Analysis of the Geographic Coverage Provided by the International Tug of Opportunity System From November 1998 – May 1999

Commandant (G-MSE-1)
U.S. Coast Guard

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Executive Summary

This report provides an investigation into the principal uncertainty regarding the International Tug of Opportunity System (ITOS); the level of ITOS coverage by location (with the issue being that western waters may largely not be covered by tug traffic). Not addressed in this analysis are issues such as the adequacy of the power of ITOS tugs or their ability to hook up to a vessel in distress.

The International Tug of Opportunity System was voluntarily developed and sponsored by the maritime industry to reduce the risk of drift groundings (vessels losing power and drifting into the shore) in Puget Sound area waters (Puget Sound, Haro and Rosario Straits, the Strait of Georgia, the Strait of Juan de Fuca and offshore regions). The risk of drift grounding was identified by the Volpe National Transportation Systems Center (in a risk assessment performed for the Coast Guard) as comprising 15% of the risk of the waterway (22% for the Strait of Juan de Fuca and offshore areas).

Overall, ITOS was found to provide an incremental improvement to safety and environmental protection in this waterway system. In the waters in the western half of the Strait of Juan de Fuca and offshore approaches, ITOS will likely be able to provide a tug that is ready and willing to provide assistance for approximately 42% of the commercial vessels plying these waters. Overall across the waterway, this coverage is higher, with the probability of coverage being approximately 71%.

While additional questions remain, this initial study does address what was the principal uncertainty for this recent addition to the Puget Sound area safety system; the ability of ITOS to provide coverage for the entire waterway (in particular, for the western regions). The Coast Guard continues to work with involved stakeholders to develop and perform additional tests of this system, including ship drift tests and tests of the ability of various sizes of ITOS tugs to slow/arrest the drift rate of a vessel in distress.

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1. Introduction

Before addressing the evaluation of the International Tug of Opportunity System (ITOS) in detail, it is important to briefly highlight a couple of historical items that have led to this evaluation in order that the results may be kept in a proper perspective. In July 1997, the Volpe National Transportation Systems Center completed a comprehensive risk assessment of the marine waters of Northwest Washington State. Based on this study and the public comments received, the Secretary of Transportation, in his November 24, 1998 notice in the Federal Register, determined that the Puget Sound area marine transportation system was relatively safe, although improvements could and should be sought.

With this charge in mind, and in keeping with the past and ongoing initiatives uniquely focused on the safety of the Puget Sound area waterways, the U.S. Coast Guard has continued to be engaged on a variety of fronts. Each activity has been designed to help identify the most efficient and effective method of managing the risks identified in the Volpe report. This included, when appropriate, the development of targeted system modifications to improve existing maritime safety. Specifically in their report, the Volpe researchers found the level of risk to be distributed as shown in Figures 1 and 2.

Figure 1

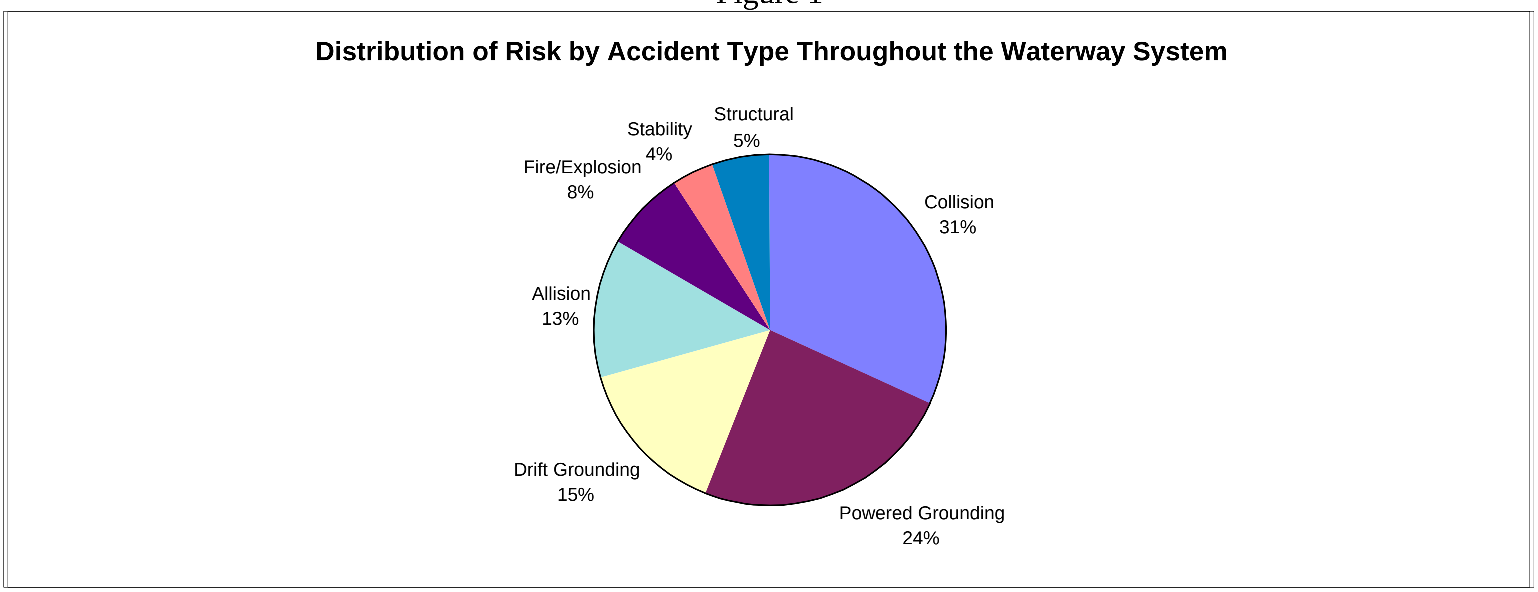
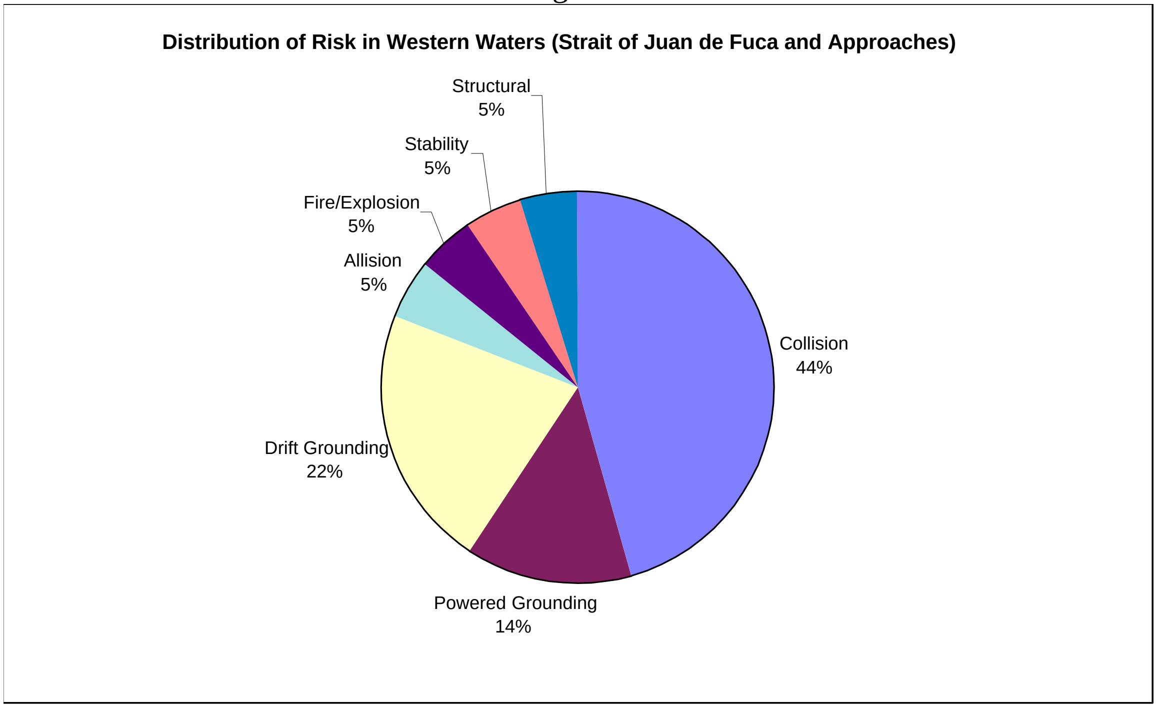
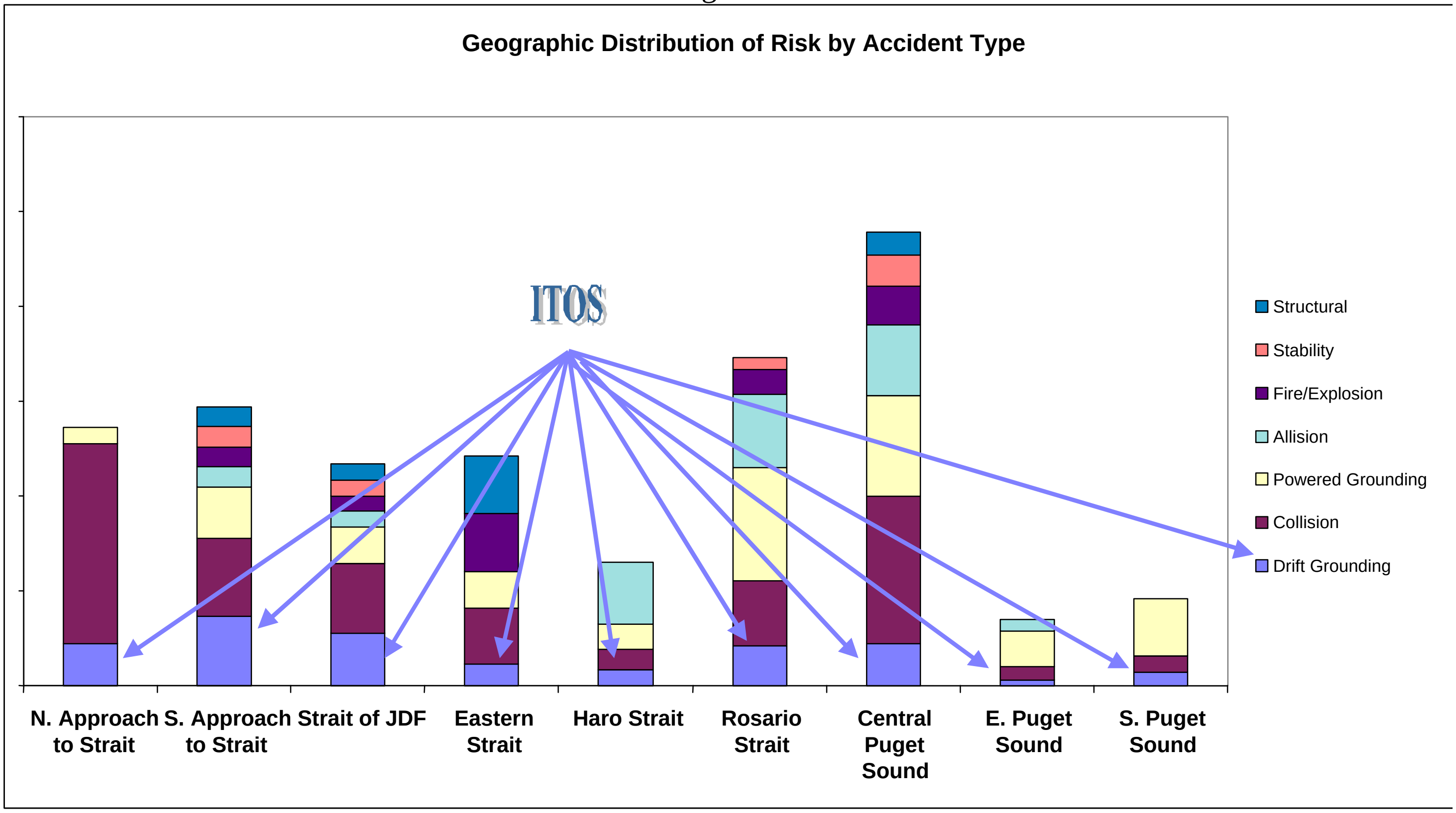


Figure 2



Separately in 1997, a joint industry coalition was formed and voluntarily sponsored the establishment of an International Tug of Opportunity System, or ITOS. ITOS was designed primarily to reduce the risk of a vessel losing power and drifting aground by providing emergency responders with timely, accurate information about the location and capability of randomly operated tugs, so they may in turn be dispatched to assist a disabled vessel. As can be seen by the previous two diagrams, and as further amplified by individual waterway segments shown in Figure 3, the level of risk that ITOS is intended to reduce (that of a vessel drift grounding) is a relatively small portion of the overall risk. When considering the entire waterway this risk equates to approximately 15% of the total. Even when looking at just the outer coast approaches and the Strait of Juan de Fuca, the risk of a drift grounding is only 22% of the total risk present in the waterway.

Figure 3



In an effort to ascertain the effectiveness of ITOS, the Coast Guard has undertaken a dynamic multi-pronged approach to the evaluation of this new emergency response aid. The first element of this approach is a comprehensive system evaluation. This will attempt to establish several quantifiable measures of system effectiveness, aimed ultimately at providing some overall measure of system value or oil spill risk reduction potential. The Coast Guard is also evaluating a number of other factors, including minimum tug size and the ability of an ITOS tug to hook up to a vessel in distress. To date, however, the principal uncertainty about the level of risk reduction provided by ITOS and the primary criticism levied by the system's detractors is the concern over an adequate number of available, capable tugs in the western portion of the Strait of Juan de Fuca and offshore approaches. To resolve this uncertainty, the Coast Guard has performed a detailed examination of the coverage provided by participating ITOS tugs, in conjunction with the deep draft traffic that ITOS is intended to help provide coverage for.

Specifically, to gain a better understanding of this level of coverage relative to vessel densities, a series of evaluations were performed using ITOS data from the Marine Exchange of Puget Sound and Cooperative Vessel Traffic System (CVTS) data from the Canadian and U.S. Coast Guards. Data sources and the primary elements obtained are shown in Table 1.

Table 1: Description of Data Sources

Data Source	Description of Data	Sampling Frequency
Marine Exchange of Puget Sound	ITOS Tugs: • Position • Maximum speed	Every eight hours and twenty minutes since November 18, 1998[1]
U.S. Coast Guard	Vessels Participating in VTS Puget Sound area of responsibility: • Position • Vessel type • Vessel flag	Every eight hours and twenty minutes since November 1, 1998.
Canadian Coast Guard	Vessels Participating in VTS Tofino area of responsibility: • Vessel type • Number of transits	Daily since June 1998

The evaluation utilized three primary measures of effectiveness, as shown and described in Table 2. These measures, as well as all others used in this study, were reviewed by sample (time at which data call was made), by month, and by geographic region (either waterway segment or response coverage area).

Table 2: Measures of Effectiveness

Measure	Description
Expected number of tugs	Average number of tugs at any given time in a given region (segment or response area).
Expected number of vessels	Average number of vessels at any given time in a given region (segment or response area).
Probability of at least one tug	Probability that there is at least one tug in a given region (segment or response area).
Probability of at least one tug	Probability that there is at least one vessel in a given region (segment or response area).
Probability of a tug given a vessel	Probability of a tug being in a given segment when there is a vessel in that segment. Does not account for ability of a tug in one segment to respond to a vessel in another segment.

As shown, each measure was considered for two different geographic distributions. First, they were considered for each of the waterway segments delineated in the Volpe National Transportation Systems Center in their risk assessment[2] for the region. These segments are repeated in Table 3 and shown in Figure 4, with the lone difference being the split of segment three into eastern and western regions. This split was done to provide additional clarification to tug availability in the western reaches of

[1] Data for April 1999 and first half of May 1999 not provided due to programming error in data capture system.

[2] Dyer, Schwenk, Watros & Boniface, Protection Against Oil Spills in the Marine Waters of Northwest Washington State, Volpe National Transportation Systems Center, Cambridge, 1997.

the Strait. Second, each measure was considered against the response coverage areas identified in the U.S. Coast Guard report to Congress[3]. A diagram of these response areas is shown in Figure 5.

Table 3: Descriptions of Geographic Decomposition

Segment	Region
1	Northern approach to the Strait of Juan de Fuca Latitude > 48º 30'N Longitude ≥ 124º 50'W
2	Southern approach to the Strait of Juan de Fuca Latitude ≤ 48º 30' N Longitude ≥ 124º 50'W
3	Strait of Juan de Fuca Longitude > 123º 35'W Longitude < 124º 50'W
3W	Western end of Segment 3 Longitude > 124º12.6'W Longitude < 124º 50'W
3E	Eastern end of Segment 3 Longitude > 123º 35'W Longitude ≤ 124º 12.6'W
4	Eastern Strait of Juan de Fuca Latitude ≥ 48º 10'N Latitude ≤ 48º 27.6'N Longitude ≤ 123º 35'W
5	Haro Strait Latitude > 48º 27.6'N Longitude > 123º W Longitude ≤ 123º 35'W
6	Rosario Strait Latitude > 48º 27.6'N Longitude ≤ 123º W
7	Central Puget Sound Latitude ≥ 47º 20'N Latitude < 48º 10'N Longitude ≥ 122º 23'W Longitude < 124º 50'W
8	Eastern Puget Sound Latitude ≥ 47º 20'N Latitude < 48º 10'N Longitude < 122º 23'W
9	Southern Puget Sound Latitude < 47º 20'N Longitude < 123º 35'W

[3] Addendum Report to Congress on the International Tug of Opportunity System, U.S. Coast Guard, Washington, DC, 1997.

Figure 4: Geographic Segmentation

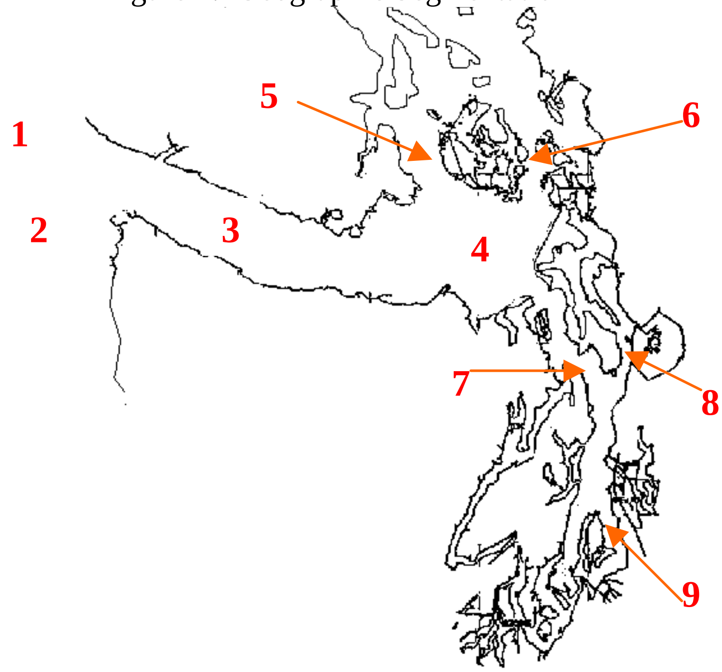
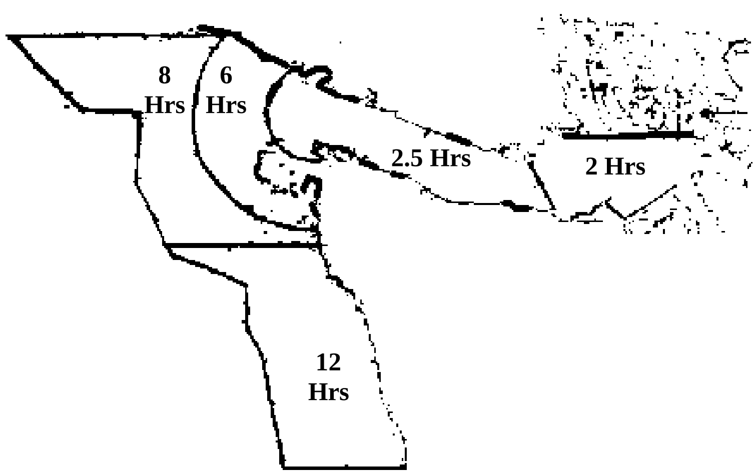


Figure 5: Response Time Zones



Coverage Areas

2. Primary Analysis of the Marine Exchange Data

Introduction

As noted, the primary focus of this analysis was to evaluate the distribution of tugs in the Puget Sound area waterway. The primary interest in this regard is to determine whether tugs are to be found in the western portions of the waterway. This portion of the current research addresses these issues directly, and answers several key questions regarding the level of effectiveness of ITOS. It should be noted that no data are available from the Marine Exchange for the month of April 1999, due to an error in the data capture mechanism.

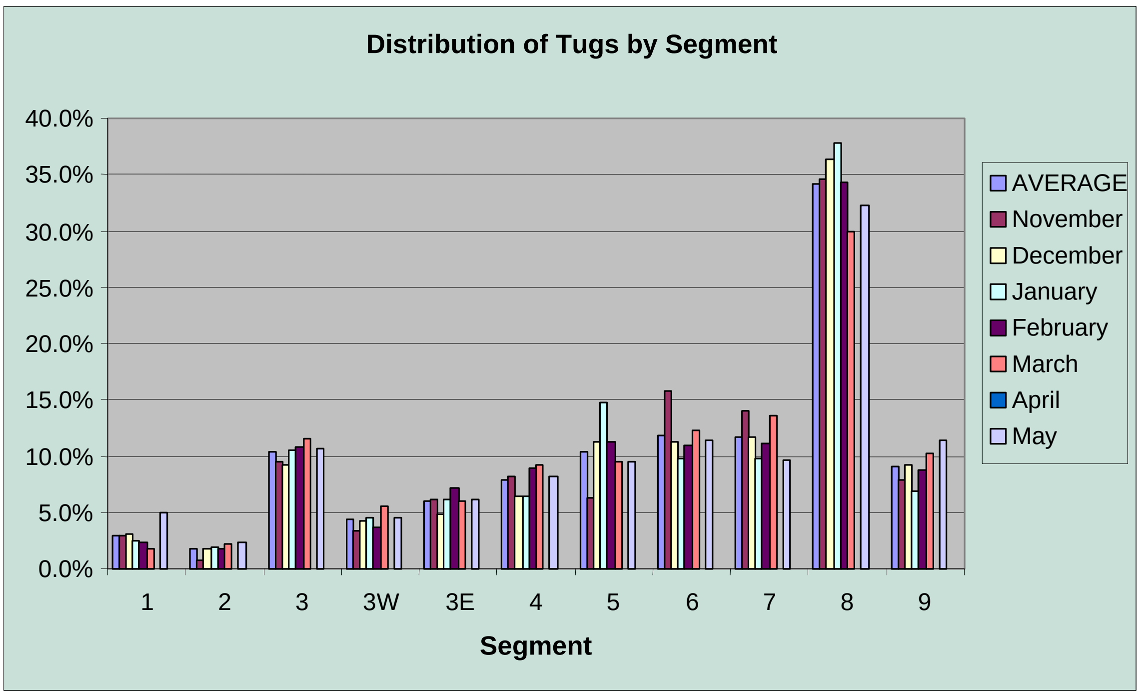
Analysis

The first portion of this analysis looked at the distribution of tugs in the ITOS system. The results of this stage strongly indicate that the majority of the tugs operating in the Puget Sound area waters are in the eastern region of the waterway. As shown in Figure 6, the majority (85%) of tugs operating in the system are found in the waters east of the Strait of Juan de Fuca. For the waters of the Strait and the western approaches, the number of tugs was less for the offshore waters than for the Strait itself, and less for the western portion of the Strait than for the eastern end. Overall, tugs were most prevalent in the eastern portion of Puget Sound, followed by Haro Strait, central Puget Sound, the Strait of Juan de Fuca, and Rosario Strait. In addition, as seen from Figure 6, the variation of the tug distribution did not vary significantly from month to month, with an average coefficient of variation[4] of 19%.

[4] The coefficient of variation (COV) is defined as the ratio of the standard deviation and the mean of a given data set. As such, it provides a measure of variation that is benchmarked by the mathematical average of that data set. Coefficients of variations of over 100% indicate a broad dispersion, while lower COV's indicate less dispersion.

Figure 6

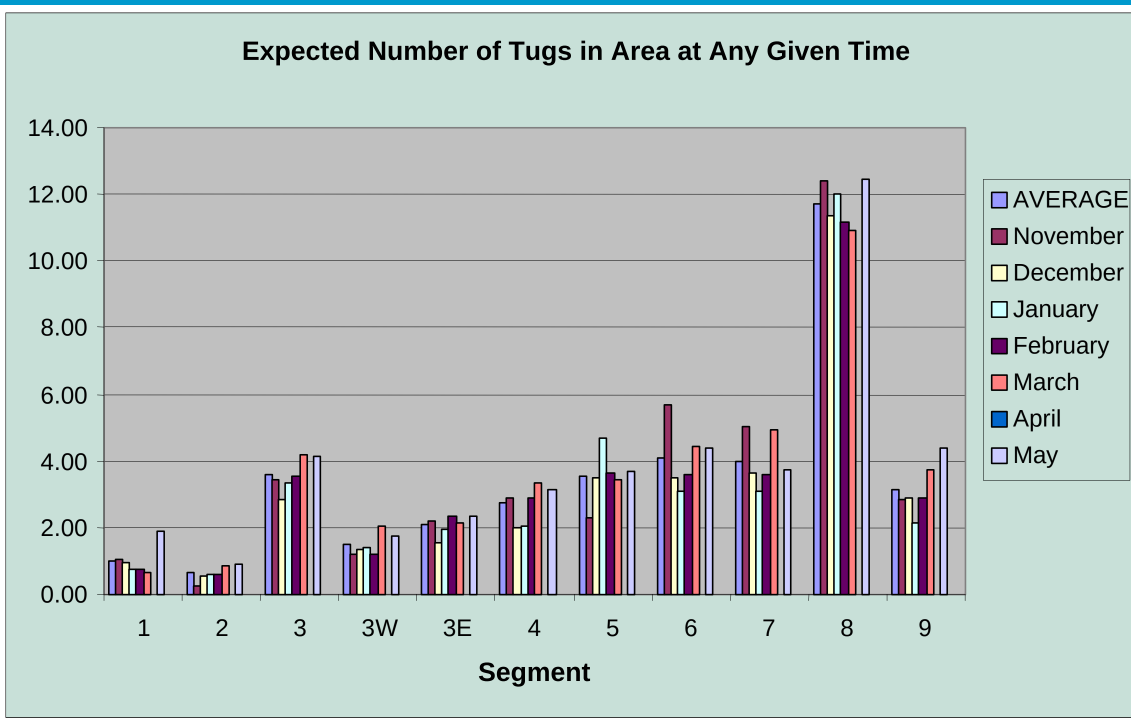
	Distribution of Tugs by Segment										
	1	**2**	**3**	**3W**	**3E**	**4**	**5**	**6**	**7**	**8**	**9**
AVERAGE	2.9%	1.8%	10.4%	4.3%	6.1%	7.9%	10.4%	11.9%	11.6%	34.2%	9.0%
November	3.0%	0.8%	9.6%	3.4%	6.2%	8.1%	6.3%	15.8%	14.0%	34.6%	7.9%
December	3.1%	1.8%	9.1%	4.3%	4.9%	6.4%	11.2%	11.2%	11.6%	36.3%	9.2%
January	2.4%	2.0%	10.5%	4.5%	6.1%	6.4%	14.8%	9.7%	9.8%	37.9%	6.8%
February	2.3%	1.8%	10.8%	3.6%	7.2%	8.9%	11.2%	11.0%	11.0%	34.3%	8.8%
March	1.8%	2.3%	11.5%	5.6%	5.9%	9.2%	9.4%	12.2%	13.6%	30.0%	10.3%
April	No Data										
May	4.9%	2.3%	10.7%	4.6%	6.1%	8.1%	9.5%	11.3%	9.7%	32.2%	11.3%



Additionally, the expected number of tugs at a given time (determined on a per sample basis) was determined by segment and month. The results are shown in Figure 7. While this measure echoed the differences in tug distribution between eastern and western portions of the waterway from Figure 6, it does indicate that there are usually several tugs operating in the western waters (where coverage was suspect). Also, as can be noted from Figure 7, for each area, the expected number of tugs at any given time is roughly constant over time, with an average coefficient of variation of 23%.

Figure 7

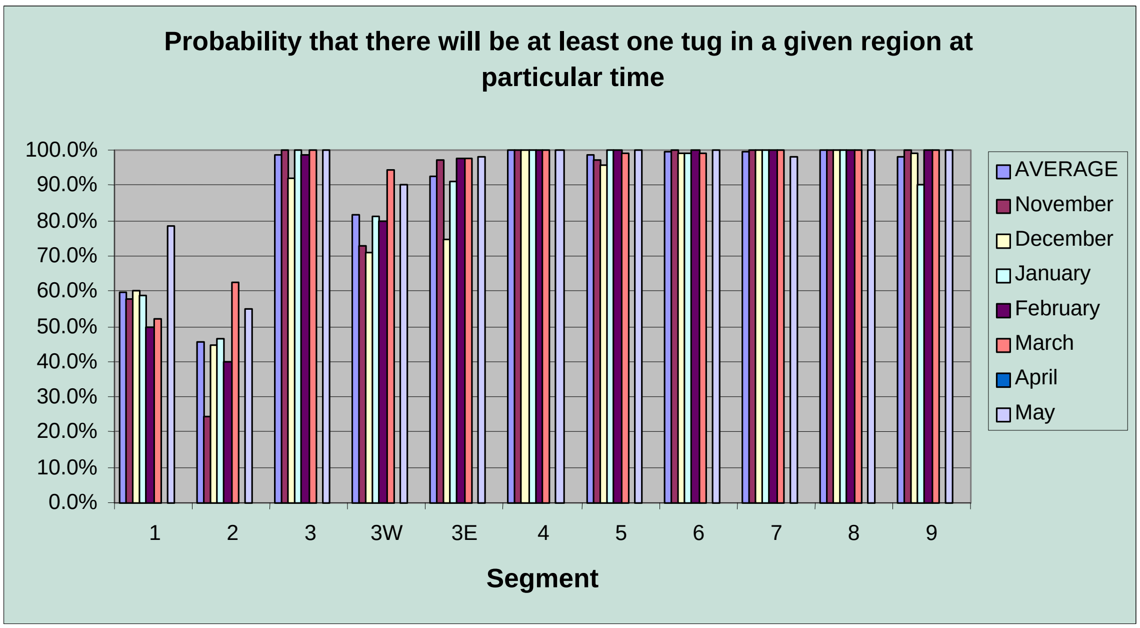
	Expected Number of Tugs in Area at a Given Time										
	1	2	3	3W	3E	4	5	6	7	8	9
AVERAGE	1.02	0.62	3.57	1.49	2.09	2.72	3.54	4.11	4.01	11.71	3.14
November	1.06	0.27	3.42	1.21	2.21	2.91	2.27	5.67	5.03	12.39	2.82
December	0.97	0.56	2.86	1.33	1.52	2.00	3.51	3.51	3.63	11.34	2.87
January	0.77	0.62	3.33	1.41	1.92	2.02	4.68	3.08	3.10	12.00	2.16
February	0.75	0.58	3.54	1.19	2.35	2.91	3.65	3.58	3.60	11.18	2.88
March	0.64	0.82	4.18	2.02	2.16	3.36	3.43	4.44	4.93	10.90	3.73
April	No Data										
May	1.90	0.90	4.12	1.76	2.35	3.14	3.67	4.37	3.75	12.45	4.37



Each sample was then assessed to determine whether there was one or more tugs in a given segment of the waterway at a particular time. This information was then used to determine the probability that there will be at least one tug in a given region at a particular time. The results, as shown in Figure 8, indicate that while it is a near certainty of a tug in the eastern waters, there is a 60% probability of at least one tug in the northern approach to the Strait of Juan de Fuca, a 45% probability of at least one in the southern approach, and a 99% probability of at least one in the Strait itself (82% in just the western half of the Strait). As can be seen in Figure 8, the variation by month was not large, with an average coefficient of variation of less than 10%.

Figure 8

	Probability that there will be at least one tug in given region at a particular time										
	1	2	3	3W	3E	4	5	6	7	8	9
AVERAGE	59.5%	45.4%	98.5%	81.6%	92.6%	100.0%	98.6%	99.4%	99.7%	100.0%	98.1%
November	57.6%	24.2%	100.0%	72.7%	97.0%	100.0%	97.0%	100.0%	100.0%	100.0%	100.0%
December	60.0%	44.4%	92.2%	71.1%	74.4%	100.0%	95.6%	98.9%	100.0%	100.0%	98.9%
January	58.9%	46.7%	100.0%	81.1%	91.1%	100.0%	100.0%	98.9%	100.0%	100.0%	90.0%
February	50.0%	40.0%	98.8%	80.0%	97.5%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
March	52.2%	62.2%	100.0%	94.4%	97.8%	100.0%	98.9%	98.9%	100.0%	100.0%	100.0%
April	No Data										
May	78.4%	54.9%	100.0%	90.2%	98.0%	100.0%	100.0%	100.0%	98.0%	100.0%	100.0%



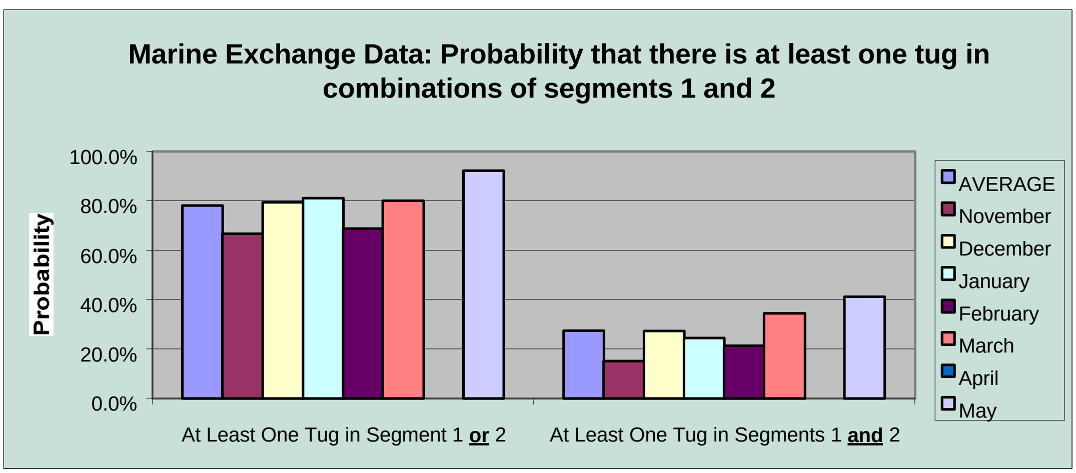
In addition to the determinations provided in Figure 8, the distributions of tugs by segment (histograms) are provided in Appendix I. As seen in Appendix I, tug distributions in the outer segments (1 and 2) appear to be roughly exponentially distributed, with 0 tugs being most likely. However, it is more likely to have at least one tug (either 1, 2, 3, 4, 5, 6 or 7 tugs) than not have any in segment 1 and evenly likely to have at least one tug (1, 2, 3, or 4 tugs) in segment 2 as not. For the other segments, the distribution of tugs can be seen as roughly normally distributed, with the means shown in Figure 7.

Even though there is not 100% coverage in every zone, tugs from neighboring zones may be able to respond within the response time (and before the vessel in distress would ground). It should be noted that, for this stage of the analysis, no determination was made regarding whether the times where no tug was to be found in Segment 1 were such that a tug could be found in Segment 2, or vice versa. Additionally, as data was not provided on the tug's status (horsepower, laden versus unladen, petrochemical versus non-petrochemical tows), some uncertainty remained over whether the tugs in these waters could actually be counted upon to provide assistance in the case of an emergency. Most of these uncertainties were, however, addressed in subsequent portions of the analysis (Chapter 5).

To address the uncertainty over whether for those times where no tug was to be found in Segment 1 were such that a tug could be found in Segment 2, or vice versa, the probability that there was at least one tug in either Segment 1 or Segment 2 was determined. The results are shown in Figure 9. As shown, averaging across all months, there was a 78% probability of at least one tug in **either** Segment 1 **or** Segment 2. Furthermore, there was a 27% probability of at least one tug in Segment 1 **and** at least one tug in Segment 2. This probability did vary throughout the months studied, although the coefficient of variation was less than 5% in each case.

Figure 9

	Probability of at Least One Tug in Segment 1 **or** 2	Probability of at Least One Tug in Segments 1 **and** 2
AVERAGE	78.0%	27.3%
November	66.7%	15.2%
December	79.3%	27.2%
January	81.1%	24.4%
February	68.8%	21.3%
March	80.0%	34.4%
April	No Data	
May	92.2%	41.2%



In addition to the probability of at least one tug by segment per sample, a determination was made regarding the probability of at least one tug per day in the offshore approaches (Segments 1 and 2). The results, shown in Table 4, indicate a strong likelihood that there was at least one tug in these offshore areas every day. This information was useful for the comparison to the Canadian VTS data described in Chapter 4 (which was provided on a daily basis). As can be seen in Table 4, the variation by month was small, with a coefficient of variation of less than 5%.

Table 4

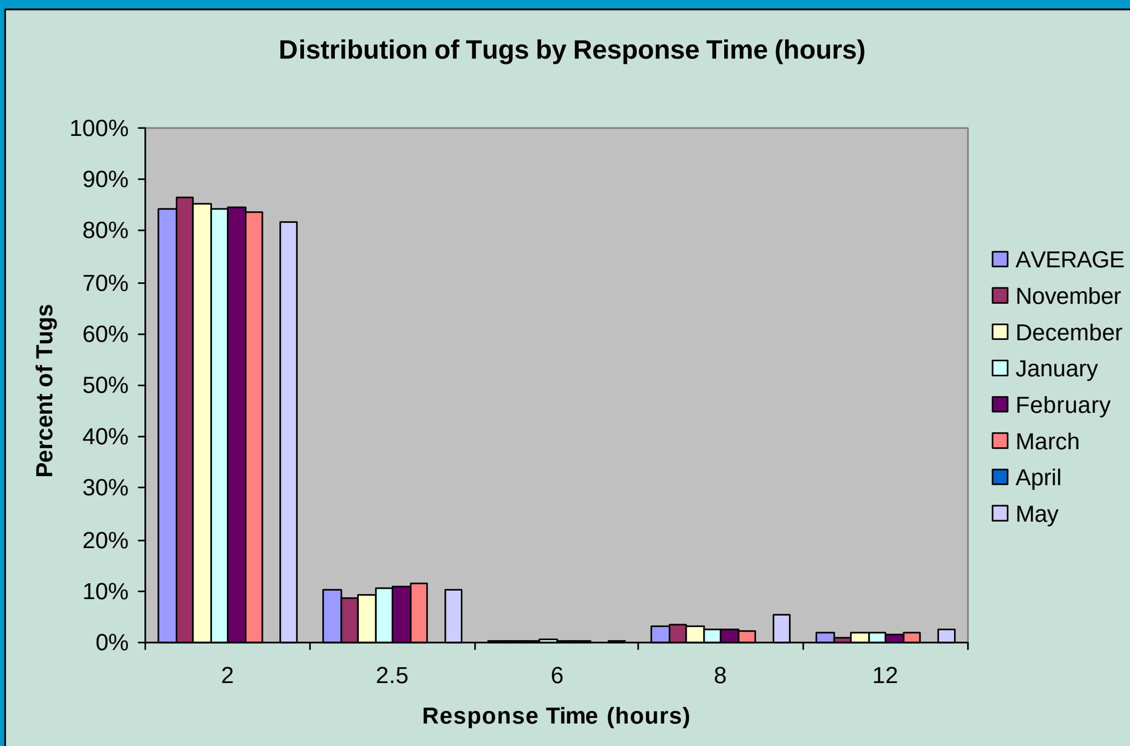
Probability that there is at least 1 tug in western waters (segments 1 & 2) per day	
AVERAGE	97%
November	92%
December	100%
January	97%
February	93%
March	100%
April	No Data
May	100%

In addition to reviewing tug distribution by geographic segment, this study also looked at the distribution by response times (as established in the report to Congress cited previously). These response times provide a characterization of the time available to respond to a vessel adrift in a particular region before that vessel could be expected to run aground. The lone difference between the waterway decomposition used in this analysis and those in the report to Congress was that those ITOS response zones with equal response times were joined as one for this analysis.

In Figure 10, the distribution of tugs by response zones (each zone being described by its response time) shows a heavy preponderance of tugs in the 2 hour response zone. This indicates that the vast majority of tugs are in a location where the time available for rescuing a vessel in distress is minimal. Furthermore, these numbers (which indicate location of the tug at the time of the sample) do not account for cases where a tug could travel throughout at least some portion of adjacent response zone(s) within the response time for each. For example, a tug in the western portion of the 2½ hour response zone (western Strait of Juan de Fuca) could cover at least a portion of the 6, 8 and 12 hour response zones before a vessel in distress in each of those regions could be expected to drift aground. These coverage levels varied somewhat on a month to month basis, with an average coefficient of variation of 23%. However, this variation was far less for the two response areas with the vast majority of tugs (the 2 and 2½ hour response areas, which had approximately 94% of all tugs). These areas had an average coefficient of variation of approximately 6%.

Figure 10

	Distribution of Tugs by Response Times (Hours)				
	2	**2.5**	**6**	**8**	**12**
AVERAGE	84.38%	10.19%	0.33%	3.30%	1.80%
November	86.63%	8.71%	0.17%	3.64%	0.85%
December	85.23%	9.32%	0.28%	3.35%	1.81%
January	84.36%	10.45%	0.49%	2.63%	2.07%
February	84.64%	10.77%	0.42%	2.61%	1.57%
March	83.81%	11.64%	0.34%	2.17%	2.05%
April	No Data				
May	81.6%	10.2%	0.3%	5.4%	2.4%



The caveat about the lack of consideration of the ability of a tug in one response zone being able to cover adjacent response zones with different response times also holds true for the expected number of tugs for a particular response zone at a particular time. The expected number of tugs is shown in Figure 11. However, even with this caveat, in this look at tug distribution, the low number of expected tugs would indicate questionable tug coverage in the areas with longer response times. This matter is investigated in greater detail in Chapter 5. However, this information - along with the determination of the probability of at least one tug in a given response region at a particular time (shown in Table 5) - does indicate that the areas with more restrictive response times (e.g., the Strait of Juan de Fuca and inland) do appear to be covered for over 96% of the time. The expected number of tugs by response regions did exhibit some variation, although not excessive, with an average coefficient of variation of 26%. The variation for the probability of at least one tug in a given response region was not large, with an average coefficient of variation of 16%.

Figure 11

Expected number of Tugs by Response Times (Hours) at a particular time (I.e., per sample)					
	2	2.5	6	8	12
AVERAGE	29.00	3.51	0.11	1.15	0.62
November	31.03	3.12	0.06	1.30	0.30
December	26.61	2.91	0.09	1.04	0.57
January	26.73	3.31	0.16	0.83	0.66
February	27.61	3.51	0.14	0.85	0.51
March	30.49	4.23	0.12	0.79	0.74
April	No Data				
May	31.55	3.96	0.10	2.10	0.94

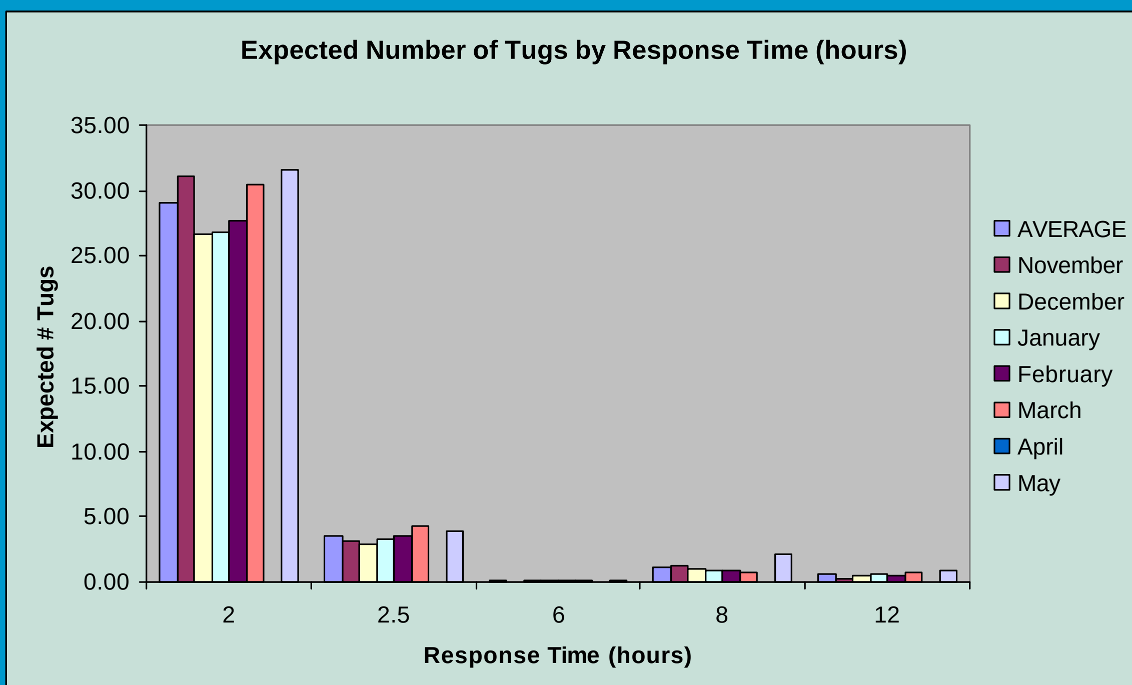


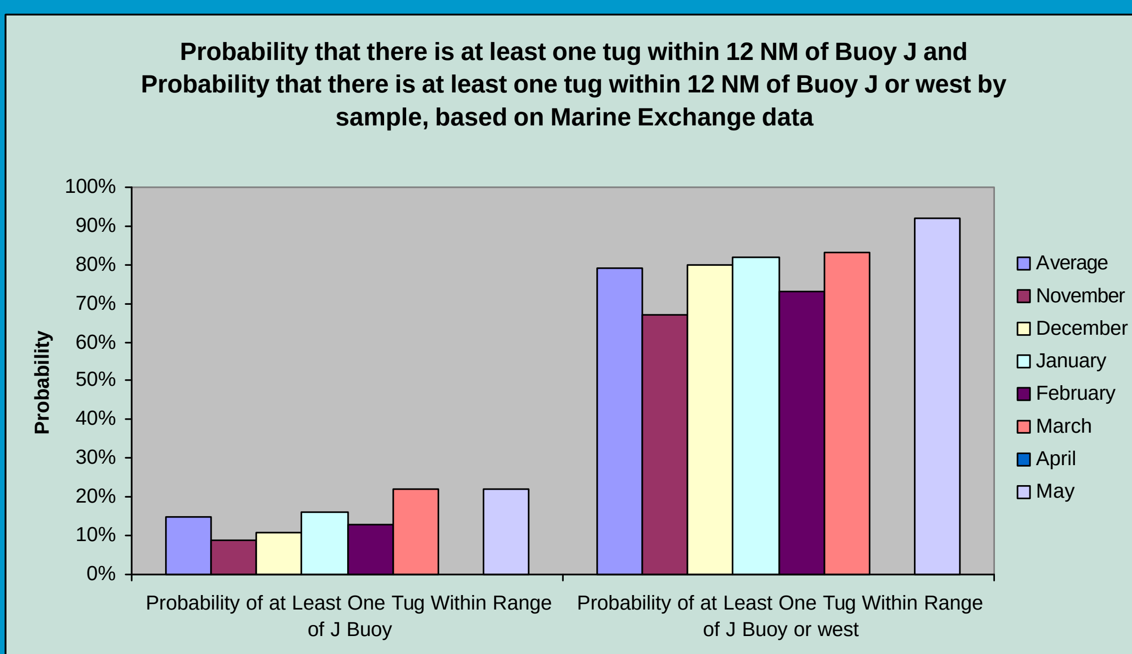
Table 5

Probability that there is at least one tug in a given response region at a given time					
	2	**2.5**	**6**	**8**	**12**
AVERAGE	97.99%	96.11%	10.48%	63.26%	41.22%
November	100.00%	100.00%	6.06%	66.67%	18.18%
December	100.00%	91.11%	8.89%	63.33%	44.44%
January	100.00%	98.89%	14.44%	60.00%	44.44%
February	100.00%	98.75%	13.75%	58.75%	37.50%
March	100.00%	100.00%	11.11%	56.67%	54.44%
April	No Data				
May	87.9%	87.9%	8.6%	74.1%	48.3%

Next, a more direct comparison to the geographic coverage of a dedicated rescue tug was sought. Here, the probability of an ITOS tug being within one hour of the J Buoy (using the average ITOS tug speed of approximately 12 knots) was determined as shown in Figure 12. Next, the probability of at least one ITOS tug being west of longitude 124° 34.5’ W (one hour east of the J Buoy at 12 knots) was determined, also as shown in Figure 12. This longitudinal position is one hour east of the J Buoy at a speed of 12 knots (average for the ITOS tug fleet), which encompasses the expected operating area of any dedicated rescue tug at the mouth of the Strait. Overall, as shown, there is approximately a 15% chance that there is an ITOS tug in the vicinity of the intended operating area of the dedicated rescue tug. However, the data also showed that there was 79% chance of a tug being somewhere in or west of the expected operating area of a potential dedicated rescue tug. These probabilities did, however, exhibit some variation over the months studied, with average coefficients of variation of over 11%.

Figure 12

	Probability of at Least One Tug Within Range of J Buoy	Probability of at Least One Tug Within Range of J Buoy or west
Average	15%	79%
November	9%	67%
December	11%	80%
January	16%	82%
February	13%	73%
March	22%	83%
April	No Data	
May	22%	92%



The correlation between the presence of ITOS tugs by segment was next tested, the results of which are shown in Table 6. As shown, there is a very low correlation (none were even remotely close to full correlation, +/- 1) between the presence of ITOS tugs in one segment and their presence in other segments. The exception is the correlation between Segment 3 and Segments 3W and 3E, which are subsets of the first. This indicates that ITOS tugs will be neither more nor less likely to be present given tugs in another segment. As such, a gap in one segment cannot be related to coverage in another segment, nor can a gap in one segment be related to a gap in another (e.g., the absence of a tug in segment 1 does not make it either more or less likely for their to be a tug in segment 2).

Table 6: Correlation Between Segment Tug Populations

MarEx Tugs to MarEx

	1	2	3	3W	3E	4	5	6	7	8	9
1		0.06	0.02	0.07	-0.04	0.04	-0.14	0.04	0.01	0.04	0.10
2			-0.02	-0.03	0.00	-0.03	0.03	0.02	0.05	-0.11	0.07
3				0.69	0.73	0.18	-0.19	0.11	0.14	-0.07	0.03
3W					0.01	0.12	-0.10	0.08	0.08	-0.06	0.11
3E						0.13	-0.16	0.08	0.11	-0.03	-0.06
4							-0.13	0.02	0.05	-0.17	0.11
5								-0.30	-0.25	0.03	-0.03
6									0.14	-0.24	0.00
7										-0.24	0.04
8											-0.14
9											

Summary

This Marine Exchange information provided a strong indication of the level of geographic coverage of the tugs participating in the ITOS system. As the data showed, ITOS coverage is very good for the eastern waters of the region, although it was less in the western waters. There was approximately an 82% probability of at least one tug in the western portion of the Strait of Juan de Fuca, and an approximately 60% and 45% probability of a tug in the northern and southern approaches respectively. Again, this counts all tugs participating were both able (of sufficient size and power) and willing (including dropping tow if encumbered) to come to the aid of a vessel in distress. While the ability of ITOS tugs is, as discussed in the Introduction, outside the scope of this study, the availability and willingness of ITOS tugs to come to the aid of a vessel in distress is addressed in Chapter 5. Additional insights are also developed in Chapter 5 with the incorporation of the vessel traffic data.

3. U.S. Coast Guard Vessel Traffic Service Data

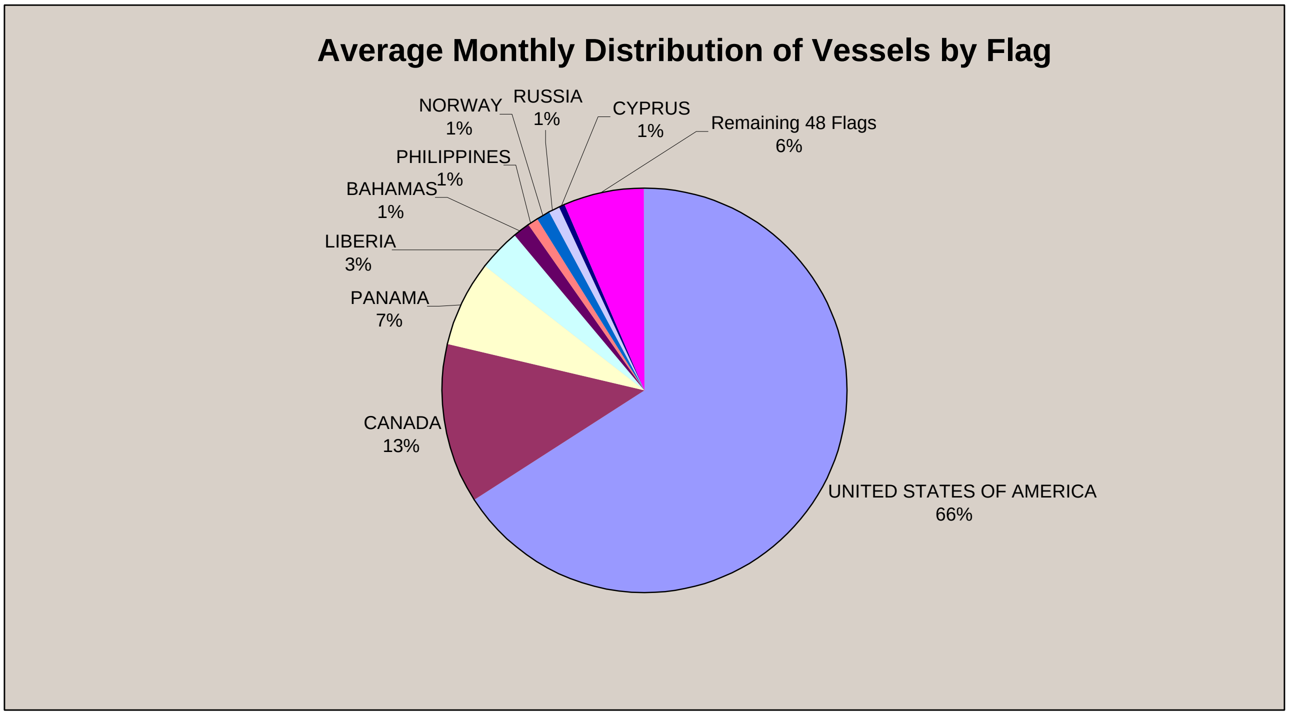
Introduction

As noted earlier in Table 1, U.S. Coast Guard data was reviewed to determine the distribution of vessels in the VTS Puget Sound area of responsibility[5] (AOR). This data capture does not include Washington State ferries, which forms the bulk of the traffic in the region, but for which ITOS was not intended to provide coverage. The purpose of this portion of the analysis was to provide a characterization of the vessel traffic that ITOS looks to safeguard.

Analysis

The first step in this portion of the analysis was to review the decomposition of the fleet by vessel flag. The results of this step are shown in Figure 13. As can be seen, the vast majority (approximately 80%) of the vessels operating in the VTS Puget Sound AOR are either U.S. or Canadian flagged.

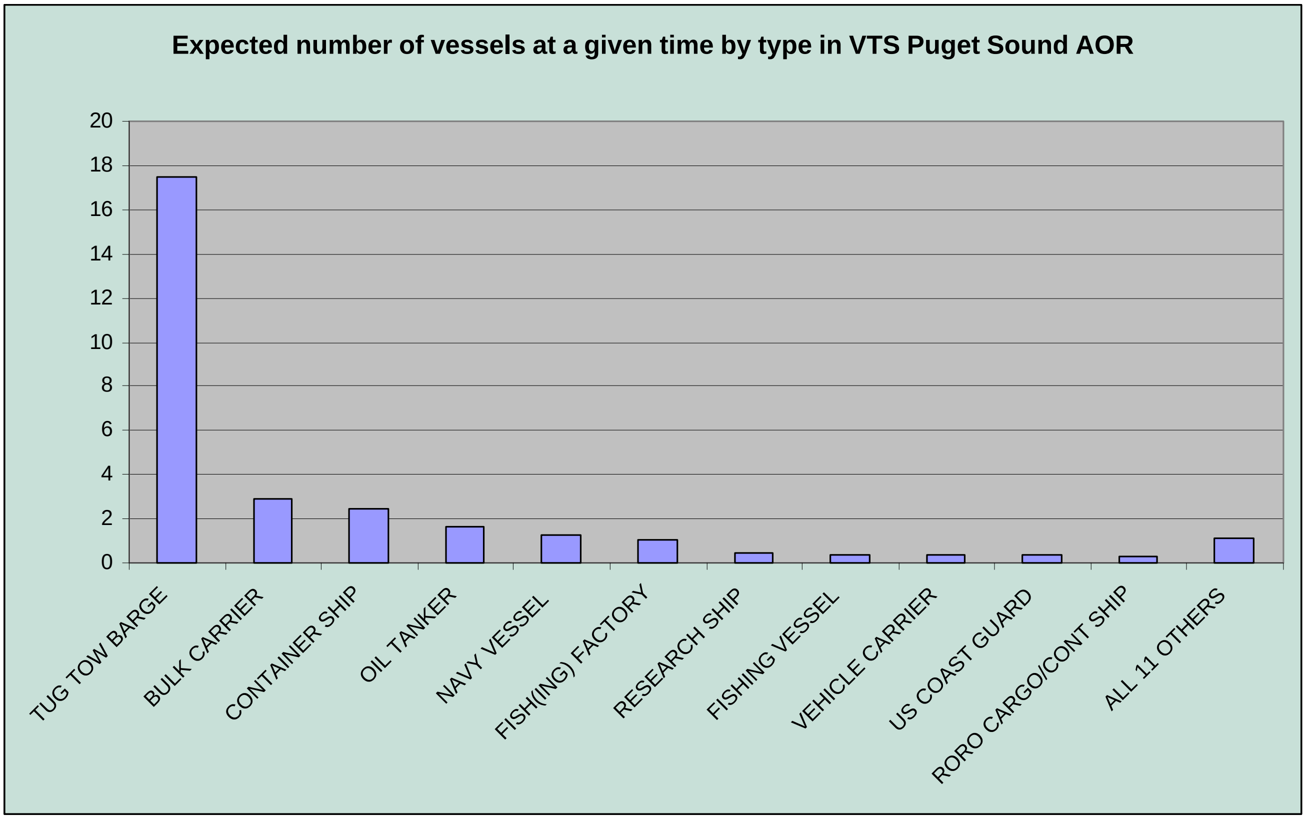
Figure 13



[5] This area is, as delineated in the Cooperative Vessel Traffic Service agreement between the United States and Canada, east of the line at 124º 40'W up until the waters off of Victoria and through the San Juan Islands to the Strait of Georgia (except Haro Strait) and south through Puget Sound into Olympia.

Continuing with this analysis of the vessels operating in the region, the average number of vessels in operation at a given time by type is shown in Figure 14. As can be seen, the majority of vessels in operation in this region are tugs and tows.

Figure 14



The distribution of vessels by geographic region was then determined, as shown in Figures 15 and 16. As can be seen, segment 7 (central Puget Sound) had the highest level of traffic, followed (in order) by segments 3 (Strait), 4 (Strait east of Port Angeles), 6 (Haro Strait), 8 and 9 (eastern and central Puget Sound respectively). This distribution did not vary much throughout the time period studied, with an average coefficient of variation of less than 20%. It should be noted that the VTS Puget Sound AOR covers only a small portion of segments 1, 2 and 5, and therefore the number of vessels shown is correspondingly small and not accurate. This issue will be addressed in Chapters 4 and 5 of this report, with the inclusion of Canadian data and reanalysis of Marine Exchange data.

Figure 15

Average Distribution of Vessels by Month and Geographic Region

	Segment #										
	1	2	3	3W	3E	4	5	6	7	8	9
Average	0.1%	0.0%	19.3%	9.9%	9.4%	15.9%	0.6%	14.1%	30.6%	9.5%	8.2%
Nov-98	0%	0%	24%	12%	12%	16%	1%	13%	30%	9%	7%
Dec-98	0%	0%	18%	10%	8%	17%	1%	13%	32%	10%	8%
Jan-99	0%	0%	18%	8%	10%	17%	1%	16%	30%	10%	9%
Feb-99	0%	0%	19%	10%	10%	15%	0%	15%	33%	9%	10%
Mar-99	0%	0%	20%	11%	9%	16%	0%	14%	30%	11%	9%
Apr-99	0%	0%	17%	10%	7%	16%	0%	13%	26%	8%	8%
May-99	0%	0%	18%	9%	9%	15%	1%	15%	33%	9%	9%

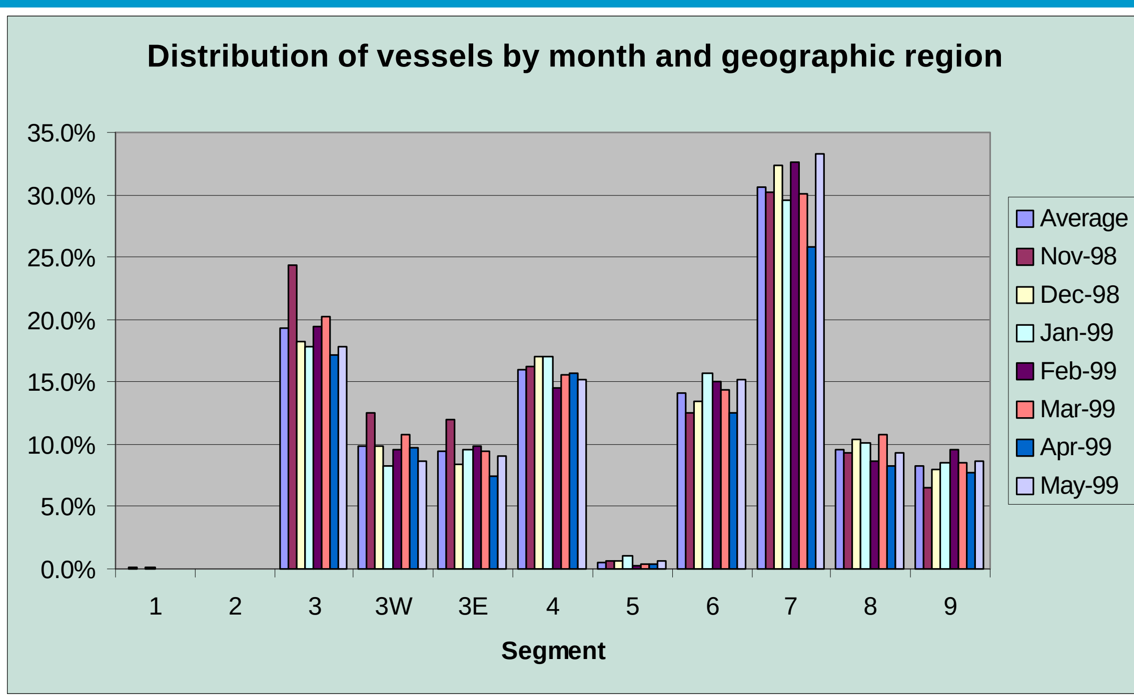
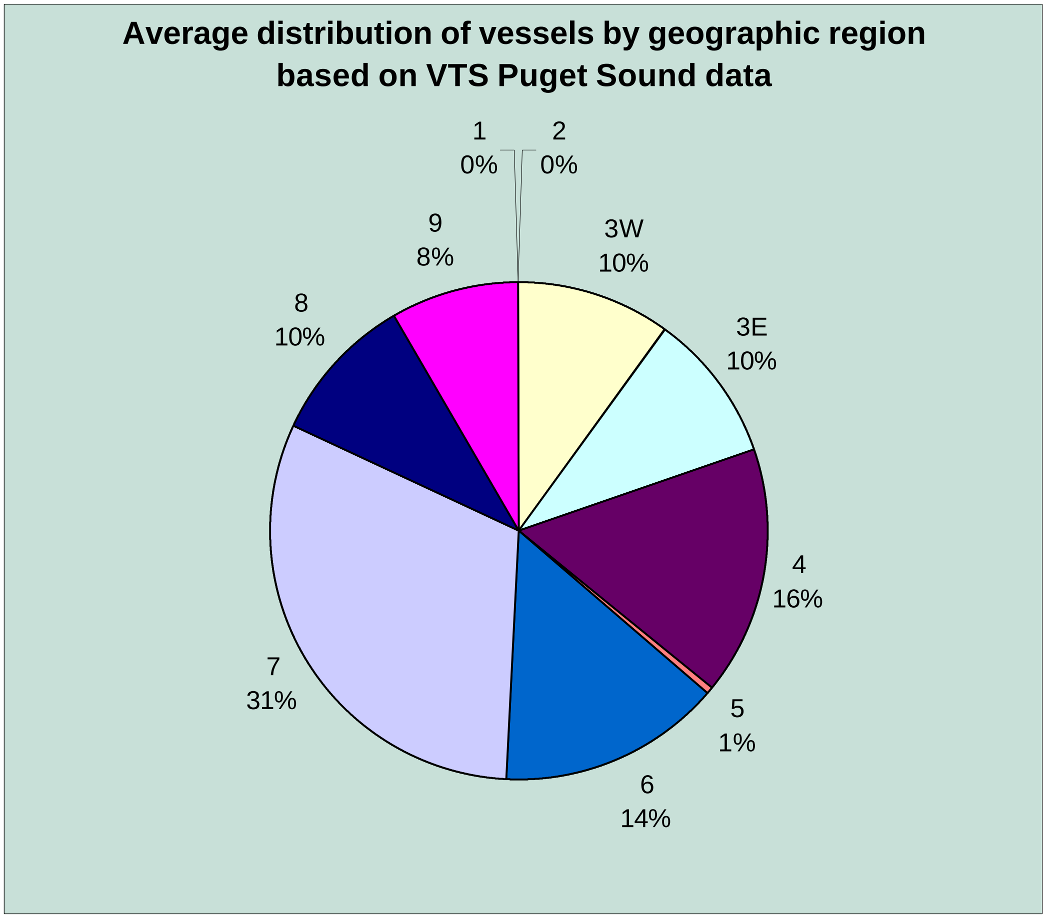


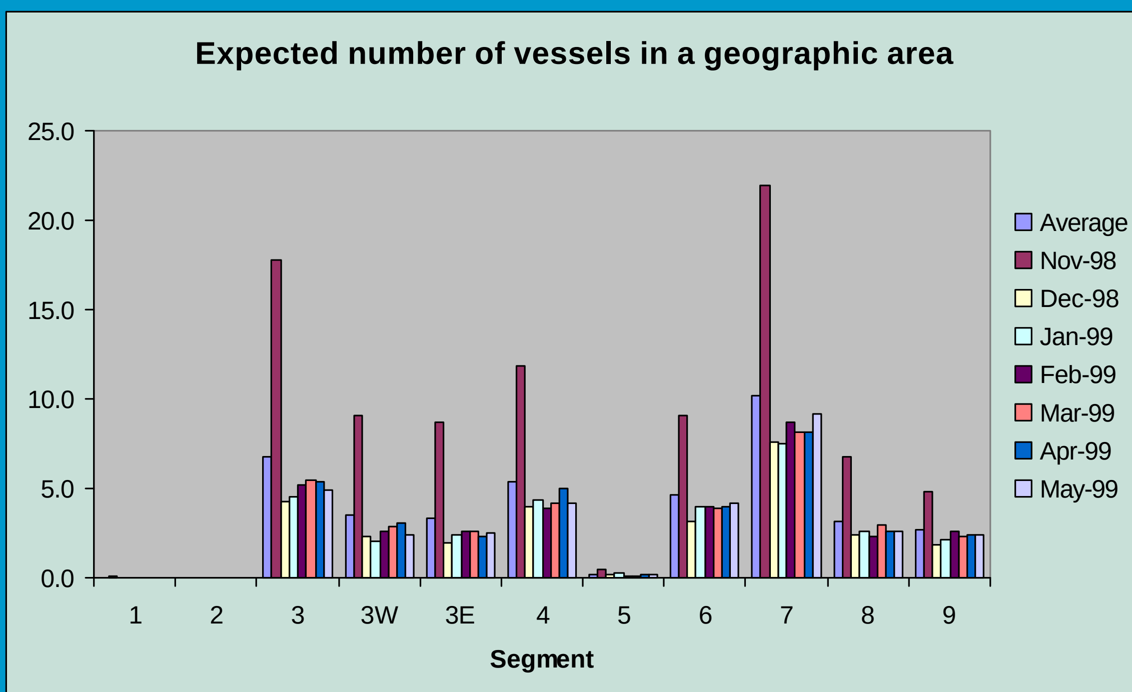
Figure 16


Average distribution of vessels by geographic region based on VTS Puget Sound data
1
0%
2
0%
3W
10%
3E
10%
4
16%
5
1%
6
14%
7
31%
8
10%
9
8%

In the next stage of this analysis, the expected number of vessels in a geographic region at any given time was determined. The results of this step are shown in Figure 17. The average coefficient of variation was approximately 68%. Additional information on the distribution of the number of vessels by geographic region is presented in Appendix II, which shows the distribution of vessels to be roughly normally distributed about the mean shown in Figure 17.

Figure 17

Expected Number of Vessels in a Given Region at a Given Time											
	Segment #										
	1	2	3	3W	3E	4	5	6	7	8	9
Average	0.0	0.0	6.8	3.5	3.3	5.3	0.2	4.6	10.2	3.2	2.6
Nov-98	0.1	0.0	17.8	9.1	8.7	11.9	0.4	9.1	22.0	6.8	4.8
Dec-98	0.0	0.0	4.3	2.3	2.0	4.0	0.1	3.1	7.6	2.4	1.9
Jan-99	0.0	0.0	4.5	2.1	2.4	4.3	0.3	3.9	7.5	2.6	2.1
Feb-99	0.0	0.0	5.2	2.6	2.6	3.9	0.1	4.0	8.7	2.3	2.6
Mar-99	0.0	0.0	5.5	2.9	2.6	4.2	0.1	3.9	8.1	2.9	2.3
Apr-99	0.0	0.0	5.4	3.1	2.3	5.0	0.1	3.9	8.1	2.6	2.4
May-99	0.0	0.0	4.9	2.4	2.5	4.2	0.2	4.2	9.2	2.6	2.4

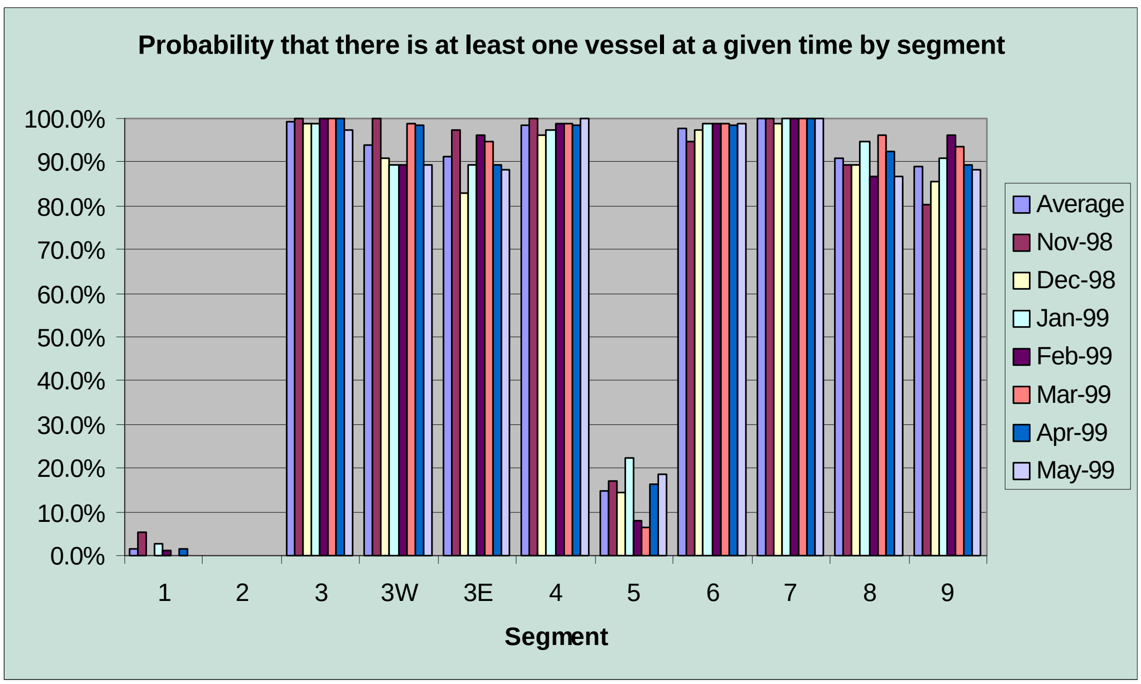


Moving to a more detailed characterization of vessel traffic in the region, the probability of at least one vessel operating in a given region at a given time was determined, as shown in Figure 18. As can be seen, there is almost always a vessel operating in each of the segments in the VTS Puget Sound AOR. Again, traffic was artificially indicated as light for segments 1, 2 and 5, since these segments are primarily outside the VTS Puget Sound AOR. There was little variation by month in the course of the study, with an average coefficient of variation of less than 20%.

Figure 18

Probability of at least one vessel at a given time

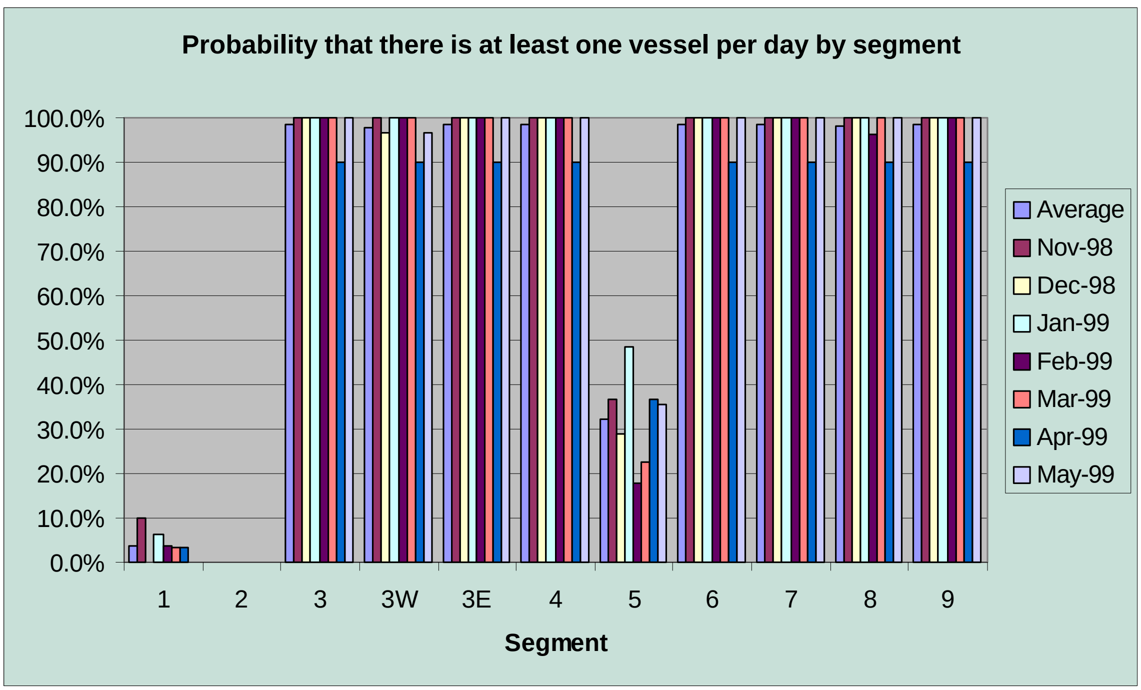
	Segment #										
	1	**2**	**3**	**3W**	**3E**	**4**	**5**	**6**	**7**	**8**	**9**
Average	1.5%	0.0%	99.2%	93.8%	91.2%	98.5%	14.8%	97.9%	99.8%	90.9%	89.1%
Nov-98	5%	0%	100%	100%	97%	100%	17%	95%	100%	89%	80%
Dec-98	0%	0%	99%	91%	83%	96%	14%	97%	99%	89%	86%
Jan-99	3%	0%	99%	89%	89%	97%	22%	99%	100%	95%	91%
Feb-99	1%	0%	100%	89%	96%	99%	8%	99%	100%	87%	96%
Mar-99	0%	0%	100%	99%	95%	99%	7%	99%	100%	96%	93%
Apr-99	1%	0%	100%	99%	90%	99%	16%	99%	100%	93%	90%
May-99	0%	0%	97%	89%	88%	100%	18%	99%	100%	87%	88%



As was done for the Marine Exchange data set, the probability of at least one vessel in a day being in any region was determined next, as shown in Figure 19. Again, the results do not provide a great deal of insight, in that all of the geographic regions with full data coverage in the VTS Puget Sound AOR had a probability of nearly 100% of at least one vessel in operation per day. Variation between months was not large, with an average coefficient of variation of less than 10%.

Figure 19

Probability of at least one vessel in a given day											
	Segment #										
	1	2	3	3W	3E	4	5	6	7	8	9
Average	3.8%	0.0%	98.6%	97.6%	98.6%	98.6%	32.4%	98.6%	98.6%	98.1%	98.6%
Nov-98	10%	0%	100%	100%	100%	100%	37%	100%	100%	100%	100%
Dec-98	0%	0%	100%	97%	100%	100%	29%	100%	100%	100%	100%
Jan-99	6%	0%	100%	100%	100%	100%	48%	100%	100%	100%	100%
Feb-99	4%	0%	100%	100%	100%	100%	18%	100%	100%	96%	100%
Mar-99	3%	0%	100%	100%	100%	100%	23%	100%	100%	100%	100%
Apr-99	3%	0%	90%	90%	90%	90%	37%	90%	90%	90%	90%
May-99	0%	0%	100%	97%	100%	100%	35%	100%	100%	100%	100%

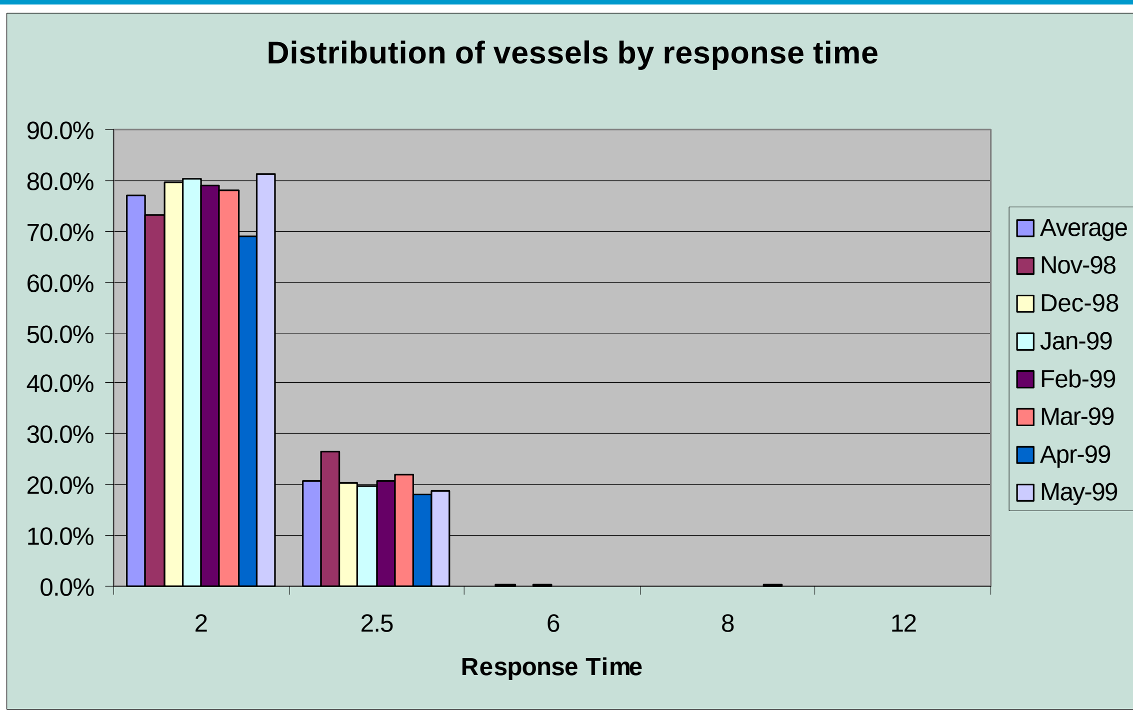


Continuing, the distribution of vessels by response zones was then determined (as was done for the Marine Exchange data). The results are shown in Figure 20. As can be seen, the majority of vessels were in the 2 hour response region, as was the case for ITOS tugs in the Marine Exchange data. It should be noted that this is at least in part due to the 6, 8 and 12 hour response zones falling outside of the VTS Puget Sound AOR. As can be seen, vessels were still primarily found in the 2 hour response zone, although they were slightly more evenly distributed between the 2 and 2½ hour response zones than were the ITOS tugs. There was little variation in the months studied, with an average coefficient of variation of less than 10%.

Figure 20

Distribution of Vessels by Response Time

	Response Times (Hours)				
	2	2.5	6	8	12
Average	77.2%	20.9%	0.1%	0.1%	0.0%
Nov-98	73%	26%	0%	0%	0%
Dec-98	80%	20%	0%	0%	0%
Jan-99	80%	20%	0%	0%	0%
Feb-99	79%	21%	0%	0%	0%
Mar-99	78%	22%	0%	0%	0%
Apr-99	69%	18%	0%	0%	0%
May-99	81%	19%	0%	0%	0%

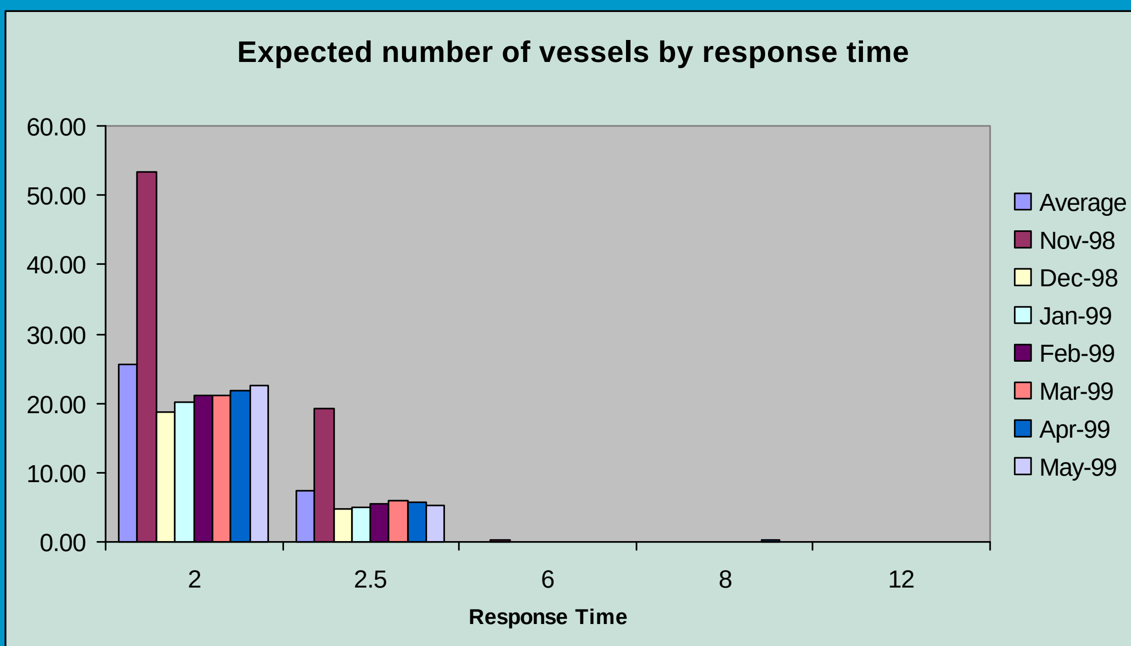


Similarly, the expected number of vessels by response region was determined, as shown in Figure 21. Again, the distribution is dominated by waters in the eastern region, although here too, this can be at least partly ascribed to the limits of the VTS Puget Sound AOR. There was strong variation by month during the time studied, with an average coefficient of variation of 97% (although the 2 hour response region, which accounted for approximately 77% of the vessels, had a COV of only 48%).

Figure 21

Expected number of vessels in given response region

	Response Times (Hours)				
	2	2.5	6	8	12
Average	25.51	7.34	0.04	0.04	0.00
Nov-98	53.32	19.24	0.15	0.12	0.00
Dec-98	18.66	4.77	0.00	0.00	0.00
Jan-99	20.22	4.95	0.05	0.00	0.00
Feb-99	21.07	5.57	0.04	0.02	0.00
Mar-99	21.11	5.92	0.01	0.01	0.00
Apr-99	21.74	5.71	0.03	0.14	0.00
May-99	22.42	5.18	0.01	0.00	0.00

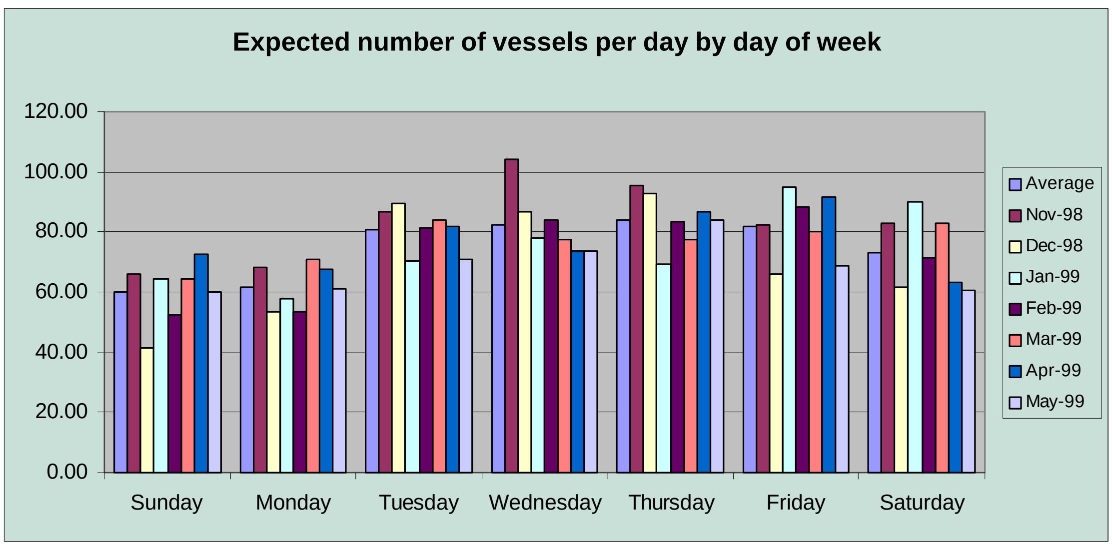


Finally, the distribution of the expected number of vessels per month was reviewed by day of the week, to determine whether there were significant differences between days. The results are shown in Figure 22. As can be seen, the only difference was that traffic levels were somewhat higher from Tuesday through Friday than for Saturday through Monday. This variation, while interesting, was not investigated further in this study.

Figure 22

Expected Number of Vessels per Day

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Average	60.14	61.81	80.60	82.41	84.21	81.72	73.29
Nov-98	66.00	68.20	86.50	104.00	95.50	82.25	83.00
Dec-98	41.40	53.60	89.25	86.75	92.75	66.25	61.75
Jan-99	64.40	58.00	70.25	77.75	69.25	94.75	89.75
Feb-99	52.20	53.60	81.25	83.75	83.50	88.50	71.50
Mar-99	64.50	70.80	84.20	77.40	77.25	80.00	83.00
Apr-99	72.50	67.50	81.75	73.50	87.00	91.80	63.20
May-99	60.00	61.00	71.00	73.75	84.25	68.50	60.80



Summary

In summary, there is almost always traffic in each of the segments in the Puget Sound area waterway. This traffic is unevenly distributed, with central Puget Sound having the highest levels of traffic, followed by the Strait of Juan de Fuca and Haro Strait. This distribution did not vary significantly throughout the months studied, and no discernible trends in traffic between the months were detected. All in all, the analysis of traffic data indicates that, to be most effective, ITOS needs to provide consistent coverage throughout the entire waterway, assuming that all traffic is equally likely to go adrift. The analysis of the level of ITOS coverage relative to these vessel densities is provided in Chapter 5.

4. Canadian Coast Guard Vessel Traffic Service Data

Introduction

To supplement the detailed analysis of vessel traffic in the VTS Puget Sound AOR, an analysis of Canadian Coast Guard data was made. These data, as was noted earlier in Table 1, were collected on a daily basis for the Tofino Marine Communications and Traffic Services AOR[6]. Although not as detailed as the VTS Puget Sound data, this set provides several key insights that are not obtainable through consideration of the U.S. VTS data.

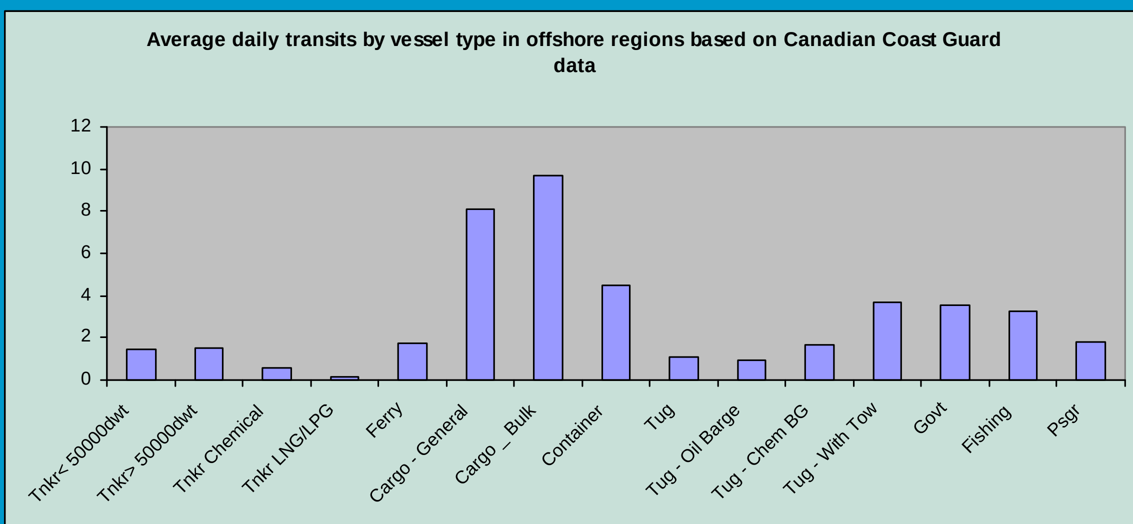
Analysis

The first step for this portion of the analysis was to characterize the expected number of vessels in a given day. As can be seen in Figure 23, overall, one can expect to see at least three tankers a day in this outer coast region (segments 1 and 2), with large versus small tankers being approximately evenly distributed. Dry cargo vessels were the most numerous (approximately 6 times more numerous than tankers).

[6] This area covers all vessels within 50 NM of Vancouver Island, or north of latitude 40° N and west of 127° W up to the handoff to VTS Puget Sound.

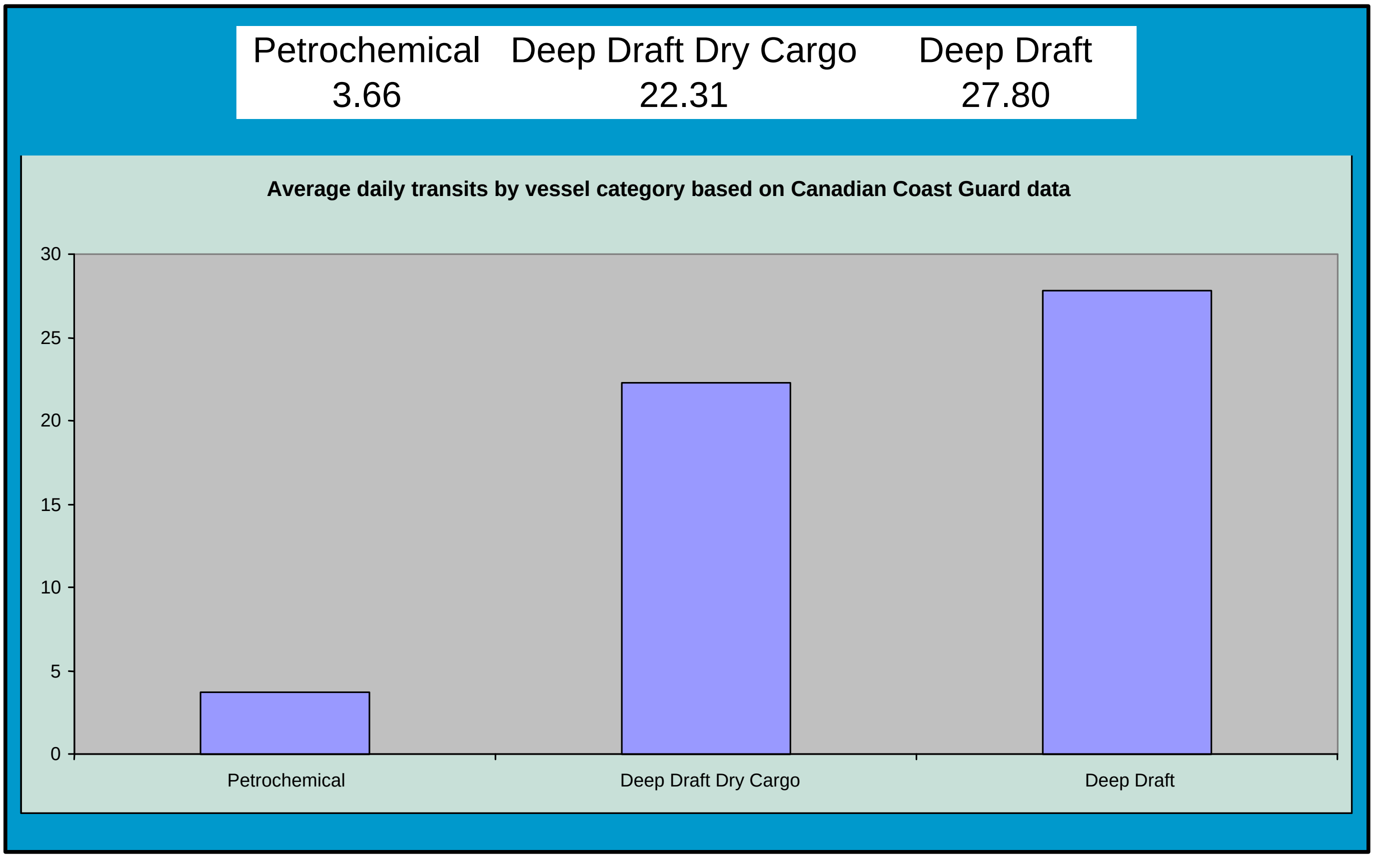
Figure 23

	Overall Average
Tnkr< 50000dwt	1.43
Tnkr> 50000dwt	1.51
Tnkr Chemical	0.60
Tnkr LNG/LPG	0.12
Ferry	1.76
Cargo - General	8.10
Cargo _ Bulk	9.72
Container	4.49
Tug	1.08
Tug - Oil Barge	0.91
Tug - Chem BG	1.67
Tug - With Tow	3.69
Govt	3.52
Fishing	3.24
Psgr	1.83



Next, deep draft vessel types were combined into three categories: (1) petrochemical (all four tanker types), (2) dry cargo (container, and general and bulk cargo) and (3) deep draft (combination of petrochemical, dry cargo and passenger vessels) -- the average daily transits are as shown in Figure 24. As can be seen, the majority of deep draft traffic is dry cargo for the offshore region.

Figure 24



In addition, the Canadian data provide insight into tug and barge traffic, with implications for tug availability in the offshore regions. With data from Figure 23, Table 7 shows that approximately 15% of tugs operating in the outer coast region are not laden, and ostensibly would be willing to aid a vessel in distress (including dropping tow if encumbered). The panel of experts used in the current cost benefit analysis[7] on dedicated rescue tugs and tug escorts (including tug operators from Foss and Crowley) estimated the probability of an unladen tug being willing to provide assistance to be approximately 88%. A further 50% of tugs are laden with non-petrochemical tows, whose willingness to come to the aid of a vessel was estimated at 37% by this same panel. Finally, approximately 35% of vessels were laden with petrochemical tows, and were estimated to have an 11% probability of being willing to come to the aid of another vessel. Laden tugs were assessed as being able to provide assistance if they could and would anchor their tow, let it drift for another tug to pick up (thereby cascading the casualty) or some other step. The overall probability of a tug being available and willing to assist is then the sum of the products of the probability of a particular state (e.g., unencumbered) with the probability of the tug being willing to come to the aid of a vessel in distress given its state. These assumptions were analyzed further in the sensitivity tests for tug availability discussed in Chapter 6.

Table 7

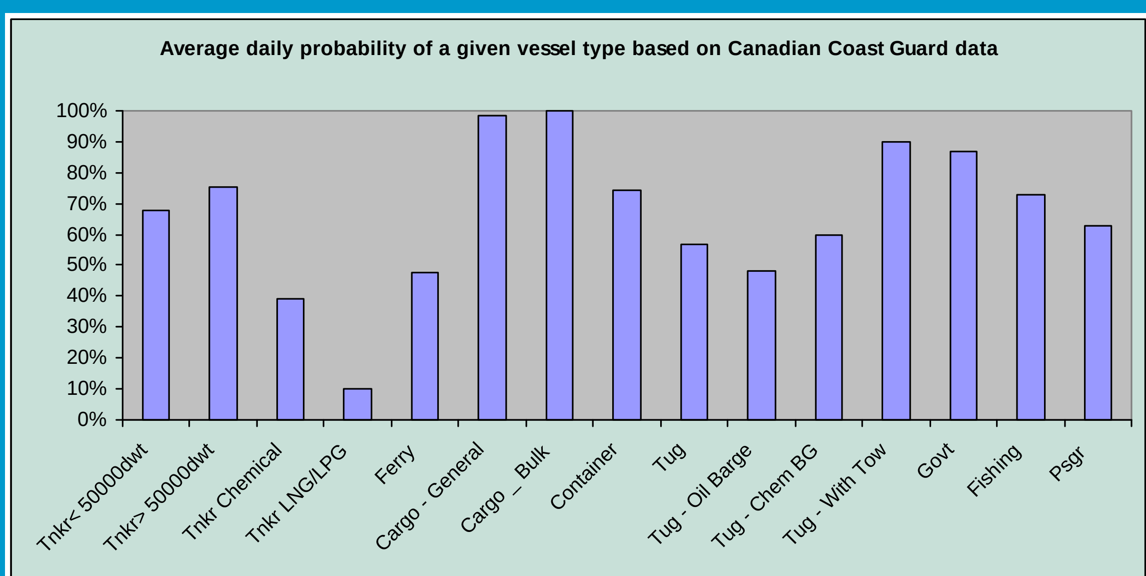
	Probability of State	Probability Willing Given State	Probability Willing and State	
Unencumbered	14.7%	88%	12.9%	
Petrochemical	35.1%	11%	3.9%	
Non-Petrochemical	50.2%	37%	18.6%	
			35.4%	<= Probability Available and Willing to Assist

[7] Cost-benefit analysis performed by Designers & Planners and Herbert Engineering Corporation, still in development.

Continuing with the analysis of the Canadian traffic data, the average daily probability of at least one transit by a particular vessel type was next calculated. The results are shown in Figure 25. As can be seen, there is a near certainty to be at least one general cargo vessel transit and at least one bulk carrier transit on a given day. Furthermore, there is a very high probability of a small tanker, tug with chemical barge, and tug with non-petrochemical tow transiting on any given day.

Figure 25

	Average Probability of Vessel Type That Day
Tnkr< 50000dwt	68%
Tnkr> 50000dwt	75%
Tnkr Chemical	39%
Tnkr LNG/LPG	10%
Ferry	48%
Cargo - General	98%
Cargo _ Bulk	100%
Container	74%
Tug	57%
Tug - Oil Barge	48%
Tug - Chem BG	60%
Tug - With Tow	90%
Govt	87%
Fishing	73%
Psgr	63%



Summary

Although detailed comparisons cannot be performed as was done with the U.S. VTS data, the Canadian data does shed additional insight into the population of vessels in the outer coast regions. First and foremost, the Canadian data shows that, on average over the past 1½ years, there are approximately 28 deep draft vessels transiting the offshore area on a given day. As such, and in combination with the U.S. VTS data, there is a strong indication that there is a high likelihood of deep draft vessels on these outer coastal waters at all times. The majority (80%) of these vessels are cargo and/or container vessels. Overall, vessels transporting petrochemical cargoes comprise 14% of traffic in these offshore areas. Additionally, the Canadian data provides the ability to differentiate between tugs that are not laden, laden with dry cargoes, and laden with petrochemical cargoes. This information, as was shown in Table 7, will be used in Chapter 5 to estimate ITOS tug availability.

5. Combined Results

Using the information from the previous three sections, a more accurate and detailed characterization of the effectiveness of ITOS can be developed. Specifically, the following two steps can be taken: (1) the ITOS tugs can be filtered to screen out those that would be unable/unwilling to come to the aid of a vessel in distress, and (2) the level of protection provided by this reduced number of ITOS tugs to the vessels in operation can be determined.

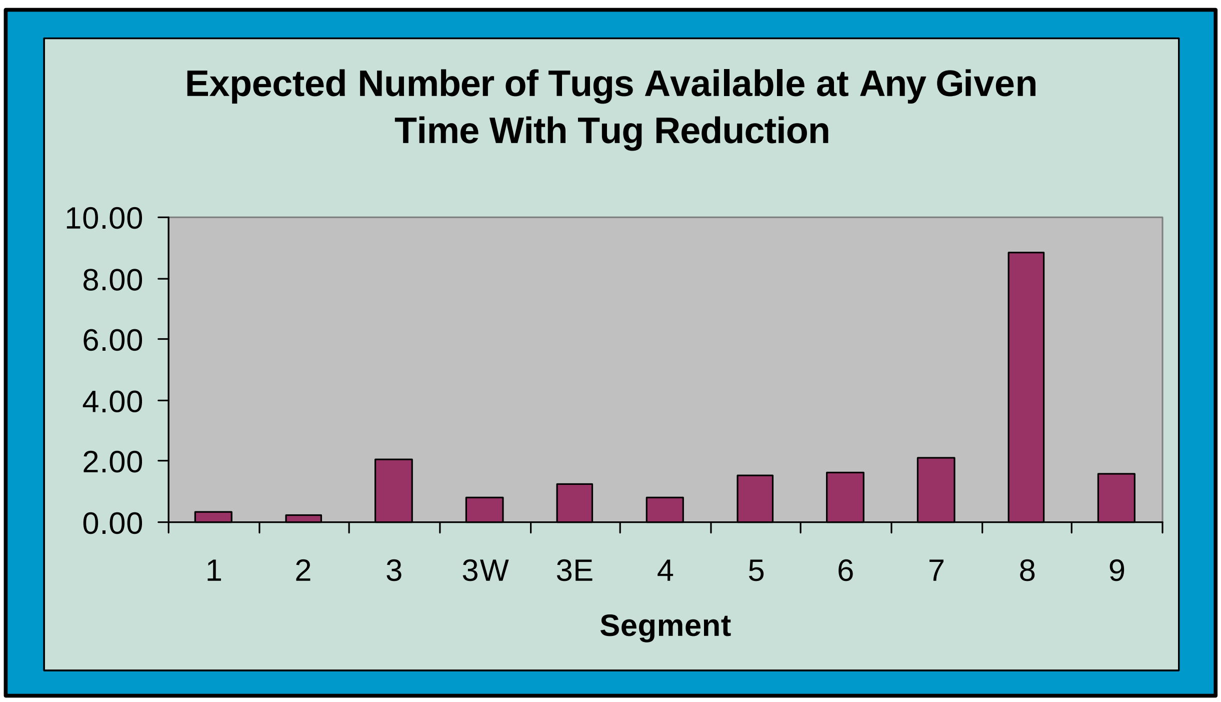
In this first step, as noted, the ITOS tugs can be filtered to screen out those that would not be in a position to either provide assistance to a vessel in distress or would not be willing to do so. This was done by developing a tug reduction factor as was done in Table 7 for the offshore region. First, the determination of a tug being laden or unladen was made on a segment by segment basis. This was done in the VTS Puget Sound AOR by comparing the number of tugs in the VTS (which are primarily laden) to the number of tugs in ITOS. This ratio was then used as the probability of a tug being laden for that segment, with the exception of segment 7 (central Puget Sound), which had more tugs in VTS than ITOS (due to ITOS participation being triggered by minimum size and VTS capturing all sizes of tugs that are laden). For segment 7, the average probability of being laden for segments 4, 8 and 9 (the adjacent segments) was used. For Haro Strait, which is outside the VTS Puget Sound AOR and therefore underrepresented, the estimates for Rosario Strait were used. For the offshore regions (segments 1 and 2), the probability of being unladen shown in Table 7 was used. For all waters, the conditional probability of a tug having a petrochemical tow given that it is laden derived from Table 7 was used to determine the probability of petrochemical and non-petrochemical tows. This process and the results are shown in Table 8. While an overall willingness factor (across the waterway) is shown for illustrative purposes, the segment by segment willingness ("Available and Willing for Segment", heretofore referred to as "Tug Reduction Factor") was used in subsequent calculations. The weighting shown below and used to determine the overall willingness is the average (across all samples and segments) percent of tugs in that segment. These and some of the following results differ slightly from what was shown in Chapter 2, where the results were shown as the average across the monthly averages. Here and in the following, the representation is the average across all samples. In all cases, the differences were slight.

Table 8: Determination of the Tug Reduction Factors[8]

	1	2	3	3W	3E	4	5	6	7	8	9
Unladen	14.7%	14.7%	51.3%	45.0%	56.0%	8.0%	26.1%	26.1%	44.0%	81.7%	42.2%
Laden With Petrochemical	35.1%	35.1%	20.0%	22.7%	18.1%	37.9%	30.4%	30.4%	23.1%	7.5%	23.8%
Laden With Non-Petrochemical	50.2%	50.2%	28.7%	32.3%	25.9%	54.1%	43.5%	43.5%	32.9%	10.8%	34.0%
Willing Given Unladen	88.0%										
Willing Given Laden with Petrochemical	11.0%										
Willing Given Laden with Non-Petrochemical	37.0%										
Weighting	2.5%	1.7%	9.5%	4.0%	5.4%	7.0%	9.8%	10.3%	10.5%	31.0%	8.2%
Available and Willing for Segment	35%	35%	58%	54%	61%	31%	42%	42%	53%	77%	52%
Weighted Probability	0.9%	0.6%	5.5%	2.2%	3.3%	2.2%	4.2%	4.4%	5.6%	23.8%	4.3%
Available and Willing Across Waterway	56.8%										

Each segment's average probability of a tug being willing and available to come to the aid of a vessel in distress was then applied to the number of ITOS tugs by sample and segment. This then formed the expected number of tugs by segment at that time. The average across all segments is shown in Figure 26, which shows a significant decrease from the results obtained in Figure 7.

Figure 26

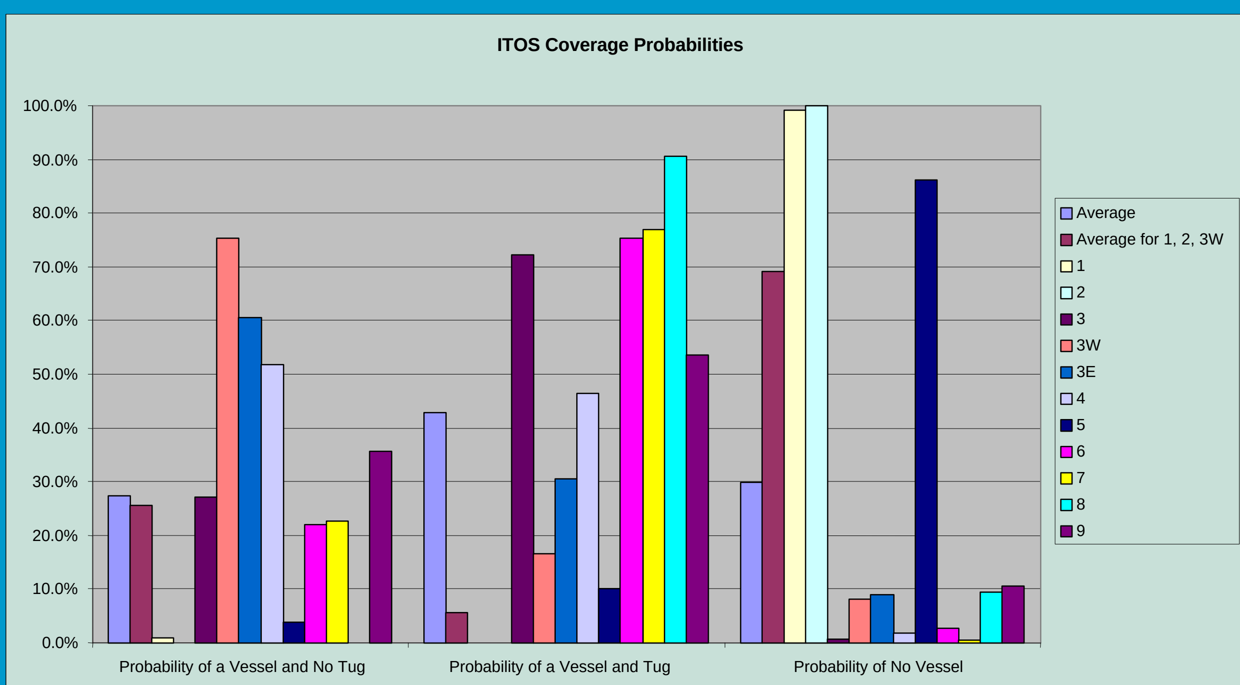


[8] Note: This uses the assumptions as outlined previously and recaptured in Table 12 later in this report, particularly the fourth assumption.

The full data set of vessels from VTS Puget Sound was then matched to the data set of ITOS tugs from the Marine Exchange. For each segment and sample, the occurrence of various combinations of tugs, “no tugs” (less than one expected tug after application of the tug reduction factor), vessels and no vessels was noted. From this information, the probabilities of an ITOS tug being in the vicinity of a vessel (i.e., in the same segment) and of “no tug” in the vicinity and no vessel were determined. The results are shown in Figure 27 both for all segments and for just the very western waters (segments 1, 2 and 3 west). As can be seen, across all segments and without the tug reduction factor described previously, the probability of there being both a vessel and a tug in the segment was approximately 68%, with the probability of a vessel but no tug of only 3%. These probabilities were slightly different for the western waters (where VTS Puget Sound coverage limitations resulted in more cases of no vessels), although even in those waters there was only a 6% probability of a vessel but no tug. With the tug reduction factor, the results change somewhat for the entire waterway (with a probability of a vessel and no tug of 27%) and for the western waters (with a probability of vessel and no tug of 26%). It is important to note, however, that the individual probabilities shown in Figure 27 are not the critical piece for the analysis. What is important is the determination of how big a gap there is in tug coverage (i.e., how many of the times where there is a vessel is there no tug).

Figure 27

	Average Without Tug Reduction		Average With Tug Reduction	
	All Segments	Segments 1, 2, 3W	All Segments	Segments 1, 2, 3W
Probability of a Vessel and No Tug	2.6%	5.6%	27.3%	25.5%
Probability of a Vessel and Tug	67.6%	25.4%	42.9%	5.5%
Probability of No Vessel	29.8%	69.0%	29.8%	69.0%



The conditional probabilities of a tug and of no tug for those times where there is a vessel (with and without the tug reduction factor) are shown in Figure 28 for the entire waterway and in Figure 29 for the western waters.

Figure 28

	Average Across All Segments Without Tug Reduction	Average Across All Segments With Tug Reduction
Probability of Tug Given a Vessel	96.3%	71.3%
Probability of No Tug Given a Vessel	3.7%	28.7%

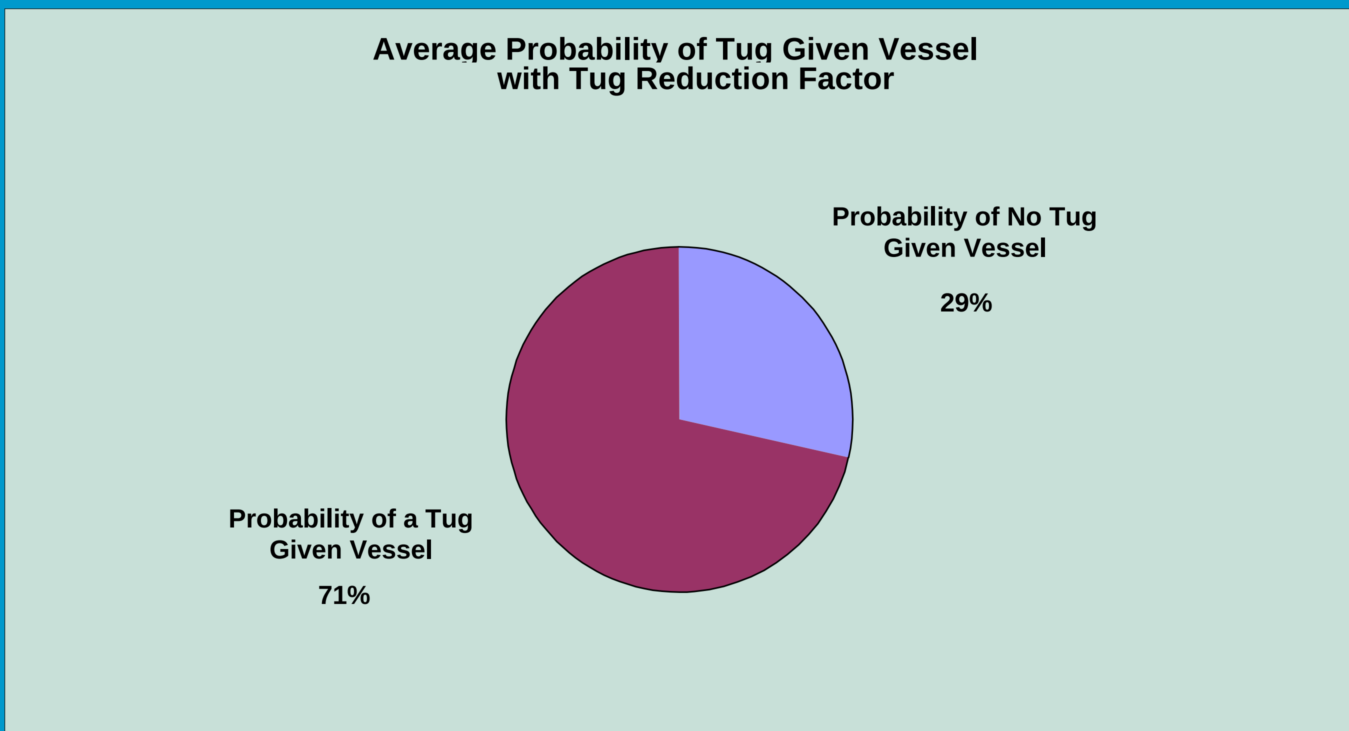
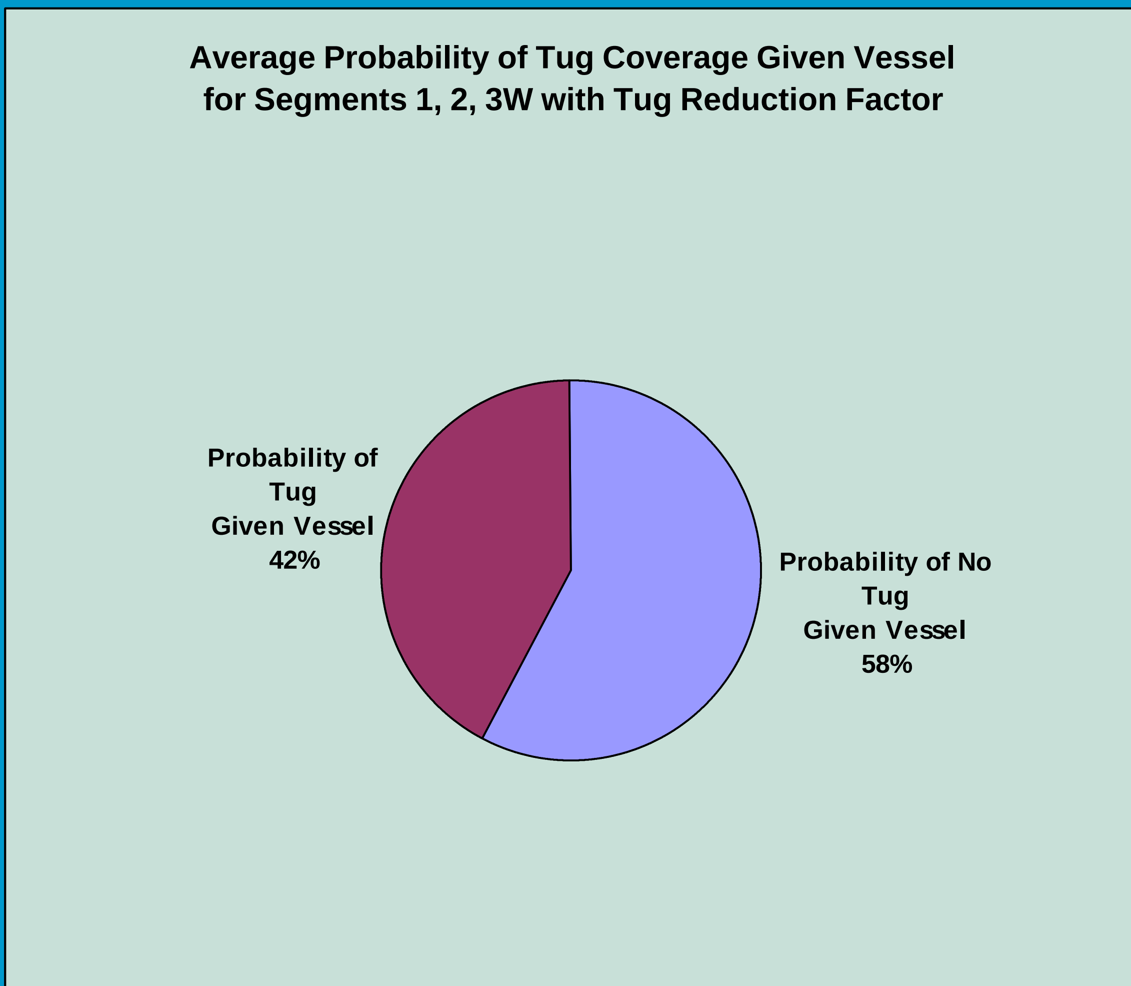


Figure 29

	Average Across Segments 1, 2 & 3W Without Tug Reduction	Average Across Segments 1, 2 & 3W With Tug Reduction
Probability of Tug Given a Vessel	81.9%	42.5%
Probability of No Tug Given a Vessel	18.1%	57.5%



As can be seen, tug coverage is good throughout the waterway (on average, given a vessel, there is a 71.3% chance of a tug being in the same segment). However, this coverage is less so for the western waters (where the probability is 42.5%). These two figures represent the primary conclusions of this report regarding tug coverage.

Next, the correlation between the presence of at least one vessel and at least one tug was tested, to see whether the presence of a vessel made it more or less likely for there to be a tug. The results are shown in Table 9 (as indicated in Segment 2, there is a lack of vessels to correlate to). As can be seen, the correlation between these two variables (the indicator functions for the presence of a vessel and the presence of a tug) is virtually nonexistent. Therefore, the presence of a vessel neither increases nor decreases the likelihood of a tug being in the same segment at the same time.

Table 9: Correlation Between Presence of Vessels in VTS Puget Sound Data Set by Segment and Tugs in Marine Exchange Data Set by Segment

		MarEx Tugs										
		1	2	3	3W	3E	4	5	6	7	8	9
	1	0.01	-0.02	0.00	-0.02	0.02	0.01	0.02	0.05	-0.07	0.04	-0.09
	2	Not Available										
	3	-0.03	0.02	0.02	-0.02	0.06	0.11	-0.17	0.07	0.13	0.07	-0.01
	3W	0.05	0.06	0.03	0.02	0.02	0.09	-0.14	0.00	0.13	0.01	0.04
	3E	-0.08	-0.03	0.01	-0.06	0.07	0.08	-0.10	0.10	0.05	0.08	-0.05
All Vessels	4	0.09	-0.02	0.10	0.05	0.09	-0.02	-0.08	0.01	0.05	-0.07	-0.01
	5	-0.08	0.06	0.00	-0.08	0.08	-0.05	-0.03	-0.04	-0.05	0.05	-0.06
	6	0.01	0.11	0.11	0.03	0.13	0.00	0.04	0.08	0.06	-0.09	0.05
	7	0.10	-0.03	0.13	0.04	0.14	0.13	-0.16	0.02	0.11	0.02	0.11
	8	-0.03	-0.04	0.02	0.08	-0.04	0.01	-0.14	0.01	0.04	0.05	0.07
	9	0.05	-0.05	0.08	0.03	0.08	0.01	0.05	-0.05	-0.03	0.04	0.10

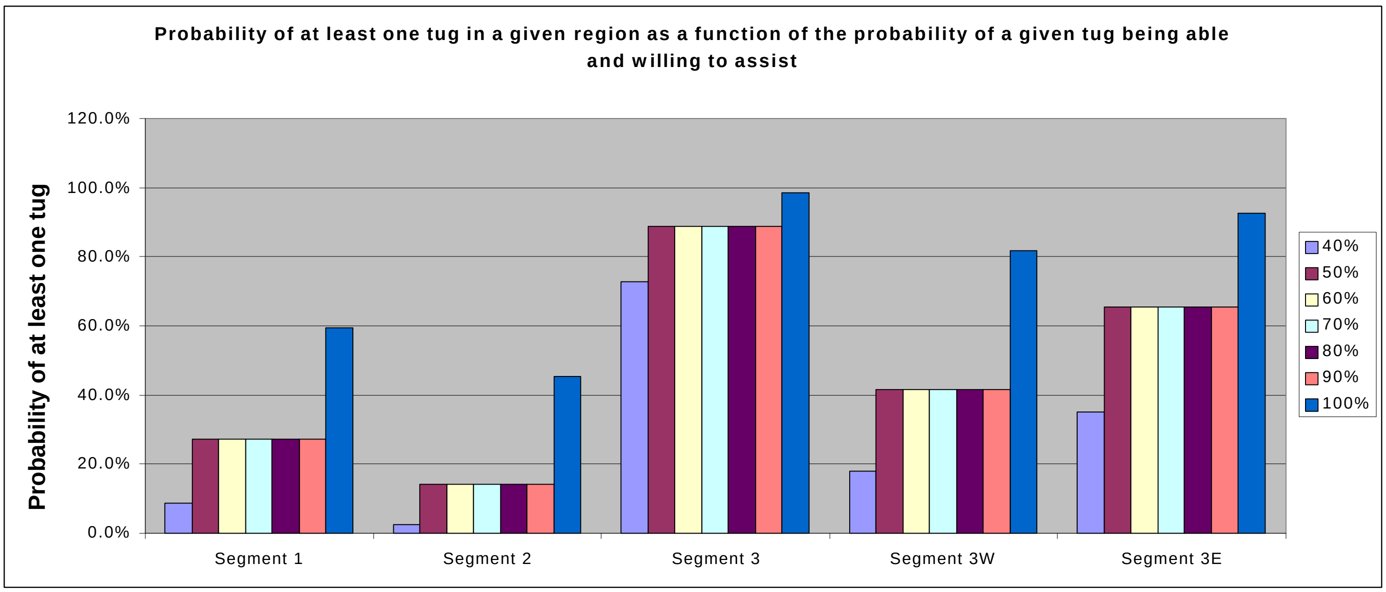
In summary, ITOS was found to provide coverage for approximately 71% of the vessels across the waterway (42% for the western waters).

6. Sensitivity Analysis

Given the sensitivity to the assumed probability of a tug being available and willing to assist (as was seen in the Chapter 5), a range of factors were tested, as shown in Figure 30. As can be seen, the probability of at least one ITOS tug being available and willing to assist at any given time is very sensitive to the probability of the tug being available and willing to aid a vessel in distress. In particular, once this probability dropped below 100%, the coverage provided by ITOS dropped by an average of 42% (ranging from just under 10% reduction in the Strait to nearly 70% reduction in the southern approach to the Strait). From there, the coverage was insensitive to this probability until it dropped below 50%, where it was reduced by approximately 45% again (ranging from 68% in the southern approach to the Strait to an 18% reduction in the Strait itself). This plateau is due to the effect of the discounting factor dropping the expected number of tugs below 1. Applying a probability of a tug being available and willing of less than 100% (say 90%) causes those times where the number of tugs was exactly equal to 1 to show up as less than 1 tug (and therefore counted as “no tug”). Similarly, applying a reduction factor of less than 50% caused those times where the number of tugs was less than or equal to two to show up as less than 1 tug (and again, counted as “no tug”). Therefore, the probability of at least one ITOS tug will reach plateaus in areas between these and other levels (e.g., applying a factor of 75% still eliminates those times with 1 tug, but does not eliminate those with 2 tugs, as 2 tugs *75% reduction =1.5 tugs >1). This is particularly evident at the 40% probability for segments 3, 3W, and 3E. Using the average number of tugs (from Figure 7- 3.57, 1.49, and 2.09 respectively), the effect of the 40% probability can be seen to reduce the expected number of tugs to 1.43, 0.60, and 0.84 respectively. As such, while segment 3 would rightly indicate that a tug that is available and willing is present (having ≥ 1 expected tug), segments 3W and 3E would not (having < 1 expected tugs). Details on the distributions of the number of ITOS tugs by segment are shown in Appendix I.

Figure 30

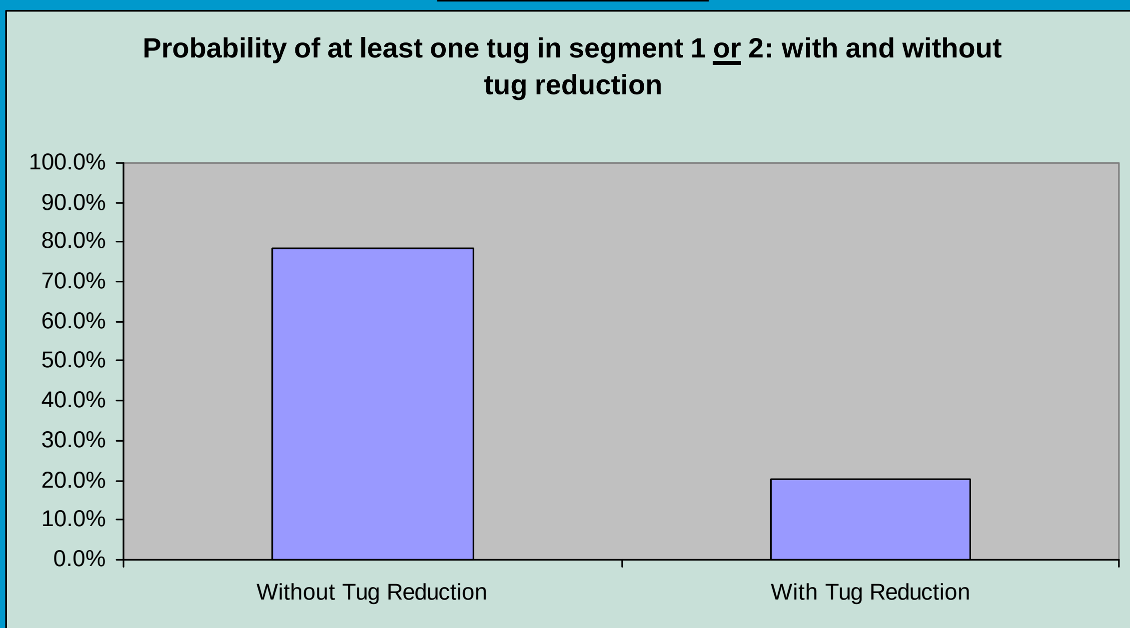
Average Probability of at least one ITOS tug being available, able and willing to assist at any given time within a given segment					
Probability Able and Willing	Segment 1	Segment 2	Segment 3	Segment 3W	Segment 3E
40%	8.6%	2.5%	72.7%	18.0%	35.0%
50%	27.1%	14.2%	88.8%	41.7%	65.5%
60%	27.1%	14.2%	88.8%	41.7%	65.5%
70%	27.1%	14.2%	88.8%	41.7%	65.5%
80%	27.1%	14.2%	88.8%	41.7%	65.5%
90%	27.1%	14.2%	88.8%	41.7%	65.5%
100%	59.5%	45.4%	98.5%	81.6%	92.6%



Additionally, the influence of the change in the probability of a tug being available and willing to come to the aid of a vessel in distress from 100% to 40% for the combined offshore region was determined, as shown in Figure 31. As can be seen, the reduction in the probability of a tug being both available <u>and</u> willing reduced the overall probability of an ITOS tug being available in the offshore region from 78% down to 20.3%.

Figure 31

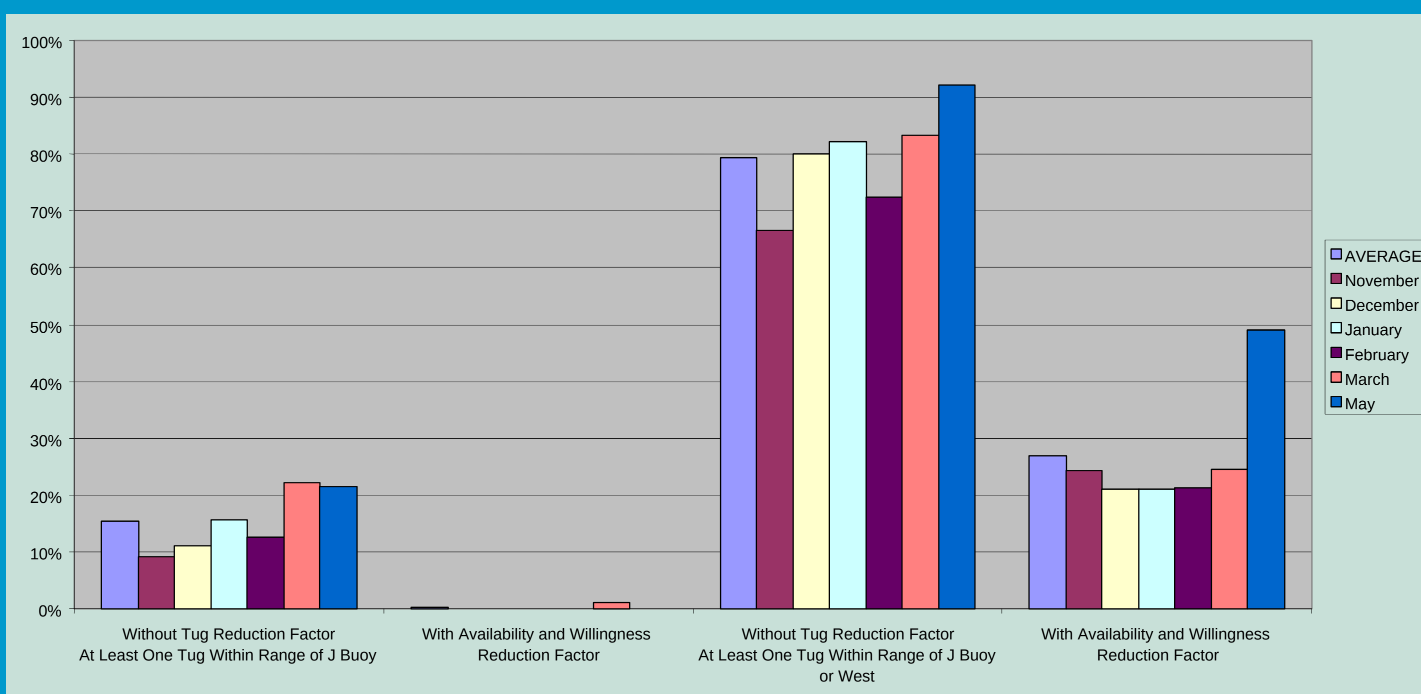
Segment 1 **or** 2	
Without Tug Reduction	With Tug Reduction
78.3%	**20.3%**



Finally, the influence of this reduced availability on the probabilities of at least one tug in the vicinity of the J Buoy (within one hour), and from this point westward, are shown in Figure 32. As can be seen, the tug availability had a substantial impact on these probabilities.

Figure 32

	Probability of At Least One Tug Within Range of J Buoy		Probability of At Least One Tug Within Range of J Buoy or West	
	Without Tug Reduction Factor	With Tug Reduction Factor	Without Tug Reduction Factor	With Tug Reduction Factor
AVERAGE	15%	0.2%	79%	26.9%
November	9%	0%	67%	24%
December	11%	0%	80%	21%
January	16%	0%	82%	21%
February	13%	0%	73%	21%
March	22%	1%	83%	24%
May	22%	0%	92%	49%



Additionally, to test the assumptions made in developing the probability of a tug being available and willing to assist (from Table 7), a more detailed examination of this factor was made. Two modifications to the development of this factor were made. First, the values of the probability of a tug being willing given that it is in a particular state (unladen, laden with petrochemical and laden with non-petrochemical tows) were changed to what is believed to be the extreme lower end of their potential values (75%, 0% and 10% respectively) as shown in Table 10. The results, as shown, indicate that overall, the probability of a tug being available and willing across segments is not very sensitive to this assumption. In individual segments, higher sensitivity was found, although with the plateauing shown in Figure 30 there was not a great deal of difference in the overall probability of at least one tug.

Table 10

	1	2	3	3W	3E	4	5	6	7	8	9
Unladen	14.7%	14.7%	51.3%	45.0%	56.0%	8.0%	26.1%	26.1%	44.0%	81.7%	42.2%
Laden With Petrochemical	35.1%	35.1%	20.0%	22.7%	18.1%	37.9%	30.4%	30.4%	23.1%	7.5%	23.8%
Laden With Non-Petrochemical	50.2%	50.2%	28.7%	32.3%	25.9%	54.1%	43.5%	43.5%	32.9%	10.8%	34.0%
Willing Given Unladen	75.0%										
Willing Given Laden with Petrochemical	0.0%										
Willing Given Laden with Non-Petrochemical	10.0%										
Weighting	2.5%	1.7%	9.5%	4.0%	5.4%	7.0%	9.8%	10.3%	10.5%	31.0%	8.2%
Available and Willing for Segment	16%	16%	41%	37%	45%	11%	24%	24%	36%	62%	35%
Weighted Probability	0.4%	0.3%	3.9%	1.5%	2.4%	0.8%	2.3%	2.5%	3.8%	19.3%	2.9%
Available and Willing Across Waterway	40.1%										

Second, these same probabilities were raised to what is believed to be the extreme high end of their potential values (100%, 20% and 67% respectively) as shown in Table 11. The results, as shown, indicate a similar degree of sensitivity found earlier in Table 10. Combined, these results (from Tables 10 and 11) closely bracket those found in Table 8, particularly given the dramatic changes in the willingness factors used.

Table 11

	1	2	3	3W	3E	4	5	6	7	8	9
Unladen	14.7%	14.7%	51.3%	45.0%	56.0%	8.0%	26.1%	26.1%	44.0%	81.7%	42.2%
Laden With Petrochemical	35.1%	35.1%	20.0%	22.7%	18.1%	37.9%	30.4%	30.4%	23.1%	7.5%	23.8%
Laden With Non-Petrochemical	50.2%	50.2%	28.7%	32.3%	25.9%	54.1%	43.5%	43.5%	32.9%	10.8%	34.0%
Willing Given Unladen	100.0%										
Willing Given Laden with Petrochemical	20.0%										
Willing Given Laden with Non-Petrochemical	67.0%										
Weighting	2.5%	1.7%	9.5%	4.0%	5.4%	7.0%	9.8%	10.3%	10.5%	31.0%	8.2%
Available and Willing for Segment	55%	55%	75%	71%	77%	52%	61%	61%	71%	90%	70%
Weighted Probability	1.4%	0.9%	7.1%	2.8%	4.2%	3.6%	6.0%	6.3%	7.4%	28.0%	5.7%
Available and Willing Able Across Waterway	73.5%										

Next, the results obtained from the overlay of vessel and tug data was tested with the tugs removed from the VTS data set, to determine the coverage levels for just deep draft traffic (and not including tugs). This eliminates approximately 59% of the vessels from the vessel data set. This deep draft data set (described as "With Tug Screening") was then run through the same analysis procedure as was done previously. The results are shown in Figure 33 for the full waterway.

Figure 33

			Segment #										
	Average	Average for 1, 2, 3W	1	2	3	3W	3E	4	5	6	7	8	9
Probability of a Vessel and No Tug	15.8%	15.7%	0.5%	0.0%	12.3%	46.6%	29.1%	64.1%	0.5%	12.1%	5.2%	0.0%	3.5%
Probability of a Vessel and Tug	34.0%	11.0%	0.0%	0.0%	83.9%	33.1%	51.5%	16.1%	0.0%	48.2%	83.9%	32.4%	25.1%
Probability of No Vessel	50.2%	73.3%	99.5%	100.0%	3.8%	20.3%	19.4%	19.9%	99.5%	39.7%	10.9%	67.6%	71.4%

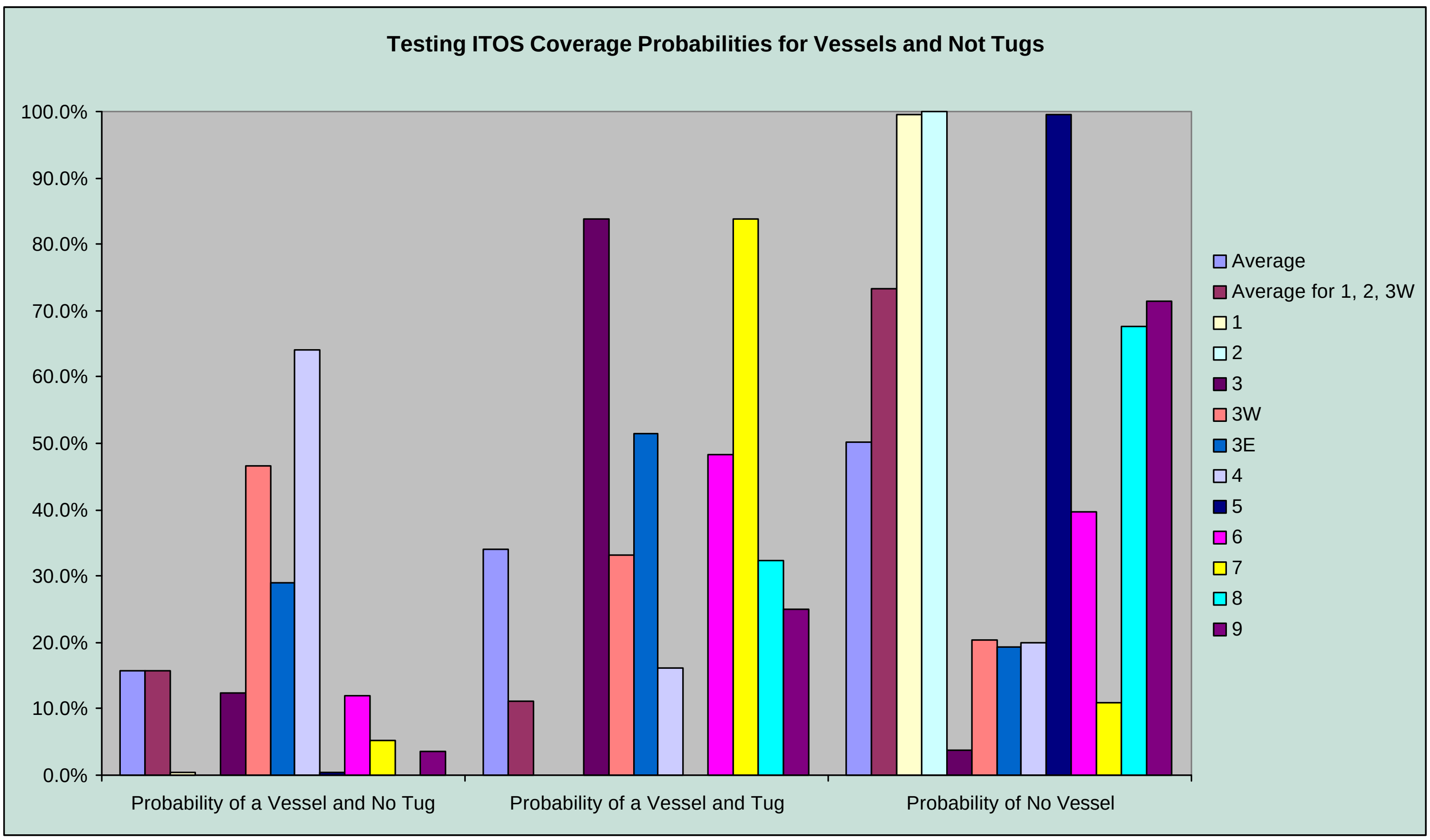


Figure 34 continues this review, by showing the average conditional probabilities of a tug or no tug given a vessel (across all segments and samples). Figure 35 gives this same information, but for the western waters only.

Figure 34

	Average Across All Segments Without Tug Screening	Average Across All Segments With Tug Screening
Probability of Tug Given a Vessel	95.8%	57.2%
Probability of No Tug Given a Vessel	4.2%	42.8%

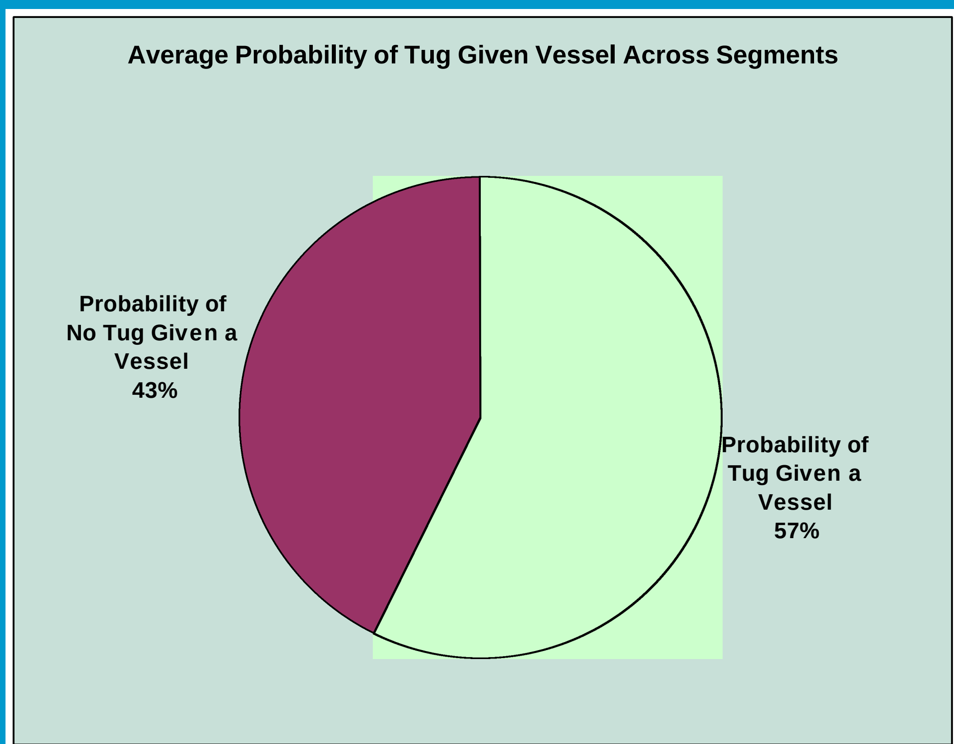
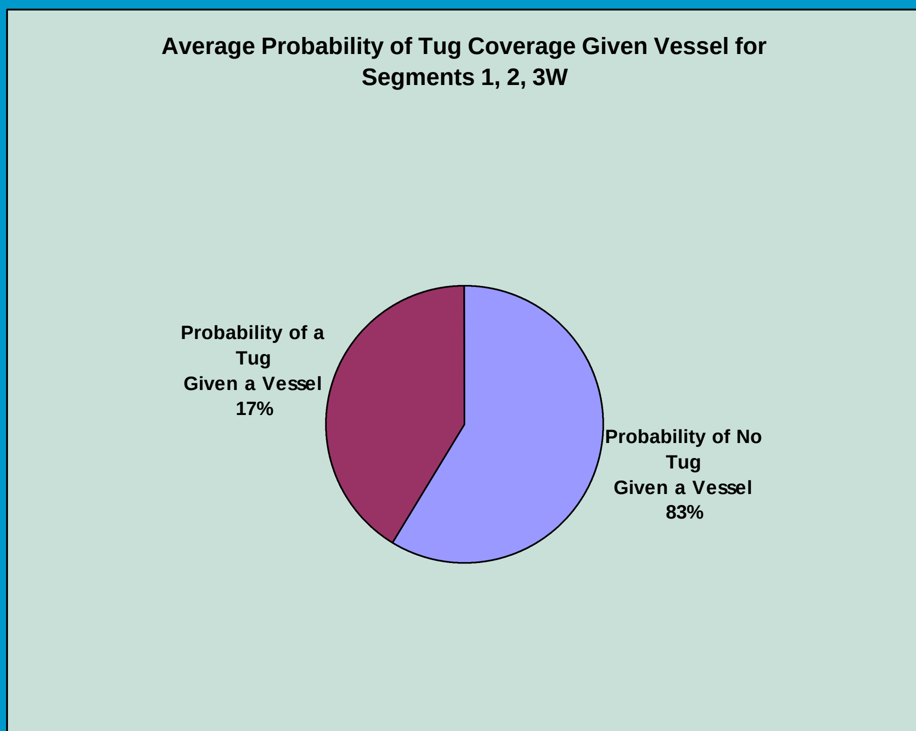


Figure 35

	Average Across Segments 1, 2 & 3W Without Tug Screening	Average Across Segments 1, 2 & 3W With Tug Screening
Probability of Tug Given a Vessel	82.0%	16.8%
Probability of No Tug Given a Vessel	18.0%	83.2%

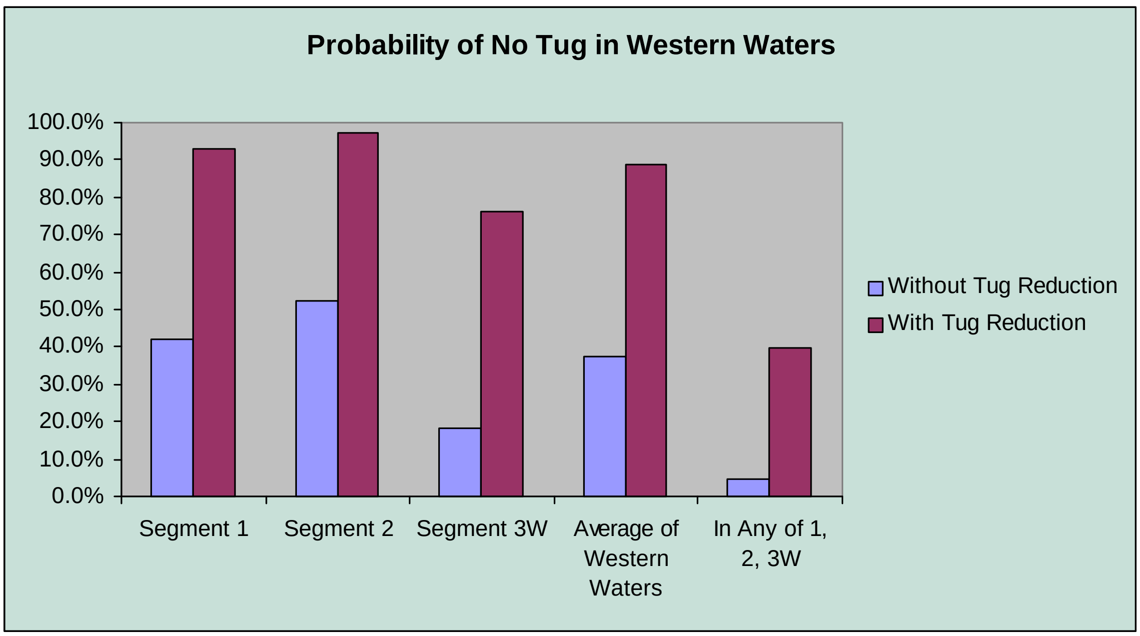


As can be seen by comparing these results to those obtained previously (Figures 28 and 29), the removal of the tugs from the vessel data set had some impact on the results. However, given that the magnitude of the difference across the waterway, and given that ITOS does provide the ability to respond to all vessels and not just deep draft, the results obtained with the tugs included were used.

Next, a check the validity of the results obtained for the probability of tug coverage for those times where a vessel was present in the western waters (from Figure 29) was made. This was viewed as an important check, as VTS Puget Sound data set indicated a relatively high probability (69%) of no vessel in these western waters, given that part of these waters fall in the MCTS Tofino AOR. Therefore, the conditional probability from Figure 29 was based on 131 of the 423 samples. To address this, two bounds on the probability of ITOS being effective were determined. First, for the lower bound, the probability of vessel and no tug can be estimated to be at worst equal to the probability of no tug (this assumes that the two are perfectly negatively correlated, i.e., that whenever a vessel is present there can be no tug and vice versa). Using this very conservative estimate, the probability of vessel and no tug can be set as being at most

41.5% for segment 1 (93.1% with tug reduction), and 54.6% for segment 2 (97.4% with tug reduction). This is illustrated in Figure 36. The results for the western portion of the Strait of Juan de Fuca (which were calculated directly and not estimated as for segments 1 and 2) indicate that the conditional probability of no tug given a vessel can be set at 18.0% (57.1% with tug reduction). Averaging across all three segments, the probability of a tug given a vessel can be estimated as 17.5%. Second, and as the best case, the assumption regarding the inability of a tug in one segment to provide coverage for adjacent segments can be relaxed in these outer waters (which is perhaps more representative, given the longer response times found here). Using this approach, which combines segments 1, 2 and 3W, the probability of at least one tug in any of these three regions was determined to be approximately 95.3% without the tug reduction factor and 60% with the tug reduction. Again, as noted, this provides the worst case for the probability of ITOS not being effective in these western waters.

Figure 36



Taking these results and comparing them to those obtained in Figure 28, it can be seen that the probability of no tug given a vessel from Figure 28 (42.7%) lies notably below the midpoint of the two bounds (26.8% and 80.2% with tug reduction) and is therefore determined to be conservative based upon available information. Additionally, the coverage rate for segment 3W (for which VTS Puget Sound data are available), which all non-coastwise through traffic in the offshore region must pass through, was 42.9% with tug reduction. The combination of all these facts led to a high degree of confidence in the results obtained in Figure 28, and therefore those original results were retained.

In summary, the assumptions used in this report and their projected effect are recaptured in Table 12. Overall, these assumptions are almost uniformly conservative (i.e., work to underestimate the effectiveness of ITOS). Altogether, the assumptions are believed to be very conservative, especially with regard to assumption #2. As such, the effectiveness of ITOS as previously outlined is believed to underestimate the actual effectiveness of this system. However, to restate what was covered in the introduction; the primary focus of this study was on the geographic uncertainty associated with ITOS (i.e., what level of coverage does it provide in the various portions of the Puget Sound area waterway). This study does not evaluate the effectiveness of the ITOS tugs to hook up to a vessel in distress, nor their ability to slow the drift rate of a vessel in distress under varying conditions.

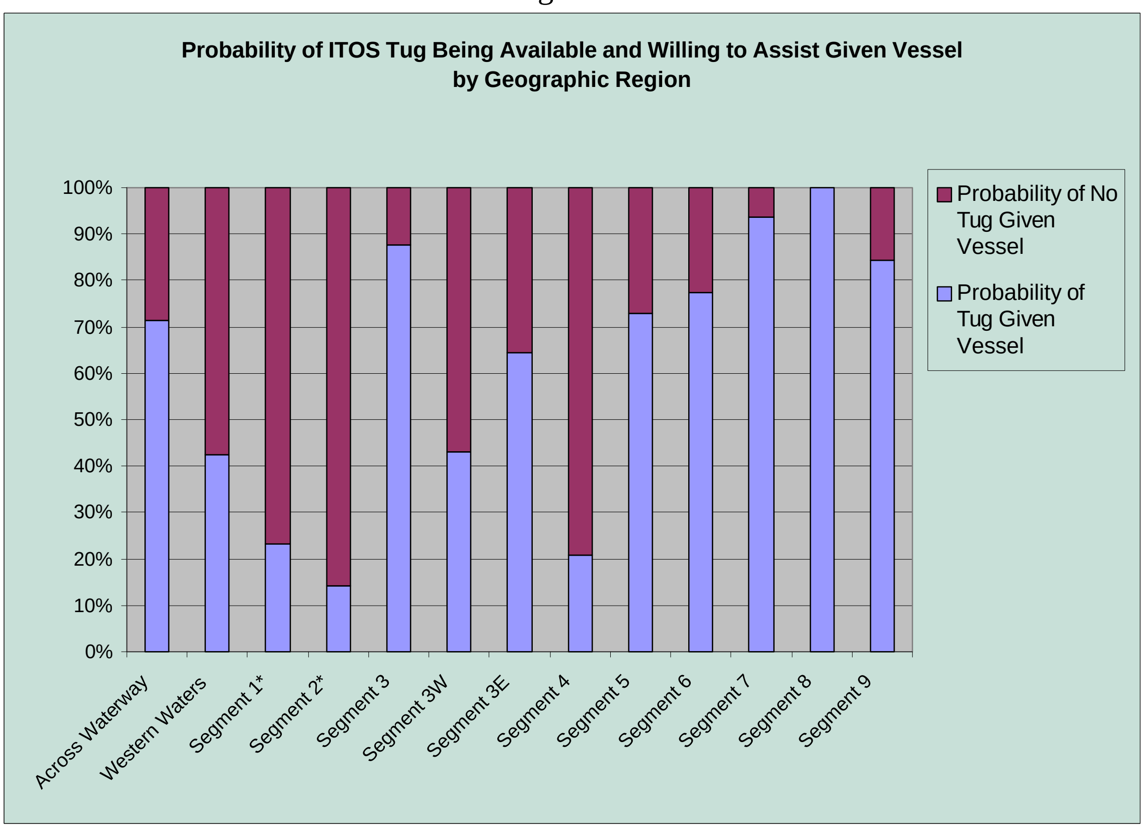
Table 12: Summary of Assumptions and Effect

Assumption	Effect
1. Tugs in the same segment as a vessel are able to assist before the drifting vessel will ground.	This assumption, with the subdivision of segment 3, is likely to be fairly accurate for most cases; more so for the western waters, where the time to ground is longer, than for the more restricted eastern waters. At worst case, this might slightly overestimate the effectiveness of ITOS.
2. Tugs not in the same segment as a vessel are not able to assist before the drifting vessel will ground.	This assumption was shown to be very conservative in Figure 29, particularly for the western waters, where longer response times would allow a vessel in one segment to come to the aid of a vessel in distress in another segment.
3. The average probability of a tug being willing can be applied to each sample (i.e., the tug's willingness is independent of the particular sample).	The effect of this assumption is unclear, but is likely to have no influence on the accuracy of the evaluation of ITOS' overall effectiveness.
4. The conditional probability of a tug being laden with petrochemical or non-petrochemical tow given that it is laden is governed by the distribution obtained from the Canadian data in Table 7.	While this assumption is known to be accurate for the western waters, it is believed to over-estimate the probability that a tug is laden with a petrochemical tow. Checking this assumptions against the traffic analysis performed as part of the Volpe study cited previously, it was determined that this assumption may overstate this probability by as much as 9 times the actual value. As such, this assumption is believed to be very conservative.
5. The probability of there not being a tug given a vessel in the western segments is approximated by the probability of there not being a tug in these same segments.	In order for this assumption to overestimate the effectiveness of ITOS, the presence of tugs and vessels by segment would have to be negatively correlated (i.e., the presence of a vessel makes it less likely for their to be a tug and vice versa). As this is highly unlikely (in fact, if anything, the opposite is believed to be true), the net effect is to underestimate the effectiveness of ITOS.

7. Conclusion

In summary, the International Tug of Opportunity System was found, as characterized in the original report to Congress, to provide an incremental improvement to the existing marine safety system. As previously stated, this system is intended to provide additional protection against the risk of drift grounding, which is approximately 15% of the risk for the waterway (22% for the Strait of Juan de Fuca and offshore approaches). In the Strait of Juan de Fuca and offshore approaches, this probability of a vessel being covered by a tug was estimated at 42.5% across the western region. Overall, ITOS was found to provide a tug in the same segment 71.3% of the times where vessels were present. This difference in the western waters is believed to be attributable to fewer tugs and the fact that most tugs in this area are in transit with tow. These results are shown in Figure 37. The asterisks shown in Figure 37 denote the fact that these figures represent the probability of an ITOS tug being available and willing, and therefore underestimate the effectiveness of ITOS. These probabilities use the screening factor for tug willingness shown in Table 8. Additionally, these probabilities use the assumptions shown in Table 12, which were collectively determined to be very conservative. Finally, neither the probability of at least one tug nor the probability of at least one vessel in a given region at a given time was seen to vary significantly on a monthly basis, i.e., there is no seasonality to these distributions.

Figure 37



The level of risk reduction provided by ITOS is thus determined by applying the probability of a tug given a vessel in distress (from Figures 28 and 29) to the percent of the overall risk of oil spill due to drift grounding (15% across the waterway, and 22% for the western waters, from the Additional Hazards Study previously cited). This makes the assumption that those tugs that are available and willing are also able to hook up to and slow the drift rate of the vessel in distress. The results, as shown in Table 13, show that ITOS eliminates approximately 11% of the risk of a significant oil spill throughout the region (9% for the offshore approaches).

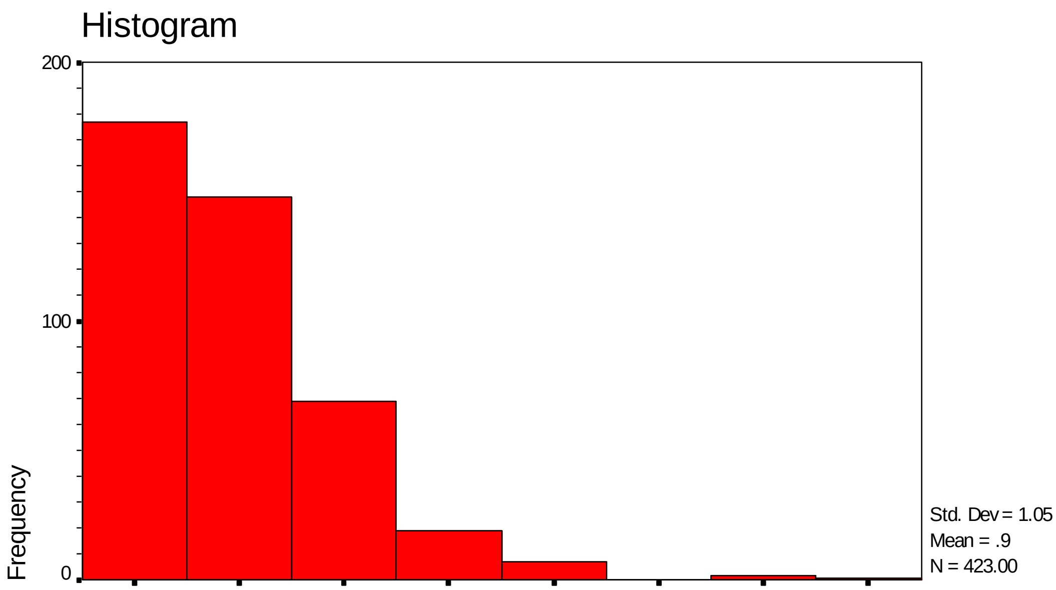
Table 13: Determination of ITOS Risk Reduction

	Percent of Risk Posed by Drift Grounding	Risk Eliminated by ITOS
Across Waterway	15%	11%
In Western Waters	22%	9%

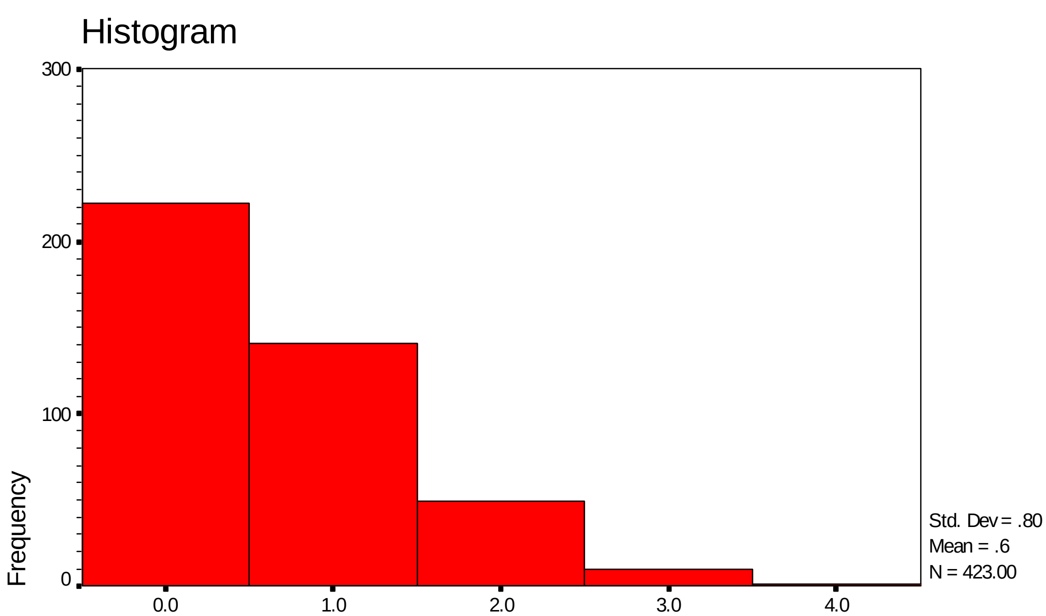
Note regarding additional data collection:

As noted in the introductory portions of this report, this study was intended to provide a preliminary analysis of the level of risk reduction provided by ITOS. This review will continue throughout the remainder of the year, allowing for more data to be collected, and for a more detailed evaluation of the probability of a tug being able to rescue a vessel in distress. However, it should be noted that no changes to the overall results are expected, given the lack of variation or trend by month. Further evaluations currently envisioned include a matching of tugs from the Marine Exchange data set to tugs in the VTS system, to perform a more detailed screening of tug availability, as well as a matching of tugs to vessels. This will be done to determine the probability of making a save on a per vessel basis. Essentially, for each vessel in the VTS, the evaluation will determine what is the probability that at least one of the ITOS tugs could reach the vessel in a time less than or equal to the response times established in the report to Congress.

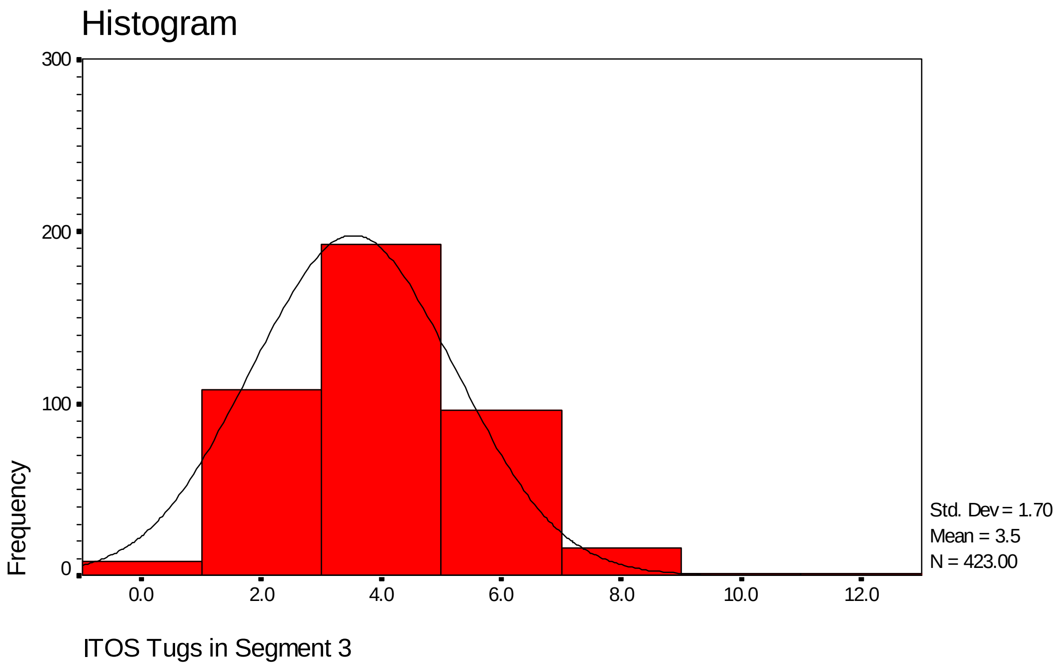
Appendix I
Histograms for ITOS Tug Distributions by Segment

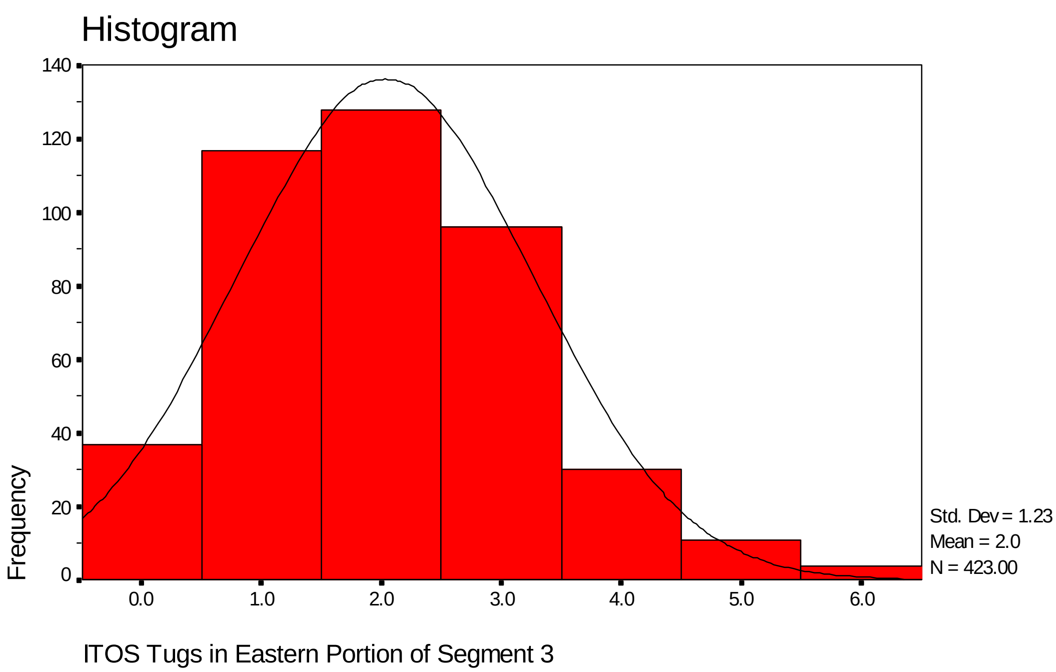


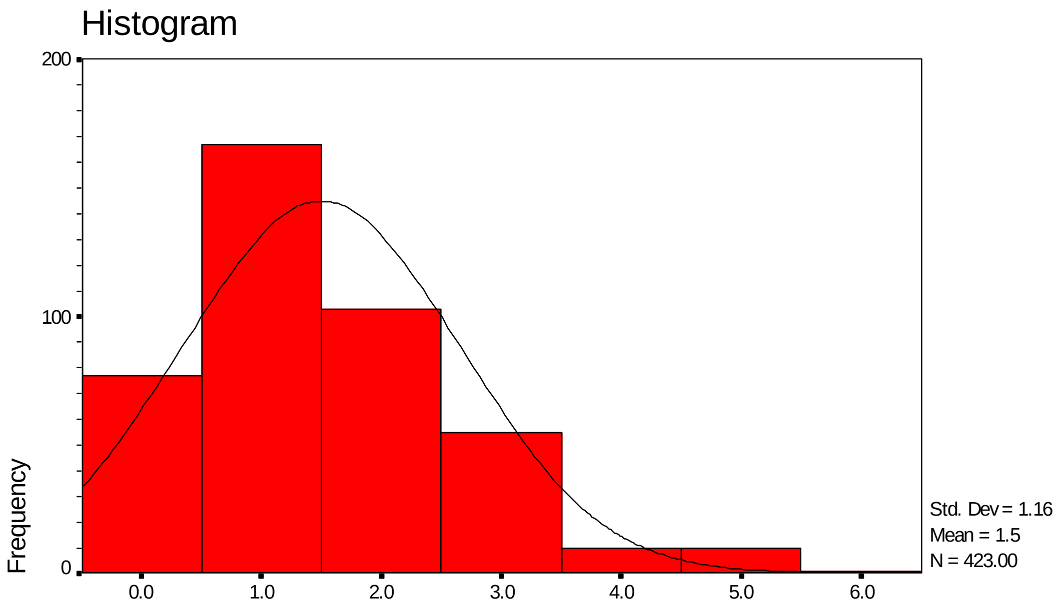
ITOS Tugs in Segment 1



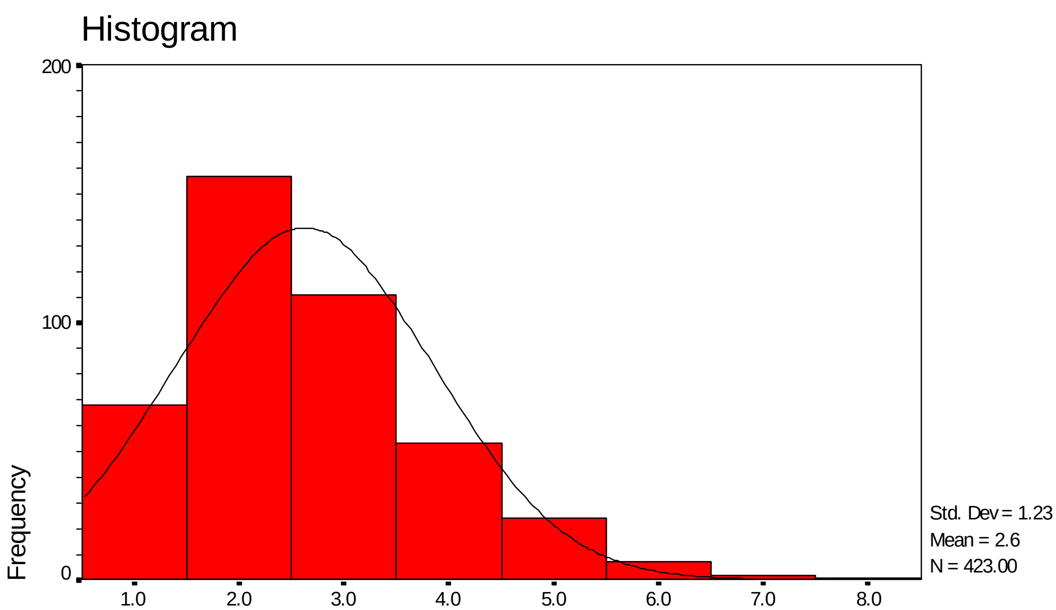
ITOS Tugs in Segment 2


Histogram
300
200
100
0
Frequency
0.0
2.0
4.0
6.0
8.0
10.0
12.0
Std. Dev = 1.70
Mean = 3.5
N = 423.00
ITOS Tugs in Segment 3

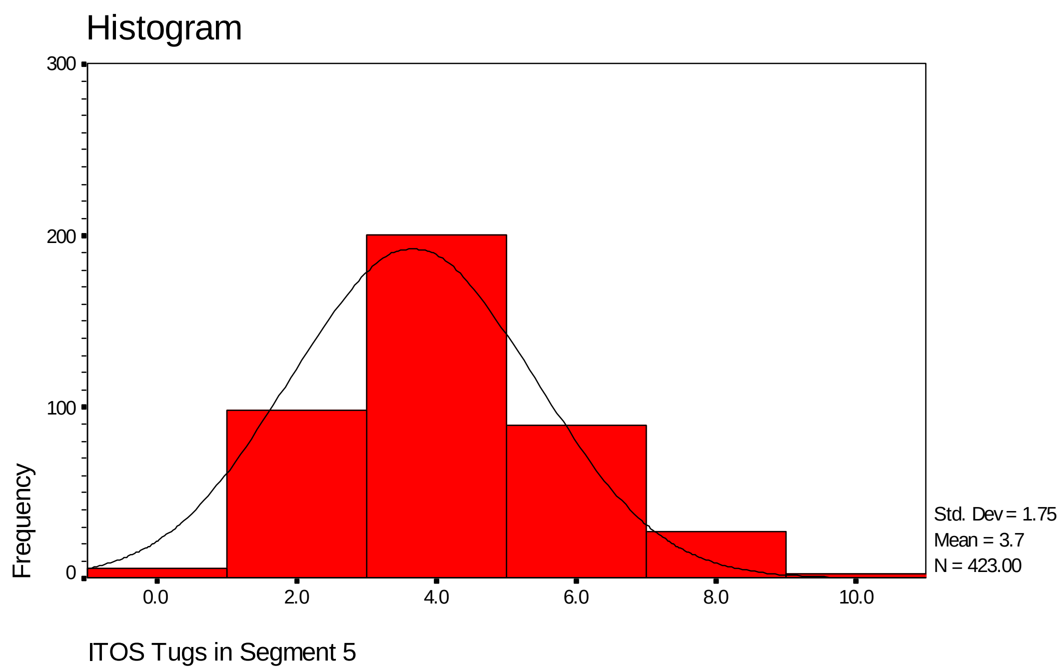

Histogram
140
120
100
80
60
40
20
0
Frequency
0.0
1.0
2.0
3.0
4.0
5.0
6.0
Std. Dev = 1.23
Mean = 2.0
N = 423.00
ITOS Tugs in Eastern Portion of Segment 3

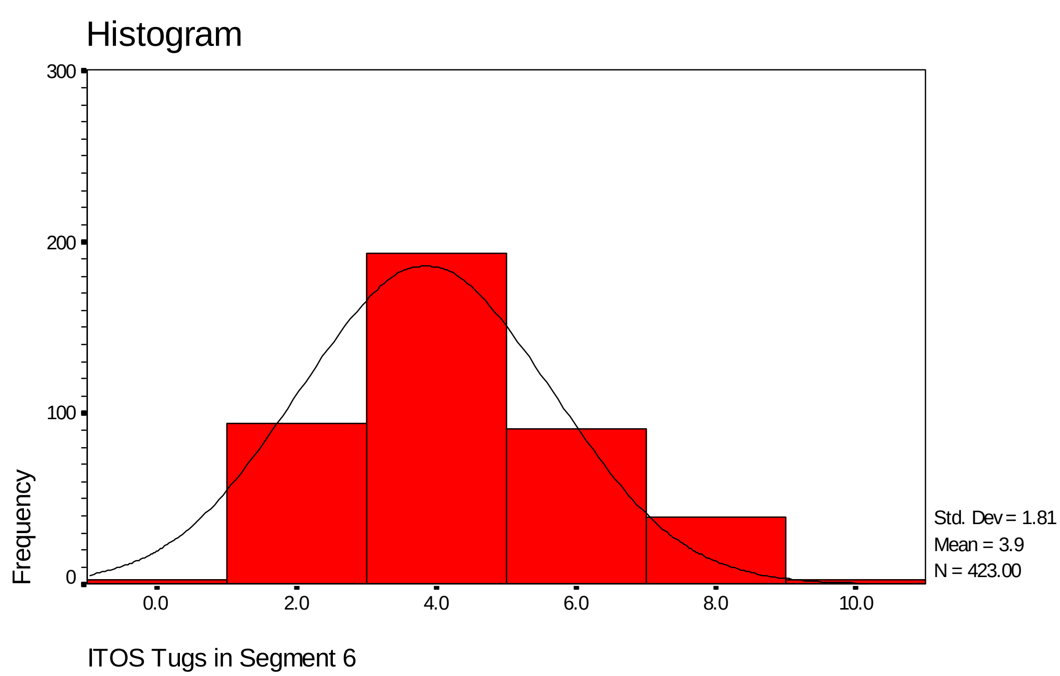


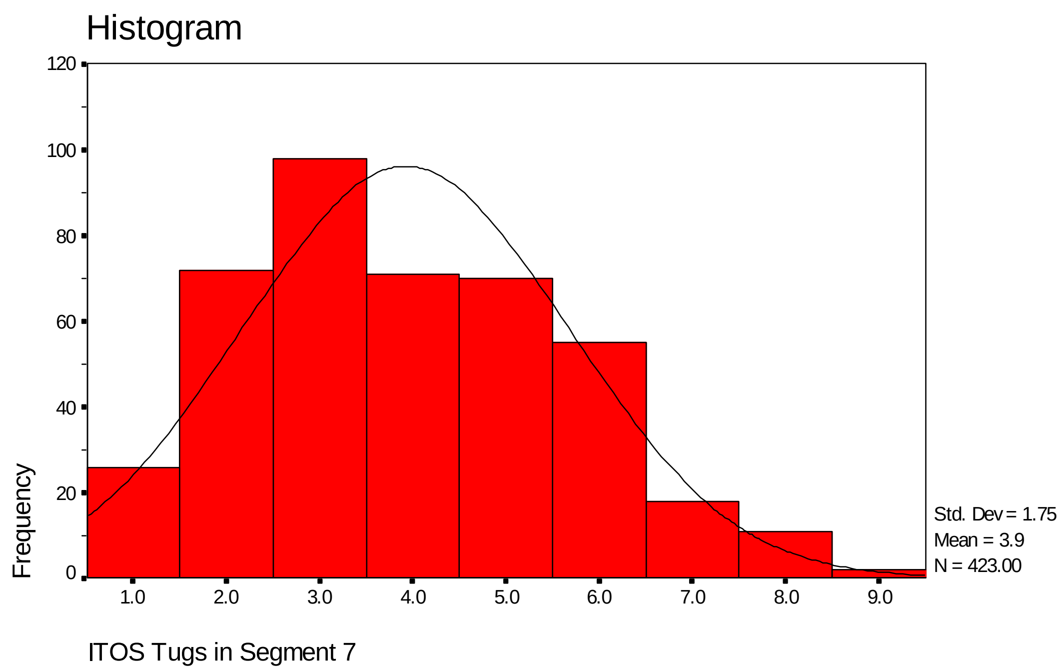
ITOS Tugs in Western Portion of Segment 3

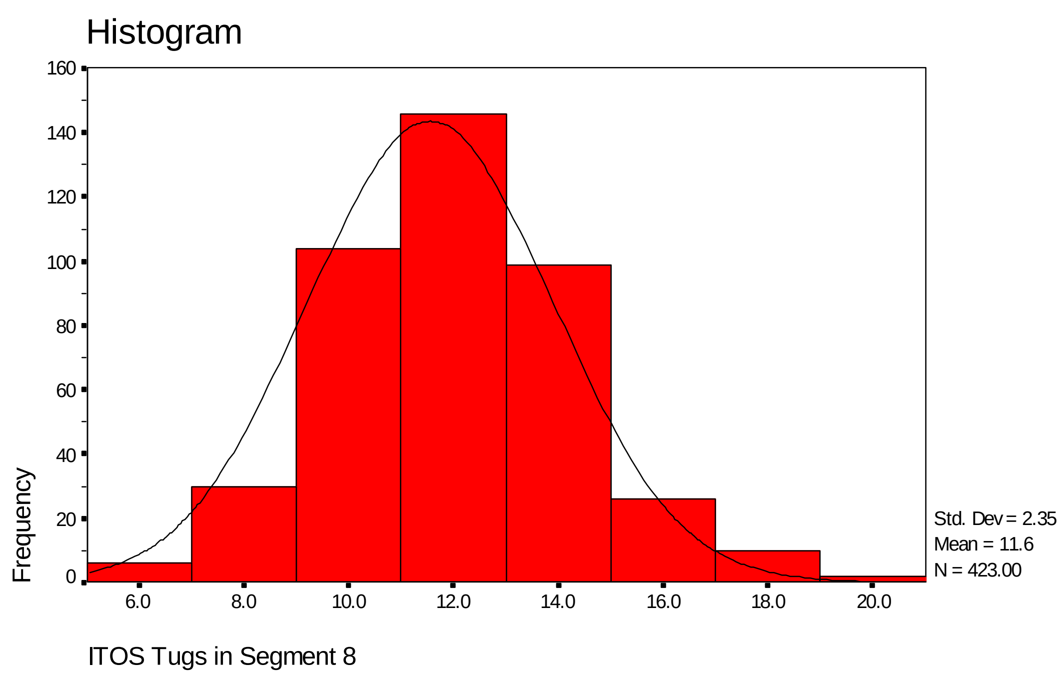


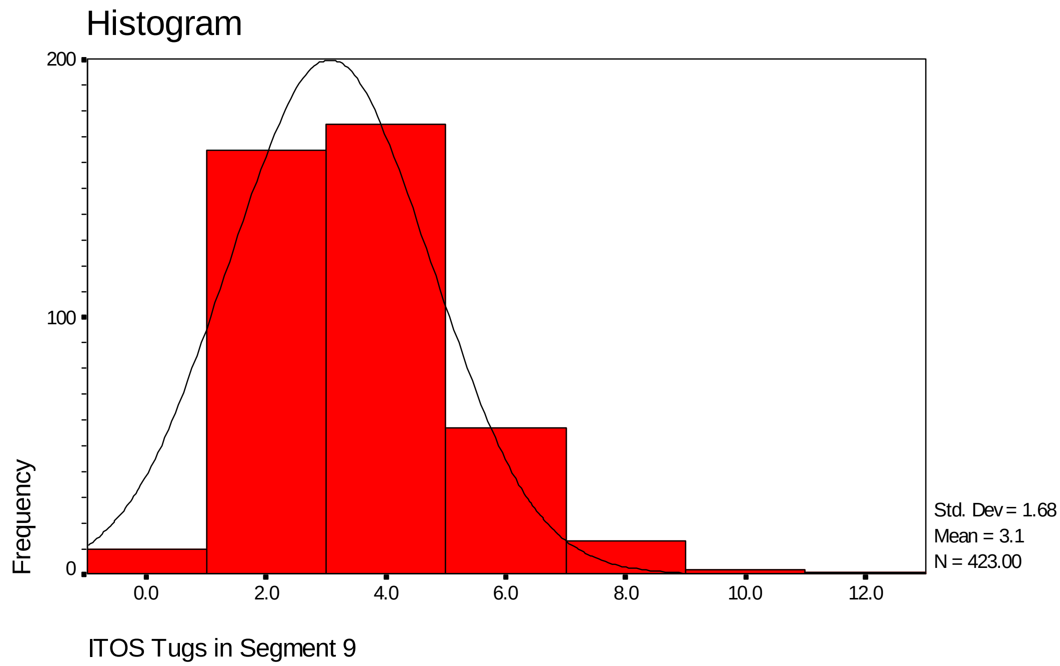
ITOS Tugs in Segment 4


Histogram
300
200
100
0
Frequency
0.0
2.0
4.0
6.0
8.0
10.0
Std. Dev = 1.75
Mean = 3.7
N = 423.00
ITOS Tugs in Segment 5


Histogram
300
200
100
0
Frequency
0.0
2.0
4.0
6.0
8.0
10.0
Std. Dev = 1.81
Mean = 3.9
N = 423.00
ITOS Tugs in Segment 6

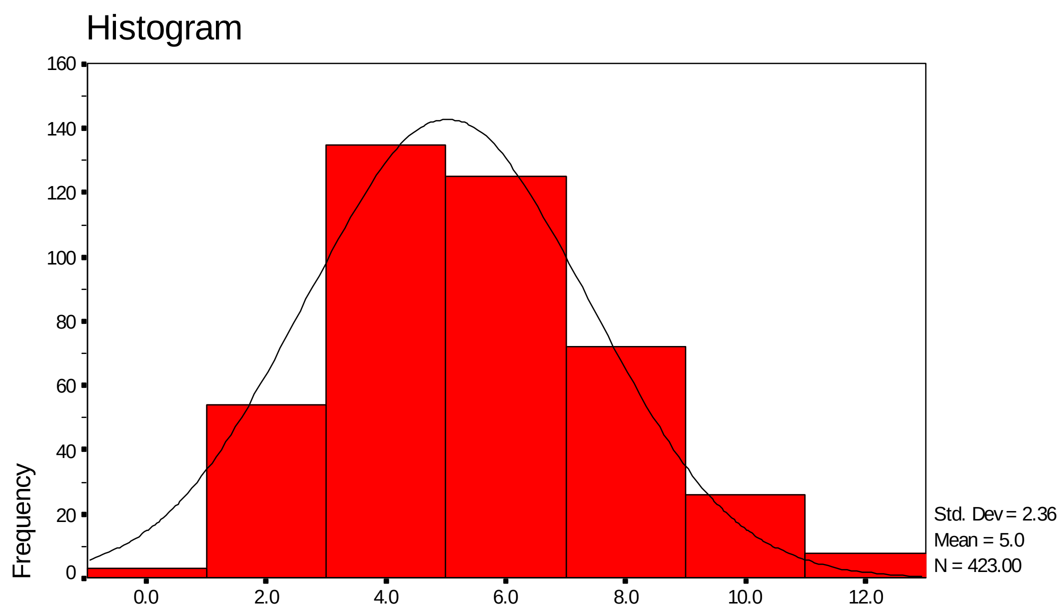

Histogram
120
100
80
60
40
20
0
Frequency
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
Std. Dev = 1.75
Mean = 3.9
N = 423.00
ITOS Tugs in Segment 7


Histogram
160
140
120
100
80
60
40
20
0
Frequency
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
Std. Dev = 2.35
Mean = 11.6
N = 423.00
ITOS Tugs in Segment 8

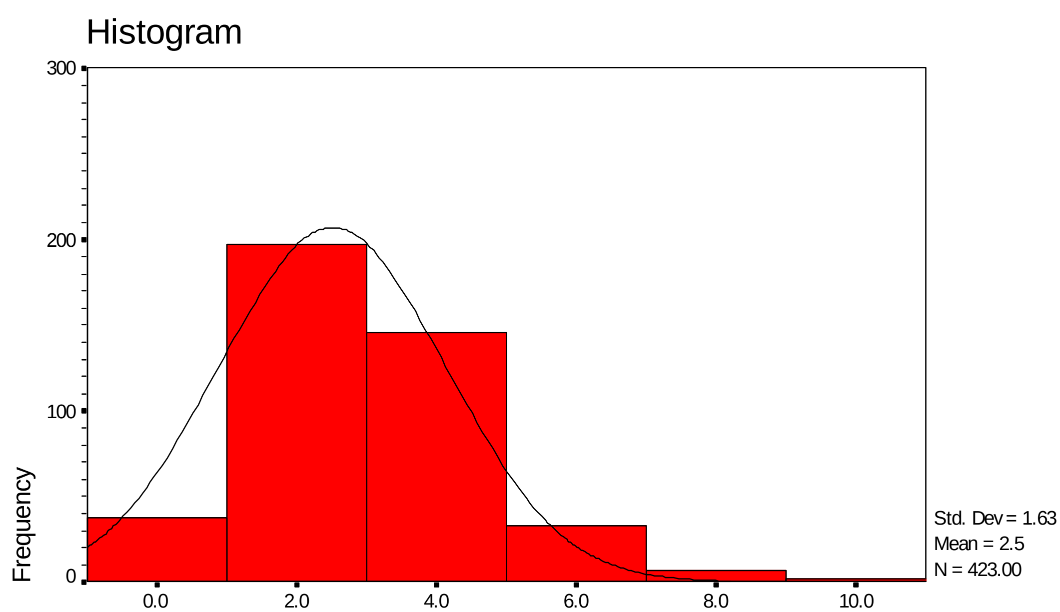


Histogram
200
100
0
Frequency
0.0
2.0
4.0
6.0
8.0
10.0
12.0
ITOS Tugs in Segment 9
Std. Dev = 1.68
Mean = 3.1
N = 423.00

Appendix II
Histograms for Vessel Distributions by Segment

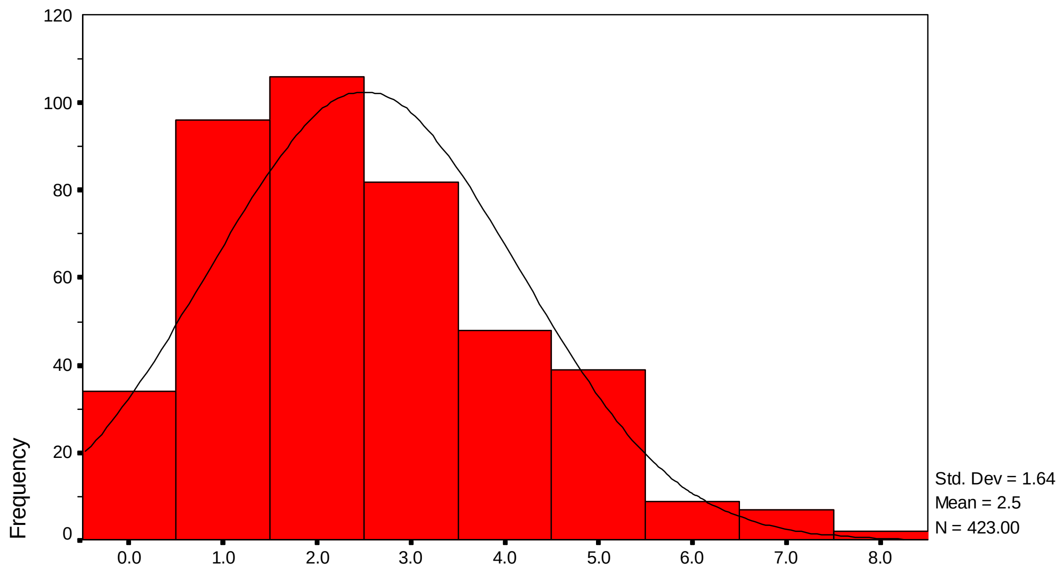


Vessels in Segment 3



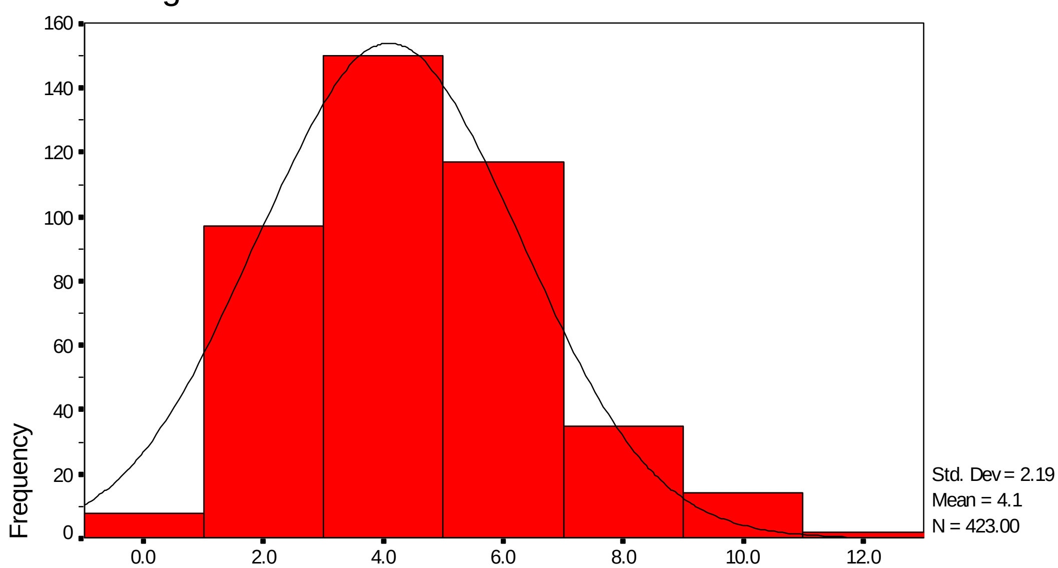
Vessels in Eastern Portion of Segment 3

Histogram

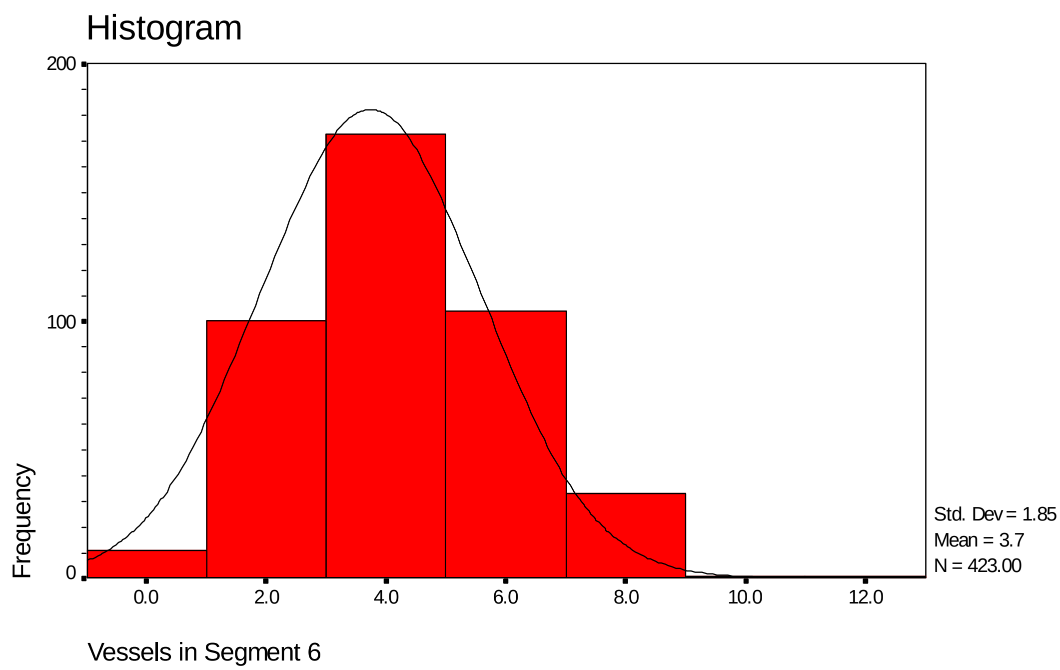


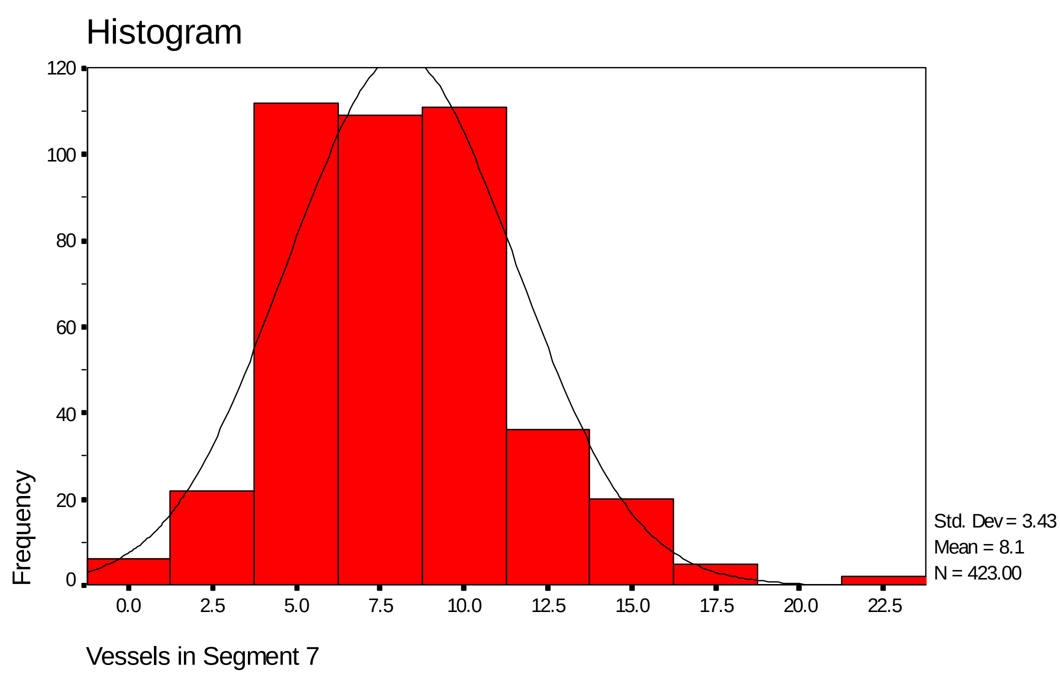
Vessels in western portion of segment 3

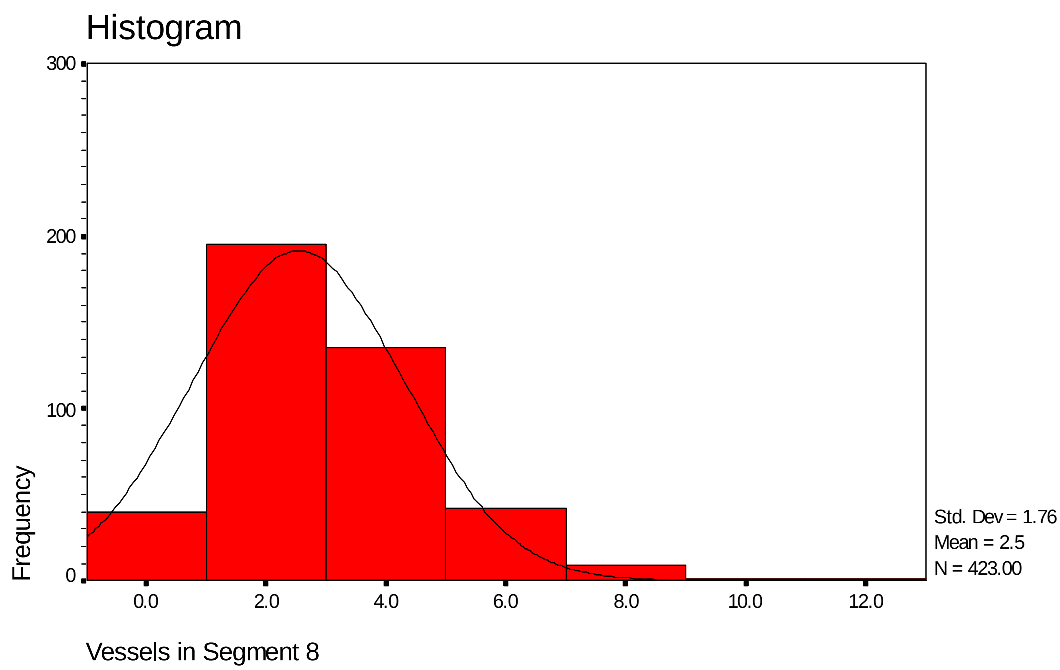
Histogram

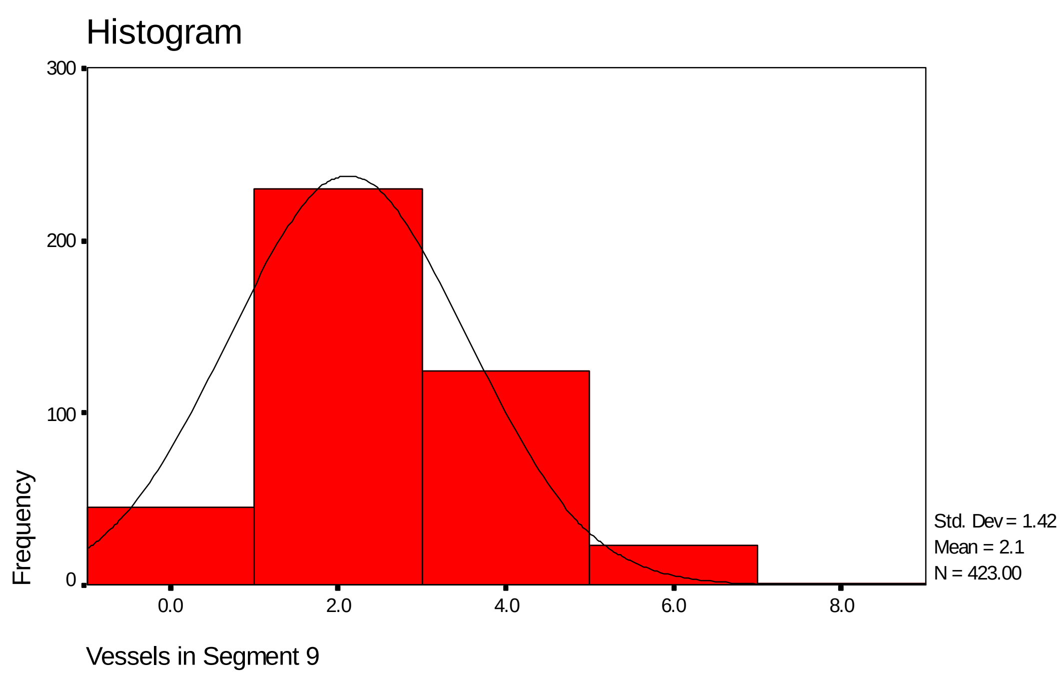


Vessels in Segment 4


Histogram
200
100
0
Frequency
0.0
2.0
4.0
6.0
8.0
10.0
12.0
Std. Dev = 1.85
Mean = 3.7
N = 423.00
Vessels in Segment 6


Histogram
120
100
80
60
40
20
0
Frequency
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
Std. Dev = 3.43
Mean = 8.1
N = 423.00
Vessels in Segment 7


Histogram
300
200
100
0
Frequency
0.0
2.0
4.0
6.0
8.0
10.0
12.0
Std. Dev = 1.76
Mean = 2.5
N = 423.00
Vessels in Segment 8


Histogram
300
200
100
0
Frequency
0.0
2.0
4.0
6.0
8.0
Std. Dev = 1.42
Mean = 2.1
N = 423.00
Vessels in Segment 9

Appendix III
Integration with U.S. Navy
Dedicated Rescue Tug Exercise

In addition to the analyses described above, the data from the drills with the U.S. Navy contracted tug at Neah Bay were analyzed. The Navy contracted for a tug during the months of March and April to assist with the ongoing evaluation of a dedicated rescue tug in the region. Over 100 drills were conducted over the 2 month period, primarily responses to locations in various portions of the western waters. This series of exercises provides the ability to compare the risk reduction of a dedicated rescue tug to ITOS by comparing coverage at or near the time of the drill. As shown in Table 24 below, for each of the drills held in March, there was at least one ITOS tug in the vicinity (defined as waters west of the mid-Strait region). On average (many of the drills occurred between ITOS samples, in which case the average number of tugs in each of the two adjacent samples from the ITOS data was used), there were between three and four tugs operating in these western waters at the time of the drill. To determine the effect of the tug being potentially unable (due to being encumbered with a petrochemical tow) and/or unwilling to respond, the data from the Canadian Coast Guard were used to determine the probabilities of a vessel being unencumbered or encumbered with petrochemical tow, as was done previously. This probability was then applied to the number of tugs indicated in the ITOS system to discount those tugs that would be unwilling and/or unable to aid a vessel in distress. The results are shown in the fourth column of the following table. As can be seen from this admittedly limited number of trials, even discounting these potentially unwilling and/or unable tugs, on 88% of these occasions, there would have been at least one ITOS tug available to render assistance in these western waters.

Number of ITOS Tugs Available,
Willing and Able to Assist during Navy Tug Exercises

DATE	EVENT #	Average # ITOS Tugs Available in Segments 1, 2 & 3W	# ITOS Tugs Available and Willing to Assist
3/2/99	01	5	2.0
3/4/99	02	4.5	1.8
3/6/99	03	3.5	1.4
3/9/99	04	1.5	0.6
3/11/99	031105	5	2.0
3/14/99	0314-02	4.5	1.8
3/16/99	031608	3.5	1.4
3/18/99	S-031809	2	0.8
3/19/99	031910	4	1.6
3/20/99	032011	2.5	1.0
3/21/99	CMS-4	3	1.2
3/21/99	CMS-5	3.5	1.4
3/22/99	032212	4.5	1.8
3/23/99	CMS-6	3	1.2
3/23/99	CMS-7	3.5	1.4
3/23/99	CMS-8	3.5	1.4
3/23/99	S-03231323	3.5	1.4
3/25/99	CMS-11	4	1.6
3/25/99	CMS-12	4	1.6
3/25/99	S0325-01	3.5	1.4
3/26/99	CMS-14	5.5	2.2
3/26/99	032615	5.5	2.2
3/26/99	CMS-15	4	1.6
3/27/99	CMS-16	2.5	1.0
3/28/99	032816	3	1.2
3/28/99	CMS-17	3	1.2
3/28/99	CMS-18	3	1.2
3/28/99	Actual	3	1.2
3/30/99	033017	4	1.6
3/31/99	CMS-25	4	1.6
3/31/99	CMS-26	3.5	1.4
3/31/99	CMS-27	3.5	1.4