DUKC
Dynamic Under Keel Clearance

Information Booklet

Prepared in association with

Dynamic Under Keel Clearance (DUKC) integrates real time measurement of tides and waves with modeled vessel motions to maximise port efficiency and safety.

By monitoring individual vessel characteristics and sea conditions, vessel drafts and tidal windows for harbor transits can be maximised. In order to achieve this, the DUKC system determines the Net Under Keel Clearance and maneuverability requirements for vessels undergoing transits through shallow water. The factors considered by the system in performing the real time analysis are vessel motion, tidal rise and fall, including meteorological effect vessel squat and heel. Fixed allowances for siltation, survey and draft tolerances are also catered for.

Vessel drafts and sailing windows are maximised by the system, subject to internationally accepted guidelines regarding minimum Bottom Clearance (BC) and Maneuverability Margin (MM) requirements. This is done by performing rigorous modeling to determine the maximum safe draft for vessels and by accurately predicting windows of opportunity for safe sailing.

The scientific methods the DUKC uses are considerably more accurate than previously used Standard Under Keel Clearance (SUKC) techniques. This allows error margins to be greatly reduced whilst maintaining high safety standards. The accurate prediction of Tidal Windows enables vessels to take the greatest advantage of available sailing times, maximizing both efficiency and safety.

Under Keel Clearance Theory

The Gross Under Keel Clearance is found by subtracting the vessel draft from the amount of water available (depth + tide). Bottom Clearance (BC) describes the clearance left from the Gross Under Keel Clearance after subtracting ship motion caused by swell, squat and heel together with safety allowances for siltation, survey tolerances and draft.

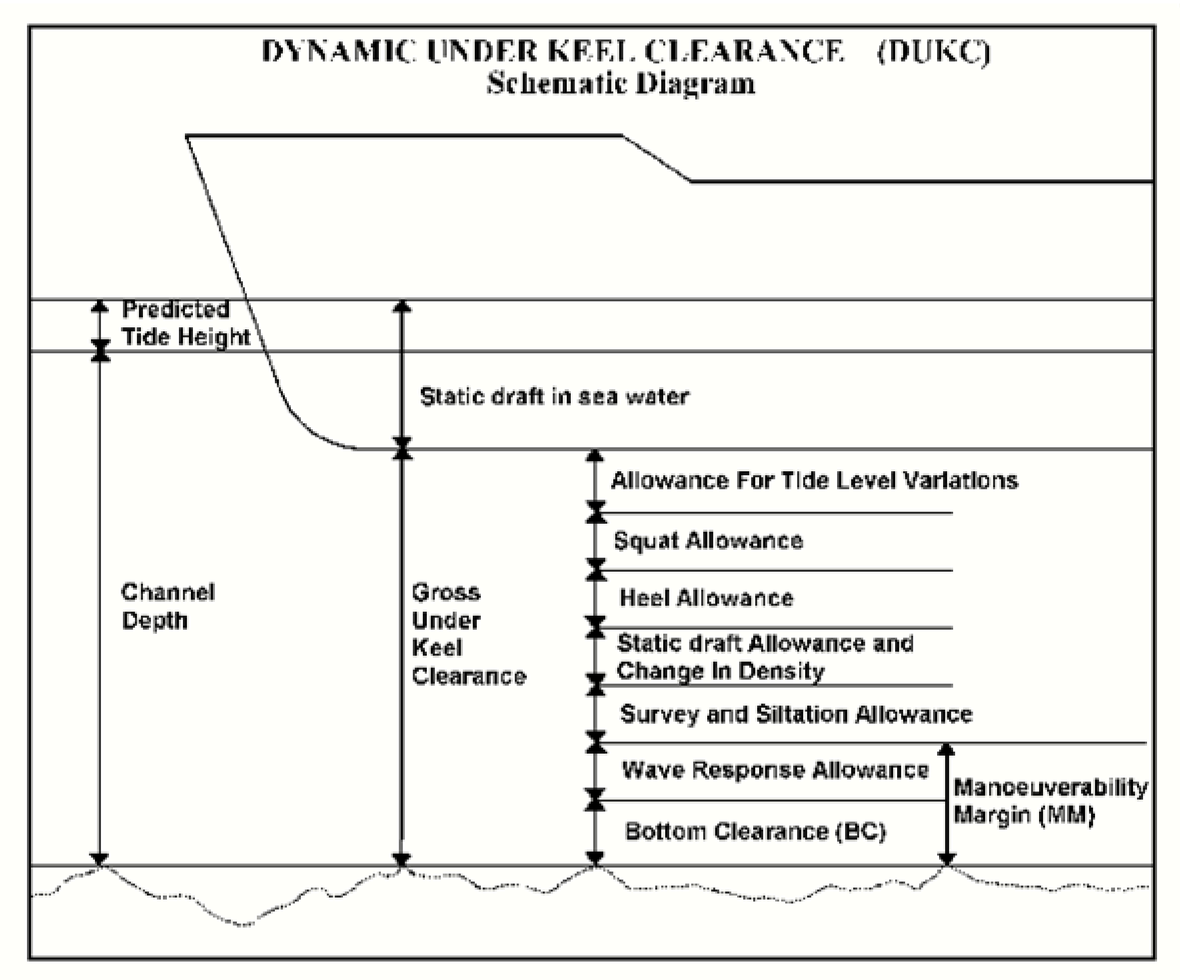


Figure 1 Factors contributing to Under Keel Clearance

Ship maneuverability is related to the ability of a ship to perform intended maneuvers without the assistance of tugs. The ability to manoeuvre will decrease and it is unsafe when the actual clearance is reduced below a critical value. This is called the Manoeverability Margin (MM). The MM is not strongly influenced by vertical ship motions caused by swell, therefore the Wave Response Allowance is not a factor in the MM. The factors determining BC and MM are illustrated in figure 1 above.

In the context of the DUKC system, BC and MM are related by;

$$MM = BC + Swell\ Allowance$$

The key variables relevant to Under Keel Clearance (UKC) are:

1. Tides,
2. Vessel Motions (caused by swell)
3. Squat
4. Heel

1. Tides
In the DUKC system, tides are modeled along the transit channel in or out of the harbour. The modeling is based on predicted tides with allowances made for variations from the predicted tide as a result of meteorological factors such as barometric pressure and wind effects.

2. Vessel Motions
Ships experience six degrees of motion freedom, that is surge, sway, heave, roll, pitch and yaw, induced by the sea state.

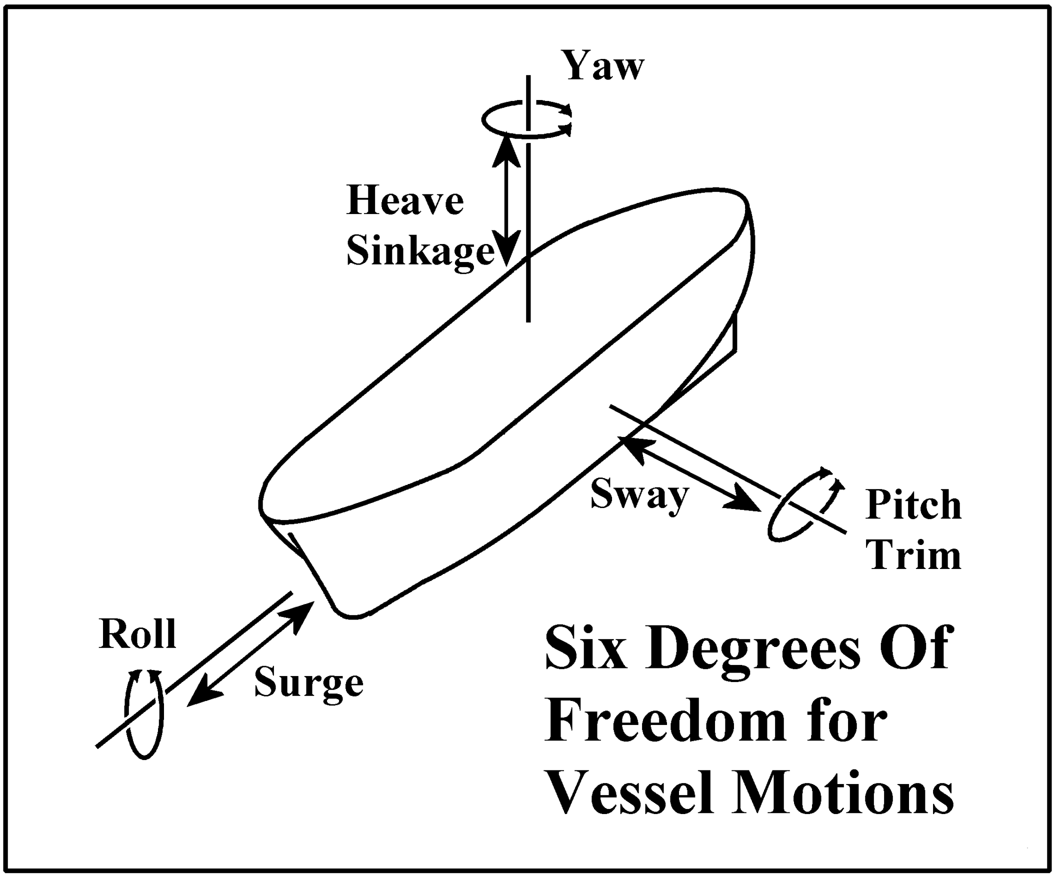


Figure 2 Six degrees of freedom for vessel motions

3. Squat
Squat is a combination of bodily sinkage and change in trim of a vessel while under way. There are several factors which affect squat, the most important being vessel speed through the water. For example, if the speed of a ship is trebled, the squat experienced is increased by more than ten times.

4. Heel

Heel as calculated by the DUKC is the dynamic angular movement of the vessel from the vertical in the traverse plane. The DUKC inputs used to calculate heel are Sailing Draft, Beam, KG, GMf, Vessel Speed and Radius of Turn.

Heel is caused by a moment setup between the water forces on the hull and an opposing force at the Center Of Gravity (COG) as the vessel turns. As the height of the COG above the water line increases, this moment increases and so too the heel, therefore the heel increases with KG and inversely with GMf. As a result, heel is only a significant factor in reducing the UKC of Container Ships, not Bulk Carriers of Tankers. The heel also increases with the velocity squared, therefore doubling the velocity causes 4 times the heel. Finally, the heel increases inversely with the radius of turn.

The angle of heel is related to a reduction in UKC by calculating the resulting vertical displacement at the beam.

In the Taranaki DUKC, Heel is only modeled on one turn. That is in an outward transit from a line joining the main light and the lee light (~DKP = 0.93km) for 0.35km (to ~DKP = 1.27km). The radius of turn is modeled as 1500m and the vessel travelling between 5.5 to 6.5 knots.

The DUKC System

Traditional measurement of these factors has been largely based on empirical observation and safety allowances were made only for ‘worst case scenarios’ and were conservative, but very inefficient.

Advances in computer technologies allows the accurate modeling of individual ships in a known sea state and hence calculate, in real time, the degree of motions experienced by ships in measured meteorological conditions. The DUKC system is designed to perform those calculations.

The DUKC system is a predictive system. It cannot be used to perform retrospective analysis. The system makes predictions for Maximum Draft or Tidal Windows for vessel transits.
Because of the possibility of rapidly changing meteorological conditions, vessel motion predictions can only be made for a limited time period of 24 – 36 hours. As a result, predictions made for the latter part of the forecast period should be treated as indicative. Firm transit decisions can only be based upon predictions made close to the time of the transit.
The DUKC system integrates vessel information with wave and tidal data to provide Under Keel Clearance predictions for Maximum Draft or for transit during Tidal Windows within the forecast period. The calculations take into account the tide level, depth of channel throughout the transit, vessel motion induced by swell, vessel squat and heel. Safety factors are built in for survey errors, siltation and swell growth together with tidal residual difference between the prediction time and that of the actual transit.

Bottom Clearance (BC) and the Manoeverability Margin (MM) are computed for each minute of the vessel transit. Minimum BC and MM are set in accordance with international guidelines. The DUKC system calculates Maximum Drafts and Tidal Windows so that the BC and MM limits are not breached for the entire vessel transit. However, they will be pushed as close as safely possible to the limits to the extent that either the BC or the MM will become the controlling criteria for the transit.

Maximum Draft

The DUKC system can calculate the Maximum Draft available for a transit on a particular tide. The predicted Maximum Draft is only available if the ship sails at the designated time.

Maximum Draft can also be calculated for a specific sailing time.

Tidal Window

The DUKC system makes predictions for the opening and closing of the available Tidal Window. The Tidal Window provides a range of times within which a transit can be safely conducted on a particular tide

Conservatism of Results

The further into the future the DUKC predicts, the more conservative are the results. The closer the program is run to the actual transit time, the less conservative the results become as allowances for swell growth and tidal residuals are progressively reduced.

DUKC Ship Motion Modeling

The DUKC system models individual vessels in a specific state of loading. The system requires the physical dimensions of the vessel, current stability characteristics and loading details and then models the specific vessel's motions in the existing wave conditions allowing precise values for the UKC allowances to be made.
In order to perform the necessary modeling, the following detailed vessel information is required. If all the required details are not available, then the DUKC system cannot run.

- Name of vessel
- Vessel displacement
- Length between perpendiculars (LBP)
- Beam
- Forward draft
- Aft draft
- Distance of the Centre of Gravity above the Keel (KG)
- Metacentric height, corrected for free surface effect (GMf)
- Modeled draft at which KG ad GM are calculated

Application of the DUKC system at Port Taranaki

It is important to remember that the DUKC system bases predictions on current meteorological phenomena and that the DUKC predictions can thus only be made from the current time to no more than 24 to 36 hours in the future, even if all the required vessel stability data is available.

For all predictions of Tidal Windows outside the above time frame, Standard Under Keel Clearance (SUKC) rules are the only ones that can be applied.

SUKC rules are conservative and are based on moderate to severe meteorological conditions. The Tidal Windows indicated under SUKC rules will often be 'bettered' under DUKC rules as the time of transit approaches. This, however, is not guaranteed and in poor meteorological conditions the DUKC rules may even occasionally result a smaller Tidal Window than under the SUKC rules or possibly even indicate that there is no transit window at all in extreme conditions.

Application by Port Taranaki of Under Keel Clearance (UKC)
Rules, is illustrated by the following flow chart. (Figure 3).

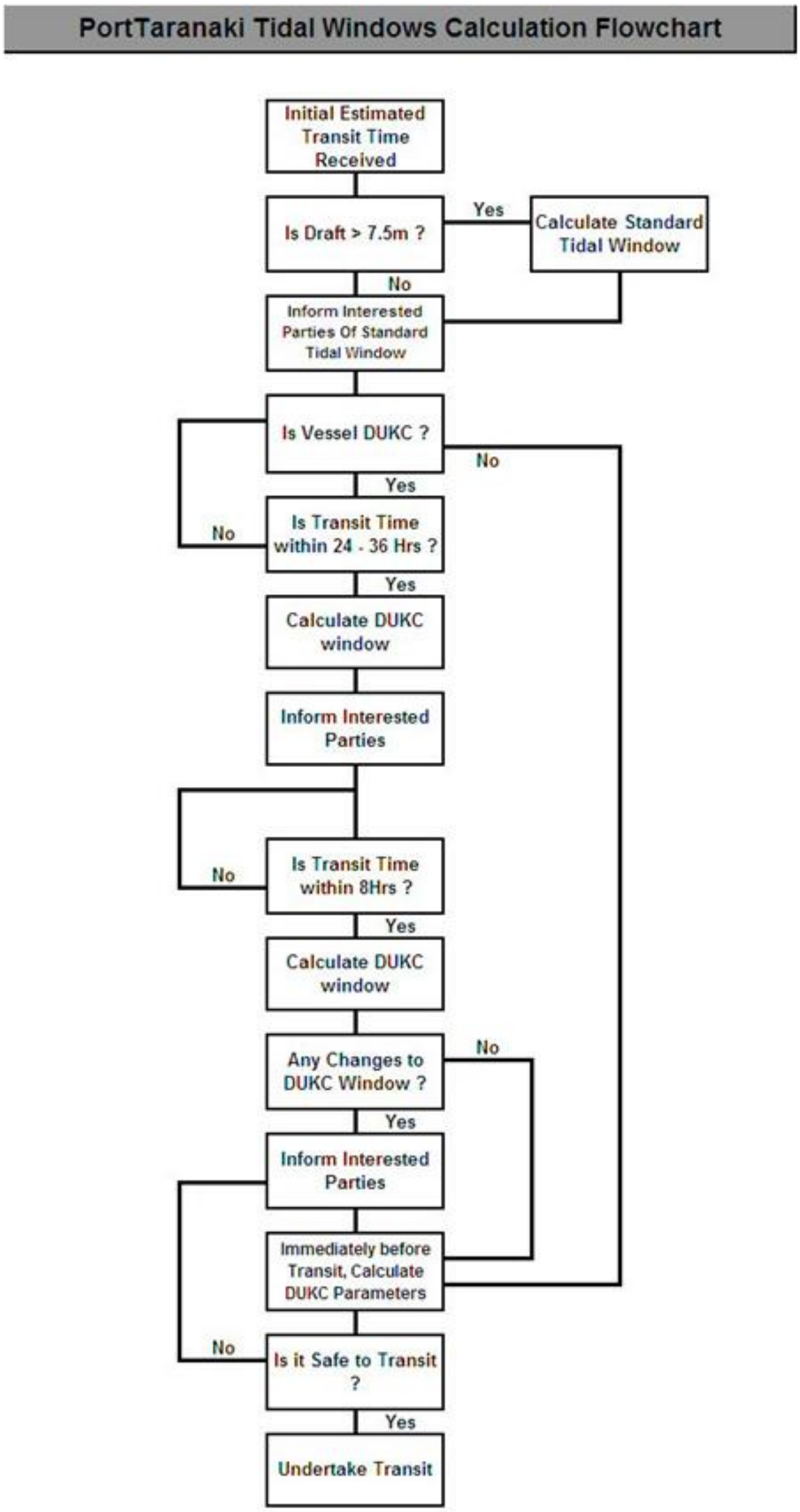


Figure 3. Application of UKC rules at Port Taranaki

Glossary

Beam

Maximum width of vessel.

Block Coefficient

CB - A measure of the fullness of form of the vessel. As used by the DUKC:

CB = Displacement (tonnes) / (LBP x Beam x Draft x Water Density)

Bottom Clearance

BC - The depth of water remaining between ship keel and seabed after subtracting allowances for static draft, Tidal Residual, squat, heel, wave response and safety factors from UKCGross.

This is one of the Controlling Criteria in the DUKC's predictions of Maximum Drafts and Tidal Windows. If BC is indicated to control a DLJKC prediction, swell induced vessel motions are a significant factor in determination of the UKC for that transit.

Control Point

Any point in a transit where BC or MM are reduced to their limits. These are the points that control the Maximum Draft and opening/closing of Tidal Windows.

Controlling Criteria

The two methods the DUKC uses to describe Under Keel Clearance. They are BC and MM. Each has a minimum limit of UKC that the DUKC will not go below, thus they are the criteria that control the predictions of Maximum Draft and Tidal Windows.

Draft

Draft at which the vessel intends to sail. Cannot differ from the Modeled Draft by more than 0.5m (otherwise wave response modeling is not considered valid for the sailing draft).

Displacement

Weight of water displaced by the vessel at a given draft in tonnes.

Forecast Period

The time period into the future that the DUKC can make predictions. This is determined by the availability of predictions of swell heights and Tidal Residuals. If no predictions of these are available, the Forecast Period of the DUKC is 24 hours from the most recent wave and tide data updates. Predictions can sometimes extend the Forecast Period to 36 hours.

GMf

The distance from the vessel center of gravity (G) to the Transverse Metacentre (M), measured in metres. The period and amplitude of vessel roll in a particular wave environment will be affected by this value.

The "f" refers to a correction for free surface. That is, a correction to the GM value to allow for the movement of uncontained fluid as the vessel rolls which will affect the roll period and amplitude.

Gross Under Keel Clearance

GUKC - A static determination of Under Keel Clearance, calculated by subtracting the ship's draft from the total depth of water available.

Heel

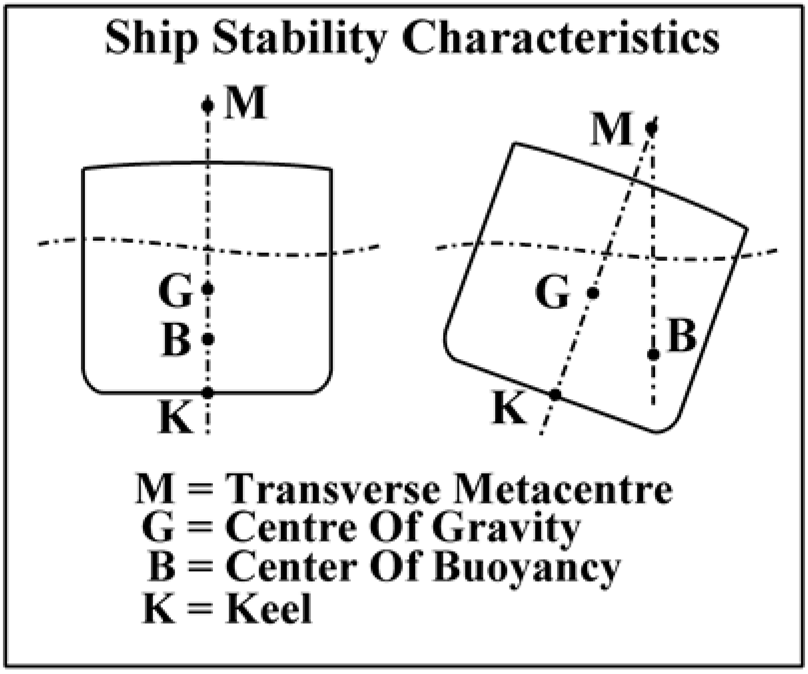
Angular bodily movement from the vertical in the transverse plane.

High Water Level

HWL - Predicted height of a particular high tide.

KG

Vertical distance from the keel to vessel center of gravity in metres.



Length Between Perpendiculars

LBP - The distance parallel to the vessel base at the level of Tropical Draft. (As stated in a vessel's stability book or ship builder's hydrostatic particulars for the vessel).

Maneuverability Margin

MM - Describes the depth of water available for the ship to manoeuvre in without the assistance of tugs. The depth of water remaining between ship keel and seabed after subtracting allowances for static draft, tidal level prediction error, squat and safety factors from UKCGross Wave response allowances are not a factor in determining **MM**.

This is one of the Controlling Criteria in the DUKC's predictions of Maximum Drafts and Tidal Windows. If MM is the Controlling Criteria for a DUKC prediction then swell induced vessel motions are not the most significant factor in determining UKC.

Maximum Draft

Describes the maximum draft to which a vessel can be loaded in a given set of conditions whilst maintaining enough Under Keel Clearance to ensure safe passage through a channel.

The Maximum Draft option in the DUKC system calculates the Maximum Draft for sailing on a particular tide, or at a particular time, taking into account the measured tide and wave conditions.

The DUKC determines the Maximum Draft as the draft at which either of the Controlling Criteria reaches its limit at any time during the simulated transit.

Modeled Draft

The vessel draft at which KG and GMf were calculated. The ship motion modeling will be done at this draft. Therefore, the wave response UKC allowance will only be accurate if the vessel is loaded to a draft similar to the modeled draft (to ±0.5 metre).

Modeled

Displacement	Water displaced in tonnes by the vessel hull at the draft at which KG and GMf are provided for wave response modeling.
Period of Peak Energy	**Tp** - Waves of this time period have the maximum energy of all waves passing a particular point in a given set of conditions.
Safety Factors	Includes allowances for survey error, siltation and change in water density.
Sea Waves	Name designated to waves of period below a predefined limit (usually 6 - 7 seconds). Primarily generated by local wind.
Significant Height	**Hs** - The average height of the highest one third of total waves (sea and swell) passing a given point over a particular time period.
Significant Swell Height	**HsSwell** - The average height of the highest one third of those waves designated as being swell (as opposed to sea waves) passing a given point over a particular time period.
Significant Swell Period	**Ts** - The average period of the highest one third of swell passing a point over a particular time period.
Specific Transit Time	Planned time of sailing for a vessel within a Tidal Windows.
Speed Envelope	A range of speeds defined by a maximum and minimum between which ships must sail in order to utilise the information provided by the DUKC system.
Squat	A combination of bodily sinkage and change in trim of the vessel while sailing. Primarily affected by vessel speed through the water, and the ratio of ship cross-sectional area to that of the channel in which it is sailing.
Static Draft	Draft of ship when stationary. Dependent on localised water properties.
Standard Under Keel Clearance	**SUKC** - In relation to Port Taranaki, this refers to the standard method used to calculate Under Keel Clearances based on international guidelines. Under Keel Clearances are calculated by adding the predicted tide height to the Chart Datum. The minimum Under Keel Clearance being calculated at 25% of maximum draft of vessel without any allowance for meteorological or ship motion factors.
Swell	Water motions not described as sea waves, usually of longer period than sea waves. Primarily generated by wind forces outside the local area.
Swell outlook 11	Program developed by OMC to interface between wave data and the DUKC. It allows configuration of wave data sources, and the integration of the DUKC with forecast predictions to 36 hours. For details on the operation of this program, refer to its Help.
Tidal Residual	The resultant at any point in time of the predicted tide subtracted from the measured tide. Can be positive or negative. Tidal Residuals are caused by barometric pressure and other meteorological effects.

Tidal Windows

A Tidal Windows is a period of time during which a vessel can set sail and safely complete the desired transit in the expected wave climate. It is called a Tidal Windows because the opening and closing of windows are usually associated with changing tide heights.

The DUKC determines the opening and closing of Tidal Windows as the sailing times at which either of the Controlling Criteria will reach its limit at some time during the simulated transit. That is, at least one of the criteria limits will be reached (but not exceeded) if the vessel sets sail at the window opening time. If the vessel sets sail between opening and closing time the limits will not be exceeded. If the vessel sets sail at the window closing time at least one of the limits will be reached (but not exceeded).

Under Keel Clearance

UKC - The depth of water between a vessel's keel and the seabed.

Wave Response Allowance

A factor used in determining Bottom Clearance that accounts for vessel motions induced by sea and swell waves. In the DUKC, the Wave Response Allowance is calculated using Dr. O'Brien's SPMS model.

Frequently Asked Questions

Q. Who are OMC International and What do they do?

A. Precise nature of business:
Provider of specialist on motions of ships along port entrance channels and when moored at berths. Development of software for use by harbour masters and pilots as tools for navigation.

Details of advice given:
Times for sailing of ships at particular drafts and/or maximum draft ship can also be loaded.

Details of any disclaimers given on advice:
All output from the software is to be used as a tool only by the harbour master, general manager, pilots and other authorised persons at particular ports.

Verbal reports always confirmed in writing

Précis of previous experience in this field:
O'Brien Maritime Consultants has been conducting work in this field since 1994, and prior to this the principal consultant and director, Dr W T O'Brien spent 30 years working in the area of ship motions and maritime engineering developing much of the technology now used by OMC International. A detailed history of Dr O'Brien's experience is available on request.

Q. My draft is less than another ship but he can sail earlier than me. Why is that? or, My draft is the same as the other vessel but he can sail earlier than me?

A. The main reason for this is that ship motions are based on KG and GM and the bigger the GM the smaller the sailing window.

Q. I have a ship arriving in a week's time, why are you unable to supply the DUKC window?

A. DUKC can only be used within 24 hours of the expected time; this is because it relies on current sea and swell conditions and predictions. Static windows will be given for the vessels prior to this time and will be adjusted accordingly as the transit approaches.

Q. Why do I have to supply ship details, and what details are needed?

A. Dynamic motion modelling need the following data, LBP, Beam, Displacement, KG, GM(VCG) and Drafts. This data can then be used to model a ship for it "six degrees of freedom" for the weather conditions. This is also why it is imperative that any changes to these figures be reported immediately to the agent or pilot.

Q. What are the benefits for using DUKC?

A. The primary benefits are being able to sail/berth for more time of the day rather than just around high water.
Vessels can load deeper than 10.0m.
A full analysis of the conditions can be made which enhances safety.

Q. Which affects the ship more, sea or swell waves?

A. Swell waves and long period waves affect the vessel. Generally, seas up to 7 seconds long are too fast to affect a vessel. The worst wave periods are ones in the region of 14-20 seconds.

Q. **The weather is very rough and DUKC says it is safe to berth; will I still berth?**

A. Berthing will still depend on the master of the vessel and the pilot. There may be times that berthing may be delayed until the weather moderates.

Q. What is meant by DYNAMIC UKC?

A. **UKC** denotes **U**nder **K**eel **C**learance, which is the *minimum* depth of water required under a ship's keel to ensure that it doesn't touch bottom. **DYNAMIC** implies a system involving *real-time* calculation of this minimum depth.

Q. What is the DYNAMIC UKC System?

A. The **DYNAMIC UKC** systems designed by OMC measure and predict tides and waves and accurately compute the *minimum* **UKC** needed in shipping channels for the specific weather conditions at the time of transit.

Q. How does DYNAMIC UKC make port services more efficient?

A. By reducing the **UKC** to the *minimum* safe amount, so that ships can enter and leave port with the *maximum* possible draft and tonnage.

Q. Can DYNAMIC UKC be used for both import and export ships?

A. Yes.

Q. How is safety considered?

A. **DYNAMIC UKC** systems ensure that the depth of water under a ship's keel always satisfied international standards for safe transit. The continuous monitoring of tide and wave data prior to each ship transit enables these criteria to be stringently applied.

Q. Who can operate DYNAMIC UKC systems?

A. **DYNAMIC UKC** systems use menu-driven input and provide both text and graphics output. They can be operated by port officers with minimum training but the results should be reviewed and approved by a responsible maritime officer such as a pilot.

Explanation of the graph on the back cover

The graph on the Back Cover illustrates the benefits for a typical tanker with a 10.0m draft operating under DUKC rules.

Generally, on neap tides and good weather these vessels can sail at any time of day under DUKC; this compares very favourably to the 2 hours before and 1 hour after High Water for the static rules.

On spring tides, a vessel may not be able to sail at all times but will still be able to sail up to about 2 hours before and after Low Water.

The average sailing window on neap tides for static rules is 5 hours and for DUKC rules is generally 24 hours.

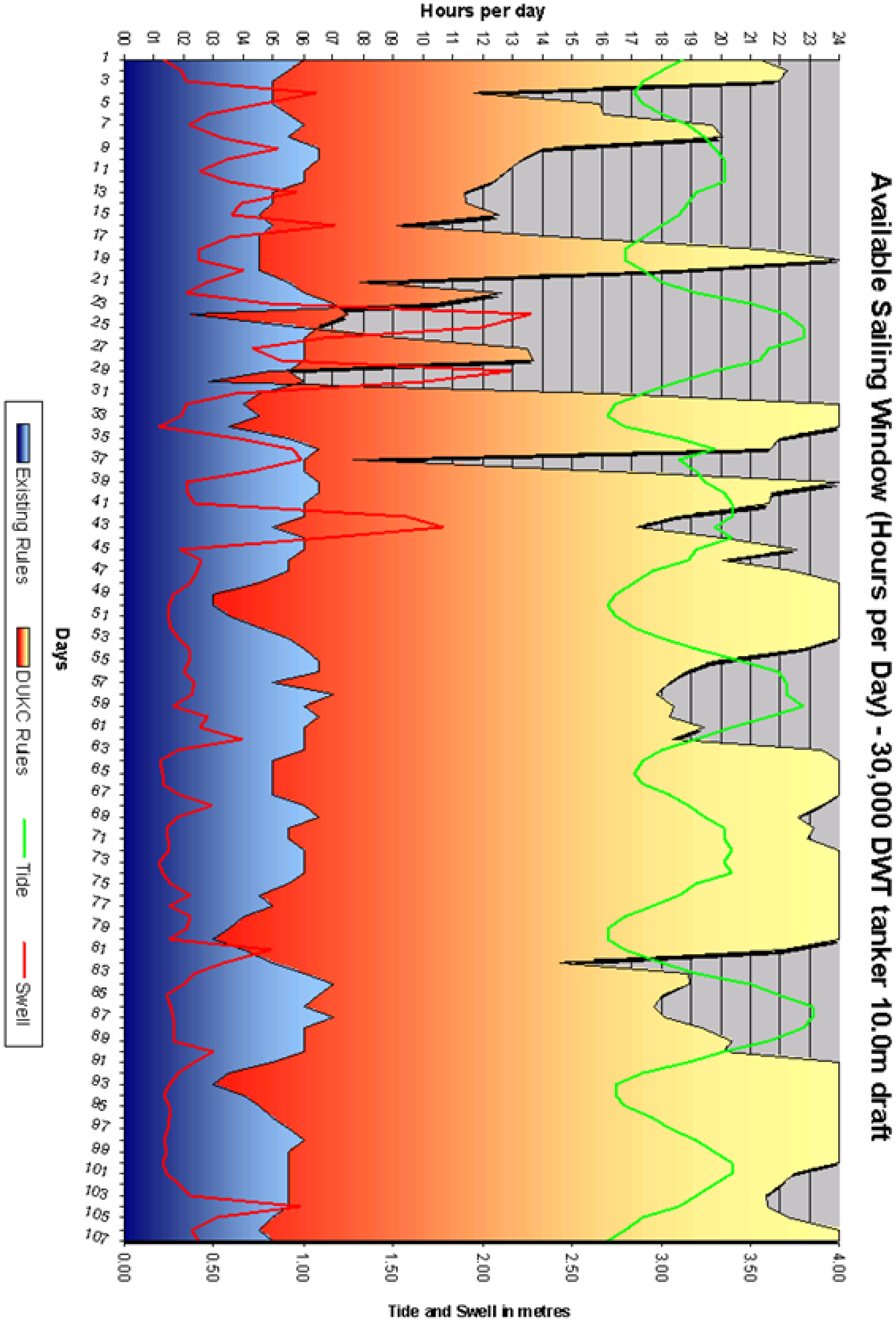
The average sailing window on springs time window for static rules is 5 hours and for DUKC rules is 18 hours.

The graph also shows two instances when the weather was too rough even for static rules. This 'exception to the rule' demonstrates that DUKC actually enhances safety as it shows that sailing should be delayed until the weather moderates. Without the DUKC analysis of conditions some vessels could conceivably sail with reduced safety margins.

GRAPH KEY

- Tide Heights are shown in green and are referenced against the right hand scale.
- Swell Heights and shown in red and are referenced against the right hand scale.
- Static tidal windows (the lower part of graph) are in blue and referenced to the hours on the left hand scale.

DUKC tidal windows (the upper part of graph) are in red/yellow and are referenced against the hours on the left hand scale


Available Sailing Window (Hours per Day) - 30,000 DWT tanker 10.0m draft
Hours per day
Days
Tide and Swell in metres
Existing Rules
DUKC Rules
Tide
Swell