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## WATER LEVEL FORECASTS AND SQUAT CALCULATION FOR THE TRAVERSE DU NORD

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### SUMMARY

Vessels with drafts of up to 15.5 m call into the port of Quebec on a regular basis, using the crest of the tide to transit a 16.6 nautical mile (M) long, 12.5 m dredged channel. The average tide in the channel is 5.5 m. Readings from tide gauges located above, below and in the dredged channel are available via AIS or the internet. The Canadian Hydrographic Service (CHS) uses an accurate mathematical model called *SPINE* (*Syst me de Pr vision et d’Interpolation des Niveaux d’Eau* - Water Level Forecast and Interpolation System) to forecast water levels that include tidal predictions, the St. Lawrence River flow, and atmospheric forcing. The Canadian Coast Guard has published a squat table and under-keel clearance requirements for the Traverse du Nord by which all ships must abide. A web-based solution called the Tide Windows Module was developed by Innovation maritime for the Corporation des pilotes du Bas Saint-Laurent to give its pilots a tool to manage under-keel clearance, which incorporates the Canadian Coast Guard UKC requirements, real-time water levels and forecasts, ship’s draft, beam and speed.

### 1 INTRODUCTION

The port of Quebec is situated at the head of the St. Lawrence River estuary in Canada. The average tide height in the harbour is 4.9 m. Downstream from the harbour exists a 16.6 nautical mile (M) long dredged channel with a maintained depth of 12.5 m called the Traverse du Nord (hereinafter the “Traverse”). It presents an average tide of about 5.5 m at the Saint-Fran ois tide station (Figure 1). Real-time tide gauge readings for locations above, below and in the middle of the dredged channel are available via AIS or the internet.

The Canadian Hydrographic Service (CHS) issues water level forecasts that include tidal predictions, with the influence of fresh water flow from the St. Lawrence River and the atmospheric forcings. These forecasts are provided through an application called *SPINE* (*Syst me de Pr vision et d’Interpolation des Niveaux d’Eau* - Water Level Forecast and Interpolation System) which uses the results of a one-dimensional numerical model of water levels and flows. In the presence of strong weather systems, it is not uncommon to see variations of up to 0.80 m between the predicted tidal level and the actual water level.



Figure 1. Quebec and the Traverse du Nord

Vessels with drafts of up to 15.5 m call safely into the port of Quebec on a regular basis, using the crest of the tide to transit through the 12.5 m dredged channel. In order to have a better control of the safety margins, the CPBSL developed, together with its partners, a “Tide Windows Module” that uses the tide gauge readings, CHS’s SPINE forecasts, vessel beam, draft and speed, as well as the specific squat table based on the “Eryuzlu with beam” model and safety and manoeuvrability margins published by the Canadian Coast Guard.

$$S = 0,181 \cdot \sqrt{T \cdot b} \cdot \left( \frac{V}{\sqrt{g \cdot T}} \right)^{2,269} \cdot \left( \frac{T}{H} \right)^{0,994}$$

**Equation 1. Eryuzlu with beam**

The processed information is available to the pilot and captain via a user-friendly, secured web application which can be adapted to vessels of different beams and drafts, and adjusted for different transit speeds.

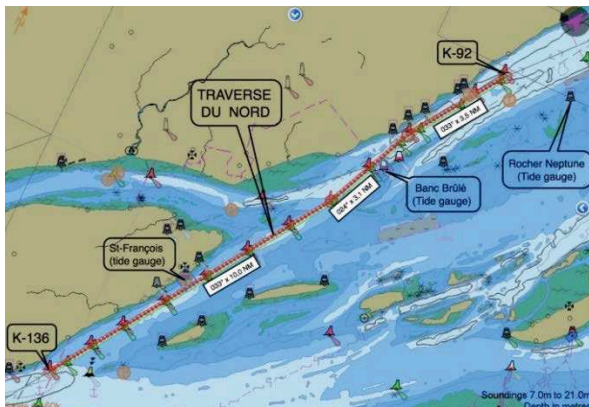
## 2 THE FIVE INGREDIENTS

### 2.1 THE TRAVERSE DU NORD

The Traverse (Figure 2) is located on the St. Lawrence River. It is 16.6 M long, 305 m wide with a maintained depth of 12.5 m and consists of three legs with 9 degrees between each of them (033° x 10’, 024° x 3.1’ and 033° x 3.6’). Its western limit is 15 M downstream from Quebec City.

The average tide at Saint-François is 5.5 m whereas at the western limit of the Traverse, only five miles away, the average tide is 30 cm less.

The natural depth of the Traverse prior to dredging was between 7 m and 8 m for approximately 50% of its length and between 10 m and 20 m for the remainder. The Traverse is not considered a confined canal as the horizontal limits outside the dredged channel do not impede water flow [1]. The coastline is situated at more than one quarter mile from the channel limits for most of its length. It is considered restricted because of the water depth available.



**Figure 2. Traverse du Nord**

### 2.2 THE SHIPS

Vessels calling the port of Quebec, that warrant careful UKC management, are mostly Suezmax crude oil tankers (Figure 3) and Capesize bulk carriers measuring up to 294 m in length, with beams between 48 m and 52 m and with drafts of up to 15.5 m.



**Figure 3. Typical Capesize vessel in Quebec City**

### 2.3 THE SQUAT MODEL

The formula used by the Canadian Coast Guard in the Traverse, to estimate vessel squats, is “Eryuzlu with beam” (Equation 1), as determined by Morse and Simard [2], to offer the best performance possible. It is thus designed to be used within the following parameters:

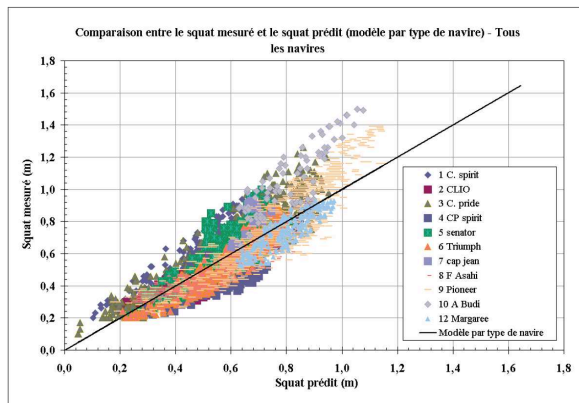
- Merchant vessel for which  $C_b = 0.80$  and static draft is 8.13 m to 20.32 m;
- Vessel without significant trim (less than 10%);
- Vessel sailing alone, with SOG of 4 to 17 knots;
- No external forces (waves, wind, etc.) affecting the vessel during the trip;
- Relatively straight channel of unrestricted width and uniform depth;
- Channel no deeper than 37.5 m, with a water depth-to-draft ratio between 1.1 and 3.0;
- Vessel travelling in the central part of the channel, given that squat may increase if the vessel gets significantly closer to shore.

Using these parameters, the *UKC for the Traverse* table (Table 1) is then computed from the equation for the mariner where he only needs to input in the table the speed and beam of the vessel, as these variables have the most impact the squat predictions at a level above critical value (>5%). The safety/manoeuvrability margin is based in part on the PIANC manoeuvrability requirement and on a safety margin that account for the different variables whose impact are individually below critical values.

**Table 1. UKC for the Traverse**

Vessel Beam Not Exceeding (m)	Vessel Speed Not Exceeding (knots)							
	7	8	9	10	11	12	13	14
<b>Required Under-Keel Clearance (m)</b>								
31	0.86	0.95	1.06	1.17	1.38	1.60	1.84	2.09
34	0.87	0.97	1.08	1.20	1.41	1.64	1.89	2.15
37	0.89	0.98	1.10	1.22	1.44	1.68	1.93	2.20
40	0.90	1.00	1.11	1.25	1.47	1.72	1.97	2.25
43	0.91	1.01	1.13	1.27	1.50	1.75	2.01	2.29
46	0.92	1.03	1.15	1.29	1.53	1.78	2.05	2.34
49	0.93	1.04	1.17	1.32	1.56	1.81	2.09	2.38
52	0.94	1.05	1.18	1.34	1.58	1.85	2.13	2.42
<b>Estimated Squat (m)</b>								
31	0.25	0.34	0.45	0.56	0.70	0.84	1.00	1.18
34	0.27	0.36	0.47	0.59	0.73	0.88	1.05	1.23
37	0.28	0.37	0.49	0.62	0.76	0.92	1.09	1.28
40	0.29	0.39	0.51	0.64	0.79	0.95	1.14	1.33
43	0.30	0.40	0.52	0.66	0.82	0.99	1.18	1.38
46	0.31	0.42	0.54	0.68	0.84	1.02	1.21	1.42
49	0.32	0.43	0.56	0.71	0.87	1.05	1.25	1.47
52	0.33	0.44	0.57	0.73	0.90	1.08	1.29	1.51
<b>Safety/Manoeuvrability Margin (m)</b>								
	0.61	0.61	0.61	0.61	0.69	0.76	0.84	0.91

The comparison of predicted squat and measured (OTF-GPS technology using the Canadian Coast Guard’s GPS network (accuracy of 5 cm @ 95%)) squat for 12 ships ranging from 294 m long container vessels and Suezmax tankers to smaller Handysize bulkers transiting in the St. Lawrence waterway was studied in [3-5], extracts of which are presented in Figure 4 and in Table 2.



**Figure 4. Predicted vs observed Squat**

**Table 2. Performance of the squat model used by the CCG UKC tables**

Vessel Type	Coefficient of Determination (-)	Bias <i>E</i> (m)		Relative Bias <i>ER</i> (%)	
		Mean	Standard Deviation	Mean	Standard Deviation
All	0.60	0.15	0.17	28	33
Container Ships	0.62	0.25	0.15	47	30
Bulk Carriers	0.78	0.07	0.12	13	26
Tankers	0.68	0.04	0.14	10	24

An overall tendency to slightly overestimate the squat (Figure 5) was observed, with a mean deviation of 4 cm and a standard deviation of 14 cm in the case of Suezmax tankers, the area’s most critical vessels.

#### 2.4 THE HYDRODYNAMIC MODEL

The hydrodynamic model has been documented by Lefavre et al. [6, 7]. It is a one-dimensional model applied to the St. Lawrence River from Montreal to Saint-Joseph-de-la-Rive, near Baie-Saint-Paul to forecast water levels in support of CHS activities. At the upstream end, the model uses the forecasted flows at Montreal from Lake Ontario outflow, the Ottawa River and other smaller tributaries to the St. Lawrence River. The atmospheric forcing is added to the tidal forecast at the downstream boundary. In the model domain, at the tidal stations in the Traverse (Rocher Neptune, Banc Brûlé, Saint-François, Saint-Jean), the model forecasts are assimilated to the last observation on a 15-minute schedule. The forecasted values of the water levels are available at every 3 km of the navigational channel, updated every 15 minutes with the observations made at the 4 stations in the area, using the forecasted wind influence for the next 48 hours and the forecasted St. Lawrence River flow for the next 30-day period.

- The St. Lawrence River is modelled from Montreal to Saint-Joseph-de-la-Rive;
- From unidirectional flow regime at Montreal to an almost symmetrical tidal cycle up to Saint-Joseph-de-la-Rive;
- Uses forecasted flows at Montreal from Lake Ontario outflow, the Ottawa River and other smaller tributaries;

- Atmospheric forcing added to the tidal forecast at the downstream boundary;
- Hourly forecasted wind intensity;
- Added values (positive or negative) at Saint-Joseph-de-la-Rive for the next 48 hours;
- Model forecasts assimilated to the last observation on a 15-minute schedule;
- Forecasted values of the water levels available at every 3 km of the navigational channel.

## 2.5 THE COMMUNICATION PROTOCOL

All tide gauges are sending their data through UHF or a cellular modem every 3 minutes. The data is sent at least twice, with a 20-second delay to implement validation, in order to ensure availability and limit problems due to collisions on UHF channels.

Installations throughout the St. Lawrence River receive the UHF data and convert it in IP data packets which are then retransmitted via commuted phone lines (128 and 56 kbs) to the Quebec server, then retransmitted via CHS intranet (DFOnet) to ODINS servers in Ottawa and Sidney, BC.

Other tide gauges, especially downstream of Saint-Joseph-de-la-Rive, transmit their data via cellular modems directly to the Ottawa and Sidney servers through the internet.

All the raw data is only available through DFO intranet (DFOnet), so SOAP (Simple Object Access Protocol) web services are used as bridges to access predictions, observations from the tide gauges, and forecast from SPINE. Those three services (PRED, OBS and SPINE) are accessible on the WDS (Windows Deployment Services) server via internet. Predictions and observations are linked to specific stations whereas forecasts are accessed via locations specified by longitude and latitude. Those services are called by the pilot's internet application website server (Figure 5).

The HTML web application running on tablets and phones can access the data through RESTful web services running on the pilot's website server. The results of a RESTful (Representative State Transfer) call can include multiple calls to CHS Web services which are less verbose, pre-validated and compressed. This helps mitigate problems with slow cellular connections or bad reception and reduce bandwidth. They are also required since SOAP services are not accessible via JavaScript queries, so the HTML application cannot access the CHS SOAP Web services directly.

It is important to note that the Tide Windows Module is a web-based application and not a native application.

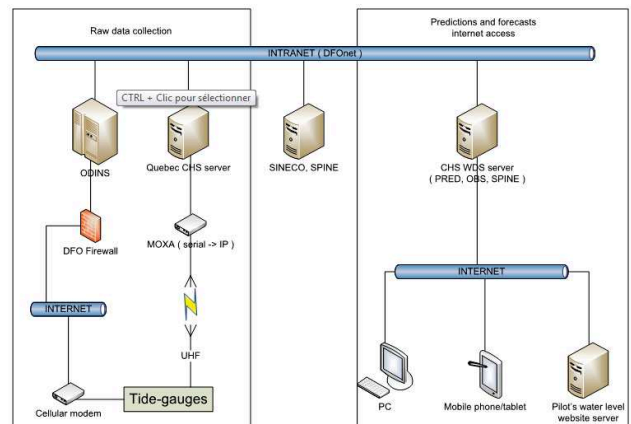


Figure 5. Data flow and process

## 3 THE TIDE WINDOWS MODULE

Every CPBSL pilot carries a Portable Pilot Unit (PPU) that consists of a tablet equipped with a state-of-the-art and sophisticated navigation software getting information from the ship's equipment, and supported by its own high precision GNSS (Global Navigation Satellite System) receiver. Pilot's tablet can also access the internet via 3G or any other better network. Cellular coverage on the St. Lawrence River approaches 95%. This allows web-based tools to be custom-developed for and used by pilots to manage predicted and forecasted water levels and the corresponding under-keel clearance.

As stated earlier, variations of up to 80 cm can be observed between predicted and actual water levels. The prudent mariner would benefit from knowing in advance when such variations are to occur. In Figure 7, taken from an actual event, the red curve is the predicted tide, as published, the black curve shows the actual tide gauge reading, whilst the green dotted line represents the SPINE corrected forecast. Note how fast the prudent mariner can lose 50 cm. One can also observe a shift of phase, particularly visible at low tide, from about 15:00 to 15:30. In this case, from the mariner's point of view, *the tide just kept falling!*

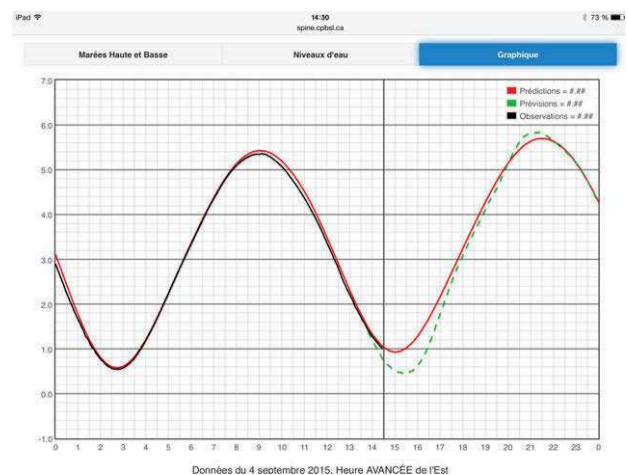


Figure 6. Tide prediction, reading and forecast

### 3.1 TIDE OPTIONS

The Tide Windows Module offers the pilot the following options:

- Simple high and low tides for 11 locations in the area;
- Tabular or graphic displays (Figure 6), featuring predictions, SPINE forecasts and actual readings of tide gauges;
- Ship's particulars' entries;
- Actual Tide Windows Module.

### 3.2 USING THE TIDE WINDOWS MODULE

To this day, the most important part of the pilot's job is to look out the bridge windows. So, one has to be extra careful when giving him another window to look at. From the beginning of the project, special attention was given to keep the Tide Windows Module as simple and user-friendly as possible, so that all the functionalities are a couple of clicks away, in order to keep the pilot's attention on the job at hand: the safe and efficient conduct of the vessel.

By feeding the ship's particulars (ship's beam, draft and speed) into the *Ships Information* dialogue box (Figure 7), and taking in consideration the channel's depth, the module will compute, using the UKC table, the water level required to proceed in the Traverse at the expected transit speed. In this case, UKC should be no less than 1.31 m and water level, no less than 4.31 m. The user can then switch to the graphic display (Figure 8) of the Tide Windows Module and assess, by observing the meeting points of the proper tide forecast curves and the shaded area, his earliest entry time for an upriver transit (red K-92 curve at 13:05) in the Traverse, as well as his exit time at the western limit of the Traverse (blue K-136 curve, at 16:05).

In this case, the vessel would have had 3 hours to transit the 16.6 M Traverse at 10 knots on the afternoon tide, from an earliest entry time of 13:05 at buoy K-92 to the latest exit time of 16:05 at buoy K-136. Note that the morning tide did not offer sufficient tide height to transit in these conditions. It can be seen at a quick glance that the appropriate curves either barely exceed the shaded area or are well inside that area, indicating inadequate water levels for safe transit.

If the pilot reduces the expected transit speed from 10 to 7 knots (Figure 9), he would be required to maintain 0.93 m UKC and then only need a water level of 3.93 m. As the transit speed is lowered, so is the shaded area on the graphic (Figure 10). The vessel could now enter the Traverse safely at about 12:45 (red K-92 curve) and exit at 16:45 (blue K-136 curve), giving it 4 hours to transit, either to accommodate other deep draft traffic or giving the vessel more operational flexibility. In that case, taking into account the expected flood current, it could

even have transited during the night tide between 01:10 and 03:30, as the required levels are met at every tide station over a long enough time period.

Information du navire	
Nom:	Tirant d'eau (mètre):
Capesize	15.5
Vitesse (kts):	Zéro des carte (mètre):
10	12.5
Largeur (mètre):	Différence (mètre):
48	3
Longueur (mètre):	DSQ (mètre):
294	1.31
	Hauteur marée requise (mètre):
	4.31

Figure 7. Ships Information dialog box

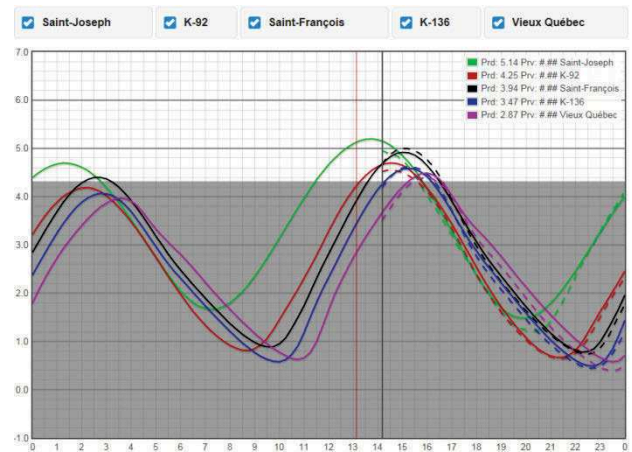
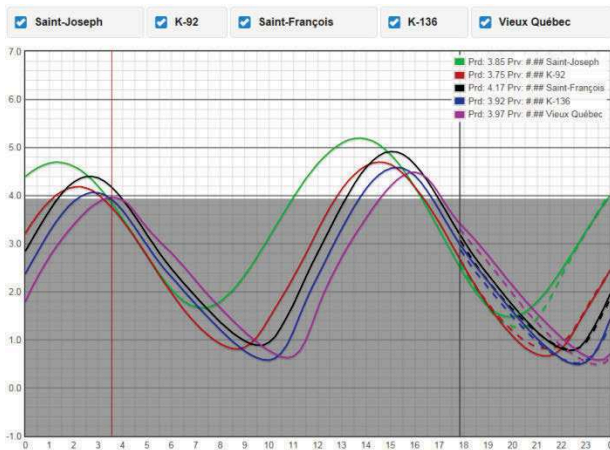


Figure 8. Water level curves

Information du navire	
Nom:	Tirant d'eau (mètre):
Capesize	15.5
Vitesse (kts):	Zéro des carte (mètre):
7	12.5
Largeur (mètre):	Différence (mètre):
48	3
Longueur (mètre):	DSQ (mètre):
294	0.93
	Hauteur marée requise (mètre):
	3.93

Figure 9. Ships Information dialog box



**Figure 10. Water level curves**

#### 4 CONCLUSIONS

The Tide Windows Module was developed with the Canadian Coast Guard e-Navigation Strategy in mind. High-quality government data was customized by professional third parties to the specific needs of an end user.

The module offers the pilot a user-friendly tool to plan, manage and monitor the water levels and the under-keel clearance necessary for the safe and efficient transit through the Traverse du Nord.

Finally, in Chapter 2, five basic ingredients were mentioned for developing the module. A sixth was left out on purpose, e.g. the people. People from various organizations, with multiple backgrounds, among which navigation, oceanography, software design and communication technologies, brought together their expertise and knowledge to make this project a success. Their collective work is now in the hands of pilots, helping to make the St. Lawrence a safer and more efficient waterway.

#### 5 ACKNOWLEDGEMENTS

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#### 7 AUTHORS' BIOGRAPHIES

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**Germain Sauvé** holds the current position of Software Analyst at Innovation maritime. He is managing and developing software projects related to electronic navigation, real-time simulation, electronic design and mobile applications. His previous experience includes research projects in medical analysis web portals, electronic design of GPS and communication systems for the marine industry, mechanical monitoring system and human machine interface running mobile device and Estimated Time of Arrival on the St. Lawrence software.

**Denis Lefavre** holds the current position of research scientist at Fisheries and Oceans Canada. He is responsible for issuing ocean forecasts for the Gulf of St. Lawrence, Canada, and specifically developing water level forecasts for the St. Lawrence River.

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