US Office of Coast Survey's Re-Engineered Process for Application of Hydrographic Survey Data to NOAA Charts

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Abstract

In 1995 NOAA's Office of Coast Survey began acquiring hydrographic data using multibeam technology. The improved acquisition systems and subsequent development of superior post acquisition processing methods vastly increased the quantity and quality of data delivered to the processing branches. Using traditional tools and processes to create the conventional products from this flood of new data resulted in a bottleneck at the already over-burdened processing branches. Moreover, much of the potential for utilization of the additional information associated with the new data, in navigational as well as other uses, was unrealized using customary tools.

In 2002, now solidly faced with these realities and motivated by a determination to enhance ENC development, design began on the CARIS-based H-Cell process. In a major departure from NOS' current practice of vectorizing raster charts to create ENC's, the H-Cell was designed to apply new survey data directly to an ENC cell. While H-Cells will also be used to compile the raster and paper products, the H-Cell was engineered primarily with the ENC in mind.

The original H-Cell concept has been expanded now, from use of Pydro, CARIS HIPS, Field Sheet Editor and HOM, to include CARIS Notebook for management of S-57 features information, and CARIS BASE surfaces for creation of bathymetric models. This enhanced H-Cell deliverable is designed to streamline hydrographic data processing from post-acquisition to chart application, yield highly accurate S-57 compliant ENC's, and integrate with the future hydrographic database.

H-Cells are now being produced at both Atlantic and Pacific Hydrographic Branches, and the Office of Cost Survey's Marine Charting Division is in the process of integrating the first H-Cells into their ENC, raster and paper chart production pipelines. Office of Coast Survey continues to look to the future for opportunities to engineer further efficiencies into hydrographic data management and the processes for developing products for navigation, charting and other uses.

INTRODUCTION

An innovative new GIS and object oriented method for processing hydrographic data for application to the chart is replacing the traditional CAD-based drawing method. The ENC is the new driving force behind this change in procedure and methodology, where highly accurate bathymetric and feature information feeds a pipeline directly to the ENC, and from which the raster chart may be derived, as well.

NOAA's Office of Coast Surveys, Hydrographic Surveys Division (HSD), in conjunction with Marine Charting Division (MCD), have evolved this new charting process with the ultimate aim of reducing ping-to-chart time, increasing efficiency, and taking greater advantage of the enumerable options current technologies allow.

The newer, very large datasets common to current hydrographic data collection necessitated a change in thinking regarding management and display of this data. Sounding data historically displayed as discreet depths are now used in the creation of continuous depth surfaces. Bathymetry surface models are created using statistical algorithms which weight horizontal and vertical uncertainty with the sounding value. This new processing product, the Bathymetry Associated with Statistical Error (BASE) surface, allows management of greater quantities of bathymetric information.

The Office of Coast Survey's prioritization of ENC over raster chart production compelled new philosophies in management of feature information as well. The inefficiencies and inaccuracies inherent with adding attribution at the end of the pipeline guided OCS's first attempts at adding S-57 attribution in the field. Now CARIS Notebook is being introduced for S-57 attribution of new feature information and management of S-57 attributed source data right in the field.

CARIS HOM is used to bring together the depth values selected from a scale-appropriate surface model and the S-57 attributed features information into one central mapping environment. This is where the H-Cell is created, yielding an S-57 data set base cell file which imports directly into the software application used by NOAA's Marine Charting Division for creation of ENC's. Conversion of this S-57 file to CAD populates the raster production pipeline.

One of the mandates of the Office of Coast Survey in developing these new processes was to use a single production pipeline for the new ping-to-chart model. The CARIS suite of software for hydrographic data processing and chart production was selected and is now used in three parts of the four part process:

1. **Bathymetry**: Managed using CARIS HIPS/SIPS and Field Sheet Editor. Pydro, a NOAA developed application, is also used for certain aspects.

2. **Features**: Managed using a NOAA developed application, Pydro, in conjunction with CARIS Notebook;

3. **H-Cell**: Bathymetry and features are brought together and the H-Cell created in CARIS HOM;

4. **Application to Chart**: An ENC creation software package, LAMPS, is used to import the H-Cell base cell file and update or create a new ENC from the H-Cell. MicroStation is used to update the raster chart.
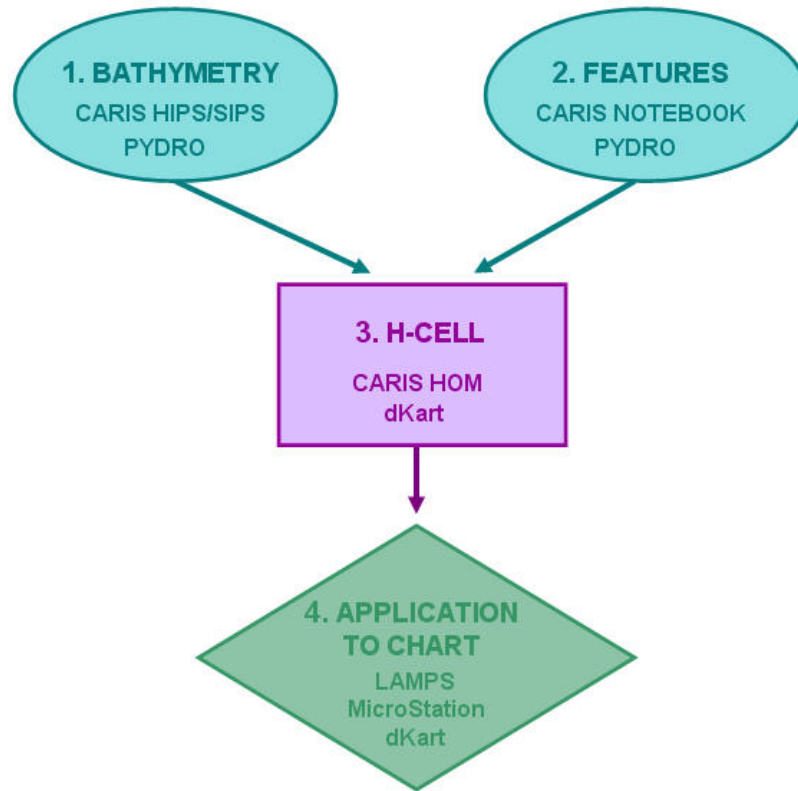
1. BATHYMETRY

The Office of Coast Survey's new processing pipeline utilizes BASE (Bathymetry Associated with Statistical Error) surfaces, created in CARIS HIPS, to synthesize hydrographic sounding data. The BASE surface represents the archived hydrographic survey product. A generalized form of the BASE surface, the Product Surface, is the source for the creation of navigational features such as contours, soundings, depth layers, and designated depths. These navigation features are used to populate the H-Cell.

Pydro, a hydrographic data management tool devised by the Office of Coast Survey's Development Lab, is used in the field and during branch processing to assimilate and correlate bathymetric data with side scan sonar features. It is also used to select significant feature depths and flag the data points as "designated", a label used by CARIS HIPS indicating that the feature will be incorporated within the BASE surface model.

Creation of the BASE Surface
BASE surfaces derived from a fully corrected data set are produced by the field unit after erroneous depth and navigation data points have been cleaned or rejected, and all static offsets and correctors have been applied. Verification and processing of the field unit's survey data includes application of final tidal zoning and approved water levels, if available, verification of the CARIS HIPS Vessel File (*.hvf), verification of all features discussed in the Descriptive Report that have depth values associated with them, review of the full density data set, including accepted and rejected data points for all features, and flagging of the designated status of all significant feature least depths.

The deliverable from the field unit to the processing branch is a single field sheet containing numerous BASE surfaces at different resolutions. In order to maintain the most accurate portrayal of the seafloor, different depth ranges are suggested for the varying surface resolutions. Generally, the shoaler areas are gridded at higher resolutions in order to portray the seafloor details, while the deeper areas are gridded using a lower resolution. Ideally, a BASE surface is created for the entire area from each of the different resolutions. The suggested resolutions and depth ranges for all NOAA survey platforms are listed below:

0.5-meter resolution → 0-15 meters depth
1.0-meter resolution → 14.5-30 meters depth
2.0-meter resolution → 29.5-60 meters depth
5.0-meter resolution → 59.5 meters & deeper

The field unit's choice of the highest resolution may not be feasible during processing branch generation of BASE surfaces. The degree of resolution depends upon the complexity of the seafloor and amount of echo sounder or sonar coverage. The branch processor may choose to deviate from OCS's standard processing guidelines and reduce the highest resolution from 0.5 meter to 1 meter or more. The reduction of resolution will not significantly alter the surface configuration or accuracy for chart scale products. The advantage of generating a surface of the highest resolution possible is that the BASE surface may be used for object detection and a variety of other uses, such as habitat mapping and geological studies.

The Finalized Surface
The BASE surface is considered Finalized when two important functions are fulfilled: First, only those nodes within a depth range are gridded, resulting in data that are within the resolution specified in the survey work order. The second important purpose incorporates the designated data points within the surface model. The "Designated" status forces the software to include the data point during surface generation, ensuring that designated data points representing the cultural or bathymetric features are reflected within the surface model.

The Combined Surface
CARIS HIPS is then used to combine all of the depth-binned Finalized BASE surfaces into one surface model comprising the entire survey area. The Combined Surface is generated using the coarsest resolution of all of the BASE surfaces. For example, if depth ranges of 0 - 15 meters, 14.5 - 30 meters and 29.5 - 60 meters were generated, the resolution for 29.5 - 60 meters (2.0 meter) will be used for the entire Combined Surface. The assembly of the BASE surfaces and the application of approved tide correctors must be accomplished at the processing branch before a survey is certified for the development of charting products.

The Product Surface
A generalized form of the Combined Surface, the Product Surface, is created with user-specified settings. Contours and soundings are drawn from the Product Surface for inclusion in the H-Cell. The surface is downsampled to some degree, using a shoal bias, sacrificing some of the finer details while preserving shoals and least depths. There are four settings for Product Surface creation that can be altered by the Cartographer to achieve the desired result:

- Target scale, for instance, survey scale or chart scale
- Radius of the sphere used to perform 3D double-buffering
- Cell size; resolution of the downsampled grid
- Defocusing radius; horizontal uncertainty estimate

The 3D double-buffering radius may be adjusted based upon the complexity of the seafloor, while the resolution typically remains the same as the Combined Surface. The standard radius is 1/100 of the map scale, and the cell resolution default value is 0.5 mm at the selected map scale (e.g. 100 m buffer radius, 5 m resolution for 1:10,000 scale). If necessitated by instrument error or other factors, horizontal defocusing is used. Depth values can be dispersed over a specified radius, depending upon horizontal positioning quality.
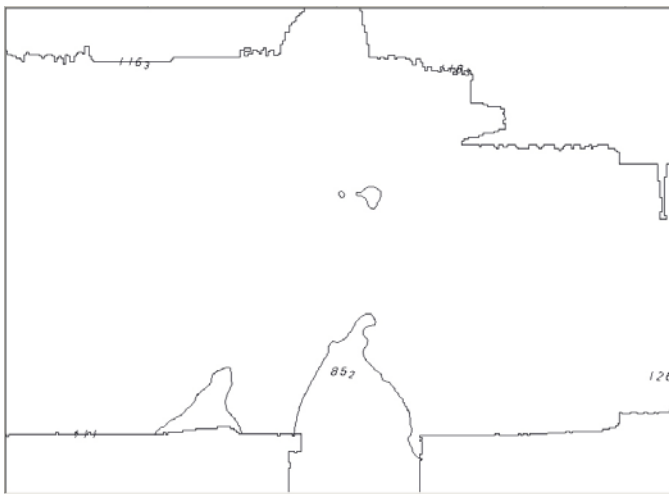
Contours are created in Field Sheet Editor, using a contour depth list appropriate for the navigational product. At this time, a fairly full set of contours are created in the event that additional contours are needed during chart compilation.

Soundings are selected from the Product Surface using a 5 mm radius shoal-biased routine. The sounding set is then used by the Cartographer in the H-Cell environment for verification and evaluation of survey hydrography and the generation of S-57 SOUNDG (sounding) features. Examples of different scale settings on sounding selection are shown in Figures 1a and 1b.

Further reduction in the density of soundings, and control of the distribution of soundings throughout the survey area to emulate that of the raster chart, is accomplished in CARIS HOM using a sounding suppression utility.
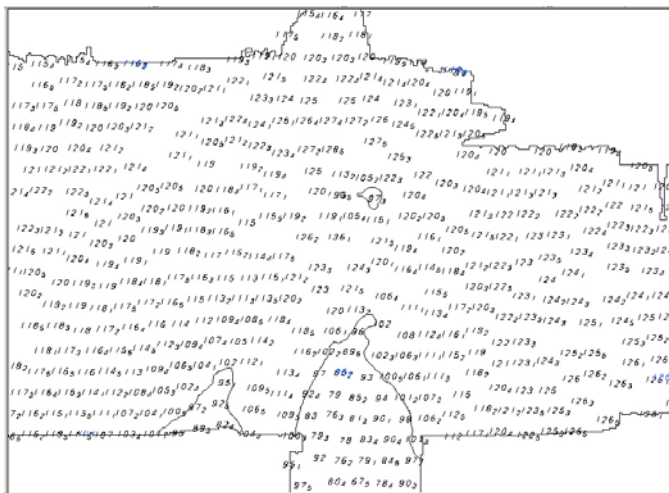
Figure 1a: Survey scale sounding selection, 1:40,000.

Figure 1b: Chart scale sounding selection, 1: 458,596.

Once contours have been created and soundings selected, the Field Sheet Editor processing is complete. For HOM processing three prime product layers, or themes, have been generated:

- The contour layer with the perimeter
- The sounding selection layers for survey scale
- Optionally, sounding selection layers for the largest scale chart

These layers may be copied into an existing CARIS HOM map, or may be used as the basis for the H-Cell in CARIS HOM.

2. FEATURES

Field units acquire and process bathymetric features data using a variety of commercial software packages. All significant hydrographic features are processed with Pydro, an OCS proprietary software package. Pydro is a special purpose Geographic Information System (GIS) program developed by the Office of Coast Survey's Development Laboratory using an object-oriented language. It is used for feature correlation and for encoding using the International Hydrographic Organization (IHO) standard for attribution, S-57, the transfer standard for digital hydrographic data. Pydro also provides nautical charting quality control and assurance functions. As a function of the new process, the responsibility for S-57 encoding falls to the Hydrographer, to be accomplished during field operations and included with the deliverables to the processing branch.

NOAA Ship Fairweather's Shoreline Processing Pilot Project
CARIS Notebook has recently been incorporated into OCS's data management pipeline alongside Pydro, on an experimental basis. Notebook is a pre and post-acquisition shoreline editing tool that allows the Hydrographer to manage geo-referenced hydrographic object data in the field. The use of Notebook will facilitate feature attribution in S-57, from collection through incorporation into the H-Cell. It is currently in the pilot project phase aboard the NOAA Ship Fairweather. The Fairweather began using the program upon re-activation, mid-field season, 2004, and is currently continuing development of the data workflow. The methods for processing are still evolving, and will continue to do so, as necessary updates are identified and eventually incorporated into the software. Many aspects of Notebook's evolution thus far, as well as capabilities that will be needed for future updates, are significant to H-Cell production. The ultimate goal of including Notebook in the data processing pipeline is to streamline the creation of a field deliverable that is a foundation for the H-Cell. For a thorough discussion of CARIS Notebook processing procedures, refer to *"Using CARIS Notebook to Streamline NOAA's Hydrographic Survey Processing" (VanSant/ Morgan, 2005).*

In the idealized workflow, field personnel work in Notebook using background reference data from various sources available for the project area. These often include shoreline ESRI Shapefiles from photogrammetry, the ENC or raster chart, and Lidar data. These files are then exported to formats compatible with the acquisition software used on survey launches. On the launches, during shoreline verification operations, source information is compared to observed features, and S-57 feature and attribute information is acquired, clarified or verified as needed.

The acquired data from the survey launches is later entered into Pydro, sorted into categories relevant to the Cartographers, then saved as an XML file for import into Notebook. In Notebook, the field data is compared to the source information and examined against the BASE Surfaces.

Necessary edits are made to the shoreline, and annotations needed to augment the information contained in the S-57 feature attribution are added using geo-referenced field notes called Marker Layers. The field's Notebook deliverables to the processing branch are comprised of the shoreline feature files in .hob format and Marker files in .mrk format.

CARIS Notebook Functionality
The field continues to strive to attain the simplicity of this idealized workflow. Early versions of Notebook were fairly unstable and equipped with only limited functionalities, but later versions provided the necessary capabilities that enabled the Fairweather to prepare complete field deliverables with significantly more stability and further enhancements.

More recent versions of Notebook improved upon the Object Import Utility (OIU), which can be used for importing shapefiles, text files and database information. The ability to import the source information into an editable S-57 attributed format is critical for comparison and verification purposes by the Hydrographer and in simplifying H-Cell production by the Cartographer.

In the most recent release of Notebook, support for viewing both the HIPS session files and the BASE Surfaces in Notebook were improved, and the user may view geo-referenced satellite and orthophoto imagery, as well. This capability could potentially be useful for referencing the data used by NOAA's Remote Sensing Division (RSD) for digitizing the source shoreline Cartographic Feature Files (CFF), although those reference files are currently not delivered to the field.

Features Management in Notebook
H-Cell creation in CARIS HOM is streamlined with the production of Notebook .hob files. The time and effort involved in importing a series of Notebook created .hob files into CARIS HOM is far less than using the CARIS shapefile conversion utility in a process similar to the more complicated and less reliable shapefile import function that existed in the earlier version of Notebook.

Before shoreline shapefiles can be imported into Notebook, the feature information must be parsed out according to the appropriate S-57 object classes. Individual OIU scripts must then be written for each S-57 object class in order to map the shapefile information to the .hob file's S-57 fields. Once created, the OIU scripts serve as a template which is re-used with each new project. These templates also promote consistency from vessel to vessel. After the shapefiles are imported in Notebook, the Hydrographer is able to annotate the source information with observations from the field.

The later version of Notebook also improves the display of shapefile attribution in Notebook. Although the information is not editable unless it is converted to a .hob file format through the OIU, full attribution can be viewed immediately upon opening the shapefiles in Notebook. This is useful both for quick comparison purposes and for the ability to view the attribution that exists in the various shapefile fields in order to write the OIU scripts that map the shapefile attribution to Notebook's S-57 fields.

One of the most useful Notebook improvements was the addition of three NOAA-specific attribute fields: UserID, Remarks and Recommendations. These unique identifier fields exist in Pydro, so their addition to Notebook allows tracking of data in Notebook and HOM back to the acquired data. On the Fairweather, the UserID and Remarks fields are typically populated at the time of acquisition, whereas Recommendations are generally added to Pydro at a later time.

The Recommendations attribute is only used by the Hydrographer to clarify shoreline to the processing branch Cartographer when the data doesn't speak for itself. Pydro information is mapped to these unique identifier fields in Notebook, upon importing the XML data, and can be viewed by the Cartographer for reference during H-Cell processing in HOM. While these three new attribute fields and the information contained in them are always available in the CARIS pipeline, they are lost once the H-Cell is exported to the base cell file.

Future Enhancements to Notebook
Although the improvements in recent Notebook versions further the field's ability to produce a more complete foundation for the H-Cell, additional tools should be incorporated in the near future to enable field personnel to benefit from the full range of tools available for parsing and attribution in Notebook. Currently, because of complications arising between the delay in the availability of Smooth Tides, typically not available for application until after the data has been submitted to the processing branch, and limitations with Notebook's Pydro Data Import function, Fairweather is only able to sort data and update attribution in Pydro.

In the current process, once the features have been corrected for tides and SVP in CARIS HIPS, they must be re-inserted into Pydro, and then re-imported into Notebook. As the field's primary shoreline processing tool, Notebook should be able to tide correct feature information that contains sounding attribution. It is particularly cumbersome for processing branch personnel to backtrack to HIPS to apply final tide correctors to the data, re-insert the data in Pydro, then re-import the tide corrected XML to Notebook.

Field personnel rely on Pydro for organizing features data into categories that help the Hydrographer determine if the field attribution is complete, and to convey that information to the processing branch Cartographer. Creating functionality that will allow data acquired in the field to be entered directly into Pydro, then imported into Notebook, would simplify this data flow.

Notebook Deliverables
The later, enhanced versions of Notebook improve the field's ability to supply the processing branch with deliverables that form a strong foundation for the H-Cell. The Fairweather submitted the first Notebook .hob file deliverables for a test project at the end of the 2004 field season. These files were subsequently used in testing the .hob file import into HOM. The Notebook Edit and Marker Layers were seamlessly imported, with the S-57 attributed data populating both spatial and feature modes, and displayed properly per S-52 standards.

The time-savings in H-Cell processing that were a primary impetus for Notebook testing were validated, as the simple .hob file import eliminates several complicated steps that were previously necessary for getting Pydro feature data into HOM.

3. H-CELL

The primary purpose of the H-Cell is to directly update NOAA ENC's with new survey information in IHO format S-57. The H-Cell is constructed using a GIS based S-57 object oriented process replacing OCS's existing CAD based hydrographic data processing pipeline. Each H-Cell is intended to provide Marine Charting Division (MCD) an S-57 base cell file that is founded on hydrographic survey data, will open in MCD's ENC creation software package, LAMPS, and import into a new or existing ENC cell. Development of the H-Cell process was undertaken as an experiment towards:

- Automating survey processing at the processing branches as much as possible to both increase speed of production and reduce potential for human introduced error inherent in the traditional process.
- Using a single Commercial Off-The-Shelf (COTS) software package for as much of the process as possible, thereby avoiding format conversions.
- Creating a chart product that would support ENC charting.
- Restructuring the processing pipeline for maximum efficiency from ping-to-chart by gathering and attributing features data in the field.

CARIS software was selected as the COTS package to use for developing and implementing the H-Cell process. CARIS electronic chart production software glows in terms of S-57 object creation and management, but was not designed for creation of H-Cell's as originally envisioned by OCS. When first conceived, the H-Cell development plan was to use the CARIS suite as-is for S-57 object management, taking full advantage of the GIS capabilities incorporated into HOM, which are far superior to the CAD-based process being replaced. The plan also called for bending the CARIS tools as required to fulfill OCS's needs for evaluating and verifying hydrographic and features information, accomplished by the branch Cartographers during creation of the traditional H-Drawing. This tactic proved largely unsuccessful. Many of the very useful aspects of the CAD-based applications that were used to good effect, such as rubber sheeting capabilities and the ability to annotate the "drawing", were not available in the CARIS environment. Development of the H-Cell process was ultimately achieved with the aid of numerous CARIS designed utilities, customized specifically for OCS purposes, as well as adjustments to OCS's existing process to better utilize the CARIS software for its intended purpose.

Once OCS's and CARIS' objectives were synchronized, CARIS' Hydrographic Object Manager (HOM) in conjunction with other CARIS tools became an ideal platform for creation of the H-Cell. The spatial aspects are used for evaluation and verification of soundings data and features information, while S-57 features, topology and other ENC aspects are managed using the feature object management capabilities.

Integrating Soundings, Contours and Features into HOM
The deliverable from the CARIS Field Sheet Editor environment is a CARIS map, or Field Sheet, that is used to form the basis for the H-Cell. This file is opened in HOM, then re-named as an H-Cell. Each of the .hob files generated in Notebook, as well as the Marker Layers containing the geo-referenced shoreline notes, are imported into the new H-Cell. The Notebook feature data was parsed out into a minimum of four separate .hob file categories according to its final disposition by field personnel:

- Add: For new features identified during survey operations. The Hydrographer recommends adding the feature to the chart.
- Modify: For features discovered to be positioned or portrayed incorrectly on the chart, or the feature was found to be attributed incorrectly or insufficiently. The Hydrographer recommends repositioning, adding or changing attributes, etc.
- Delete: The feature was disproved using approved search methods and guidelines. The Hydrographer recommends removal from the chart.
- Retain: The feature was found during survey operations to be positioned correctly or was not investigated. The Hydrographer recommends retaining the feature as charted.

Receiving the features data from the field pre-sorted into these categories greatly facilitates the H-Cell process, and is especially useful in terms of the evaluation and verification process.

H-Cell Process Overview
H-Cell creation uses CARIS mapping software and dKart Inspector in a multi-step process:

In CARIS HOM
- Open the HIPS Field Sheet with soundings, contours and perimeter, then "Save As" a new file for the H-Cell.
- Import Notebook .hob files.
-

In CARIS HOM
- Set up a layering structure that separates items by feature type (point, line and area) and final disposition (to be included in the base cell file, or to be used only for reference purposes in creating the H-Cell).
- Perform evaluation and verification of hydrography and features against existing charts and the Descriptive Report; Rectify shoreline issues.
- Run HOM Sounding Suppression routines to create chart density and distribution of depths.
- Create the Blue Notes layers, one layer each containing notes for items to be added, modified, removed, retained, and other actions for purposes of application to the chart.
- Separate out or duplicate, as needed, items for creating Skin Of The Earth (Group 1) objects to layer 200.
- Isolate soundings, new point features, shoreline updates and other items to be included in M_COVR, CATCOV1 areas.
- Build and clean Group 1 and 2 network (line) topology in the necessary layers.
- Build and clean polygon topology in the necessary layers.
- Add polygon labels for Group 1 objects.
- Create Group1 polygon objects (Depth Areas, Land Areas, etc.).
- Create other area objects (reefs, danger areas, etc.).
- Create Meta objects.
- Create depth contour objects.
- Create other line objects (shoreline features, etc.).
- Create sounding objects.
- Group soundings.
- Create remaining point objects.
- Run CARIS HOM Quality Assurance routines.
- Export to the .000 base cell file

CARIS HOM Utility
- Convert the base cell file to NOS chart units

dKart Inspector
- Run tests for Geometry, Spatial Redundancy, Encoding Rules, etc.

CARIS GIS
- Generate a GeoTiff from the H-Cell file showing Blue Notes and shoreline.

ENC Viewer, CARIS HOM, dKart Inspector
- Perform Quality Assurance on the survey and deliverables.

H-Cell Coverage Area

The finished H-Cell is a shape whose extent is defined by the Coverage metadata object, M_COVR, which may be coded for "Coverage" or "No Coverage". For navigable area hydrographic surveys, an inshore limit, generally 4 meters, is specified for collection of hydrography and features such as rocks, reefs and shoals. Cultural features, such as piers, are often collected from shore. This leaves some intertidal and nearshore areas from the shoreline seaward not addressed by the Hydrographer. Because only information specifically addressed during surveying operations is included in the H-Cell, isolated pockets of coverage outside the main coverage area may result. See Figures 2a, 2b and 2c.

Defining this area for surveys that include cultural features and complex shoreline, while successfully creating the topology needed to export to the base cell file, is one of the most difficult aspects of H-Cell creation.
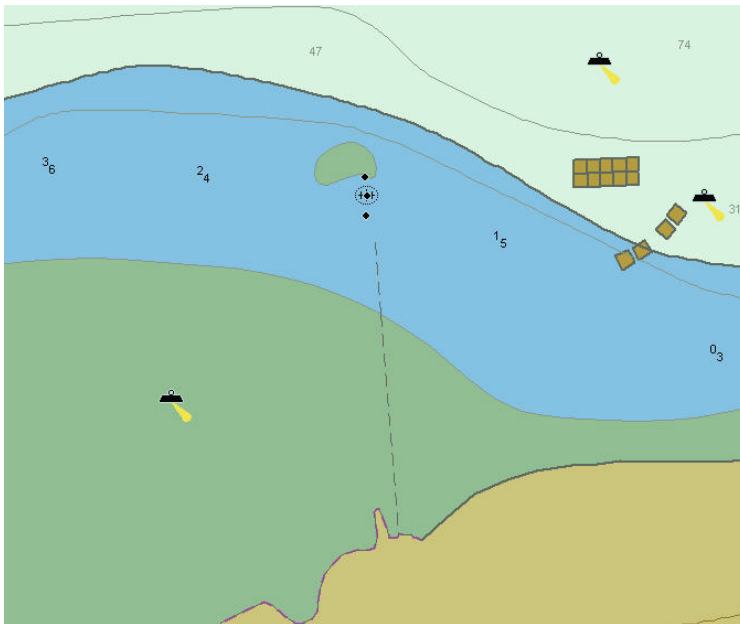
Figure 2a. An area of the existing Valdez, Alaska, ENC US5AK23M, showing pier ruins extending seaward across the intertidal area. New survey data has yet to be applied to this ENC.
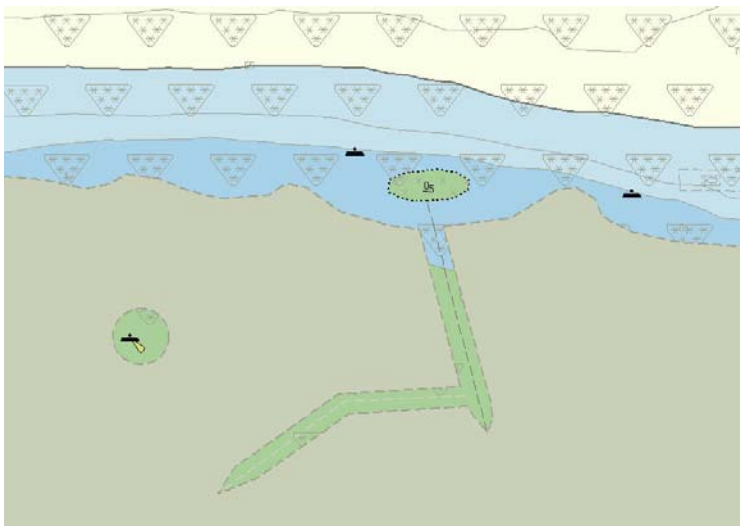
Figure 2b. A section of H-Cell showing all S-57 features including the isolated lighted mooring buoy collected outside the area of hydrography, and the pier ruins extending seaward across the intertidal area. In this graphic, the area shown in gray surrounding the mooring buoy and the pier were not surveyed during field operations, so are not included in the M_COVR, CATCOV 1, coverage area.
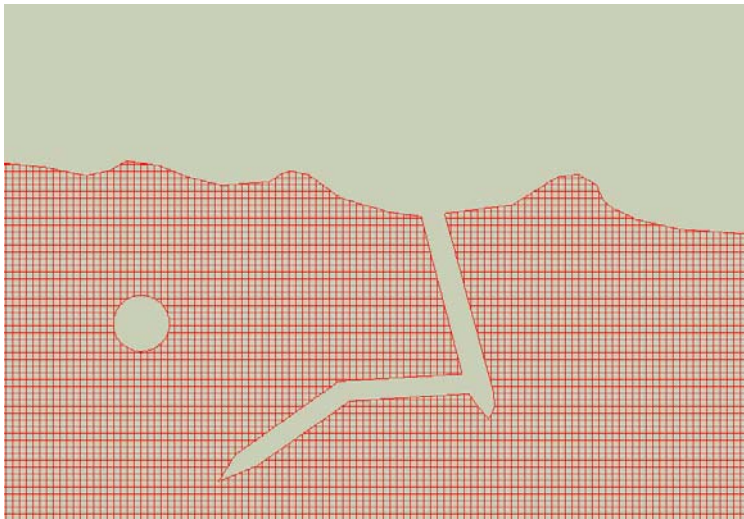
Figure 2c. A section of the same H-Cell area as shown in Figure 2b. In this graphic, the red shading shows the M_COVR, CATCOV 2, area of no coverage. The gray is M_COVR, CATCOV 1, area of coverage.

As in the traditional CAD-based deliverable, there is a list of excluded features for H-Cells, including oil platforms, gas pipelines, sewer pipelines, dredge areas and federally maintained aids to navigation. These sources are provided separately to the charting divisions for inclusion on the charts. The excluded features may be collected by the field and are useful for completing evaluation and verification of the hydrographic survey information during branch processing, but are not used for creation of feature objects that will be exported with the S-57 base cell file.

Meta Object Areas Included in the H-Cell
The M_COVR metadata object is one of five included in the H-Cell:

- M_QUAL: Assessment of the quality of data in the described area.
- M_COVR: Extent of coverage of a geographic area.
- M_CSCL: The compilation scale for a designated area. (For insets only.)
- M_NSYS: The navigational system of marks that applies to the described area.
- M_SREL: An area of equal assessment of reliability of source survey information.

The metadata object, M_CSCL, is used only when an inset is included in the H-Cell. Insets are compiled in place and the difference in scale from the remaining H-Cell specified by the attribute CSCALE, Compilation Scale of Data. Figure 3.
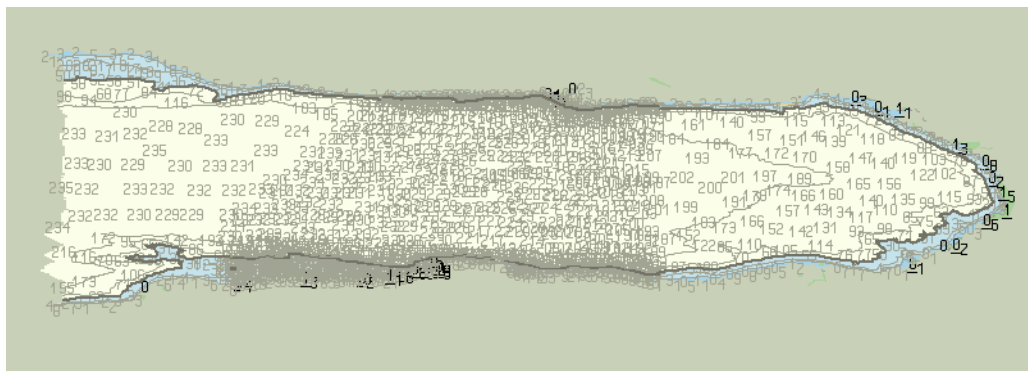

Figure 3. The 1:40,000 scale Valdez H-Cell showing the 1:10,000 scale inset compiled in place.

Distinguishing Between Different Sources of Data in the H-Cell
A typical H-Cell might contain several sources of information, such as shoreline features originating from the National Geodetic Survey's Remote Sensing Division photogrammetry, the NOAA ENC to be updated, and the current hydrographic survey. The S-57 attributes SORDAT (Source Date), and SORIND (Source Indication), are applied by the branch Cartographer during H-Cell creation, and help the MCD compiler to distinguish between the various sources of data in the H-Cell.

Blue Notes
Blue Notes have traditionally been used as a supplementary tool for communicating crucial information from the branch Cartographer to the MCD compilers. The complexity and novelty of these new H-Cell deliverables called for some extra effort in elucidation. The Blue Notes tradition is being modernized and carried forward with the new process. Blue Notes are supplied with the deliverable to MCD in two separate GeoTiff graphics, one unprojected, for use in ENC production, and one in Mercator projection for use in raster chart production. Figure 4.
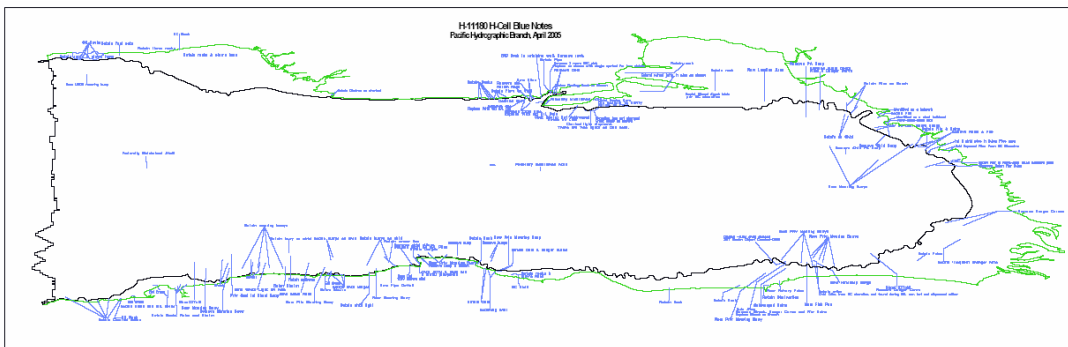
Figure 4. Example of Blue Notes. Shoreline is shown in green, limits of hydrography in black, and notes to the MCD compiler in blue.

Deliverables from the Processing Branches to Marine Charting Division
The final deliverables from the processing branches to Martine Charting Division include:

- Product Surface (the combined BASE surfaces)
- CARIS H-Cell Map
- S-57 Base Cell (.000) file, IHO, metric
- S-57 Base Cell (.000) file, chart units
- Blue Notes, LLDG GeoTiff
- Blue Notes, Mercator GeoTiff
- Descriptive Report

Specifications and Guidelines for Creation of H-Cells
Such a drastic change in the processing pipeline, with far-reaching effects amongst the different factions of the Office of Coast Survey, required a serious re-examination of the specifications and guidelines currently in use for charting processes. Frequent consultations between OCS's Hydrographic Surveys Division (HSD), responsible for collection and processing of hydrographic data, and Marine Charting Division (MCD), responsible for producing the navigational charts and related publications, have yielded the first draft of these documents. They will provide guidance for creation of H-Cells, and provide the basis for consistency between deliverables within and between the processing branches.

Branch QA/QC
Documentation in checklist form for conducting the processing branch review of H-Cells is also currently being developed. These guidelines are a necessary tool for ensuring a thorough inspection of the H-Cell and certifying both the H-Cell process and the H-Cell product before it leaves the branch. The review includes:

- A layer by layer examination of features and information in HOM against the report.
- A review of the Blue Notes against the report and the existing ENC.
- Spot checks of attribution in HOM.
- HOM Quality Assurance checks.
- A review of the .000 file against the existing ENC.
- An independent check using dKart Inspector.

The dKart Inspector tests, developed by HydroService AS, are an industry standard in ENC data quality control. The tests ensure the .000 file conforms to international standards and is topologically correct. The H-Cell must pass all but a specified list of dKart tests before being certified at the processing branch and cleared for delivery to the Marine Charting Division and application to the ENC and raster charts.

4. APPLICATION TO CHART

Within the Office of Coast Survey the Marine Charting Division (MCD) creates and maintains all nautical charts, both the traditional raster charts and Electronic Navigational Charts (ENC's). Raster charts are maintained by directly applying the source information, such as shoreline digitized from photogrammetry, hydrography and new features discovered during survey operations. Source shoreline and critical updates are also digitally applied to ENC's for updates.

The current process for maintaining ENC's entails digitizing the raster charts. Reference of the raster chart for updating the ENC with new hydrographic and features information is considered valid because both charting products originate from the same source materials.

Marine Charting Division manages numerous types of source materials. While hydrographic surveys are small in number relative to other source documents, they are large in area of coverage and can affect a significant change in a chart. Hydrographic surveys are regarded as vital sources and are given top priority in terms of charting. This priority will not change with the introduction of the H-Cell into MCD's charting pipeline. The aspects of chart production chiefly affected will be the speed of application of new survey information to the charts, and the primary end product. In the traditional process, application of information to the ENC is secondary to the raster; the new model favors the ENC over the raster product.

Currently, a hydrographic survey is processed and delivered to the Marine Chart Division (MCD) geared towards primary support of the raster chart. The final data of a survey is built to fit the scale and projection space of the one to three raster charts that the survey may effect. The data is delivered in MCD's preferred format for raster charts, a MicroStation Design File (dgn). MicroStation is a CAD-based application developed by Bentley Systems Inc. The deliverables from the traditional process supplied to MCD from the processing branches include:

- The H-Drawing digital design file: A design file built to scale for a particular raster chart. The H-Drawing is designed to replace most of the hydrographic depth and feature data in the survey area in a cookie cutter fashion. The H-Drawing contains annotations to the MCD compiler from the processing branch Cartographer to assist in compilation to the raster chart. The H-Cell will replace the H-Drawing.

- The Smooth Sheet digital design file: Displays all of the hydrographic data at the scale of the survey in a much denser display of soundings and features than the H-Drawing. The Smooth Sheet is used for reference when applying the survey to the raster chart and ENC's.

- The Descriptive Report (DR): The full text description of the survey. The DR follows the deliverables from the field to the processing branch and to MCD. It is initially compiled by the Lead Hydrographer, then footnoted heavily during branch processing.

The Traditional Process

As with all source materials that are received at MCD, a hydrographic survey is processed first in the Office of Coast Survey's Nautical Data Branch (NDB). The NDB examines the survey and determines which charts it will be applied to. The various components of the survey, the H-Drawing, Smooth sheet and Descriptive Report, are assigned internal numbers for tracking and archiving. These components are now referred to as *source documents*. They are inserted into a database that is accessible by different users within MCD.

Cartographers in both the raster and ENC teams review and download the source documents through an intranet interface, Digital Registry (DREG). The DREG system uses the Safe Software mapping data manipulation and transformation tool, Feature Manipulation Engine (FME), to re-project both the Smooth Sheet and H-Drawing .dgn files so that they can be applied to raster chart space. This facilitates compilation of the new survey data to the raster charts. Application of new survey data to the raster chart is currently accomplished using Bentley MicroStation software and a Bentley raster manipulation software tool, IRAS/B.

The process of importing .dgn files into MCD's current ENC production system is clumsy and time consuming. While the ENC Cartographers download both the Smooth Sheets and H-Drawings from the DREG intranet site, for much of the new survey material, digitizing the geo-referenced raster chart is the most effective method of compiling to the ENC.

The DREG system is also a tracking tool for MCD Cartographers and others involved in the compilation process, used to assess the stage of completion of a survey—In Process, In Review or Completed. This tracking system is vital for the ENC Cartographer in determining when the compiled raster chart may be used for application to the ENC. The LaserScan software application, LAMPS, is the current production software use for application to the ENC.

The New Process

H-Cells are designed to update ENC's directly, rendering the application to ENC process much more straightforward than the traditional method. Because H-Cells are in S-57 format and must past S-58 checks, MCD Cartographers have a minimal amount of pre-processing to perform on the H-Cell. The cookie cutter approach of applying new survey information to the chart that works so well for raster chart production is also employed by the new process, with the H-Cell designed to simply replace a specific section of the ENC. The metadata object M_COVR, coverage area, establishes the area of survey, while the attributes SORDAT and SORIND, Source Date and Source Indication, clarify new data from old.

Registration of H-Cell and Pre-Processing by Nautical Data Branch

The Nautical Data Branch receives H-Cells as part of the hydrographic survey submission from the processing branches. The submission includes the base cell (.000) file, the CARIS HOM file used to produce the H-Cell, and the Descriptive Report. The entire deliverable is digital, eliminating the traditional Smooth Sheet and H-Drawing plots. The H-Cell will undergo preprocessing using FME to convert the S-57 base cell file to a .dgn with a projection space of the specified chart. The raster teams will use this .dgn for application to the raster chart. Attribute labels for some of each object's attributes, based on the NOS Chart 1 symbology, are derived from the S-57 objects. This converted .dgn, along with the H-Cell, will be placed in the DREG System to be accessible to MCD Cartographers.

Raster Application

The raster teams access the H-Cell and newly converted .dgn from the DREG system to apply the hydrographic survey. The converted .dgn is the main source of information used in application to the raster chart, supplemented by the H-Cell base cell file, the HOM files and Descriptive Report. The .dgn fits directly in place on the raster chart. The Cartographer makes edits to the chart by simply deleting old features and adding new ones from the H-Cell base cell file derived .dgn.

Reference to the HOM files and Descriptive Report assists the Cartographer in clarifying which information is to be added, removed and retained. Another tool to help de-conflict new survey information is the Blue Notes GeoTiff that may be referenced directly into the .dgn workspace. This is a geo-referenced graphic that contains annotations relating to chart features, directed to the MCD compiler from the processing branch Cartographer. Access to the CARIS HOM file allows the Cartographer latitude to view the surface and select different depth values from the full density sounding set.

An information function in MicroStation can be used to click on any object on the converted .dgn to access the full attribute information from the H-Cell. This functionality allows the compiler to easily access the DORDAT and SORIND attribute information required for distinguishing new features originating from the survey from those that were carried through from the chart or source shoreline.

Preparation for Application to the ENC

Using the new process, the ENC team is no longer required to wait for the raster team to apply a hydrographic survey to the raster chart before it can be applied to the ENC. The H-Cell base cell file, HOM files, Descriptive Report and Blue Notes GeoTiff, downloaded or linked from the DREG system, are the source documents needed to apply a new survey.

Once all the files have been collected the Descriptive Report is examined to get a full understanding of the survey and to alleviate any uncertainty regarding features and information. As a final preparatory step, the H-Cell is loaded into dKart Inspector and checked for errors. This step in the preparation process is very important in ensuring seamless application of the H-Cell to the ENC. Any error in an H-Cell can greatly slow the application process and may require the H-Cell be returned to the processing branch for re-work. Errors in geometry and redundancy cause serious problems in application of the H-Cell to the ENC. Some encoding rules may be purposely broken on an H-Cell in order for the branch Cartographer to convey additional information to the ENC compiler. These encoding errors will not be fixed during the preparation process, but will be changed when the survey is applied to the ENC.

The H-Cell may now be loaded into LAMPS as a new dataset using the import process. It will be loaded into a database founded on Coast Guard Districts. For example, an H-Cell located in Alaska is loaded into database 17 for the 17th Coast Guard District. The Blue Notes GeoTiff is also imported as a raster or background file into the same database. Once this preparation is complete the application of the survey may begin.

Application to the ENC
Located in the same database with H-Cell and Blue Notes file is the ENC that is to be updated. All three items will be loaded for editing using the LAMPS "long form", which allows the Cartographer to set datums and color palettes, and transform rasters. Setting the color palette of the H-Cell to entirely red makes it easier for the Cartographer to distinguish objects from one dataset to another.

With the display complete the H-Cell is made active and queried to select objects that have Source Dates and Source Indicators that differ from the new survey. These objects, some from the existing ENC and others from shoreline or other source, are on the H-Cell to provide continuity and for clarity. Because they are not "new" objects, they will be deleted or disregarded. These objects, usually linear shoreline constructions, are generally included in the H-Cell because they are difficult to exclude from within the survey area without disrupting or over-complicating topology.

Once the new survey source information is isolated, the metadata object M_COVR, coverage available, is selected and propagated from the H-Cell to the ENC. The geometry of that object is now used to delineate the identical area on the existing ENC, and to delete the appropriate objects within it. The Cartographer must consult all source documents for a full understanding of the survey and to determine which objects can be removed from the existing ENC. All DEPARE (depth area), DEPCNT (depth contour) and SOUNDGS (sounding) objects, will be removed within the existing ENC useless otherwise noted. In general all bathymetry within the M_COVR, coverage available, area will also be removed. Once all appropriate objects are removed from the existing ENC, it is a simple matter to propagate objects from the H-Cell into the ENC.

Much of the work on object attribution is accomplished in the field and at the processing branches, while some additional work in this area is required by MCD. Additionally, sounding objects must be re-bundled, and linear depth areas, eliminated from the H-Cell for topological reasons, are now created.

Metadata objects are addressed once all other objects have been replaced and topology is correct. The M_COVR object used to describe the survey area is discarded, replaced by other metadata objects in the ENC. The M_QUAL, quality of data, object from the H-Cell, with identical geometry to the M_COVR area, will now be propagated into the ENC. The area defined by the M_QUAL area boundary will indicate an area of much higher quality of data such that, with proper display in an ECDIS, a user will easily be able to determine the area containing the new survey information.

As a final step the ENC is exported and checked for errors to ensure that application of the hydrographic survey was completed correctly and that no errors were introduced. Once this process is complete the ENC will be posted on the Office of Coast Survey's web server for free download. All ENC's with hydrographic surveys applied to them will be posted as new editions.

CONCLUSION

The direct application of survey information to the ENC vastly improves the quality of the chart product and will enhance the mariner's confidence in using it. The Office of Coast Survey's Marine Charting Division is in the process of refining procedures for application of H-Cells to the ENC and raster charts even as the H-Cell process itself continues to evolve. All of the tools in this re-engineered process are stepping stones to even greater streamlining and better management of hydrographic survey and other source information. A centralized hydrographic database, with capabilities to store and maintain hydrographic and features data, from which any number and variety of charting and non-charting products may be extracted, is on the near horizon. This advance will not only better promote safe navigation, but will benefit climate, oceanic and tsunami modeling, fisheries research and other users with higher quality data customizable for specific needs.

GLOSSARY

Base Cell File: A new ENC edition, data set or re-issue; a .000 base cell file is one of the H-Cell deliverables.

Bathymetry Associated with Statistical Error (BASE): A geo-referenced depiction of the seafloor bathymetry based on an algorithm that factors beam footprint size and a weighting system skewed to favor inner nadir beams and depth values with low uncertainty. Resultant depth values are applied to a dense grid of statistically weighted mean observations rather than a collection of shoal-biased excessed soundings. The vertical and horizontal uncertainty of each data point is used as a weighting scheme to generate a high resolution surface model of the seafloor. The intent is to preserve and archive the highest resolution data possible

Binning: A method of subdividing a Field Sheet to create a network of equal-sized bins from which the shoalest depth value is selected and recorded at its correct location.

Blue Notes: Geo-referenced notes from the processing branch Cartographers to the MCD chart compilers in a graphic format using the shoreline for reference. These notes are traditionally shown in blue.

Descriptive Report (DR): A written report that accompanies every hydrographic survey for the purpose of supplementing it with information that cannot be shown graphically, and to direct attention to important details and results.

Downsample: The process of reducing the number of data points in a data set, generally by keeping shoaler soundings when they are near deeper soundings.

Electronic Navigational Chart (ENC): Vector representations of nautical charts which are intended to be used in conjunction with ECDIS (Electronic Chart Display and Information Systems). ENC's are standardized as to content, structure and format and may contain supplementary nautical information useful for safe navigation.

H-Cell: The S-57 map created in CARIS HOM, containing all of the new survey and chart information necessary for updating or creating a new ENC and raster chart product using a "cookie cutter" approach.

H-Drawing: Compiled digital drawing of the nautical chart reflecting revisions based upon new source data, such as hydrographic surveys or other sources.

Highest Resolution Obtainable: Refers to the highest resolution that the data can support. High resolution would entail creating a BASE surface using the smallest cell size that the data can support. The smaller the cell size or bin, the higher the resolution.

Hydrographic Surveys Division (HSD): The division under NOAA's National Ocean Service, Office of Coast Survey, that collects and processes hydrographic survey information.

IHO (The International Hydrographic Organization): An intergovernmental organization established in 1921 whose mission includes a mandate to support safe navigation through the development of standards that promote uniformity of navigation related products and services.

Marine Charting Division (MCD): The division under NOAA's National Ocean Service, Office of Coast Survey, that is responsible for applying source data, including hydrographic surveys, to navigational charts.

National Oceanic and Atmospheric Administration (NOAA): The office under the US Department of Commerce that houses, among other services, weather, fisheries, oceans and atmospheric research, and charting and navigation.

Office of Coast Survey (OCS): The NOAA, National Ocean Service organization that is responsible for navigation products and services for U.S. waters.

Raster Nautical Chart (RNC): A geo-referenced digital depiction of a paper chart which is commonly used in a raster chart navigation system.

S-57: The IHO Transfer Standard for Digital Hydrographic Data which dictates rules for the coding and exchange of hydrographic data. The standard includes an Object Catalogue of features with codes for characterizing them as well as the rules for developing S-57 ENC's.

S-58: The IHO recommended validation checks.

Skin Of The Earth (SOTE) Objects: Also known as Group 1 Objects. Area objects which together cover the entire H-Cell or ENC cell area with no overlap or underlap of coverage. There are seven possible Group 1 objects including DEPARE (depth area) and LNDARE (land area). All other objects are Group 2 objects; these must be underlain by Group 1 objects.

Smooth Sheet: The name given to a plotted representation of data acquired during a hydrographic survey. A record of the soundings and features gathered during the field survey, as well as other data necessary for a proper interpretation of the survey, such as depth curves, bottom characteristics, names of geographic features, and control stations.

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