Sentinel Tug Requirements for Gulf of Alaska: Ship Drift Study

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Prepared for:

Prince William Sound Regional Citizens' Advisory Council
Anchorage, AK

Prepared by:

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Sentinel Tug Requirements for Gulf of Alaska: Ship Drift Study

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Prepared By:	*Professional Engineer of Record:*
Robert G. Allan, P. Eng.	**Robert G. Allan, P. Eng.**

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Client Acceptance Status

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EXECUTIVE SUMMARY

In 2012 Robert Allan Ltd conducted a study for the Prince William Sound Regional Citizen's Advisory Committee (PWSRCAC) on the technical requirements for a Sentinel Tug to be stationed at Hinchinbrook Entrance. One of the conclusions of that report [1] was the following;

- *It is recommended that a formal drift study be conducted, accounting for the precise influence of wind, waves and currents on a disabled tanker on a time domain basis to verify that 17 miles is the correct offshore tanker transit distance during which the Sentinel Tug should standby.*

In 2015 PWSRCAC contracted with Robert Allan Ltd to conduct this drift study in order to close this gap in the knowledge of ship behaviour and response capability within the study area. The drift study modelled both 125,000 DWT and 193,000 DWT tankers drifting from pre-determined start points in the shipping lanes, in the defined closure condition at Hinchinbrook Entrance of 45 knot winds and 15 ft. significant waves, as measured by the buoy at Seal Rocks. It is important to note that due to effects including wave sheltering, topographic sheltering, and buoy anemometer height, this closure condition is actually equivalent to approximately 57 knots of wind (at 10m elevation) and 20 ft. significant waves in the gulf areas offshore of Hinchinbrook, where a rescue tow of a disabled tanker would potentially take place.

The following are some of the key findings of this study, as well as a summary of the average drift times (for all vessel types and load states considered) for varying starting distances from Hinchinbrook:

1. Smaller, lighter vessels drift more quickly than do larger vessels
2. A vessel in ballast (or partly loaded) will draft faster than the same vessel fully laden
3. Vessels adrift before the peak of the closure condition tend to drift towards the north-west, towards Montague Island and Hinchinbrook Island
4. Vessels adrift at and after the peak of the closure condition tend towards the north-east.
5. Vessels adrift from the southern shipping lane reach shore on average 21% faster than do ships adrift in the eastern shipping lane

Start Location			Time to Shore[1]	Mean Time	Drift Velocity[3]	Mean Drift Velocity	Typical End Location Landmark
Number	Radius	Location	Hours	Hours	Knot	Knot	
1	50 NM	Eastern Shipping Lane	10.77	11.97	2.12	2.36	Copper River Estuary
2	50 NM		13.17		2.59		
3	50 NM	Southern Shipping Lane	15.06	14.93	2.36	2.33	Southern Montague Island Wooded Islets
4	50 NM		14.79		2.30		
5	25 NM	Eastern Shipping Lane	6.44	6.95	2.31	2.35	Eastern Hinchinbrook Island
6	25 NM		7.46		2.39		
7	25 NM	Southern Shipping Lane	9.21	8.67	2.38	2.34	Central Montague Island
8	25 NM		8.12		2.29		
9	17 NM	Eastern Shipping Lane	4.52	4.75	2.06	2.16	Western Hinchinbrook Island
10	17 NM		4.98		2.27		
11	17 NM	Southern Shipping Lane	6.52	6.19	2.27	2.26	Northern Montague Island Seal Rocks
12	17 NM		5.85		2.25		

The updated B.A.T. analysis for the Sentinel Tug [2] affirms that the minimum required BP for the Sentinel Tug is 185 tonnes BP in order to satisfy a zero drift criteria, and as such some allowance must be made for the fact that even the PRT class of tugs, which are the most powerful in the current SERVS fleet, would be losing ground in the defined closure conditions, at least until the storm conditions begin to abate or until a second tug arrives to provide additional assistance with the tow.

Given this, and considering the drift rates identified by the drift study (summarized in table above), and probable Sentinel Tug response speeds, *it is recommended that the requirements for the Sentinel Tug as defined in the VERP be modified to require a response to at least 30 nautical miles from Hinchinbrook, as follows*:

> *"Hinchinbrook Tug – A vessel (PWS, PRT, or Theriot Class) capable of ocean escort and rescue service. The vessel is stationed in the vicinity of Hinchinbrook Entrance to provide assistance as a Sentinel escort for tankers in ballast transiting Hinchinbrook Entrance, and laden tankers transiting into or out of the Gulf of Alaska to* ***30 miles of Cape Hinchinbrook****. This vessel may also be utilized as a close escort for laden tankers transiting through Hinchinbrook Entrance."*

* * *

Project 215-067
May 4, 2016
Rev. 1

Sentinel Tug Requirements for Gulf of Alaska: Ship Drift Study

For: Prince William Sound Regional Citizens' Advisory Council
Anchorage, AK

1.0 BACKGROUND

In 2012 Robert Allan Ltd conducted a study for the Prince William Sound Regional Citizen's Advisory Committee (PWSRCAC) on the technical requirements for a Sentinel Tug to be stationed at Hinchinbrook Entrance. One of the conclusions of that report [1] was the following:

- *It is recommended that a formal drift study be conducted, accounting for the precise influence of wind, waves and currents on a disabled tanker on a time domain basis to verify that 17 miles is the correct offshore tanker transit distance during which the Sentinel Tug should standby*

In 2015 PWSRCAC contracted with Robert Allan Ltd to conduct this drift study in order to close this gap in the knowledge of ship behaviour and response capability within the study area.

2.0 TERMS OF REFERENCE

The terms of reference given to Robert Allan Ltd for this work were the following:

(a) Review the Mission requirements for the Sentinel Tug and address any apparent deficiencies/discrepancies.
(b) Review the current regulatory requirements and standing orders for the Sentinel Tug(s).
(c) Conduct a computer based drift study, using the sub-contracted services of Tetra Tech Consulting Group (www.tetratech.com*), a well-respected consulting group with whom Robert Allan Ltd. are currently working on a very similar drift study. The study will be based on the following parameters:*

- Met-Ocean Conditions:
  - the simulation period will be selected as the one that best represents the occurrence of the defined closure conditions of 45 knot winds and app. 15 ft. H_s (approximately equivalent to the 99th percentile of prevailing local conditions)

- the drift model will make use of the best available gridded data. These are:
  - Winds: Alaska Experimental Forecast Facility (AEFF), University of Alaska, WRF archived forecast data, provided courtesy of AEFF. Backup data source is the Alaska Ocean Observing System (AOOS) ROMS model, Prince William Sound
  - Waves: Wave Watch III, Alaskan Waters. Backup data source is SWAN Wave Simulation (AOOS), Prince William Sound
  - Currents: AOOS ROMS model, Prince William Sound. Backup data source is the AOOS HYCOM model, Global Forecast
- Two charted courses (regulated/monitored shipping channels) (as per Annex A attached)
- Two tanker sizes: 125,000 t DWT and 193,000 t DWT
- Two Load Conditions: Full load and ballast
- Geographic Area: Hinchinbrook Entrance to the 200 n. mile limit of US waters
- Start Points of Tanker Drift (from Hinchinbrook Entrance): 17 n. miles; 25 miles, 50 miles

(d) Compare the predicted tanker drift rates to the response speed of the tug from the point of separation.
(e) Update the Sentinel Tug report to incorporate the results of this study.

3.0 METHODOLOGY

As the drift analysis technology is an area of study outside the realm of the professional practise of Robert Allan Ltd. as naval architects, this part of the work was sub-contracted to Tetra Tech EBA Inc. of Vancouver, B.C. The process of the analysis is described in detail in their report, attached as Annex A.

The results of this analysis were then used by Robert Allan Ltd to identify the recommended deployment of a so-called "Sentinel Tug".

4.0 ANALYSIS

The drift analysis process is fully described in Annex A.

5.0 RESULTS

In the defined closure conditions at Hinchinbrook Entrance (45 knots, 15 ft. H_s), the analysis reveals the following:

1. Smaller, lighter vessels drift more quickly than do larger vessels.
2. A vessel in ballast (or partly loaded) will draft faster than the same vessel fully laden
3. Vessels adrift before the peak of the closure condition tend to drift towards the north-west, towards Montague Island and Hinchinbrook Island
4. Vessels adrift at and after the peak of the closure condition tend towards the north-east.
5. Vessels adrift from the southern shipping lane reach shore on average 21% faster than do ships adrift in the eastern shipping lane

The average drift times (for all vessel types and load states considered) for varying starting distances from Hinchinbrook are shown in Table 1 below (Ref. Table 6-8 of Annex A):

Start Location			Time to Shore[1]	Mean Time	Drift Velocity[3]	Mean Drift Velocity	Typical End Location Landmark
Number	Radius	Location	Hours	Hours	Knot	Knot	
1	50 NM	Eastern Shipping Lane	10.77	11.97	2.12	2.36	Copper River Estuary
2	50 NM		13.17		2.59		
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12	17 NM		5.85		2.25		

Rather obviously, the closer a vessel is to shore at the time of drift initiation, the shorter the time to grounding. The least time indicated in the analysis was 3.2 hours; the maximum 29.3 hours.

6.0 CONCLUSIONS

The critical operative criteria for a Sentinel Tug, in the context of this study, is the ability to respond to an emergency aboard a disabled ship anywhere in the given response area in sufficient time to render effective assistance and prevent a grounding. It must be borne in mind that the closure conditions for the tankers as defined in this study are severe, and much more so for a tugboat, (even a large one of over 40 metres length), than for any of the much larger tankers considered.

The tug must be able to make headway in those conditions at a reasonable response speed, then manoeuvre and make a safe towing connection to the ship, and then at the very least slow its drift to as close to zero speed as possible until the storm conditions abate to the point where the tug can make headway with the ship in tow. The updated B.A.T. analysis for the Sentinel Tug [2] affirms that the minimum required BP for the Sentinel Tug is 185 tonnes BP in order to satisfy a zero drift criteria, and as such some allowance must be made for the fact that even the PRT class of tugs, which are the most powerful in the current SERVS fleet, would be losing ground in the defined closure conditions, at least until the storm conditions begin to abate or until a second tug arrives to provide additional assistance with the tow.

Using the data from the table above, the response times and positions for a tug to make contact with a disabled ship have been calculated as shown in Table 2 below. Although the tug response speeds are shown ranging from 8 to 12 knots, it is considered that in these sea conditions 8 knots is likely a reasonable average speed. Note that since drifts are generally towards Hinchinbrook entrance, tug response times are actually reduced from what they would be in calm conditions.

Start Location from shore (n.m.)	Location	Minimum time to 1 n.m. offshore (hours)	Tanker Drift Velocity	Response Time to Tug Arrival at Tanker, at Average Tug Speed (knots)			Tanker Position at Time of Tug Arrival (n.m. from shore)		
				8	10	12	8	10	12
50	Eastern Shipping lane	10.77	2.12	4.9	4.1	3.5	39.5	41.3	42.5
50	Southern Shipping lane	14.79	2.30	4.9	4.1	3.5	38.8	40.7	42.0
25	Eastern Shipping lane	6.44	2.31	2.4	2.0	1.7	19.4	20.3	21.0
25	Southern Shipping lane	8.12	2.29	2.4	2.0	1.7	19.4	20.3	21.0
17	Eastern Shipping lane	4.52	2.06	1.7	1.4	1.2	13.5	14.1	14.5
17	Southern Shipping lane	5.85	2.25	1.7	1.4	1.2	13.3	13.9	14.3

The challenge then is to determine how much time or distance is appropriate for a tug response in these critical situations. The rendezvous takes place at the positions indicated above, but then the two vessels will continue to drift at the tanker drift rate for the time it takes to make the towing connection, which must be assumed to be at least 1 hour, and could indeed be more. In a worst case scenario (similar to the Kulluk incident), there could be a towline failure and then the tow connection must be remade, which could easily take 2 hours, in addition to the initial 1 hour connection period. That further reduces the margin of error.

If the initial response range for a tanker in the southern shipping lane is only 17 miles, and one assumes that only 1 re-connection must be allowed for, then by the time the tug is reconnected it is a further 7 miles towards the beach (3 hours at approx. 2.25 knots), leaving only 6.5 miles to the beach. Since the stated closure conditions have a defined peak endurance of 4-6 hours (Ref. Sec.3.3 of Annex A) there can be zero tolerance for any final drifting of the tanker once connected. Starting at a distance of 6.5 miles from the beach, a 1 knot drift rate after tow connection for 6 hours would see the tanker within the 1 mile "margin line" from the beach used in this analysis…a potentially unacceptable condition. For that reason, it is recommended that the requirements for the Sentinel Tug as defined in the VERP be modified to require a response to at least 30 nautical miles from Hinchinbrook, as follows:

*"Hinchinbrook Tug – A vessel (PWS, PRT, or Theriot Class) capable of ocean escort and rescue service. The vessel is stationed in the vicinity of Hinchinbrook Entrance to provide assistance as a Sentinel escort for tankers in ballast transiting Hinchinbrook Entrance, and laden tankers transiting into or out of the Gulf of Alaska to **30 miles of Cape Hinchinbrook**. This vessel may also be utilized as a close escort for laden tankers transiting through Hinchinbrook Entrance."*

The extra margin afforded by an additional 13 miles of offshore distance is sufficient to allow a closure condition storm to abate and thus enable the tug to start making headway.

for **ROBERT ALLAN LTD.**

Robert G. Allan, P. Eng.
Executive Chairman of the Board

RGA/MP:da

REFERENCES

[1] *A Review of Best Available Technology in Tanker Escort Tugs*; for PWSRCAC, Robert Allan Ltd., Project 212-090, Revision 1, November, 2013.

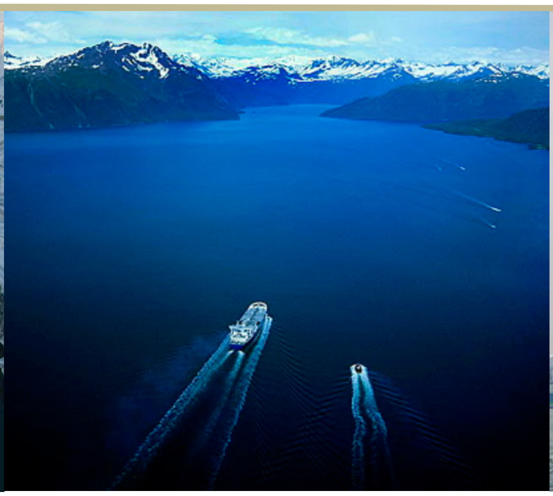
[2] *A Review of Best Available Technology in Tanker Escort Tugs*; for PWSRCAC, Robert Allan Ltd., Project 212-090, Revision 2, April, 2016.

* * *

Annex A

Tetra Tech Report: *Gulf of Alaska, Ship Drift Study*

Gulf of Alaska, Ship Drift Study


PRESENTED TO
Robert Allan Ltd.

MARCH 7, 2016
ISSUED FOR REVIEW
FILE: 704-V13203270

This "Issued for Review" document is provided solely for the purpose of client review and presents our interim findings and recommendations to date. Our usable findings and recommendations are provided only through an "Issued for Use" document, which will be issued subsequent to this review. Once our report is issued for use, the "Issued for Review" document should be either returned to Tetra Tech EBA Inc. (Tetra Tech) or destroyed.

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LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of Robert Allan Ltd. and their agents. Tetra Tech EBA Inc. (Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than Robert Allan Ltd., or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this report is subject to the terms and conditions stated in Tetra Tech EBA Inc.'s Services Agreement. Tetra Tech's General Conditions are provided in Appendix C of this report.

1.0 INTRODUCTION

Robert Allan Ltd. (Robert Allan) has been contracted by the Prince William Sound Regional Citizen's Advisory Council (PWSRCAC) to establish operational guidelines for the distance offshore of Hinchinbrook Entrance over which laden tankers should be accompanied by escort tugs to assist in the event of a tanker losing power. To provide input to this analysis, Robert Allan has contracted Tetra Tech EBA Inc. (Tetra Tech) to provide drift rates and data for disabled tankers, both loaded and in ballast, under closure conditions. This data will be used to assess the required offshore tanker transit distance during which the sentinel tug shore standby, such that the probability of a disabled tanker grounding is extremely low.

2.0 PROJECT LOCATION AND PARAMETERS

Prince William Sound is located on the south coast of the state of Alaska. The eastern shore of Prince William Sound is formed by the Kenai Peninsula, with the western shore formed by the Chugach Mountains and the southern edge comprised of the principal barrier islands Montague Island, Hinchinbrook Island and Hawkins Island. The principal port in Prince William Sound is located at Valdez, Alaska, and is the southern terminus of the Trans-Alaska Pipeline System.

Crude oil transported by the Trans-Alaska Pipeline is loaded on to ocean going vessels at Valdez for export. Vessels transiting Prince William Sound and approximately 50 NM into the Gulf of Alaska must adhere to the shipping lanes presented on Figure 1 as red and blue shaded areas to avoid navigational hazards. To ensure safe transit to open water, safety fairways are provided outside of Prince William Sound to the east and south to safely navigate vessels around Middleton Island to the south and Kayak Island to the east.

Once at the southern terminus of Hinchinbrook Entrance, which is the passage between Montague and Hinchinbrook Islands, vessels are exposed to the full wind, wave and current conditions present in the Gulf of Alaska. Therefore, safe operating conditions, termed the 'closure condition' (Section 3), have been established at Hinchinbrook Entrance to ensure that vessels are not put at risk by extreme winds, waves and currents.

For the purposes of this study, ship drift has been simulated during a closure condition. While a closure condition is not the largest storm event that can occur offshore of Prince William Sound, it is the largest event during which vessels could conceivably be transiting these waters. The procedure of the Port of Valdez is such that if a closure condition or greater event is reached, vessels are not be permitted to enter or exit Prince William Sound meaning they are either delayed within the protected waters of Prince William Sound or in the relative safety of the open ocean. Therefore, the most hazardous condition encountered by un-escorted vessels is transiting the safety fairways during conditions at or near the closure condition.

To simulate vessel behaviour during a closure condition, drift scenarios have been initiated with initial vessel positions along the eastern and southern safety fairways at 17 NM, 25 NM and 50 NM radii from the southern terminus of Hinchinbrook Entrance. These locations are plotted as red circles on Figure 1. From each of the 12 initial drift locations, four vessel configurations are simulated:

- 125,000 t Dwt. class vessel, full load condition, 16 m draft
- 125,000 t Dwt. class vessel, ballast load condition, 9 m draft
- 193,000 t Dwt. class vessel, full load condition, 19 m draft
- 193,000 t Dwt. class vessel, ballast load condition, 9 m draft

Details of these vessel configurations and initial drift locations are presented in Section 6.

3.0 DETERMINATION OF SIMULATION PERIOD

Ship drift has been simulated over a period that is representative of the 'closure condition' of the Port of Valdez, the environmental conditions at which vessel traffic is no longer permitted to enter or leave Prince William Sound for the purpose of loading at the Valdez terminal facility. The closure condition is defined at Hinchinbrook Entrance as a sustained wind speed in excess of 45 knots, with a significant wave height in excess of 4.6 m.

Data between February 2011 and January 2016 have been considered for this study for periods that are concurrent with archived current, wind and wave data available from the Alaska Ocean Observing System (AOOS) for the Gulf of Alaska.

3.1 DATA SOURCES

The Gulf of Alaska and Prince William Sound are fairly well represented by measured data on which to base analysis. Wind and wave data are collected at the following four locations:

- **46061, Seal Rocks:** Wind-wave buoy located in Hinchinbrook Channel and is somewhat sheltered as compared to the larger project area.
- **46076, Cape Cleare:** Wind-wave buoy within the project area, located 52 NM southwest of Hinchinbrook Entrance.
- **70343, Middleton Island Airport:** Airport meteorological station located within the project area, 50 NM south of Hinchinbrook Entrance.
- **46082, Cape Suckling:** Nearest offshore wave buoy to the project area, located 101 NM east-southeast of Hinchinbrook Entrance.

The location of each of these meteorological stations is presented on Figure 2. Since the closure condition is defined at Hinchinbrook Entrance, buoy 46061 at Seal Rocks is the most representative data source for identifying instances of the closure condition. However, buoy 46061 is somewhat sheltered from the full wind and wave climate of the project area by Hinchinbrook Island and Seal Rocks. Therefore, buoys 46076, 46082 and Middleton Island Airport are used to ensure a representative closure condition is selected rather than, for instance, a 1 in 10 year storm event from a direction that is sheltered at buoy 46061 and, hence, registered as a lower severity event (e.g. a closure condition).

Buoys 46061, 46076 and 46082 report wind speed at their anemometer elevation of 5 m. Therefore, the wind speeds reported by these buoys will be lower than the winds reported by either the Middleton Island Airport or most weather forecasts. Unless indicated otherwise, wind speeds recorded at the buoys have not been converted to the standard 10 m elevation (e.g. Large et al. 1995).

3.2 REGIONAL WINDS

High wind events in the vicinity of Hinchinbrook Entrance are typically the result of two processes:

- Strong gap winds can result from high pressure centered over mainland Alaska combined with a low pressure system in the Gulf of Alaska. These winds are typically northerly and localized within Prince William Sound and at Hinchinbrook Entrance (Macklin et al. 1988, Winstead et al. 2006, Liu et al. 2008).
- Extra-tropical cyclones in the Gulf of Alaska, are the source of the most severe winds in the project area and result in strong easterly and south-easterly winds between Hinchinbrook Entrance and Middleton Island (Overland and Cardone 1980, Rodionov 2007, Mesquita 2009, Pickart 2009, Olsson 2015).

The effect of these two processes can be seen on the wind roses presented on Figure 3. The strong easterly winds associated with the vast majority of storm events can be clearly seen at all three locations, while the Seal Rocks station also displays a distinct northerly component lacking at the other two stations as the result of gap winds from Prince William Sound. It is clear from these wind patterns that the large extra-tropical cyclones that characterize the winter storm conditions are the most dominant weather pattern in the project area and, therefore, will be considered in determining an appropriate closure condition to simulate.

3.3 TYPICAL 'CLOSURE CONDITION'

Conditions exceeding the closure condition of a sustained 45 knot wind speed and waves in excess of 4.6 m occur semi-regularly at and offshore of Hinchinbrook Entrance. Based on winds recorded at buoy 46061, at the southern terminus of Hinchinbrook Entrance, the events that trigger a closure condition are remarkably uniform and consist entirely of strong easterlies and south-easterlies:

- An event exceeding the closure condition (both wind and wave) occurs, on average, 1 to 3 times per year.
- A closure condition event represents a 90th percentile storm event: it exceeds 90% of recorded gales (winds in excess of 33 knots) at Hinchinbrook Entrance.
- Closure conditions typically have a peak duration of 4 to 6 hours with an overall duration (initial rise to final easing) of 1.5 to 2 days.
- As a closure condition level event approaches the project site, winds typically shift to between south-easterly and north-easterly. As the peak of the storm approaches, winds shift to easterly and then gradually veer to a south-easterly as the peak of the storm subsides.
- The direction of the peak wind speed associated with a closure condition ranges from 78˚ to 106˚, has a mean direction of 92˚ (easterly), with a standard deviation of 7˚.
- The wave direction associated with the peak of a closure condition ranges from 100˚ to 140˚, with a mean incident wave direction of 119˚ (from the southeast). Insufficient data exists to determine a standard deviation for incident wave direction.

During an event that triggers a closure condition at Hinchinbrook Entrance, the wind and wave conditions across the project area are relatively uniform. Wind direction is essentially uniform at Hinchinbrook Entrance, Cape Cleare, Cape Suckling and Middleton Island, with the mean closure condition wind direction across all sites varying between 91˚ and 95˚. Wind speeds reported at Hinchinbrook Entrance tend to be similar to those reported at Cape Suckling and Middleton Island and approximately 2% to 5% higher than wind speeds reported 50NM to the west at Cape Cleare. Wave height reported at Hinchinbrook Entrance, as expected, is significantly lower than at either Cape Cleare (25% lower) or Cape Suckling (30% lower) during a typical closure condition.

It should be noted that the closure condition corresponds to a Beaufort Force 9 wind speed, but only a Beaufort Force 7 wave height. While this condition is possible at Hinchinbrook Entrance due to the sheltering effects of Seal Rocks, winds and waves throughout the project site generally follow the wind-wave growth pattern described by the Beaufort Scale and wave growth formulations such as Pierson-Moskowitz. For a closure condition at Hinchinbrook Entrance winds and waves recorded at Cape Cleare and Cape Suckling fit nicely within Beaufort Force 9. That is, waves in the more open waters out to 50 NM from Hinchinbrook Entrance are considerably greater than waves recorded at Seal Rocks, during closure conditions.

3.4 SELECTED PERIOD

Between February 2011 and December 2014 (period for which both measured and model data is available), four candidate closure conditions appropriate for simulation have been identified at Hinchinbrook Entrance. These candidate simulation periods are summarized in Table 3.2 for data recorded at buoy 46061, Seal Rocks.

Table 3-1: Candidate Closure Conditions, 46061 Seal Rocks

Date	Peak Wave	Peak Wind		Peak Duration
	H_s	Speed	Direction	
	M	knot	°	hours
20/09/2011	5.8	47	82	1
12/12/2011	8.1	52	96	4
18/12/2011	6.0	45	97	5
10/01/2012	7.2	45	96	4

Of the four candidate simulation periods 18/12/2011 is the most appropriate simulation period based on the following interpretation:

- **20/09/2011:** appropriate wind speed and wind direction, acceptable wave height, but unacceptably short peak duration.
- **12/12/2011:** appropriate wind direction and peak duration, but unacceptably high wind speed and wave height.
- **18/12/2011:** appropriate wind speed, wind direction and peak duration, acceptable wave height.
- **10/01/2012**: appropriate wind speed, wind direction and peak duration, unacceptably large wave height.

For the selected event on 18/12/2011, wind speed (upper panel), wind direction (lower panel) and wave height (middle panel) are plotted on Figure 4. Based on the wind and wave conditions at Hinchinbrook Entrance and the surrounding area, it can be surmised that the selection of 18/12/2011 is appropriate based on the following:

- At Hinchinbrook Entrance, the peak wind speed is almost exactly 45 knots and holds steady for 5 hours, which meets the two wind speed criteria of the closure condition. Wind speed and direction at Cape Suckling and Middleton Island, although not plotted on Figure 4, are within 5% of the reported values at Hinchinbrook Entrance. The buoy at Cape Cleare was out of service on 18/12/2011.
- As the closure condition approached, wave height comes up with the winds and holds steady around the 4.6 m threshold for several hours. At Cape Suckling, the peak wave height is 25% higher (8m) than at Hinchinbrook Entrance, which is in line with historical trends.
- The wind direction associated with the closure condition is initially southerly, shifting to easterly before veering southerly again. This wind direction is somewhat more southerly than the other three potential simulation periods, which likely results in a more onshore drift trajectory.
- At Middleton Island the minimum barometric pressure associated with the 18/12/2011 closure condition is 980 mB. This is a low atmospheric pressure, which is to be expected during a winter storm, but not as low as large (e.g. 5 year storm) events which can result in atmospheric pressures as low as 940 to 950 mB (Olsson, 2015).

4.0 CURRENT, WAVE AND WIND DATA

4.1 MODEL DATA SOURCES

Data employed in this study was obtained from the following sources:

- **Currents:** Data covering the simulation period and project area has been obtained, via AOOS, from the Cooperative Ocean Prediction System (COPS) 3 km resolution Regional Ocean Modelling System (ROMS) model of Prince William Sound.
- **Winds:** Data for the period of interest has been obtained from the 0.5 degree resolution Climate Forecast System Re-Analysis and Reforecast (CRSRR) model, as reported in NOAA's Wave Watch III data products. This model is operated by the National Centers for Environmental Information (NCEP).
- **Waves:** Data covering the period of interest wave obtained from NOAA's Wave Watch III Gulf of Alaska Model, at 12 km resolution.

The data resolution for each of the above models at the project site is shown on Figure 2.

4.2 MODEL DATA VALIDATION

Data sources have been validated against available recorded wave and wind data during the simulation period. Figure 4 presents a comparison between recorded wind and wave data at buoy 46061, Seal Rocks, and Wave Watch III/CRSRR data at the location of the buoy. Similar comparisons for buoy 46082, Cape Suckling, and station 70343, Middleton Island Airport, are presented on Figures 5 and 6, respectively. During the simulation period buoy 46076, Cape Cleare, was not operational. As can be seen from these figures, the selected model ensemble performs exceptionally well at reproducing the measured data record and is, therefore, an appropriate data source for use in the drift simulations.

It should be noted that the use of the High Resolution Rapid Refresh (HRRR) model operated by the Arctic Region Supercomputing Center (ARSC) and the North American Mesoscale Forecast System (NAM-12) model operated by the NCEP were investigated as sources of wind data for this study but were found to compare less well to measured data than the selected ensemble.

5.0 DRIFT MODEL

5.1 MODEL DESCRIPTION

The drift model employed in the study was developed previously to simulate the trajectory of vessels adrift within and offshore of Juan de Fuca Strait, on the south-west coast of British-Columbia, Canada. This model calculates the drift speed and direction of a vessel based on three primary environmental forces:

- **Wind:** The force imparted to the vessel by wind. Wind force is derived on the basis of the drag force imparted to the ship due to the relative wind speed (i.e. subtracting the ship velocity from the wind speed). The above-water projected area acted upon by the wind forcing is determined by the angle between the ship heading and the wind vector, with the associated drag coefficient ranging from 0.7 to 1.6 based on the aspect ratio of the ship geometry encountered by the wind (Newman 1977, Sørgård and Vada 1998, Journée and Massie 2011).

- **Wave:** The force imparted to the vessel by waves. The wave force is derived on the basis of the wave spectrum of the incident wave field and the response and damping amplitude operators associated with the vessel. These response and damping amplitude operators are interpolated to each specific vessel configuration from a database of response and damping amplitude operators published by DNV (Sørgård and Vada 1998)
- **Hydrodynamic:** The force imparted to the vessel by the ambient currents and the hydrodynamic drag for resisting the wind and wave forcing. Hydrodynamic forces on the vessel are derived on the basis of the drag force imparted to the ship due to the relative velocity of the ship and surrounding water (i.e. subtracting the ship velocity from the current velocity). The underwater projected is determined by the angle between the ship heading and the current vector, with the associated drag coefficient ranging from 1.27 to 1.44 based on the aspect ratio of the ship geometry encountered by the currents (Newman 1977, Sørgård and Vada 1998, Journée and Massie 2011).

The approach of the drift model to the calculation of current forcing is to assume a Lagrangian system in which the accelerations of the ship and water body are essentially negligible, with the set of linearized equations describing the above three forces solved numerically. A detailed description of the modelling framework is presented in Appendix A.

5.2 CALIBRATION

The drift model has been calibrated against a series of full-scale tanker drift tests undertaken by StatOil and the Ship Maneuvering Simulator Centre off the west coast of Norway between December 1994 and March 1995 (as presented in Sørgård and Vada 1998). For these tests, tankers ranging in length from 245 m to 260 m under ballast and loaded conditions were set adrift under a variety of wind and wave conditions and their drift tracks recorded via a GPS affixed to the vessel. To our knowledge this is the most comprehensive recent full scale test of tanker drift behaviour.

Based on this data set, the vessel-specific response amplitude spectra and the air and water drag coefficients were calibrated to reproduce, as best possible, the field scale drift tracks. The results of this calibration exercise are presented in Figure 7. As can be seen on that figure, the model reproduces the recorded drift velocities to a high degree of accuracy, performing slightly better for vessels in a ballast configuration. The drift rates calculated in this calibration compare well to disabled tanker drift rates published by the Oil Companies International Marine Forum (OCIMF 1981, 1982).

6.0 DRIFT SIMULATION

6.1 SIMULATED VESSELS

Two vessel types, each under ballast and loaded conditions, were simulated in this study. The characteristics of each vessel type and load case are presented below in Table 6.1. The drift initiation locations for the vessels presented in Table 6.1 are given in Table 6.2 below.

Table 6-1: Summary of vessel properties

Name	LWL[1]	Beam	Draft	Underwater Area		Above Water Area	
				Frontal	Lateral	Frontal	Lateral
	m	m	m	m^2	m^2	m^2	m^2
265m, Loaded (125,000 t Dwt.[2] Class)	265	46	16	740	4,160	728	2,272
265m, Ballast (125,000 t Dwt. Class)	265	46	9	412	2,094	1,073	4,350
280m, Loaded (193,000 t Dwt. Class)	280	50	19	931	5,424	896	2,850
280m, Ballast (193,000 t Dwt. Class)	280	50	9	446	2,730	1,343	5,553

[1] Waterline Length

[2] Deadweight Tonnage

Table 6-2: Start locations of vessel drift

Location Number	Lon	Lat	Radius	Course	Nearest Major Landmark
1	-145.240	59.789	50 NM	Eastern Shipping Lane, Inbound	Kayak Island
2	-145.355	59.698	50 NM	Eastern Shipping Lane, Outbound	Kayak Island
3	-147.024	59.371	50 NM	Southern Shipping Lane, Inbound	Middleton Island
4	-147.128	59.382	50 NM	Southern Shipping Lane, Outbound	Middleton Island
5	-145.910	60.052	25 NM	Eastern Shipping Lane, Inbound	Copper River Estuary
6	-145.976	59.978	25 NM	Eastern Shipping Lane, Outbound	Copper River Estuary
7	-146.730	59.769	25 NM	Southern Shipping Lane, Inbound	Montague Island
8	-146.856	59.776	25 NM	Southern Shipping Lane, Outbound	Montague Island
9	-146.157	60.101	17 NM	Eastern Shipping Lane, Inbound	Hinchinbrook Island
10	-146.211	60.040	17 NM	Eastern Shipping Lane, Outbound	Hinchinbrook Island
11	-146.631	59.904	17 NM	Southern Shipping Lane, Inbound	Seal Rocks
12	-146.764	59.904	17 NM	Southern Shipping Lane, Outbound	Seal Rocks

6.2 DRIFT TRACKS

In each simulation case, the vessels summarized in Table 6.1 were set adrift at the start locations summarized in Table 6.2 on hourly intervals from 4 hours prior to the closure condition peak to 8 hours after the closure condition peak, for a total of 12 start times. From each start time, vessel drift is simulated until the "shoreline" is contacted, defined as the vessel being within 1 NM of shore. This definition of "shoreline" applies throughout the remainder of this document. The fastest drift track over the 12 start times from each start location is presented below for each of the four vessel types: 265 m Loaded, Table 6.3; 265 m Ballast, Table 6.4; 280 m Loaded, Table 6.5; 280 m Ballast, Table 6.6. In each table, the columns are given as follows:

- **Column 1:** Drift start location presented in Table 6.2;
- **Column 2:** Start radius presented in Table 6.2;
- **Column 3:** Date and time of drift initiation for the fastest time to shore drift track from that start location;
- **Column 4:** Hourly offset of drift initiation from the peak of the closure condition, negative indicating start before the peak;
- **Column 5:** Longitude of shoreline contact;
- **Column 6:** Latitude of shoreline contact;
- **Column 7:** Nearest landmark to point of shoreline contact;
- **Column 8:** Total drift time in hours from the start position to shoreline contact, for the fastest drift track from that start location;
- **Column 9:** Average drift velocity over the duration of the drift time.

The drift tracks summarized in these tables are presented on Figure 8 (265 m Loaded), Figure 9 (265 m Ballast), Figure 10 (280 m Loaded) and Figure 11 (280 m Ballast). The start location for each vessel is indicated by a green point, shoreline contact (within 1 NM of shore) is indicated by a red point, and the drift track is shown by the thin black line with hourly markers. Each presented drift track from each start location is the fastest drift track simulated from that location over the 12 start times. For reference, each of the 576 drift tracks simulated in this study, the time to shoreline contact data is presented in Appendix B.

Table 6-3: Fastest vessel drift track per start location, 265 m Vessel, Loaded Condition

Location Number	Start Location			End Location			Time to Shore[1]	Drift Velocity[2]
	Radius	Start Date	Peak +/-	Lon	Lat	Landmark	Hours	Knot
1	50 NM	Dec 18, 22:00	+6 hrs	-145.328	60.240	Copper River Estuary	10.75	1.90
2	50 NM	Dec 18, 23:00	+7 hrs	-145.308	60.232	Copper River Estuary	13.33	1.94
3	50 NM	Dec 18, 16:00	0 hrs	-147.330	59.863	Wooded Islets	14.67	1.91
4	50 NM	Dec 18, 16:00	0 hrs	-147.451	59.830	Wooded Islets	13.75	1.84
5	25 NM	Dec 18, 19:00	+3 hrs	-146.249	60.314	Hinchinbrook Island	6.92	1.88
6	25 NM	Dec 18, 21:00	+5 hrs	-146.279	60.318	Hinchinbrook Island	8.33	1.88
7	25 NM	Dec 18, 22:00	+6 hrs	-146.874	60.160	Seal Rocks	9.83	1.78
8	25 NM	Dec 18, 15:00	-1 hrs	-147.300	60.057	Montague Island	9.42	1.95
9	17 NM	Dec 18, 19:00	+3 hrs	-146.438	60.289	Hinchinbrook Island	5.08	1.75
10	17 NM	Dec 18, 18:00	+2 hrs	-146.546	60.243	Hinchinbrook Island	5.58	1.90
11	17 NM	Dec 18, 22:00	+6 hrs	-146.840	60.148	Seal Rocks	7.33	1.43
12	17 NM	Dec 18, 17:00	+1 hrs	-147.177	60.140	Montague Island	7.25	2.01

[1] Total drift time in hours from the start position to 1 NM from shore

[2] Average drift velocity over the duration of the drift time

Table 6-4: Fastest vessel drift track per start location, 265 m Vessel, Ballast Condition

Location Number	Start Location			End Location			Time to Shore[1]	Drift Velocity[2]
	Radius	Start Date	Peak +/-	Lon	Lat	Landmark	Hours	Knot
1	50 NM	Dec 18, 22:00	+6 hrs	-145.597	60.295	Hinchinbrook Island	9.42	2.52
2	50 NM	Dec 18, 16:00	0 hrs	-146.242	60.319	Hinchinbrook Island	11.33	3.42
3	50 NM	Dec 18, 17:00	+1 hrs	-147.621	59.810	Montague Island	8.67	2.86
4	50 NM	Dec 18, 16:00	0 hrs	-147.671	59.785	Montague Island	8.00	2.89
5	25 NM	Dec 18, 17:00	0 hrs	-146.379	60.313	Hinchinbrook Island	4.92	2.91
6	25 NM	Dec 18, 17:00	0 hrs	-146.504	60.266	Hinchinbrook Island	5.25	3.06
7	25 NM	Dec 18, 16:00	0 hrs	-147.262	60.081	Montague Island	5.83	3.15
8	25 NM	Dec 18, 17:00	+1 hrs	-147.335	60.042	Montague Island	5.08	2.88
9	17 NM	Dec 18, 18:00	+2 hrs	-146.480	60.272	Hinchinbrook Island	3.17	2.50
10	17 NM	Dec 18, 17:00	+1 hrs	-146.581	60.233	Hinchinbrook Island	3.58	2.78
11	17 NM	Dec 18, 16:00	0 hrs	-147.103	60.170	Montague Island	4.83	3.16
12	17 NM	Dec 18, 18:00	+2 hrs	-147.192	60.131	Montague Island	4.17	2.90

[1] Total drift time in hours from the start position to 1 NM from shore

[2] Average drift velocity over the duration of the drift time

Table 6-5: Fastest vessel drift track per start location, 280 m Vessel, Loaded Condition

Location Number	Start Location			End Location			Time to Shore[1]	Drift Velocity[2]
	Radius	Start Date	Peak +/-	Lon	Lat	Landmark	Hours	Knot
1	50 NM	Dec 18, 22:00	+6 hrs	-145.192	60.227	Copper River Estuary	13.58	1.57
2	50 NM	Dec 18, 22:00	+6 hrs	-145.258	60.224	Copper River Estuary	16.50	1.63
3	50 NM	Dec 18, 17:00	+1 hrs	-146.942	60.239	Montague Island	28.00	1.88
4	50 NM	Dec 18, 15:00	-1 hrs	-147.157	60.149	Wooded Islets	29.25	1.62
5	25 NM	Dec 18, 19:00	+3 hrs	-146.226	60.322	Hinchinbrook Island	9.00	1.58
6	25 NM	Dec 18, 20:00	+4 hrs	-146.241	60.317	Hinchinbrook Island	10.92	1.58
7	25 NM	Dec 18, 21:00	+5 hrs	-146.646	60.218	Seal Rocks	15.33	1.61
8	25 NM	Dec 18, 15:00	-1 hrs	-147.304	60.054	Montague Island	12.92	1.49
9	17 NM	Dec 18, 17:00	+1 hrs	-146.499	60.266	Hinchinbrook Island	6.67	1.58
10	17 NM	Dec 18, 17:00	+1 hrs	-146.570	60.231	Hinchinbrook Island	7.17	1.66
11	17 NM	Dec 18, 21:00	+5 hrs	-146.810	60.153	Seal Rocks	9.00	1.32
12	17 NM	Dec 19, 0:00	+8 hrs	-146.850	60.146	Seal Rocks	7.83	1.31

[1] Total drift time in hours from the start position to 1 NM from shore

[2] Average drift velocity over the duration of the drift time

Table 6-6: Fastest vessel drift track per start location, 280 m Vessel, Ballast Condition

Location Number	Start Location			End Location			Time to Shore[1]	Drift Velocity[2]
	Radius	Start Date	Peak +/-	Lon	Lat	Landmark	Hours	Knot
1	50 NM	Dec 18, 22:00	+6 hrs	-145.583	60.289	Copper River Estuary	9.33	2.49
2	50 NM	Dec 18, 16:00	0 hrs	-146.231	60.323	Hinchinbrook Island	11.50	3.38
3	50 NM	Dec 18, 17:00	+1 hrs	-147.613	59.817	Montague Island	8.92	2.81
4	50 NM	Dec 18, 16:00	0 hrs	-147.664	59.788	Montague Island	8.17	2.84
5	25 NM	Dec 18, 17:00	+1 hrs	-146.373	60.310	Hinchinbrook Island	4.92	2.87
6	25 NM	Dec 18, 17:00	+1 hrs	-146.506	60.268	Hinchinbrook Island	5.33	3.05
7	25 NM	Dec 18, 17:00	+1 hrs	-147.272	60.078	Montague Island	5.83	2.99
8	25 NM	Dec 18, 17:00	+1 hrs	-147.328	60.039	Montague Island	5.08	2.84
9	17 NM	Dec 18, 19:00	+3 hrs	-146.475	60.275	Hinchinbrook Island	3.17	2.39
10	17 NM	Dec 18, 17:00	+1 hrs	-146.577	60.231	Hinchinbrook Island	3.58	2.75
11	17 NM	Dec 18, 16:00	0 hrs	-147.106	60.173	Montague Island	4.92	3.15
12	17 NM	Dec 18, 19:00	+3 hrs	-147.191	60.132	Montague Island	4.17	2.77

[1] Total drift time in hours from the start position to 1 NM from shore

[2] Average drift velocity over the duration of the drift time

The drift behaviour of four vessel configurations are summarized and compared in Table 6.7 below. Based on the simulated drift tracks, several observations regarding the behaviour of drifting vessels can be made:

- Loaded vessels drift at a slower rate than vessels in ballast. This is because the loaded vessels present a smaller above water profile (lower wind force), with a larger underwater profile (higher hydrodynamic drag). Waves impart slightly more force to a loaded vessel than a vessel in ballast, however, this effect is secondary to the additional hydrodynamic drag of the loaded vessel.
- The loaded 265 m vessel tends to drift slightly faster than the loaded 280 m vessel. This is because the loaded 280 m vessel is proportionately deeper draft, giving rise to a proportionately higher hydrodynamic drag. This behaviour is similar to the difference between loaded and ballasted vessels noted above.
- The 265 m vessel in ballast tends to drift at approximately the same rate as the 280 m vessel in ballast. This is because both vessels, when in ballast, have the same draft and similar proportional underwater and above water areas. However, because, for this wave climate, the wave force imparted to a vessel increases as a vessel's draft to length ratio increases, the 265 m vessel in ballast (9 m / 265 m) has slightly more wave force imparted to it than the 280 m vessel in ballast (9 m / 280 m), causing the 265 m vessel to drift slightly faster.
- Because loaded vessels drift slower than ballast vessels, they have a longer time to shore contact. This results in the loaded vessel drift tracks shifting from northwest to northeast as the peak of the closure event passes and the winds and waves shift direction, as can be seen in Figures 8 to 11. This effect is particularly evident for drift tracks from the 50 NM radius of the eastern shipping lane, where the shortest drift tracks result from drifts initiated after the peak of the closure event when a northwest drift trajectory is dominant.

Table 6-7: Summary of vessel drift tracks, by vessel type

Parameter	265m, Loaded	265m, Ballast	280m, Loaded	280m, Ballast	Unit
Minimum Time to Shore	5.08	3.17	6.67	3.17	Hours
Maximum Time to Shore	9.35	6.19	13.85	6.24	Hours
Mean Time to Shore	14.67	11.33	29.25	11.50	Hours
Minimum Drift Rate	1.43	2.50	1.31	2.39	Knot
Maximum Drift Rate	1.85	2.92	1.57	2.86	Knot
Mean Drift Rate	2.01	3.42	1.88	3.38	Knot
Critical Locations	Copper River Hinchinbrook I. Montague I.	Hinchinbrook I., Montague I.	Copper River, Hinchinbrook I. Montague I. Seal Rocks	Copper River, Hinchinbrook I. Montague I.	

Beyond the behaviour of the individual vessels, the characteristics of the drifting vessels in the project area are summarized by start location in Table 6.8. In Table 6.8 the drift characteristics are averaged over all vessel types and load scenarios for a general representation of drift properties and typical shoreline contact locations. The general drift behaviour can be summarized as follows:

- Vessels adrift before the peak of the closure condition tend to drift towards the north-west, towards Montague Island and Hinchinbrook Island. This is due to the easterly to south-easterly winds and southerly to south-southeasterly waves that characterize the approach of the closure condition peak.
- Vessels adrift at and after the peak of the closure condition tend towards the north-east. For vessels in the eastern shipping lane, this results in drift towards the Copper River Estuary (specifically, toward the barrier

islands off the Copper River Estuary) and for vessels in the southern shipping lane, this results in drift towards the northern end of Montague Island and Seal Rocks.

- For vessels adrift within 25 NM of Hinchinbrook Entrance, northern Montague Island and the entire Hinchinbrook Island are the most likely locations for shoreline contact. For vessels adrift 50 NM from Hinchinbrook Entrance, the barrier islands off the Copper River Estuary and southern Montague Island are the most likely locations for shoreline contact.
- Of the 576 ship drift tracks simulated in this study, 1 vessel (0.2%) drifted through Hinchinbrook Entrance and into Prince William Sound. An initial investigation of this process showed that by scaling up the current forces relative to winds and waves, as many as 5 of the 576 vessels (0.9%) may drift through Hinchinbrook Entrance.
- Vessels adrift from the southern shipping lane reach shore, on average, 21% faster than vessels adrift from the eastern shipping lane.
- Vessels adrift from a 17 NM radius reach shore an average of 30% faster than vessels adrift from a 25 NM radius which, in turn, reach shore an average of 42% faster than vessels adrift from a 50 NM radius. Vessels adrift from a 17 NM radius reach shore an average of 60% faster than vessels adrift from a 50 NM radius. This is almost entirely due to the nearer to shore starting locations of the 17 NM and 25 NM vessels.
- The specific start location within the project area does not have a significant influence on drift velocity, however, vessels farther out to sea drift marginally faster.

Table 6-8: Summary of vessel drift tracks, by start location and averaged over all vessel types and load configurations

Start Location			Time to Shore[1]	Mean Time	Drift Velocity[3]	Mean Drift Velocity	Typical End Location Landmark
Number	Radius	Location	Hours	Hours	Knot	Knot	
1	50 NM	Eastern Shipping Lane	10.77	11.97	2.12	2.36	Copper River Estuary
2	50 NM		13.17		2.59		
3	50 NM	Southern Shipping Lane	15.06	14.93	2.36	2.33	Southern Montague Island Wooded Islets
4	50 NM		14.79		2.30		
5	25 NM	Eastern Shipping Lane	6.44	6.95	2.31	2.35	Eastern Hinchinbrook Island
6	25 NM		7.46		2.39		
7	25 NM	Southern Shipping Lane	9.21	8.67	2.38	2.34	Central Montague Island
8	25 NM		8.12		2.29		
9	17 NM	Eastern Shipping Lane	4.52	4.75	2.06	2.16	Western Hinchinbrook Island
10	17 NM		4.98		2.27		
11	17 NM	Southern Shipping Lane	6.52	6.19	2.27	2.26	Northern Montague Island Seal Rocks
12	17 NM		5.85		2.25		

[1] Total drift time in hours from the start position to 1 NM from shore, averaged over all vessel types and load configurations

[2] Average drift velocity over the duration of the drift time, averaged over all vessel types and load configurations

7.0 DISCUSSION

For vessels adrift within 50 NM of Hinchinbrook Entrance, the shoreline will be reached in as little as 3.2 hours or as much as 29.3 hours, depending on the initial ship position and the time the vessel loses power. On average, it takes a vessel 12 to 15 hours to reach shore from a 50 NM radius, 7 to 9 hours from a 25 NM radius and 5 to 6 hours from a 17 NM radius. Vessels tend to drift at an average speed of 2.3 knots with a northwest drift direction as the peak of the closure condition approaches and a northeast drift direction as the peak passes. The most common location for shoreline contact is the northern coast of Montague Island and Hinchinbrook Island for vessels within 25 NM of shore and the southern coast of Montague Island and the barrier islands off the Copper River estuary for vessels 50 NM from shore.

The closure condition selected for simulation was selected on the basis of its representativeness of other closure conditions and larger storm events. It is anticipated that the drift tracks simulated in this report are generally representative of ship behaviour during most closure conditions. It is expected that the locations of typical shoreline contact noted in this report also apply to return-period storm events, but the drift velocities and time to shore values presented here would not necessarily apply to a more severe storm.

This study makes use of the best available data that covers the extent of the project site, however, the accuracy of the results in the near shore zone may be improved by incorporating higher-resolution data available in the immediate vicinity of Hinchinbrook Entrance: 1km ROMS data (currents) and 500m SWAN data (winds and waves). If further investigation in to the possibility of vessels drifting into Prince William Sound through Hinchinbrook Entrance (not shown on the Figures, 1 track from 576 simulated tracks) is warranted, it is recommended to employ these higher resolution data sets. The simulated event was selected such that there is overlap with both of these data sources.

8.0 CLOSURE

We trust this report meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech EBA Inc.

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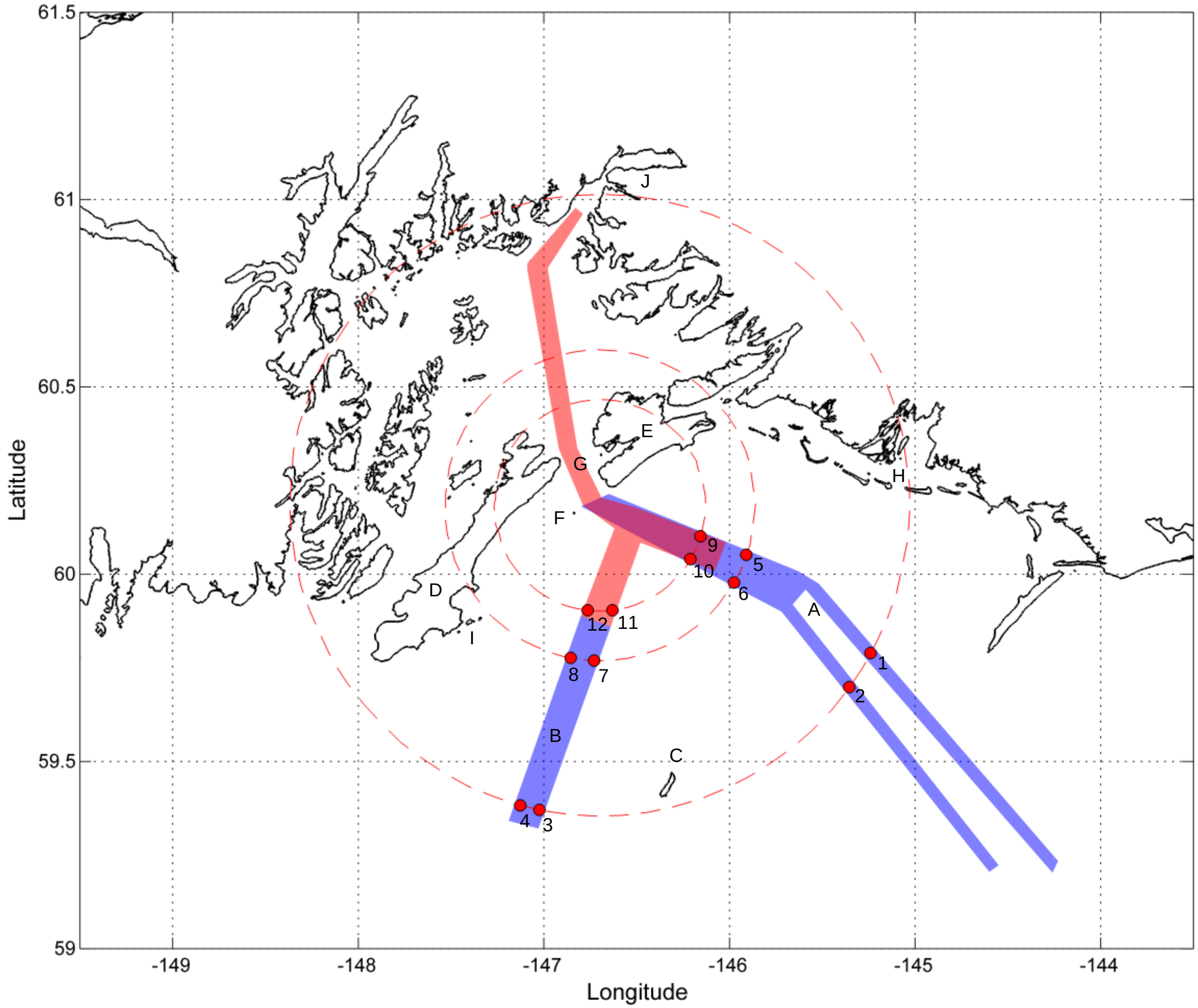
FIGURES



NOTES

- Traffic Lanes
- 17NM, 25NM and 50NM radii
- Initial Ship Positions

Locations:

A Eastern Shipping Lane
B Souther Shipping Lane
C Middleton Island
D Montague Island
E Hinchinbrook Island
F Seal Rocks
G Hinchinbrook Entrance
H Copper River Estuary
I Wooded Islets
J Port of Valdex Export Terminal

STATUS
ISSUED FOR REVIEW

CLIENT
ROBERT ALLAN LTD.
NAVAL ARCHITECTS AND MARINE ENGINEERS

TETRA TECH EBA

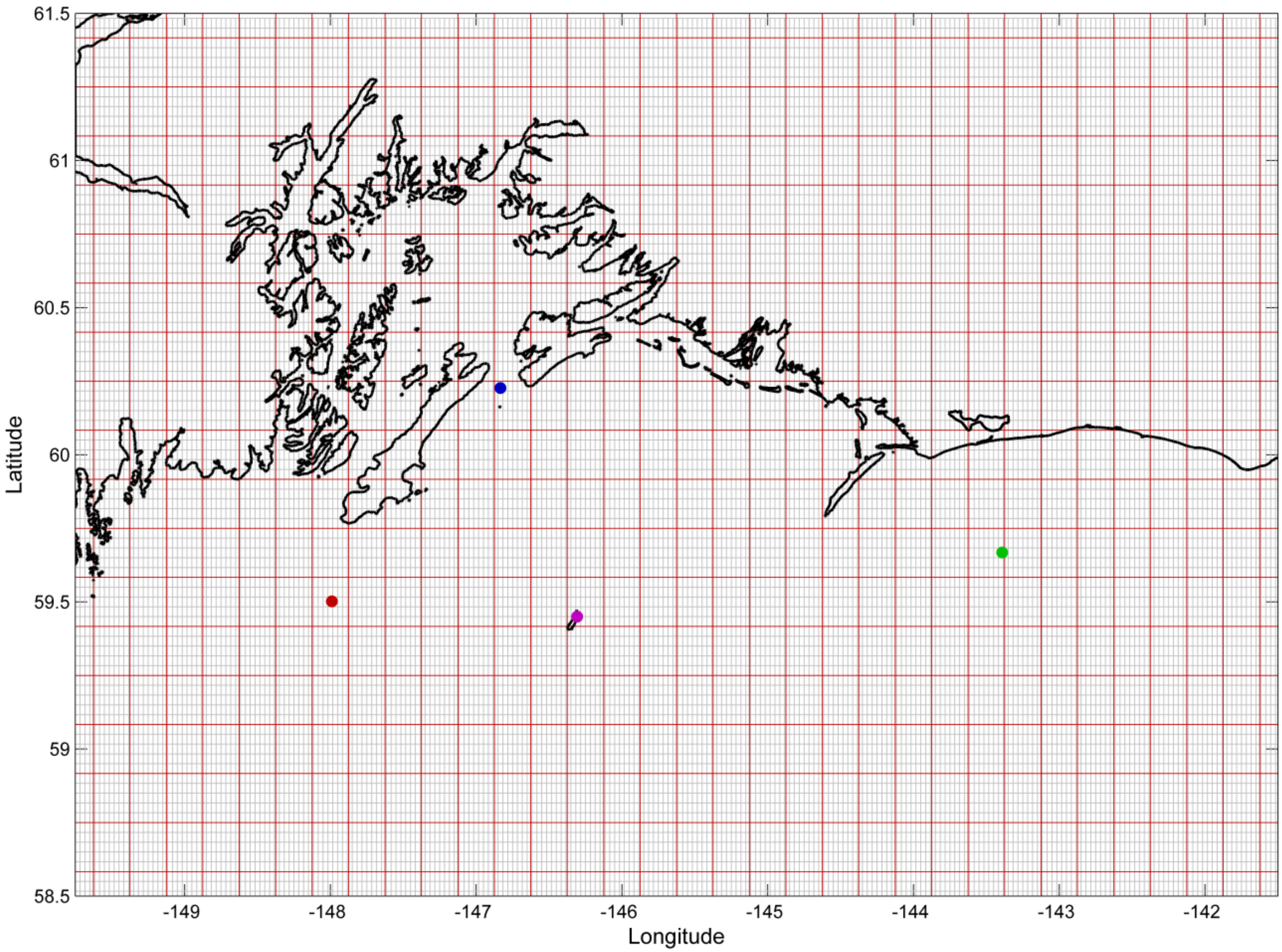
Gulf of Alaska, Ship Drift Study

Project Location

PROJECT NO.	DWN	CKD	APVD	REV
V13203270	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	February, 2016

Figure 1



NOTES

Shoreline

ROMS Model Grid, Currents

Wave Wave III Model Grid, Winds and Waves

46076 Cape Cleare Buoy

46061 Seal Rocks Buoy

46082 Cape Suckling Buoy

70343 Middleton Island Airport

STATUS
ISSUED FOR REVIEW

CLIENT
ROBERT ALLAN LTD.
NAVAL ARCHITECTS AND MARINE ENGINEERS

TETRA TECH EBA

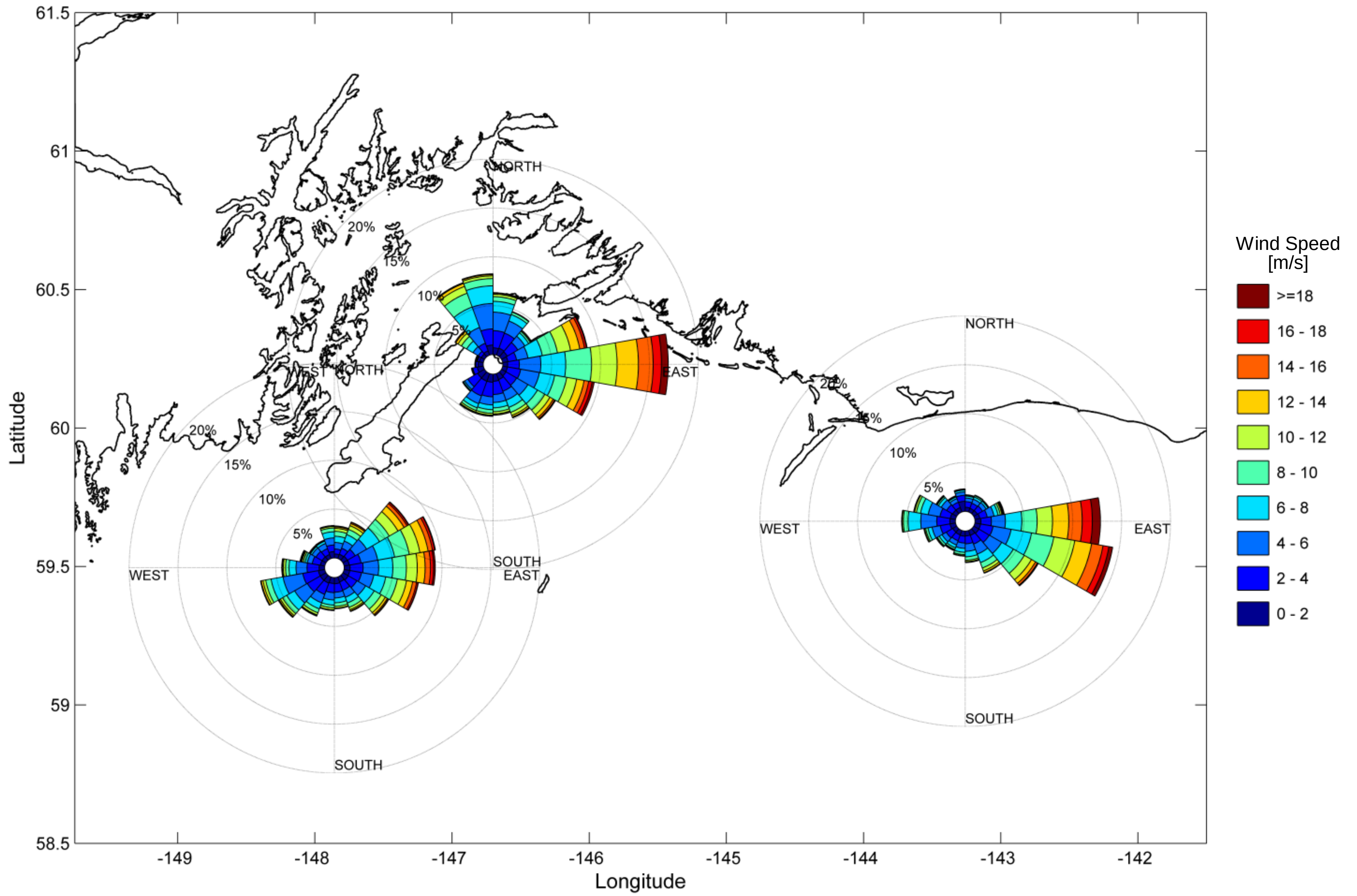
Gulf of Alaska, Ship Drift Study

Data Source Overview

PROJECT NO.	DWN	CKD	APVD	REV
V13203270	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	February, 2016

Figure 2



NOTES

Left Rose: 46076 Cape Cleare
59°30'9" N 147°59'24" W
June 2005 - Ongoing
Center Rose: 46061 Seal Rocks
60°13'39" N 146°50'3" W
May 1995 - Ongoing
Right Rose: 46082 Cape Suckling
59°40'6" N 143°23'32" W
August 2002 - Ongoing
Not shown: 70343 Middleton Island

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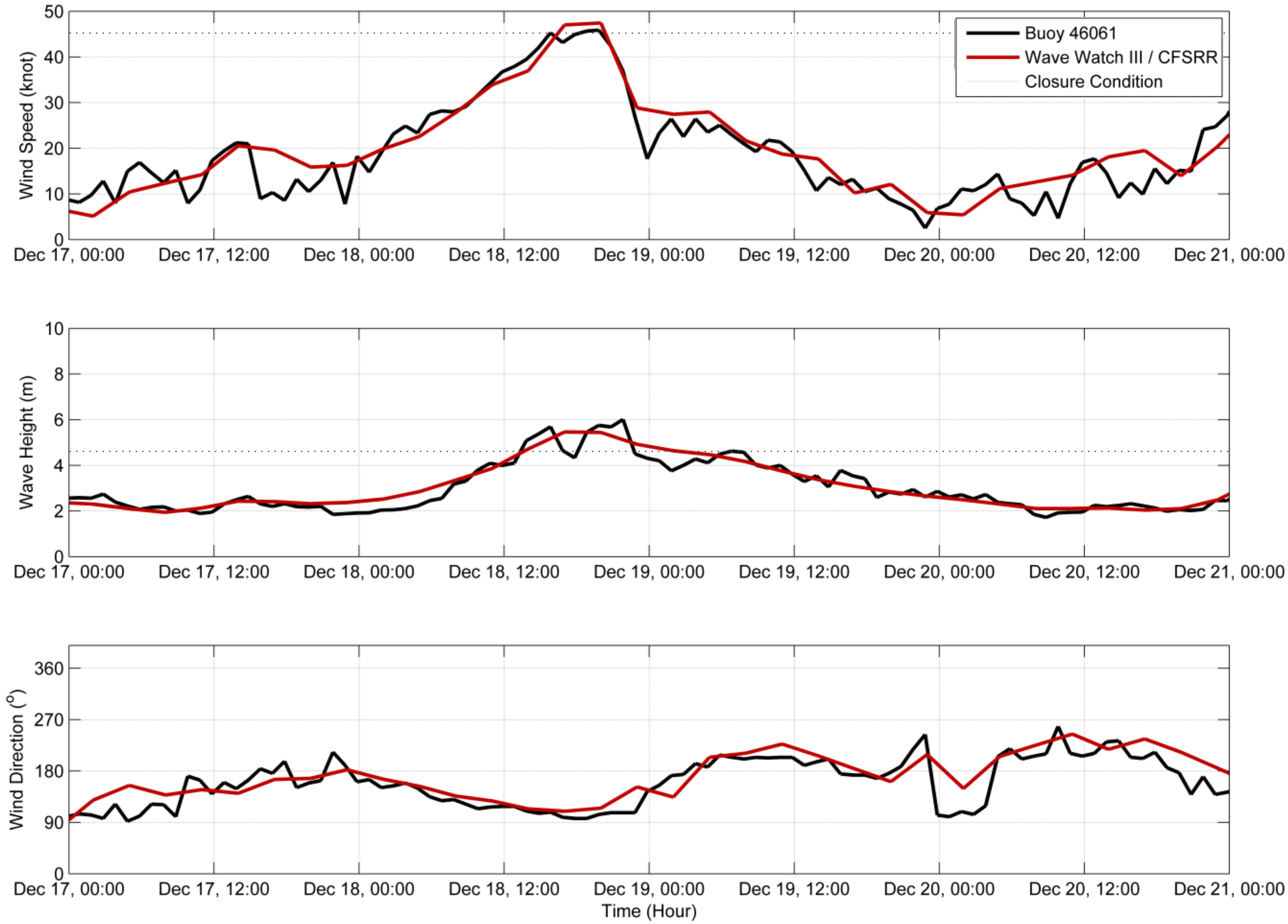
Gulf of Alaska, Ship Drift Study

Regional Wind Patterns

PROJECT NO.	DWN	CKD	APVD	REV
V13203270	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	February, 2016

Figure 3



NOTES

Measured Data:
NOAA Buoy 46061, Seal Rocks
60°13'39" N 146°50'3" W

Modelled Data:
Waves, Wave Watch III
Winds, CFSRR

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Gulf of Alaska, Ship Drift Study

Closure Condition
Buoy 46061, Seal Rocks

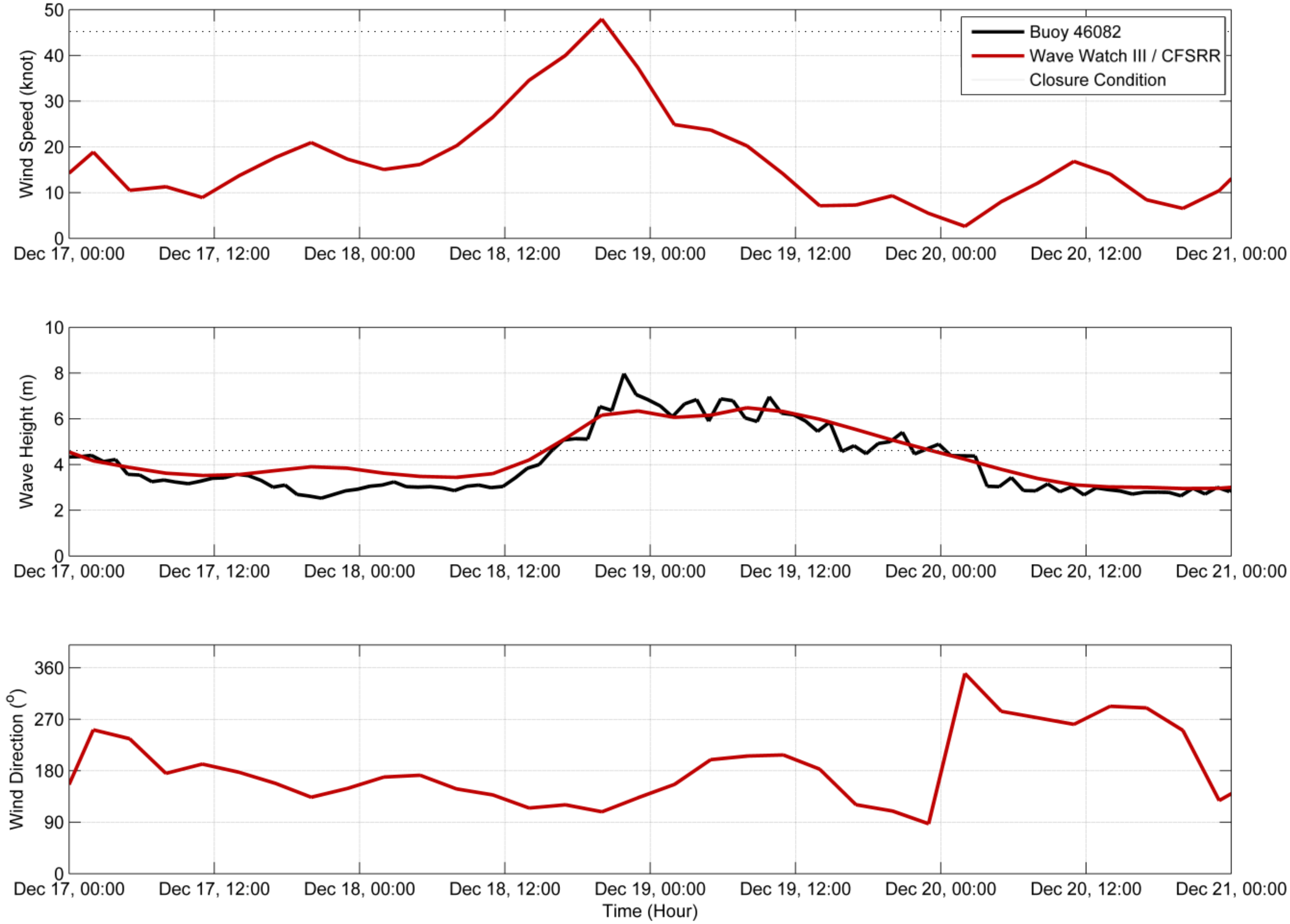
PROJECT NO.	DWN	CKD	APVD	REV
V13203270	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	February, 2016

Figure 4

V:\V13203270_PWSDriftModel\report\Figures\Figure4_ClosureCondition_46061.lay

22 Feb 2016 10:55:27



NOTES

Measured Data:
NOAA Buoy 46082, Cape Cleare
59°40'06" N 143°23'32" W

Modelled Data:
Waves, Wave Watch III
Winds, CFSRR

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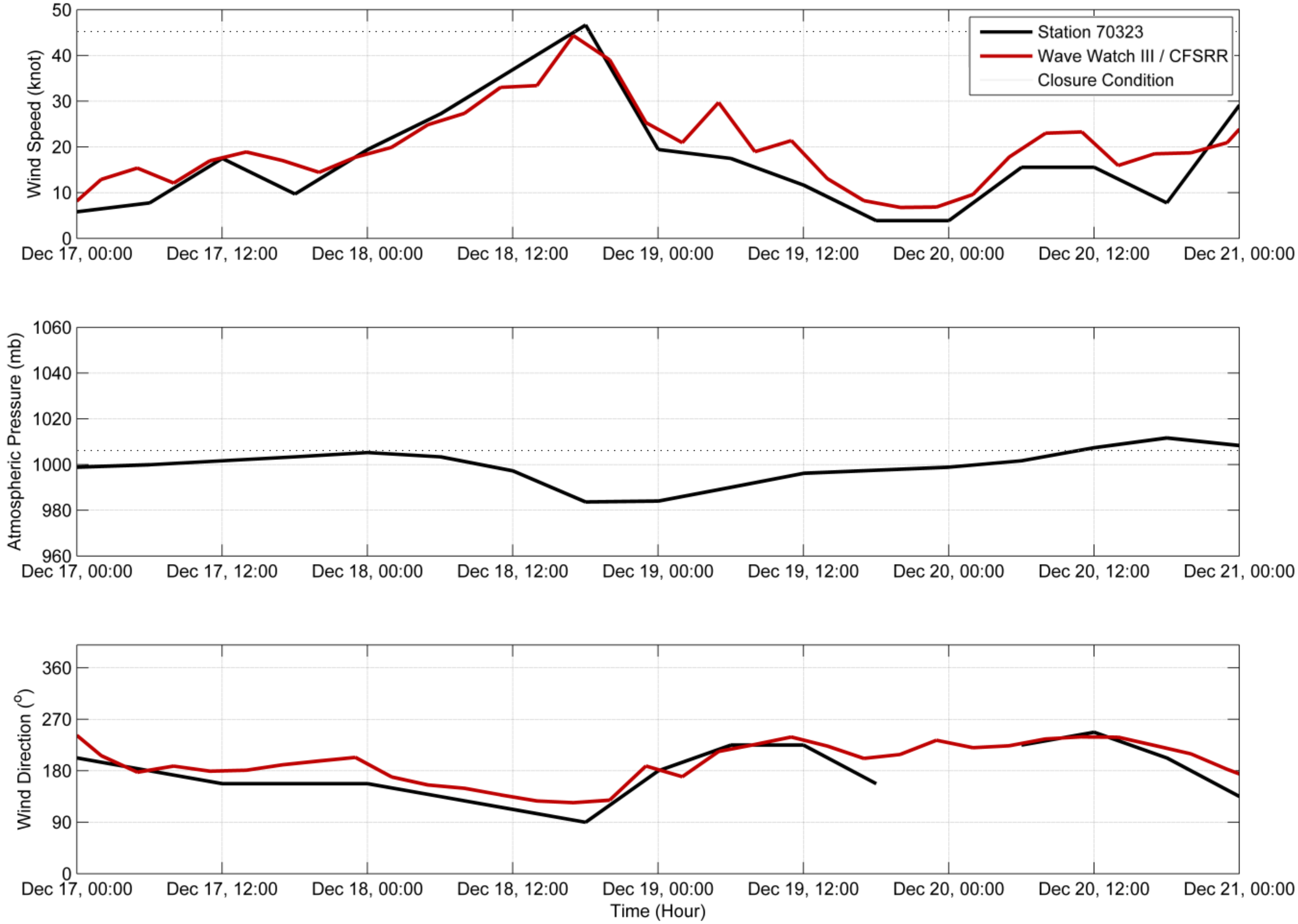
Gulf of Alaska, Ship Drift Study

Closure Condition
Buoy 46082, Cape Cleare

PROJECT NO.	DWN	CKD	APVD	REV
V13203270	JM	JM	JAS	0

OFFICE: Tetra Tech EBA - VANC
DATE: February, 2016

Figure 5



NOTES

Measured Data:
NOAA Station 70323, Middleton Island Airport
59°26'59" N 146°18'26" W

Modelled Data:
Winds, CFSRR via Wave Watch III

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Gulf of Alaska, Ship Drift Study

Closure Condition
Station 70323, Middleton Island Airport

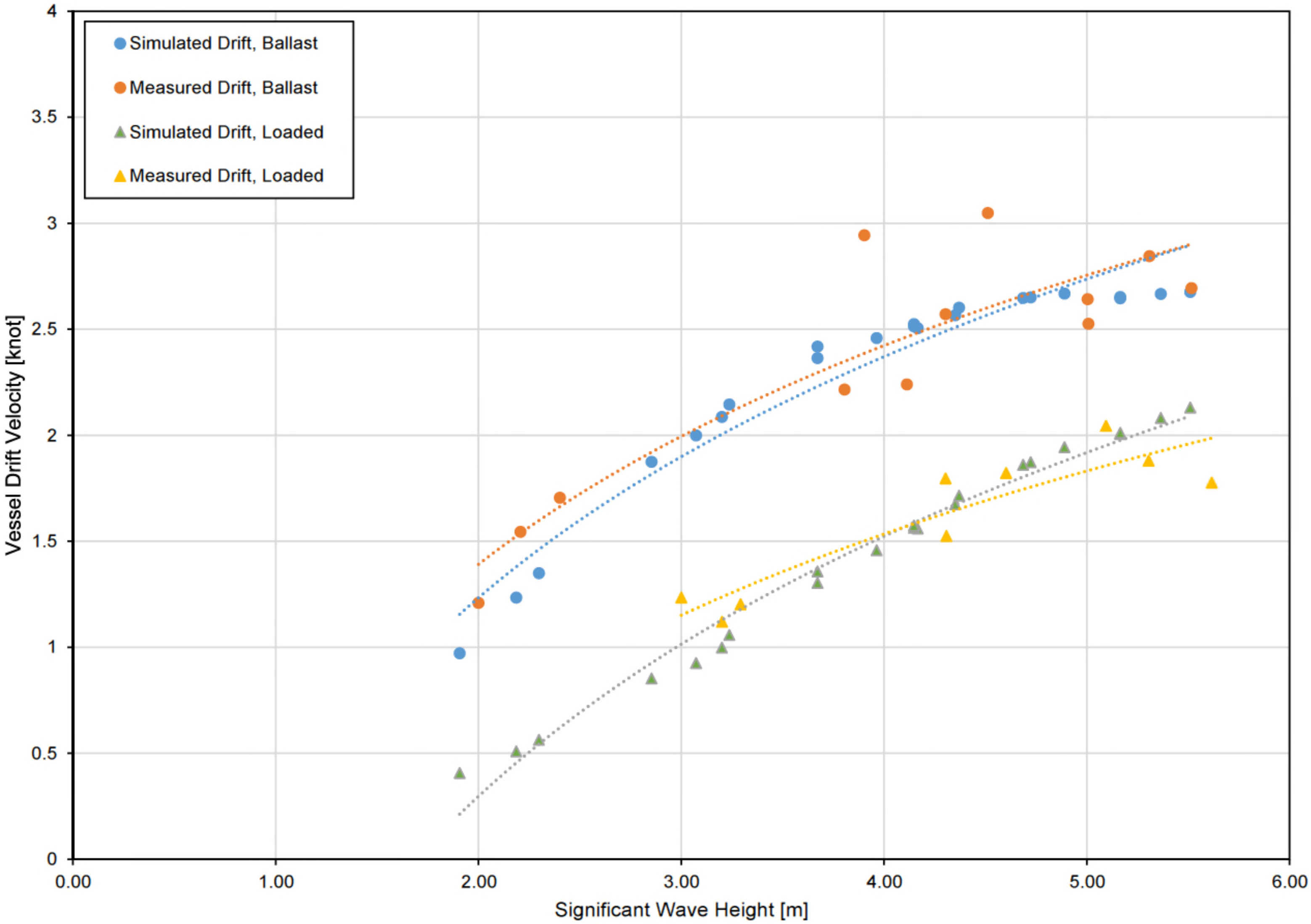
PROJECT NO.	DWN	CKD	APVD	REV
V13203270	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	February, 2016

Figure 6

V:\V13203270_PWSDriftModel\report\Figures\Figure6_ClosureCondition_70323.lay

22 Feb 2016 11:12:36



NOTES

Observed drift velocities collected by Statoil and Ship Maneuvering Simulator Centre between December 1994 and March 1995

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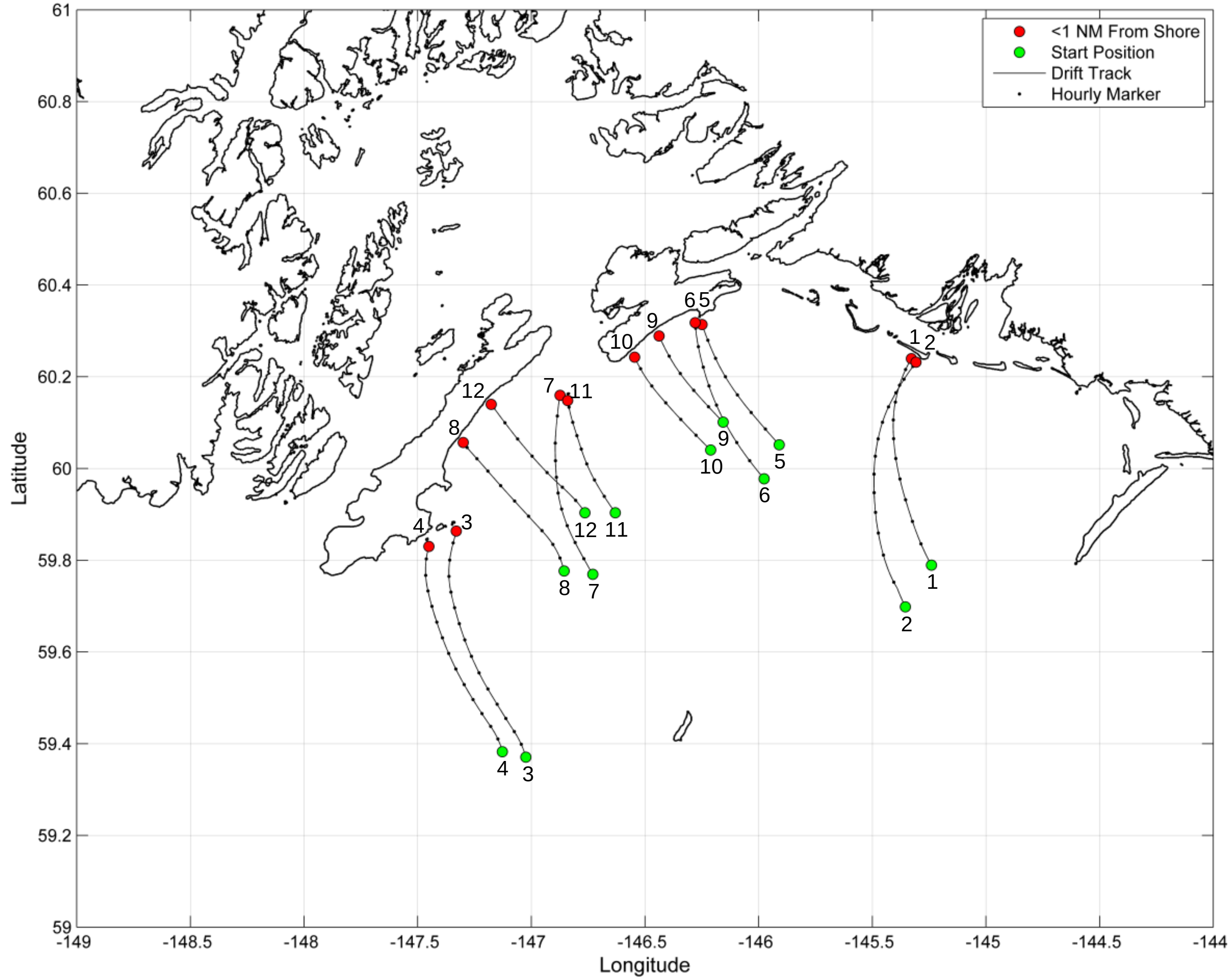
Gulf of Alaska, Ship Drift Study

Drift Model Calibration

PROJECT NO.	DWN	CKD	APVD	REV
V13203270	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	February, 2016

Figure 7



NOTES

From a given start location each drift track represents the shortest time to shore of all simulated tracks between December 18, 2011, 12:00 GMT and December 19, 2011, 00:00 GMT.

Maximum condition at December 18, 2011 at 16:00 GMT

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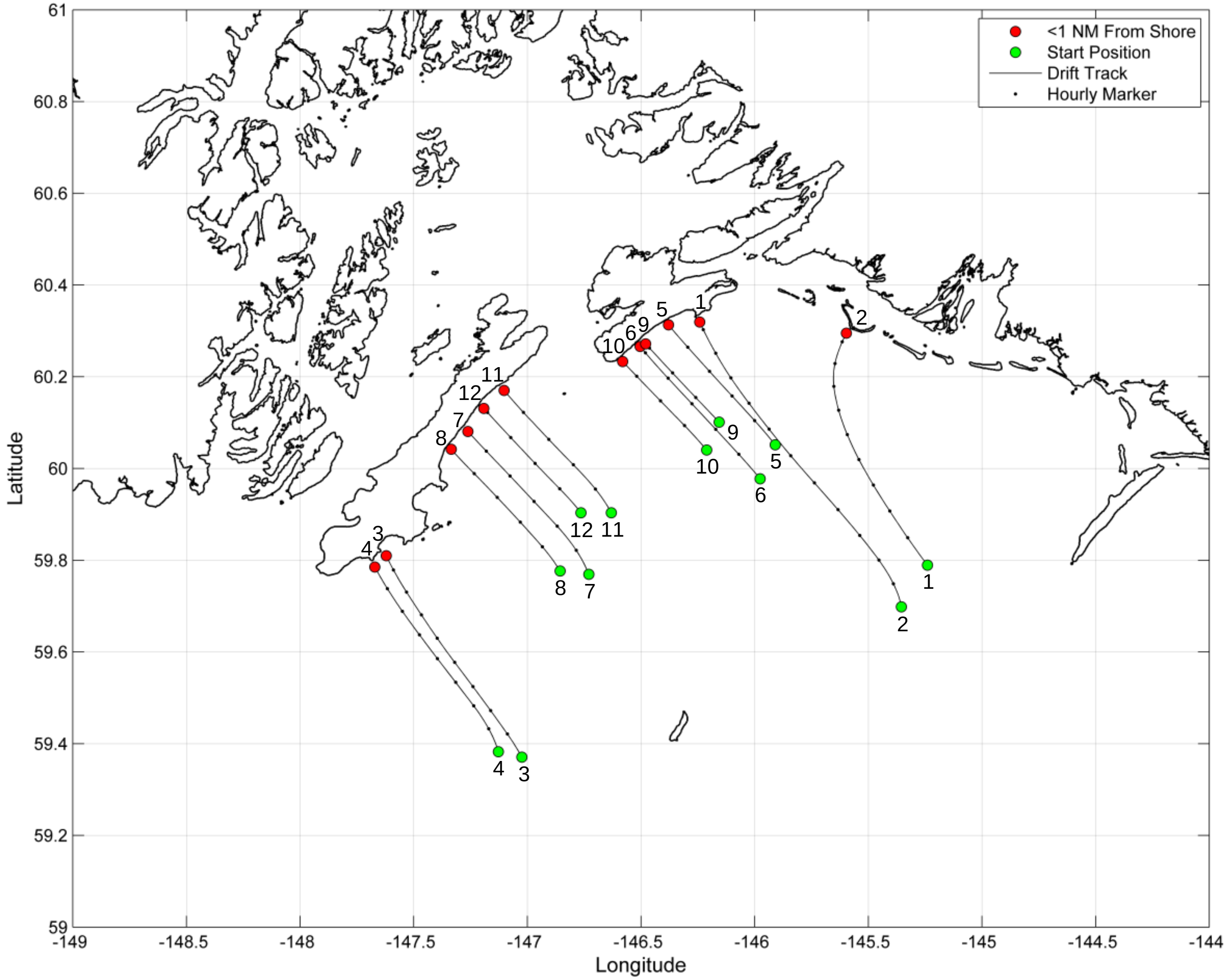
Gulf of Alaska, Ship Drift Study

Drift Tracks
265m Vessel, Loaded Condition

PROJECT NO.	DWN	CKD	APVD	REV
V13203270	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	February, 2016

Figure 8



NOTES

From a given start location each drift track represents the shortest time to shore of all simulated tracks between December 18, 2011, 12:00 GMT and December 19, 2011, 00:00 GMT.

Maximum condition at December 18, 2011 at 16:00 GMT

STATUS
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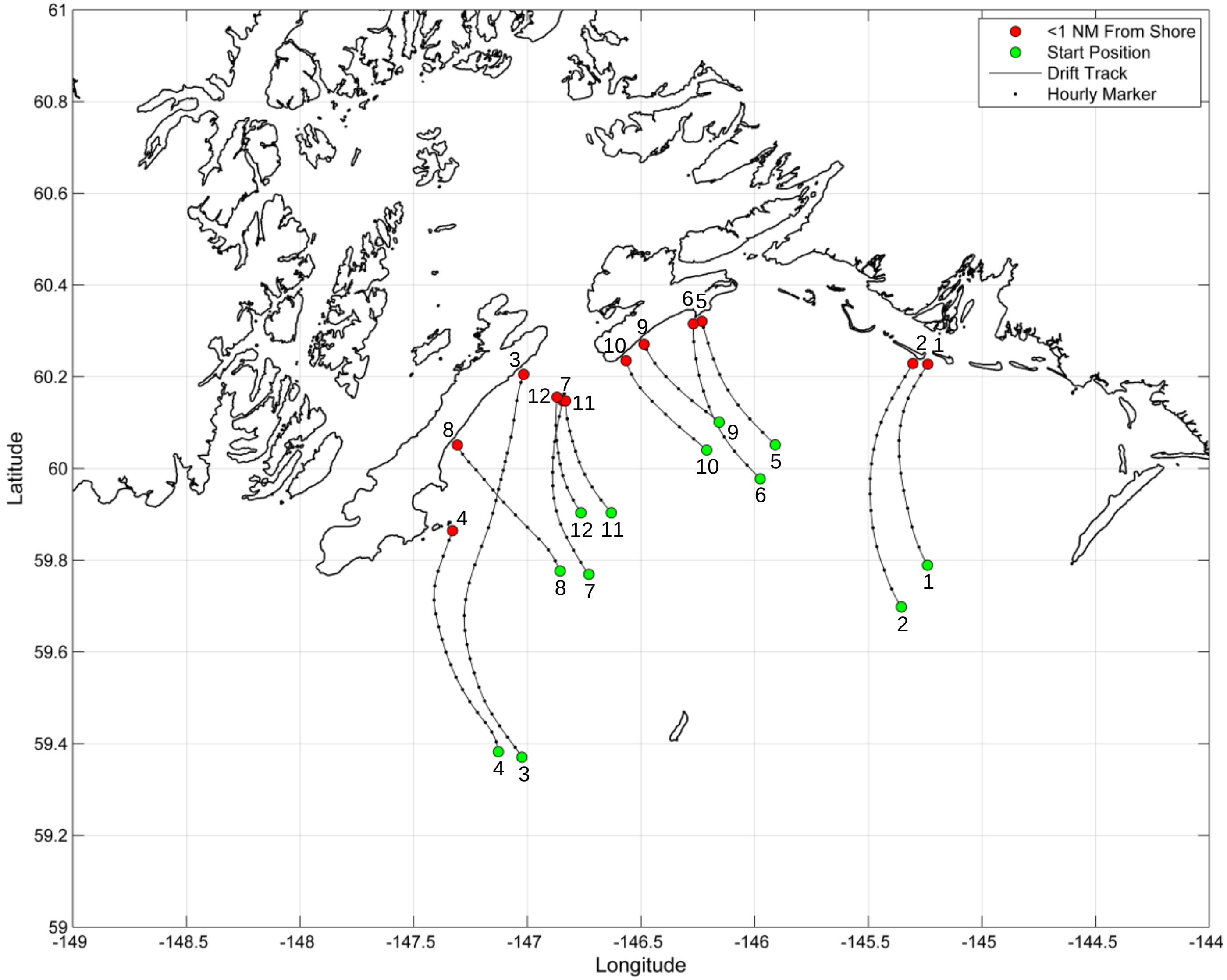
Gulf of Alaska, Ship Drift Study

Drift Tracks
265m Vessel, Ballast Condition

PROJECT NO.	DWN	CKD	APVD	REV
V13203270	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	February, 2016

Figure 9



NOTES

From a given start location each drift track represents the shortest time to shore of all simulated tracks between December 18, 2011, 12:00 GMT and December 19, 2011, 00:00 GMT.

Maximum condition at December 18, 2011 at 16:00 GMT

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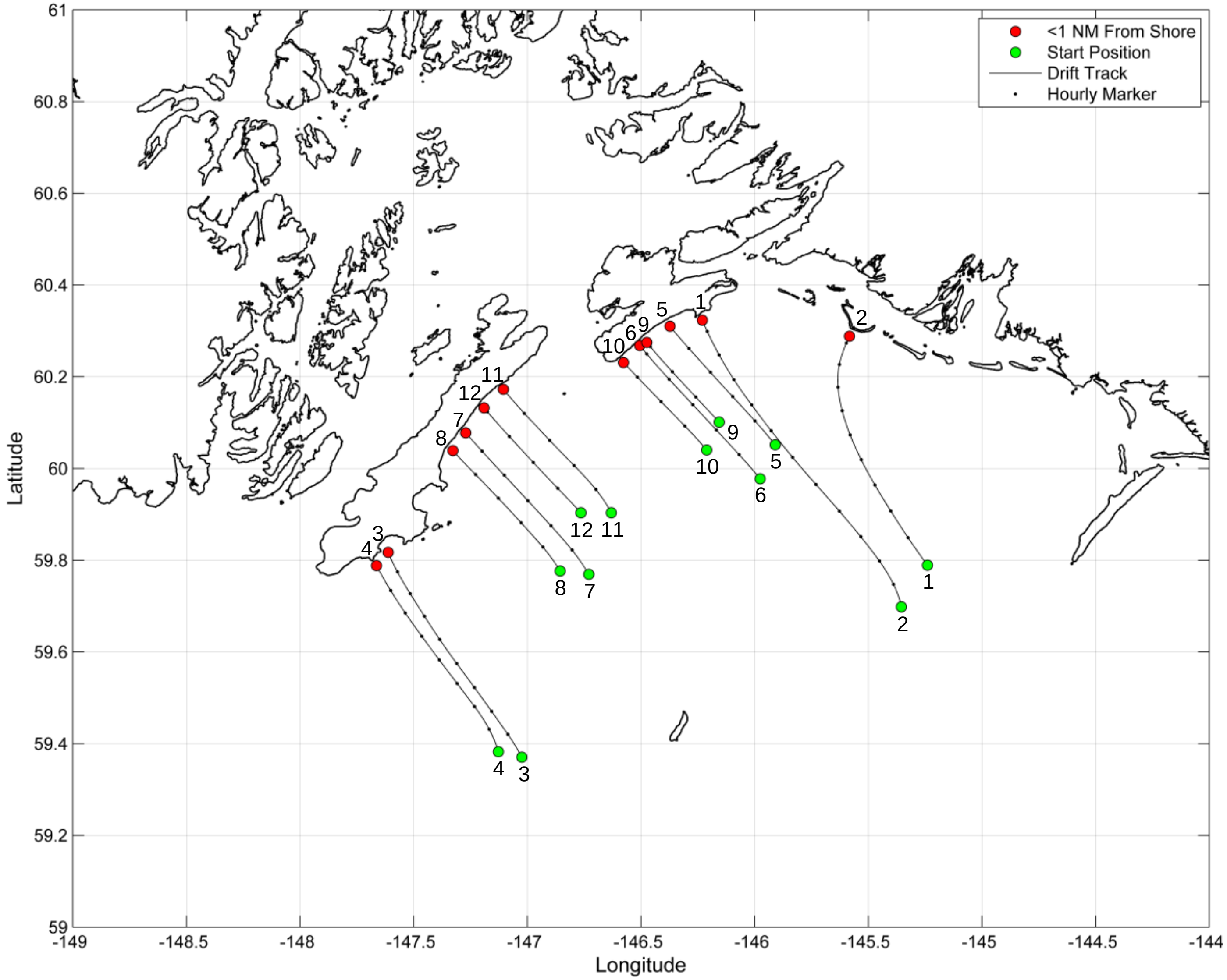
Gulf of Alaska, Ship Drift Study

Drift Tracks
280m Vessel, Loaded Condition

PROJECT NO.	DWN	CKD	APVD	REV
V13203270	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	February, 2016

Figure 10



NOTES

From a given start location each drift track represents the shortest time to shore of all simulated tracks between December 18, 2011, 12:00 GMT and December 19, 2011, 00:00 GMT.

Maximum condition at December 18, 2011 at 16:00 GMT

STATUS
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TETRA TECH EBA

Gulf of Alaska, Ship Drift Study

Drift Tracks
280m Vessel, Ballast Condition

PROJECT NO.	DWN	CKD	APVD	REV
V13203270	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	February, 2016

Figure 11

APPENDIX A

SHIP DRIFT THEORY

Unpowered vessels are exposed to combined current, wind and wave forcing. These environmental factors combine to influence the track of the drifting ship in often complex ways. Data to drive the ship drift model is obtained from three dimensional hydrodynamic models for currents, spectral numerical wave models for waves and either numerical atmospheric models or field measurements for winds. The force imparted to drifting ships has been characterized into hydrodynamic forces (Section 3), wind forces (Section 4) and wave forces (Section 5).

1.0 ASSUMPTIONS

In developing the ship drift estimates, the following assumptions were made:

- The Coriolis force (Ekman currents) have been neglected as a contributor to the environmental forces acting on the drifting ship.

  The Coriolis force is rightly and obviously included in the hydrodynamic model(s) underlying the generation of the current fields, but is neglected as a contributor to the forces acting directly on the vessel. It is common to assume that the Coriolis force will generate a drift force vector inclined at approximately 30° to the primary wind direction. However this effect is only observed under conditions of extraordinarily steady wind, which are practically never present in nature. Therefore, this effect has been neglected, not only as a simplifying assumption but also to reflect the physical reality of natural systems.

- Ships will lie broadside to the incident wave angle, if waves are present.

  This is an assumption borne out of both the practical experience of mariners and a simple moment-balance on a floating vessel. Essentially, when a vessel lies with its major axis parallel to incoming wave crests, the rotational moment that the passing waves exert on the ship is minimized and this, therefore, represents an equilibrium position from the perspective of rotational moments. In conditions in which waves and winds are non-incident (e.g. at some angle relative to each other), the forcing on the vessel is calculated from the projected area perpendicular each applied environmental force. The force calculation for winds, waves and currents is then repeated to iterate until the forces acting on the ship are in balance.

2.0 SHIP DRIFT MODEL FRAMEWORK

Given the dependence of drift velocity on space and time, the following time stepping procedure was used. The drift velocity is first calculated at a specific location for a given time. This velocity is then applied over a specified period (time step) to extrapolate the ship's new position. The drift velocity is then recalculated at this new position to determine the velocity to apply to the ship over the next time step. In this way an explicit Lagrangian (i.e. particle tracking) model is built up for the ship drift, following the form of:

$$P_{n+1} = P_n + \overrightarrow{U_{ship,n}}\Delta t, \qquad t = t_o + n\Delta t$$

in which n represents the current time step number, Δt is the time step, t is the current calculation time, t_o is the initial calculation time, P_{n+1} is the ship's position at time $t + \Delta t$, P_n is the ship's position at time t and $\overrightarrow{U_{ship,n}}$ is the drift velocity vector at time t. The product $\overrightarrow{U_{ship,n}}\Delta t$ represents the distance the ship has drifted over the time step *Δt*.

As the ship drift model is based on a Lagrangian framework, it does not adhere to a traditional gridded model domain, but interpolates gridded environmental data (current, wind, wave) to the ship's location. Although the model does not perform calculations on a computational grid, the time step employed in the model remains constrained by considerations of accuracy: during each time step, the time step size and length of ship drift should be small compared to the temporal and spatial variability in the environmental factors

The total force acting on the vessel is:

$$\overrightarrow{F_{Tot}} = \overrightarrow{F_{wind}} + \overrightarrow{F_{wave}} + \overrightarrow{F_{current}}$$

In which $\overrightarrow{F_{wind}}$ is the force vector resulting from wind forcing, $\overrightarrow{F_{wave}}$ is the force vector resulting from wave forcing and $\overrightarrow{F_{current}}$ is the force vector resulting from current forcing. Each of these forces depends on the relative motion of the ship to the forcing: the difference in wind velocity and ship velocity, the difference in water currents and ship velocity, and a wave force that is damped in a similar way by the ship drift itself. DNV showed that the motion of a drifting ship is well-represented by an equilibrium (i.e.,no net force is acting on the ship as a whole) between these acting environmental forces (Sørgård and Vada 1998). In other words, the ship finds a drift velocity that causes the environmental forces to balance out.

Thus, the forces on the vessel can be solved in the zero-acceleration equilibrium condition in which the driving and resisting forces are balanced ($\overrightarrow{F_{Tot}} = 0$):

$$\overrightarrow{F_{wind}} + \overrightarrow{F_{wave}} + \overrightarrow{F_{current}} = 0$$

The above equation is presented in terms of force vectors, with the individual force components determined along x (east-west) and y (north-south) axes associated with u and v vector components of force and velocity:

$$F_{wind,x}(x, y, t) + F_{wave,x}(x, y, t) + F_{current,x}(x, y, t) = 0$$

$$F_{wind,y}(x, y, t) + F_{wave,y}(x, y, t) + F_{current,y}(x, y, t) = 0$$

in which $F_{wind,x}$ *and* $F_{wind,y}$ are the forces resulting from the component of the wind velocity acting in the x-direction and y-direction, $F_{wave,x}$ *and* $F_{wave,y}$ are the forces resulting from the component of the wave field acting in the x-direction and y-direction, $F_{current,x}$ and $F_{current,y}$ are the force resulting from the component of the current velocity acting in the x-direction and y-direction. Each of the drift velocity vectors is a function of both spatial position (x,y) and time.

3.0 HYDRODYNAMIC FORCES

The approach of the drift model to the calculation of current forcing is to assume a Lagrangian system in which the accelerations of the ship and water body are essentially negligible and in the absence of other forcing the ship drifts at the speed and direction of the surrounding water mass.

Estimates of currents for driving the current induced drift component averaged over the draft of the ship to determine the mean current velocity acting on the ship. The total hydrodynamic force vector acting on the ship, $\overrightarrow{F_{current}}$, is calculated as:

$$\overrightarrow{F_{current}} = \frac{1}{2}\rho_{water}C_{D,water}A_{water,projected}\left(\overrightarrow{U_{current}} - \overrightarrow{U_{ship}}\right)\sqrt{\left(U_{current,x} - U_{ship,x}\right)^2 + \left(U_{current,y} - U_{ship,y}\right)^2}$$

$$A_{water,projected} = \left|A_{beam-on}\sin\left(\theta_{ship} - \theta_{current}\right)\right| + \left|A_{stern-on}\sin\left(\theta_{ship} - \theta_{current}\right)\right|$$

Wherein ρ_{water} is the density of seawater, $C_{D,water}$ is the bulk hydrodynamic drag coefficient of the ship hull, $A_{water,projected}$ is the projected cross-sectional area of the submerged ship hull, $\overrightarrow{U_{ship}}$ is the drift velocity vector of the ship, $\overrightarrow{U_{current}}$ is the current velocity vector.

The underwater projected area ($A_{water,projected}$) acted upon by the current forcing is determined by the angle between the ship heading (θ_{ship}) and the current vector ($\theta_{current}$), with the ship heading taken as perpendicular to the wave field. Two areas are considered, the broadside submerged area of the vessel ($A_{beam-on}$) and the frontal (i.e. bow-on or stern-on) submerged area of the ship ($A_{stern-on}$)

4.0 WIND FORCES

Wind force is derived on the basis of the drag force imparted to the ship due to the relative wind speed (i.e. subtracting the ship velocity from the wind speed). The overall wind force, $\overrightarrow{F_{wind}}$, on the ship is calculated as:

$$\overrightarrow{F_{wind}} = \frac{1}{2}\rho_{air}C_{D,air}A_{air,projected}\left(\overrightarrow{U_{wind}} - \overrightarrow{U_{ship}}\right)\sqrt{\left(U_{wind,x} - U_{ship,x}\right)^2 + \left(U_{wind,y} - U_{ship,y}\right)^2}$$

$$A_{air,projected} = \left|A_{beam-on}\sin\left(\theta_{ship} - \theta_{wind}\right)\right| + \left|A_{stern-on}\sin\left(\theta_{ship} - \theta_{wind}\right)\right|$$

wherein ρ_{air} is the density of air at sea level, $C_{D,air}$ is the bulk air drag coefficient of the ship, $A_{air,projected}$ is the projected cross-sectional area of the above-water ship hull, $\overrightarrow{U_{ship}}$ is the drift velocity vector of the ship, $\overrightarrow{U_{wind}}$ is the wind velocity vector.

The above-water projected area ($A_{air,projected}$) acted upon by the wind forcing is determined by the angle between the ship heading (θ_{ship}) and the wind vector (θ_{wind}), with the ship heading taken as perpendicular to the wave field. Two areas are considered, the broadside above-water area of the vessel ($A_{beam-on}$) and the frontal (i.e. bow-on or stern-on) above water area of the ship ($A_{stern-on}$).

5.0 WAVE FORCES

A natural wave field consists of locally and non-locally generated waves superimposed to form a complete wave climate. The waves that a ship will encounter in a given storm or wave event will have a variety of periods and heights, which in turn excite differing responses of the ship. In a wave field, the net force exerted by the waves on the ship will be in the direction of wave propagation. This force is denoted below as $\overrightarrow{F_{wave}}$, and it is a function of the drift speed $\overrightarrow{U_{ship}}$.

Assuming the velocity of the ship is small relative to the wave field group velocity, the force of the wave field on the ship can be expressed as a Taylor series expansion:

$$\overrightarrow{F_{wave}} = \overrightarrow{F_{wave}}\,(0) + \frac{\partial\,\overrightarrow{F_{wave}}}{\partial\,\overrightarrow{U_{ship}}}\overrightarrow{U_{ship}}$$

in which $\overrightarrow{F_{wave}}$ is the total force exerted by the wave field on the ship. $F_{wave}(0)$ is the *wave drift force*, which is defined as the force exerted by the wave field on the ship when the ship is at rest (zero drift velocity). The derivative term $\partial\,\overrightarrow{F_{wave}}/\partial\,\overrightarrow{U_{ship}}$ is a damping function expressing the decay of wave force with the drift velocity of the ship and is termed the *drift damping*.

The highly variable instantaneous wave conditions of a natural sea state are expressed in terms of a wave spectrum in which the natural wave field is resolved into number of bands characterized by different wave periods (frequencies), each with an associated energy. A given ship will have a varied response to a range of frequencies expressed by the wave energy spectrum. Depending on the design, size and ballast of the ship, it will respond more strongly to waves of one frequency over another, resulting in a spectrum of responses corresponding to the range of natural wave frequencies. The amplitude of the ship's excitation or damping to a given range of frequencies is termed a *transfer function*, which is essentially a Response Amplitude Operator (RAO) for a given ship type.

The wave drift force can be expressed as:

$$\overrightarrow{F_{wave}}\,(0) = \sum_{j=1}^{N} S^2(\Delta\omega(j)) \cdot G(\Delta\omega(j))$$

in which $j = 1,N$ is the index of angular frequency steps considered in the analysis of the discreet wave and transfer function spectra. $S(\omega)$ is the wave power spectrum. $G(\omega)$ is the transfer function of wave forcing for specific ship dimensions and ballasting scenarios.

The wave drift damping can be expressed as:

$$\frac{\partial\overrightarrow{F_{wave}}}{\partial\,\overrightarrow{U_{ship}}} = \sum_{j=1}^{N} S^2(\Delta\omega(j)) \cdot H(\Delta\omega(j))$$

in which $j = 1,N$ is the index of angular frequency steps considered in the analysis of the discrete wave and transfer function spectra. $S(\omega)$ is the wave power spectrum. $H(\omega)$ is the transfer function of wave damping for specific ship dimensions and ballasting scenarios.

Combining the above equations, the total wave force due to wave loading on a ship can be expressed as:

$$\overrightarrow{F_{wave}} = \sum_{j=1}^{N} S^2(\Delta\omega(j)) \cdot G(\Delta\omega(j)) - \sum_{j=1}^{N} S^2(\Delta\omega(j)) \cdot H(\Delta\omega(j)) \cdot \overrightarrow{U_{ship}}$$

6.0 NUMERICAL SOLUTION

The above equations for wind, current and wave forcing are all dependant on the ship's drift velocity, which is itself dependant on the environmental forcing. Therefore, the solution to these equations must be solved numerically to yield the ship's drift velocity. To enable a numerical solution, the equations must be combined and simplified in a logical manner.

Firstly, the terms common to the three sets of equations can be factored out and combined as follows:

For the hydrodynamic forcing, the constants and quadratic terms are brought under the variable $W_{current}$:

$$\overrightarrow{F_{current}} = (\overrightarrow{U_{current}} - \overrightarrow{U_{ship}})W_{current}$$

$$W_{current} = \frac{1}{2}\rho_{water}C_{D,water}A_{water,projected}\sqrt{(U_{current,x} - U_{ship,x})^2 + (U_{current,y} - U_{ship,y})^2}$$

Similarly, the constants and quadratic terms of the wind forcing are brought under the variable W_{wind}

$$\overrightarrow{F_{wind}} = (\overrightarrow{U_{wind}} - \overrightarrow{U_{ship}})W_{wind}$$

$$W_{wind} = \frac{1}{2}\rho_{air}C_{D,air}A_{air,projected}\sqrt{(U_{wind,x} - U_{ship,x})^2 + (U_{wind,y} - U_{ship,y})^2}$$

For the sake of simplicity of notation, the wave forces are similarly brought under the variables A_{wave} and B_{wave}:

$$\overrightarrow{F_{wave}} = A_{wave} - B_{wave}\overrightarrow{U_{ship}}$$

$$A_{wave} = \sum_{j=1}^{N} S^2(\Delta\omega(j)) \cdot G(\Delta\omega(j))$$

$$B_{wave} = \sum_{j=1}^{N} S^2(\Delta\omega(j)) \cdot H(\Delta\omega(j))$$

By combining these simplified equations with the equilibrium equation outlined in Section 2, a system of equations capable of being solved numerically for $\overrightarrow{U_{ship}}$ can be defined:

$$\overrightarrow{F_{wind}} + \overrightarrow{F_{wave}} + \overrightarrow{F_{Current}} = 0$$

$$(\overrightarrow{U_{water}} - \overrightarrow{U_{ship}})W_{water} + (\overrightarrow{U_{wind}} - \overrightarrow{U_{ship}})W_{wind} + A_{wave} - B_{wave}\overrightarrow{U_{ship}} = 0$$

$$\overrightarrow{U_{water}}\,W_{water} + \overrightarrow{U_{wind}}W_{wind} + A_{wave} = \overrightarrow{U_{ship}}(W_{water} + W_{wind} + B_{wave})$$

$$\overrightarrow{U_{ship}} = \frac{\overrightarrow{U_{water}}\,W_{water}(\overrightarrow{U_{ship}}) + \overrightarrow{U_{wind}}W_{wind}(\overrightarrow{U_{ship}}) + A_{wave}}{(W_{water} + W_{wind} + B_{wave})}$$

The above formulation is not explicit in terms of $\overrightarrow{U_{ship}}$ and therefore must be solved numerically, taking a previous value of $\overrightarrow{U_{ship}}$ (i.e. from the previous time step of the model) as a starting point to iterate a new solution for $\overrightarrow{U_{ship}}$:

$$\overrightarrow{U_{ship,n}}(i) = \frac{\overrightarrow{U_{water,n}}\, W_{water,n}(\overrightarrow{U_{ship,n}}(i-1)) + \overrightarrow{U_{wind,n}} W_{wind,n}(\overrightarrow{U_{ship,n}}(i-1)) + A_{wave,n}}{\left(W_{water,n} + W_{wind,n} - B_{wave,n}\right)}$$

in which n represents the time step number, i represents the iteration number and $i-1$ represents the previous iteration number. In the first iteration of $\overrightarrow{U_{ship,n}}(i)$ (i.e. the drift velocity at the current time step), $\overrightarrow{U_{ship,n-1}}$ (i.e. the drift velocity from the previous time step) is used as a starting value. The solution for $\overrightarrow{U_{ship,n}}$ is iterated until there is a less than 1% deviation between $\overrightarrow{U_{ship,n}}(i)$ and $\overrightarrow{U_{ship,n}}(i-1)$.

Returning to the equation presented in Section 2, the ship's position at the end of time step number n is then given as:

$$P_{n+1} = P_n + \overrightarrow{U_{ship,n}}\Delta t, \qquad t = t_o + n\Delta t$$

in which n represents the current time step number, Δt is the time step, t is the current calculation time, t_o is the initial calculation time, P_{n+1} is the ship's position at time $t + \Delta t$, P_n is the ship's position at time t and $\overrightarrow{U_{ship,n}}$ is the drift velocity vector at time t. The product $\overrightarrow{U_{ship,n}}\Delta t$ represents the distance the ship has drifted over the time step *Δt*.

To initiate the next time step $(n+1)$, the environmental forcing at P_{n+1} is determined, and from these forces the ship drift rate $\overrightarrow{U_{ship,n+1}}$ is calculated and used to calculate the ship's position at time $(n+1)$.

APPENDIX B

TIME TO SHORE DATA TABLES

Tables A.1 to A.4 below present the complete time to shoreline contact data for each of the 576 ship drift simulations undertaken in this study. Shoreline contact is taken to be 1 NM from shore. For the sake of comparison, the values in the tables are shaded to a common color scheme, with darker shading indicating a faster time to shore.

Table A.1 Time to Shore, 265m Vessel, Loaded Condition

		Drift Initiation Time on 18/12/2011											
		12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Ship Number	1	17.5	16.8	16.3	15.8	16.6	15.4	13.7	12.0	11.8	11.3	10.8	10.8
	2	19.7	19.2	18.7	18.5	18.0	19.2	17.3	15.6	14.6	14.4	13.9	13.4
	3	16.1	15.8	15.4	15.1	14.6	23.8	24.0	24.0	N/A[1]	27.1	29.8	36.2
	4	14.9	14.6	14.4	14.2	13.7	13.9	13.7	22.8	22.8	23.3	21.4	23.8
	5	10.3	9.6	8.9	8.4	8.2	7.7	7.4	7.0	7.0	7.0	7.7	7.9
	6	10.6	9.8	9.4	8.9	8.6	8.6	8.6	8.6	8.6	8.4	8.6	9.8
	7	11.8	11.3	10.8	10.6	10.6	10.6	11.0	11.3	11.3	11.8	9.8	12.0
	8	10.8	10.1	9.8	9.4	9.4	9.4	9.6	9.8	10.6	10.8	11.3	19.2
	9	7.9	7.2	6.5	6.0	5.5	5.3	5.3	5.0	5.3	5.3	5.5	5.5
	10	8.2	7.4	6.7	6.2	6.0	5.8	5.5	5.5	5.8	6.0	6.2	6.7
	11	10.1	9.4	8.6	8.4	8.2	8.2	8.4	8.6	9.6	9.8	7.4	10.6
	12	9.1	8.4	7.9	7.4	7.2	7.2	7.2	7.4	7.7	7.9	8.4	8.9

[1] This vessel drifted through Hinchinbrook Entrance into Prince William Sound

Table A.2 Time to Shore, 265m Vessel, Ballast Condition

		Drift Initiation Time on 18/12/2011											
		12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Ship Number	1	11.8	11.8	13.2	11.8	10.8	10.8	12.0	12.0	10.6	11.3	9.4	9.4
	2	13.4	12.7	12.0	11.5	11.3	11.3	11.5	12.5	13.0	12.5	12.0	11.3
	3	9.6	9.1	8.9	9.4	8.6	8.6	9.1	8.9	8.9	16.8	19.7	20.4
	4	8.9	8.6	8.9	8.4	7.9	7.9	7.9	8.2	8.6	8.6	18.0	18.5
	5	7.2	6.2	5.5	5.5	5.0	4.8	4.8	4.8	4.8	4.8	4.8	4.8
	6	7.4	6.7	6.0	5.8	5.5	5.3	5.3	5.3	5.3	5.5	6.0	6.2
	7	7.9	7.2	6.7	6.2	5.8	5.8	5.8	6.0	6.2	6.7	7.4	7.9
	8	7.2	6.5	6.0	5.5	5.3	5.0	5.0	5.3	5.5	5.8	6.2	6.7
	9	5.5	4.8	4.3	3.8	3.6	3.4	3.1	3.1	3.1	3.4	3.4	3.6
	10	6.0	5.3	4.6	4.1	3.8	3.6	3.6	3.6	3.6	3.6	3.8	4.1
	11	5.5	6.0	5.5	5.0	4.8	4.8	4.8	4.8	5.0	5.3	5.8	6.2
	12	6.2	5.8	5.3	4.6	4.3	4.1	4.1	4.1	4.3	4.6	4.8	5.3

Table A.3 Time to Shore, 280m Vessel, Loaded Condition

		Drift Initiation Time on 18/12/2011											
		12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Ship Number	1	22.6	21.8	20.2	18.7	17.3	15.6	14.9	14.6	13.7	13.2	13.0	13.2
	2	25.4	24.0	22.8	21.8	20.4	19.4	18.7	18.5	17.8	17.0	16.1	16.1
	3	30.2	30.2	29.8	29.3	28.1	27.6	27.8	42.7	33.1	34.6	49.2	51.4
	4	18.5	18.2	18.0	17.5	27.8	28.8	28.1	26.2	42.5	27.1	33.1	34.6
	5	11.3	10.8	10.1	9.8	9.6	9.4	8.6	8.4	8.4	9.4	9.4	12.0
	6	12.0	11.5	11.0	10.8	10.8	10.8	10.8	11.0	10.1	10.8	12.0	14.6
	7	14.2	13.9	13.7	13.7	13.9	13.9	14.2	14.2	18.7	11.8	16.6	18.0
	8	12.7	12.5	12.2	12.0	12.0	12.2	12.5	13.7	13.9	20.9	14.6	11.0
	9	8.6	7.9	7.4	6.7	6.5	6.2	6.2	6.2	6.5	6.5	6.7	6.5
	10	8.9	8.2	7.7	7.2	7.0	6.7	7.0	7.2	7.4	7.9	8.2	8.4
	11	11.5	10.8	10.8	10.6	10.3	10.3	10.6	11.5	11.8	8.9	11.8	9.6
	12	10.3	9.8	9.6	9.1	8.9	8.9	9.4	9.6	9.6	10.3	10.6	8.2

Table A.4 Time to Shore, 280m Vessel, Ballast Condition

Ship Number	Drift Initiation Time on 18/12/2011											
	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	12.0	12.0	13.2	13.2	11.0	11.0	12.2	11.0	10.6	11.3	9.4	9.4
2	13.7	13.0	12.0	11.8	11.5	11.5	11.8	12.5	13.0	12.5	11.8	11.5
3	9.6	9.4	9.1	9.1	9.1	8.9	9.4	8.9	9.1	17.8	19.7	21.4
4	9.1	8.9	9.1	8.4	8.2	8.2	8.2	8.4	8.6	9.4	18.7	19.0
5	7.0	6.2	6.0	5.5	5.3	4.8	4.8	4.8	4.8	5.0	4.8	5.0
6	7.4	6.7	6.2	5.8	5.5	5.3	5.3	5.3	5.5	5.8	6.0	6.5
7	7.9	7.4	6.7	6.2	6.0	5.8	6.0	6.0	6.2	6.7	7.7	8.2
8	7.2	6.7	6.0	5.5	5.3	5.0	5.3	5.3	5.5	5.8	6.2	7.0
9	5.5	5.0	4.3	3.8	3.6	3.4	3.4	3.1	3.4	3.4	3.6	3.6
10	6.0	5.3	4.6	4.1	3.8	3.6	3.6	3.6	3.6	3.6	3.8	4.1
11	5.5	6.2	5.8	5.3	4.8	4.8	4.8	4.8	5.0	5.5	5.8	6.5
12	6.2	5.8	5.3	4.8	4.3	4.3	4.1	4.3	4.3	4.8	5.0	5.3

APPENDIX C

TETRA TECH'S GENERAL CONDITIONS

GENERAL CONDITIONS

HYDROTECHNICAL

This report incorporates and is subject to these "General Conditions".

1.0 USE OF REPORTS AND OWNERSHIP

This report pertains to a specific site, a specific development, and a specific scope of work. The report may include plans, drawings, profiles and other supporting documents that collectively constitute the report (the "Report").

The Report is intended for the sole use of Tetra Tech EBA's Client (the "Client") as specifically identified in the Tetra Tech EBA Services Agreement or other Contract entered into with the Client (either of which is termed the "Services Agreement" herein). Tetra Tech EBA does not accept any responsibility for the accuracy of any of the data, analyses, recommendations or other contents of the Report when it is used or relied upon by any party other than the Client, unless authorized in writing by Tetra Tech EBA.

Any unauthorized use of the Report is at the sole risk of the user. Tetra Tech EBA accepts no responsibility whatsoever for any loss or damage where such loss or damage is alleged to be or, is in fact, caused by the unauthorized use of the Report.

Where Tetra Tech EBA has expressly authorized the use of the Report by a third party (an "Authorized Party"), consideration for such authorization is the Authorized Party's acceptance of these General Conditions as well as any limitations on liability contained in the Services Agreement with the Client (all of which is collectively termed the "Limitations on Liability"). The Authorized Party should carefully review both these General Conditions and the Services Agreement prior to making any use of the Report. Any use made of the Report by an Authorized Party constitutes the Authorized Party's express acceptance of, and agreement to, the Limitations on Liability.

The Report and any other form or type of data or documents generated by Tetra Tech EBA during the performance of the work are Tetra Tech EBA's professional work product and shall remain the copyright property of Tetra Tech EBA.

The Report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of Tetra Tech EBA. Additional copies of the Report, if required, may be obtained upon request.

2.0 ALTERNATIVE REPORT FORMAT

Where Tetra Tech EBA submits both electronic file and hard copy versions of the Report or any drawings or other project-related documents and deliverables (collectively termed Tetra Tech EBA's "Instruments of Professional Service"), only the signed and/or sealed versions shall be considered final. The original signed and/or sealed version archived by Tetra Tech EBA shall be deemed to be the original. Tetra Tech EBA will archive the original signed and/or sealed version for a maximum period of 10 years.

Both electronic file and hard copy versions of Tetra Tech EBA's Instruments of Professional Service shall not, under any circumstances, be altered by any party except Tetra Tech EBA. Tetra Tech EBA's Instruments of Professional Service will be used only and exactly as submitted by Tetra Tech EBA.

Electronic files submitted by Tetra Tech EBA have been prepared and submitted using specific software and hardware systems. Tetra Tech EBA makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.

3.0 STANDARD OF CARE

Services performed by Tetra Tech EBA for the Report have been conducted in accordance with the Services Agreement, in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this Report. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of the Report.

If any error or omission is detected by the Client or an Authorized Party, the error or omission must be immediately brought to the attention of Tetra Tech EBA.

4.0 ENVIRONMENTAL AND REGULATORY ISSUES

Unless expressly agreed to in the Services Agreement, Tetra Tech EBA was not retained to investigate, address or consider, and has not investigated, addressed or considered any environmental or regulatory issues associated with the project.

5.0 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with Tetra Tech EBA with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for Tetra Tech EBA to properly provide the services contracted for in the Services Agreement, Tetra Tech EBA has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

6.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

During the performance of the work and the preparation of this Report, Tetra Tech EBA may have relied on information provided by persons other than the Client.

While Tetra Tech EBA endeavours to verify the accuracy of such information, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

7.0 GENERAL LIMITATIONS OF REPORT

This Report is based solely on the conditions present and the data available to Tetra Tech EBA at the time the Report was prepared.

The Client, and any Authorized Party, acknowledges that the Report is based on limited data and that the conclusions, opinions, and recommendations contained in the Report are the result of the application of professional judgment to such limited data.

The Report is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present at or the development proposed as of the date of the Report requires a supplementary investigation and assessment.

It is incumbent upon the Client and any Authorized Party, to be knowledgeable of the level of risk that has been incorporated into the project design, in consideration of the level of the hydrotechnical information that was reasonably acquired to facilitate completion of the design.

The Client acknowledges that Tetra Tech EBA is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

8.0 JOB SITE SAFETY

Tetra Tech EBA is only responsible for the activities of its employees on the job site and was not and will not be responsible for the supervision of any other persons whatsoever. The presence of Tetra Tech EBA personnel on site shall not be construed in any way to relieve the Client or any other persons on site from their responsibility for job site safety.