The TerraNautical Approach to Hydrographic Data Acquisition and Dissemination

The Solution to the 60 Billion Dollar Problem

By

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ABSTRACT

This TerraNautical Data, Inc.* report proposes a cost effective remedy to deficiencies in the National Oceanic and Atmospheric Administration (NOAA) nautical survey plans. The report addresses the fact that NOAA is responsible for surveying approximately 3.2 million square nautical miles of coastal waters, yet with NOAA's plan, it will take more than 20 years just to survey the most critical 1.3% of their mandated coverage area. In addition, NOAA acknowledges that for lack of sufficient resources their Plan must ignore the needs of the 72 million Americans who participate in recreational boating each year.

TerraNautical has created and tested a data acquisition system that will supply huge quantities of new and accurate depth data in the vast areas ignored by NOAA's plan, and at a cost far less than traditional NOAA surveying methods. This system is meant only to supplement NOAA's current surveys, which are mainly in critical areas for commercial vessels. The proposed system would provide additional depth data for NOAA survey plans, but, more importantly, would obtain new depth data in regions not addressed by NOAA's plan, mainly the areas that lie in between the shoreline and the deep draft shipping lanes, as well as marina harbors and their entrance channels.

TerraNautical will use what it has termed *incidental platforms*, a platform that collects data for its own use, but does not usually record or disseminate it, like aircraft, automobiles, and in this case vessels of the boating public. These vessels would be used Instead of expensive government-run survey vessels. Every year, over 16 million recreational boats traverse the nation's coastal waters, compared to NOAA's fleet of five hydrographic vessels. A high percentage of these boaters, especially among the larger vessels, use GPS and echo sounder systems, and in essence collect new, high quality depth data every time they transit from one place to another. TerraNautical has assembled and tested a device that captures and records these data and has developed and tested a way to process the data to NOAA specifications utilizing a NOAA-style Quality Assurance review.

An incentive plan will attract volunteering boaters to install recording systems and regularly submit data to TND. The TerraNautical system requires virtually no hands-on involvement by boaters. They would send TerraNautical a CompactFlash cards in a postage paid envelope two or three times a year. With 0.5% participation in the Chesapeake Bay alone, the entire Bay could be charted in one year, and at less than ten percent of NOAA's typical survey costs. Along the Atlantic Intracoastal Waterway, the density of soundings by 10% of the recreational boaters moving down and back up over a year would exceed sounding density of a multi-beam survey. Participation by vessels from NOAA, NOAA contract survey companies, Corps of Engineers, Coast Guard, as well as university research vessels, ferryboats, and commercial ships and barges, would greatly enhance the data created by these incidental platforms.

Although TerraNautical has completed a proof-of-concept test in the Chesapeake Bay with one vessel, funding is needed to perform a pilot test with at least 40 vessels. Alternatively, the pilot test could be performed on vessels from NOAA, Coast Guard, and Corps of Engineers, as well as on ferryboats, and university research vessels. The test will produce depth data having a value of at least two or three times its cost. Following successful completion of this pilot test, TerraNautical will work with NOAA, the Army Corps of Engineers, marine electronic manufacturers, and chart companies to fully implement the system.

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* TerraNautical Data, Inc. is a small company consisting of a former NOAA Corps Hydrographic Officer and systems engineer, as well as a retired physics professor who served as Executive Director of the National Science Teachers Association for 16 years.

Problem

The recreational boating community generates over $25 billion annually to the national economy. Some 16 million recreational boaters ply the lakes and coastal waters of the United States in some 1.6 million documented vessels[1] 40 feet in length or greater. However, these 16 million recreational boaters currently rely on navigational charts whose depth data are mostly wrong.

Old, Outdated Surveys

According to Captain Sam DeBow of NOAA,

> *Fifty percent of the data on NOAA charts is more than 60 years old, collected before sonar was commonly available…many soundings …made by… dropping lead lines and positions … fixed by sextant.*[2]

To add to the inherent inaccuracies of such primitive soundings, decades of natural bottom shifting have occurred since they were taken. According to BoatU.S.,

- *Half of NOAA's nautical charts are based on pre-1940 hydrographic data (much of it likely taken with lead lines);*
- *A 20-year backlog to resurvey 40 of the nation's waters deemed in "critical" need pertains entirely to commercial tonnage; there is very little overlap with the most popular recreational waters, which are not on the "critical" list.*
- *In the 1970s, NOAA had 11 ships to perform hydrographic survey work; now it has three.*

> *Boaters using electronic chart plotters, with highly accurate navigational instruments such as Differential GPS and WAAS should be aware that the "charts" in most of these products may be "snapshots" of existing paper charts. For example, your DGPS can conceivably place you within 30 feet of a shoal, but the chart image loaded in the plotter could be one in which that area has not been resurveyed for decades.*[3]

Surveys and Survey Plans: NOAA and Corps of Engineers

NOAA is responsible for charting over 3.2 million square nautical miles of coastal waters. According to its National Survey Plan[4], NOAA has previously neglected the recreational boater's needs and must continue to do so for the future.

According to BoatU.S., problems with shoaling and poor charting on the Intracoastal Waterway are very serious:

> *As boaters on the East Coast begin planning cruises south on the Intracoastal Waterway (ICW), BoatU.S. is asking for their help to report navigation problems and neglected channels along their route. Boat/U.S… is asking boaters to report problems with shoaling in dredged channels, inaccurate chart depths, … on the ICW. To make it easy, boaters can file ICW Condition Reports at*

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[1] NMMA, "Statistics, 2000," *www.nmma.org/facts/boatingstats/2000stats/index.html*, (National Marine Manufacturers Association , 2001)

[2] S. Featherstone, "NOAA is Sinking," www.boatingmag.com/features/features.html?FeatureID=43, (2001)

[3] E. Dickinson, **"**Charts Lag Behind Technology*," Boat/U.S. Magazine* (May 18 2001)

[4] Office of Coast Survey, *National Survey Plan, (NOAA, November 2000)*

> *www.boatus.com/icw. …Michael G. Sciulla BoatU.S. vice president for government affairs… said boaters traveling the ICW every autumn complain about … running aground on unmarked shoals where charts show a dredged channel. The problem, he said, is that budgets for the U.S. Army Corps of Engineers' ICW maintenance are based only on commercial shipping activity, which has been declining along with the condition of the waterway. Recreational boat traffic, which is increasing every year, is not counted at all.*

Companies that produce electronic charts are all aware of the serious limitations of the survey data. GARMIN, for example, which produces the *BlueChart*, offers the typical disclaimer:

> *Please Note: GARMIN strives to provide its customers with the most economical, accurate, and up-to-date electronic maps available. However, features are continually changing, so the data may not reflect the latest modifications and/or additions in your area.*[5]

Why must NOAA ignore the vital navigation interests of recreational boaters?

According to NOAA's Captain DeBow,

> *We're completely ignoring the interests of the recreational boater … because NOAA is in a crisis*[6]

Yet, NOAA recognizes that practically *all* regions of US Coastal waters need to be re-surveyed with modern echo sounders and GPS technology.

NOAA has already implemented its National Survey Plan. The Plan prioritizes the nation's coastal waters for re-surveying, starting with the nation's top commercial deep-draft shipping lanes. Unfortunately, as Captain DeBow observes, NOAA's priority in this plan *"completely ignores the interests of recreational boaters."* This is evident by the fact that NOAA's plan almost entirely overlooks shallow areas of less than 30 feet, which include the approach to nearly every marina, small town harbor, inlet, and cove in the United States. In addition, NOAA admits that it will take 25 years just to re-survey the high-priority shipping lanes, which comprise only 1.3% of their mandated 3.2 million square nautical miles. And 25 years from now when the top 1.3% is finished, NOAA plans on re-surveying much of this 1.3% all over again to keep up with natural shoaling and shifting. In essence, this means that 98.7% of our nation's coastal waters, comprising over 3.1 million square nautical miles, including the vast expanse of shallow coastal waters transited by America's recreational boaters, will likely never be re-surveyed by NOAA.

Much of the 98.7% of our waterways that NOAA will never re-survey is traversed by over 16 million recreational boats (and the 75 million people onboard them) every year. These are far more vessels (and chart users) than the commercial tankers and freighters, whose needs are NOAA's first priority. Additionally, recreational vessels spend most of their time in depths below the 30-foot contour. Although these recreational vessels may not have the same economic impact as large commercial shipping vessels, one would think that the annual expenditures on recreational boats and related equipment of over $25 billion, plus what must be huge expenditures in associated "tourism" travel would justify greater attention to recreational boater's needs. In addition, such boating activity is often vital to the economies of small towns and harbors up and down America's waterways.

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[5] GARMIN, "BlueChart Disclaimer" www.garmin.com/cartography/bluechart/disclaimer.html (2001)
[6] S. Featherstone, *ibid*

SHOALS[7] Lidar Data

Lidar technology offers a new much less expensive innovation in shoal depth data acquisition. Laser beams from aircraft record the depths. However, in practical application of lidar technology, laser energy is lost due to refraction, scattering, and absorption at the water surface, sea bottom, and as the pulse travels through the water column. The combination of these effects limits the strength of the bottom return and therefore limits the maximum detectable depth to around three times the Secchi (visible) depth. Unfortunately, for most coastal shoal waters, including essentially all of the ICW North of Florida, the Secchi depth is often less than a meter.

Third Party Depth Data

NOAA has taken a step toward resolving the paucity of accurate charting data for the recreational boater. NOAA is going to use third-party depth data.

> *Maureen Kenny also gave an overview of the Bathymetric Database and Third Party Data Project. This initiative was born out of the Electronic Nautical Charting (ENC) Program. There is a need for a good bathymetric dataset to support the ENC's and other non-navigational users. The goal is to organize and document all bathymetric surveys, convert to a common datum, and make them available. Third-party data collected outside of NOAA specifications will also be included in the database and documented as such.[8]*

"Third-party" data is any data acquired from outside the realm of NOAA's traditional two parties (1. NOAA ships, 2; contract ships.). NOAA recognizes that there is a huge potential for third-party data, and, even though it may or may not meet NOAA specifications, much of it is better than very old lead line and sextant data and in any case should be used if it is better than the older official NOAA data it could replace.

The TerraNautical Data, Inc. (TND) Approach

We propose a unique and novel solution to the problem of producing accurate depth data. The idea is inspired in part by the Mission Statement of the International Seakeepers Society (www.seakeepers.com/mission.htm) as well as a project of The Search for Extraterrestrial Intelligence (SETI) (www.setiathome.ssl.berkeley.edu/). The TND idea is to use what we term, *Incidental platforms*. An incidental platform, whether it is a vessel, airplane automobile or person, is a platform that acquires data, but does not store, process or disseminate that data, which may in itself have great value. Why not take advantage of even a small percentage of the over 16 million recreational boats in the United States---these incidental platforms---and use them as one large collective system of survey craft to scour the floor of our coastal waters? In addition to recreational boaters, why not include government, academic and private vessels from NOAA, NOAA survey contract companies, the Coast Guard, the Army Corps of Engineers, commercial ships and barges, university research laboratories, and ferry boats?

Incidental Platform Depth Data Acquisition

In essence, recreational boaters are already “collecting” better data than the 60 year-old lead line and sextant data currently shown on so many NOAA charts. In addition, unlike NOAA, recreational boaters are inherently “collecting” data in the exact locations for which those same recreational boaters most need accurate data. Except for survey vessels, most government, academic and private ships, barges, and ferryboats also “collect” such data. However, just as

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[7] US Army Corps of Engineers (USACE) SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey)

[8] E. Sipos, Personal knowledge (Internal NOAA Document, not classified or restricted)

quickly as their sounding data flashes onto their depth sounder it is, regrettably, lost forever. However, this does not need to be the case. With the advent of small high capacity microelectronic storage devices (CompactFlash), mobile telecommunications, and precise positioning technology such as WAAS GPS, most of these vessels could be *recording* the sounding data needed to improve nautical charts.

What would be the data quality from such incidental platforms? NOAA goes to great lengths to ensure that the survey data they provide on charts is as precise and accurate as possible. NOAA uses a single vessel to survey a limited, well-defined area. After the NOAA vessel completes a project area, the vessel moves on to a new project area, with no intent of returning to that location for many years, if ever again. Because NOAA has, in essence, only one chance to collect quality data in a given area, NOAA makes a great effort to control and minimize all possible errors in their depth measurements. Their survey vessels use state-of-the-art multi-beam echo sounders, well-calibrated electronics, and they have rigorous standards for sound velocity, draft, and tidal corrections, as well as for acquisition procedures for collecting raw depth data.

We propose to modify these NOAA procedures, and offset any loss in precision or accuracy by letting statistics work in our favor. Our approach is to use numerous boats with less accurate or precise instruments than current NOAA ships, but ping the same area repeatedly. (An approach to a marina would be a good example … it will be pinged by hundreds of vessels every week.) We still intend to correct for tide, and will make draft and simplified sound velocity corrections, but we will employ statistical averaging and analyses so that our final derived depth values are comparable to what NOAA would have achieved, had they surveyed the same area. Boaters will install an integral system (*TND System*) of WAAS GPS, Depth Sounder, Temperature Transducer, and CompactFlash data recorder.

How is the Boater Data Collected

Under full implementation of this approach, recreational boaters, along with government, academic and private vessels will purchase and install a *TND System* on their boats. When the unit is installed, *type of vessel*, *LOA, GW*, and depth sounder and GPS antenna *transducer offsets* are recorded. When collecting data, NMEA data streams would be recorded only under certain conditions associated with SOG, number of satellites/HDOP, and WAAS status.

Position, depth, and water surface temperature data would be recorded each second on a *CompactFlash* card, and the card periodically sent to TND on some regular schedule for analysis and utilization. Eleven hours of position, depth and water temperature data produce a 3.2 MByte text file. When this text file is compressed using a ZIP algorithm, the file is only 640 Kbytes. A typical recreational boater would cruise an average of no more than 6 hours per day, for an average of 4 days per week. If data were sent to TND quarterly, the card would contain only about 18 MBytes of compressed data. A ferryboat operating 12 hours per day, seven days per week for a year would produce 15,724,800 soundings. A 64 Mbyte CompactFlash card could contain three months of data from such a ferryboat. A 256 Mbyte card would hold data for an entire year. When the technology supports it, a system will be developed for automatic upload either to a cellular system, or via satellite.

TND Systems would be manufactured by a company, which would market and sell the units. TND would be responsible for processing, analysis, quality control and distribution of chart data derived from *TND Systems*.

Depth Data would be provided mainly to NOAA and the Corps of Engineers under survey contracts, or provided at cost of processing when data is derived from their vessels. NOAA, in turn would make these data available to electronic chart companies like Nobeltec, Navionics, and Nautical Technologies through their agreement with Maptech. Depth data could also be used by TND to create paper and electronic charts of harbors and anchorages.

Why Participate in this Program?

Boaters would be strongly motivated to participate for the following reasons:

1. Recreational boaters would be the primary beneficiaries of accurate depth data. They are also, as a group, dedicated and concerned about improving charts. TND believes that this sense of responsibility will be a major incentive for boaters to participate in this program.
2. Government, Academic and Commercial groups would participate to improve the quality of depth data and to acquire important research data in areas like environmental studies and fisheries.
3. A partner in this effort, as for example, BoatU.S., could offer participating boaters discounts on GPS/Sounder systems, as well as cartography. With electronic charts being as expensive as they are, this would provide the participating boater with a reduced cost for new or updated charts.
4. Upon return of each CompactFlash cards containing three months of data, boaters could receive a discount coupon.
5. Were the partner a commercial GPS manufacturer that also provides charts, like GARMIN, which creates the BlueChart, electronic charts would be discounted to participating boaters at 20 to 30 percent.

Thus, as boaters participate in this program, they benefit directly. They not only produce good depth data, but are also the users of data that they, themselves, have produced. They also would save far more than the initial system cost in reduced chart prices over two or three years. TND estimates that no fewer than 160,000 recreational boaters would participate in this data gathering/ownership project, for sales of 160,000 units and untold amounts of depth data to replace the decades old data now used on charts. In addition, hundreds of vessels from NOAA, the Corps of Engineers, the Coast Guard, as well as university research vessels, ferryboats and barges, would provide very high densities of data.

Utilization of Data

TND depth data would be an accumulation of depths measured by thousands of boats, often over regions where neither NOAA nor the Corps of Engineers has conducted recent surveys. These depth observations would be maintained in a database of cells matched to charts. Cells would range from 5 m x 5 m for harbors, narrow channels and regions of high depth gradient, to as large as 80 m x 80 m for open water regions of negligible depth gradient. Thus, TND depths would be reasonably spaced for 1:5000 scale charts, and densely spaced for charts scaled at 1:20000 or 1: 40000

For purposes of display, each cell would contain two depths, rounded to the nearest foot: the most recent NOAA survey depth and the TND mean depth minus its standard error of the mean (assuring a shoal bias to the TND depth). Using these TND data in electronic charts, the boater would have the choice of displaying NOAA depth data, TND depth data, or both. When both are displayed, the software might show the NOAA depth in black. When the TND depth is greater than the NOAA depth, the TND depth could be shown in green. When the TND depth is less than the NOAA depth, it could be in red. Thus, the two layers, NOAA and TND depths, would allow the chart user to be suspicious of regions shown in red, and relaxed in regions shown in green. When the TND depth equals the NOAA depth, both could be in black.

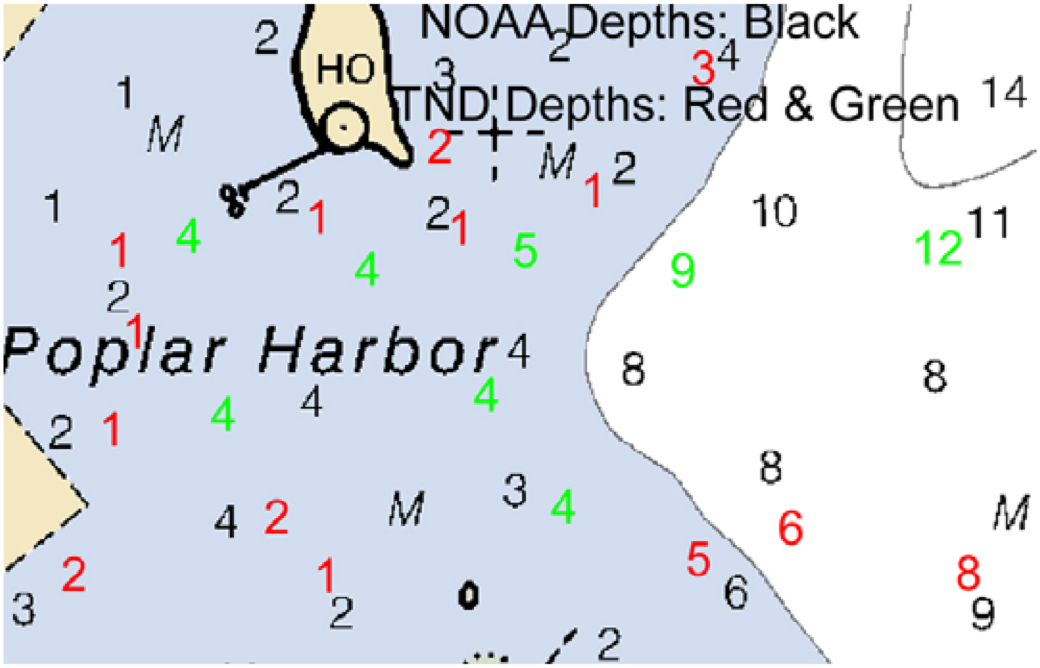

Figure 1. Example of TND depths in red and green, NOAA chart depths in black

Validation of Methodology

To see how well a recreational boater could provide depth data, it was necessary to identify and equip a vessel to carry out depth and position data acquisition. Then these data were compared with a standard to verify the data quality.

Collection of Depth Data

The 40-foot, 26-ton trawler "Rainbow" was used to survey a recently NOAA-surveyed site (NOAA Sector H10823, 1999) in the Chesapeake Bay.

Figure 2. The Trawler, "Rainbow

Depth and position data were collected using the Standard Communications DS150 sounder and transducer, and Axiom Navigation Swift B2 OEM WAAS GPS. Data from both of these units were fed via serial ports into a Dell *Inspiron* 4000 laptop computer and recorded using Portable Navigator III, software created for navigation and data logging for hydrographic surveys.

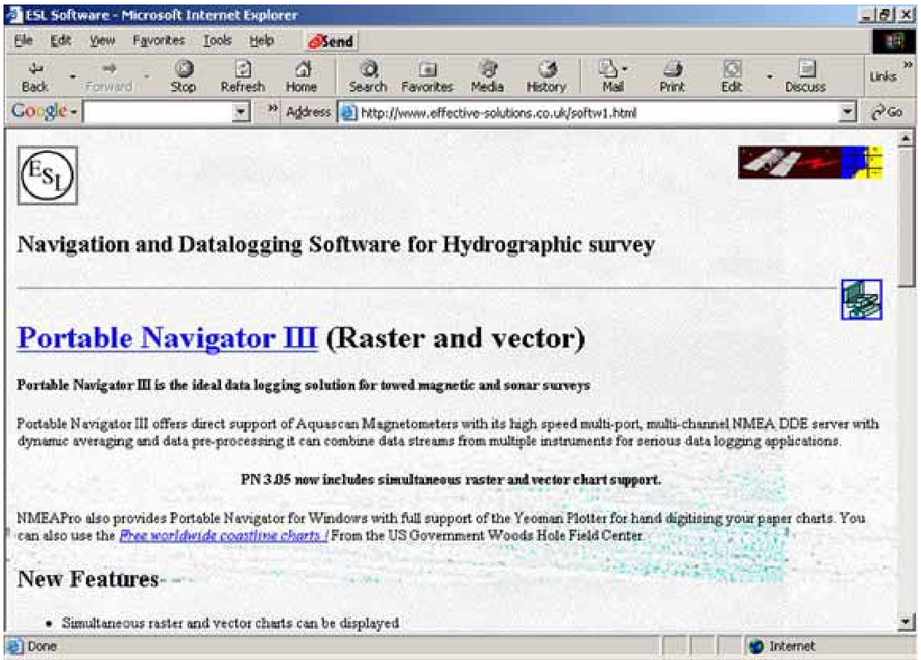

Figure 3. URL for Portable Navigator III: www.effective-solutions.co.uk/softw1.html

Initial data acquisition was done on August 4, 2001. These data include an approach and entrance to Herrington Harbor South Marina, just off the Chesapeake Bay. NOAA will never survey this approach or entrance. A more systematic and more thorough data acquisition was done on October 3, 2001.

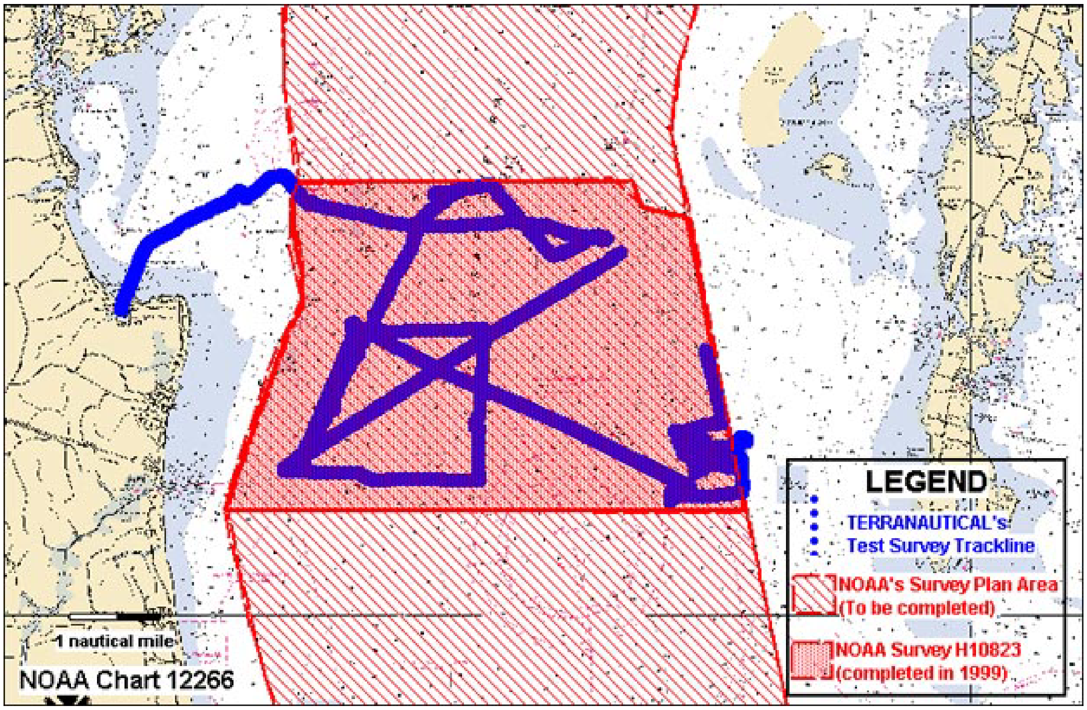

Figure 4. August 4, 2001 TND Survey

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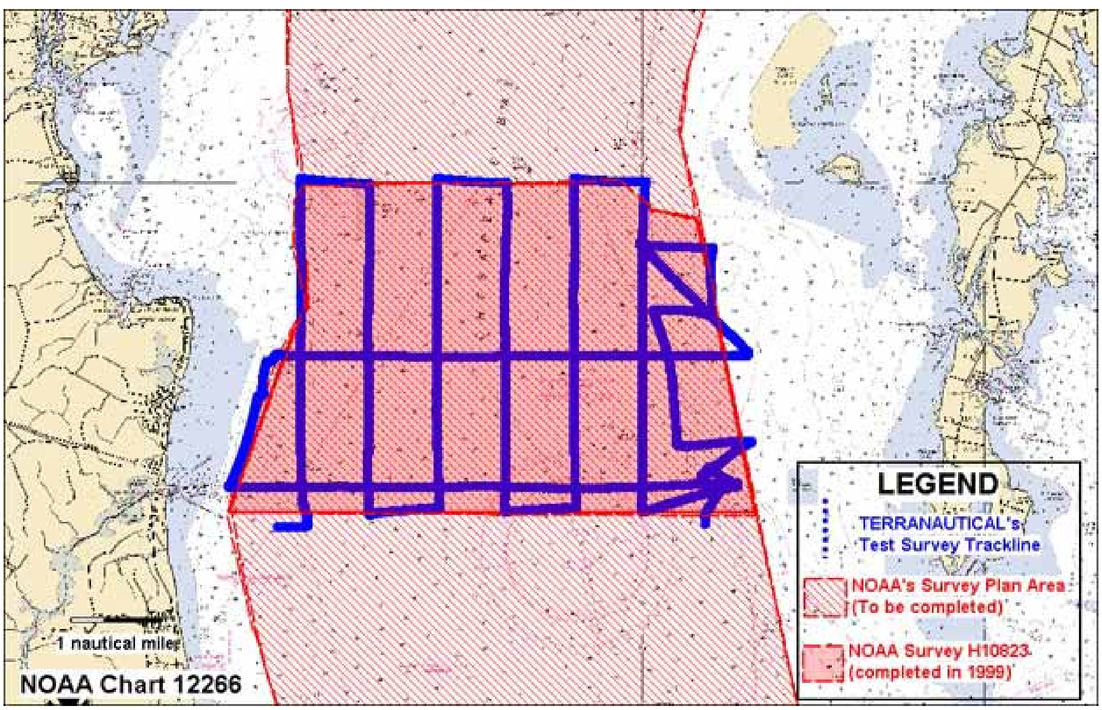

Figure 5. October 3, 2001 TND survey

The merger of these two sets of data provides substantially greater coverage of the survey area.

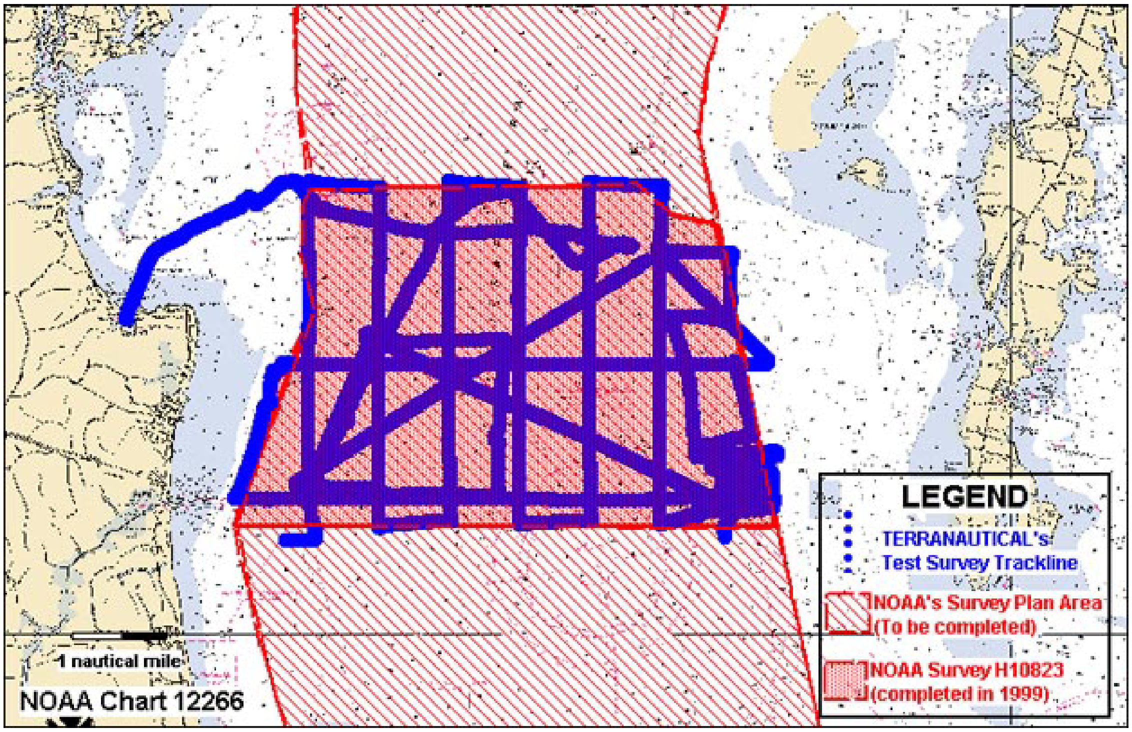

Figure 6. Merged TND Survey data for 8-4-01 and 10-03-01

After making tidal and sound velocity corrections, these data were merged into one file for analysis. Having two sets of data from two different dates two months apart allows for a test of consistency of the method for differing tides and differing sound velocities, since both the salinities and water temperatures were different on those separate dates.

Results

Data sets acquired and corrected for tide, sound velocity and vessel draft were then compared with data acquired by NOAA (Sector H10823) in 1999. The results were most impressive. Figure 7 shows how TND results compared with NOAA survey results over and near a sharp gradient in depth. Note how much closer spaced the TND depths are on this close-up than are the NOAA depths.

Depths taken for the approach and entrance to Herrington Harbor show the kind of results that will be of great value to boaters. These results will never be provided again by NOAA, and either must be gathered through private surveys by Marinas or others, or must be gathered as proposed here. Note the comparisons of TND depths with old NOAA survey results for the approach.

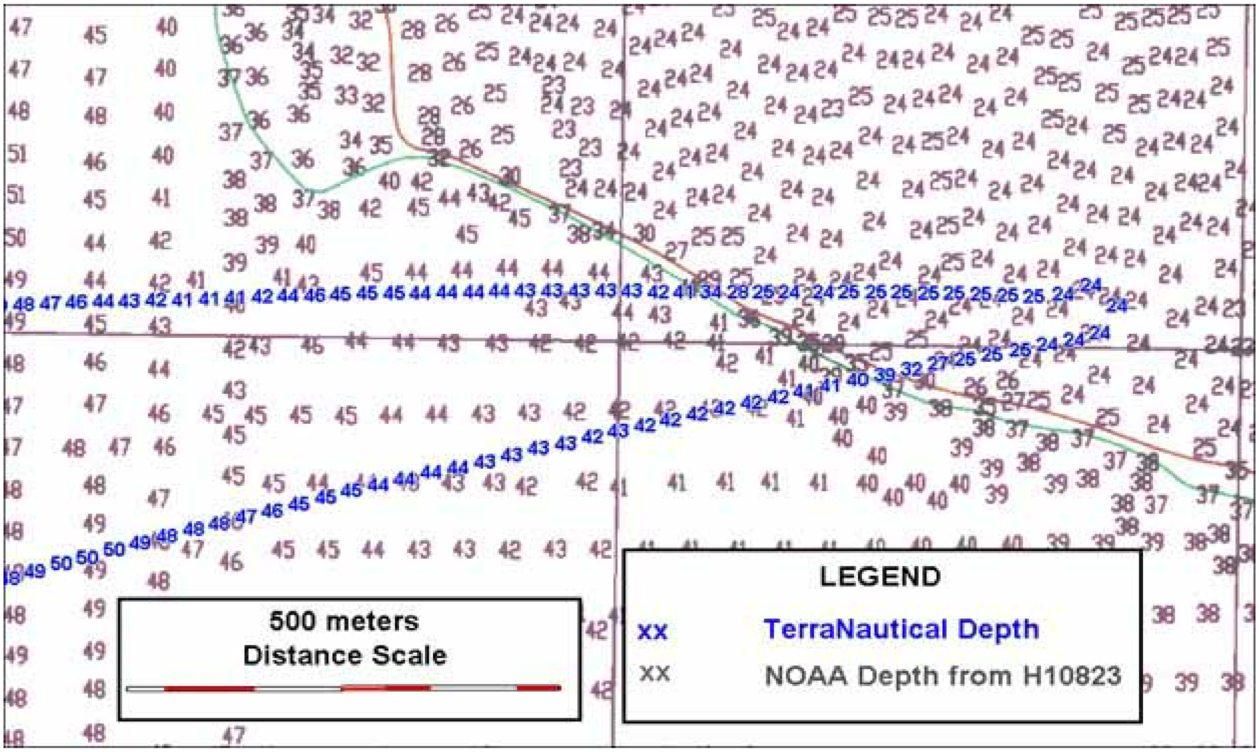

Figure 7. TND depths closely match recent NOAA survey depths, even at deep gradients.

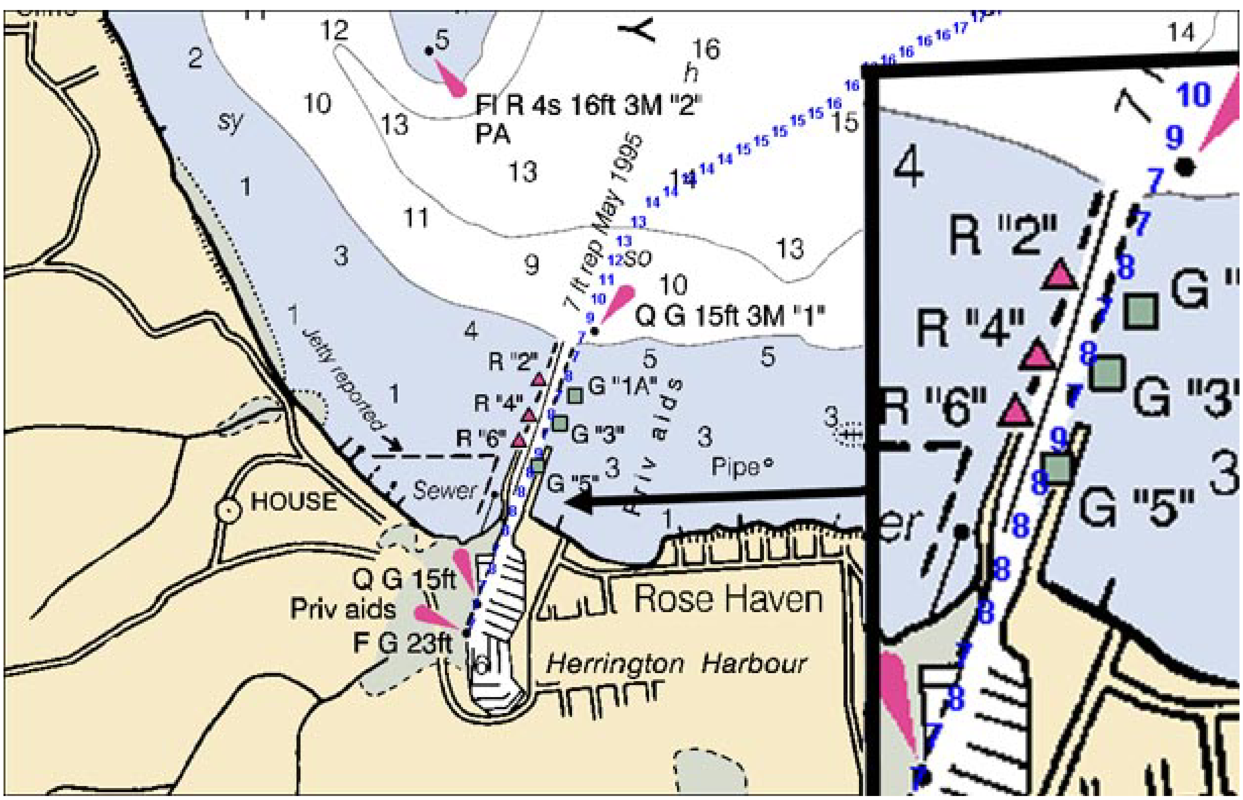

Figure 8. The approach and entrance to this harbor would never be surveyed by NOAA

Comparisons of Results with NOAA Data

Over these two TND survey dates, TND had collected 39,000 depths (corrected for sound velocity and tides to WL MLLW) corresponding to 39,000 WAAS GPS coordinates. These data were then compared to 127,438 depths (WL MLLW) in the NOAA set. All latitude and longitude coordinates in both the NOAA data set and the TND data set were converted to *eastings* and *northings* (zone 18), and a fixed grid was established. This grid was made to be 633 cells wide (*eastings*) by 375 cells high (*northings*). Each cell was 20 meters x 20 meters. A computer program was written to search for NOAA and TND data that fell within each of those cells. The TND depths were then compared with the NOAA depths taken as standards.

The computer program searched first for all NOAA data that fell within each cell. There were 24,022 NOAA points (depth measurements) found within the 237,375 cells in this sector. Then the program searched for TND points in each cell. There were 8,660 TND cells containing TND data. Means of the TND depths in each cell and their standard error were calculated, with the mean value used to indicate the TND depth for that cell.

The average TND depth over the cell was compared with the average NOAA depth over the same cell. The TND data consistently contained four or five soundings per cell. However, the NOAA data contained a median of only one sounding per cell, even though for a few cells NOAA had as many as 400 soundings (probably multibeam, looking for point objects). Thus, the TND mean depth was usually compared with a single NOAA depth.

Although TND used both feet and meters in data analyses, conversions were made at appropriate points as needed. The use of both units is mainly because charts in U.S. waters are mostly expressed in feet.

NOAA standards for conducting Hydrographic Surveys require the following error limits:

> *Measurement error: This includes the instrument error for the sounding system, the effects of imperfectly measured roll/pitch and errors in detection of the sea floor due to varying density of the bottom material. The minimum achievable value is expected to be 0.20 meter at 10 meters depth. The maximum allowable error is 0.30 meter plus 0.5% of the depth.*[9]

When TND data were matched to NOAA data, 1,166 matching cells contained both TND and NOAA depths. These were compared, and the results were impressive. Some 92.2% of the TND results fell within NOAA survey specifications, while only 7.8% failed to do so.

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[9] NOAA, *Specifications and Deliverables, Section 5 (for depth data)* (NOAA 2000)

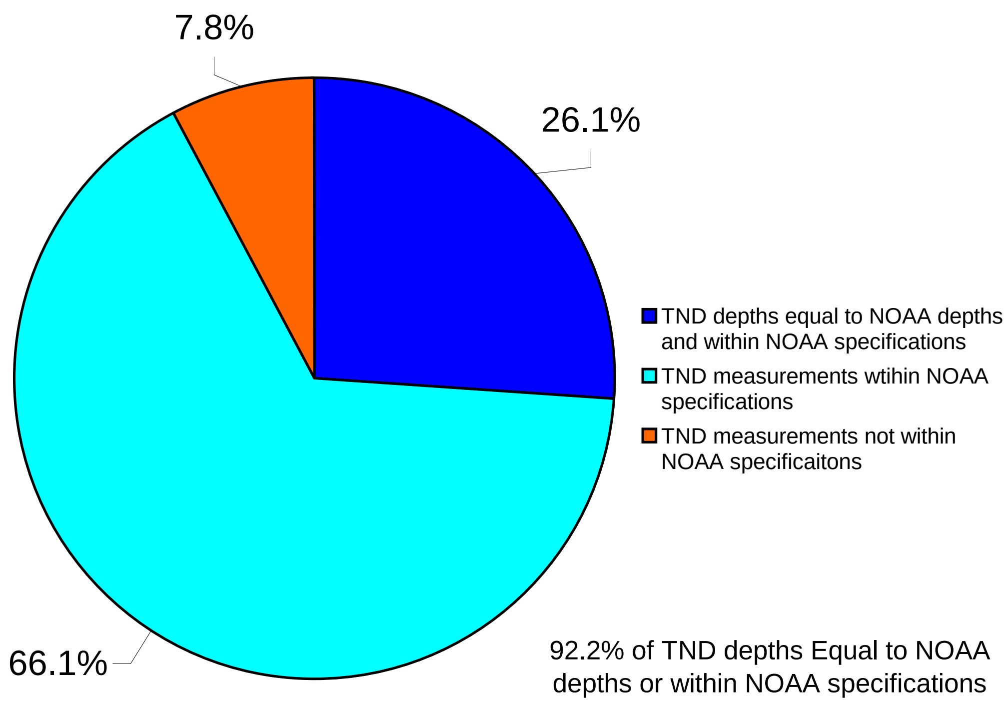

Figure 9. MLLW comparisons between TND (2001) and NOAA (1999) using fixed grid for cells

What about the 7.8%

The results showed that for 26.1% of the TND depths, there was an exact match with the corresponding NOAA depth used as a standard. For 66.1% of the soundings, the TND depths differed from the NOAA standard depth by no more than 30 cm, well within the NOAA specifications for total error. But what about the 7.8%, where differences were larger than 30 cm, and in some cases were as large as 7 feet?

In an effort to understand these discrepancies, the TND and NOAA depths were charted onto *Mapinfo*, and the depths in the 7.8% category identified by position and characteristics from existing NOAA charts. In almost every case the error was associated with large gradients of depth, where the closest TND depth to the NOAA comparable depth in that cell placed them at such different depths, that the error was due entirely to a gradient. Indeed, the TND depths were undoubtedly correct.

Figure 10 shows a 20 m x 20 m cell in a region of large gradient. Red crosses show boundaries of 20 m by 20 m cells. Figure 11 shows an exploded image of the region surrounding the 20 m x 20 m cell under examination. Note how small a 20 m by 20 m cell appears on a typical nautical chart. Consider how small TND's smallest cells of 5 m by 5 m will appear. TND depths are in green, and NOAA depths from their recent survey are in blue. Black depths are from the chart overlay, and represent older depth data.

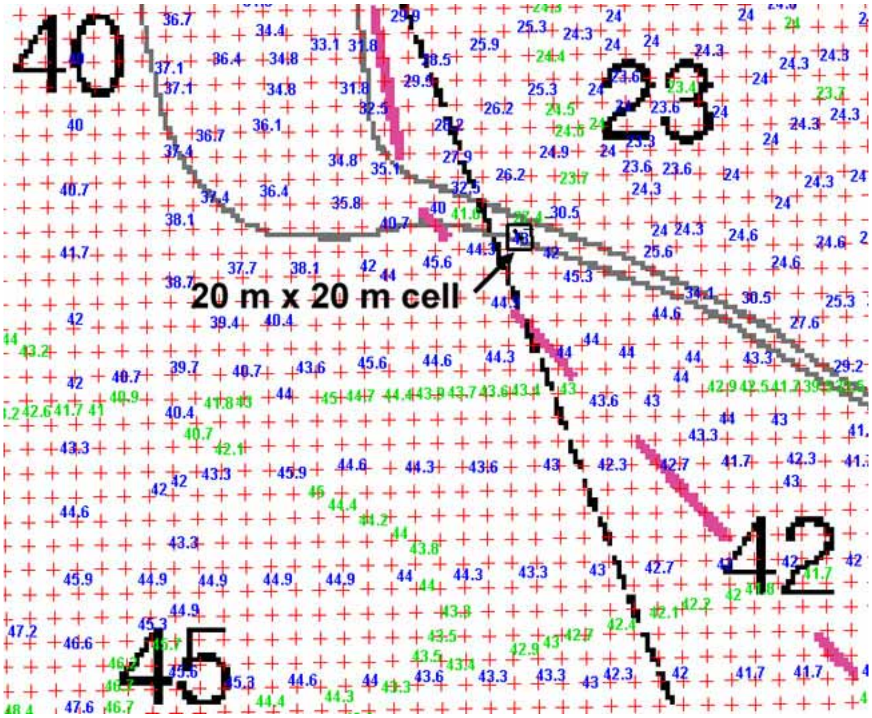

Figure 10. A region of the Chesapeake Bay showing survey cell sizes and a particular cell along a boundary of large depth gradient.

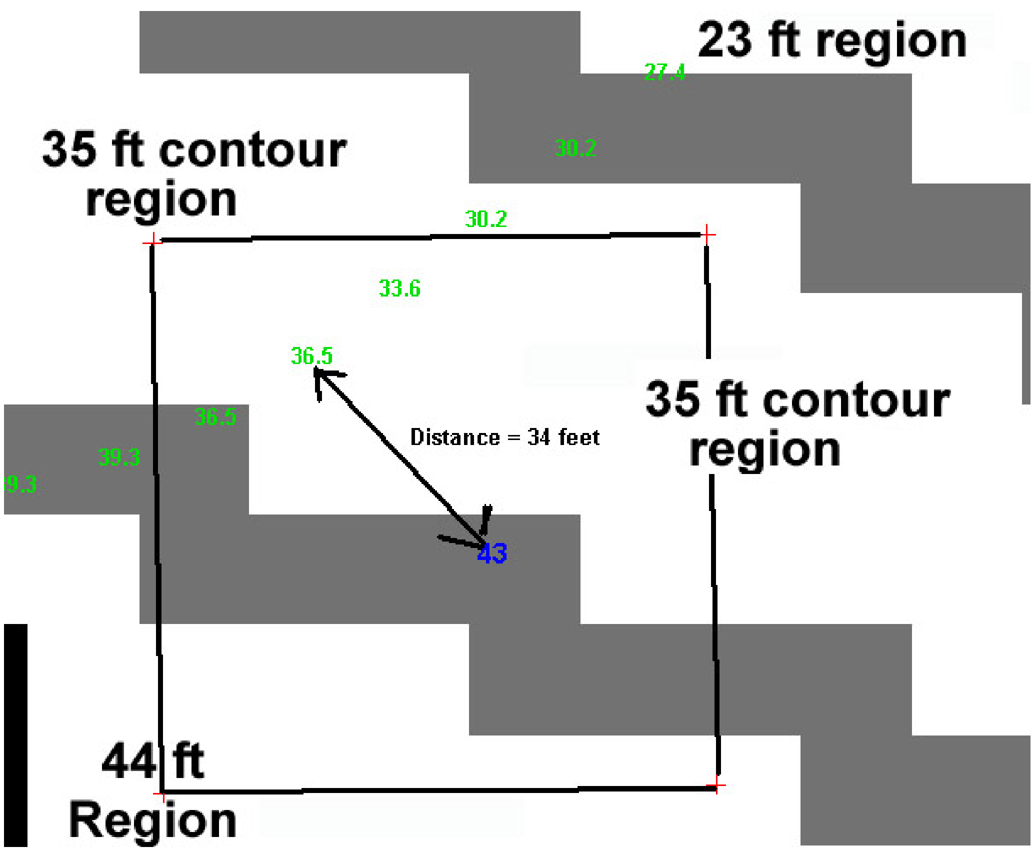

Figure 11. An expanded view, showing gradient-introduced false "error" in TND depth sounding

As can be seen in Figure 11, the TND depth soundings were along the upper left corner of the cell, and based upon contour lines from existing charts, appear to be correct. The 43 ft NOAA depth used for a comparison was in the same cell, but was some 34 feet away from the nearest TND sounding. The NOAA depth was also along the contour line, where the depth drops from 44 feet down to 35 feet. Thus, the "error" turns out not to be an error at all. Instead, the difference is attributable to a gradient.

In almost every case examined, TND has found the same factor contributing to depth differences between TND observations and the NOAA standard. Thus, NOAA depths and TND depths differ by no more than 30 cm for 99% of the test results. This would appear to be conclusive evidence for the viability of the TND approach.

Detailed Methodology

Several steps were taken to assure the precision of TND WL MLLW depths, as well as the coordinates assigned to those depths. In addition to known sources of error requiring corrections, random errors were estimated through a propagation of error analysis.

Corrections for Sound Velocity

When the typical depth sounder is set to measure depth in feet, the calibration is based upon a sound velocity of 4,800 feet/second. However, the actual sound velocity depends upon water temperature, salinity and depth. The sounder will therefore produce erroneous depth readings. For this reason, we must either directly measure the velocity of sound or infer its value, and then correct the sounder reading for the sound velocity variation from 4800 ft/sec.

Since depth acquisition by recreational boaters would not include direct sound velocity measurements, some other way of arriving at the sound velocity must be used, so that the depths may be appropriately corrected. Sound velocities in seawater can be calculated from several different equations.

The *Coppens* Equation

Because of the range of depths and salinities observed in the Chesapeake Bay and most coastal waters, the *Coppens* Equation is most appropriate.

$$V = V_0 + (16.23 + 0.0253T)D + (0.213 - 0.01T)D^2 + [0.0016 + 0.00002(S - 35)](S - 35)TD$$

where

$$V_0 = 1449.05 + 4.57T - 0.0521T^2 + 0.00023T^3 + (1.333 - 0.0126T + 0.00009T^2)(S - 35)$$

and *V* is in m/s, *T* is in Celsius degrees, *D* is in km, and S is salinity in parts per thousand. The depth variable has very little effect on the sound velocity. For depths from zero to 50 meters, the velocity change associated with depth is only 0.8 m/s (holding T and S constant).

Sound Velocity as a Function of Seawater Temperature and Salinity

The major contributor to sound velocity in seawater is temperature. Salinity affects sound velocity, but much less than does temperature. Figure 12 shows the temperature dependence of sound velocity for salinities of 5 to 25 (holding depth in km constant at a low typical value).

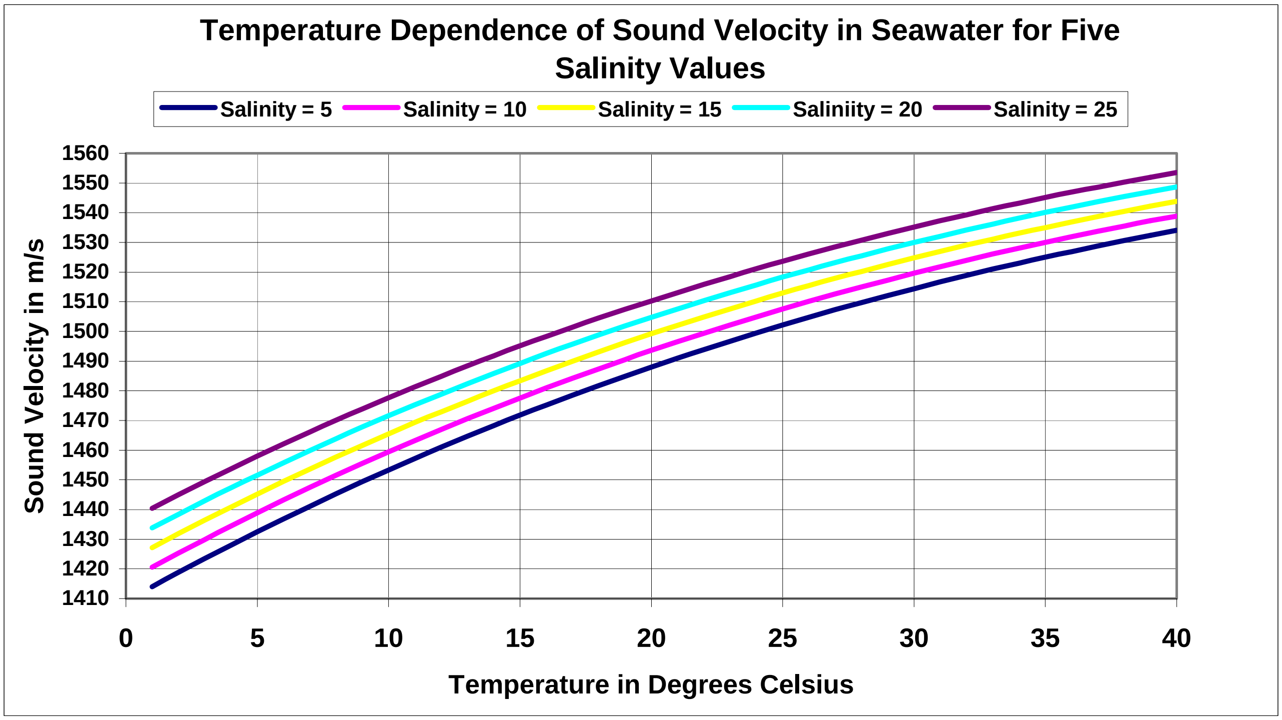

Figure 12. Temperature Dependence of Sound Velocity in Seawater for Five Salinity Values *(From the Coppens equation, 1981)*

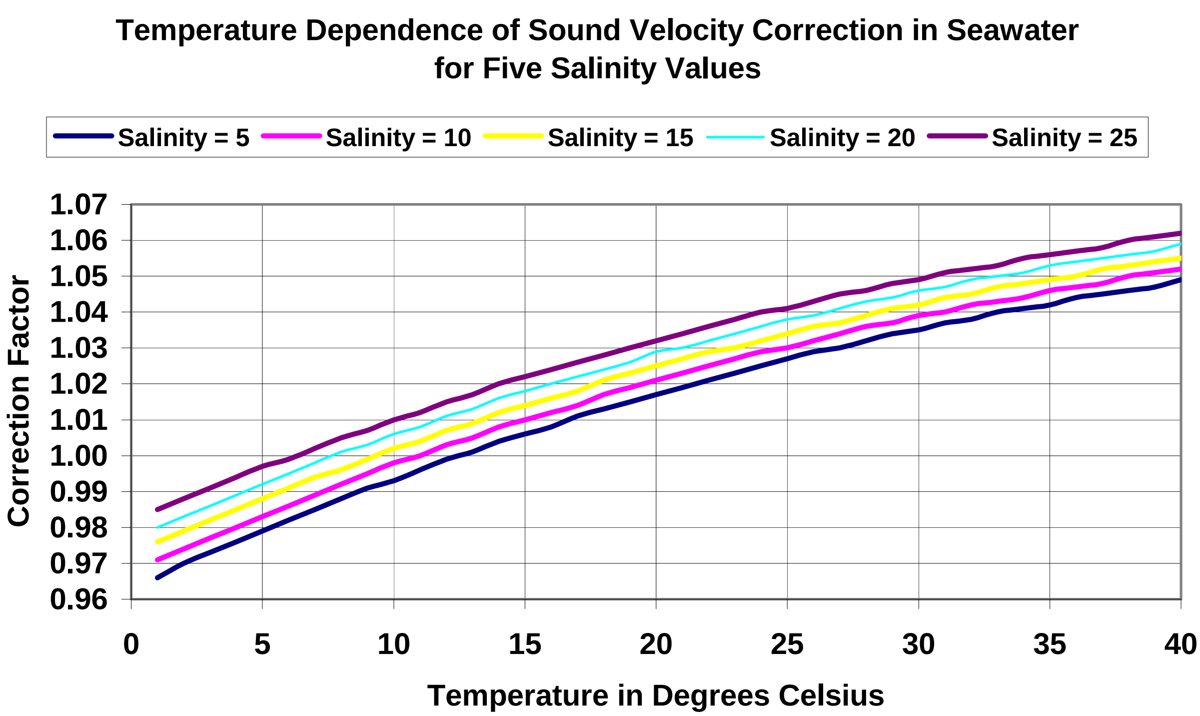

Figure 13. Temperature Dependence of Depth Sounder Correction for Sound Velocity in Seawater for Several Salinity Values

The Correction Factor

The correction factor for sound velocity is needed for sounders calibrated with a sound velocity of 4800 feet/second. (Some sounders are calibrated for a sound velocity of 1500 m/s.) With a sounder displaying feet/second, as would be the case for most recreational boaters in U.S. waters, the correction factor has the temperature dependence for five salinity values, as shown in Figure 13.

Data Sources for Temperature and Salinity

For the proof-of-concept test, temperatures were acquired on the Internet from a data buoy in the Chesapeake Bay. This buoy station provided data on water temperature at the surface, at 8 feet depth, and at 62 feet depth. It provided salinity at 8 feet depth and at 62 feet of depth. Observations are recorded by the buoy and made available for 20-minute to half-hour increments. This mid-bay buoy is located very near the observation region for data taken by TND for this proof-of-concept part of this report.

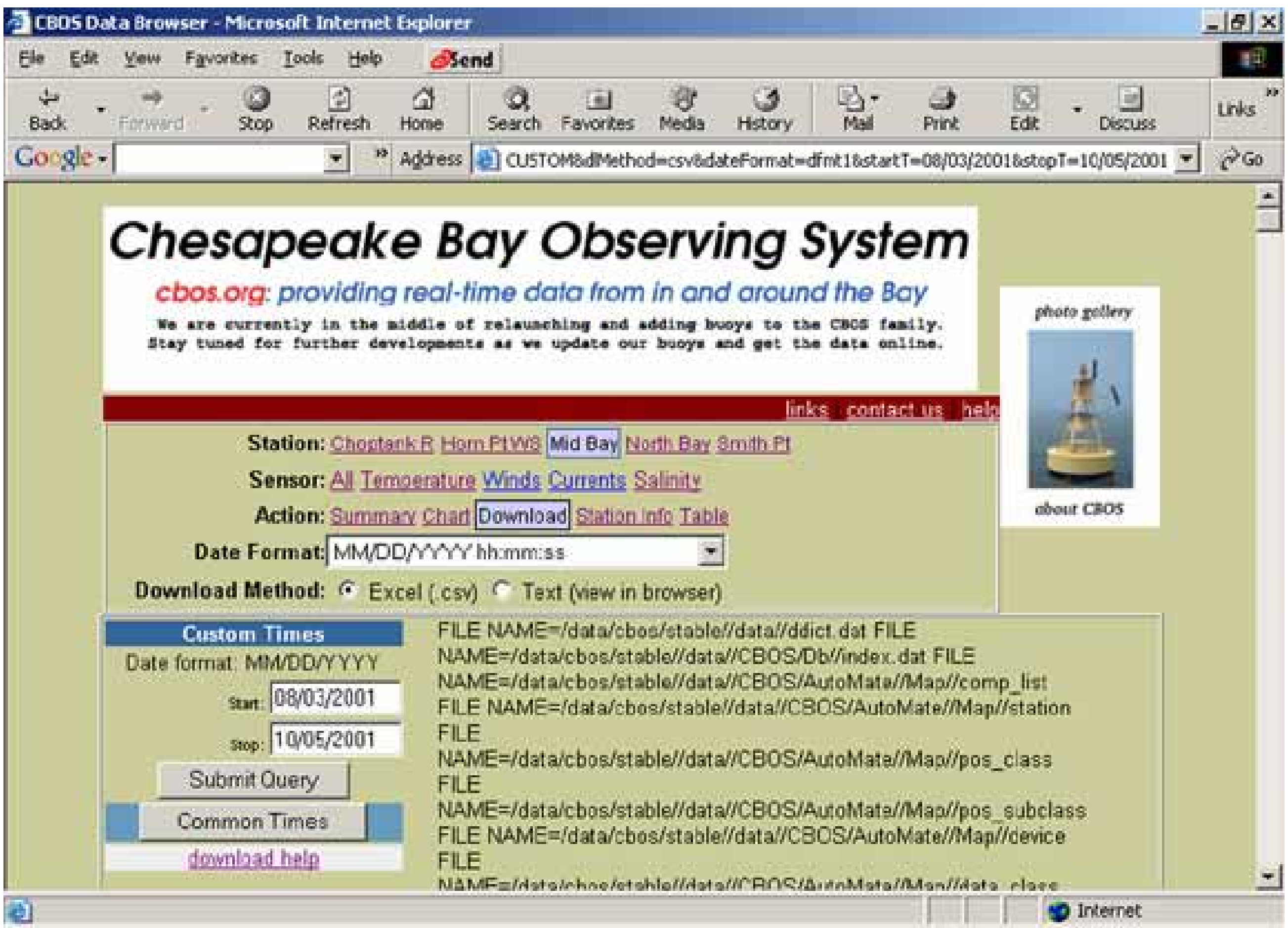

Figure 14. URL for Chesapeake Bay Observing System (CBOS) Mid-Bay Buoy Data: www.cbos.org/client.cgi

The download web page has the appearance shown in figure 15. The downloaded files are .CSV files, which can be loaded into a spreadsheet, like Excel.

save	Water Surface	surf	Temperature	C
save	Water Surface	surf	Temperature	F
save	Mooring	62ft Endeco	Salinity	
save	Mooring	62ft Endeco	Temperature	C
save	Mooring	62ft Endeco	Temperature	F
save	Mooring	8ft Endeco	Salinity	
save	Mooring	8ft Endeco	Temperature	C
save	Mooring	8ft Endeco	Temperature	F

Figure 15. Sample of .CSV files downloaded from CBOS

To use data from these downloads, least square curve fitting was applied to data for the day and time when observations were made. These were typically second or third degree polynomials, giving the values of *T* or *S* as a function of time. These equations were determined for each recorded depth. These equations could then be used to determine values of *T* and *S* for each of the 39,000 TND depth observations. Their values were determined at a TND time and depth-averaged for the depth being observed at that time.

The *Coppens* equation could then be applied to each of the 39,000 TND depth observations to get the sound velocity at the time of the observation. With this sound velocity, the depth below the transducer could be corrected by the factor,

$$d = (V/1463.04)d_m$$

where d is the sound velocity-corrected depth below the transducer and d_m is the sounder-recorded depth below the transducer.

Analyses were carried out on Excel spread sheets. A sample of four of the 39,000 TND data points shows the kinds of steps taken to arrive at the MLLWL values used to compare with the NOAA survey data.

This table shows four values during the first four seconds of data acquisition.

T (UTC as Decimal)	Longitude	Latitude	GPS	Surface Temperature of water (Fahrenheit)	8 ft water Temperature	4 ft water Temperature (average of surface and 8 ft)	62 ft water Temperature	Average Water Temperature for Observed Average Depth (Fahrenheit)	Average Water Temperature for Observed Average Depth (Celsius)	Water Salinity at 8 feet
16.400000	-76.505440	38.683972	2-10	68.8	66.8	67.8	71.1	68.4	20.2	12.8
16.400278	-76.505393	38.683972	2-10	68.8	66.8	67.8	71.1	68.4	20.2	12.8
16.400556	-76.505343	38.683972	2-10	68.8	66.8	67.8	71.1	68.4	20.2	12.8
16.400833	-76.505295	38.683972	2-10	68.8	66.8	67.8	71.1	68.4	20.2	12.8

Figure 16. First half of Excel spreadsheet columns used for TND data analysis

Water Salinity at 62 feet	Average Water Salinity for observed average Depth	Speed of Sound Vo (Coppens) in m/s	Speed of Sound for Average Depth (Coppens) in m/s	Average Sounder Water Line Depth in km	Sounder Depth (feet below transducer)	Velocity Corrected Depth (feet below transducer)	Corrected Water Line Depth	Tide (From 3rd degree polynomial)	MLLW (Fully Corrected)
17.8	13.7	1519.64	1519.71	0.0043739	26.0	27.0	29.7	0.99249363	28.7146585
17.8	13.7	1519.64	1519.71	0.0043739	26.0	27.0	29.7	0.99254013	28.7146117
17.8	13.7	1519.64	1519.71	0.0043739	26.0	27.0	29.7	0.99258663	28.7145649
17.8	13.7	1519.63	1519.70	0.0043586	25.9	26.9	29.6	0.99263314	28.6104168

Figure 17. Second half of Excel spreadsheet columns used for TND data analysis (*Insignificant decimal places were left in the last two columns to show how values change from tide equation*)

Errors and Error Propagation

One can examine how random errors propagate through the *Coppens* Equation. An error propagation analysis can also be done for the correction factor. Through such an analysis we find that $\delta d/d_m = 0.0042$, where $\delta d/d_m$ is the relative error in depth.

For a measurement of 110 feet, the random error is therefore no more than plus or minus 6 inches, or plus or minus 20 centimeters. For the average depth of 40 feet, the random error is no more than 2 inches or 6 centimeters.

The latter errors do not include systematic errors associated with *WAAS GPS measurements of position*, *static draft*, *settlement*, *squat*, and *heave*. Settlement, squat and heave errors are averaged out with several vessels with multiple depths within a cell. Locating the GPS antenna directly above the depth transducer minimized the horizontal offset errors. Error bounds for this GPS were determined by means of measurements made over a period of eight hours with the antenna at a fixed location. The result was a mean error with a radius of 4.7 feet.

Since the region being surveyed had few locations where the depth contours were extreme over a horizontal distance of 20 feet, the GPS error can be ignored.

Static draft was measured directly. First, the vertical distance from the transducer face to a marked reference point on the vessel hull above the waterline was measured at the time the transducer was installed and the vessel was out of the water. When the boat was in the water, the distance from the waterline to the reference point was then measured under several loading situations. The best value for that static draft was determined to be 2.72 feet plus or minus 0.02 feet.

For a 52,000-pound, full-displacement vessel, settlement, squat and heave would be negligible. First, consider the tidal adjustment to the TND data.

Tidal corrections

Once sound velocity corrections were made, tide corrections had also to be made. The nearest harmonic-established tide data was downloaded for the dates and times of data acquisition, and temporal and amplitude corrections applied. Thus, the vessel depth data was corrected for both sound velocity and tides.

Tide data was obtained from the NOS web site.

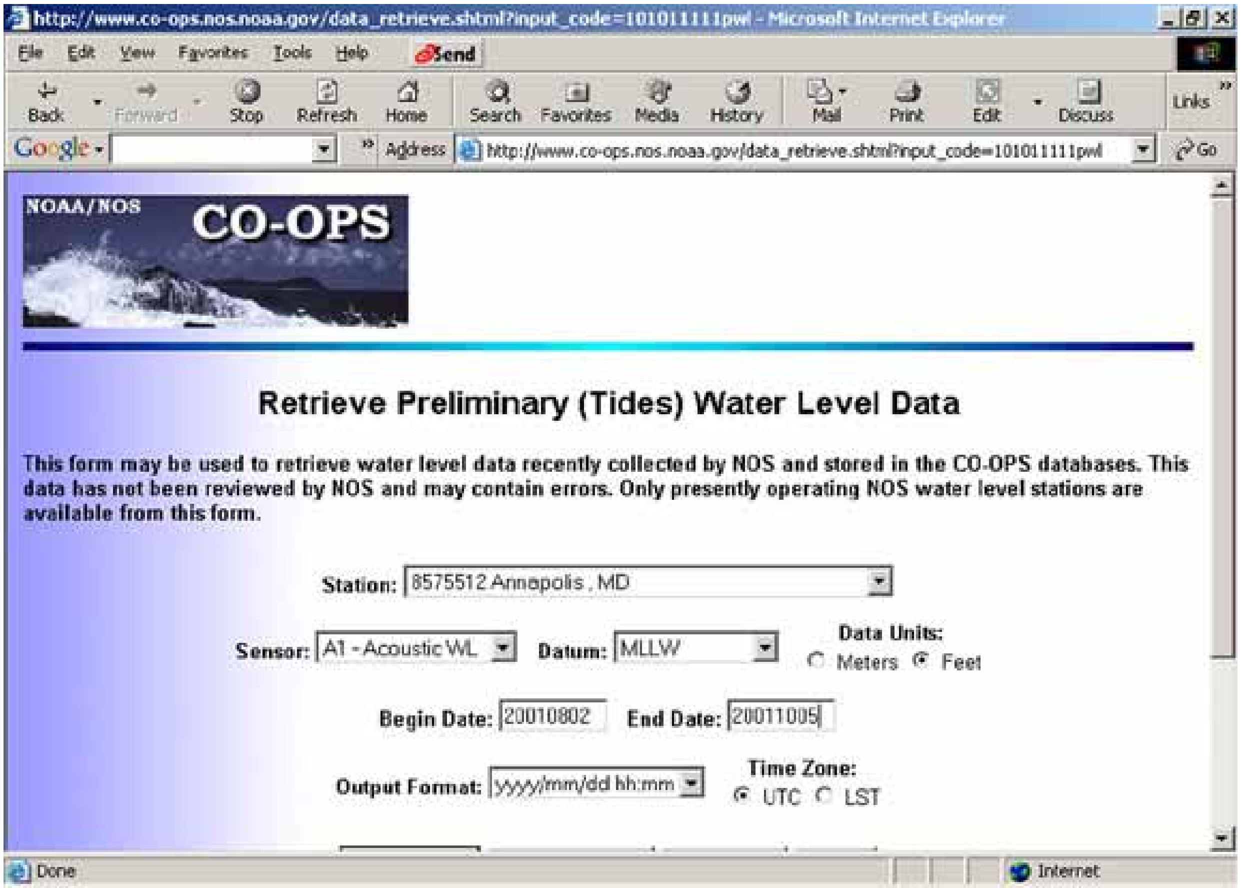

Figure 18. URL for downloading NOAA tide data: www.co-ops.nos.noaa.gov/data_res.html

Although there is a tide station at Chesapeake Beach, which is very near the survey area, it has not been in operation long enough to establish the essential periodic patterns (19 years). In addition, the NOAA data collected for this sector referenced Annapolis Tide Data in its establishment of the phase and amplitude factor. For these reasons, and because we had to compare our results with those of the 1999 NOAA survey, we used Annapolis Tide Data and the same phase and amplitude factor used by NOAA.

The Annapolis data is available in 6-minute increments. We downloaded the files for the dates and times of our surveys. Then we made the phase correction of 48 minutes (e.g. high tide would occur 48 minutes earlier in the sector being observed than in Annapolis) and we applied the amplitude corrector, 1.09. Since the tide data was in 6-minute increments, and the TND observations were every second, we needed a method to ascertain those values at each of the 39,000 TND times of observation.

The Annapolis tide data (corrected to the sector) was limited to the UTC period of the TND observations for each of the two observation days. Then for each day, a least squares fit of the data was made to produce 3rd degree polynomials. The resulting equations could then be used in a spreadsheet to calculate the tide correction to MLLW at each second of the TND observations.

Generalization of Method

The method used in this survey could be applied to any defined cell at any location. The various methods of analysis can be built into efficient software. Although we used a cell size of

20 meters by 20 meters in the proof of concept test, the “errors” introduced by gradients suggest a variable grid size.

In the Full Process Pilot Test, and for Full Implementation, TND will use a variable cell size from 10 m x 10 m to as high as 80 m x 80 m. TND defines the cell gradient as 2.576 multiplied times the standard deviation of all vessel soundings for that cell. This provides a confidence interval of 99.0% for the cell gradient. The NOAA specification is defined as an error of 0.20 meters for depths below 10 meters, and 0.30 meters plus 0.5% of depth for soundings greater than 10 meters. Initial analyses will be conducted with a cell size of 40 m x 40 m. If depths from vessels show a gradient that exceeds the NOAA specification as a criterion, then the cell size is reduced to 20 m x 20 m. If again the sounding variations show a gradient in excess of the criterion, then the size is further reduced to 10 m x 10 m. This process continues until the gradient-induced variations are less the criterion or until there are only three soundings in the cell. If the resulting TND mean depths show a gradient in excess of the criterion, then the soundings for that cell are retained, but not reported.

If the initial analysis in a 40 m x 40 m cell shows a cell gradient that is less than the criterion, the cell size is increased to 80 m x 80 m, and gradient again tested against the criterion. If the gradient is still less than the criterion, the 80 m x 80 m cell size is used. If the gradient becomes greater than the criterion, the 40 m x 40 m cell size data is used. Over a period of time, this process will establish cell sizes, while simultaneously creating a pattern of depth contours.

Tide station observations are made in numerous locations in the bays, coastline, and ICW. Those data are routinely available for download. Using phases and amplitude factors, tidal corrections can be made to the data.

As will be described in the next section of this report, the TND system will collect and record depth, surface water temperature, and position (as well as other GPS information, SOG, date and UTC time). Since TND will not have a temperature profile for the water column at each depth, and are using instead, the water surface temperature, how will this affect our results? In addition, TND may have great difficulty getting accurate salinity profiles as well. How will these problems be addressed?

To answer these questions, further analyses were made on the 15,874 depth measurements made on 8-04-01 and on the 20,368 depth measurements made on 10-03-01. The water surface temperature from the buoy was used to replace the temperature profile values. In addition, salinity was assumed to be constant over the depth, and set equal to the average salinity for that location at that depth. Such data is more easily available than that needed for a salinity profile for the water column. Charts and tables of salinities are often found for a given date, month or season. These average salinity values would be the source of data TND would use. Now what is the effect of such a simplified approach?

Figure 19 shows a graph that compares the Coppens-calculated depths using surface water temperature and average salinity with the original results using temperature and salinity profiles (For 93% of the original depths, they matched NOAA depth measurements within plus or minus the NOAA criterion).

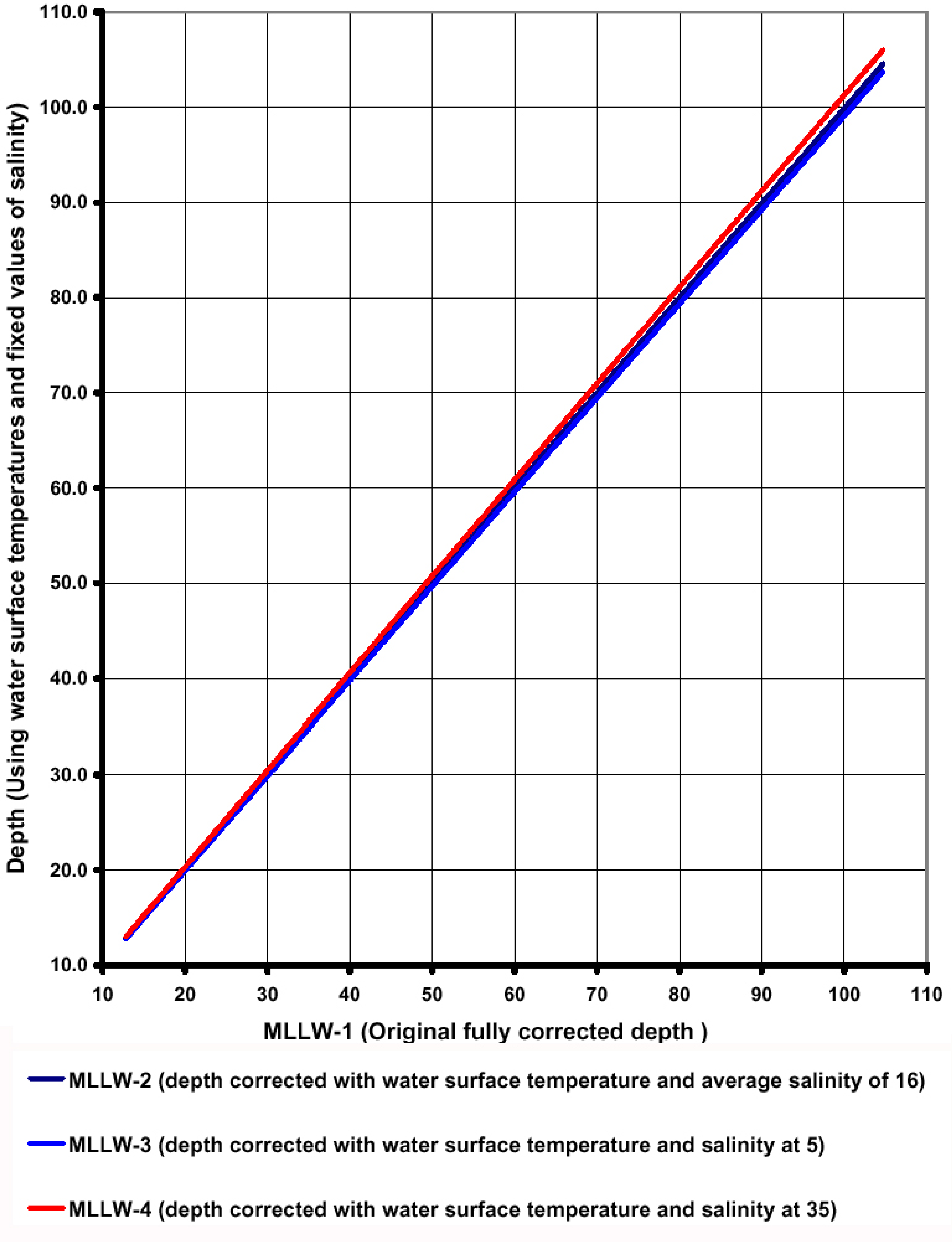

Figure 19. Graph Showing Negligible Effect of Using Average Salinity and Water Surface Temperature in Coppens Equation to Correct for Sound Velocity

When we look at the *differences* between using average salinity and water surface temperature instead of water temperature and salinity profiles, we get the following graphical results. And one can see that the errors introduced are quite negligible. Out to depths of 80 feet, the depth errors introduced are 0.1 feet (3 cm) or less. Indeed, even at the extremes of salinities, if we use water surface temperature, for depths below 30 feet, the depth errors are less than 0.5 feet (15 cm). These comparisons show vividly that using water surface temperatures and average even rough estimates of average salinity will give very precise depth results using the Coppens Equation.

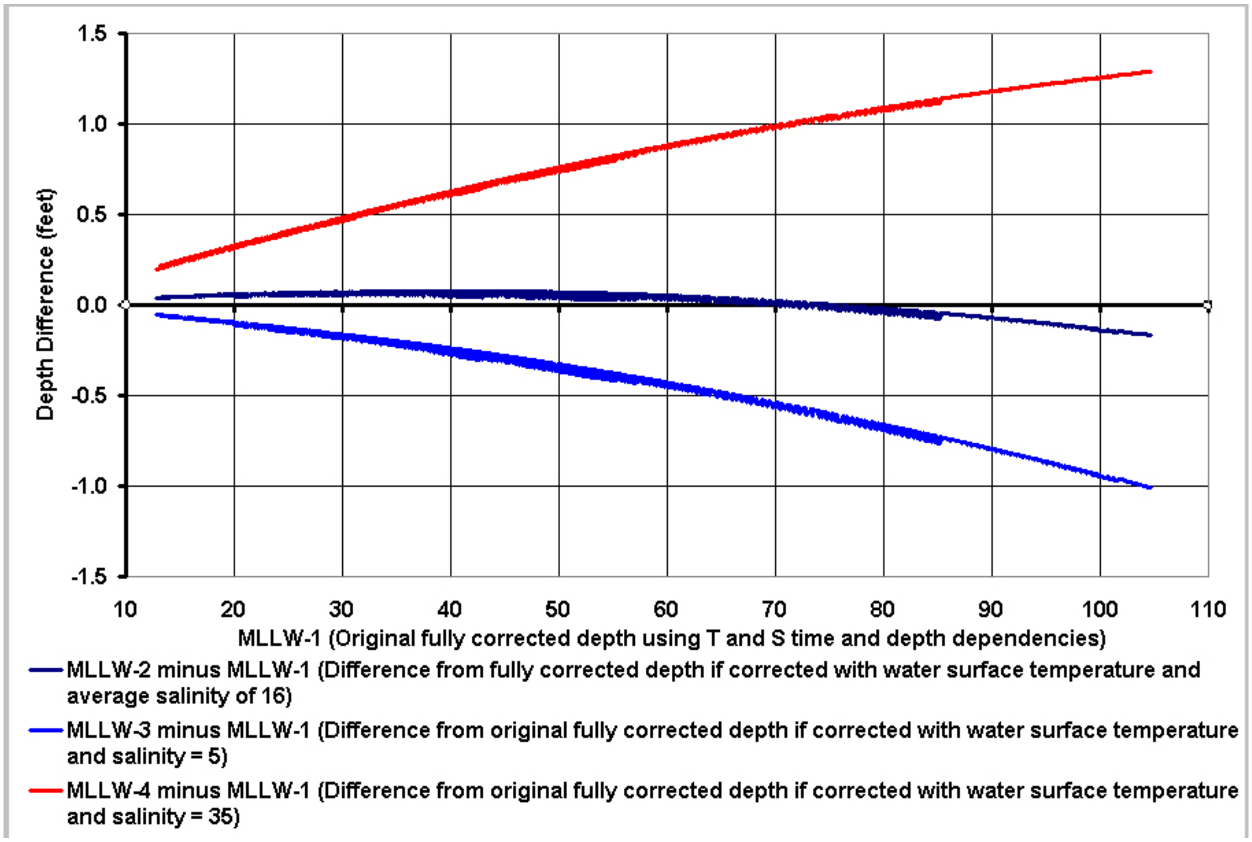

Figure 20. Differences From Original Results That Used Temperature and Salinity Profiles and Results from Coppens-Calculated Depths using Water Surface Temperatures and Average Salinity.

Thus, analyses of boater data would be possible under this same method. TND needs only the coordinates provided by a WAAS GPS, the depth, water surface temperature and the static draft of the vessel's depth transducer.

TND would maintain records of cell depths, organized by NOAA chart designations. Data would be purged on some appropriate schedule, depending upon the numbers of data points accumulated in each cell and how recently they were taken. Comparisons would be made between a boater's results and those already in the cell. A Mean of the boater's results and that of the cell would be averaged, with each mean weighted by the precision of the mean. One can show by maximum likelihood theory, assuming a Gaussian error distribution that the various means should be weighted by the inverses of their individual variances, and the standard error of this mean weighted by the same weighting factors. TND has written and tested an Iteration program that is easily compiled, creating a Windows executable Program (using, PowerBASIC a 32-bit Console Compiler for Windows,Version 2.00).

This accumulated weighted average minus the standard error of that mean would constitute the cell's published depth. This would provide a shoal bias to the published depths. Thus, TND would accumulate and disseminate accurate and precise depths in 10 m x 10 m, 20 m x 20 m, 40 m x 40 m, and 80 m x 80 m cells over regions no longer surveyed, or not recently surveyed by NOAA or the Corps of Engineers.

Proposed Prototype Device

General Specifications

The ideal hardware design would be an integrated *TND System*. The system would have a WAAS GPS and depth sounder with a CompactFlash removable data storage card. The system would contain circuitry and an algorithm to compress the data. The depth transducer assembly should include a temperature transducer. Thus, each sounding would have a corresponding water surface temperature. This temperature, along with salinity data derived from charts or download, would enable depth correction for the difference between the sounder calibration velocity and the actual velocity that sound travels in seawater at the water temperature.

When the technology permits, the system should replace the CompactFlash storage with a satellite transmitter, so that data is automatically sent to a satellite and back to the TND data acquisition and analysis center. Alternatively, the system could have components of a cellular transmitter; allowing data upload to a cellular system.

TND System Prototype

The *TND System* prototype consists of the following products being used as components. This system has been assembled and is being tested.

- The GARMIN GPS 17N for positioning. The GARMIN GPS 17N, designed primarily for use in marine applications. This pole-mount self-contained GPS sensor has an integrated antenna housed in a rugged, waterproof design. The 12-channel receiver allows for continuous tracking of all visible satellites. It is WAAS capable, with position accuracy of less than 3 meters on average.
  (See: http://www.garmin.com/products/gps17n/.)

Figure 21. The GARMIN GPS 17N

- An Airmar P66 SmartSensor unit is to be used for the depth sounding and temperature. It is self-contained unit that includes the sounder components, depth transducer, temperature sensor and electronic circuitry, all in one unit. The output is a NMEA string. The P66 is their latest transom mount unit, which allows for the easiest mounting on vessels. Airmar's SmartSensor has embedded in it a transceiver and digital signal processing circuitry. Digital depth and temperature are output on the established NMEA 0183 format. Custom communications protocols are available as an option. With the transceiver literally millimeters away from the transducer's piezoceramic element, depth sounding performance is enhanced, because there is no signal loss in the cable. Cable lengths of up to 100 meters are possible with no degradation. Since 200 kHz is used on

most sounders and fish finders, we shall use a SmartSensor operating at 235 kHz to eliminate mutual interference with fish finders or other onboard sounders. At high boat speeds, the water flowing off the hull strikes the transom mounted housing causing buffeting and flow noise. As the boat speed increases, the transducer's signal-to-noise ratio decreases until the echo sounder is unable to track the bottom. Airmar has a Noise Suppression System attenuates the sonic energy generated by buffeting which improves the signal-to-noise ratio. The P66 SmartSensor is able to track the bottom at higher speeds.
See: http://www.airmar.com/whatsnew/smartSensor.html.

Figure 22. The Airmar P66 Transom SmartSensor for Depth and Temperature

- An Oceanographic Embedded Systems UART 4 will allow NMEA strings from the sensors to be collected simultaneously. The UART 4 is a Four-Port Serial Interface for the Persistor CF-1 PERCF1C computer. The *UART 4* multiplexes NMEA-0183 data streams. It uses real-time buffer storage to handle simultaneous arrival of data on each channel without conflict.
  See: http://www.oes.to/uart4.html

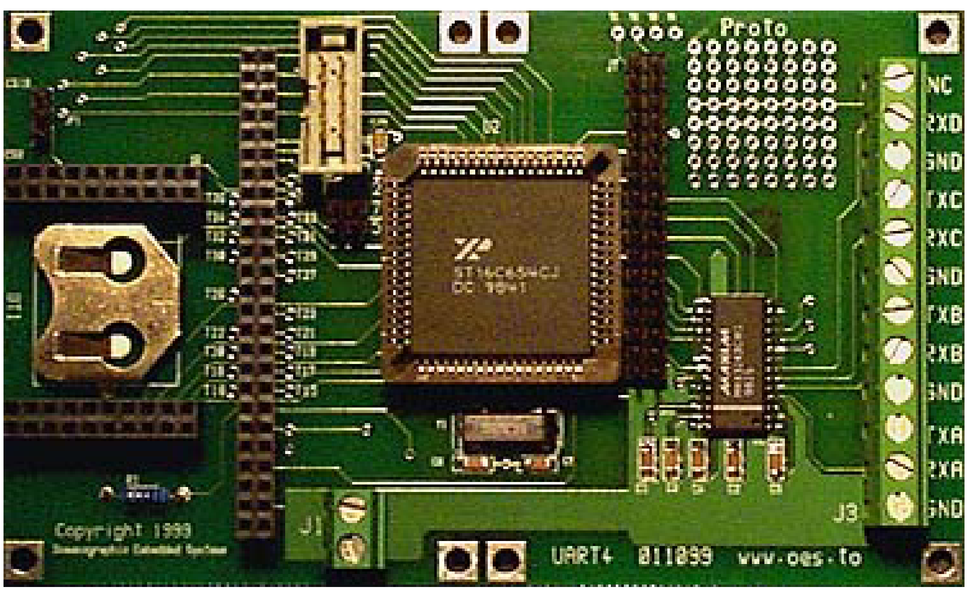

Figure 23. The UART 4 Multiplexer for NMEA Data

- The GARMIN GPS 17N, Airmar P66 SmartSensor, and the UART 4 will direct NMEA strings to a Persistor Instruments PERCF1C Single Board CF1 Computer for logging the data to a CompactFlash card.
  See: http://www.persistor.com/web/products.htm

Figure 24. The Complete TND Hardware, including Multiplexer Box, Garmin WAAS GPS, and Temperature and Depth transducers in One Airmar Unit

The TND prototype system has been assembled and successfully tested. Figure 25 shows the computer and multiplexer box, and the CompactFlash card is shown inserted in one end of the box. In one 8.5-hour data run of this system, 2.7 Mbytes of depth, position, and temperature data were recorded on the CompactFlash card. These data compressed to 191 Kbytes.

Figure 25. Assembled TND Prototype Multiplexer and Computer Showing CompactFlash Card

TND Quality Control and Data analysis

NOAA employs rigorous quality checking[10] of all sounding data that it collects for use on nautical charts. In addition to ensuring that data is acquired and corrected in a manner that minimizes systematic errors, NOAA performs rigorous post-processing analyses to ensure that all false bottom pings are properly removed. Even when using the best state of the art technology, false bottom pings, such as erroneous pings on fish, or spurious noise in the water caused by crossing another vessel's wake, are unavoidable when working in real-world at-sea conditions.

For example, a typical NOAA multi-beam survey of 2-3 billion soundings can easily have several hundred thousand erroneous depths that need to be removed before applying the data to an official NOAA chart. To accomplish proper removal of erroneous data, NOAA relies on a combination of automated removal techniques and intense manual scrutiny of the data by highly trained personnel who have developed a "hydrographer's eye" for visually identifying erroneous data. NOAA calls this process "data verification." This is done by comparing preliminary survey data to all existing correlating information (prior surveys, the current NOAA chart, Army Corps of Engineer surveys, USCG Local Notice to Mariners, Wreck and Obstruction Databases, etc.) for either corroboration or disproval.

TND recognizes that similar quality control of the raw data from recreational boaters is critically important. Fortunately, due to the extensive, previous NOAA hydrographic background of key TND executives, TND has strong practical experience in cleaning raw hydrographic data, correcting it to a processed form, and performing final verification. TND proposes a quality assurance process similar to NOAA's, using many of the identical tools that NOAA uses (most notably, *MapInfo* and *CARIS*) to verify our data against correlating information. In particular, we have access to copies of the latest NOAA charts, prior surveys, and NOAA's wreck and obstruction databases.

As previously discussed in this paper, NOAA has recently begun large-scale efforts to accept what it calls "third party" data, or data acquired by sources other than NOAA ships and NOAA contractors, and use it to update nautical charts. By performing a NOAA-style quality assurance process, TND ensures that NOAA will view TND's data as acceptable "third party" data.

Quality Control

TND quality control would limit the type of boat and operating conditions for data acceptance. Highest quality data would be from full-displacement or semi-displacement vessels. Data from planing vessels would be acceptable under certain operating conditions.

Vessel Static Draft

All data strings would provide depths to TND relative to the sounder transducer. Thus, TND would need accurate information on the depth of the transducer face below the waterline. In most cases this information would be derived from a measurement of the sounder transducer face below a fixed point on the vessel hull above waterline, followed by a measurement from waterline to this point. Alternatively, a lead line could be used to set the sounder offset, and the offset value would constitute the data needed by TND for waterline depths.

There is a statistical method for ascertaining the depth of the sounder transducer face below waterline. A series of depth measurements from the same boat over cells whose depths are known precisely by TND would allow this determination. These boater depth measurements

[10] E. Sipos and C. Parker, *NOAA AHB Quality Assurance Inspections for Contract Hydrographic Surveys*, (NOAA, 1999). Because of its importance and relevance, this paper is included here as Appendix A3.

would first be corrected for sound velocity and tide. By finding the mean difference between the TND cell depth and the mean of the vessel's below-transducer corrected depth for a number of cells of differing depth, a systematic error would appear between the vessel below-transducer corrected depth and the TND cell depths. That systematic error would constitute the distance between the sounder transducer and the waterline. This statistical method would serve as a quality control check against the direct measurements for those cases where direct measurements are provided of transducer offsets.

GPS Signals

The NMEA data from the system will provide WAAS status and number of satellites, as in 2-08, or 1-05, indicating respectively, WAAS differential corrections with eight satellites, or no WAAS corrections with five satellites. TND's quality control system will accept only those NMEA data for which this field has a value of 2-07 or higher (i.e. 2-12), with WAAS corrections. In addition, the Horizontal Dilution of Precision field (HDOP) must have values of 1.5 or lower. On a recent survey, the following data string was produced by TND's WAAS GPS and sounder devices:

03-10-01,125703,38.352567,-76.345458,6.91,2-10,0.9,044.0

These data were acquired on 10/03/2001 at 1257.03 UTC with coordinates of 38.342567 N and 76.345458 W. The SOG was 6.91, with WAAS, ten satellites, HDOP of 0.9, and depth of 44.0 feet below the transducer. Such signals as this would be recorded by the system. But

03-10-01,225401,38.590182,-76.404843,8.36,1-07,1.5,041

would be rejected. Even though there are seven satellites and the HDOP is 1.5T, there are no WAAS corrections (1-07); therefore, this data would be rejected. Obviously the string,

03-10-01,132608,38.395735,-76.350223,6.23,2-06,2.7,065.2

with only six satellites and an HDOP of 2.7 would be rejected, even though there are WAAS corrections.

Vessel Configuration and Operation

Full displacement or semi-displacement vessels offer the best and most stable sources for TND data. This would include most trawlers and essentially all single keel sailboats. Sailboats have the disadvantage that the orientation would provide acceptable data only when the vessel is under power. However, much of the desired data acquisition would be for narrow channels and marina approaches, where sailboats would operate under power.

Planing vessels offer special challenges. Data from such vessels should be limited to SOG/Length ratios of 0.20 or less. Thus, an 80-foot yacht moving at 16 knots would provide acceptable data, whereas a 24-foot fishing boat must be traveling at 5 knots or less. For smaller craft, loading also becomes a far more serious concern.

The displacement of a vessel is proportional to the cube of its draft. Suppose that the draft increase due to loading is required not to change by more than 2 inches; then, for a typical 4-foot draft vessel, the load cannot exceed 13% of the GW. For a 52,000-pound vessel, this would limit the load to 6,760 pounds. Variations in fuel, water and passengers from zero to maximum on this vessel would not provide load changes in excess of 6,000 pounds (Based on TND's Vessel's actual configuration). Therefore, the load factor may be ignored.

SOG

SOG is only important as it relates to planning. A planning vessel must be on plane to assure proper angle with respect to the sea floor. This will occur most dependably for low SOG values. For planning vessels of 40 feet or greater in length, depth data can be restricted to low ranges of less than 8 knots or high speeds of greater than 20 knots. Mostly the vessels producing TND data will be non-planning vessels that are displacement or semi-displacement. Of course, the lower the SOG, the greater the number of vessel soundings in a particular cell.

Data Analysis

When TND receives CompactFlash cards from vessels, the data is uploaded into a computer for analyses using TND's proprietary software. After corrections have been made for sound velocity and tides, the resulting data is synthesized by means of commercial hydrographic processing software (MapInfo, CARIS, ISS 2000, HYPACK).

The depth system measures and records both depths and water surface temperatures. Average values of salinity can be derived from either Buoys or published charts or tables of average salinities by date, month or season. We have shown that errors in Coppens-calculated depths, introduced by using water surface temperatures and average salinity, are quite negligible. Sound velocity corrections with the Coppens Equation will therefore use water surface temperatures and average salinities.

The resulting set of data is matched with existing data in TND cells of variable size ranging from 10 m x 10 m to 80 m x 80 m size, by referencing the *northing* and *easting* coordinates of latitude and longitude measurements from the WAAS GPS. TND cells are identified by their corner *northing* and *easting* coordinates and their corresponding values of latitude and longitude (WGS 84). Coordination with existing charts is therefore routine.

TND data cells contain depth data from accumulated recreational boater "surveys." When a vessel contributes data to this cell, the new cell mean and new standard error of that mean are determined. When data in the cell reach a certain age, they are discarded. This assures the most up-to-date depth data in all cells.

Full Process Pilot Test

Having conducted a successful proof of concept test, TND is now preparing to carry out a full process pilot test. The proof of concept test used only one vessel and used a collection of separate devices that did not measure water surface temperature. With only one vessel, the statistical methods could not be applied for multiple cell crossings by multiple vessels. Several other features of the concept also remain untested, including *calibration cells*, variable cell size, inferred tidal zoning, and uncharted shoal identification.

Test Region, Vessels, and Harbors

For this full process pilot test, the Chesapeake Bay has the advantage that tidal zoning is well known, there are several established tide stations, salinity data is available, and the region is accessible to TND for support of the hardware used by the vessels.

Test Region: The Chesapeake Bay

The Chesapeake Bay is about 200 statute miles long, stretching from Havre de Grace, MD to Norfolk, VA. The Bay's width ranges from 3.4 statute miles near Aberdeen, MD to 35 statute miles near the mouth of the Potomac River. The square footage (surface area) of the Bay and its tidal tributaries is 200 billion square feet (or around 7,000 square miles). Taking only the Bay, itself, without including the tidal tributaries, the surface area is 3237 square miles (2440 square nautical miles).

As shown in Figure 26, survey areas deemed critical by NOAA, covering the Chesapeake Bay, the Delaware Bay, and the coastal regions between these bays remains largely unsurveyed (More than 90% of areas of the NOAA-designated critical areas are unsurveyed). The task, and costs involved, are simply too great. With NOAA's very limited budget, and the irreducible costs of conducting conventional hydrographic surveys, NOAA will never be able to survey these critical areas, unless it relies on a new or different technology, or could utilize third-party data, as proposed here.

The main channel of the Chesapeake Bay ranges from several miles wide in deeper sections, to as narrow as a few hundred feet wide in the northern sections. Recreational boaters often avoid the main channel in favor of the 15 to 30 ft shoal sections on either side of that channel. These shoal components of the Bay constitute an average of about two and one-half nautical miles on each side of the main channel, for a surface area of about 500 square nautical miles. NOAA does not survey these areas at all. If we include those tributary sections that contain most marinas and anchorages, this adds another 200 or so square nautical miles.

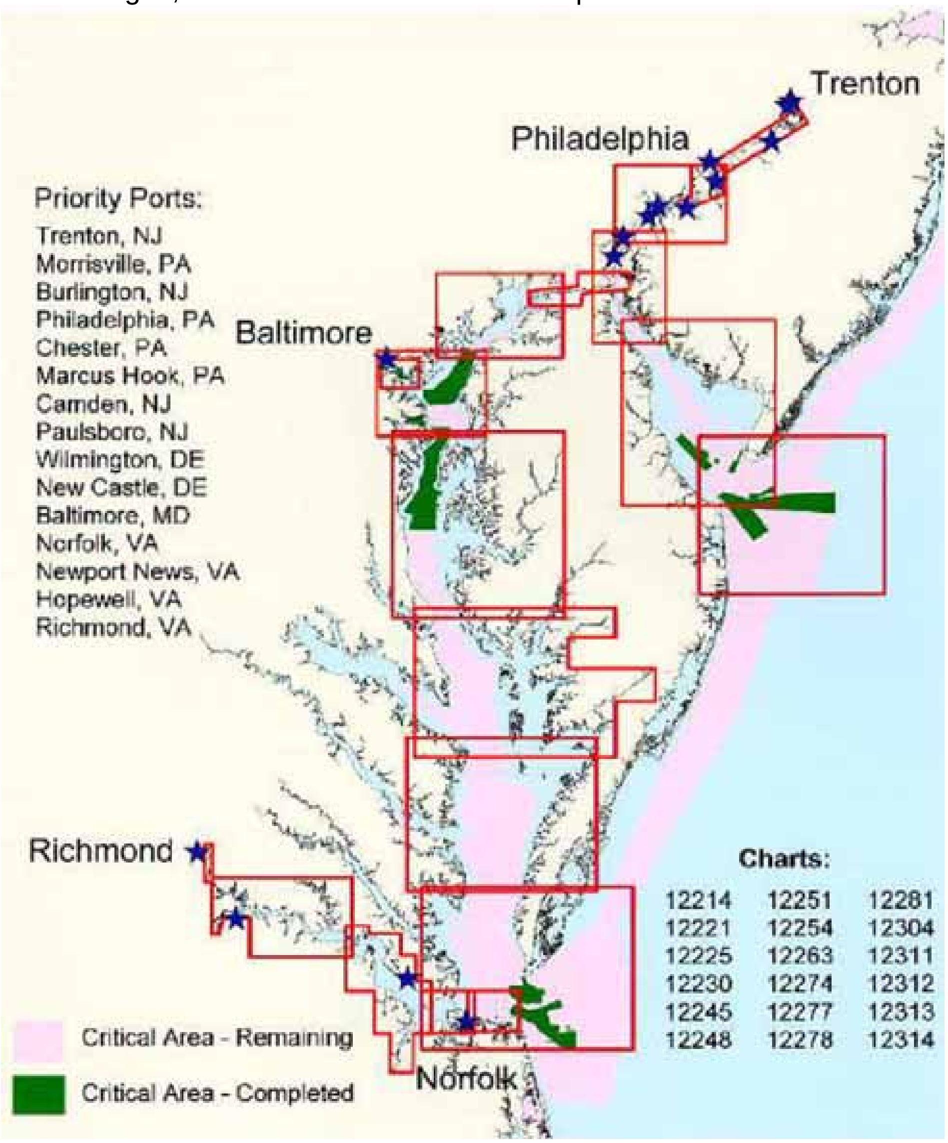

Figure 26. The Chesapeake Bay, showing the paucity of completed surveys of critical areas

The recreational boater could therefore survey about 700 of the 2440 square nautical miles of the Chesapeake Bay and its tributaries not surveyed by NOAA. Thus, in addition to the 1740 square nautical miles deemed critical by NOAA (but for which less than 10% has been surveyed), recreational boater surveys could cover the entire 2440 square nautical miles of the Bay. Since depth gradients will produce cell sizes of 10 m by 10 m all the way up to 80 m x 80 m, we assume an average cell size of 40 m by 40 m. In each square nautical mile of surface, one can create 2144 cells of 40 meters by 40 meters. Thus, there are some 5,231,000 of these cells crossed regularly by recreational boaters on the Chesapeake Bay.

Vessels Needed

The typical recreational boater will cruise the Chesapeake Bay an average of 50 days/year, for an average of six hours/day. This could provide 300 hours/year of data for each boater. Since the TND system takes depth data once each second, there would be 1,080,000 soundings per year per vessel. A vessel with an average SOG of 8 knots is within a given average-sized cell of 40 m x 40 m for 8 seconds. That vessel will therefore provide depth data of eight soundings each for 135,000 cells/year. If the vessels moved randomly over the 5,231,000 cells of the Bay, full process pilot test would need only 39 vessels to get an average of eight soundings/cell for the entire Bay. However, the cruising patterns will not be random, and, therefore, it is proposed that the number of vessels be made more than twice as great, 100 vessels. This will give an average of 21 soundings per 40 m x 40 m cell, and should expand coverage to include most regions of the Bay. It also assures that in regions of high gradient, where the cell size reduces to 10 m x 10 m, or even 5 m by 5 m, there is a reasonable probability of soundings.

Harbors and Marinas to be Used

Three harbors involving four marinas will be utilized, providing extensive data on those harbors and approaches. TND will select 25 boats from Herrington Harbor South, 25 from Herrington Harbor North, 25 from Solomons, and 25 from Annapolis. Solomons and Annapolis both have established tide stations. Herrington Harbor Marinas form one of the largest marinas on the East coast. Boaters often stay on their boats for several days to a week, without cruising, often to do maintenance or just to relax. Therefore, not only will the vessels selected take depth data while cruising, they will also periodically take depth data over two days to a week at a time, while stationary in their slips. The latter data will provide huge amounts of tidal zoning depths for the location of that marina.

For example, if 10 vessels, all in the same marina, provide simultaneous stationary depth data for several days to a week, and this is done periodically over several months, the appropriately averaged results would provide strong evidence on the phase and amplitude factor from the nearest harmonic tide station.

Figure 27. Herrington Harbor, South with 620 slips

Figure 28. Herrington Harbor North with 654 Slips with extensive boatyard facilities

Solomons, MD, is one of the largest yachting centers on the East Coast, with eleven different boatyards and marinas. Annapolis is, of course, one of the premier yachting centers in the United States. It has dozens of marinas and boating facilities. It also has the best tidal data on the East coast.

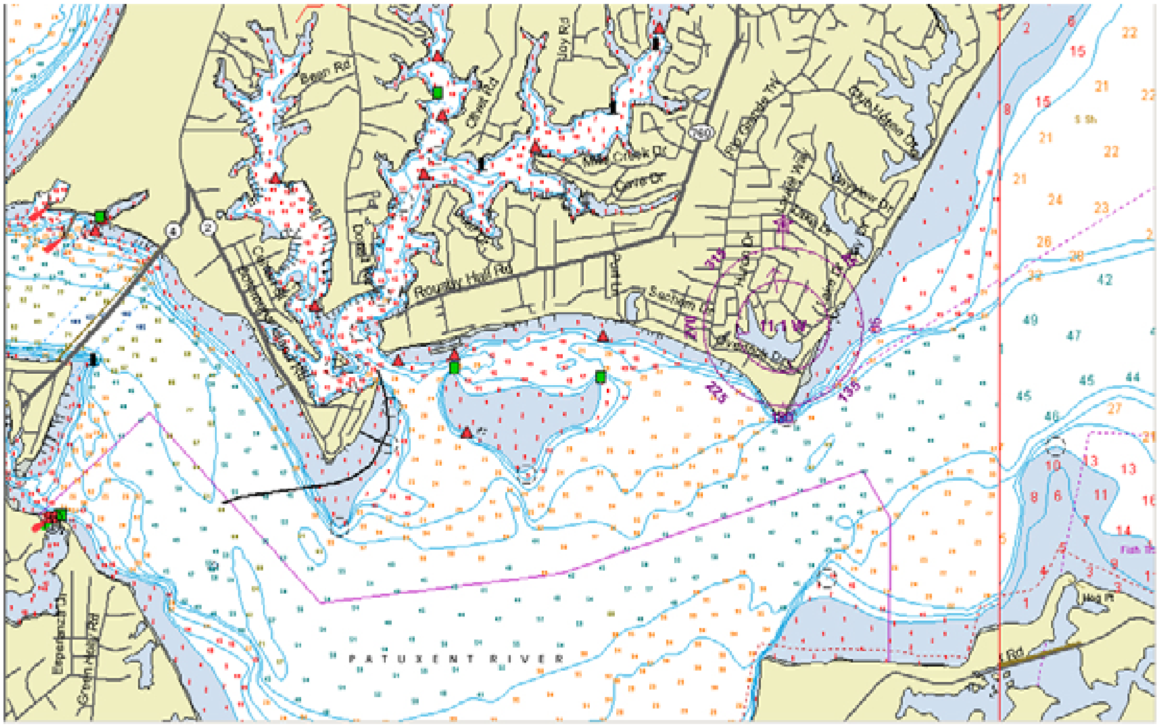

Figure 29. Patuxent River Entrance and Solomons, MD

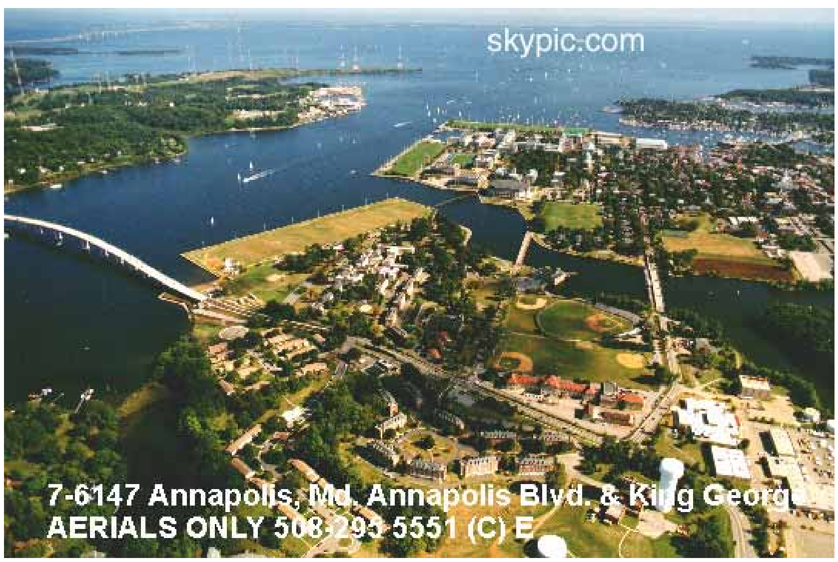

Figure 30. Annapolis approach and harbors

Vessel Selection

Selecting 25 vessels from each of these four marina locations will provide the best choice for a large-scale test of the TND approach. Vessels will be selected on the basis of length, of displacement/planning, sail/power, with a minimum length of 30 feet. Sufficient variety of boat types will assure the ability to make comparisons and carry out statistical analyses.

TND will purchase and install the TND Phase II prototype system on each of these 100 vessels. We will provide support to the boaters participating

Simultaneous Data Acquisition

If Interference problems associated with sounder frequency and sounder location can be resolved, TND is proposing to utilize an SAIC Hydrographic Vessel to collect data with the TND system along side standard depth data collection being carried out as part of SAIC's assignments. Additionally, TND is proposing that at least one NOAA Hydrographic vessel use a TND system side-by-side with its survey equipment.

This side-by-side collection of data offers a superb mechanism for validating the TND System against depth data acquired simultaneously that fully meets NOAA standards and specifications.

Through this test process, all of the features of the TND Approach can be tested. The various statistical methods, the use of calibration cells, the collection, quality control, analyses, syntheses and dissemination of depth data, all can be systematically tested.

Costs and Funding

Costs are mainly for purchasing instruments, installing them, and supporting the 100 participating vessels in the test.

Needed Funding

For TND to carry out this phase, funds are needed for purchasing components for the 100 vessels, assembling those components into systems, purchasing the necessary flash memory cards, identifying vessels, installing the TND Systems on the vessels, and carrying out quality control, analyses, and syntheses of data as it accumulates from boaters. In addition, boaters may need occasional support.

The hardware costs, including installation and memory cards, would be no more than $1,000/vessel, for a total of approximately $100,000. Staff support would require at least one full-time person for QA and analyses. Another half to full-time person would be needed for synthesis, boater support and dissemination. It would be preferable to have that second person on a full-time basis. A third person is needed for statistical analyses, preliminary coding, and similar technical work. This 0.5 FTE will be provided without cost to the project. Staff costs to carry out this phase over a one-year period would therefore be no less than $100,000 for 1.5 FTE persons, to $130,000 for 2.0 FTE persons. Other costs would include communications and travel, plus computer and office expenses totaling another $20,000 for the year. Thus, as a rough estimate, this project phase will cost some $220,000 to $250,000. TND would charge no indirect costs; nor would TND earn or charge for a profit.

Costs could be reduced by using only 39 vessels, which, with random cruising patterns, would provide full cell coverage on the Bay in one year. This would reduce the project costs to about $190,000. However, as discussed previously, this reduction would seriously limit coverage of depth data derived from the test, since cruising patterns are not likely to be random.

Value of Depth Data from Full Process Pilot Test

The proof of concept test showed that it is feasible to generate high-quality chart data using recreational vessels. The second phase test involving 100 Chesapeake Bay vessels will determine actual coverage, soundings per cell, and the efficacy of the statistical methods utilized.

The value of the TND data generated by this test can be comparatively estimated against what it costs NOAA to perform its own hydrographic surveys in support of nautical charting. In FY 2000, NOAA spent $18.9 million for contractors to survey 550 square nautical miles. In that same year NOAA spent $12.5 million for its own ships to survey 1100 square nautical miles.

Thus, NOAA had an expenditure of $31.4 million to acquire new chart data for 1650 square nautical miles. The extrapolation would suggest an average survey cost of $19,000/square nautical mile. With 2144 cells of 40 m by 40 m in each square nautical mile, this translates into a NOAA survey cost of $8.86 per 40 m by 40 m cell. NOAA's surveys cost $19,000/square nautical mile because they search for every one-meter cube object on the sea floor (using side scan sonar). This thorough sweep of the sea floor guarantees that ALL obstructions and hazards and been found ... i.e., every single needle in the haystack. Finding these"needles" is of incalculable value to mariners

There is no easy way to separate NOAA's "bottom depth cost" from the "finding the obstruction cost" and then compare TND's "bottom depth cost" to NOAA's "bottom depth cost". If we could do this, TND data would be a huge bargain, One hundred participating vessels in this pilot test would, in a random cruising pattern, produce an average of 21 soundings per cell for the 5,231,000 cells (2440 square nautical miles) of the Chesapeake Bay. Some 93% of the cells contain no point features, and, as established in TND's proof-of-concept survey, the mean TND depth is equivalent to the NOAA-surveyed depth.

At NOAA survey rates of $19,000 per square nautical mile, this same 2440 square nautical mile survey would cost NOAA $46 million. Assume that the point-feature component of the survey would account for two-thirds of the total cost. The full process pilot test, costing $250,000, will therefore produce depth data having a nominal value of $15 million. The depth data may even produce indications of heretofore-uncharted point objects or shoals, for which NOAA can target side scan and multibeam surveys. If these targeted survey costs were half of the $15 million, TND depth data would still have a value of some $7.5 million.

Should NOAA fund this full process pilot test, NOAA will receive high quality and recent depth survey data for the full Chesapeake Bay at four percent of the normal survey costs for these depth components.

Alternative Pilot Test

As an alternative to equipping and using 40 to100 recreational vessels on the Chesapeake Bay for the full process pilot test, vessels from NOAA, the Army Corps of Engineers, the U.S. Coast Guard, as well as university research vessels and commercial ships, barges and ferryboats could be utilized. This alternative would not provide coverage of the Chesapeake Bay, but, instead would provide high-density coverage of widely dispersed areas on both Coasts. Ferryboats from Alaska to San Diego, and from Maine to North Carolina, including the Staten Island Ferry, could participate. NOAA and NOAA-Contract vessels could do simultaneous data collection, which would be of very high density, and would provide superb situations for comparing the TND results to the most recent survey results. The latter would also fully validate the SV methodology used. University research vessels would have great interest, not only in depth soundings, but also in the water surface temperature data. Thus, TND could supply the research labs with all of the temperature data from all regions used by participating vessels, in addition to what the research vessels themselves produce, a strong incentive for the research vessels to participate.

Ferryboats offer some of the most interesting opportunities. A typical ferryboat follows a fixed route, several times per day, and remains in a fixed, loading position for long periods at each terminus. This kind of repetitive and fixed route cruising pattern is ideal for establishing precise tidal zoning data.

Time Line and Next Steps

Testing of the latest prototype has been successfully completed. The full process pilot test could begin as early as late Spring 2002. This phase could be completed by the end of 2002. Subsequently full implementation could begin.

Full Implementation

Full Implementation of the TND system could begin as early as the Summer of 2003. It could begin with vessels on the Chesapeake Bay and vessels that traverse the Atlantic ICW. It could also include vessels from NOAA, the Coast Guard, the Corps of Engineers, as well as those from commercial fishing boats, cargo vessels, barges and ferryboats.

The 1997 NMMA statistics show how many boats were registered in Chesapeake Bay states: MD: 189,000, VA: 229,000, for 418,000 boats. At least half, or 209,000 of these boats, have both GPS and depth sounders, and are taking valuable depth data that is being discarded. If 1.0% (one percent) of these boats were to record GPS WAAS position, water surface temperature and depth data, there would be 2,090 vessels collecting and recording depth data on the Chesapeake Bay for TND. When 10% of the 3,000-4,000 cruising vessels traversing the Bay from points north on their annual movement down the ICW, an additional 350 vessels would be involved (10% is justified for these more dedicated cruising boats). These 2,440 boats will spend an average of 50 days/year cruising on the bay. Some long-range cruising vessels stay longer and cruise the bay for as many as 70 days/year.

With an average of 50 days/year, and 6 hours/day, each participating vessel would provide 300 hours/year of depth, surface water temperature and position data. This would be 732,000 vessel-hours/year of survey data on the Chesapeake Bay for the 2,440 participating vessels. Since the TND system takes depth data once each second, there would be 2,635,200,000 soundings taken per year. This translates into an average of 504 soundings for each of the 5,231,000 cells. Soundings per cell would range from eight per cell for 10 m x 10 m cells in regions of high gradient, to as many as 2,000 soundings per 80 m x 80 m cell (regions of no gradient). Harbor entrances, narrow channels and canals would have 10 m x 10 m cells and have a high density of soundings.

Value of TerraNautical's Depth Data

For one survey of the 3.2 million square miles in NOAA's mandated coverage area, it would it would therefore cost more than ***$60 billion.*** Just for one survey of the remaining 1650 nautical square miles NOAA-deemed critical areas of the Chesapeake Bay, NOAA would need to spend its entire $31 million annual survey budget, and ignore the millions of other square miles in its mandated coverage areas.

Another way to measure the value of TND's depth data is to consider costs of vessel groundings that will be avoided due to better charts. Even though TND depth data will be acquired by recreational vessels, it will also benefit commercial vessels that transit shoal waters close to shore. The 1992 grounding of the Queen Elizabeth II (QE2) in Martha's Vineyard highlights the enormous costs of a commercial vessel grounding in such an area. The QE2, with a draft of 32 feet, traveled over an area where the nautical chart produced by NOAA showed a depth of 39 feet. However, uncharted rocks ripped a hole through the ship's hull, causing over $60 million in damage and lost revenues. In addition, damages to recreational vessels due to groundings exceeded $2.9 million in 1999 alone. TND's approach can provide an enormous volume of new chart data in a relatively short time and will assist greatly in finding previously uncharted shoals. This will dramatically lessen the likelihood of vessel groundings due to inadequate chart data.

The Atlantic Intracoastal Waterway: Norfolk, VA to Key Largo, FL

Some 10,000 vessels go down and back up the ICW each year. These vessels are much larger and far more likely to participate in the TND depth data-recording project. Some come from as far as Canada and go as far as Key West. From Norfolk to Key Largo, the ICW has a 12 ft project depth and an average 164-foot width (50 meters), and is 1143 statute miles long (993.9 nm, 1,839,480 meters). Each vessel going down the ICW takes data at one depth/second. The vessels travel at an average speed of 8 knots. So each vessel will take 993.9 nm/8knots = 124.24 hours of data. That is, each vessel will take 447,264 soundings during the 124.24 hours of travel down just the 993.9 nm of the ICW from Norfolk to Key Largo. If we had only 10% of the 10,000 vessels traversing the ICW annually, or 1,000 vessels, we would have 447,264,000 soundings each way.

Because the ICW is narrow and has canals and cuts, an average 40-meter by 40-meter cell size is too large. Instead, we shall use an average cell size of 10 meters by 10 meters (scale of about 1:1000). The ICW from Norfolk to Key Largo is 1,839,480 meters long and 50 meters wide. This part of the ICW therefore has an area of 91,974,000 square meters. Each average cell has a surface area of 100 square meters. Thus, from Norfolk to Key Largo on the ICW, there are 919,740 cells 10 meters on edge. With 447,264,000 soundings each way, the recreational boater will record some 486 soundings per cell. Since these vessels make a round-trip annually, there would be a total of 894,528,000 soundings per year, and 972 soundings per 10 m by 10 m cell.

According to the Corps of Engineers Hydrographic Survey Cost Manual, daily costs for a survey vessel in the 40- to 65-ft-long range can run between $1,500 and $5,000 per day (1999 dollars). Smaller launches (18 ft to 26 ft) are far less--typically $300 to $1,000 per day. Labor costs for survey crew personnel usually range between $500 and $2,000 per day, depending on number of party members, complexity of equipment operated, and geographical area. Thus, a fully automated hydrographic survey team can cost between $800 and $7,000 per day to field. The cost for a Corps of Engineers survey, based upon the NOAA costs, $3.81 per 20 meter by 20-meter cell, would be $0.9525 per 10 meter by 10-meter cell.

For 919,740 cells, this would have a value of $878,000. Furthermore, since TND would have an average of 972 soundings per cell, this exceeds the 673 soundings per 10 m by 10 m cell by a multibeam system. For a very long and narrow channel, like the ICW, the contractor cost would undoubtedly exceed the $3.81 rate, which is established for more rectangular regions where criss-crossing patterns are possible.

Value of Depth Data From Full Implementation

For depth data derived only from the Chesapeake Bay and the Atlantic ICW (from Norfolk, VA to Key Largo, FL), the annual “wholesale” value of the depth data to NOAA and the Corps of Engineers is not less than $3 million annually (10% of an actual survey cost).

The ICW includes several other waterways, and on the Gulf of Mexico, extends all the way to Mexico. In addition, the coastal regions of the Pacific are traveled extensively from San Diego to Alaska, providing vast amounts of additional recreational boater depth data. These sources add another $3-$4 million annually to TND depth data value.

With very small percentages of recreational boaters participating in automatic depth and position data collection with TND systems, and sending in CompactFlash memory cards quarterly, TND would process and have available data having a value of some $6-$10 million/year. Added data from government, university labs, and commercial vessels would increase this value even more.

Water surface temperature data, incidental to determining sound velocity, has its own independent value. Such temperature data could be disseminated to environmental quality, weather, climate and fishery research groups, and it may turn out to be almost as valuable as the depth data.