A Methodology to Design a Rational Static Under-keel Clearance Rule for Dredging and Operations

Mark Bennet[1] and Giles Lesser[1]
[1] OMC International, Melbourne, Australia; m.bennet@omcinternational.com

Abstract

An under-keel clearance (UKC) rule of some form exists at all draft limited ports with a direct impact on throughput and dredging. Dynamic UKC (DUKC®) systems [1] are now used by many ports in Australasia as a tool to manage UKC more efficiently and reduce grounding risk. However, some ports still use a static UKC rule such as “10% of draft” based on a declared channel depth. This static UKC allowance must include all safety factors and components of the anticipated vertical keel position of vessels transiting the port. For some ports, a simple rule is adequate, has been put in place entirely rationally, and may have served the port well for many years. Often though, static UKC rules are overly conservative and occasionally unsafe. Further they can be applied incorrectly, or the origins are not known or understood by those who rely on them.

This paper describes a methodology developed using state-of-the-art DUKC® modelling to design a rational static UKC rule for a port with implications for navigation, scheduling, accessibility, and dredging clearly defined. The method uses measured environmental data to calculate required depths for many simulated transits. By comparing the DUKC® required depth with the proposed static UKC calculation, a distribution of required UKC allowance throughout the port is extracted. This allows assessment of the UKC allowance required for any given percentage of transits to be performed within best-practice DUKC® safety allowances for real environmental conditions.

The methodology has been previously applied as part of the Port of Lyttelton’s recent capital dredging program, however this paper illustrates application of the methodology at South Port NZ where it was used to validate the Port’s existing static UKC rule, which was long-standing, but not well understood by all parties. The methodology highlighted details of the application of the rule which were critical to safe operations, and clarified the applicability of the Port’s traditional UKC rule to the proposed capital dredging and deeper vessels.

Keywords: under-keel clearance, navigation, dredging, channel design, port planning.

1. Introduction

At all draft limited ports under-keel clearance (UKC) is a key factor in their design and operations. The UKC affects the draft and load capacity of each individual vessel, the navigation and passage planning of any transit, and overall port throughput. The UKC management is a key variable in channel design and any dredging the port may undertake.

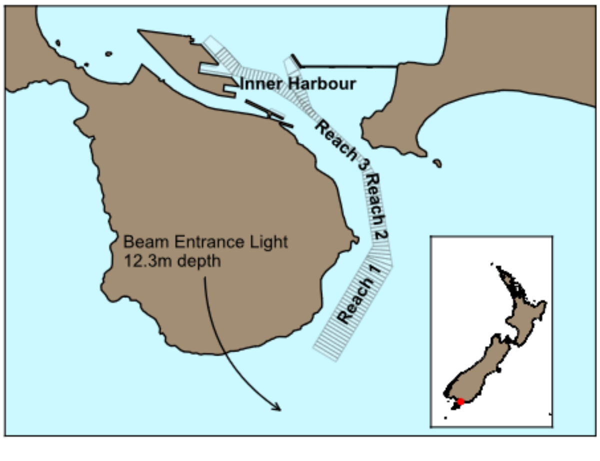

Figure 1 Map of Bluff operated by South Port NZ, showing the different reaches of the channel. Reach 3 and the Inner Harbour are UKC controlling.

South Port, who operate in Bluff NZ, were looking to increase the maximum departure draft of vessels from the port on a “standard” tide, from 9.7m to 10.45m. A preliminary plan had been prepared by the port to dredge the channel to the depth required by their existing operating procedures and static UKC rule to accommodate the increase in draft. The existing static UKC allowance was 1.2m in Reach 3 and 10% of draft in the Inner Harbour [3], both calculated using the daily predicted astronomical high-water levels. This UKC rule was well established at the port and had served safely for many years, but its origins were not well understood.

South Port NZ approached OMC International to investigate the suitability of the UKC rule and to answer two key questions:

- Is there a rational basis for the UKC rule?
- Could the UKC rule be safely modified to reduce dredging volumes?

This is a familiar scenario to many ports, albeit with different physical challenges and operating criteria. This study refined and applied a rational method to evaluate and design a static UKC allowance for the port using a best-practice dynamic UKC analysis.

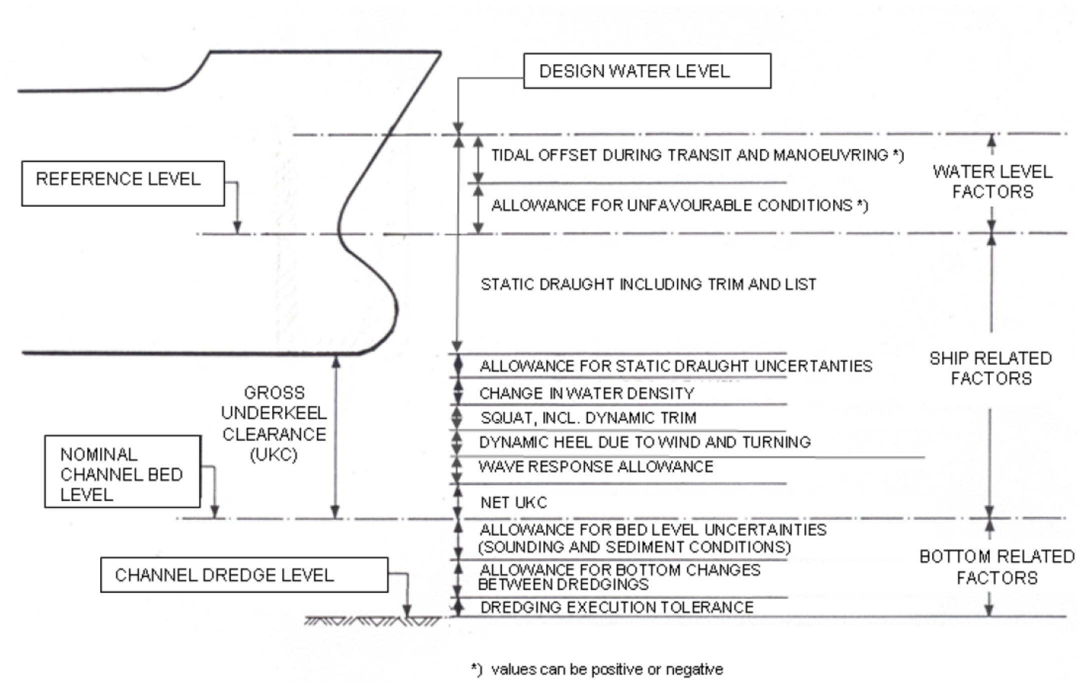

Figure 2 Channel depth factors, showing all factors relating to channel design and a UKC calculation (Source: [2]).

2. Under-keel Clearance Methods

Under-keel clearance is the vertical distance between the keel of a vessel and the seabed. A UKC rule at any port is the method the port uses to ensure this vertical distance remains great enough to maintain safety through the whole channel for any transit.

For the design of vertical channel dimensions, guidelines are given by PIANC in the 2014 Harbour Approach Channels Design Guidelines [2]. These outline how the vertical design of the channel and a UKC rule is influenced by three groups of factors: water level, ship-related, and bottom-related factors.

When designing a channel there will always be a trade-off between minimising dredging and maximising the draft of vessels using the channel. There will also be a planned percentage of time and conditions where transits can safely occur in the channel without restrictions. In other words, for operations to continue X% of the time, channel design and usage must allow for the X% worst combination of all vertical factors. The variation of conditions on all fronts, is usually encompassed by the UKC rule at the port.

For operational decision making the port must apply some kind of UKC “rule” to decide whether each individual transit can occur given the conditions expected at the time. In general, they can choose to use an all-encompassing “static” UKC rule or use a dynamic UKC system to make a specific prediction for each individual transit.

A static UKC rule is a vertical factor which allows for all vertical variables and consistently applies to all transits. It must allow (conservatively) for all conditions that could occur up to the port’s appetite for risk. For example, if a static UKC allowance was designed for 95% operability, then every transit will occur in that port allowing for a 95% percentile worst combination of tidal residual, wave, current etc. By definition, this allowance would be overly conservative 95% of the time, and non-conservative 5% of the time.

In contrast, a port using a DUKC® system will perform passage plans using the specific vessel characteristics, planned route and speeds, and measured or forecast conditions at the time of sailing. All vertical factors will be predicted, together with a net UKC allowance for safety and manoeuvrability for that vessel on the day. When conditions are unfavourable the allowable drafts will decrease as the dynamic UKC allowance increases. When conditions are benign the opposite is true, and drafts will increase while the same risk profile is maintained.

For this paper, dynamic DUKC® modelling is used to design or check a suitable static UKC allowance.

3. Design Methodology

3.1 Set up a Dynamic Model and Run Simulations

A DUKC® model of the port is set up. This includes high resolution bathymetry, channels and routes, navigational speed profiles and planned manoeuvres and a list of design vessels for the planned port operations. An environmental model is also defined with spatial models for all significant metocean conditions at the port including tides, water currents, winds, waves, and long period waves.

With the DUKC® model configured, a history of measured or hindcast environmental data at key reference locations is sourced for performing the simulations. This period should span at least a year to capture any seasonality, and ideally would be more. Through this study period, design vessels are simulated through the DUKC® model for inbound and outbound transits for all tide cycles. This generates a database of DUKC® transits, simulating real conditions at the port, for all times when vessel could possibly undertake transits. This database of transits provides a statistical distribution of the UKC required for bottom clearance and manoeuvrability calculated by the DUKC® for all sections of the channel, over a wide range of real conditions at the port and forms the basis for the statistical analysis to design the required static UKC allowance.

3.2 Define a Static UKC Rule

A static UKC rule can be written as

$$Tide + Minimum\ Channel\ Depth - Draft \geq UKC_{static} \qquad (1)$$

Where the UKC_{static} is the **Required Static UKC Safety Allowance**. For any port extra variables could be included in the left hand side of this equation, such as an applicable squat calculation or a wave response lookup table, effectively taking them out of the single catch-all UKC Allowance and making the UKC rule somewhat “dynamic”. In this case any extra variables would need to be included in Equation 2 below.

3.3 Calculate Required UKC Allowance

The method uses the DUKC® results as a measure of best-practice UKC management. The UKC allowance required by DUKC® was calculated for each transit and position along the channel (t and i respectively) by

$$Required\ UKC\ Safety\ Allowance_{t,i} = DUKC\ Required\ Depth_{t,i} - (Draft - Tide) \qquad (2)$$

By repeating this process for all the transits and channel nodes, a distribution of the UKC Allowance required by DUKC® can be calculated for all positions along the channel, accounting for all the environmental, vessel, and transit conditions included in the DUKC transit database. An example distribution for a single location is shown in Figure 2.

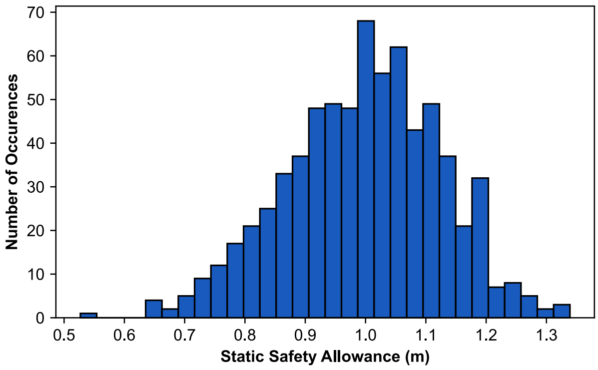

Figure 3 An example distribution of Required Static UKC Safety Allowance for all departure transits of a 280x40m container design vessel in a range of conditions at a single point in a channel. In this example a static UKC safety allowance of 1.3m is required to enable almost all transits to safely occur.

3.4 Assess and Select an Appropriate Static UKC Allowance

The resulting distribution of static UKC safety allowance required for each point along the channel can be extracted and the upper percentiles plotted for each vessel class. This allows assessment of the UKC allowance required to allow any given percentage of transits to be performed within best-practice DUKC® safety allowances at each location along the channel.

This process is performed for each vessel class to determine if different rules are applicable for different vessels, before consolidating into an understanding across all vessel classes and transit directions for the port.

4. Application at South Port NZ

4.1 Area Description

South Port runs a container trade as well as export of logs; there is also import of alumina and export of aluminium from the Tiwai Point smelter. Inbound vessels approach from the south into Reach 1 and 2 before turning into Reach 3 and entering the inner harbour (Figure 1). Reach 3 is typically the controlling location for UKC and manoeuvrability. It is the shallowest stretch of channel with a rock bottom, and experiences high tidal currents through the constriction.

At South Port the existing UKC rules stated that, *“A safe draft is one whereat a given vessel will maintain an under keel clearance (UKC) of at least 1.2m in No.3 Reach and 10% of its draft in the Inner Harbour.”* [3] This is calculated using the predicted astronomical HW. Additionally, in the port procedures there was a table of maximum drafts for a range of tide heights from 0 to 3.0 metres. For tides less than 1.5m, during the low water slack, the static UKC allowance applied in this table was 1.5m. During the highest high tides, from 2.5-3.0m the UKC allowance also increased from 1.2 to 1.5m, thereby limiting the maximum allowed drafts somewhat. The reason for this difference was not clear, and so became part of the purpose of this study: to answer the question, is there a rational basis for the existing UKC rule?

Sailing windows at South Port are controlled by current speeds in Reach 3. These current limits were determined by the port and pilots during bridge simulation exercises in 2017 [3]. Arrivals target HW slack at Reach 3 while departures target the last of the flooding tide with current speeds no more than 1 knot.

4.2 Model Setup and Simulations

A DUKC® model of the port was set up for the inner harbour and approach channel. The DUKC® environmental model was set up with port and environmental data and was configured using the results of a separate hydrodynamic modelling study completed by others in parallel with this project.

The DUKC® model for South Port included:

- High resolution bathymetry data
- Channel definitions, berths, and manoeuvring areas
- Measured tide and tidal residual differences from astronomical predictions
- Spatial tide variations through the port and channel
- Long period waves (LPW)
- Squat, per vessel class, using standard DUKC® formulations
- Inertial heel

Wave response was not modelled for the region of the channel being investigated as it is sheltered from swell.

The DUKC® performs two UKC checks in line with PIANC recommendations [2]. These consist of bottom clearance (BC) and manoeuvrability margin (MM) checks. BC checks for touching the bottom due to all vessel motions. MM checks for loss of manoeuvrability due to insufficient water flow around the keel. For South Port standard DUKC® dynamic BC and MM UKC limits were applied.

Simulated transits were configured for the fleet of design vessels to operate inbound and outbound from the port. This included typical speeds through water and manoeuvre times determined in consultation with South Port Pilots. Every vessel/transit combination was simulated to transit on every tide cycle during the simulation period. In line with procedures at South Port [3] arrivals targeted HW slack in Reach 3 and departures targeted the last of the flooding tide, about 30 minutes before HW slack. 704 transits were modelled per vessel/transit combination using environmental conditions observed between June 2019 and June 2020.

4.3 Results

The UKC rule at South Port is calculated using the astronomical high-water prediction. Therefore, using the DUKC® simulated transits, the required static UKC safety allowance was calculated as

$$Required\ UKC\ Safety\ Allowance_{t,i} = DUKC\ Required\ Depth_{t,i} - (Draft - Astonomical\ HW\ height) \qquad (3)$$

The resulting distribution of required UKC allowance for each node along the channel was extracted and the upper percentiles were plotted for each vessel class. In the following discussion, results for an outbound large container vessel (Figure 4) and inbound bulk carrier (Figure 5) are presented. These were the two most controlling vessels as they are modelled to have the greatest squat in Reach 3. They further illustrate the difference that transit timing and direction can make to UKC requirements.

These visualisations enable the range of UKC allowances through the channel to be seen clearly and show the points at which critical UKC occurs.

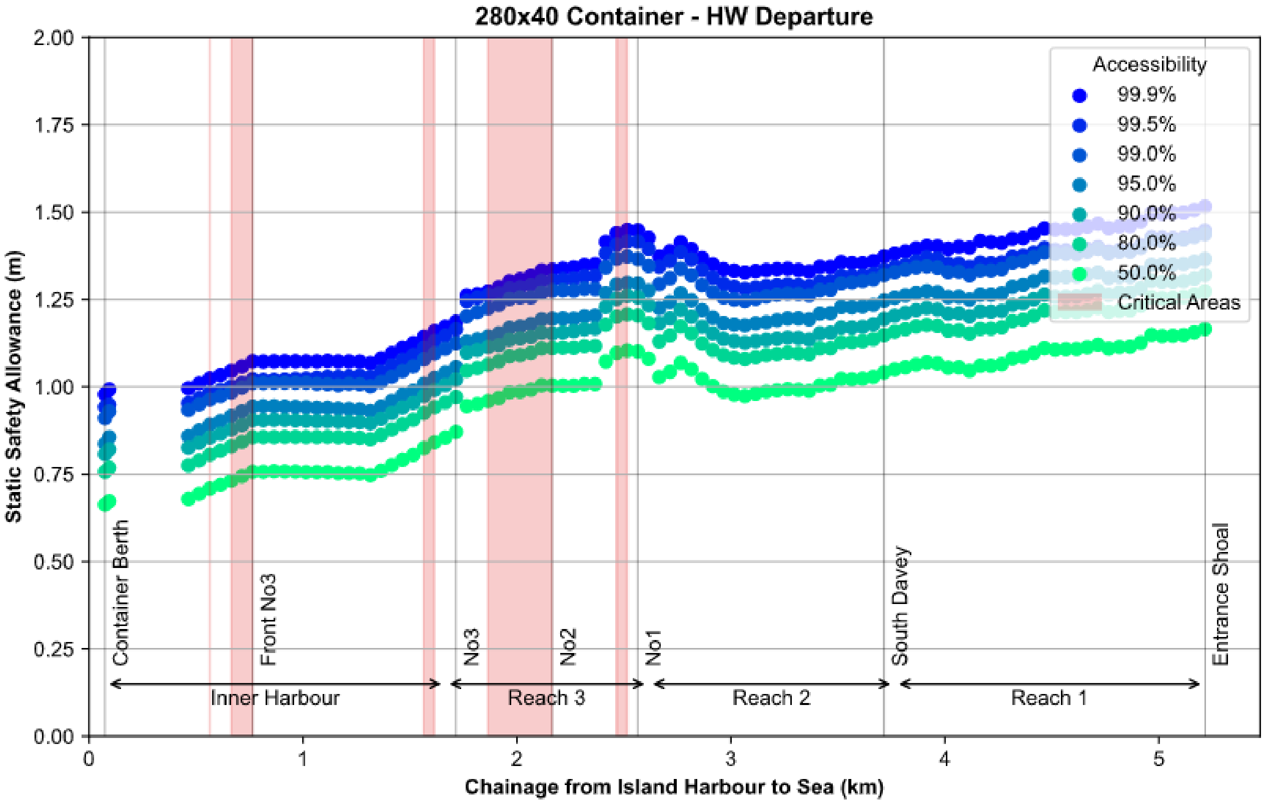

Figure 4 Calculated UKC allowance required along the channel for the 280x40m Container outbound on the HW for a range of accessibility percentages. The critical UKC areas are shaded in red. This enables a UKC allowance to be chosen to enable transits to occur safely in a selected percentage of conditions.

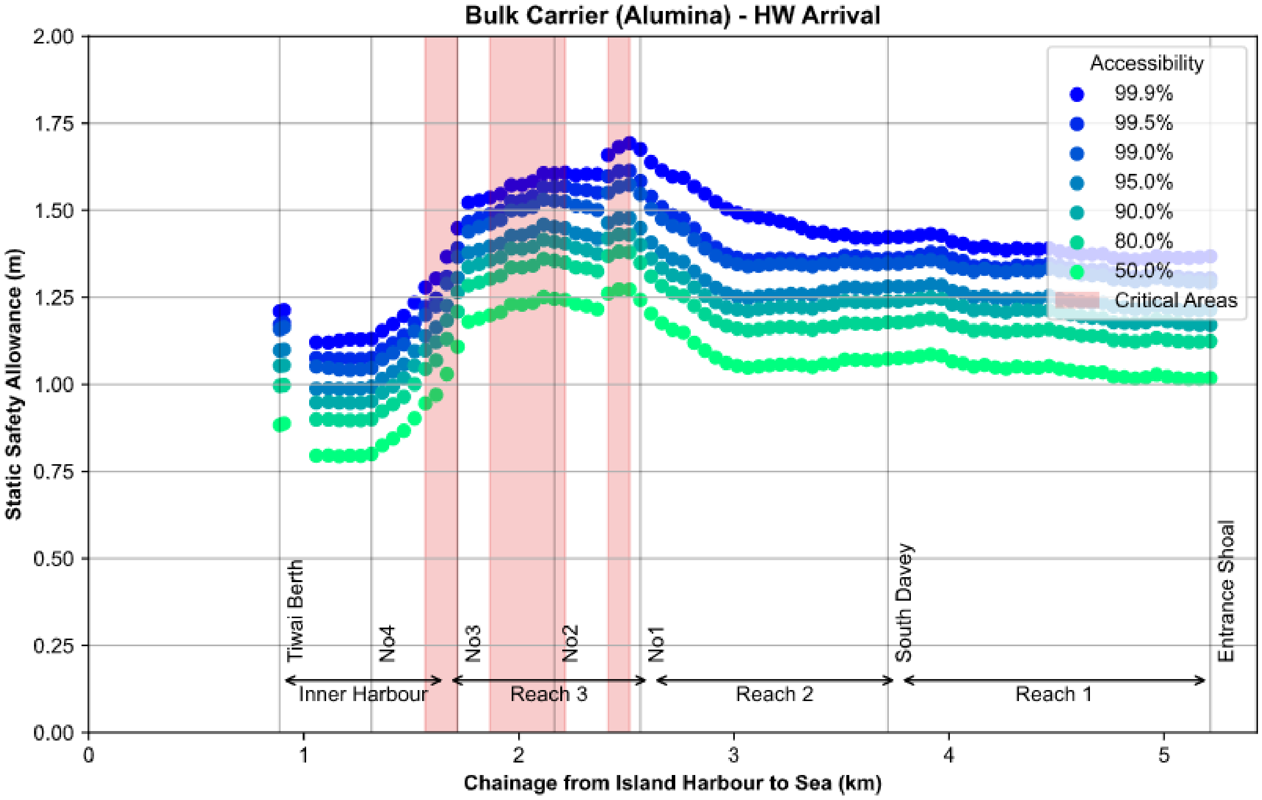

Figure 5 Calculated UKC allowance required along the channel for the 200x38m Bulk Carrier (Alumina) inbound on the HW for a range of accessibility percentages. The critical UKC areas are shaded in red.

In both cases Reach 3 is the critical region, especially at the outer end at the bend into Reach 2. The analysis showed that, if simply applied to the astronomical HW/LW predicted tide levels, the existing static UKC allowance used at South Port is non-conservative in Reach 3 when compared to dynamic allowances for all factors which need to be allowed for in a simple static UKC allowance.

Taking a 99.0% confidence level as a reasonable level for the purpose of illustration, results show that a UKC allowance of 1.4m is required in Reach 3 for the outbound container vessel, and 1.6m for the inbound alumina carrier – both significantly more than the 1.2m allowance.

A key consideration at South Port is that the existing static UKC rule was stated to use the astronomical HW prediction. Analysis showed that this simplification introduces a large amount of uncertainty through a combination of three factors that are not included in the astronomical high water prediction:

1. Tide residuals at the Pilot Wharf range between -20cm up to +40cm.
2. There is a delay between HW (when the UKC is calculated) and slack water (when the vessel is in Reach 3). For the transits modelled this results in a lower water level at sailing time by as much as -20cm.
3. Deep-draft transits occur at slack high water when there is a spatial water level gradient arresting flow of water before ebb flow starts. For the simulated transits, this water level gradient resulted in water level at locations of critical UKC being up to 20cm lower than at the Pilot Wharf tide gauge in the Inner Harbour.

These effects can combine and result in much less water available at critical UKC locations than indicated by simplistic application of the port's static UKC rule.

4.4 Discussion

The objective of this study was to understand and assess the existing static UKC rule used at South Port.

This analysis confirmed that Reach 3 is a critical region for UKC. By using the DUKC® to test the common understanding of the static UKC rule which is stated as "at least 1.2m in No.3 Reach" calculated using the astronomical HW, it was found that, under certain circumstances, this allowance was insufficient and should be increased by as much as 40cm. The analysis also identified that the static UKC rule needed to allow for the deviation of actual tide levels from astronomical predictions, the fact that HW does not occur at slack water, the spatial gradient in tide level experienced at slack water, and the possible impact of transient water level set down due to LPW.

Discussing these findings with the full pilotage team at South Port revealed subtleties in the application of the port's UKC rule which effectively addressed most of these potentially concerning outcomes. The static rule as stated using the astronomical HW is used for planning purposes, but for operational decisions there are extra allowances made.

- In the maximum draft table in port procedures [3] described in Section 4.1, the increased UKC allowance of 1.5m for higher tides exists to allow for greater fall between HW and transits at slack water during these large tides.
- Pilots do check the tidal residual at the time of sailing, and if there is a lower tide than predicted, maximum drafts are reduced accordingly.
- Pilots are aware of, and avoid, the shallowest areas of the entrance channel. This effectively introduces extra available UKC compared with the calculation performed using the shallowest channel depths.

This study highlighted the importance of these subtleties and enabled them to be understood by the full pilotage team, while also highlighting the presence of the tidal gradient through Reach 3 and the effect of LPW on the UKC of vessels in the port.

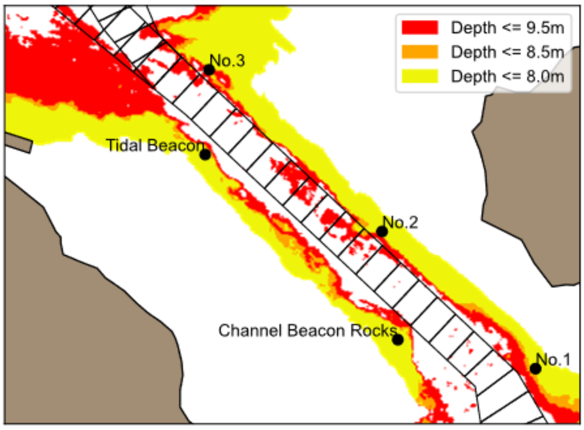

Figure 6 Shallow depths and future dredged regions after dredging in Reach 3.

A further outcome was identified relating to depths, with ramifications after planned dredging. The declared depth in Reach 3 was 8.5m which the UKC is calculated to. As Figure 6 shows this depth was at the northern edge of the channel. This was well known by pilots, and they accordingly keep towards deeper water on the southern side of the channel. Thus, effectively having somewhat more static UKC than required by the written procedures. However, when dredging occurs to a new declared depth, the new shallow areas will not be able to be avoided, and operations would become riskier if the UKC rule was not properly applied.

The result of applying this methodology with South Port was confirmation of the rationale behind a deceptively simple static UKC rule and clarification of the manner in which it should be applied in operations and planning. This improved understanding serves as a firm foundation for the design of capital dredging and ongoing safe operation of whatever channel and future vessel fleet the pilots are required to operate with.

5. Conclusions

The methodology presented provides a clear scientific method to design and assess a static UKC rule at any port or channel. By using a DUKC® system, informed by a history of environmental and operational data, a static UKC rule can be designed and appropriate UKC allowances chosen to allow any required percentage of transits at the port to do so safely within best-practice DUKC® safety allowances.

This method has been successfully applied at South Port to aid them in understanding their long-standing UKC rule. The analysis validated the existing UKC rule but clarified the way that the rule must be applied at the port, which previously appeared to be understood by only a few key stakeholders. The study enabled South Port to confidently move forward with planned changes and quantify dredging in UKC critical areas identified by this study.

6. Acknowledgements

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7. References

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