automated approach will always create the same generalization regardless of the order in which done. The product generalization will be applied to the original surface each time, not the next lower level generalization. Furthermore, except at the shoalest points on the surface, any depth picked from the product surface will differ from a depth picked from the same latitude and longitude on a product surface at a different scale or level of generalization.

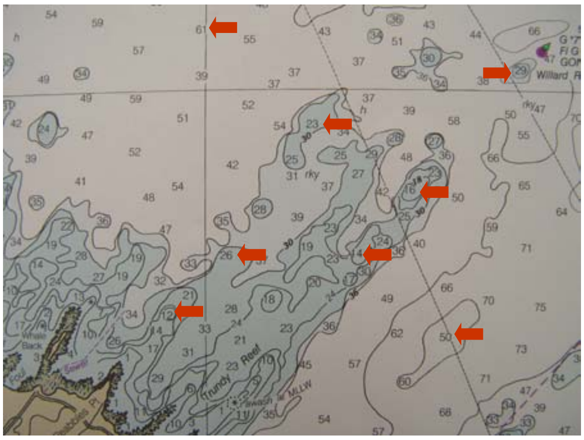

Figure 12a. Section from 1:20,000 scale chart

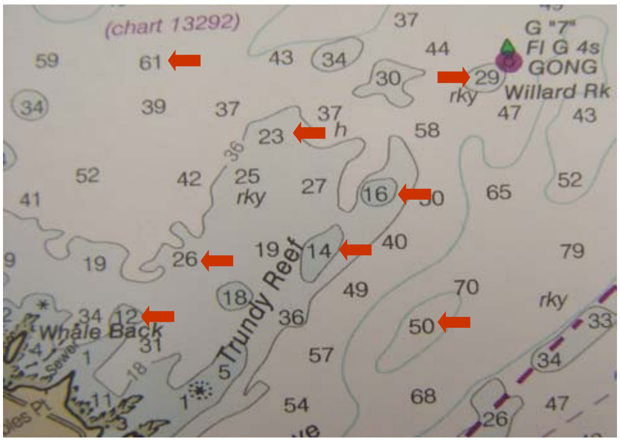

Figure 12b. Section from 1:40,000 scale chart

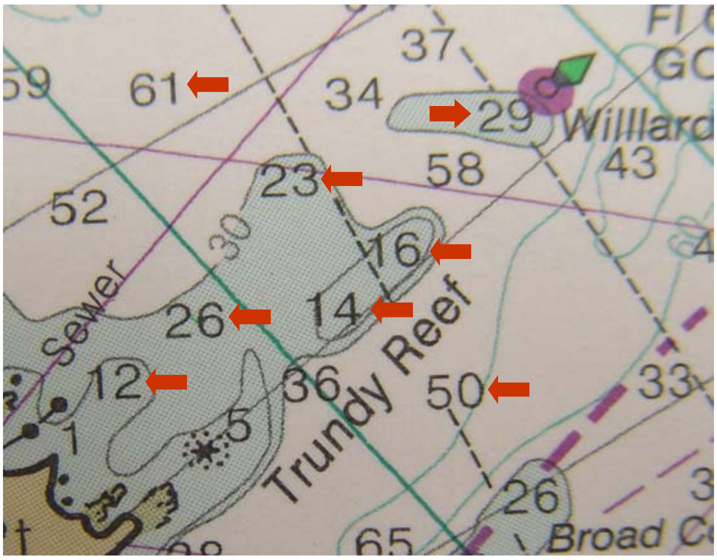

Figure 12c. Chart section from 1:80,000 scale chart

Figures 13a and 13b show that a depth drawn from a point midway between the two higher elevations will be different at the two scales. Since the important shoal depths will remain constant, and since as always, the appropriate scale representation should be selected for the intended navigational use, this should be of no practical concern to the mariner.

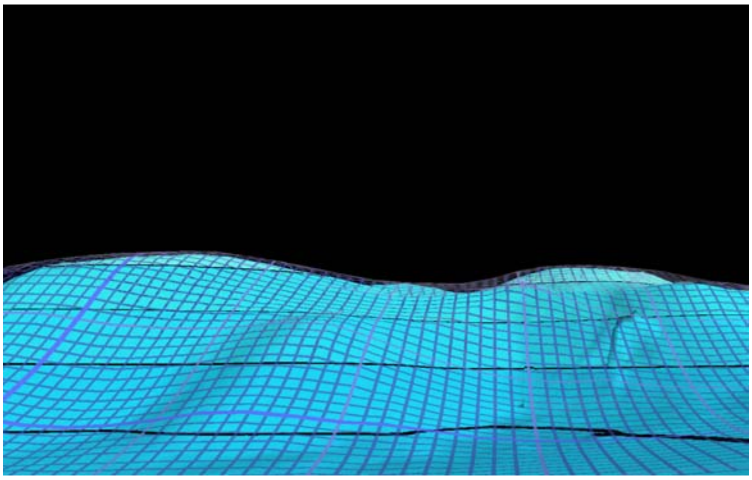

Figure 13a. Survey surface and product surface at 1:5000 scale generalization

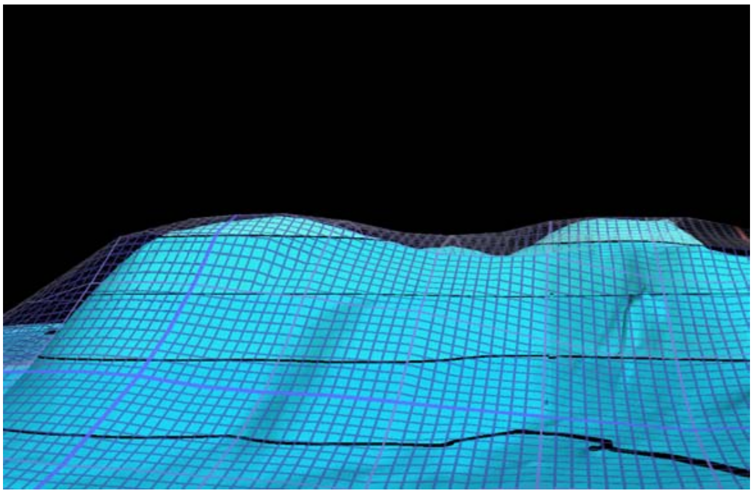

Figure 13b. Survey surface and product surface at 1:10,000 generalization

2. CONCLUSIONS

The increasing redundancy of depth measurement and the greatly improved confidence provided by swath sounding techniques provides us the opportunity to improve our products and reduce the manual effort required to create them. We should end our practice of shoe-horning high resolution surveys into lead line molds and adopt new approaches to our charting process. It is inevitable that when we do this, things will be different.

REFERENCES

Smith, S., 2001, The Navigation Surface: A New Approach to Multiple Product Creation from Hydrographic Surveys, Shallow Survey 2001, Portsmouth, NH, September 2001, conference CD, available at http://www.ccom.unh.edu/shallow/abstracts/the_navigation.htm

Smith, S., 2003, The Navigation Surface: A Multipurpose Bathymetric Database, Master of Science Thesis, University of New Hampshire, Durham, New Hampshire

BIOGRAPHIES

Captain Andrew Armstrong, NOAA (retired) is the Co-Director of the NOAA-UNH Joint Hydrographic Center at the University of New Hampshire. In this capacity, he oversees the hydrographic and ocean mapping education and training program at UNH and coordinates the Center's cooperative research with NOAA. He is currently an IHO-sponsored member of the FIG/IHO/ICA International Advisory Board on the Standards of Competence for Hydrographic Surveyors and Nautical Cartographers. Captain Armstrong has nearly 30 years of hydrographic experience with NOAA, including positions as Officer in Charge of hydrographic field parties, Commanding Officer of the NOAA Ship WHITING, and Chief, Hydrographic Surveys Division. He has a B.S. degree in Geology from Tulane University and a M.S. degree in Technical Management from the Johns Hopkins University.

LT Rick Brennan is a NOAA Corp Officer and has served exclusively in the hydrographic community for the past ten years. His assignments have ranged from a junior officer aboard the NOAA Ship RUDE, to Officer In Charge of the NOAA Survey Vessel BAY HYDROGRAPHER, and most recently as the Operations Officer aboard the NOAA Ship WHITING. He has extensive experience with side scan sonar and shallow water multibeam and their use in surveys for nautical charting. LT Brennan is currently pursuing a master's degree at the University of New Hampshire in Ocean Mapping.

LT Shepard Smith is a NOAA Corps officer currently assigned as Executive Officer aboard the NOAA Ship THOMAS JEFFERSON. He recently received his M.S. degree in Ocean Mapping from the University of New Hampshire. LT Smith has also served aboard the NOAA Ship RAINIER and NOAA Survey Vessel BAY HYDROGRAPHER conducting hydrographic surveys for charting in Alaska and along the U.S. east coast. He is a 1993 graduate of Cornell University in mechanical engineering.

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