

Article

A PRACTICAL APPROACH TO THE PRODUCTION OF ENC WITH HIGH DENSITY BATHYMETRIC CONTENT

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Abstract

Over the last two years, the Australian Hydrographic Office (AHO) has published and maintained Electronic Navigational Charts (ENC) with greater scale and higher density bathymetric content than those derived from paper nautical charts. Land Information New Zealand (LINZ) is investigating the production of ENCs with high density bathymetric content which will likely replace the traditional berthing ENC.

This article describes the approaches adopted by AHO and LINZ to produce such ENC using current IHO standards. The article describes also how AHO and LINZ engaged with stakeholders to meet the demands of large ships navigating in confined waters with small safety margins.

ENCs with greater scale and high density-bathymetric content represent an opportunity for Hydrographic Offices to not only enhance safety of navigation under normal circumstances in confined waters, but also to potentially expand the range of weather and tidal conditions in which safe navigation may be conducted.

Résumé

Ces deux dernières années, le Service hydrographique australien (AHO) a publié et tenu à jour des cartes électroniques de navigation (ENC) à plus grandes échelles et contenant des données bathymétriques à plus haute densité que celles issues des cartes marines papier. Le Land Information New Zealand (LINZ) étudie la production d'ENC contenant des données bathymétriques à haute densité, qui remplaceront sûrement les traditionnelles ENC d'accostage.

Le présent article décrit l'approche adoptée par l'AHO et le LINZ pour produire ces ENC en utilisant les normes de l'OHI en vigueur. L'article décrit également la manière dont l'AHO et le LINZ se sont impliqués auprès des parties prenantes afin de répondre aux contraintes des navires de grande taille qui naviguent dans des eaux resserrées avec de faibles marges de sécurité.

Des ENC contenant des données à plus grandes échelles et des données bathymétriques à haute densité représentent l'opportunité pour les services hydrographiques non seulement d'améliorer la sécurité de la navigation dans des eaux resserrées dans des circonstances normales, mais également d'étendre potentiellement l'éventail des conditions météorologiques et de marées dans lesquelles il est possible de naviguer en toute sécurité.

Article

Resumen

En los dos últimos años, el Servicio Hidrográfico Australiano (AHO) ha publicado y mantenido Cartas Náuticas Electrónicas (ENCs) de mayor escala y con un contenido batimétrico de mayor densidad que las derivadas de las cartas náuticas de papel. *Land Information New Zealand* (LINZ) está investigando la producción de ENCs con un contenido batimétrico de alta densidad, que probablemente sustituirán a las tradicionales ENCs de las zonas de atraque.

Este artículo describe los enfoques adoptados por el AHO y por LINZ para producir tales ENCs utilizando las normas actuales de la OHI. Este artículo también describe cómo el AHO y LINZ se comprometieron con las partes interesadas para satisfacer las demandas de los grandes buques que navegan en aguas confinadas con pequeños márgenes de seguridad.

Las ENCs de mayor escala y de contenido batimétrico de alta densidad representan una oportunidad para que los Servicios Hidrográficos no sólo mejoren la seguridad de la navegación en circunstancias normales en aguas confinadas, sino que también amplíen potencialmente la variedad de condiciones meteorológicas y de mareas en las que se puede llevar a cabo una navegación segura.

1. Why official ENCs with high density bathymetric content?

In response to IMO ECDIS carriage requirements, many Hydrographic Offices used their paper chart series as the source for the relatively quick creation of ENCs. This is why most of the ENCs today contain only the standard series of contour lines mirroring the paper chart. The result is that ECDIS may not display a safety contour that is optimised for a vessel's draught, thus not allowing mariners the ability to clearly identify non-navigable waters and the full extent of navigable waters.

This is where ENC with larger scale and higher density bathymetric content (than any equivalent paper chart) enable ECDIS to fulfil its full potential. This emerging need is driven by the increasing size of vessels in relation to ports and their channels, pressure to maximise use of tidal windows, counteract stronger crosswinds or currents, and the consequent reduction of safety margins.

Electronic charts with greater scale and bathymetric content are not a novelty for many ports around the world. However, such charts are typically produced in 'closed' proprietary formats by Port Authorities and are used only by marine pilots on the Portable Pilot Units (PPU). Furthermore, not being official ENC, they cannot be used on ships' ECDIS. The difference in detail available to the Master and Pilot undermines one of the basic principles of Bridge Resource Management (BRM) which is the need to share the same mental model of the operation.

On the other hand, official ENC with greater scale and bathymetric content – equally available to both ECDIS and PPUs – can help ships' crews and marine pilots to be on the same page while navigating vessels in confined waters. Use of S-57 / S-63 ENC allows all parties to access and use the same information and is the solution preferred by the IHO ENC Working Group.

Before describing the experiences of AHO and LINZ with the planning, production and maintenance of ENC with high-density bathymetric content, it is important to clarify definitions and terminology used by the authors.

2. Definitions and acronyms

In 2018, the AHO decided to adopt the term High Density bathymetric ENC (HDbENC) to refer to an ENC product that includes bathymetry depicted with depth area intervals of 1 metre or closer, with the area of coverage generally limited to below the high water line, focussed on a physically constrained waterway, and only including relevant infrastructure in or directly affecting that area. The additional bathymetric information is incorporated in the base ENC dataset. Under the current IMO ECDIS Performance Standards, this product is suitable to be displayed and operated on any type-approved ECDIS and consequently it can be used to fulfil the IMO's chart carriage requirements.

The AHO specifies that "High Density" refers to a level of detail greater than the norm, which, for bathymetry, is generally taken to mean depth contours of 2, 5, 10, 15, 20 and 30 metres within the range applicable to surface navigation. Depth contours are therefore considered High Density when the interval between them is one metre or closer throughout the depth range applicable to surface shipping within the depicted area.

The suffix "Bathymetric" indicates that an ENC has been clipped such that the area of coverage is generally limited to below the high water-line and focussed on the bathymetry within a physically constrained waterway, but still containing all relevant information regarding aids to navigation and seabed features existing within the area of coverage. The AHO clarifies that HDbENC should not be confused with bespoke products – often misleadingly referred to as 'bENC' – where the additional bathymetric information is provided as a transparent overlay, but is not incorporated in the base ENC dataset. Under the current IMO ECDIS Performance Standards, this product is not suitable to be operated on all type-approved ECDIS and therefore it cannot be used to fulfil the IMO's chart carriage requirements.

In June 2019, the IHO ENC Working Group drafted production and maintenance guidance for High Density ENCs (HD ENCs) for inclusion as an annex to IHO S-65 (IHO, 2019). The AHO definition has been accepted in full, with only addition of the following sentence: "the product may also include more detailed port infrastructure". The IHO ENC Working Group has opted for the more general suffix High Density (HD) without the descriptor of the primary content being presented (e.g. bathymetric or topographic). The idea is to leave the High-Density concept open to either bathymetric or topographic content, or both.

However, to date, the IHO Hydrographic Dictionary Working Group has not endorsed the new acronym and definition of HD ENC yet.

In this article, the AHO author has chosen to keep the original HDbENC acronym, whereas the LINZ author has decided to use the HD ENC acronym. In both cases, the production processes described in the article refer to products with high-density bathymetric content only.

3. AHO experience – Background and Planning

In 2015 a cruise ship operator engaged in testing – by using a ship simulator – the safety margins of its 260m long vessels navigating within the 90m wide channel that leads to the Port of Cairns (***Figure 1***).

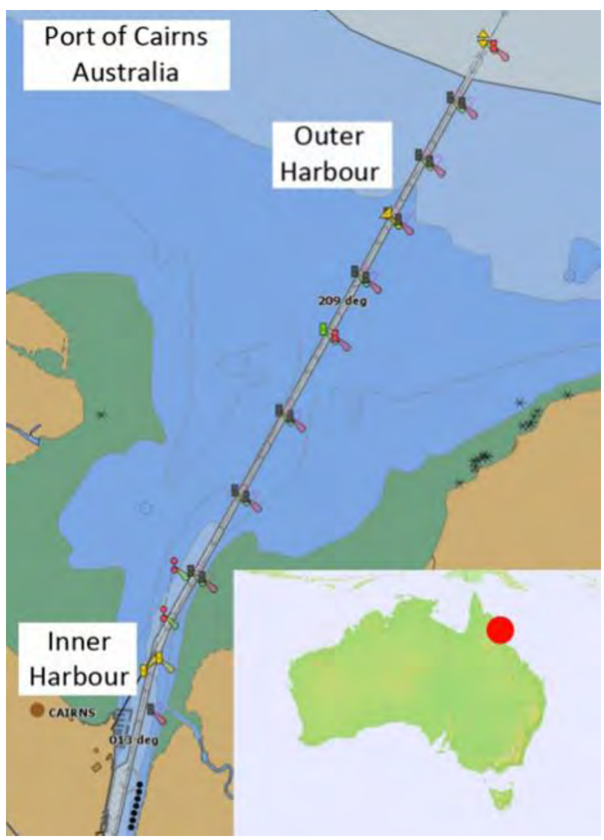

***Figure1**: Port of Cairns (Australia)*

However, the level of detail shown in the existing ENC (AU5 @ 1:22000) for the Port of Cairns was inadequate to assess the narrow safety margins. More resolution in depth contours and soundings was needed, and the AHO decided to support this existing project and produce the first HDbENC.

In 2016, the AHO organised a stakeholder meeting with the Harbour Master, Senior Pilots, a Port Surveyor and the AHO's regional production manager. Stakeholder meetings are a key milestone in achieving a mutual understanding before the production of HDbENC starts. Expected quality, geographic extent, and frequency of survey data need to be agreed with the Port.

Today, the AHO requires ports to submit a business case justifying the need for HDbENC and the proposed areas. On this basis, the AHO determines the best way to support each port's request and to establish production priorities as necessary.

In order to produce 'fit for purpose' HDbENCs, since 2016 the AHO has invested in training by enabling cartographers to attend simulator based ECDIS training together with Marine Pilots at Smartship Australia simulation facility. The intention has been to develop a mutual understanding between Australasian marine pilots, vessel masters and AHO cartographers on operational and cartographic needs based on simulation scenarios.

The need for larger compilation scales and for more depth contour ranges were often discussed with marine pilots. The most important realisation though, was that official HDbENC – available to both PPU and ships ECDIS – support effective Bridge Resources Management (BRM) practices in confined waters. With HDbENC, marine pilots and ships' crew can share the same understanding of safety margins (***Figure. 2***).

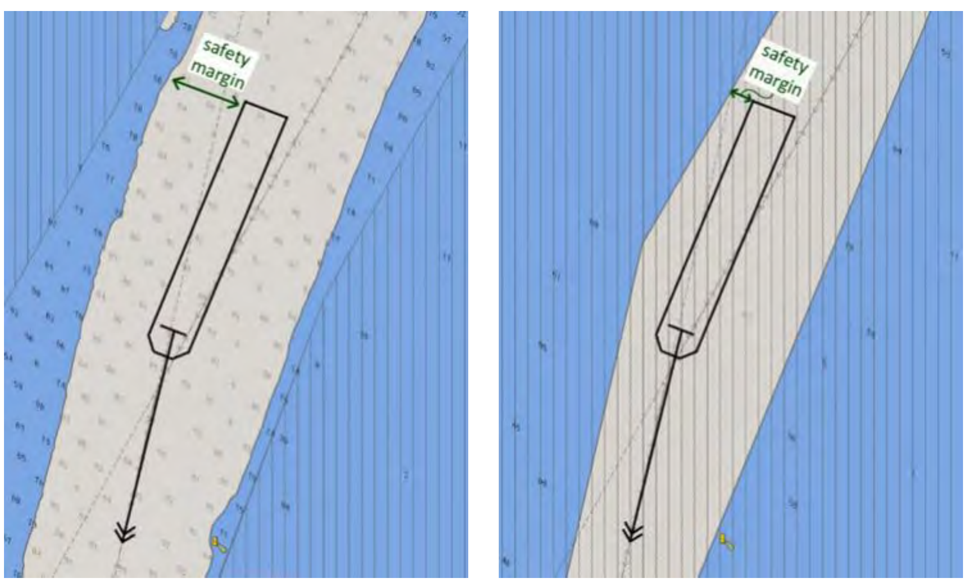

Figure 2*: Differences in safety margins displayed on HDbENC (left) and on Harbour ENC derived from paper chart (right)*

The mutual learning gained through simulation training has brought the AHO to define HDbENC as a product that:

- contains significantly denser depth contour ranges (every one metre or closer),
- are produced from S-44 Order 1 surveys
- cover dredged areas or congested waters in narrow passages
- are compiled at scales larger than 1:4000 (the AHO uses 1:2500)
- require frequent updates when new survey data is available

In order to update HDbENC within short timeframes the following principles were followed:

- Product extents should be defined based on specific port survey areas and frequency.

For example, if two geographically adjoining areas are surveyed at different times (quarterly and twice a year) two different HDbENC cells will be required.

- Once a HDbENC is produced its limits should change only in exceptional circumstances and with the agreement of the AHO.
- Survey data must completely overlap and exceed the HDbENC coverage area (M_COVR, CATCOV=1) by at least 20 metres. This is to simplify the automated generation of depth areas (DEPARE) and contours (DEPCNT).
- HDbENC are maintained by completely replacing its bathymetric content with new survey data. Therefore, replacement surveys must exceed the limit of the HDbENC and old survey data must not be merged.

4. AHO experience – Production and maintenance

The most important and time-consuming stage is the generation of the depth contours and their corresponding depth areas. For this task, the AHO used Caris Base Editor tool.

The first step was to create a bathymetric surface using the survey point data (ASCII) as a source. The key parameters used were 1 metre grid and shoalest depth true position.

The next step was to use Base Editor's function to automatically draw DEPCNT objects at a pre-defined interval (e.g. 1 metre) using the bathymetric surface as source. This step was repeated, but only to generate what the AHO calls 'intermediate' contours, which are depth contours with a value based on the maintained depth of any DRGARE that is now covered by the HDbENC (e.g. 8.7m). This step is included in order to satisfy specific stakeholder requirements, as it was determined that mariners would probably use these values as they are, to a certain extent, linked to the maximum operational depths.

Once all the depth contours were generated, the AHO used the 'Safe Laplacian' algorithm to slightly smooth the resulting line work and to reduce the overall "noise", i.e. a large number of very tiny and very close isolated depth areas. Bundling together these tiny areas into larger areas drastically improves the clarity of display. By using up to 10 iterations of the Laplacian algorithm, the horizontal accuracy of the depth contours is affected by up to 2 metres on the ground (see ***Figure 3 and Figure 4***).

Figure 3*: Difference between smoothing with 0 Laplacian (left) and 10 Laplacian (right) iterations*

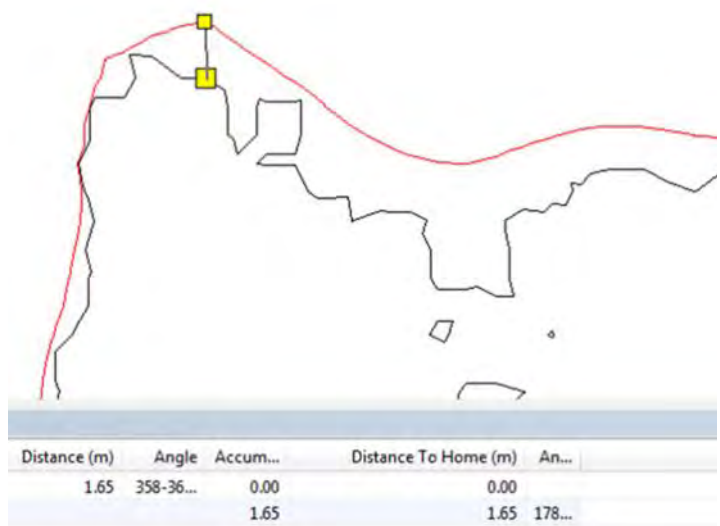

***Figure 4**: 10 Laplacians in red colour. Loss of horizontal accuracy is, on average, less than 2 metres*

'Tiny deeps' may be also deleted from the file in order to further declutter the screen. Depending on the sea bottom configuration, this step may not be necessary.

Using the line work prepared before, depth area (DEPARE) objects were automatically created by the software. The attributes DRVAL1 and DRVAL2 were auto populated using the DEPCNT values available in the sequence. This last step is not perfect and manual intervention may be required to encode DRVAL2 of the deepest deeps with a meaningful value (e.g. if deepest available contour was 16m, some deeps were encoded as DRVAL1=16 and DRVAL2=Unknown). There were also some problems with the DRVAL1 of the depth areas situated along the boundary of the survey, which also needed to be manually populated.

The last step to finalise the bathymetric component of a HDbENC is to crop (and delete outside) the DEAPREs and DEPCNTs using the M_COVR, CATCOV=1 previously supplied by the stakeholders. Considering that one of the survey requirements was to exceed the product coverage by at least 20 metres, this action will automatically create a topologically correct S-57 file.

A sounding suppression at the distance agreed with the stakeholders was performed and added to the file. SCAMIN was populated to soundings so they remain readable as ECDIS and PPU users zoom out. For the first HDbENC produced, soundings were requested at 50m intervals.

If at any point in time, Port authorities or the Hydrographic Office suspect that the accuracy of the data may have been compromised either by extreme events (such as heavy floods or cyclones) or simply when the agreed survey frequency cannot be guaranteed, HDbENC should be cancelled. The cancellation must be promulgated in advance via the NtM publication for, at least, a fortnight.

Once new survey data becomes available and the HDbENC is re-compiled, it can be re-issued as a New Edition (*.000 - Edition n / Update 0). The edition number must be one higher than the edition number of the cell that was cancelled.

In all cases, the Hydrographic Office should contact key stakeholders to discuss the situation that causes concern and decide on the most appropriate way forward.

5. LINZ experience – background and planning

In October 2018 'Navigation in pilotage waters' was put on New Zealand's Transport Accident Investigation Commission's watch-list (TAIC, 2018). This situation has arisen as a result of several recent incident investigations that identified that bridge resource management did not meet international standards. Miscommunication and a lack of common understanding among the bridge management team were recurring factors of these incidents. In November 2018, during the New Zealand Maritime Pilots Association conference, the pilotage community discussed how HD ENCs could help to achieve a shared mental model among the bridge management team.

LINZ has been working with the Port of Napier for the past year to develop a prototype of HD ENC. The aim is to accurately define non-navigable waters when approaching the harbour as well as to improve the use of available manoeuvring space.

When creating HD ENCs it is critical to achieve high levels of accuracy and completeness in areas of minimal under-keel clearance. Completeness, consistency, accuracy and timeliness standards need to be defined. Whilst most of these requirements were achieved during the hydrographic survey, which was executed to a specified standard, it is essential that data quality is maintained throughout all stages of production of HD ENCs.

Working in close collaboration with port stakeholders, LINZ learned the importance of ensuring the channel width and shape is charted as accurately as possible. This helped cartographers to understand the need for higher resolution data and how it will be used for safe navigation in confined waters. The usability of HD ENCs depth contours and soundings during pilotage, as well as their display on Portable Pilot Units and ECDIS (with regard to "small" or "angular" contours) were discussed during several meetings.

During stakeholder meetings it was agreed that the HD ENC for Port of Napier would be defined as follows:

- contain significantly denser depth contour intervals – 0.5m
- contain significantly denser soundings spacing – 30m
- produced from S-44 Special Order surveys to achieve CATZOC A1
- cover dredged areas or congested waters in narrow passages
- for update purposes a fixed boundary is to be defined which will reflect the extents of the HDENC
- compiled at scale 1:2500
- channel width needs to be retained as best as possible

6. LINZ experience – production

LINZ investigated different algorithms at the model level to find the "ideal" process to create uncluttered soundings and depth contours that clearly display the boundary between safe and unsafe water. The aim was to create an automated process that requires minimal or even no additional modifications.

The current common practice to generate depth contours and to select soundings for charting is either by gridding (where only the shallowest point is retained for every cell in a grid) or by interpolation (where each cell is assigned a depth that is an inversely distance weighted sum of nearby points).

Both methods produce the shallowest point for each grid cell but they do not guarantee safe contours because linear interpolation is used for contour creation. Using this approach with high resolution data may introduce topology issues like self-intersections.

A new approach to surface smoothing has become available in CARIS Base Editor software. Surface smoothing reduces noise by generalising the elevation model. The smoothing is guaranteed to move elevation values upward to maintain navigational safety.

The goal was to apply sufficient smoothing so that the resulting HD ENC is still safe, uncluttered and with correct topology and morphology. The focus was put on specific areas (deeps, shoals and channels) which were defined as important for safe navigation.

Caris Base Editor provides the following surface smoothing algorithms:

- Laplacian (restrained and cumulative)
- Rolling Coin and
- Expand Shoal

Surfaces smoothed with the Rolling Coin algorithm reduced the complexity of depth contours. Shoals are aggregated to larger areas within a distance tolerance, deeps are ignored and channel width and shape are preserved. However, contours produced from such an elevation model may appear to follow pixel boundaries to some degree and appear with rough edges.

These rough edges were reduced by applying the Laplacian 'restrained' algorithm to the Rolling Coin smoothed surface. Only a moderate amount of Laplacian smoothing needs to be applied as the majority of noise reduction has already been accomplished by the Rolling Coin algorithm.

Machine contouring of the Rolling Coin/Laplacian smoothed surface created a lot of tiny shoals outside of the Rolling Coin tolerance that required manual intervention as there is no automated tool to correctly enlarge them. The manual effort required to edit these shoal contours had a significant impact on the time and efficiency of creating the HD ENC.

One of the goals of the prototype exercise was to establish an automated process for producing HD ENCs that require minimal or even no additional manual interventions. The Rolling Coin/ Laplacian approach did not meet this goal.

The third surface smoothing option in Base Editor, Expand Shoal, can be used to automatically enlarge tiny peaks in the bathymetric grid. Choosing appropriate parameters for shoal expansion ensures that soundings fit within the derived contours. In ***Figure 5*** the black contour is the result of the expand shoal smoothing, as opposed to the blue contour, without expand shoal function.

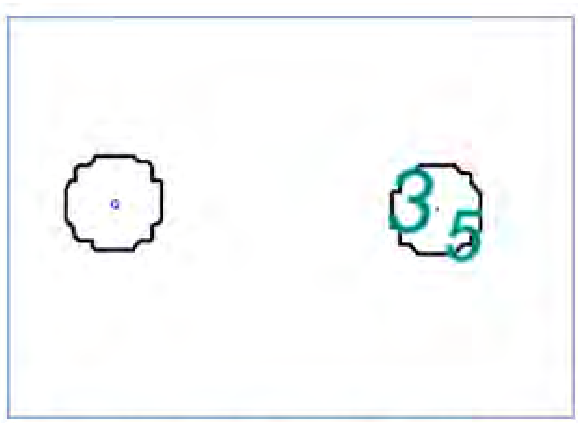

Figure 5: *Result of Caris Base Editor "expand shoal" functionality*

LINZ as found that three steps are required to produce the optimum smoothed surface; firstly the Expand Shoal algorithm is applied to the grid which is then smoothed using the Rolling Coin and finally the Laplacian restrained algorithm.

The next step is the generation of depth contours, which, in HD ENCs, have smaller intervals than traditional ENCs. If depth contours have been created based on a re-gridded surface, topology issues like self-intersections are likely to appear. To eliminate these problems within HD ENCs, depth contours should be generated from the smoothed surface.

LINZ has identified that choosing the optimum smoothed surface is vital for automated depth contour creation, so that the contours are fit for purpose and do not require further generalisation (***Figure 6***).

***Figure 6**: Contours based on Rolling Coin smoothing only (left), on Rolling Coin with contour generalisation (centre), on Rollin Coin and Laplacian smoothing (right)*

Comparing HD ENC contours derived from a smoothed surface, with contours derived from a re-gridded surface, it is very clear that the channel width and shape have been preserved without sacrificing the depth of the channel (***Figure 7).***

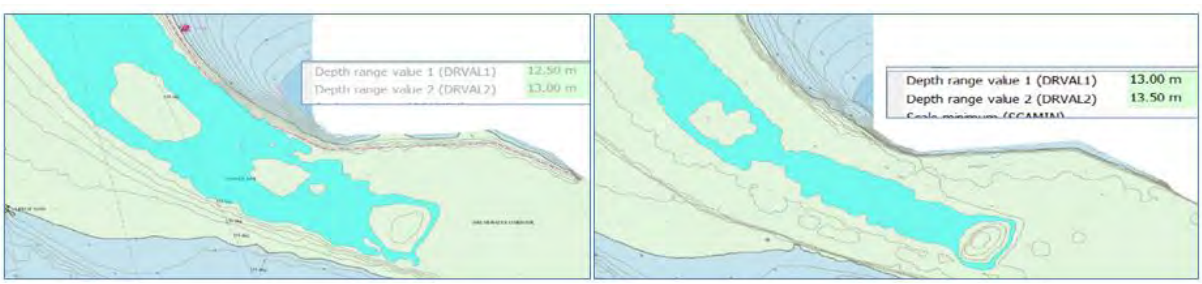

***Figure 7**: Contours based on re-gridded surface (left) and based on smoothed surface (right)*

HD ENC soundings have been generated from the unsmoothed original surface to force depths to be in their true position. This can lead to a few soundings that are deeper than the surrounding depth area, but they can be ignored because they are not safety critical.

LINZ is now investigating how to fully automate the production process for creating a high quality and reliable product. A business case will be developed to justify the need for a HD ENC and a decision matrix for the prioritisation of requests for HD ENCs from port operators. From experience, stakeholder engagement will be an important component in the development of future HD ENCs to ensure their expectations are met and they understand their role in these products.

7. Conclusions

ENCs derived from paper charts were necessary to make possible the transition from paper charts to ECDIS navigation. Today's surveying and cartographic technologies make it possible for Hydrographic Offices to enhance the ENC content and deliver products that can meet the demands of navigation of large vessels in confined waters, as well as enabling marine pilots and ships' crew to share the same mental model of the pilotage on Portable Pilot Units and ECDIS.

After more than one year of testing, process improvement and ongoing discussions with stakeholders, the Australian Hydrographic Office and Land Information New Zealand have proven that it is possible to fulfil emerging mariners' needs to incorporate high-density bathymetric content in official charting products using existing IHO standards.

By using appropriate software tools and following well-structured workflows, these complex products can be produced, quality controlled, validated and made available to mariners in a timely manner using existing distribution channels.

Meanwhile as IHO S-100 products make their way to the bridge of ships as 'official' products, ENCs with greater scale and high-density bathymetric content represent an opportunity for Hydrographic Offices not only to enhance safety of navigation, but also to "enable" navigation in confined waters, thus contributing to develop blue economies.

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