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Production and Validation Solutions for Improving ENC Consistency

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Abstract

Paper charts have traditionally been produced as discrete entities. With the advent of the Electronic Navigation Chart (ENC) and the Electronic Chart Display and Information System (ECDIS) it has become possible to view multiple "charts" of varying scales on one seamless display. The ECDIS display has revealed that some of the assumptions and processes used to produce stand alone chart products are no longer valid for ENC production, and result in data inconsistencies and a disjointed chart display.

The ENC is not a chart in the traditional sense. From the mariner's point of view, the dynamic and seamless ECDIS display is the chart. Cartographic principles that apply to individual charts need to be applied to the seamless display, whether it is composed of one or multiple ENCs. The challenge for ENC producers today is to ensure consistent encoding of features that span multiple ENCs. The growing need for hydrographic offices to implement spatial data infrastructures (SDI) and the current development of the S-101 ENC Product Specification provide the perfect opportunity to address ENC consistency.

With the aid of modern enterprise production suites, production guidelines and validation software, ENC producers will be in a position to produce high quality and consistent ENCs.

Introduction

The production and validation of individual Electronic Navigation Charts (ENC) is well established. The S-58 standard, *Recommended ENC Validation Checks* (IHO 2010a), defines a set of validation checks that need to be met in order for an ENC to be published by a Regional ENC Coordination Centre (RENC). Producers of ENCs have the necessary procedures and software in place to ensure that their ENCs comply with S-58.

The challenge facing ENC producers today is the consistent encoding of ENCs of the same geographic area. Features that are common to adjacent ENCs, and overlapping ENCs of different scale bands, are often encoded from different data sources, potentially leading to inconsistencies in the encoding of a feature's spatial geometry and attributes. These inconsistencies become apparent when multiple ENCs form a seamless display in an Electronic Chart Display and Information System (ECDIS).

Background

The introduction of the *IHO Transfer Standard for Digital Hydrographic Data*, S-57 (IHO 2000), in 1992 generated a great effort on the part of hydrographic offices to publish their chart portfolios as ENCs. A number of commercial ENC validation software tools became available and formed an integral part of the ENC production workflow. During the late 1990's the International Hydrographic Organization (IHO) and various RENCs saw the need to standardise the validation of ENC datasets, and S-58 was developed.

S-57 does not provide much guidance on the consistent encoding of adjacent and overlapping ENCs. Similarly, S-58 is only focused on the validation of individual ENCs in isolation. The International Centre for ENCs (IC-ENC) highlighted a number of inconsistencies that occur when multiple ENCs are viewed together on a seamless ECDIS display (Bisset & Fowle 2003). Following on from this, the IHO (2009) published S-65, which contains recommendations for the consistent encoding of ENCs. Even though the problems associated with ENC consistency have been well documented, the validation of overlapping and adjacent ENCs is currently a lengthy and manual process that is prone to error.

Initiatives, such as the INSPIRE Directive 2007/2/EC (EU 2007) in Europe and the Geospatial Information Infrastructure and Services Joint Project 2064 Phase 3 (Australian Government Department of Defence 2009), are encouraging hydrographic offices to migrate their ENC production environments to enterprise GIS solutions. An enterprise GIS that distinguishes between scale dependent and independent data eliminates the need for duplicate and redundant encodings of spatial features, and in doing so, eliminates many of the inconsistencies associated with multiple ENCs.

Methodology

Tackling the problem of ENC consistency is not a trivial task and requires standards bodies, data producers and industry to work together.

The solution to the ENC consistency problem is three-fold:

1. **Production Environment**
   Data producers should endeavour to adopt enterprise GIS solutions for their ENC capture and management. Rather than compiling individual ENCs from varying sources, data producers should focus on building up an enterprise spatial database of hydrographic data from the best possible source data. This will eliminate the need for duplicate and redundant encoding of spatial features, which are the source of many inconsistencies.
2. **Production Specifications and Guidelines**
   Specify additional ENC production guidelines that address the various issues surrounding ENC consistency.
3. **Validation**
   Include, within S-58, a standardised set of checks for cross cell validation that can be implemented in ENC validation software.

Types of Inconsistencies

This section provides examples of the most common types of inconsistencies found in ENC cells.

Inconsistent Spatial Geometry

Spatial inconsistencies occur when the geographic location of real world features, encoded in multiple ENCs, do not match. *Figure 1* shows an example of a navigation line that is encoded in two overlapping ENCs of different scales.

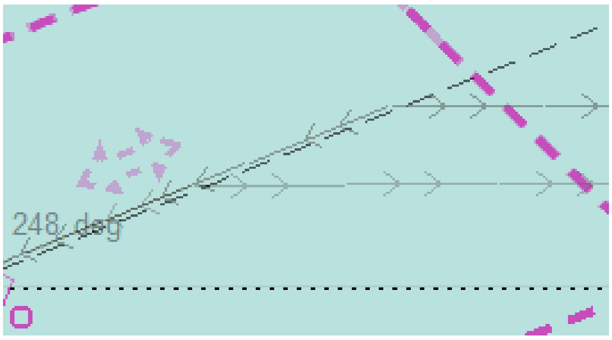

Figure 1. This example shows a partially transparent view of two overlapping ENCs. The same real world navigation line feature is encoded in both. A clear NE / SW shift can be seen.

Attribute Encoding

The inconsistent encoding of attributes of same world features doesn't only result in logical errors. Attributes are a main driver of the S-52 (IHO 2010b) display engine, so there is potential for these features to be symbolised inconsistently (*Figure 2*).

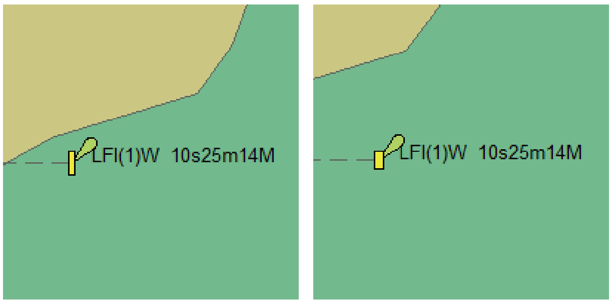

Figure 2. The same navigational mark has been encoded on two ENCs of different scales. Aside from having its position encoded inconsistently, the attribute specifying the beacon's shape (BCNSHP) has been encoded differently, resulting in the differing symbolisations of the mark.

Encoding of SCAMIN

The inconsistent usage of SCAMIN across cell boundaries results in a very inconsistent chart display (*Figure 3*).

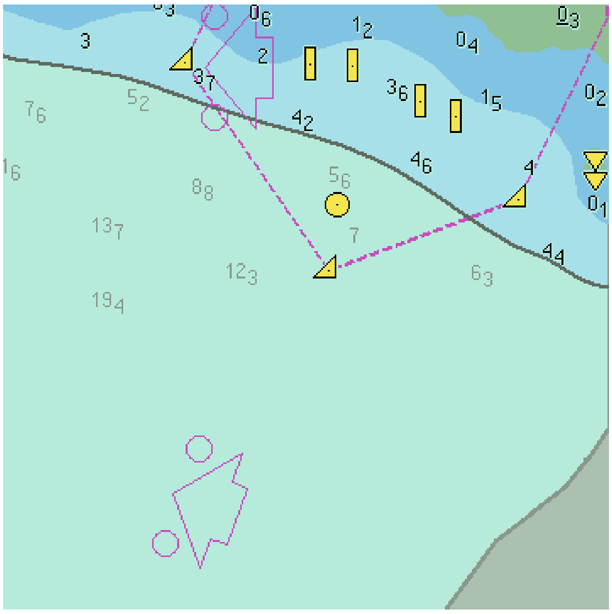

Figure 3. The two ENCs depicted here use different SCAMIN encodings for their soundings, resulting in soundings being displayed in the northern, but not the southern ENC.

Inconsistent Contour Intervals

Adjacent ENCs need to have the same depth contour intervals encoded. Inconsistent encoding of contour intervals leads to a disjointed safety contour and depth display (*Figure 4*).

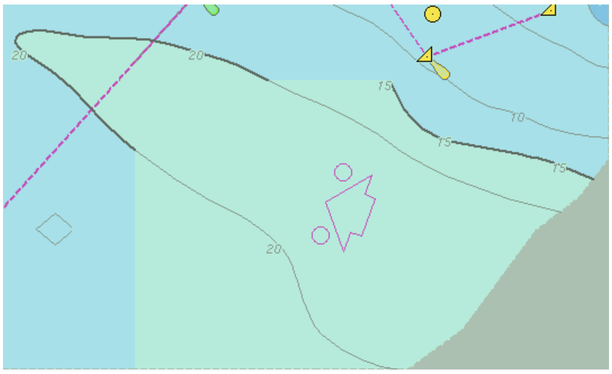

Figure 4. The northern ENC has the 15m contour omitted. This results in a broken and disjointed safety contour.

Edge Matching

Line and area features need to be continuous at cell boundaries (*Figure 5*). As far as the mariner is concerned, the seamless ECDIS display represents a chart, whether it is composed of one or multiple ENCs. Basic cartographic principles, such as having continuous contours and unbroken area boundaries, should apply.

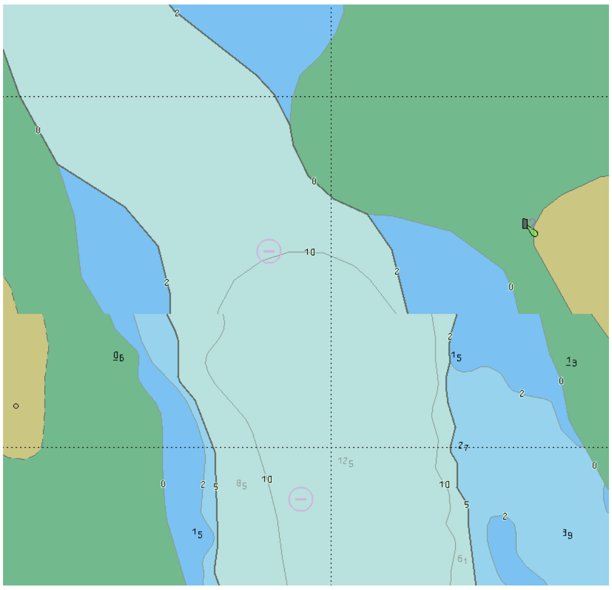

Figure 5. This example depicts broken contours and area boundaries. Note the inconsistent use of SCAMIN on soundings.

Use of M_CSCL

The use of "compilation scale of data" regions (M_CSCL), i.e. the combining of small and large scale data into a single ENC, can lead to a grossly over scale display when the M_CSCL regions are viewed at their compilation scale (*Figure 6*). ENCs that have M_CSCLs encoded contain a combination of high and low density vertex data, resulting in inefficient ECDIS displays. Given the problems associated with the use of M_CSCLs, and the fact that they can be encoded as separate large scale ENCs, their use should be avoided.

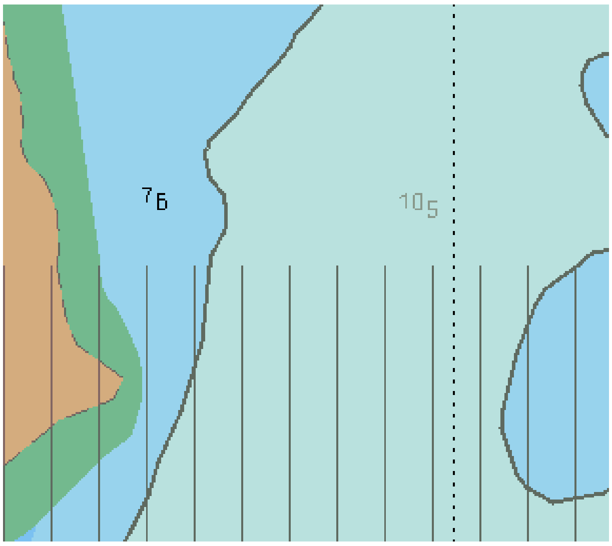

Figure 6. This example depicts a single ENC, whose compilation scale is 1:90000, being viewed at 1:12000. The northern part of the ENC lies within an M_CSCL and generates no over scale warning. The southern portion of the ENC is grossly over scale and should not be viewable at the current scale. If data contained within the M_CSCL were encoded as a separate ENC, only the large scale data would be displayed, as intended.

Holes in Data Coverage

Small scale ENCs sometimes have areas of "no data coverage" encoded where there is large scale data available. This leads to holes in the display when the system only has the small scale ENCs installed (*Figure 7*).

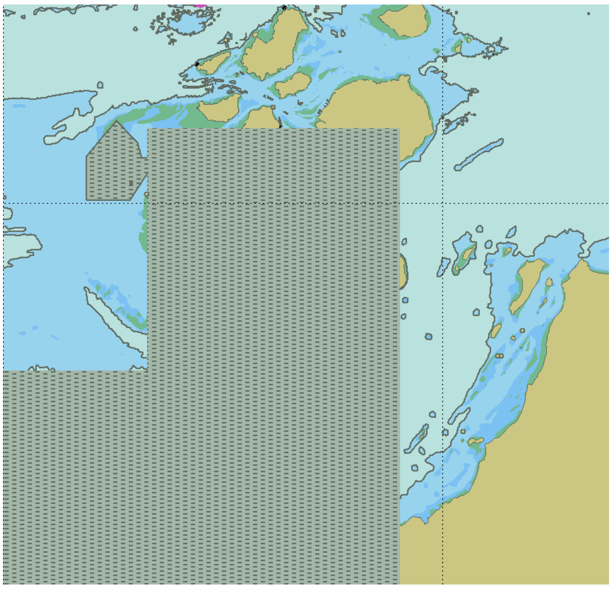

Figure 7. This particular ENC display only has small scale data installed. Note the area of no data coverage that is only filled once the large scale data is installed. The hole could easily have been filled with generalised large scale data.

Gaps and Overlaps

Gaps and overlaps between adjacent ENCs can lead to unpredictable results in an ECDIS display (Bisset & Fowle 2003). Whilst it is not difficult to avoid gaps and overlaps within a country's jurisdiction, they are more difficult to avoid at national boundaries.

S-57 has the concept of a coordinate multiplication factor (COMF). Positions are stored as integers and are converted to real world coordinates by dividing by the COMF. ENCs need to have the same COMF encoded to ensure that cell boundaries are matched according to the same spatial precision (IHO 2009).

Addressing the Problem

Issues surrounding the consistent encoding of ENCs can be addressed by dealing with the following topics:

1. ENC Production
2. Production Guidelines
3. S-58 Validation.

ENC Production

The most effective way to deal with inconsistencies within ENCs is to put in place a production environment that prevents these errors from occurring in the first place.

The vast majority of errors associated with inconsistent encoding of ENCs are to do with duplicate and redundant encodings of vector objects. ENCs of the same region often have the same real world features encoded from different data sources, often paper charts of varying scales. For example, a particular navigational mark is encoded onto a large scale ENC from a large scale paper chart, whilst the same navigational mark is encoded onto a small scale ENC from a small scale paper chart. This can lead to inconsistencies in the spatial and attribute encoding of that navigational mark feature.

Hydrographic offices have traditionally compiled individual paper charts and the paper chart represented a unit of work (*Figure 8*). ENCs should not be viewed as charts in this traditional sense, and data compilation should not be focused on producing individual ENCs. An ENC should simply be thought of as a tile whose extents may or may not overlap one or more traditional charts. The World Geographic Reference System (GEOREF) as employed by the Vector Product Format (VFP) (US Dept Defense 1996) is a good example of such a tiling mechanism.

Figure 8. The traditional method of ENC production involves the compilation of individual ENCs from source data. There is no database and the ENC functions as both product and data repository.

An ENC is an end product that should be generated from a higher order data store. The data store itself is compiled from the best possible data sources. ENCs of themselves should not be compiled or edited, and should not form the basis of a data repository. Larger hydrographic offices are starting to migrate their ENC production environments to enterprise GIS solutions for the hydrographic domain. The focus behind such systems is the compilation and management of digital hydrographic databases, rather than the production of individual ENCs (*Figure 9*). Scale independent features, such as navigational marks, soundings, wrecks, etc. are only encoded once. Scale dependent features, such as contours, can be encoded for multiple scale bands or be generalised automatically from large scale data. A careful application of SCAMIN ensures that only the desired features are visible at a particular scale. It is important that the enterprise GIS allow for the encoding of continuous line and area features that span across multiple ENCs. Only when the ENCs are generated are the features clipped to the ENC extents.

The enterprise GIS is responsible for generating the resultant ENCs, or data sets of other formats, such as the Geography Markup Language (GML) (OGC 2007) and S-101 (IHO 2011a). An enterprise GIS such as this removes the need for the redundant encoding of data and therefore avoids many of the issues surrounding ENC consistency.

The draft S-101 specification provides the ability to encode scale dependent and scale independent cells. This fits in well with enterprise GIS systems that already support scale dependent and independent data.

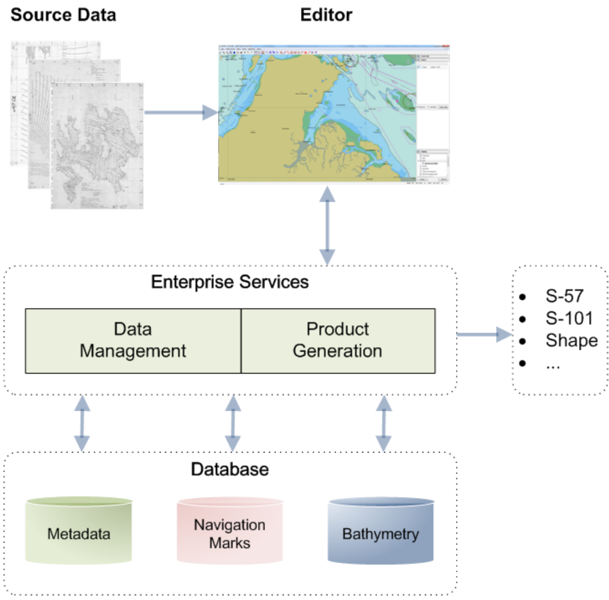

Figure 9. An enterprise GIS production system consists of one or more databases, which are accessed via enterprise services. These services are responsible for the maintenance and discovery of data, and for the generation of multiple products. Note that the ENC is only one of many possible products; it is not edited and doesn't form a data repository.

In addition to ensuring more consistent encoding of data, enterprise GIS solutions for ENC production allow for a smooth transition to marine spatial data infrastructures (SDI). S-57 maritime data is very rich in content and has many uses beyond navigation (IHO 2011b), including:

- coastal zone management
- exploration
- environmental protection
- maritime defence.

Government bodies are increasingly seeking the data interoperability that SDIs offer and are keen to realise the full potential of digital maritime data.

SCAMIN

S-65 provides a comprehensive recommendation for the encoding of SCAMIN for S-57 features. The encoding of SCAMIN can be automated accordingly within the production environment. Manual fine tuning of SCAMIN for certain features may be necessary; for example, a large scale ENC may encode a cluster of underwater rocks, whereas the respective small scale ENC may represent the hazard by a single underwater rock feature.

Inconsistent Contour Intervals and Edge Matching

VPF (US Dept Defense 1996) provides a practical mechanism of how adjacent data sets (tiles) are to be matched. First of all, tile boundaries are well defined by the GEOREF system. The GEOREF system will not allow for all of the scale ranges that are possible under S-57, but it does serve as a useful example on how to avoid data gaps and overlaps.

VPF also has the concept of "cross-tile topology", where geometry common to multiple tiles can be referenced by each tile. S-57 does not have the concept of "cross-tile topology", but features that span multiple ENCs can be assigned the same feature object identifier (FOID). S-65 states:

> Editing should also only be done within a specific tolerance so that the accuracy of the data is not impaired to too great a degree (IHO 2009, p. 18).

For adjacent ENCs, it is possible to go one step further and say that features that span cell borders need to join at the exact location(s) on the cells' borders. In ISO-8211 (ISO 1994) encoding this is possible since coordinates are stored as integers, before being translated to latitude and longitude via a coordinate multiplication factor.

Edge matching for overlapping ENCs of different scales is more complex. If the line work of a small scale ENC is generalised from data sourced from a larger scale, edges will match within a small tolerance. Of particular interest are depth contours. Not only can depth contours match particularly poorly between different scales (*Figure 5*), they are often encoded at different intervals. Data producers need to ensure that consistent contour intervals are displayed, throughout the seamless display, no matter what scale the data sets are being viewed at. For example, a data producer may decide that for a particular region, within the scale range of 1:22000 and 1:45000, the following contours are to be displayed, 0, 5, 10, 20, 30 and 50. Any ENC (large or small scale) that is viewable within that scale band needs to have the above mentioned contours encoded. This will necessitate careful encoding of SCAMIN on depth contours.

Large to Small Scale Transition Areas

Imagine the situation where a large scale ENC partially overlaps a small scale ENC. The large scale ENC has a series of 10 metre shoals encoded near its cell extents. The overlapped small scale ENC has the shoals generalised into a single contour. The contours are broken when the ENCs are displayed side by side (*Figure 10*).

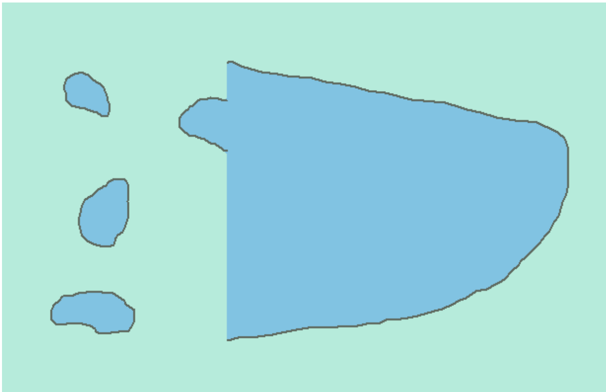

Figure 10. This is an example of a large scale ENC (left) overlapping a small scale ENC (right). The large scale ENC has a number of 10m shoals encoded, whilst the small scale ENC has the shoals generalised into a single 10m contour. The display is discontinuous at the boundary of the large scale ENC.

To resolve this situation, a *transition area* can be encoded at the boundary of the large scale ENC (*Figure 11*). The transition area provides the missing link between the large and small scale ENCs.

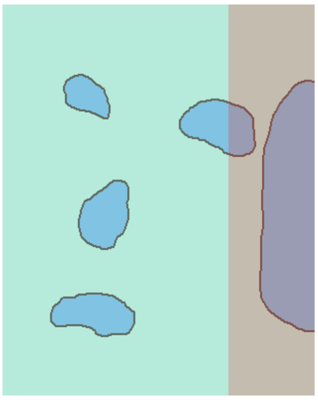

Figure 11. A transition area (shaded) has been added onto the eastern boundary of the large scale ENC.

Encoding the transition area removes the inconsistency and the display is now seamless (*Figure 12*).

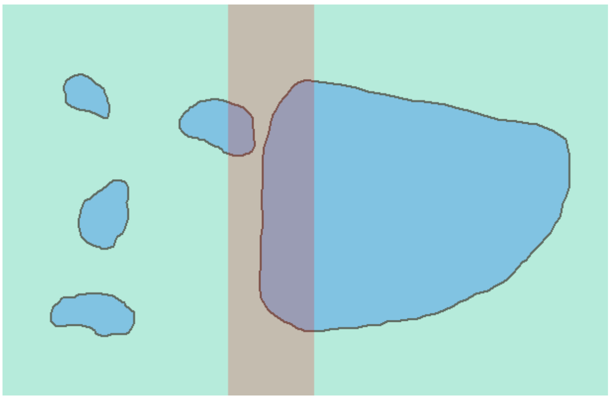

Figure 12. The transition boundary provides a seamless link between the large and small scale ENCs.

Vertical Reference Datum

It is important to note that, in order to match depth contours at cell boundaries, each ENC needs to have its depth values encoded relative to the same vertical datum. Lowest astronomical tide (LAT) is the recommended vertical datum (Hecht et al. 2006, pp. 75-76).

M_CSCLs and Holes in Data Coverage

Areas of large scale data need not be encoded in small scale ENCs as M_CSCL areas. It is better to encode such areas as separate large scale ENCs. The M_CSCL areas can be replaced with data generalised to the appropriate scale range of the ENC. Similarly, holes in data coverage (*Figure 7*) can be filled with appropriate generalised data, where available. The ENC production system should be capable to perform this generalisation as part of the ENC generation process.

Proposed Production Guidelines and Validation Checks

The implementation of the following production guidelines will result in greater consistency of ENC data. The guidelines also serve as validation checks, which can be included in S-58 and incorporated into ENC validation software packages. The current development of the S-101 ENC Product Specification provides a good opportunity to adopt these recommendations.

Overlapping Cells

This set of guidelines applies to cells that share the same geographic region and have different compilation scales:

1. Scale independent features that refer to the same real world feature must:
   - share the same geographic location;
   - have an identical set of attributes;
   - share the same feature object identifier (FOID).
2. Navigable water of a small scale cell must not overlap non-navigable areas of a large scale cell.
3. Navigable water of a small scale cell must be shallower or equal in depth to overlapping areas of navigable waters of a large scale cell.
4. Small scale cells should not have areas of no coverage (M_COVR with CATCOV=2) where there is coverage available in a larger scale cell (IHO 2009).
5. Small scale cells should not have areas of a higher quality rating (M_QUAL) than overlapped features of a larger scale cell.

6. Features that cross the cell boundaries of a large scale cell should have a corresponding match in the overlapped small scale cell. The corresponding features must:
    - meet at the cell boundary (within a small tolerance) (IHO 2009);
    - have an identical set of attributes;
    - share the same FOID;
    - have their exterior boundary edges masked (IHO 2009).

Adjacent Cells

This set of guidelines applies to cells that are of the same scale and are adjacent to one another:

1. Features that are continuous across shared cell boundaries must:
    - meet at the cell boundary (IHO 2009);
    - have an identical set of attributes;
    - share the same FOID;
    - have their exterior boundary edges masked (IHO 2009).
2. There should be no gaps or overlaps between cell boundaries (IHO 2009).

General Consistency

The following guidelines are applicable for all cells:

1. SCAMIN should be applied consistently, as set out in S-65 (IHO 2009).
2. The coordinate multiplication factor COMF should be the same for all cells and is recommended to be set to 10^7 (IHO 2009).
3. The vertical datum should be the same for all cells within the same geographic region.

Conclusions

Addressing ENC consistency is important for the overall quality of data, the ECDIS display, and ultimately the confidence that the mariner places in the underlying datasets. Guidelines for the production of individual ENCs are well established and the process of validating these has been achieved with great success. The challenge remains to produce ENCs that have data encoded consistently along cell boundaries and throughout the scale bands. The use of modern enterprise GIS systems, production guidelines and the ability to automate cross cell validation will result in consistent and higher quality ENCs. Enterprise GIS systems are required not only for the production of consistent ENCs, but also to meet the increasing government and inter-government requirements to develop spatial data infrastructures.

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