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Lynn Canal Wind and Wave Climatology—Multi-Year Extremes

PREPARED FOR:	BY:	
HDR, Inc. Anchorage, Alaska	K.V. Sultani-Wright,PE PROJECT ENGINEER	
	CHECKED: Thomas Mathai, PhD PROJECT MANAGER	
THE GLOSTEN ASSOCIATES 1201 Western Avenue, Suite 200, Seattle, WA 98101-2921 TEL 206.624.7850 FAX 206.682.9117 www.glosten.com	APPROVED: David W. Larsen, PE PRINCIPAL-IN-CHARGE	
DOC: REV: B FILE: 11163.03	DATE: 31 May 2013	Digitally Signed 31-May-2013

References

1. Gilleland, E. and Katz, R. W., "New Software to Analyze How Extremes Change Over Time," *Eos Transactions American Geophysical Union*, 92 (2), pp 13-14, January 2011.
2. R Core Team, *R: A language and environment for statistical computing*, R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/, 2012.
3. *Juneau Access Improvements SEIS: Lynn Canal Wind and Wave Climatology Study for Vessel Operations*, The Glosten Associates, Rev. A, 22 May 2013.

Revision History

Rev	Description	Date	Approved
—	Rev. — was stamped and signed by K.V. Sultani-Wright, PE, Washington Registration No. 44822, on 15 May 2013.	15 May 2013	BLH
A	Added results for selected field points. Added Conclusion.	28 May 2013	DWL
B	Corrected Figures 6 and 7.	31 May 2013	DWL

The stamp and signature above applies only to the content of the current revision.

Introduction

This report contains the 2-year, 50-year, and 100-year wind and wave environment at several near-shore locations in Lynn Canal that may be considered for Alaska Marine Highway System (AMHS) ferry terminal sites and at several field points along possible routes along Lynn Canal. The extreme wave conditions at the near-shore sites reported herein may be used for terminal and breakwater design, provided that the appropriate return period (typically 50 or 100 years) is selected.

A return period, by definition, is the average period between successive occurrences of that event. Thus, for example, a 100-year return period wave occurs or is exceeded, on average, once every 100 years. The encounter probability, which is the probability that an N-year return period event is equaled or exceeded in 'n' years of service life, can then be calculated as follows:

$$PE = 1 - \left(1 - \frac{1}{N}\right)^n$$

In the above equation, *PE* is the probability of encounter, *N* is the return period in years, and *n* is the service life in years. The encounter probabilities for a matrix of return period and service life combinations are shown in Table 1. The table shows, for example, that a structure designed for a 50-year return period event will stand an 18% chance of encountering such an event in 10 years of service, 33% chance in 20 years of service, 40% chance in 25 years of service, and a 64% chance in 50 years of service. The selection of an appropriate return period, therefore, has to be based on the acceptable risk level. One must carefully balance the economics of increasing the initial cost versus the cost of maintenance and repair, as well as the cost and extent of potential damage to assets that the structure is designed to protect.

Table 1 Encounter probability as a function of return period and service life

	Service Life, Years			
Return Period	10	20	25	50
10-year	65%	88%	93%	99%
25-year	34%	56%	64%	87%
50-year	18%	33%	40%	64%
100-year	10%	18%	22%	39%

Extreme Wind Speed

Historical wind data from Skagway Airport, Eldred Rock, Point Retreat, and Cape Decision was used as the basis for extreme value wind speed extrapolations. Reference 3 contains details of all wind speed data sets used for the extreme analysis. Table 2 shows a summary of the multi-year extreme wind speeds at the four locations for which a wind record was available. The data analysis is described in the following sections.

Table 2 Summary of multi-year extreme wind speeds

	Expected Value Wind Speed (2-min avg at 10 m), kts			
Return Period	Cape Decision	Point Retreat	Eldred Rock	Skagway
2-year	58.7	64.0	62.4	43.2
50-year	69.7	76.5	69.6	70.9
100-year	71.7	77.8	70.5	75.7

Eldred Rock

Wind speed data at Eldred Rock from 10/2006 through 2012 was used as the basis for the extreme value analysis.

Due to the limited data, a Generalized Pareto Distribution (GPD) was fit to declustered peaks-over-threshold data to obtain estimates of the 2-year, 50-year, and 100-year return period wind speed for Eldred Rock, Alaska. The extRemes toolkit was used, which is a software package for analyzing extreme value data using the R statistical programming language (References 1, 2).

The GPD distribution has a cumulative probability distribution function defined as:

$$H(y;\tilde{\sigma},\xi) = 1-\left(1+\frac{\xi y}{\tilde{\sigma}}\right)^{-1/\xi} \quad \text{where} \quad y>0 \ \text{ and } \left(1+\frac{\xi y}{\tilde{\sigma}}\right)>0 .$$

Table 3 shows the parameter estimates of the GPD fit to the Eldred Rock data.

The data was declustered using a run length of 48 hours, meaning that measurements belonging to the same cluster are separated by fewer than 48 hours of data below the threshold. The lower threshold was chosen as 50 knots. The dataset for which the GPD was fit consisted of 52 threshold exceedances.

Diagnostics of the GPD fit are shown in Figure 1. The probability plot compares the empirical probability distribution of data with probability predicted by the GPD fit function. The quantile plot compares the empirical data with the data predicted by the GPD fit. Linear fits in the probability plot and the quantile plot (line indicated on plots) show that the GPD is a good fit to the data. The return level plot in Figure 1 shows the approximate symmetric 95% confidence interval, in addition to the empirical data and the GPD fit. The actual confidence intervals are calculated using the profile likelihood method. The GPD curve should agree well with the data, as exemplified by the plot. The density plot is a histogram of the empirical data.

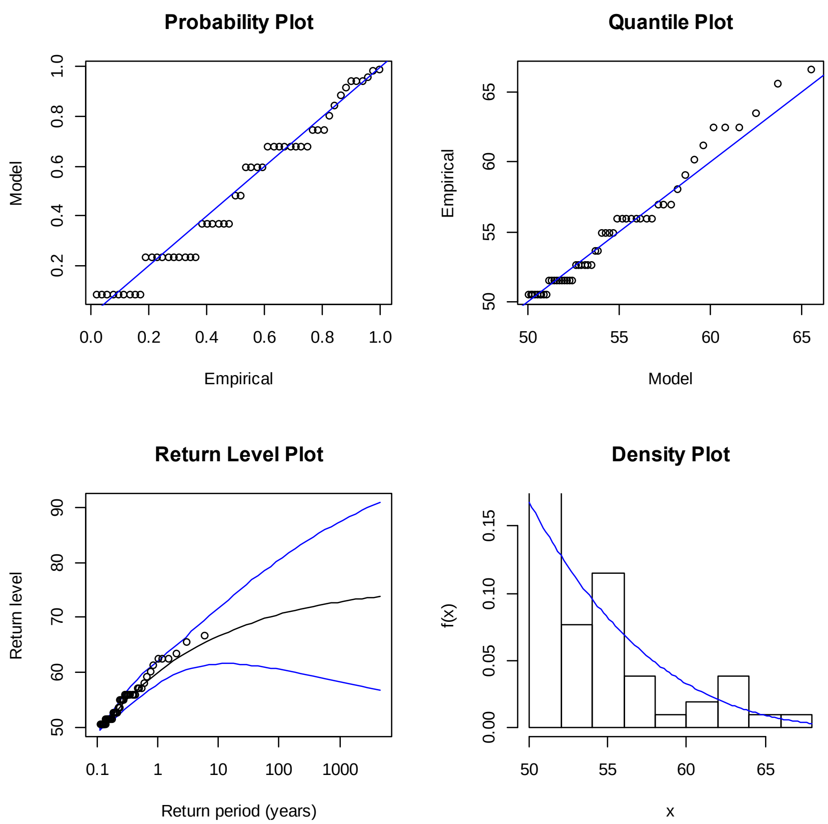

Figure 1 GPD distribution fit of annual extreme wind speeds at Eldred Rock

Table 3 Maximum likelihood estimates of parameters of GPD fit

Parameter	Name	Value	Standard Error
$\tilde{\sigma}$	Scale	5.963	1.244
ξ	Shape	-0.227	0.159

The 2-year, 50-year, and 100-year return period wind speeds were estimated from the GPD fit. These values are shown in Table 4. Return level confidence intervals were calculated using the profile log-likelihood function, as implemented in Reference 1. These confidence intervals might be properly interpreted as prediction intervals with a 95% probability that an N-year return value falls within the given bounds.

Table 4 Extreme 2-minute average wind speeds at 10 m above local ground at Eldred Rock

Return Period	Expected Value, kts	95% Confidence Interval, kts
2-year	62.4	[60, 67]
50-year	69.6	[66, 95]
100-year	70.5	[66, 104]

Skagway

Wind speed data at Skagway Airport from 1973 through 2012 was used as the basis for the extreme value analysis.

Annual maximum wind speeds were selected from the complete data set in order to perform an extreme value analysis. A generalized extreme value (GEV) distribution was fit to the annual maxima to obtain estimates of the 2-year, 50-year, and 100-year return period wind speed for Skagway, Alaska. The extRemes toolkit was used, which is a software package for analyzing extreme value data using the R statistical programming language (References 1, 2). The data set of annual maximum wind speeds is shown in Table 6.

The GEV distribution has a cumulative probability distribution function defined as:

$$G(z;\mu,\sigma,\xi) = \exp\left[-\{1+\xi(z-\mu)/\sigma\}^{-1/\xi}\right] \quad \text{where} \quad -\infty < \mu,\xi < \infty \text{ and } \sigma > 0 .$$

Table 5 shows the parameter estimates of the GEV fit to the Skagway Airport data.

Diagnostics of the GEV fit are shown in Figure 2. The probability plot compares the empirical probability distribution of data with probability predicted by the GEV fit function. The quantile plot compares the empirical data with the data predicted by the GEV fit. Linear fits in the probability plot and the quantile plot (line indicated on plots) show that the GEV is a good fit to the data. The return level plot in Figure 2 shows the approximate symmetric 95% confidence interval, in addition to the empirical data and the GEV fit. The actual confidence intervals are calculated using the profile likelihood method. The GEV curve should agree well with the data, as exemplified by the plot. The density plot is a histogram of the empirical data.

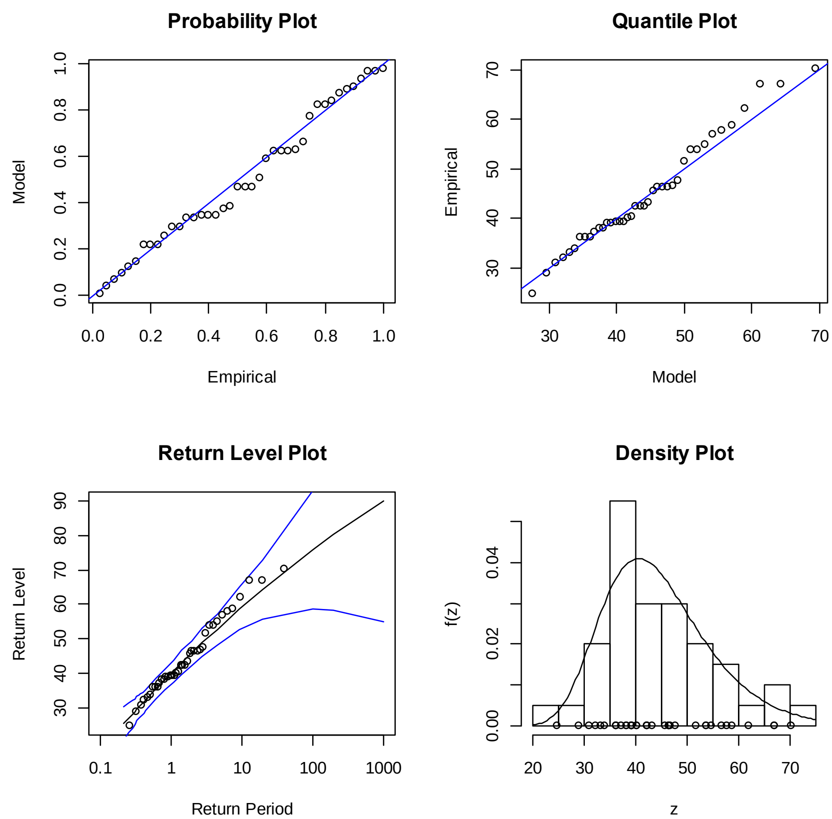

Figure 2 GEV distribution fit of annual extreme wind speeds at Skagway

Table 5 Maximum likelihood estimates of parameters of GEV fit

Parameter	Name	Value	Standard Error
μ	Location	39.90	1.61
σ	Scale	9.90	1.16
ξ	Shape	-0.0652	0.12

Table 6 Annual maximum 2-minute average wind speeds at 10 m above local ground at Skagway

Year	Speed, kts	Year	Speed, kts	Year	Speed, kts	Year	Speed, kts
1973	70.2	1983	51.6	1993	57.8	2003	40.3
1974	67.0	1984	53.8	1994	24.7	2004	46.4
1975	67.0	1985	54.8	1995	46.4	2005	39.3
1976	28.9	1986	53.8	1996	39.1	2006	39.3
1977	40.1	1987	32.1	1997	37.1	2007	38.1
1978	33.9	1988	30.9	1998	36.1	2008	39.3
1979	58.8	1989	46.6	1999	45.6	2009	42.3
1980	39.1	1990	62.0	2000	36.1	2010	38.1
1981	36.1	1991	33.1	2001	43.3	2011	42.3
1982	56.8	1992	46.4	2002	42.3	2012	47.6

The 2-year, 50-year, and 100-year return period wind speeds were estimated from the GEV fit. These values are shown in Table 7. Return level confidence intervals were calculated using the profile log-likelihood function, as implemented in Reference 1. These confidence intervals might be properly interpreted as prediction intervals with a 95% probability that an *N*-year return value falls within the given bounds.

Table 7 Extreme 2-minute average wind speeds at 10 m above local ground at Skagway

Return Period	Expected Value, kts	95% Confidence Interval, kts
2-year	43.2	[40, 47]
50-year	70.9	[63, 96]
100-year	75.7	[66, 110]

Point Retreat

Wind speed data at Point Retreat from 10/2006 through 2012 was used as the basis for the extreme value analysis.

Due to the limited data, a Generalized Pareto Distribution (GPD) was fit to declustered peaks-over-threshold data to obtain estimates of the 2-year, 50-year, and 100-year return period wind speed for Point Retreat, Alaska. The extRemes toolkit was used, which is a software package for analyzing extreme value data using the R statistical programming language (References 1, 2).

The GPD distribution has a cumulative probability distribution function defined as:

$$H(y;\tilde{\sigma},\xi) = 1 - \left(1 + \frac{\xi y}{\tilde{\sigma}}\right)^{-1/\xi} \quad \text{where} \quad y > 0 \text{ and } \left(1 + \frac{\xi y}{\tilde{\sigma}}\right) > 0\,.$$

Table 8 shows the parameter estimates of the GPD fit to the Point Retreat data.

The data was declustered using a run length of 48 hours, which means that measurements belonging to the same cluster are separated by fewer than 48 hours of data below the threshold. The lower threshold was chosen as 35 knots. The dataset for which the GPD was fit consisted of 52 threshold exceedances.

Diagnostics of the GPD fit are shown in Figure 3. The probability plot compares the empirical probability distribution of data with probability predicted by the GPD fit function. The quantile plot compares the empirical data with the data predicted by the GPD fit. Linear fits in the probability plot and the quantile plot (as the line indicated on the plots) show that the GPD is a good fit to the data. The return level plot in Figure 3 shows the approximate symmetric 95% confidence interval in addition to the empirical data and the GPD fit. The actual confidence intervals are calculated using the profile likelihood method. The GPD curve should agree well with the data, exemplified by the plot. The density plot is a histogram of the empirical data.

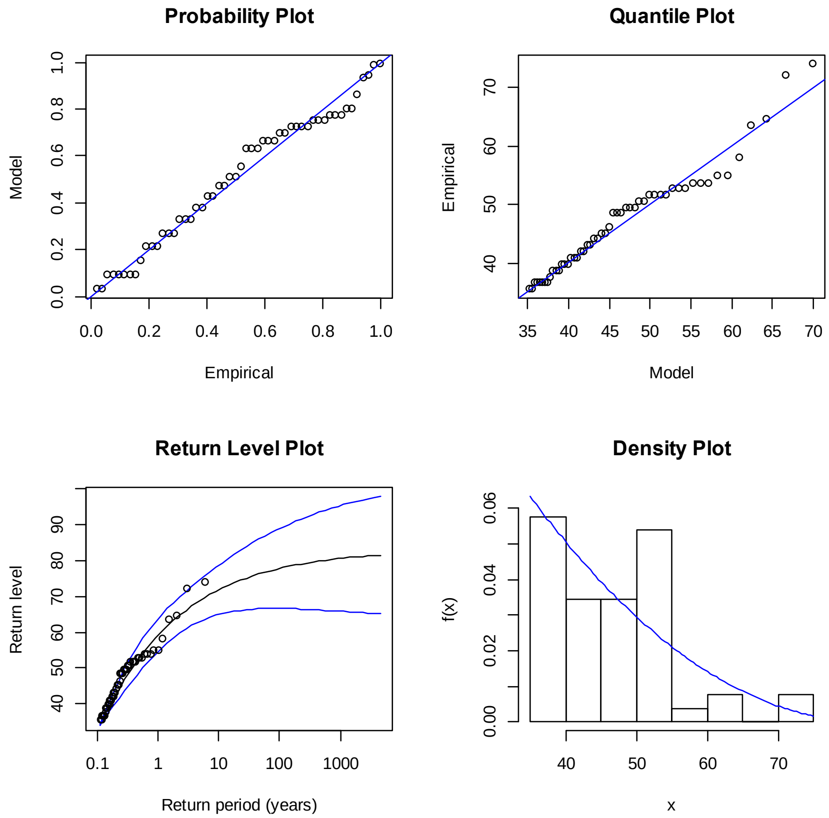

Figure 3 GPD distribution fit of annual extreme wind speeds at Point Retreat

Table 8 Maximum likelihood estimates of parameters of GPD fit

Parameter	Name	Value	Standard Error
$\tilde{\sigma}$	Scale	15.764	2.739
ξ	Shape	-0.328	0.114

The 2-year, 50-year, and 100-year return period wind speeds were estimated from the GPD fit. These values are shown in Table 9. Return level confidence intervals were calculated using the profile log-likelihood function, as implemented in Reference 1. These confidence intervals might be properly interpreted as prediction intervals with a 95% probability that an *N*-year return value falls within the given bounds.

Table 9 Extreme 2-minute average wind speeds at 10 m above local ground at Point Retreat

Return Period	Expected Value, kts	95% Confidence Interval, kts
2-year	64.0	[60, 71]
50-year	76.5	[71, 102]
100-year	77.8	[72, 108]

Cape Decision

Wind speed data at Cape Decision from 10/2006 through 2012 was used as the basis for the extreme value analysis.

Due to the limited data, a Generalized Pareto Distribution (GPD) was fit to declustered peaks-over-threshold data to obtain estimates of the 2-year, 50-year, and 100-year return period wind speeds for Cape Decision, Alaska. The extRemes toolkit was used, which is a software package for analyzing extreme value data using the R statistical programming language (References 1, 2).

The GPD distribution has a cumulative probability distribution function defined as:

$$H(y;\tilde{\sigma},\xi) = 1 - \left(1 + \frac{\xi y}{\tilde{\sigma}}\right)^{-1/\xi} \qquad \text{where} \quad y > 0 \ \text{and} \ \left(1 + \frac{\xi y}{\tilde{\sigma}}\right) > 0 .$$

Table 10 shows the parameter estimates of the GPD fit to the Cape Decision data.

The data was declustered using a run length of 48 hours, which means that measurements belonging to the same cluster are separated by fewer than 48 hours of data below the threshold. The lower threshold was chosen as 45 knots. The dataset for which the GPD was fit consisted of 60 threshold exceedances.

Diagnostics of the GPD fit are shown in Figure 4. The probability plot compares the empirical probability distribution of data with probability predicted by the GPD fit function. The quantile plot compares the empirical data with the data predicted by the GPD fit. Linear fits in the probability plot and the quantile plot (line indicated on plots) show that the GPD is a good fit to the data. The return level plot in Figure 4 shows the approximate symmetric 95% confidence interval in addition to the empirical data and the GPD fit. The actual confidence intervals are calculated using the profile likelihood method. The GPD curve should agree well with the data, as exemplified by the plot. The density plot is a histogram of the empirical data.

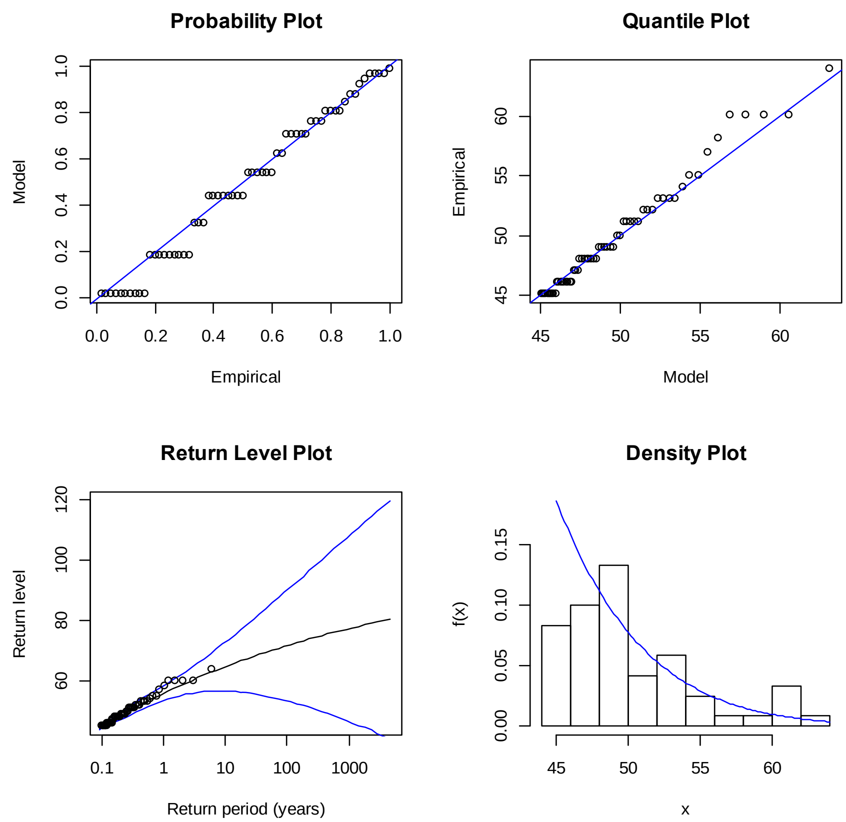

Figure 4 GPD distribution fit of annual extreme wind speeds at Cape Decision

Table 10 Maximum likelihood estimates of parameters of GPD fit

Parameter	Name	Value	Standard Error
$\tilde{\sigma}$	Scale	5.368	1.126
ξ	Shape	-0.100	0.166

The 2-year, 50-year, and 100-year return period wind speeds were estimated from the GPD fit. These values are shown in Table 11. Return level confidence intervals were calculated using the profile log-likelihood function, as implemented in Reference 1. These confidence intervals might be properly interpreted as prediction intervals with a 95% probability that an *N*-year return value falls within the given bounds.

Table 11 Extreme 2-minute average wind speeds at 10 m above local ground at Cape Decision

Return Period	Expected Value, kts	95% Confidence Interval, kts
2-year	58.7	[56, 65]
50-year	69.7	[63, 120]
100-year	71.7	[63, 141]

Extreme Wave Conditions

The SWAN model detailed in Reference 3 was used to determine the extreme wave conditions.

Several near-shore points were selected to represent possible terminal locations for AMHS ferry service. These points are shown in Figure 5 and in Table 12. The extreme wave conditions at the near-shore sites reported herein may be used for terminal and breakwater design, provided that the appropriate return period (typically 50 or 100 years) is selected.

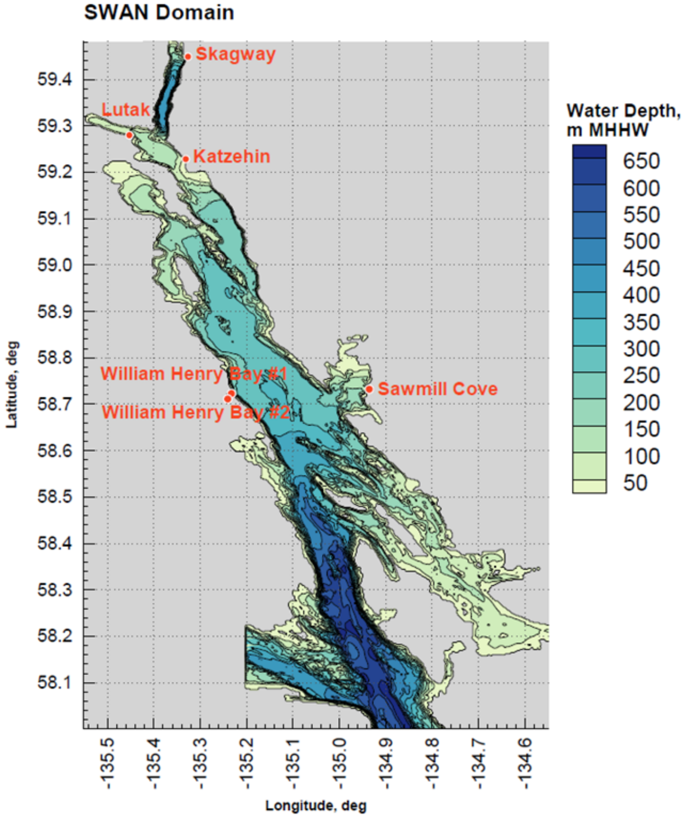

Figure 5 SWAN domain with near-shore points of interest shown

Table 12 Near-shore points of interest

Near-Shore Point Name	Latitude, N		Longitude, W		Water
	degrees	minutes	degrees	minutes	Depth, m
Sawmill Cove	58	43.942	134	56.132	49.6
William Henry Bay #1	58	43.384	135	13.950	140.1
William Henry Bay #2	58	42.678	135	14.432	25.2
Katzehin	59	13.698	135	19.856	14.5
Lutak	59	16.789	135	27.147	59.5
Skagway	59	26.938	135	19.570	16.9

The 2-year, 50-year, and 100-year extreme wind speeds were applied to the SWAN domain in all directions. The wind association scheme presented in Reference 3 was not used in its entirety for the multi-year extreme cases. Instead, the *N*-year return period wind at Skagway, Eldred Rock, and Point Retreat were applied simultaneously, and wind speed varied over the domain according to Reference 3. The *N*-year return period winds were applied from the most likely directions, and the results for the most likely directions, from the north and from the south, are reported. As was the case for the monthly climatology (Reference 3), based on the wind rose for Eldred Rock, "south" was defined as wind at Eldred Rock from 150° to 180° true, and "north" was defined as wind at Eldred Rock from 330° to 360° true.

Table 13, Table 14, and Table 15 show the worst case waves due to winds from the north and from the south for each return period at the near-shore points. Figure 6 and Figure 7 show contours for two example 50-year return period cases.

Table 13 2-year return period wave conditions at near-shore points

2-year Return Period						
	Wind from the North			Wind from the South		
Near-shore Point Name	H_S, m	T_P, sec	θ_P, deg true	H_S, m	T_P, sec	θ_P, deg true
Sawmill Cove	1.8	4.9	312.5	2.4	6.0	222.5
William Henry Bay #1	3.2	7.2	12.5	3.3	7.9	127.5
William Henry Bay #2	2.3	6.0	17.5	0.6	2.3	187.5
Katzehin	0.6	4.5	307.5	1.0	3.4	202.5
Lutak	1.0	3.4	322.5	0.3	2.3	87.5
Skagway	0.3	1.6	7.5	1.0	4.1	217.5

Table 14 50-year return period wave conditions at near-shore points

50-year Return Period						
	Wind from the North			Wind from the South		
Near-shore Point Name	H_S, m	T_P, sec	θ_P, deg true	H_S, m	T_P, sec	θ_P, deg true
Sawmill Cove	2.3	5.4	312.5	3.0	6.5	222.5
William Henry Bay #1	4.0	7.9	12.5	4.0	8.7	127.5
William Henry Bay #2	2.8	6.5	17.5	0.7	2.6	187.5
Katzehin	1.2	5.4	307.5	1.6	4.1	207.5
Lutak	1.9	4.5	317.5	0.5	3.1	87.5
Skagway	0.6	2.3	7.5	2.0	4.9	212.5

Table 15 100-year return period wave conditions at near-shore points

100-year Return Period						
	Wind from the North			Wind from the South		
Near-shore Point Name	H_S, m	T_P, sec	θ_P, deg true	H_S, m	T_P, sec	θ_P, deg true
Sawmill Cove	2.3	5.4	312.5	3.0	6.5	222.5
William Henry Bay #1	4.0	7.9	12.5	4.1	8.7	127.5
William Henry Bay #2	2.8	6.5	17.5	0.8	2.6	187.5
Katzehin	1.3	6.0	307.5	1.7	4.1	207.5
Lutak	2.1	4.9	307.5	0.6	3.4	87.5
Skagway	0.6	2.3	12.5	2.1	5.4	212.5

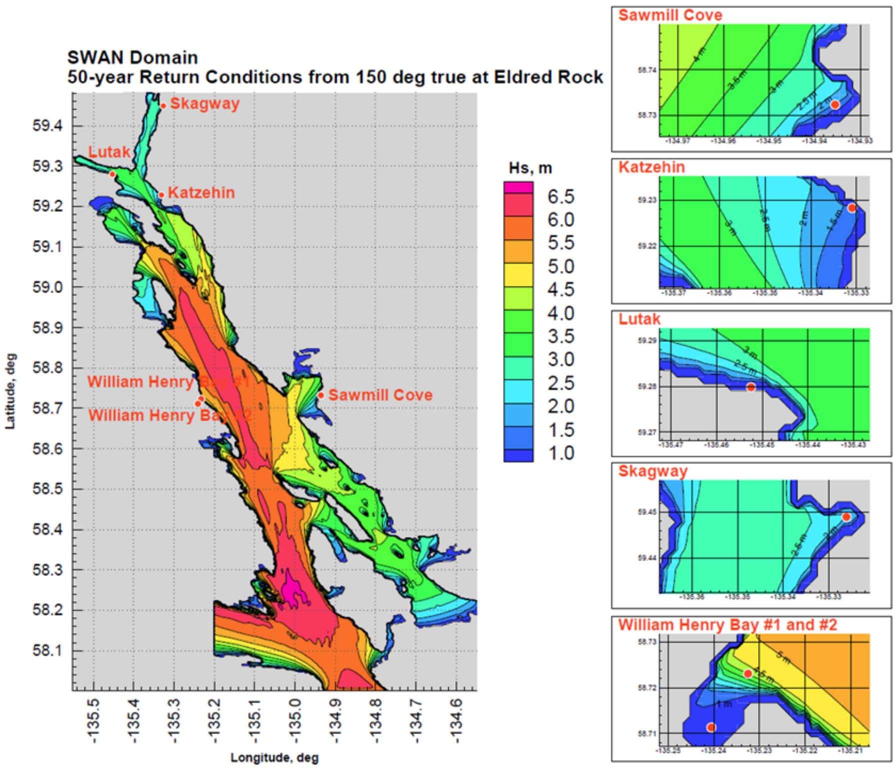

Figure 6 SWAN domain with near-shore points of interest shown

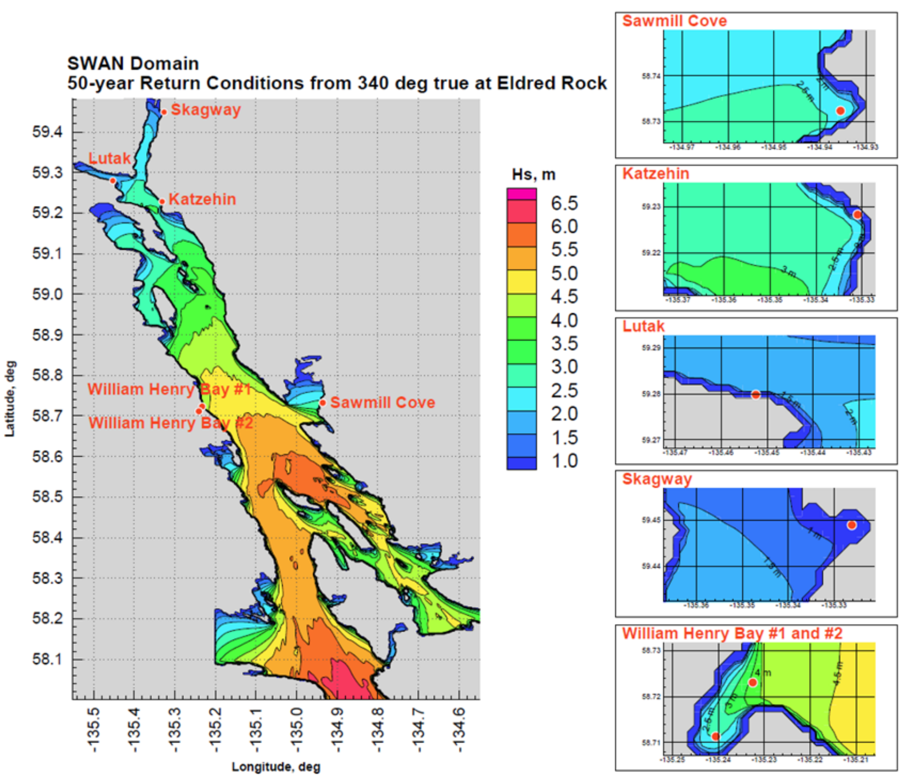

Figure 7 SWAN domain with near-shore points of interest shown

Extreme wave conditions at the field points along possible routes in Lynn Canal were also calculated. The field points correspond to those at which the highest waves occur, as shown in Reference 3. Table 16 shows the details of the field points at which extreme waves were determined.

Table 16 Selected field points of interest

Field Point Name	Latitude, N		Longitude, W		Water Depth, m
	degrees	minutes	degrees	minutes	
Abrest Talsani Island	59	4.689	135	15.038	244.2
Abrest Eldred Rock	58	58.259	135	12.065	213.6
Abrest Pt. Sherman	58	51.194	135	11.498	295.3
JNU EIS Alt 3 route mark #1	58	43.385	135	7.576	310.2
Abrest Vanderbilt Reef	58	35.105	135	3.433	379.9

Table 17, Table 18, and Table 19 show the worst case waves due to winds from the north and from the south for each return period at the selected field points.

Table 17 2-year return period wave conditions at selected field points

2-Year Return Period						
	Wind from the North			Wind from the South		
Near-Shore Point Name	H_S, m	T_P, sec	θ_P, deg true	H_S, m	T_P, sec	θ_P, deg true
Abrest Talsani Island	2.3	5.4	337.5	3.6	8.7	172.5
Abrest Eldred Rock	3.0	6.0	352.5	4.6	8.7	172.5
Abrest Pt. Sherman	3.5	6.5	337.5	5.1	8.7	167.5
JNU EIS Alt 3 route mark #1	4.0	7.2	327.5	4.8	7.9	172.5
Abrest Vanderbilt Reef	4.5	7.9	337.5	4.4	7.2	177.5

Table 18 50-year return period wave conditions at selected field points

50-Year Return Period						
	Wind from the North			Wind from the South		
Near-Shore Point Name	H_S, m	T_P, sec	θ_P, deg true	H_S, m	T_P, sec	θ_P, deg true
Abrest Talsani Island	3.4	6.5	337.5	4.5	7.9	172.5
Abrest Eldred Rock	3.9	7.2	352.5	5.5	9.5	172.5
Abrest Pt. Sherman	4.3	7.2	357.5	6.3	9.5	167.5
JNU EIS Alt 3 route mark #1	4.9	7.9	327.5	6.0	8.7	172.5
Abrest Vanderbilt Reef	5.5	8.7	342.5	5.5	7.9	177.5

Table 19 100-year return period wave conditions at selected field points

100-year Return Period						
	Wind from the North			Wind from the South		
Near-Shore Point Name	H_S, m	T_P, sec	θ_P, deg true	H_S, m	T_P, sec	θ_P, deg true
Abrest Talsani Island	3.6	6.5	337.5	4.6	7.9	172.5
Abrest Eldred Rock	4.0	7.2	352.5	5.6	9.5	172.5
Abrest Pt. Sherman	4.4	7.9	357.5	6.4	9.5	167.5
JNU EIS Alt 3 route mark #1	5.0	7.9	327.5	6.1	8.7	172.5
Abrest Vanderbilt Reef	5.6	8.7	347.5	5.7	7.9	177.5

Conclusion

Extreme wind speeds were extrapolated from available wind records at the 2-year, 50-year, and 100-year return period levels. They are tabulated here for each wind station. The design wind speed for a specific project site will have to be conservatively selected considering extremes determined for nearby wind stations, local topographic effects, and applicable design standards. Corresponding waves were estimated using SWAN at several near-shore points and at selected field points. The wave predictions could not be validated with actual measurements, since no wave data is available. This study does not cover currents at the project sites, which is also an important factor to be considered in terminal and breakwater design.