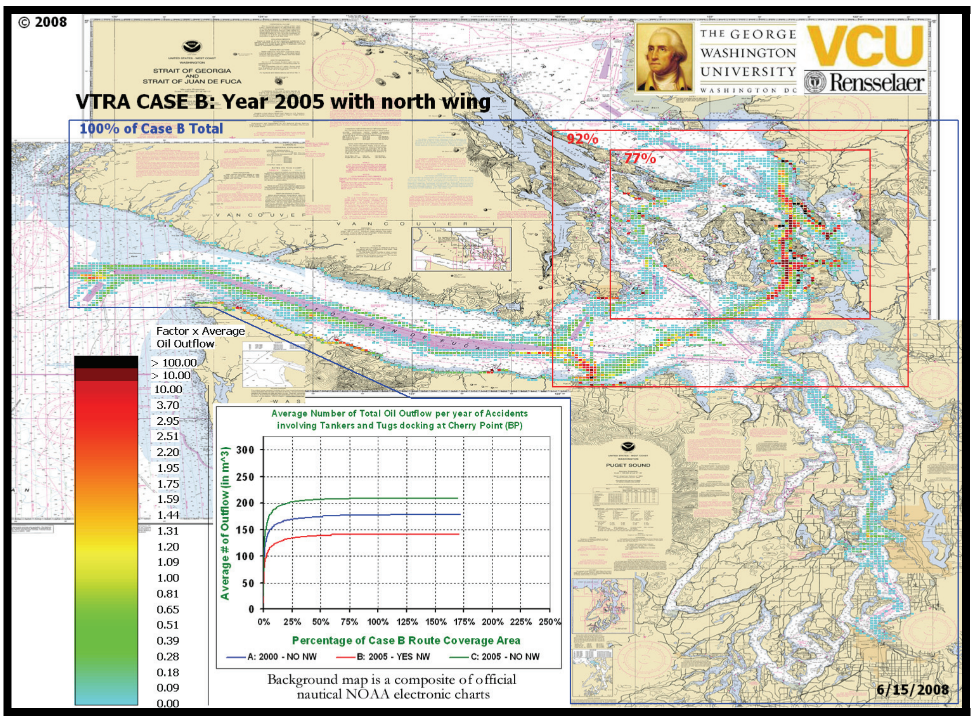
TECHNICAL APPENDIX C: SIMULATION CONSTRUCTION



Assessment of Oil Spill Risk due to Potential Increased Vessel Traffic at Cherry Point, Washington

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C-1. VTS Traffic Modeling

In 1979 by formal agreement, the Canadian and the United States Coast Guards established the Co-operative Vessel Traffic System (CVTS) for the Strait of Juan de Fuca region. The purpose of the CVTS is to provide for the safe and efficient movement of vessel traffic while minimizing the risk of pollution by preventing collisions and groundings and the environmental damage that would follow.

C-1.1. The Vessel Traffic Operation Support System (VTOSS) repository

Within our study area, vessels are tracked by multiple VTS centers, including those at Tofino, Vancouver, and Victoria for the Canadian Coast Guard and Seattle for the US Coast Guard. Tofino Traffic provides VTS for the offshore approaches to the Juan de Fuca Strait and along the Washington State coastline from 48 degrees north. Seattle Traffic provides VTS for both the Canadian and US waters of Juan de Fuca Strait and Victoria Traffic provides VTS for both Canadian and US waters of Haro Strait, Boundary Passage, and the lower Georgia Straits. Figure C-1 shows the breakdown of the areas of responsibility in the shared areas. Seattle VTS is also responsible for all areas south of those marked.

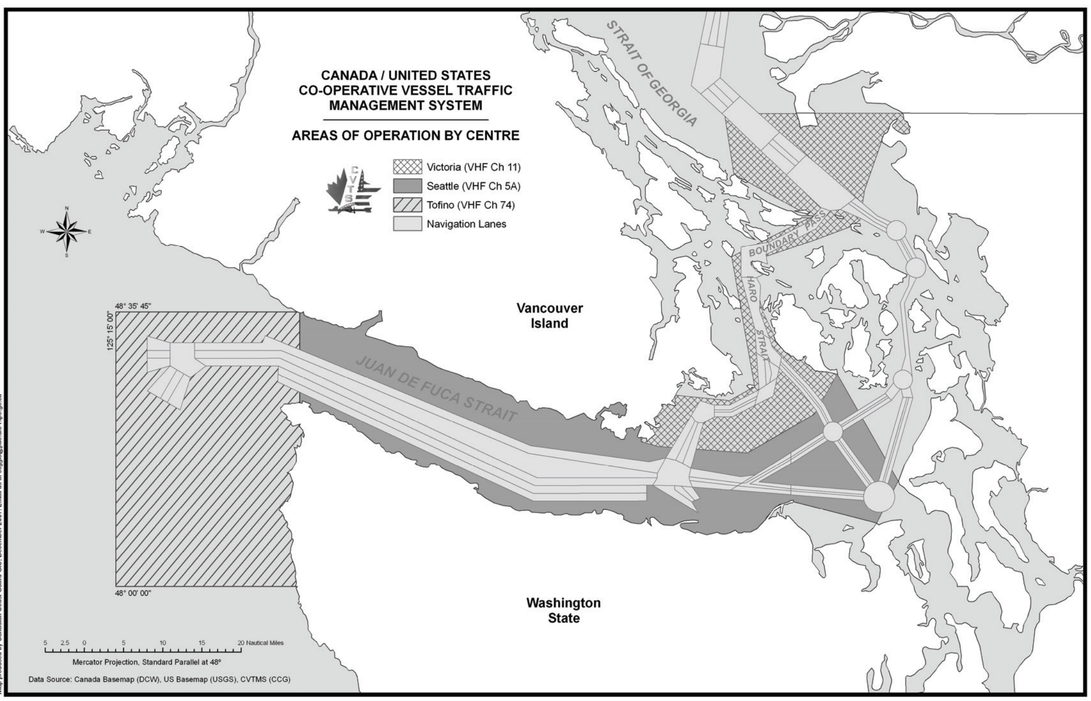

Figure C-1. The Cooperative Vessel Traffic Management System.

The requirements for a vessel to report to the VTS are:

(a) Every power-driven vessel of 40 meters (approximately 131 feet) or more in length, while navigating;

(b) Every commercial towing vessel of 8 meters (approximately 26 feet) or more in length, while navigating;

(c) Every vessel certificated to carry 50 or more passengers for hire, when engaged in trade.

The VTS records the transit and also monitors the movement of vessels on screens in their operating center. Each VTS receives radar signals from strategically located radar sites throughout their defined area of responsibility. Additionally, close circuit TV provides coverage of various critical waterways. The newest ship location technology is the Automatic Identification System (AIS).

Table C-1. A sample of records from the VTOS database.

TK041101														
LAST_UDDTG	VSL_ID	NAME	CALLSIGN	LLOYDS_ID	FLAG	TYPE_DEC	POS_LAT	POS_LONG	COURSE	SPEED	POS_SRC	CVTS_ZONE	FROM_AT	NEXT_TO
200405311538	VSSL20010321162640	GOA	VTST	8511665		BULK CARRIER	48.278	123.42	19	12.7	RDR	VIC	PORTL	CONST
200405311538	VIC720010925142443	HECATE PRINCE	CY7049	0320279	CA	TUG	49.42	123.765	116	4	RDR	VIC	PEARS	NORTH
200405311538	CSTL19931231000526	EVCO SPRAY	CY8295	0323624	CA	TUG	49.683	124.55	0	0	MAN	VIC	BEALE	TILBU
200405311538	UNK120040507103108	VICTORIA EXPRESS II	WDB6455		US	FERRY	48.43	123.357	0	0	RDR	VIC	VICTO	
200405311538	CSTL19931231002612	COMOX CROWN	CZ4330	0348790	CA	TUG	49.158	123.498	252	6	RDR	VIC	VANCO	CROFT
200405311538	CSTL19940124102341	QN OF OAK BAY	VG8234	7902283	CA	FERRY	49.258	123.687	74	20.5	RDR	VIC	DEPAR	HORSE
200405311538	CSTL19940112170039	COHO	WN4599	5076949	US	FERRY	48.342	123.392	166	13.9	RDR	VIC	VICTO	PORT
200405311538	VIC620010513123854	ISLAND EXPLORER 2	WDCS		US	MISCELLANEOUS	48.85	123.192	112	14.2	RDR	VIC	ANACO	ANACO
200405311538	CSTL19931231001069	PERSUADER			CA	TUG	48.585	123.278	0	0	RDR	VIC	D ARC	
200405311538	CSTL19931231002350	SS MONARCH	VY7687	7636028	CA	TUG	49.128	123.06	0	0	MAN	VIC	VANCO	BISHO
200405311538	TOF119991226223416	GANGES HAWK			CA	MISCELLANEOUS	48.71	123.398	191	16.9	RDR	VIC	MINER	SWART
200405311538	VSSL19961029133558	SCHOLARSHIP		0809734	CA	MISCELLANEOUS	48.852	123.485	0	0	MAN	VIC	GANGE	PORT
200405311538	CSTL19931231002357	SS NAVIGATOR	VDPW	7043324	CA	TUG	49.308	123.452	293	8.4	RDR	VIC	NORTH	ALASK
200405311538	CSTL19931231002375	SS VICTOR	VDPB	7041247	CA	TUG	49.282	123.712	52	4.1	RDR	VIC	GABRI	WOODF
200405311538	CSTL19931231002338	SS CHAMPION	VDPS	7041235	CA	TUG	49.732	124.777	0	0	MAN	VIC	NODAL	VANCO
200405311538	CSTL19931231002348	SS FOAM	CY9631		CA	TUG	48.42	123.393	0	0	RDR	VIC	PRODU	VICTO
200405311538	CSTL19931231002320	NA CHAMPION	CFC6672	7406681	CA	TUG	49.148	123.03	0	0	MAN	VIC	LAFAR	STEVE
200405311538	CSTL19940124101906	QN OF COQUITLAM	CZ8058	7411155	CA	FERRY	49.293	123.47	267	21.2	RDR	VIC	HORSE	DEPAR
200405311538	CSTL19931231002373	SS VALIANT	CY9526	7005889	CA	TUG	49.458	124.127	0	0	RDR	VIC	BLIND	GABRI
200405311538	CSTL19931231002351	SS KING	VGXJ	6823052	CA	TUG	49.402	123.457	0	0	RDR	VIC	ANDYS	SOUTH
200405311538	CSTL19931231002534	CARRIER PRINCESS	CZ3582	730647	CA	RAIL FERRY	49.143	123.038	0	0	RDR	VIC	TILBU	NANAI
200405311538	CSTL19960505113116	HMCS WINNIPEG	CGAI	338	CA	WARSHIP	48.432	123.442	0	0	MAN	VIC	ESQUI	CONST
200405311538	CSTL19931231000573	STORM COASTER	CY3040	8137079	CA	TUG	49.198	122.9	0	0	MAN	VIC	RIVTO	NEW W
200405311538	TOF119991226223416	GANGES HAWK			CA	MISCELLANEOUS	48.852	123.485	0	0	MAN	VIC	GANGE	MINER
200405311538	CSTL19931231002336	SS CAVALIER	CZ5656	7434808	CA	TUG	49.125	123.203	302	11.6	RDR	VIC	SYLVA	VANCO
200405311538	CSTL19960505112549	HMCS NANAIMO	CGAV	702	CA	WARSHIP	48.34	123.298	270	6.9	RDR	VIC	CONST	
200405311538	CSTL19931231000484	HARMAC CEDAR	CY7692	0323250	CA	TUG	49.32	123.458	138	1.9	RDR	VIC	BLIND	NORTH

This involves a shipboard broadcast that relies on the global positioning system to get an accurate position, heading, and speed, and transponders to send out this information to other vessels and shore-based receiving equipment for the VTS centers. Each VTS center, therefore, can track vessels in their area by both radar (if the vessel is in line of site of a radar station) and AIS. The VTS centers record the tracks of the vessels that report in. This information is sent to a central data repository called the Coast Guard Vessel Traffic Operation Support System (VTOSS). This database consists of records of the longitude, latitude, heading, speed, vessel type, name, call sign, Lloyd's ID, departure port, destination port, and positional data source (AIS or Radar) every 3-7 minutes of a vessel's transit. Table C-1 shows a sample of records and the major columns in the VTOSS database. The entire VTOSS repository includes all Canadian VTS centers as well as Seattle Traffic from the US Coast Guard, meaning all position records for the study area are included for the vessels that participate in the VTS.

C-1.2. Turning track data in to simulation routes

The simulation model needs two pieces of information from the VTOSS database. What is the path that a vessel follows? And what is the date and time of each vessel's arrival? With these two pieces of information, we can add the vessel to the simulation at the appropriate date and time and then have it navigate through the study area in the simulation. In this manner, we simulate a transit of the vessel.

Each record in the database is the location of a vessel at a given time. A sequence of such records for one transit of a vessel show the path it follows and the first record gives us the date and time of the arrival of the vessel in the study area. However, an examination of Table C-1 shows us that the database gives all vessel location records at a given time for different records. We must sort the database in a different order to get the sequences of records for one vessels transit.

If we re-order the database, by vessel name then we can see all the records for each value of the column vessel name. Then if we sort within each vessel name by date and time, we will see the succession of records for that vessel over time. There are some problems here though. It is possible for two different vessels to share the same name. Their Lloyds ID is unique, but this is sparsely recorded. However, two vessels of the same name in this area will be of different types, so if we sort by vessel type, then by names for each vessel type, then by date and time for each vessel name, then we can separate these vessels. Table C-2 shows a piece of the database sorted in this manner. In some cases, the vessel name was misspelled or entered differently (for instance with a "II" rather than a "2), so these different versions had to be corrected.

Table C-2. The VTOSS database ordered to allow routes to be found.

TYPE_DEC	NAME	TIMESTAMP	FROM_AT	NEXT_TO	POS_LAT	POS_LONG
BULK CARRIER	ABAKAN	38757.1819444444	RUSSI	OLYMP	47.068	122.911
BULK CARRIER	ABAKAN	38757.1861111111	RUSSI	OLYMP	47.062	122.908
BULK CARRIER	ABAKAN	38757.1916666667	RUSSI	OLYMP	47.056	122.907
BULK CARRIER	ABAKAN	38757.1958333333	RUSSI	OLYMP	47.054	122.907
BULK CARRIER	ABAKAN	38757.5069444444	RUSSI	OLYMP	47.585	122.431
BULK CARRIER	ABAKAN	38757.5111111111	RUSSI	OLYMP	47.569	122.443
BULK CARRIER	ABAKAN	38757.5145833333	RUSSI	OLYMP	47.552	122.455
BULK CARRIER	ABAKAN	38757.51875	RUSSI	OLYMP	47.535	122.468
BULK CARRIER	ABAKAN	38757.5229166667	RUSSI	OLYMP	47.516	122.482
BULK CARRIER	ABAKAN	38757.5263888889	RUSSI	OLYMP	47.497	122.495
BULK CARRIER	ABAKAN	38757.5263888889	RUSSI	OLYMP	47.497	122.495
BULK CARRIER	ABAKAN	38757.5326388889	RUSSI	OLYMP	47.469	122.514
BULK CARRIER	ABAKAN	38757.5388888889	RUSSI	OLYMP	47.439	122.523
BULK CARRIER	ABAKAN	38757.5402777778	RUSSI	OLYMP	47.429	122.524
BULK CARRIER	ABAKAN	38763.7	OLYMP	SEAT	47.052	122.906
BULK CARRIER	ABAKAN	38763.7041666667	OLYMP	SEAT	47.052	122.906
BULK CARRIER	ABAKAN	38763.7083333333	OLYMP	SEAT	47.052	122.906
BULK CARRIER	ABAKAN	38763.7125	OLYMP	SEAT	47.057	122.907
BULK CARRIER	ABAKAN	38763.7173611111	OLYMP	SEAT	47.065	122.908
BULK CARRIER	ABAKAN	38763.7194444444	OLYMP	SEAT	47.068	122.911
BULK CARRIER	ABAKAN	38763.7236111111	OLYMP	SEAT	47.075	122.918
BULK CARRIER	ABAKAN	38763.7277777778	OLYMP	SEAT	47.082	122.925
BULK CARRIER	ABAKAN	38763.7319444444	OLYMP	SEAT	47.089	122.927
BULK CARRIER	ABAKAN	38763.7361111111	OLYMP	SEAT	47.099	122.923
BULK CARRIER	ABAKAN	38763.7409722222	OLYMP	SEAT	47.111	122.916

To derive one path (or route) for a vessel's transit, we start at the first record and see what the ports of departure and destination are. We take the records in sequence until we reach a record from a different transit. But how do we know that a record is from a different transit? Firstly, if the port of departure or destination changes, then we can assume that this is a different transit. Also, if the vessel name or vessel type changes, then we can assume that we have reached a different transit. For some records, these critical fields were blank, so we had to ignore those records. Taking the sequence of locations for this transit, we can then plot the points on our map. This sequence of points is one route. However, this sequence of points taken every 3-7 minutes for a transit from BP Cherry Point to Buoy J and out to sea, for instance, can be very long. If we have routes that are defined by too many points, then the simulation will take too long to run. So we must reduce the number of points without making inaccurate routes. Thus we run through each route taking each sequence of 3 points in a row. If the middle point is on a straight line between the first and third points, then we can remove it. This actually means calculating the perpendicular distance between the middle point and the line between the first and third points. If this distance is less than 0.001 nautical miles, then we remove the middle point. Thus we achieve routes that accurately reflect the paths of the vessels, but without needlessly slowing the simulation. Figure C-2 shows one such route for an oil tanker transiting from BP Cherry Point to South America.

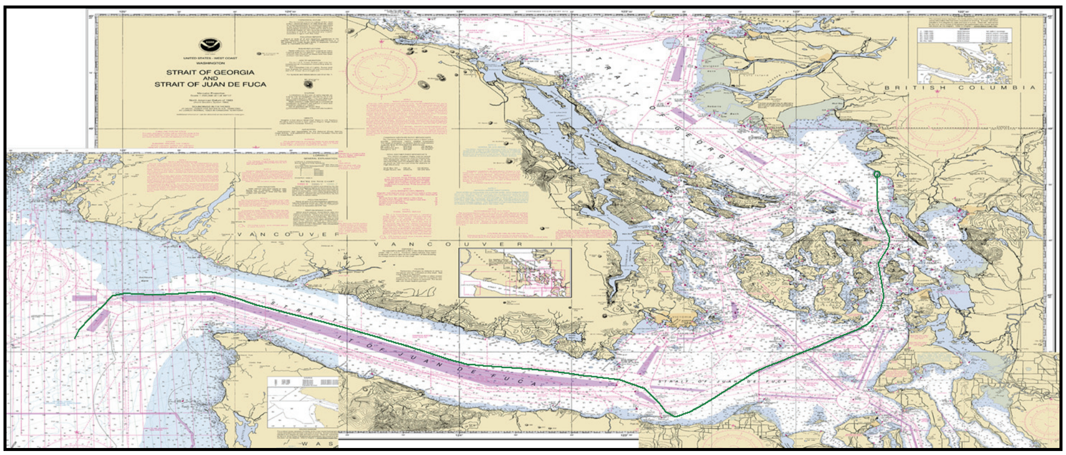

Figure C-2. An oil tanker route from BP Cherry Point to South America

However, not all such routes obtained are as perfect as that shown in C.2. Figure C-3 shows one problem route for a bulk carrier transiting from Anacortes to California. The points on this route are mostly derived from AIS recordings, but towards the end of the Straits of Juan de Fuca, the AIS signal weakened and radar recordings took over for a while. With radar, we can sometimes find blips like those shown. To remove as many of these blips as possible, we found the time between successive points and calculated the maximum distance that a vessel could travel in this time. If we take three points, and the distance between the first and second point is more than a vessel could travel in that time and the distance between the second and third point is greater than a vessel could travel in that time, then we know the middle point is a radar blip and we remove it. This removed many of these problems, but it is possible to have more than one point in a row that is the result of a radar blip, so we had to manually clean the routes by plotting them one by one on the map and writing functions in the simulation program that would allow us to remove specific points.

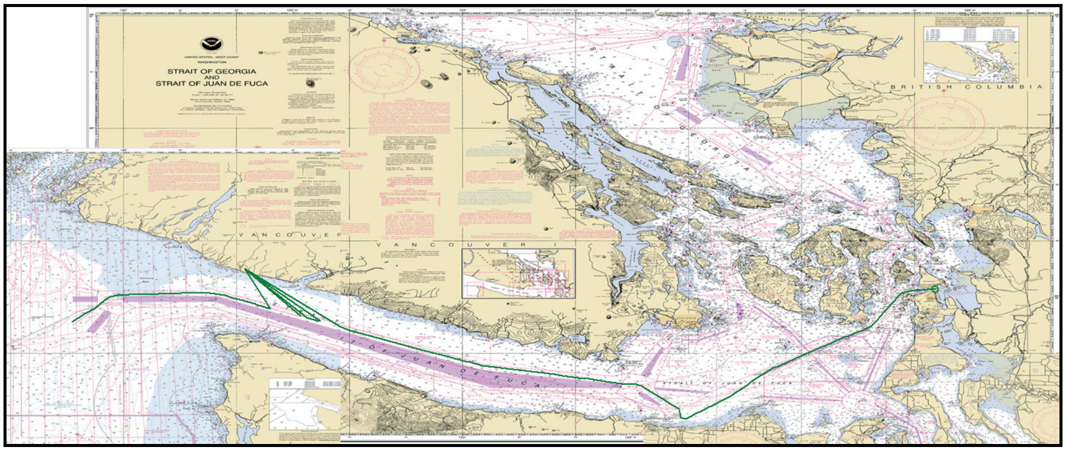

Figure C-3. A bulk carrier route from Anacortes to California

Even with these cleaned routes, we still had problem routes. Figure C-4 shows one such problem. Did the vessel just appear passed Buoy J and then disappear just passed Port Angeles? Examining the sequence of records reveals the problem. This route is for a bulk carrier transiting from Guatemala to Vancouver. As this vessel passed through the system, its location was recorded by different VTS stations as shown in Figure C-1. Tofino recorded the ports of departure and destination as "GUATE" and "VANCOUVER". Seattle recorded them as " GT" and "VANCOUVER". Victoria and Vancouver then went back to "GUATE" and "VANCOUVER". Thus our approach for finding routes breaks up this transit in to pieces because of the different names used for the same ports.

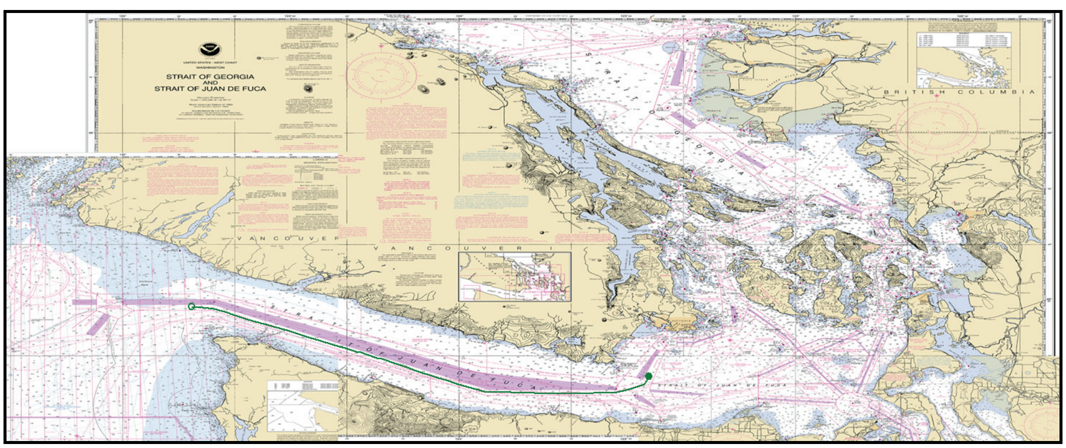

Figure C-4. A bulk carrier from Guatemala to Vancouver.

Obviously in this case, we can simply replace all instances of " GT" with "GUATE" and redo the route to join all the pieces together. This must then be done for all instances of non-unique names for a given port. We took all possible values of the departure and destination port names and sorted them. This showed many such instances of alternative names for the same port, so we determined one unique value for each and replaced all the alternatives for a given port with this unique value. We also found that while, for instance, Seattle VTS might say a vessel is heading for "VANCOUVER", Vancouver VTS might record a specific dock or terminal that the vessel is heading for. Thus we also had to replace all names of places within a given port, with the unique name for that port for ports outside our study area, like Vancouver and Delta port. For ports within our study area, we kept a finer level of detail of the different locations within, for instance, Seattle and Tacoma.

With these steps completed, many of the routes were now smooth and complete. There were, however, missing transits due to recording problems with VTOSS, so a vessel might transit from A to B and then C to D, but with no transit from B to C. There were also still incomplete routes. Thus we chose representative routes. For each type of vessel transiting from A to B, we would find one complete route to use for each such transit in the simulation. This does somewhat discretize the simulation, but without it some transits would be incomplete (leading to inaccuracies in the traffic patterns) and the simulation would run very slowly, which would not allow a complete analysis of the different cases. At first, we tried to automate the selection of routes, but this did not lead to good selection for many routes, so the selection was performed visually for all routes (just over 6,000 in all).

C-1.3. Routes used in the simulation

Figures C.5 to C.12 show the routes used in the simulation. Each figure shows all representative routes used for one type of vessel.

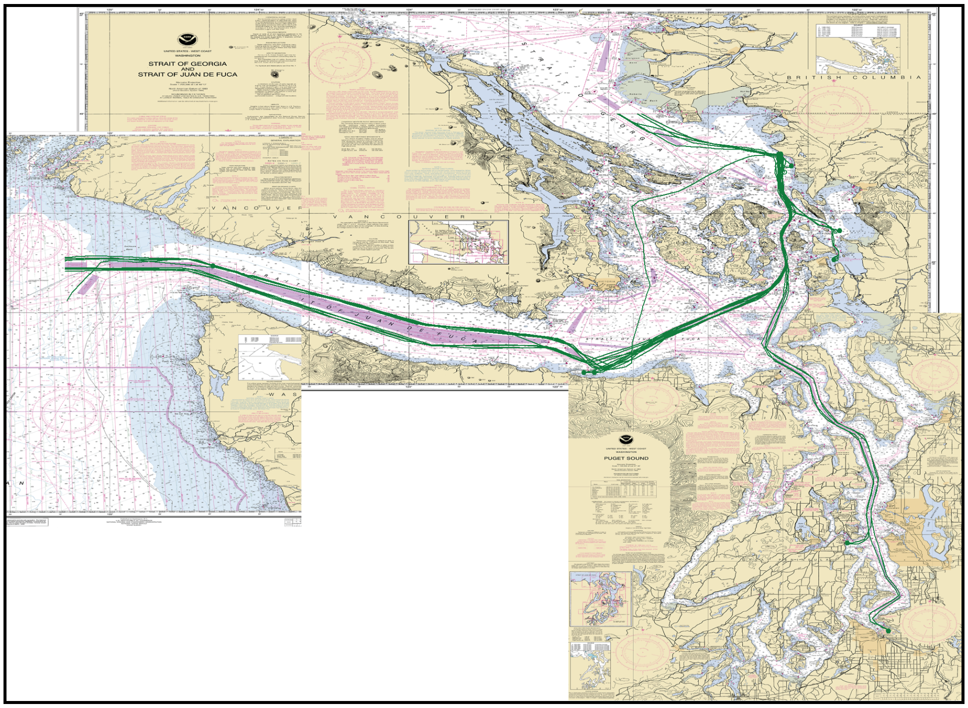

Figure C-5. Representative Routes Used by Tankers Calling at BP Cherry Point.

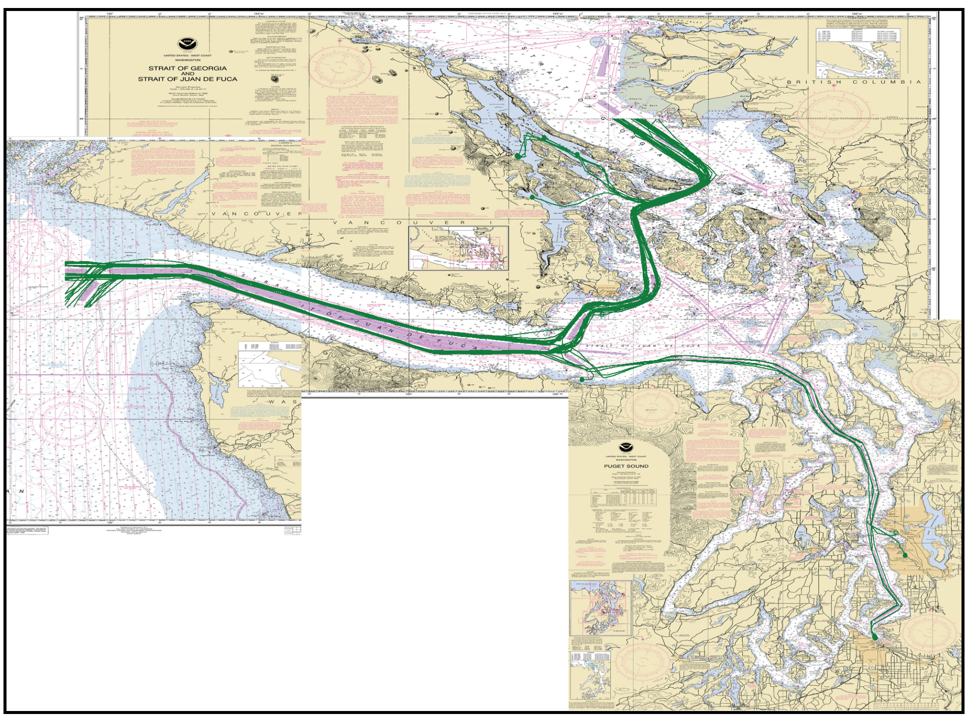

Figure C-6. Representative Routes Used by Bulk Carriers.

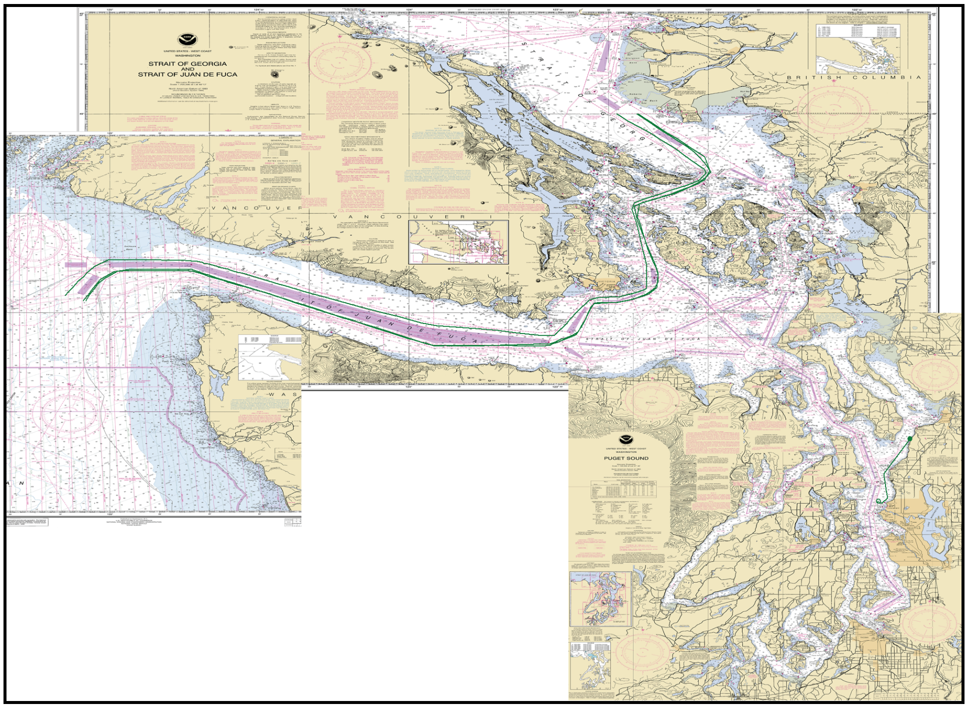

Figure C-7. Representative Routes Used by Chemical Carriers.

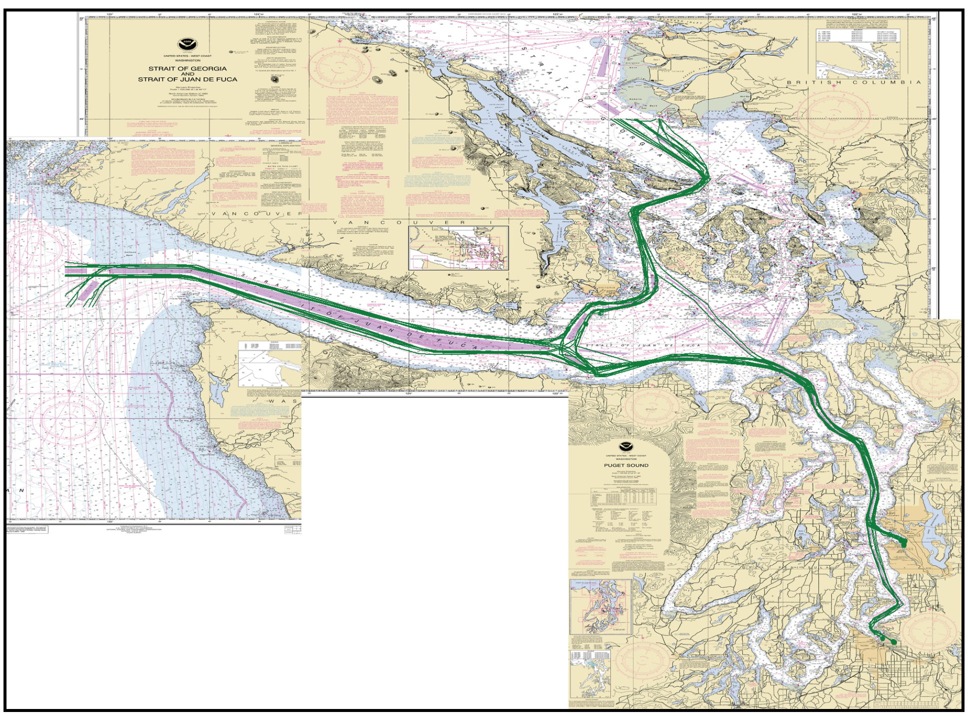

Figure C-8. Representative Routes Used by Container Vessels.

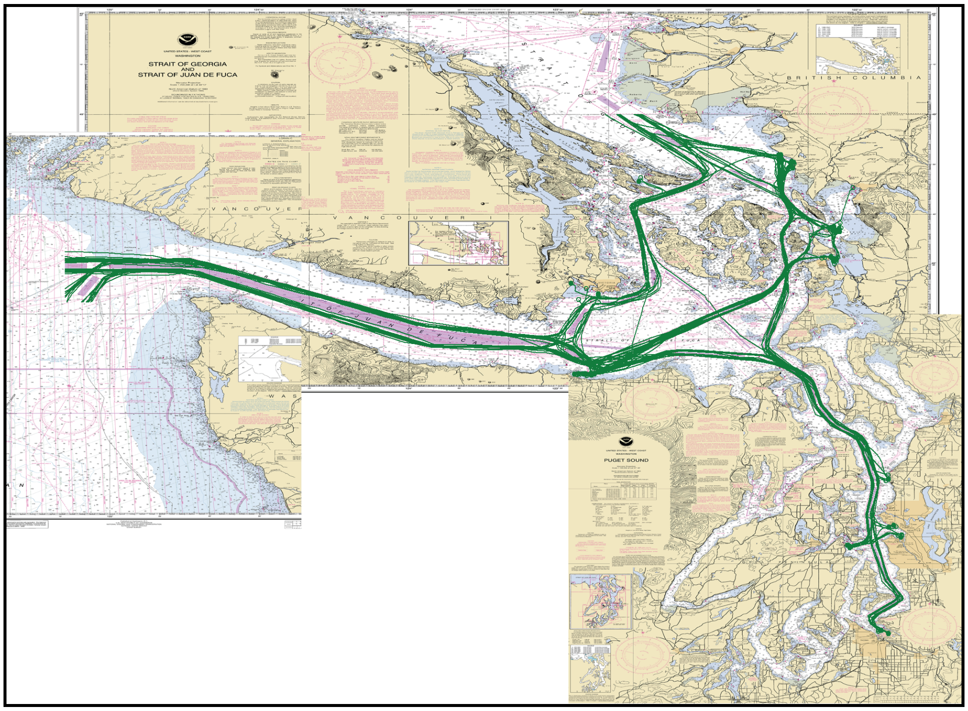

Figure C-9. Representative Routes Used by all Oil Tankers.

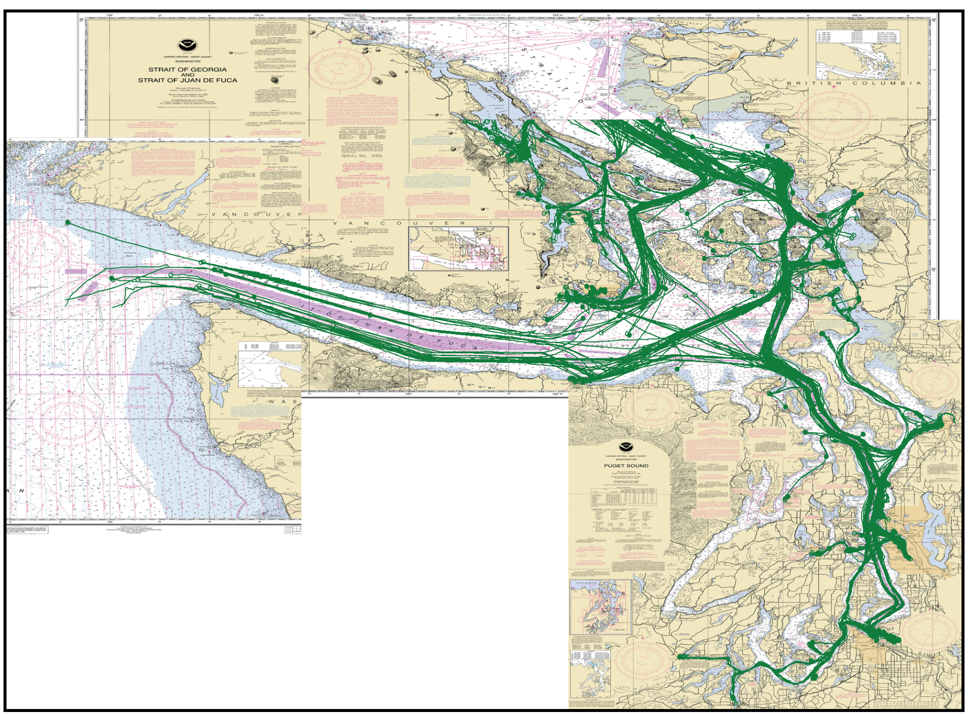

Figure C-10. Representative Routes Used by Tug Tow Barges.

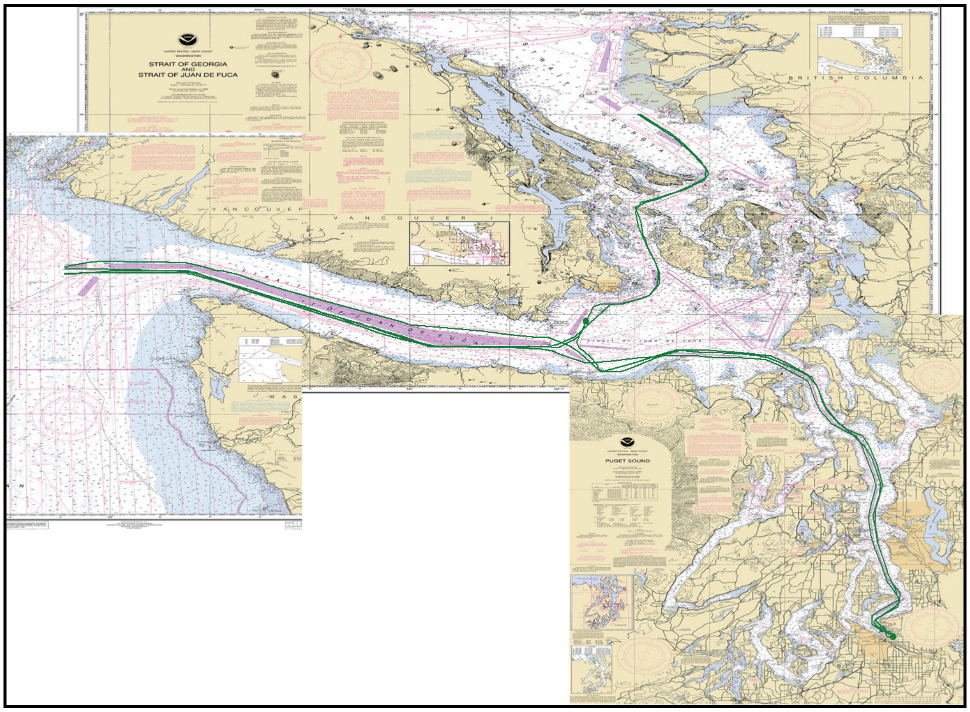

Figure C-11. Representative Routes Used by Vehicle Carriers.

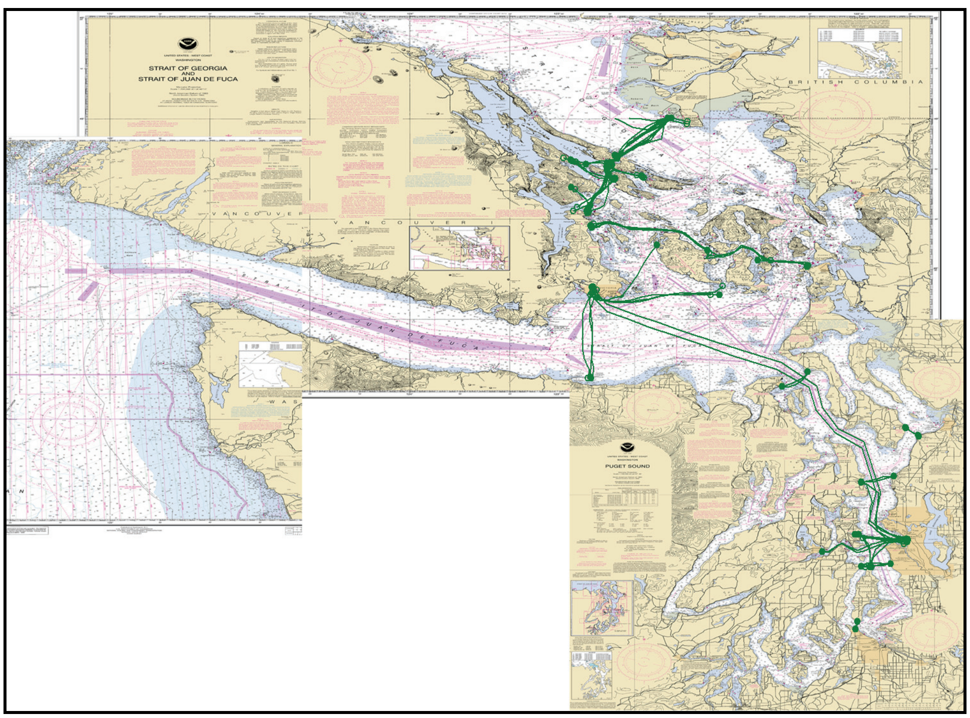

Figure C-12. Representative Routes Used by Ferries.

C-1.4. Vessel Dimensions

Table C-3 shows the vessel information used in the simulation for tankers, ATBs, and ITBs.

Table C-3. Tanker, ATB, and ITB type vessel information used in the simulation.

Vessel Name	Cargo	Type	Hull	DWT	Displ.	Length	Beam	Draft
AEGEAN TRADER	Product	Tanker	SH	31374	8912	162.95	27.93	11.53
AKAMAS	Product	Tanker	DH	41448	9758	182.04	28.94	11.93
ALASKAN EXPLORER	Crude	Tanker	DH	193050	38826	286.85	50	18.8
ALASKAN FRONTIER	Crude	Tanker	DH	193050	38826	286.85	50	18.8
ALASKAN NAVIGATOR	Crude	Tanker	DH	193048	38826	286.85	50	18.8
ALIAKMON	Product	Tanker	DH	38858	11321	200	33.1	12.41
ANDES	Crude	Tanker	DH	68487	12446	200	33.1	12.41
ANGELICA SCHULTE	Crude	Tanker	DH	100036	16533	200	33.1	12.41
AP STAR	Product	Tanker	DB/SS	23876	8330	200	33.1	12.41
ARABIAN WIND	Product	Tanker	DB/SS	17482	7864	200	33.1	12.41
ASTRAL EXPRESS	Product	Tanker	DH	45770	9311	179.8	32.23	12.12
BARENTS WIND	Product	Tanker	DB/SS	22622	8237	179.8	32.23	12.12
BELSIZE PARK	Product	Tanker	DH	19937	8040	179.8	32.23	12.12
BOW CLIPPER	Product	Tanker	DH	37221	9393	179.8	32.23	12.12
BOW PRIMA	Product	Tanker	DH	46454	10207	179.8	32.23	12.12
BRIGHT PACIFIC	Product	Tanker	DH	46454	9306	179.8	32.23	12.12
BRITISH BEECH	Crude	Tanker	DH	106138	16521	240.5	42	14.88
BRITISH EXCELLENCE	Product	Tanker	DH	37333	9403	240.5	42	14.88
BRITISH HARRIER	Crude	Tanker	DH	120000	22890	179.9	32.23	12.8
BRITISH HAZEL	Crude	Tanker	DH	106085	16574	240.5	42	14.88
BRITISH LAUREL	Crude	Tanker	DH	106395	17507	240.5	42	14.88
BRITISH LOYALTY	Product	Tanker	DH	46803	9439	183.22	32.2	12.22
BRITISH OAK	Crude	Tanker	DH	106395	16159	240.5	42	14.88
BUM YOUNG	Product	Tanker	DH	19999	8045	240.5	42	14.88
BUNGA KANTAN DUA	Product	Tanker	DH	19774	8028	240.5	42	14.88
CABO HELLAS	Crude	Tanker	SH	69636	12576	240.5	42	14.88
CABO SOUNION	Crude	Tanker	DH	40038	13213	228	32.22	13.62
CAPE AVILA	Crude	Tanker	DH	105337	17341	228	32.22	13.62
CAPE BONNY	Crude	Tanker	DH	159152	28147	274.27	48	17.07
CAPTAIN H A DOWNING	Crude	Tanker	DH	39385	10820	207	27.43	11.19
CARIBBEAN SPIRIT	Product	Tanker	DH	46383	10201	207	27.43	11.19
CEDAR GALAXY	Product	Tanker	DH	19983	8043	207	27.43	11.19
CHAMPION ADRIATIC	Product	Tanker	DH	37658	9430	207	27.43	11.19
CHAMPION PACIFIC	Product	Tanker	DH	38465	9499	207	27.43	11.19
CHAMPION TRADER	Product	Tanker	SH	30990	8881	207	27.43	11.19
CHAMPION VENTURA	Product	Tanker	DB/SS	45574	10127	207	27.43	11.19
CHEMSTAR ACE	Product	Tanker	DH	19481	8007	207	27.43	11.19

Vessel Name	Cargo	Type	Hull	DWT	Displ.	Length	Beam	Draft
CHEMTRANS SEA	Product	Tanker	DH	72365	12888	207	27.43	11.19
COASTAL RELIANCE	Product	ATB	DH	19000	7973	207	27.43	11.19
CSL ACADIAN	Product	Tanker	DH	37498	9417	207	27.43	11.19
DA YUAN HU	Crude	Tanker	DH	159149	26829	274	48.03	17.3
DAWN	Product	Tanker	DH	11668	7463	274	48.03	17.3
DENALI	Crude	Tanker	DB/SS	188000	36491	274	48.03	17.3
DESH GAURAV	Crude	Tanker	DH	113928	18735	274	48.03	17.3
ERIK SPIRIT	Crude	Tanker	DH	115525	19006	274	48.03	17.3
ETERNITY	Product	Tanker	DH	94993	15800	274	48.03	17.3
FAIRCHEM COLT	Product	Tanker	DH	19998	8045	274	48.03	17.3
FAIRCHEM GENESIS	Product	Tanker	DH	14281	7641	274	48.03	17.3
FAIRCHEM STALLION	Product	Tanker	DH	19947	8041	274	48.03	17.3
FAIRCHEM STEED	Product	Tanker	DH	19992	8044	274	48.03	17.3
FEDOR	Product	Tanker	DH	70156	12635	274	48.03	17.3
FJORD CHAMPION	Product	Tanker	SH	32477	9001	274	48.03	17.3
FORMOSA 15	Product	Tanker	DH	45400	10111	274	48.03	17.3
FRONT BRABANT	Crude	Tanker	DH	153320	21861	269.19	46	17.21
FRONT CLIMBER	Crude	Tanker	DH	149999	25921	269.19	46	17.21
FRONT SPLENDOUR	Crude	Tanker	DH	124999	21882	269	46	16.86
FRONT SYMPHONY	Crude	Tanker	DH	150500	22751	272	45.6	17.08
GINGA LION	Product	Tanker	DH	25441	8448	272	45.6	17.08
GINGA SAKER	Product	Tanker	SH	19996	8044	272	45.6	17.08
GUADALUPE	Product	Tanker	DH	47037	10261	272	45.6	17.08
GULF PROGRESS	Product	Tanker	DH	64959	13664	228.6	32.2	13.17
GULF SCANDIC	Crude	Tanker	DH	151459	26264	228.6	32.2	13.17
HEBEI MERCY	Product	Tanker	SH	10151	7362	228.6	32.2	13.17
HEBEI TREASURE	Crude	Tanker	SH	54158	10940	228.6	32.2	13.17
HELLESPONT TATINA	Crude	Tanker	DH	105535	17372	228.6	32.2	13.17
HELLESPONT TRINITY	Crude	Tanker	DH	148018	25463	228.6	32.2	13.17
HIGH CONSENSUS	Product	Tanker	DH	45800	8884	179.88	32.23	12.02
HIGH LIGHT	Crude	Tanker	DH	46843	10243	179.88	32.23	12.02
HOUSTON	Product	Tanker	DH	32689	9018	179.9	32.23	12.8
HUDSON	Crude	Tanker	DH	124999	20698	179.9	32.23	12.8
IASONAS	Crude	Tanker	DH	71500	12788	179.9	32.23	12.8
IKAROS	Crude	Tanker	DH	72828	12942	179.9	32.23	12.8
IONIAN TRADER	Product	Tanker	DH	39317	9572	179.9	32.23	12.8
IPANEMA	Crude	Tanker	DH	68781	12479	179.9	32.23	12.8
ISLAND MONARCH	Product	ATB	DH	8954	7283	179.9	32.23	12.8
ITB BALTIMORE	Product	ITB	DB/SS	48067	10357	179.9	32.23	12.8
ITB GROTON	Product	ITB	DB/SS	48067	10357	179.9	32.23	12.8
ITB NEW YORK	Product	ITB	DB/SS	48067	10357	179.9	32.23	12.8
JAG LEELA	Crude	Tanker	DH	84999	14440	179.9	32.23	12.8
JILL JACOB	Crude	Tanker	DH	72909	12952	179.9	32.23	12.8

Vessel Name	Cargo	Type	Hull	DWT	Displ.	Length	Beam	Draft
JOHN ERICSSON	Product	Tanker	DH	28256	8665	179.9	32.23	12.8
KENAI	Crude	Tanker	DH	123113	20350	179.9	32.23	12.8
KEYMAR	Crude	Tanker	SH	92017	15382	179.9	32.23	12.8
KODIAK	Crude	Tanker	DH	124822	24726	179.9	32.23	12.8
KOYAGI SPIRIT	Crude	Tanker	SH	95987	15941	182.5	32.2	12.67
KRITI CHAMPION	Product	Tanker	DB/SS	47618	10315	179.88	32.23	12.02
KUDU	Product	Tanker	DH	45948	8832	179.88	32.23	12.02
KYRIAKOULA	Crude	Tanker	DH	72354	12887	179.88	32.23	12.02
LAUREL GALAXY	Product	Tanker	DH	19805	8031	179.88	32.23	12.02
LEPTA MERMAID	Product	Tanker	DH	45908	10157	179.88	32.23	12.02
LETO PROVIDENCE	Crude	Tanker	DB/SS	49999	10538	179.88	32.23	12.02
LOUKAS I	Product	Tanker	DH	45557	10125	179.88	32.23	12.02
LUDOVICA	Product	Tanker	DH	47198	9276	182.5	32.2	12.67
MAPLE EXPRESS	Product	Tanker	DH	45798	10147	182.5	32.2	12.67
MARITIME MAISIE	Product	Tanker	DH	44404	10021	182.5	32.2	12.67
MERMAID EXPRESS	Product	Tanker	DH	45763	10144	182.5	32.2	12.67
ITB MOBILE	Product	ITB	DB/SS	48067	10357	179.9	32.23	12.8
MONTE LUNA	Product	Tanker	DB/SS	39742	9609	182.5	32.2	12.67
NEW AMITY	Crude	Tanker	DH	84999	14440	182.5	32.2	12.67
NEW ENDEAVOR	Product	Tanker	DB/SS	38960	9542	182.5	32.2	12.67
NEW HORIZON	Product	Tanker	SH	38891	9536	182.5	32.2	12.67
NORCA	Product	Tanker	DH	47094	10266	182.5	32.2	12.67
NORD SOUND	Product	Tanker	DH	45975	10163	182.5	32.2	12.67
NORD STRAIT	Product	Tanker	DH	45934	10160	182.5	32.2	12.67
NORTH CHALLENGE	Product	Tanker	DH	12181	7498	182.5	32.2	12.67
OCEAN RELIANCE	Product	ATB	DH	19000	7973	182.5	32.2	12.67
OS ARIADMAR	Product	Tanker	DH	46205	10185	182.5	32.2	12.67
OS CHICAGO	Crude	Tanker	DB/SS	92091	15392	182.5	32.2	12.67
OS PEARLMAR	Crude	Tanker	DH	69697	13153	182.5	32.2	12.67
OS POLYS	Crude	Tanker	DH	68623	12461	182.5	32.2	12.67
OS RUBYMAR	Crude	Tanker	DH	69599	12571	182.5	32.2	12.67
OS WASHINGTON	Crude	Tanker	DB/SS	91967	15375	182.5	32.2	12.67
OTTAWA	Product	Tanker	DH	70296	13907	228	32.23	13.8
PANAGIA LADY	Crude	Tanker	DH	46684	10229	228	32.2	13.62
PANAM ATLANTICO	Product	Tanker	DH	14003	7622	228	32.2	13.62
PAUL BUCK	Product	Tanker	DH	29500	8912	228	32.2	13.62
PECOS	Crude	Tanker	DH	157406	27708	228	32.2	13.62
PEDOULAS	Crude	Tanker	SH	96172	15968	228	32.2	13.62
PETRO VENUS	Crude	Tanker	SH	124999	20698	257.71	37.29	10.28
PLATINUM	Product	Tanker	DH	45614	10130	188.6	29.35	10.28
POLAR ADVENTURE	Crude	Tanker	DH	191460	31769	268.5	45	16
POLAR ALASKA	Crude	Tanker	DB/SS	191460	37645	286.93	43.94	10.28
POLAR CALIFORNIA	Crude	Tanker	DB/SS	191460	37645	286.93	43.94	10.28

Vessel Name	Cargo	Type	Hull	DWT	Displ.	Length	Beam	Draft
POLAR DISCOVERY	Crude	Tanker	DH	141740	31769	268.5	45	16
POLAR ENDEAVOUR	Crude	Tanker	DH	141740	31769	268.5	45	16
POLAR RESOLUTION	Crude	Tanker	DH	141740	31769	268.5	45	16
POLAR TEXAS	Crude	Tanker	DB/SS	91393	15296	236.24	33.93	10.28
POTOMAC	Crude	Tanker	DH	159999	28362	274.63	40.79	10.28
PRINCE WILLIAM SOUND	Crude	Tanker	DH	122941	23525	247.5	40.8	15
PRINCESS NADIA	Crude	Tanker	DH	152328	26470	271.26	40.02	10.28
PUGET SOUND	Product	Tanker	DB/SS	27894	8637	154.89	27.58	10.28
REGINAMAR	Product	Tanker	DH	70313	13890	228	32.22	13.77
RICHARD G MATTHIESEN	Product	Tanker	DH	29526	8765	158.79	27.74	10.28
ROMOE MAERSK	Product	Tanker	DH	34807	9192	170.07	28.27	10.28
ROSETTA	Product	Tanker	DH	47037	9486	182.5	32.2	12.67
SABREWING	Product	Tanker	DH	49323	10474	193.96	29.72	10.28
SAMOTHRAKI	Crude	Tanker	DH	46538	10215	189.98	29.44	10.28
SAMUEL L COBB	Product	Tanker	DH	32572	23304	170.07	28.27	10.28
SANKO COMMANDER	Crude	Tanker	DH	71010	12732	218.94	31.89	10.28
SANKO CONFIDENCE	Crude	Tanker	DH	71010	12732	218.94	31.89	10.28
SANKO DYNASTY	Crude	Tanker	DH	106644	17546	246.82	35.46	10.28
SANKO QUALITY	Crude	Tanker	DH	95628	15890	239.35	34.35	10.28
SANMAR SERENADE	Product	Tanker	DH	45696	10138	188.73	29.36	10.28
SCF URAL	Crude	Tanker	DH	167931	23304	274.48	48	17.07
SEA RELIANCE ATB	Product	ATB	DH	19000	7973	128.57	26.69	10.28
SEABULK ARCTIC	Product	Tanker	DH	46094	10174	189.32	29.4	10.28
SEABULK PRIDE	Product	Tanker	DH	46094	10174	189.32	29.4	10.28
SEAMASTER	Crude	Tanker	DH	109266	17965	248.49	35.72	10.28
SICHEM PALACE	Product	Tanker	DH	8807	7274	75.86	25.67	10.28
SINGAPORE VOYAGER	Crude	Tanker	DH	105850	17421	246.31	35.38	10.28
SKIROPOULA	Crude	Tanker	DH	68232	12418	216.21	31.61	10.28
SKOPELOS	Crude	Tanker	DH	70146	12633	218.1	31.81	10.28
SMT CHEMICAL EXPLORER	Product	Tanker	DB/SS	34930	9202	170.31	28.28	10.28
SONANGOL GIRASSOL	Crude	Tanker	DH	159056	23313	274	48	17.02
SOUND RELIANCE ATB	Product	ATB	DH	19000	7973	128.57	26.69	10.28
SOUTH SEA	Crude	Tanker	DH	150000	25921	270.21	39.79	10.28
SPIRIT II	Crude	Tanker	SH	100336	16578	242.64	34.82	10.28
SR BAYTOWN	Crude	Tanker	DB/SS	59625	11492	206.96	30.75	10.28
SR COLUMBIA BAY	Crude	Tanker	DB/SS	124999	20698	257.71	37.29	10.28
SR HINCHINBROOK	Crude	Tanker	DB/SS	48869	10432	193.33	29.68	10.28
SR LONG BEACH	Crude	Tanker	SH	94999	15800	238.89	34.29	10.28
ST.GEORG	Product	Tanker	SH	5850	7083	47.82	25.38	10.28
STAVANGER VIKING	Crude	Tanker	DH	105400	17351	246.02	35.33	10.28
STENA COMMANDER	Crude	Tanker	DH	72290	12880	220.17	32.02	10.28
STENA COMPANION	Crude	Tanker	DH	72768	12935	220.62	32.07	10.28
STENA COMPATRIOT	Crude	Tanker	DH	72736	12931	220.59	32.06	10.28

Vessel Name	Cargo	Type	Hull	DWT	Displ.	Length	Beam	Draft
STENA CONSUL	Product	Tanker	DH	47171	10273	190.9	29.51	10.28
SWIFT FAIR	Crude	Tanker	DH	75469	13253	223.12	32.34	10.28
THEO T	Product	Tanker	DH	73021	12965	220.86	32.09	10.28
TIGER	Product	Tanker	DH	44987	10073	187.65	29.29	10.28
TORBEN SPIRIT	Crude	Tanker	DH	98600	16321	241.44	34.65	10.28
TROMSO RELIANCE	Crude	Tanker	DH	154970	20502	274	43.93	17.52
TURCHESE	Product	Tanker	DH	12000	7486	97.07	25.99	10.28
VOIDOMATIS	Product	Tanker	DH	61325	11669	208.89	30.92	10.28
WASHINGTON VOYAGER	Product	Tanker	DH	39167	9559	178.16	28.71	10.28
XANTHOS	Crude	Tanker	DH	61369	11674	208.94	30.93	10.28

Information about vessels that call at BP Cherry Point most frequently was provided by BP Shipping. Information for other tankers was obtained from a variety of online databases, including those of the classification societies, the Shipping Intelligence Network, and owners.

Information was not available from BP about the amount of crude or product each tanker, ATB, or ITB carried on each transit. Instead, the following assumptions were developed in conjunction with BP Shipping. For crude vessels, the tanker is assumed to be carrying 100% of its capacity when it arrives in the study area and 0% when it leaves the study area. However, some crude tankers call at multiple refineries in the visit to the study area. In this case, the tanker is assumed to offload equal amounts at each refinery. For product tankers, the vessels are assumed to leave the study area carrying 100% of its capacity and arrive empty. Transits between refineries in the study area are moving various products between them, and so are assumed to carrying 50% of its capacity. All vessels are assumed to be carrying 100% of their fuel capacity.

For other vessels, the US Coast Guard provided information on DWT, length, beam, and draft for as many vessels as were available in their VTS database. The Puget Sound Marine Exchange provided additional DWT and displacement data. The Washington State Ferries provided complete information on all their vessels. The vessels for which dimension information was complete were used to estimate relationships between the various dimensions for each type of vessel. These relationships were then used on the partial information for other vessels to estimate missing information. For vessels with no information, an average for that vessel type was used. Again, all vessels are assumed to be carrying 100% of their fuel capacity.

C-2. Fishing Seasons Modeling

C-2.1. US, Canadian, and tribal fishing data

Three primary commercial fishery vessel fleets are identified: State Commercial fisheries, Tribal Commercial Fisheries, Canadian Commercial Fisheries. Each is further delineated below.

C-2.1.1. State Commercial Fisheries

State Commercial Fisheries include all commercial fisheries that are wholly regulated by the Washington Department of Fish and Wildlife (WDF&W). The state commercial fishery fleet incorporates a diverse body of vessel types operating in U.S. regions of the VTRA study area. The WDF&W was contacted in October 2006 to initiate a conversation pertaining to modeling the movement of this fleet for a representative year (2005). During this initial conversation, the defined VTRA Study Area (see Systems Description) was utilized to determine the segments of the commercial fishing fleet that would be considered for further investigation. These were identified using the species and gear-type:

- Salmon-Seine
- Salmon-Gillnet
- Shrimp-Pod
- Crab-Pod

In order to approximate the movement of the commercial fisheries fleet, the WDF&W fisheries manager for the species and gear-type were contacted individual. Each was elicited for data pertaining to typified movements of the commercial fishery fleet over which the manager had regulatory authority. Through an iterative process, wherein data was elicited, compiled and returned, a series of rules were established that would allow each fleet to be modeled for a representative year. These rules are listed below:

- For each fishery and gear type

  - regulatory boundaries of fishery
  - regulatory times of fishery
    - time of year (months)
    - time of day (day light, clock, 24 hour)
  - typical transit habits of fishers between fishing grounds and home-port or intra-fishery port of call (to deliver days/weeks catch)
    - time of day
  - number and type of vessel participating in fishery
    - number of vessel participating as a function stage of fishery
      - first third
      - second third
      - final third
    - typified design of participating vessel
      - length
      - draft
      - fuel capacity
      - speed

The WDF&W fisheries managers offering this information were long term WDF&W employees with a body of in-office and on-water managerial experience that would allow them to offer insight to specific and general habits of the commercial fishing fleet and commercial fishers. The quality and quantity of data gathered during this iterative process ranged from allegorical (based on 20-years experience in managing fishery), to the purely quantitative (based on documented catch records of locations, dates, times and ports of call).

C-2.1.2. Tribal Commercial Fisheries

Tribal Commercial Fisheries include all commercial fisheries that are regulated by individual sovereign tribal authorities. The tribal commercial fishery fleet incorporates a diverse body of vessel types operating in U.S. regions of the VTRA study area, and an equally diverse body of tribal regulatory authorities. This data gathering process specifically focused on fisheries that utilize vessels under 20 meters in registered length. Vessels over 20 meters are expected to be captured as active or passive participants in the Puget Sound Vessel Traffic System.

The Northwest Indian Fisheries Commission was contacted in October 2006 to initiate a conversation pertaining to modeling the movement of the tribal commercial fisheries fleet for a representative year (2005). During this initial conversation, the defined VTRA Study Area was utilized to determine the tribal organization that would be considered for further investigation. These were identified as:

- Lummi Nation
- Makah Tribe
- Nooksack Tribe
- Suquamish Tribe
- Tulalip Tribe
- Puyallup Tribe
- Suquamish Tribe
- Muckleshoot Tribe
- Squaxin Island Tribe
- Point-No-Point Tribal Council

Each of these tribal organizations was contacted independently in an effort to elicit information pertaining to the commercial fishing fleet over which each tribal organization had regulatory authority. Participation of each tribal organization was wholly up to the discretion of the tribal organization contacted. For those organizations that chose to participate, a person with specific knowledge of the commercial fisheries activities was contacted for the purpose of approximating the movement of the commercial fishing fleet for a representative year. In the context of all tribal organizations, the fisheries considered are (by species and gear-type):

- Salmon-Seine
- Salmon-Gillnet
- Crab-Pod
- Shrimp-Pod

- Halibut-Longline

Not all tribal organizations have 'Usual and Accustom" rights to each of these fisheries. For those fisheries that each participating tribal organization does participate, a competent authority was requested to supply information that would approximate typified movements of the fishery fleet. Through an iterative process, wherein data was elicited, compiled and returned, a series of rules were established that would allow each fleet to be modeled for a representative year. These rules are listed below:

- For each fishery and gear type
    - regulatory boundaries of fishery
    - regulatory times of fishery
        - time of year (months)
        - time of day (day light, clock, 24 hour)
    - typical transit habits of fishers between fishing grounds and home-port or intra-fishery port of call (to deliver days/weeks catch)
        - time of day
        - route of transit
    - number and type of vessel participating in fishery
        - number of vessel participating as a function stage of fishery
            - first third
            - second third
            - final third
        - typified design of participating vessel
            - length
            - draft
            - fuel capacity
            - speed

The tribal organizations' fisheries managers generally had long-term managerial experience, as well as significant experience as commercial fishers, that would allow them to speak authoritatively as to the specific and general habits of the commercial fishing fleet and commercial fishers. The quality and quantity of data gathered during this iterative process ranged from allegorical (based on 20-years experience in managing fishery), to the purely quantitative (based on documented catch records of locations, dates, times and ports of call).

C-2.1.3. Canadian Commercial Fisheries

The Canadian commercial fishers are not delineated as Tribal (termed First Nations) and non-tribal fisheries. This is because the Canadian Department of Fisheries and Oceans (DFO) holds regulatory authority over both user groups, thus the DFO fishery managers are the singular competent authority for all commercial fisheries.

The Canadian commercial fishery fleet incorporates a diverse body of vessel types operating in the Canadian regions of the VTRA study area. The DFO was contacted in October 2007 to initiate a conversation pertaining to modeling the movement of this fleet for a representative year (2005). During this initial conversation, the defined VTRA Study Area (see Systems Description) was utilized to determine the segments of the commercial fishing fleet that would be considered for further investigation. These were identified by species and gear-type:

- Salmon-Seine
- Salmon-Gillnet
- Shrimp-Pod
- Crab-Pod

The competent managerial authority for all Canadian Commercial fisheries in the VTRA Study Area is housed in the Victoria office of the DFO. This office was contacted and elicited for data pertaining to typified movements of the commercial fishery fleet over which the manager had regulatory authority. An initial meeting took place in December 2007. This initial meeting began an iterative process through which data was elicited, compiled and returned in order to develop a series of rules that would allow typified fleet movements to be modeled for a representative year. These rules are listed below:

- For each fishery and gear type
    - regulatory boundaries of fishery
    - regulatory times of fishery

        - time of year (months)
        - time of day (day light, clock, 24 hour)
    - typical distribution of fleet across regulatory area
    - typical transit habits of fishers between fishing grounds and home-port or intra-fishery port of call (to deliver days/weeks catch)
        - time of day of transits
    - number and type of vessel participating in fishery
        - number of vessel participating as a function stage of fishery
            - first third
            - second third
            - final third
        - typified design of participating vessel
            - length
            - draft
            - fuel capacity
            - speed

The DFO fisheries managers participating in this process were long-term DFO employees, with a body of in-office and on-water managerial experience that would allow them to offer insight to specific and general habits of the commercial fishing fleet and commercial fishers.

C-2.2. Creating fishing transits in the simulation

In the simulation, the number of fishing vessels leaving each port on a given day was determined from the data provided by the various organizations. The data was also used to determine where they would fish and what patterns of movement they would follow based on the type of fishing. The length of time that the vessel would fish before returning to port was also determined from the data provided.

The first step in modeling fishing traffic is to define the areas in which different types of fishing occurs. Maps of the fishing areas were provided by the various experts and organizations contacted. For each fishing area, a grid of cells was defined over the map of the study area in the simulation. These cells could then be clicked to identify them as part of a given fishing area. The maps of the fishing areas provided were then transcribed in to the simulation by clicking the areas on the grid to match the maps. The next step in modeling fishing traffic was to define the routes used to get from the fishing vessels home port to the fishing area and back again. These routes were clicked in to the simulation and verified with experts in fishing in the area.

With the routes and fishing areas defined, we could then determine when and how many fishing vessels to add to the simulation. Table C-4 shows the information derived from the various organizations. The table shows the various types of fishing. SC and TC indicate State Commercial and Tribal Commercial respectively. The dates within which each type of fishing occurs are also shown, along with the time of day that a fishing vessel would leave and the length of time that a vessel would fish for. Also determined, but not shown in the table, were the probability that vessels would leave on any given day of the week and the number of vessels that would leave from each home port if fishing did occur on that day. Thus in the simulation, it was first determined if a given type of fishing would occur on that day and then each vessel would determine which fishing area it would go to. Given the home port and the fishing area, the vessel would follow a prescribed route to the fishing area, fish for the specified length of time, and then return on the same route to the home port.

Fishing vessels will behave differently depending on what type of fishing they are involved in. A gillnet requires that the vessel drift with the current, while a seine net is pulled slowly behind the vessel. On arrival in a fishing area, the vessels were made to move mostly in a straight line, but with a random deviation to mimic their search for fish. They would then follow their prescribed fishing movement, either drifting or slowly trolling. Shrimp pods and crab pots are dropped at chosen locations and later picked up, so this motion was also mimicked. Vessels moving close to the edge of a fishing area would turn to one side or the other to remain in the defined fishing area. Thus the movements of each vessel were designed to mimic as closely as possible their actual movements and not just travel at speed in straight lines and bounce like a billiard ball at the edge of the area as has been used in other maritime simulation models.

Table C-4. The fishing vessel arrival information fed in to the simulation.

Catch	Fleet	Net Type	Begin Date	End Date	Start Time	Duration
Salmon	SC	Gillnet	7/20	8/20	7:00 AM	0.5
Salmon	SC	Gillnet	7/20	8/20	7:00 AM	0.5
Salmon	SC	Gillnet	7/20	8/20	7:00 AM	0.5
Salmon	SC	Gillnet	8/21	9/28	7:00 AM	0.5
Salmon	SC	Gillnet	9/29	10/17	7:00 AM	0.5
Salmon	SC	Gillnet	10/18	11/30	7:00 AM	0.5
Salmon	SC	Seine	7/20	8/20	7:00 AM	0.5
Salmon	SC	Seine	7/20	8/20	7:00 AM	0.5
Salmon	SC	Seine	7/20	8/20	7:00 AM	0.5
Salmon	SC	Seine	8/21	9/28	7:00 AM	0.5
Salmon	SC	Seine	9/29	10/17	7:00 AM	0.5
Salmon	SC	Seine	10/18	11/30	7:00 AM	0.5
Salmon	TC	Seine	7/20	8/20	7:00 AM	0.5
Salmon	TC	Seine	7/20	8/20	7:00 AM	0.5
Salmon	TC	Gillnet	7/20	11/15	7:00 AM	0.5
Shrimp	SC	na	5/1	5/1	7:00 AM	0.5
Shrimp	SC	na	5/2	9/30	7:00 AM	0.5
Shrimp	TC	na	4/1	5/31	7:00 AM	0.5
Shrimp	SC	na	5/1	5/1	7:00 AM	0.5
Shrimp	SC	na	5/2	9/30	7:00 AM	0.5
Shrimp	TC	na	4/1	5/31	7:00 AM	0.5
Salmon	SC	Gillnet	10/1	10/15	7:00 AM	0.5
Salmon	SC	Gillnet	10/16	11/30	7:00 AM	0.5
Salmon	SC	Seine	10/16	11/30	7:00 AM	0.5
Shrimp	SC	Trawl	5/1	9/30	7:00 AM	5
Shrimp	SC	Pod	5/1	9/30	7:00 AM	2.5
Crab	SC	Pod	3/1	2/28	7:00 AM	3.5
Salmon	TC	Makah Dragger - A	3/1	2/28	7:00 AM	0.5
Salmon	TC	Makah Dragger - B	7/16	10/15	7:00 AM	0.5
Salmon	TC	Makah Troll - A	5/1	9/30	7:00 AM	1
Salmon	TC	Makah Troll - B	10/1	2/28	7:00 AM	1
Salmon	TC	Makah Gillnet	7/15	8/31	7:00 AM	0.5
Salmon	TC	Makah Gillnet	9/1	11/30	7:00 AM	0.5
Crab	SC	Pots	10/1	10/31	7:00 AM	1
Crab	SC	Pots	11/1	11/30	7:00 AM	1
Crab	SC	Pots	12/1	12/31	7:00 AM	1
Crab	SC	Pots	1/1	1/31	7:00 AM	1
Crab	SC	Pots	2/1	2/28	7:00 AM	1
Crab	SC	Pots	3/1	3/31	7:00 AM	1

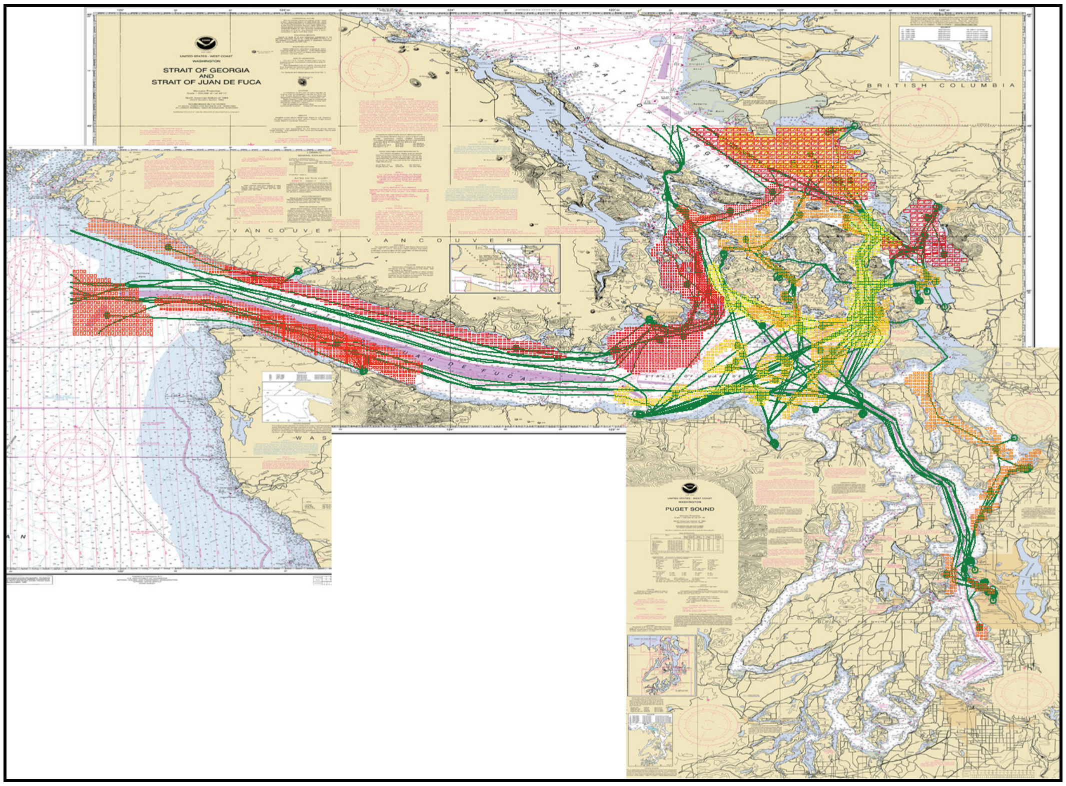

Figure C-13. Fishing areas and representative routes used by fishing vessels.

C-2.3. Routes and fishing areas used in the simulation

The fishing areas and routes used by fishing vessels in the simulation are shown in Figure C-13.

C-3. Regatta Modeling

C-3.1. US regatta data

Permitted non-commercial traffic is all traffic that does not actively participate in a commercial venture (commercial fishing or whale watching), but that does answer to some regulatory authority through a permitting process. Included in Figure 1 are:

- Sailing regattas
- Vessel parades
- Sport fishing competitions
- Powerboat races.

The primary driver to non-commercial permitted traffic being delineated in this manner is the US Coast Guard Permitting process, which has specific categories the person or organization seeking a permitted is required to complete. During the permitting process the permitted is required to submit the additional information below:

- Date of event
- Start time and end time of event
- Type of event
- Number of vessels involved in event
- Starting location of event
- Ending location of event

With data at this detail, the VTRA can incorporate permitted non-commercial traffic as a separate fleet of vessels operating in the VTRA study area.

C-3.2. Creating yacht transits in the simulation

The Coast Guard data indicates the location of each event, the date and time, the type of event, and the number of vessels involved. A sample of the data is shown in Table C-5. For each event, a route was added to the simulation. Events that occurred in areas outside the main waterways in the study area were not included as they could not affect the risk measures of interest. At the appropriate time, the specified number of vessels is added on the representative route. All vessels in the event will not travel at the same speed and they will not travel on exactly the same route. Thus each vessel was given a speed that followed a probability distribution for that type of vessel, making some vessels pull ahead and others fall behind. Each vessel was also given a random dither from the route. In this manner, each regatta event was represented in the simulation.

C-3.3. Regatta routes used in the simulation

Figure C-14 shows the routes used in the simulation for the regattas.

Table C-5. A sample of the regatta records from the US Coast Guard.

Event Location	Event Type	Date and Time	Nos. of Boats
Des Moines around Blakely Rock and return	Sailboat Race	1/7/05 12:00 PM	100
Commencement Bay	Sailboat Race	1/14/05 8:00 AM	40
Blakely Rocks to Point Jefferson	Sailboat Race	1/14/05 12:00 PM	25
Des Moines around Blake Island and return	Sailboat Race	1/14/05 12:00 PM	10
Edmonds to Alki	Sailboat Race	1/14/05 12:00 PM	25
Commencement Bay	Sailboat Race	1/21/05 8:00 AM	40
Everett	Sailboat Race	1/22/05 12:00 PM	25
Everett	Sailboat Race	1/29/05 12:00 PM	25
Commencement Bay	Sailboat Race	2/4/05 8:00 AM	40
Blakely Rocks to Point Jefferson	Sailboat Race	2/11/05 12:00 PM	25
Des Moines around Vashon Island and return	Sailboat Race	2/11/05 12:00 PM	10
Edmonds to Alki	Sailboat Race	2/11/05 12:00 PM	25
Everett	Sailboat Race	2/12/05 12:00 PM	25
Olympia Shoal around Anderson Island and Return	Sailboat Race	2/18/05 12:00 PM	100
Commencement Bay	Sailboat Race	2/25/05 8:00 AM	40
Everett	Sailboat Race	2/26/05 12:00 PM	25
Commencement Bay	Sailboat Race	3/4/05 8:00 AM	40
Commencement Bay	Sailboat Race	3/11/05 8:00 AM	40
Everett	Sailboat Race	3/12/05 12:00 PM	25
Blakely Rocks to Point Jefferson	Sailboat Race	3/18/05 12:00 PM	25
Edmonds to Alki	Sailboat Race	3/18/05 12:00 PM	25
Gig Harbor to Blake Island	Sailboat Race	3/18/05 12:00 PM	90
Commencement Bay	Sailboat Race	3/25/05 8:00 AM	40
Everett	Sailboat Race	3/25/05 12:00 PM	25
Budd Inlet	Sailboat Race	4/1/05 11:30 AM	40
Budd Inlet	Sailboat Race	4/2/05 11:30 AM	40

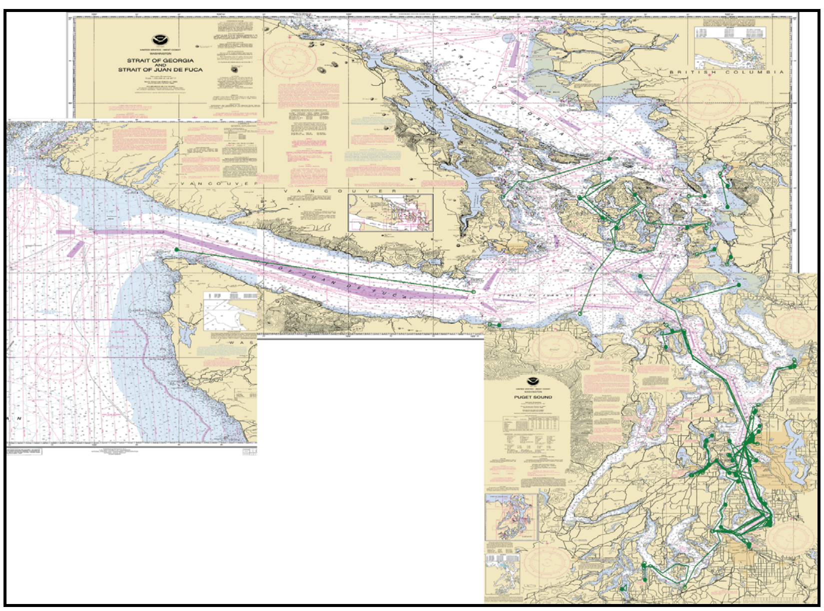

Figure C-14. Representative Routes Used by USCG Registered Yacht Regattas.

C-4. Whale Watcher Modeling

C-4.1. The Sound Watch records of interaction with whales

There is a robust commercial whale watching industry that typically operates in the region of the San Juan Islands Archipelago. Commercial whale watching vessels that participate on a daily bases can number in the hundreds at the height of the summer season, with vessels transiting the waters of Straits of Georgia, Rosario Strait, Haro Strait, Boundary Pass and Juan de Fuca-East as J and K pods of Orca Whales migrate the region. The US/Canadian international boundary is typically transparent to the commercial whale watching vessels that transit from near all port cities in the region, with US and Canadian fleets freely mixing in all locations during whale watching activities.

Unlike the commercial fisheries, there is no specific US or Canadian government competent regulatory authority with the body of knowledge that would allow the commercial whale watching fleet to be modeled. Therefore, raw data pertaining to the commercial whale watching fleet was obtained through a publicly accessible database developed and maintained Sound Watch (as part of The Whale Museum).

Sound Watch is a privately funded boater education program, with no regulatory authority over the commercial whale watching fleet. However, the intent and purpose of Sound Watch is to observe and document the activities of the whale watching fleet (commercial or private). This documentation process includes capturing specific data pertaining to:

- the number of vessels within a 2-mile radii of the whale-pod at every half hour
- the home port of vessels commonly seen within the 2-mile radii of the whale pod
- the location of the whale pod documented every half hour as Latitude and Longitude.

This data was made available packaged as the Orca Watch database. The Orca Watch database allowed the typical size and movement of the whale watching fleet to be reasonably approximated and included in the simulation.

C-4.2. Creating whale watching transits in the simulation

The movements of whale watching vessels are determined by the movements of the orca pods. The Sound Watch data gives the location of the orcas and then the number of vessels within a 2 mile radius of them. Removing the types of vessels that we have already modeled, we could move the orcas in the simulation and then add a swarm whale watching vessels around them. The number of vessels in the swarm is varied over time according to the counts in the Sound Watch data.

Each record in the Orca database consists of the date and time of the observation, the location of the orcas (actually the Sound Watch vessel), and the number of various types of vessels in a 2 mile radius around them. The number of vessels varies over the day as some vessels leave port early and some later and vessels have different lengths of trips. While it is known how many commercial whale watching vessels come from each port, it is not known which ones are present on any given day or at any given time. Thus it was not possible to model the transit from port to the orcas' location and back. Instead, successive records on a given day are used to determine a route for the orcas to follow and a speed (based on the distance and time between observations). The orcas are then moved along a straight line at the calculated speed. We then know the number of vessels that were observed near the orcas and so we add the specified number of vessels randomly dithered within a 2 mile radius of the orcas at any given time. These vessels move with the orcas in a straight line and at the calculated speed.

C-4.3. Routes used in the simulation

The movements recorded in the Orca database are shown in Figure C-15.

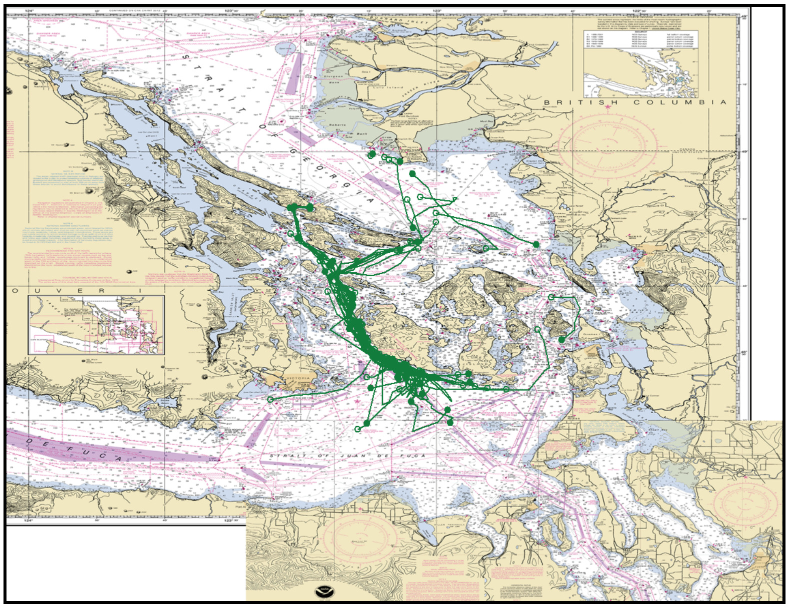

Figure C-15. Routes of whale watching movements record by Sound Watch.

C-5. Traffic Rules

C-5.1. Regulations used

Reporting to the VTS is not the only requirement for vessels transiting the region. There are restrictions on where a vessel may transit, called traffic separation schemes, restrictions on speed, one-way zones, specified anchorage areas, escorting rules for oil tankers, and pilotage requirements.

Each of the charts showing representative routes also includes pink areas along certain waterways. These depict traffic separation schemes for vessels over 20 meters in length, or regions in which vessels should not travel, keeping vessels transiting in opposite directions separated from each other. Areas of convergence of traffic are also depicted and caution is required in these areas. Vessels crossing the separation scheme must do so as close to a right angle as possible. No fishing or anchoring is allowed in the separation scheme area and vessels smaller than 20 meters and sailing vessels are not allowed to impede vessels in the scheme. Vessels not participating in the scheme or crossing the scheme must stay away from the areas depicted. There are also speed restrictions in various areas. In Elliot Bay, vessels are restricted to 5 knots; in Rosario Strait, deep draft vessels are restricted to 12 knots; and in the Saddlebags and Guemes Channel area, vessels are restricted to 6 knots.

The US Coast Guard has also designated a special navigation zone in Rosario Strait. This means that a vessel longer than 100 meters or more than 40,000 DWTs cannot meet, overtake, or cross within 2,000 yards of another vessel that meets these size limits within Rosario Strait. Also towing vessels cannot impede the passage of vessels more than 40,000 DWTs in this area. A similar designation is made in Haro Strait, but just applies to the smaller area at Turn Point, not the whole of Haro Strait. Guemes Channel and the area around Saddlebags and Vendovi Island are also areas where it is difficult for two vessels over 40,000 DWTs to maneuver around each other. While the area is not specifically designated as a special navigation zone, the Puget Sound VTS operates the area as if it were to avoid dangerous situations. Thus the Rosario Strait rules are essentially extended to include the waters east of Rosario Strait in practice.

Vessels requiring anchorage must get approval from the relevant VTS. There are many designated anchorage areas in the region, but four are specifically relevant to this study. Firstly, there is a large general anchorage area at Port Angeles for all deep draft vessels. There are then three anchorages with more limited capacity. Cherry Point anchorage is a short-term anchorage for tankers waiting to dock at Cherry Point or Ferndale. Anchorages around Vendovi Island can be used for longer; there are three designated anchorages for deep draft vessels and two for tugs. Finally, there are four anchorages at Anacortes, with one specifically designated for lightering operations.

The Puget Sound Pilots provide pilotage service for all U.S. ports and places East of 123 degrees 24' W longitude in the Strait of Juan de Fuca, including Puget Sound and adjacent inland waters. Pilotage is compulsory for all vessels except those under enrollment or engaged exclusively in the coasting trade on the west coast of the continental United States (including Alaska) and/or British Columbia. The pilot station is at Port Angeles, meaning that vessels picking up or dropping off a pilot will pass by Port Angeles at a slow speed, allowing a pilot boat to pull aside and the pilot to board or disembark on a pilot ladder. The pilots will navigate vessels to the dock and then back to the Port Angeles on their outbound trip.

Vessels transporting crude oil or petroleum products that are over 40,000 DWTs are required to have a tug escort beyond a point east of a line between Discovery Island and New Dungeness Light.

C-5.2. Implementing traffic rules in the simulation

While these rules are easy for a person to follow, we must be much more literal and specific in the simulation. Let us consider a tanker passing Buoy J and heading for BP Cherry Point. Figure C-16 shows the locations of interest in the implementation of the traffic rules in the simulation. The tanker will follow its representative route through the Straits of Juan de Fuca at sea speed, specifically 16 knots. At Port Angeles it must pick up a Puget Sound pilot from the pilot boat. In the simulation, the tanker will slow to 10 knots as it approaches Port Angeles and then to 6 knots when it nears the pick up area, before returning to 10 knots.

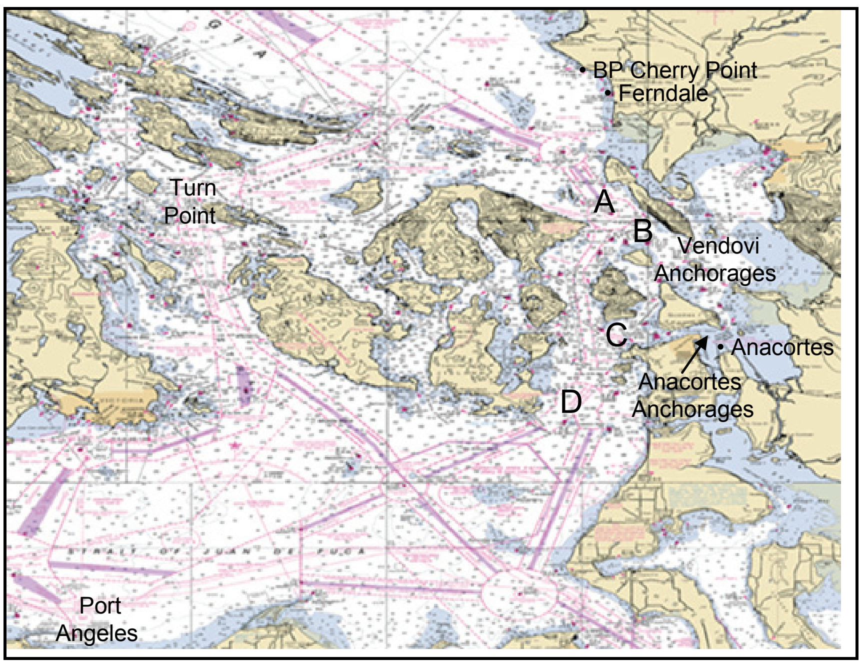

Figure C-16. The locations involved in implementing the traffic rules.

However, as the tanker continues from Port Angeles, we must now figure out when it can pass through the one-way zone at Rosario Strait. In the simulation, we find the vessel that will pass through the one-way zone ahead of the tanker, if any, and what time it is scheduled to arrive at the beginning of the one-way zone. We must then consider the directions through Rosario of the two vessels. The tanker will enter the one-way zone at point D shown in Figure C-16 and wishes to transit to point A. If the other vessel, is entering at points B, C, or D, and leaving at point A, then the tanker can follow it while maintaining the required 2,000 yard separation. We then calculate the time that the tanker can arrive at point D and slow the vessel, if need be, as it approaches to make sure it does not get there before its scheduled time. However, if the other vessel is leaving Rosario at point D or even entering at A and leaving at B or C, then the two vessels are heading for each other and the tanker must not reach point A until the other vessel is clear. We then calculate the time it will take the vessel to reach its exit point and the time that it will take the tanker to reach that point and slow the tanker to ensure that there will not be a conflict. Interviews with both Puget Sound Pilots and tanker masters from BP Shipping and ATC informed us that the vessels will not actually pass at the boundary of the one-way zone, but instead they leave room for error and pass beyond the one-way zone. Thus our calculations had to include this room for error as well. Thus we calculate the time it will take the other vessel to pass a safe distance beyond its exit point.

Using these calculations, we can now find the appropriate speed for the vessel to transit between Port Angeles and point D. If this speed falls below 5 knots, then tanker can remain at anchorage at Port Angeles, but this is rare. Through Rosario Strait, the maximum speed for the tanker is 10 knots, but if it is following another vessel then it must slow to maintain the required separation.

Once the tanker reaches a point east of a line between Discovery Island and New Dungeness Light then the simulation must check if an escort tug is needed. If the tanker is over 40,000 DWT and if it is carrying crude or product then an escort tug is added to the simulation, following behind the tanker until it arrives at dock or anchorage.

At the same time as considering the one-way zone, the tanker must also consider whether a dock is available at BP Cherry Point. Crude tankers must check if the south wing is available. Product tankers will check the north wing first (if we are running a case that includes the north wing) and then check the south wing if the north wing is not available. If a dock is not available, then there are various options.

The first choice is anchoring at the Cherry Point anchorage, which is actually just south of Ferndale in the current anchorage configuration. However, this anchorage is for short term stays, so the tanker will only use this anchorage if there is no other vessel here and a dock will become available within 12 hours. If using the Cherry Point anchorage, then the tanker will anchor here until a dock becomes available and then it will proceed to that dock.

If not using Cherry Point anchorage, then the next option is the anchorages near Vendovi Island. There are three anchorages at Vendovi. If the tanker is going to anchor at Vendovi to await a dock, then it will proceed through Rosario Strait and exit at point B and proceed to its anchorage. If other vessels are intending to leave an anchorage at Vendovi, then they will have to wait, as they cannot pass either in Rosario because of the one-way zone or between point B and the anchorage due to the effective one-way zone here.

If the Vendovi anchorages are not available, then the tanker may use the Anacortes anchorages. There are four anchorages at Anacortes. If the tanker is going to anchor at Anacortes to await a dock, then it will proceed through Rosario Strait and exit at point C and proceed to its anchorage. If other vessels are waiting to leave an anchorage at Anacortes or docks at Anacortes, then they will have to wait as they cannot pass either in Rosario because of the one-way zone or between point C and the anchorage due to the effective one-way zone here. The final option, if all possible anchorages are not available, then the tanker may anchor at Port Angeles.

Once the tanker arrives at BP Cherry Point, the relevant dock is recorded as unavailable and the time that the vessel stays at dock for loading or unloading is found from the VTOSS transit data. Two hours before the end of this time, if the tanker is scheduled to pass through Rosario again, then the simulation once again checks when the last vessel is scheduled to arrive through Rosario. The time that the tanker can arrive at point A is then calculated by considering the last vessels direction through Rosario as before for the inbound vessel. If the vessel will be delayed by more than 4 hours waiting for the one-way zone to open up, then the pilot and master will consider using a route through Haro Strait if they are heading to Port Angeles or out to sea. Some pilots and masters will choose to use Haro Strait, while others will choose to wait. Thus we use a 50% chance in the simulation that Haro Strait will be used, as developed through interviews with both pilots and tanker masters. Again an escort tug will transit with the tanker if it is over 40,000 DWT and carrying crude or product until the tanker passes a point east of a line between Discovery Island and New Dungeness Light or it reaches its destination.

C-6. Modeling weather and current within the VTRA Simulation

At a minimum the objective of the environmental modeling in the VTRA simulation should achieve a refinement similar to that of the locations definitions as displayed in Figure C-17. This location refinement is used in the expert judgment elicitation questionnaires and a weather modeling refinement at that level of detail ensures a seamless integration of the accident probability analysis model layer with the exposure analysis layer. The annual accident frequency analysis layer uses as input the incident-accident database analysis (Appendix A), the expert judgment (Appendix D), and the frequency of various scenarios occurring within the VTRA simulation (i.e. the exposure analysis).

At the outset of the project we commenced with the modeling of the dynamics of current, wind (in terms of wind speed and wind direction) and visibility. At that time little was know about the availability of traffic data for the modeling of traffic routes and traffic dynamics and we set out to produce a weather simulation for the years 2002-2005. As it turned out, due to VTOS traffic data availability at a certain level of detail we were able to model a traffic picture for the year 2005. The available VTOS data for 2005 allowed us to "replay" vessel traffic movements on a set of representative constructed routes. The previous sections have discussed this process in more detail. We shall discuss in the following sections the current model, the wind modeling and finally the visibility model as implemented within the VTRA simulation.

C-6.1. Current Modeling

A total of 130 current stations in the VTRA Study area were modeled within the VTRA study area. The primary data sources to model current were the WXTIDE software by Michael Hopper, the NOAA tides and current web-site and the MAPTECH software.

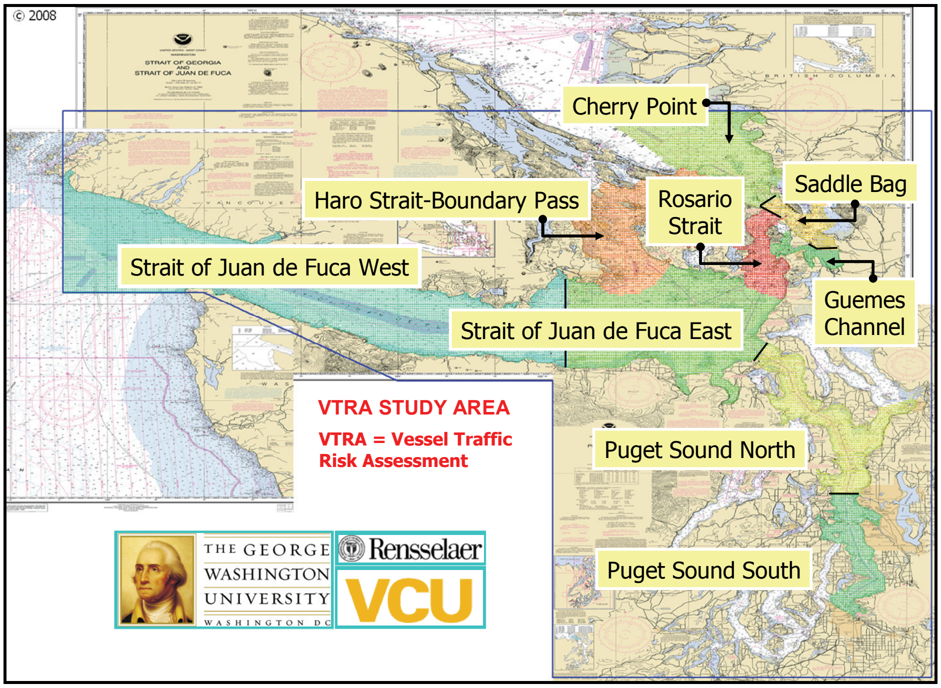

Figure C-17. The Vessel Traffic Risk Assessment (VTRA) study area and the definition of its nine different locations for expert judgment purposes.

Figure C-18 displays all the current stations within the VTRA study area for which we able to produce current tables and other information such as max ebb, max flood and ebb and flood direction parameters. Figure C-18 displays the max ebb and max flood directions and levels for the current stations in the VTRA simulation.

C-6.1.1. Current data and list of current stations.

Information from the various data sources listed in Figure C-18 was reconciled to create this figure. For " the current reference stations": Admiralty Inlet, Deceptions Pass, Gray Harbor, Rosario Strait, San Juan Channel South Entrance, Strait of Juan de Fuca and The Narrows End, current tables were generated for the years 2002-2005 from the WXTIDE Software. These tide tables were cross-checked with those available on the NOAA tides and currents web site. Figure C-19 provides a snapshot view of a section of the tide table for the reference station Rosario Strait. These tables were next electronically transferred into a database format that could be read by the VTRA simulation.

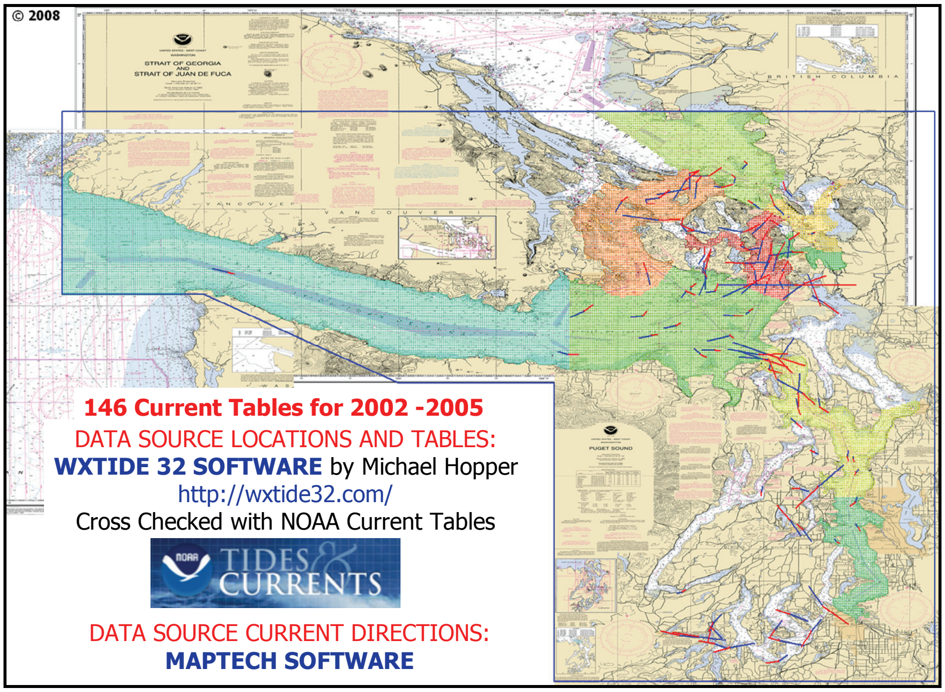

Figure C-18. Geographic locations of 130 current stations in the (VTRA) study area.

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Rosario Strait, Washington Current
Units are knots, initial timezone is PST
January 2005 low is -3.5kt, high is 2.7kt, range is 6.2kt.
Predicted historical low is -4.8kt, high is 4.0kt, range is 8.8kt.

Sunday     Monday     Tuesday    Wednesday   Thursday   Friday     Saturday

Full 12-26     12-27      12-28      12-29      12-30      12-31      01-01
F0314  2.0 S0032 -0.0 S0105  0.0 S0137  0.0 S0208  0.0 S0240  0.0 S0310  0.0
S0725 -0.0 F0338  2.1 F0404  2.1 F0435  2.2 F0510  2.1 F0547  2.1 F0621  1.9
E0954 -1.0 S0757 -0.0 S0826 -0.0 S0852 -0.0 S0916 -0.0 S0938 -0.0 S0952 -0.0
S1256  0.0 E1023 -1.1 E1056 -1.2 E1132 -1.2 E1213 -1.3 E1257 -1.4 E1338 -1.5
F1347  0.2 S1352  0.0 S1501  0.0 F1605 -0.1 F1657 -0.1 F1747 -0.1 F1839 -0.0
S1443 -0.0 F1431  0.1 F1516  0.0 E2217 -2.5 E2239 -2.2 E2303 -1.9 E2338 -1.5
E2047 -2.9 S1510 -0.0 S1532 -0.0            E2121 -2.8 E2151 -2.7

   01-02   LQtr 01-03     01-04      01-05      01-06      01-07      01-08
S0344  0.0 E0030 -1.0 E0238 -0.6 S0137 -0.0 S0347 -0.0 F0024  1.5 F0109  1.9
F0658  1.7 S0420  0.0 S0459  0.0 E0404 -0.3 E0520 -0.3 S0504 -0.0 S0556 -0.0
S1007 -0.0 F0736  1.4 F0818  1.1 S0548  0.0 S0703  0.0 E0638 -0.3 E0753 -0.5
E1421 -1.7 S1020 -0.0 S1035 -0.0 F0905  0.7 F1001  0.5 S0922  0.0 S1040  0.0
S1857  0.0 E1502 -2.0 E1541 -2.2 S1059 -0.0 S1132 -0.0 F1101  0.4 F1158  0.3
F1933  0.1 S1931  0.0 S2009  0.0 E1621 -2.5 E1705 -2.8 S1215 -0.0 S1306 -0.0
S2011 -0.0 F2033  0.3 F2145  0.5 S2049  0.0 S2131  0.0 E1754 -3.0 E1848 -3.2
           S2200 -0.0            F2314  1.0            S2213  0.0 S2255  0.0
```

Figure C-19. Example section of a tide table generated by the WXTIDE software by Michael Hopper.

C-6.1.2. Overview of current model in the simulation

The currents of the other 123 current stations are derived from the reference stations (see, e.g. the NOAA tides and currents web-site). The parameters to generate these currents for the first 30 stations are specified in Table C-6. The HTTM parameter in this table indicates if the current station's high tide is delayed or not relative to its reference station. The parameters HTHM, and HTMM are the delay or advance times in terms of hours and minutes (for high tide) whereas the HTM is a multiplier of the current station's reference stations' current speed. Similar parameters are displayed for the low tide scenario in Table C-6 as well.

Table C-6. Current data for the first 30 currents stations in the VTRA maritime simulation.

ID	Name	Lat	Long	RS	FD	ED	HTTM	HTHM	HTMM	HTM	LTTM	LTHM	LTMM	LTM	MF	ME
1	Admiralty Head	48.1500	122.700	2	145	25	+	0	03	1.29	+	0	07	1.2	2.1	3.1
2	Admiralty Inlet	48.0333	122.633	2	179	3	+	0	00	1	+	0	00	1	1.6	2.6
3	Agate Pass 1	47.7167	122.550	2	230	32	-	1	00	0.8	+	0	59	0.69	0	0
4	Agate Pass 2	47.7128	122.565	2	216	37	+	0	53	2	+	0	47	1.39	3.3	3.6
5	Alden Point	48.7578	122.980	107	25	185	+	0	26	0.89	+	0	53	1.1	1	2.1
6	Alki Point	47.5755	122.428	2	160	330	+	0	44	0.3	+	0	39	0.2	0.5	0.5
7	Apple Cove Point	47.8167	122.466	2	168	8	+	0	11	0.3	+	0	29	0.3	0.5	0.8
8	Balch Passage	47.1875	122.697	126	296	107	-	1	07	0.4	+	0	40	0.8	1.1	2.2
9	Barnes Island	48.6858	122.788	107	315	140	+	1	20	0.6	+	0	08	0.5	0.6	0.9
10	Bellingham Channel	48.5603	122.663	107	45	185	-	0	08	1.1	+	0	51	1.2	1.2	2.2
11	Blake Island	47.5250	122.499	2	131	326	-	2	37	0.2	+	0	25	0.2	0.3	0.5
12	Boundary Pass	48.6953	123.235	107	41	203	-	0	34	1.6	+	0	02	1.39	0.7	1.6
13	Burrows Bay	48.4628	122.682	107	22	209	+	0	48	0.89	+	0	43	0.2	1	0.4
14	channel	47.4667	122.700	107	304	96	+	0	34	2	+	0	57	0.69	0	0
15	Burrows Island Light	48.4833	122.733	107	15	200	+	0	03	1	+	0	16	1.1	1.1	2.1
16	Bush Point Light	48.0333	122.616	2	144	309	+	0	21	1.1	+	0	35	1.1	1.7	2.9
17	Cattle Point 1	48.4338	122.947	108	340	195	+	0	20	0.3	+	0	01	0.89	0.8	2.4
18	Cattle Point 2	48.4000	123.000	2	46	187	-	0	52	0.4	+	0	42	0.2	0.6	0.4
19	Cattle Point 3	48.3833	123.016	2	120	210	+	1	11	0.6	+	0	44	0.3	0.9	0.9
20	Clark Island	48.7333	122.766	107	335	150	+	1	14	0.6	+	0	02	0.6	0	0
21	Colville Island 1	48.4000	122.816	107	55	235	+	0	31	1	+	0	07	1.2	1.1	2.3
22	Colville Island 2	48.4167	122.783	107	55	215	-	0	14	1.39	+	0	14	1	1.6	1.9
23	Crane Island	48.5895	122.998	108	288	75	+	0	35	0.2	+	0	07	0.1	0.4	0.3
24	Dana Passage	47.1633	122.867	126	249	76	+	0	09	0.5	+	0	12	0.8	1.5	2.2
25	Deception Island 1	48.4197	122.698	107	17	161	+	1	14	0.6	-	1	23	0.5	1.3	1.1
26	Deception Island 2	47.4000	122.700	107	35	210	-	0	04	1.2	-	2	29	0.6	0	0
27	Deception Island 3	48.4125	122.739	107	15	190	-	0	50	0.8	+	0	34	0.69	0.9	1.3
28	Deception Pass	48.4062	122.643	28	90	270	+	0	00	1	+	0	00	1	5.2	6.6
29	Discovery Island 1	48.3833	123.200	2	25	250	+	0	15	0.6	+	0	04	0.89	0	0
30	Discovery Island 2	48.4500	123.150	2	345	170	+	1	03	0.8	+	0	59	0.6	1.3	1.6

C-6.1.3. Representative results of current in the simulation

Tide tables only specify when a current station's high tide, low tide and slack states are occurring and provide the current speeds at these times. To model the current in the VTRA simulation in between the max ebb and max flood stages, a harmonic curve was fitted between these time points. Figure C-20 provides a section of the resulting fitted time series for the reference current station Rosario Strait. Similar time series were generated during the VTRA maritime simulation for the other current stations as well. The current experienced by a particular vessel within the VTRA maritime simulation was determined by looking up the current of its closest current station within the VTRA study area (see Figure C-18 for a geographic depiction of the available current stations within the study area).

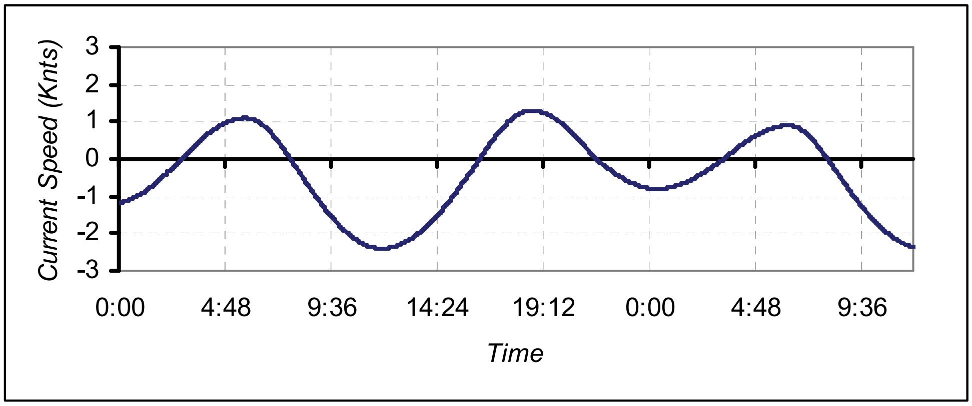


Figure C-20. A time series section of the Rosario Strait reference current station.

C-6.2. Wind Modeling

Figure C-21 provides a geographical depiction of the different weather stations for which various meteorological data was downloaded from the National Climatic Data Center's website. Tables C-7 and C-8 describes this downloaded data in more detail. Table C-7 provides the lat-long coordinates of the 30 weather stations that we queried to simulate weather within the VTRA simulation. Table C-8 details the specific meteorological data that we were able to download from the National Climatic Data Center for these weather stations. In the subsections below we shall further elaborate which weather stations were selected for particular "pieces" of our weather simulation model.

C-6.2.1. NOAA weather station data

Figure C-22 provides a geographical depiction of the weather stations that were used to provide wind speed and wind direction by the hour for the locations within the VTRA study area.

C-6.2.2. Overview of wind modeling

Table C-9 provides an example section of the wind data downloaded from the national climatic datacenter for the Race Rocks Campbell weather station.

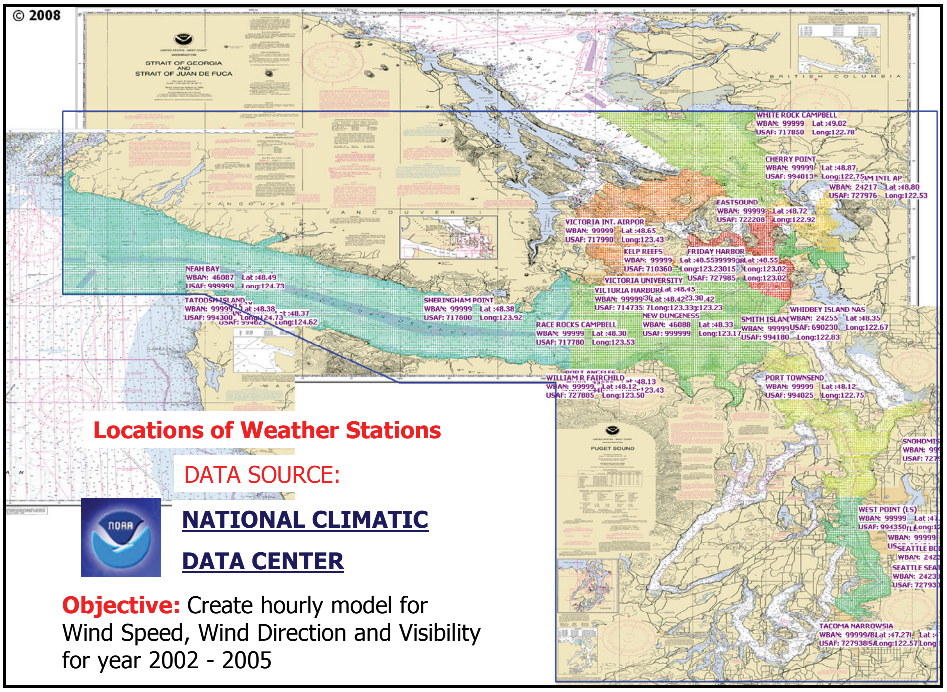


Figure C-21. Geographic locations of weather stations in the (VTRA) study area queried to model hourly behavior of environmental variables.

Table C-7. Geographic locations of thirty weather stations queried from the National Climatic Data Center to model weather in the VTRA maritime simulation.

ID	USAF	WBAN	NAME	CALL	LAT	LONG
1	727976	24217	BELLINGHAM INTL AP	KBLI	48.8	122.533
2	994013	99999	CHERRY POINT	CHYW1	48.867	122.75
3	722208	99999	EASTSOUND	KORS	48.717	122.917
4	727985	99999	FRIDAY HARBOR	KFHR	48.517	123.017
5	994015	99999	FRIDAY HARBOR	FRDW1	48.55	123.017
6	999999	46087	NEAH BAY		48.49	124.73
7	994021	99999	NEAH BAY	NEAW1	48.367	124.617
8	994024	99999	PORT ANGELES	PTAW1	48.133	123.433
9	994025	99999	PORT TOWNSEND	PTWW1	48.117	122.75
10	994014	99999	SEATTLE	EBSW1	47.6	122.333
11	727935	24234	SEATTLE BOEING FIELD	KBFI	47.533	122.3
12	727930	24233	SEATTLE SEATTLE-TACOMA INTL A	KSEA	47.467	122.317
13	994180	99999	SMITH ISLAND	SISW1	48.317	122.833
14	727937	99999	SNOHOMISH CO	KPAE	47.9	122.283
15	994048	99999	TACOMA	TCNW1	47.267	122.417
16	727938	99999	TACOMA NARROWS	KTIW	47.267	122.567
17	994300	99999	TATOOSH ISLAND	TTIW1	48.383	124.733
18	994350	99999	WEST POINT (LS)	WPOW1	47.667	122.433
19	690230	24255	WHIDBEY ISLAND NAS	KNUW	48.35	122.667
20	727885	99999	WILLIAM R FAIRCHILD	KCLM	48.117	123.5
21	710310	99999	DISCOVERY ISLAND		48.417	123.233
22	717780	99999	RACE ROCKS CAMPBELL		48.3	123.533
23	717800	99999	SHERINGHAM POINT		48.383	123.917
24	717990	99999	VICTORIA INT. AIRPOR		48.65	123.433
25	717830	99999	VICTORIA UNIVERSITY		48.45	123.3
26	717850	99999	WHITE ROCK CAMPBELL		49.017	122.783
27	710360	99999	KELP REEFS		48.55	123.233
28	714735	99999	VICTORIA HARBOR		48.417	123.333
29	994070	99999	DESTRUCTION ISLAND		47.667	124.483
30	999999	46088	NEW DUNGENESS		48.33	123.17

Table C-8. Meteorological data downloaded from the National Climatic Data Center for the weather stations specified in Table C-7.

ID	NAME	WS	WD	LAND VIS	DEW	WTMP	PERIOD
1	BELLINGHAM INTL AP	1	1	1	1	0	01-02 12-05
2	CHERRY POINT	0	0	0	0	1	01-05 12-05
3	EASTSOUND	1	1	1	1	0	08-04 12-05
4	FRIDAY HARBOR	1	1	1	1	0	01-02 12-05
5	FRIDAY HARBOR	0	0	0	0	1	04-05 12-05
6	NEAH BAY	1	0	0	1	1	01-04 12-05
7	NEAH BAY	0	0	0	0	1	01-05 12-05
8	PORT ANGELES	0	0	0	0	1	04-05 12-05
9	PORT TOWNSEND	0	0	0	0	1	04-05 12-05
10	SEATTLE	1	1	0	0	1	04-05 12-05
11	SEATTLE BOEING FIELD	1	1	1	1	0	01-04 12-05
12	SEATTLE SEATTLE-TACOMA INTL A	1	1	1	1	0	01-02 12-05
13	SMITH ISLAND	1	1	0	0	0	01-02 12-05
14	SNOHOMISH CO	1	1	1	1	0	01-02 12-05
15	TACOMA	0	0	0	0	1	04-05 12-05
16	TACOMA NARROWS	1	1	1	1	0	01-02 12-05
17	TATOOSH ISLAND	1	1	0	0	0	01-02 12-05
18	WEST POINT (LS)	1	1	0	1	0	01-02 12-05
19	WHIDBEY ISLAND NAS	1	1	1	1	0	01-02 12-05
20	WILLIAM R FAIRCHILD	1	1	1	1	0	01-02 12-05
21	DISCOVERY ISLAND	1	1	0	0	0	12-02 12-05
22	RACE ROCKS CAMPBELL	1	1	0	0	0	01-02 12-05
23	SHERINGHAM POINT	1	1	0	1	0	01-02 12-05
24	VICTORIA INT. AIRPOR	1	1	1	1	0	01-02 12-05
25	VICTORIA UNIVERSITY	1	1	0	1	0	01-02 12-05
26	WHITE ROCK CAMPBELL	1	1	0	1	0	01-02 12-05
27	KELP REEFS	1	1	0	0	0	06-03 12-05
28	VICTORIA HARBOR	1	1	1	1	0	01-02 12-05
29	DESTRUCTION ISLAND	1	1	0	0	0	01-02 12-05
30	NEW DUNGENESS	1	1	0	1	1	07-04 12-05

Table C-9. A section of a downloaded wind data table for the Race Rock Campbell weather station from the National Climatic Data Center.

Date	HrMn	WD	WS
20051010	200	10	3.6
20051010	300	90	2.5
20051010	400	350	0.5
20051010	500	150	2
20051010	600	999	0
20051010	700	40	1
20051010	800	70	3
20051010	900	10	3

Simple because one can download specific meteorological data for a particular weather station for a selected from the National Climatic Data Center does not mean that this data is of a good quality. Please note for example the presence of the observation 999 in Table C-9. This indicates that for that particular hour no observation is available. In the presence of such an observation, the wind of the previous hour is selected to continue for one additional hour.

C-6.2.3. Representative results of wind in the simulation

Wind speeds and directions were replayed utilizing similar downloaded tables as Table C-9 for various selected weather stations. The weather stations in Figure C-22 were primarily selected based on the quality of their data (i.e. based on the absence of long sequences of similar 999 records as displayed in Table C-9) and their location relative to the definition of the different locations within the VTRA study area. For example, Figure C-22 depicts that the West point (LS) weather stations was used to both provide wind speed and wind direction for the Puget Sound North and the Puget Sound South locations.

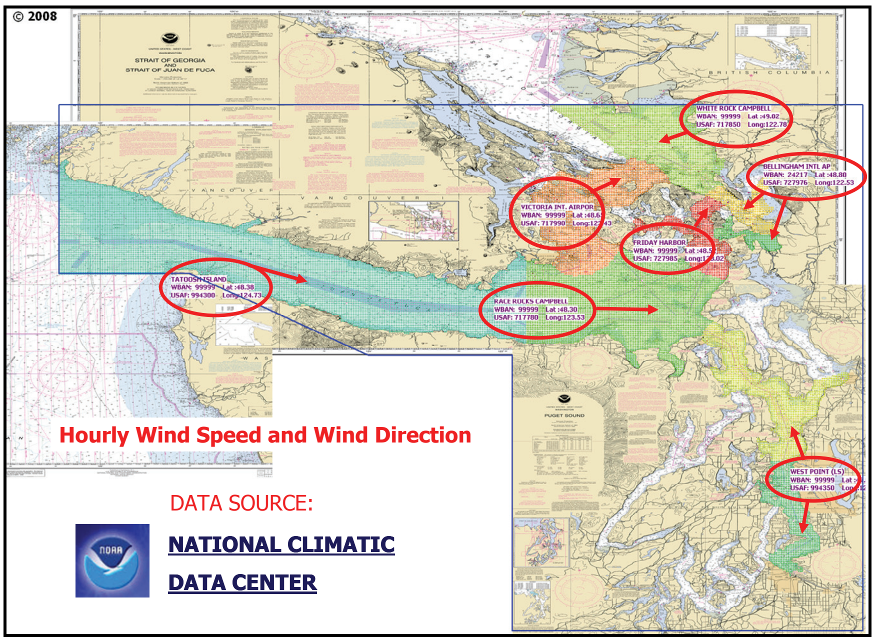
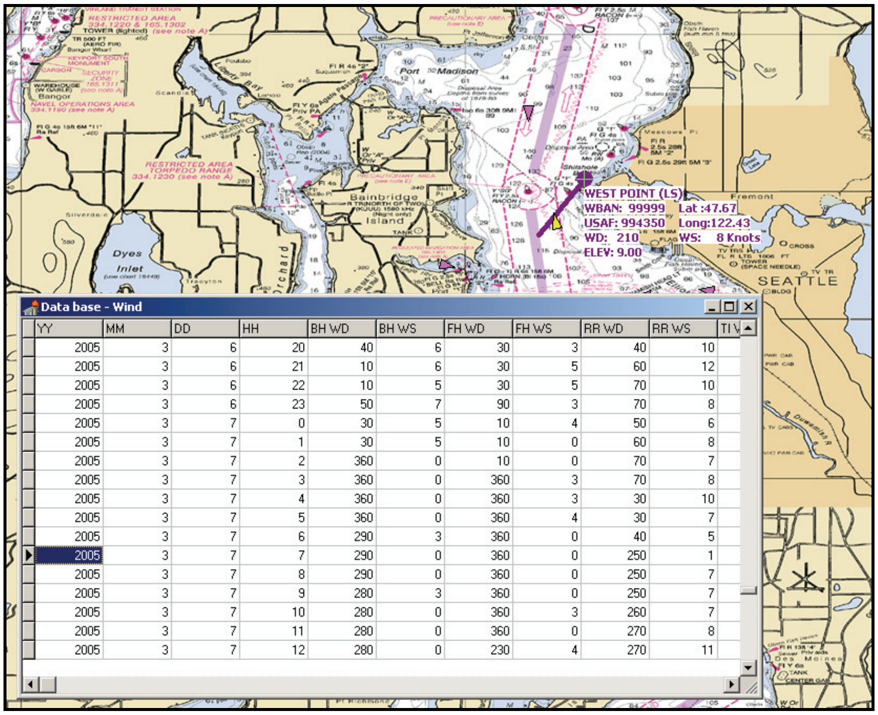


Figure C-22. Geographic locations of weather stations in the VTRA study area queried to model hourly behavior of wind speed and wind direction.

Figure C-23 displays a screenshot of the wind speed and wind direction databases within the VTRA maritime simulation. It also specifically displays the current wind speed and wind direction of the West Point (LS) weather stations. The length of the arrow varies as the wind speed changes and the angle changes according to the angles as specified in wind databases.



YY	MM	DD	HH	BH WD	BH WS	FH WD	FH WS	RR WD	RR WS
2005	3	6	20	40	6	30	3	40	10
2005	3	6	21	10	6	30	5	60	12
2005	3	6	22	10	5	30	5	70	10
2005	3	6	23	50	7	90	3	70	8
2005	3	7	0	30	5	10	4	50	6
2005	3	7	1	30	5	10	0	60	8
2005	3	7	2	360	0	10	0	70	7
2005	3	7	3	360	0	360	3	70	8
2005	3	7	4	360	0	360	3	30	10
2005	3	7	5	360	0	360	4	30	7
2005	3	7	6	290	3	360	0	40	5
2005	3	7	7	290	0	360	0	250	1
2005	3	7	8	290	0	360	0	250	7
2005	3	7	9	280	3	360	0	250	7
2005	3	7	10	280	0	360	3	260	7
2005	3	7	11	280	0	360	0	270	8
2005	3	7	12	280	0	230	4	270	11

Figure C-23. A screen shot of the resulting wind speed and direction database in the VTRA maritime simulation.

C-6.3. Visibility Modeling

Figure C-22 provides a geographical depiction of the weather stations that were used to provide land visibility data by the hour for the locations within the VTRA study area. One observes that the locations of these weather stations coincide with the various airports within the VTRA study area. No electronic data source with hourly land visibility data was available at the entrance of the West Strait of Juan de Fuca. Hence, the land visibility data from the William Fairchild airport had to be used for both the West and East Strait of Juan de Fuca locations.

While certainly land visibility is one of the components that determine bad visibility on the water another type of fog that is modeled within the VTRA maritime simulation is sea fog. Indeed, it is not uncommon to have perfect visibility on land, but fog on the water. Unfortunately, no electronic data repositories are available (to the best of our knowledge) with hourly sea fog data. In the sections below we will further discuss in some detail the specifics of the sea fog visibility model that we implemented within the VTRA simulation model. This model had previously been used in the Washington State Ferry Risk Assessment (Van Dorp et. al (2001)) and in the San Francisco Bay Exposure Assessment (Merrick et. al (2003). For convenience these journal papers are attached as sub-appendices.

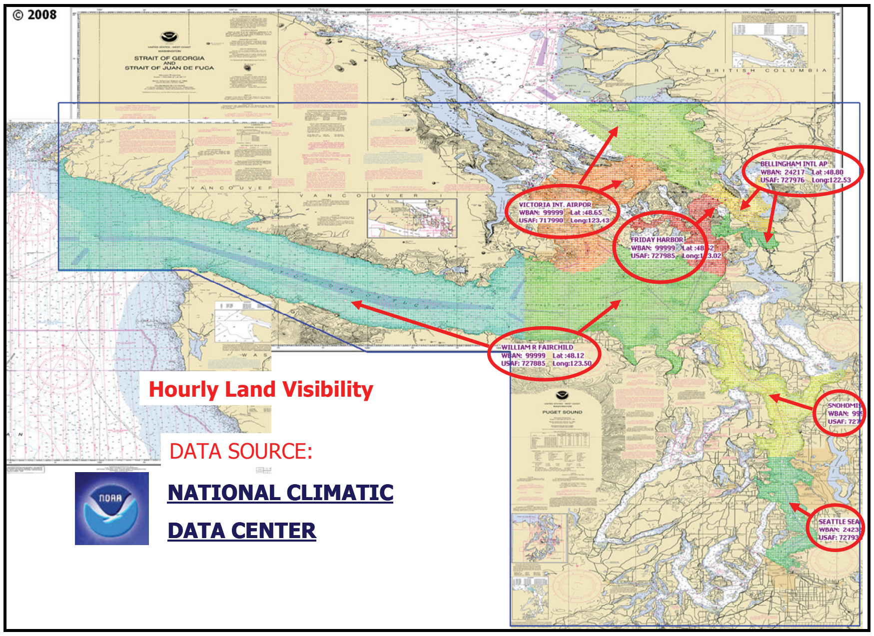


Figure C-24. Geographic locations of weather stations in the VTRA study area queried to model hourly behavior of land visibility.

Perhaps with the advance of AIS on board of vessels, the vessels within a specific area could serve as a future data source for collecting sea fog data. Indeed, under foggy conditions in a particular area vessel are required to operate their fog signals. This data could be transmitted to an AIS datacenter at the same time when its location is transmitted. At this time, however, we have to rely on the sea fog visibility model discussed below.

C-6.3.1. Overview of visibility modeling.

Our sea visibility model is a meteorological model taken from Sanderson (1982) and is explained in more detail in Figure C-25. The model specified the occurrence of sea fog when the difference between the dew point temperature and the water temperature reaches a certain threshold Δ. The model states that when Δ is between 0 and 2 degrees Celsius patches of fog develop and when Δ is larger than two degrees Celcius a dense fog develops.

This phenomenon requires that wind do not exceed 3 Beaufort. We utilized the information from the wind model discussed in the previous section to apply the 3 Beaufort threshold.

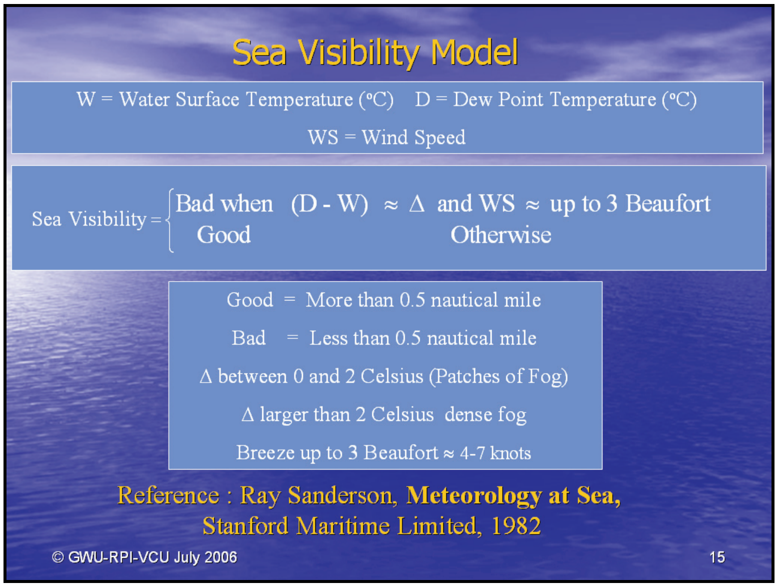


Figure C-25. Sea visibility model used in the VTRA maritime simulation.

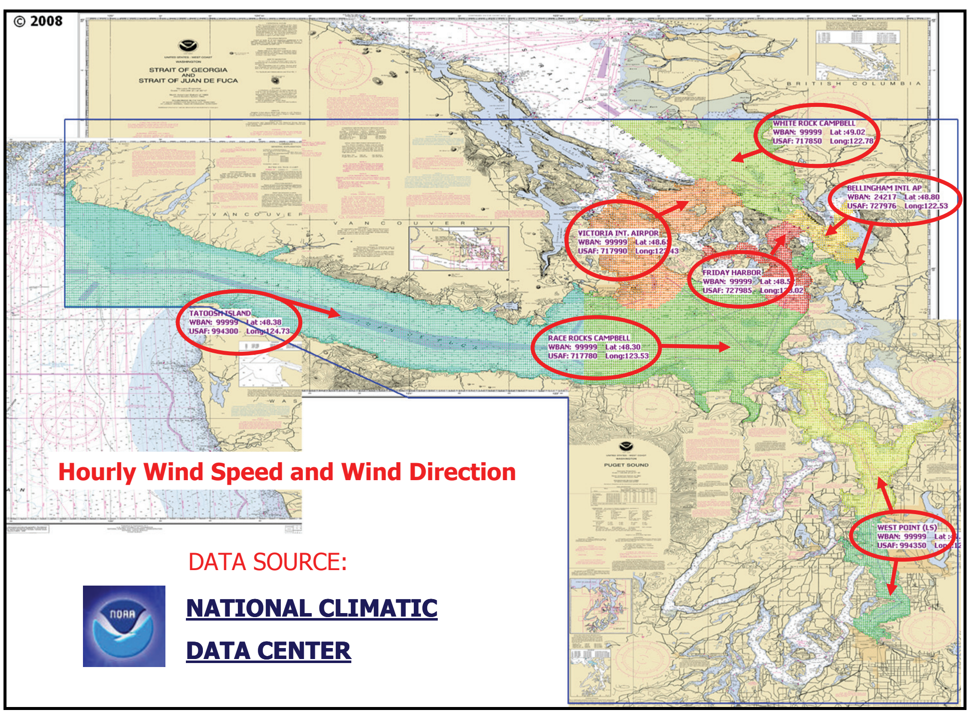


Figure C-26. Geographic locations of weather stations in the VTRA study area queried with hourly dew point data.

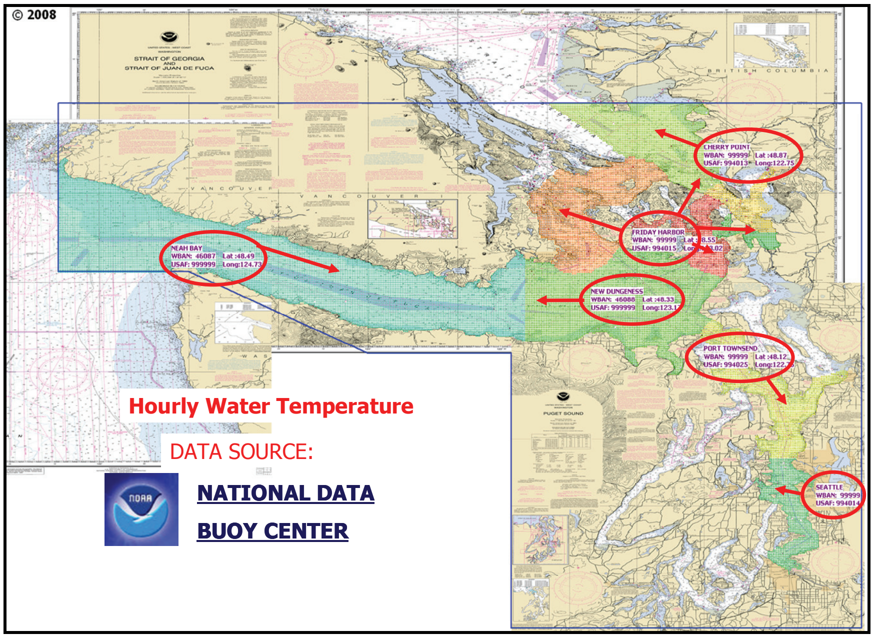


Figure C-27. Geographic locations of weather stations in the VTRA study area queried with hourly water temperature data.

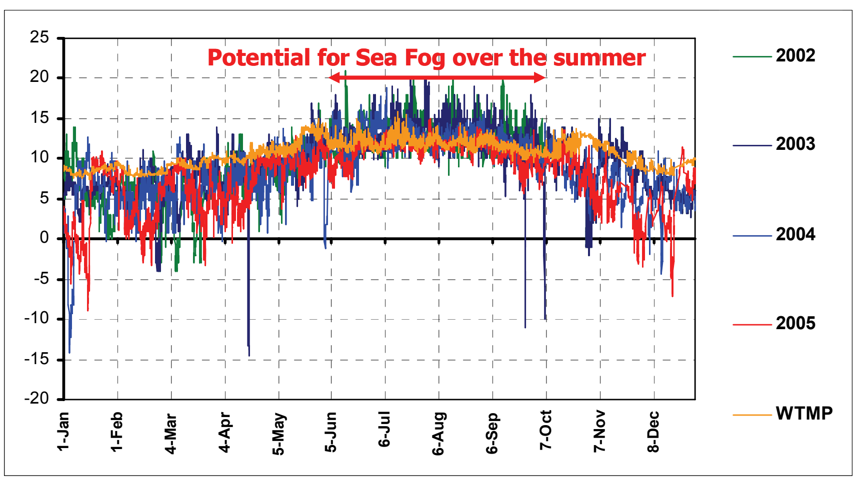


Figure C-28. Hourly time series of water temperature and dew point for the West Strait of Juan de Fuca location in Figure C-17.

Figure C-26 provides a graphic of those weather stations for which were able to obtain hourly dew point data from the National Climatic Data Center. Figure C-27 provides a graphic of those weather stations for which were able to obtain hourly water temperature data from the National Climatic Data Center. Please note that some of these weather stations coincide with the NOAA weather buoys. Combining the information from Figures C-26 and C-27 we obtain the hourly time series for the West Strait of Juan de Fuca location as displayed in Figure C-17.

Unfortunately, we were only able to obtain one full year of water temperature data. Also note when comparing Figures C-26 and Figure C-27 that these observation are not taken at the same location. Hence, rather than implementing the threshold parameter Δ settings from Figure C-25 literally this parameter was used as a calibration parameter to ensure an average set number of bad visibility days in the locations defined in Figure C-17. Prior to this calibration process the land visibility information from Figure C-24 was integrated with the sea visibility model. The land visibility data contains an hourly distance of visibility.

Figure C-29 provides the anecdotal information that we were able to obtain from the US Coast pilot publication (2006 edition). Figure C-30 provides similar information that we were able to obtain for the East Strait of Juan de Fuca. Figure C-29 and Figure C-30 detail that we were able to calibrate at 0.75 miles to an average of 54 days (as opposed to the 55 days specified by the US Coast Pilot) for the West Strait of Juan de Fuca location and 35 days for the East Strait of Juan de Fuca location. This results next in an average of 50 days of bad visibility in the West Strait of Juan de Fuca at 0.5 miles and an average of 31 days of bad visibility at the East Strait of Juan de Fuca. The 0.5 miles threshold is used in the expert judgment elicitation for accident probabilities (see Appendix D).

After calibration of our visibility model, Figure C-31 displays the resulting percentage of time bad visibility by the hour for the West Strait of Juan de Fuca. Figure C-32 displays the same information for the East Strait of Juan de Fuca. Please note the presence of primarily a channel sea fog phenomenon in the early morning hours and early evening hours in the months of June, July, August and to a lesser extent in the month of September in the West Strait of Juan Fuca location. A similar channel fog phenomenon followed from our sea visibility model for the Golden Gate Bridge location in the San Francisco Bay exposure assessment (see, Merrick et. al 2003). The bad visibility within these months during the day time is primarily a land visibility phenomenon.

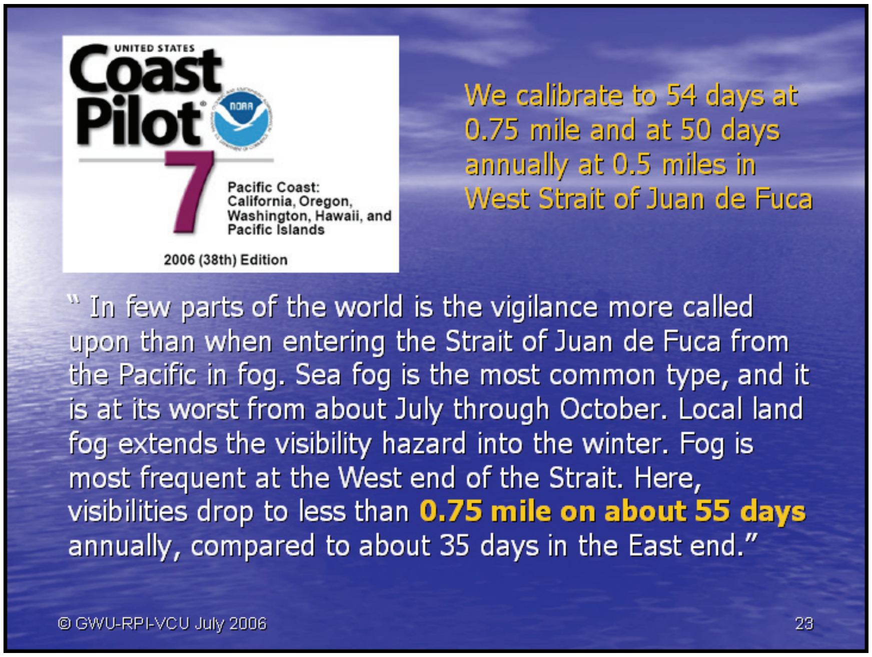


Figure C-29. Anecdotal data from the US Coast Pilot (2006 edition) regarding the average number of bad visibility days at the West Strait of Juan de Fuca.

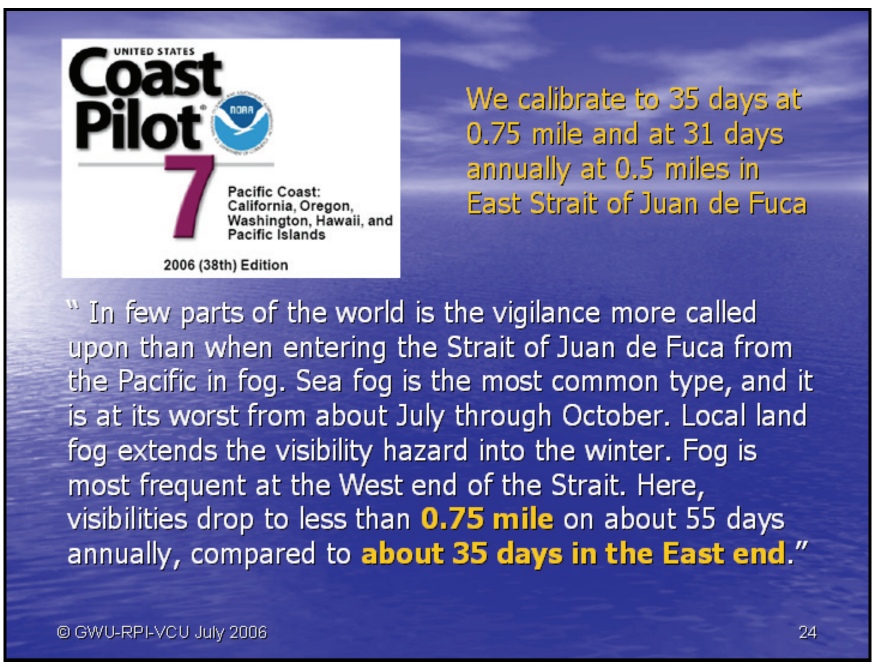


Figure C-30. Anecdotal data from the US Coast Pilot (2006 edition) regarding the average number of bad visibility days at the East Strait of Juan de Fuca.

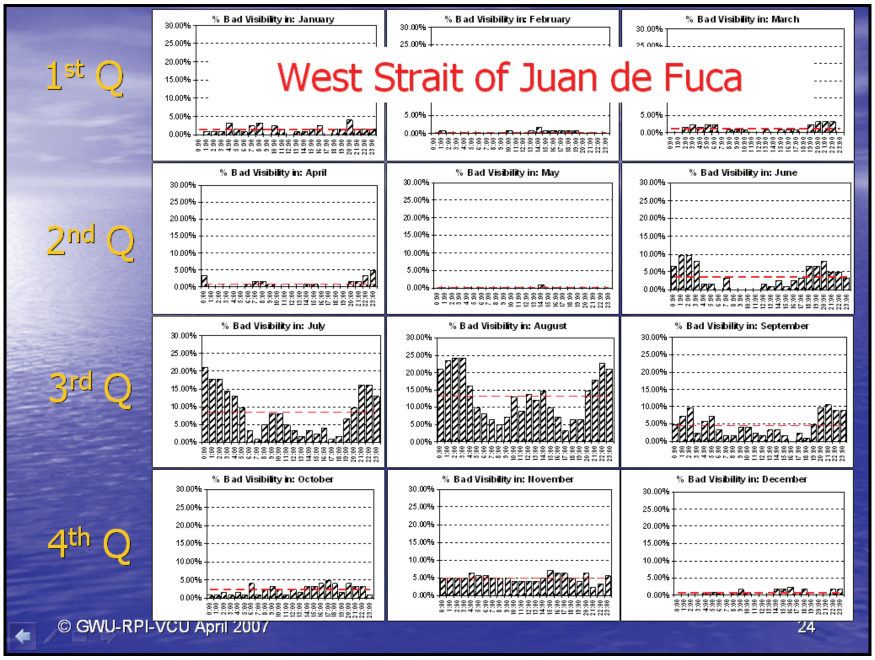


Figure C-31. Hourly modeled percentage of time bad visibility by month in West Strait of Juan de Fuca.

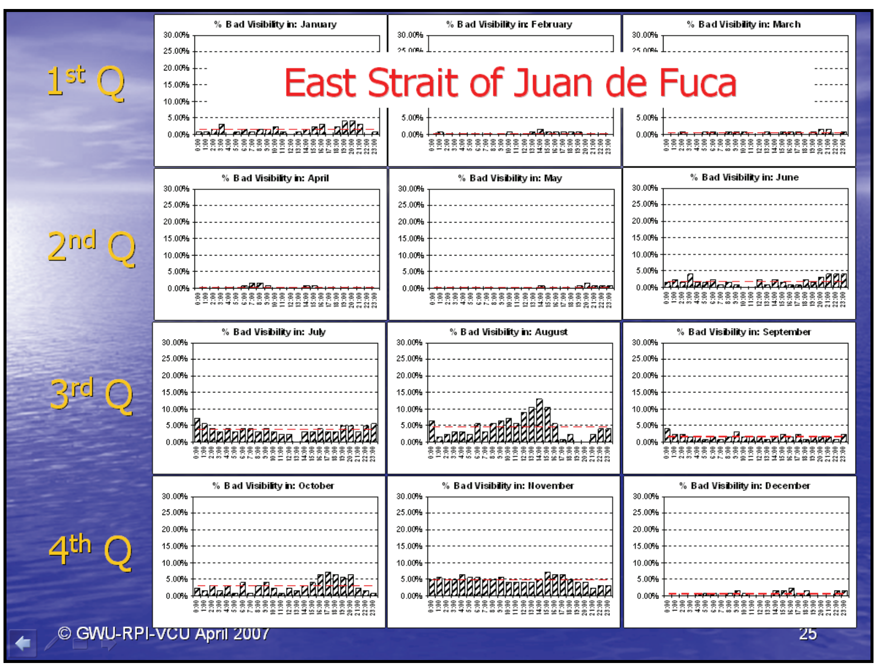


Figure C-32. Hourly modeled percentage of time bad visibility by month in East Strait of Juan de Fuca.

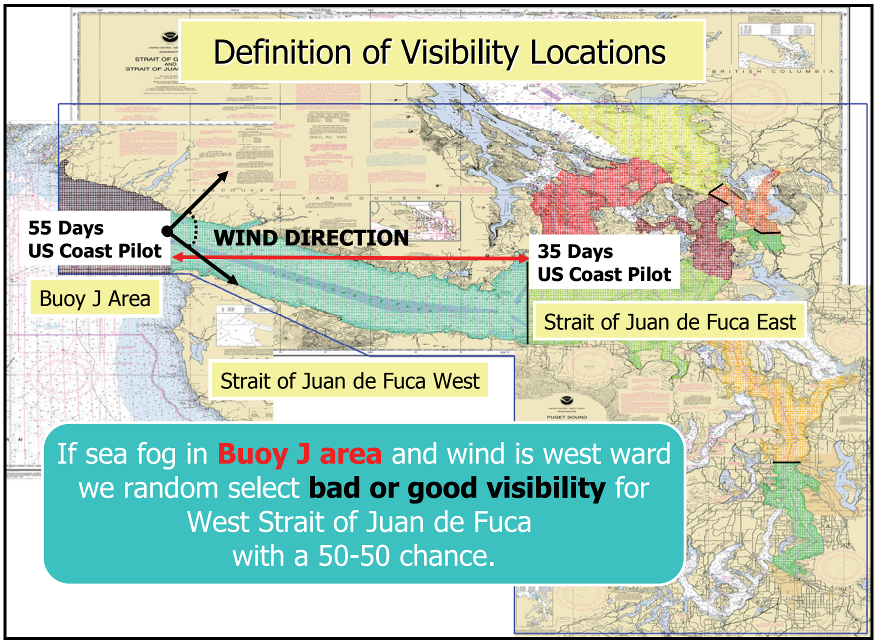


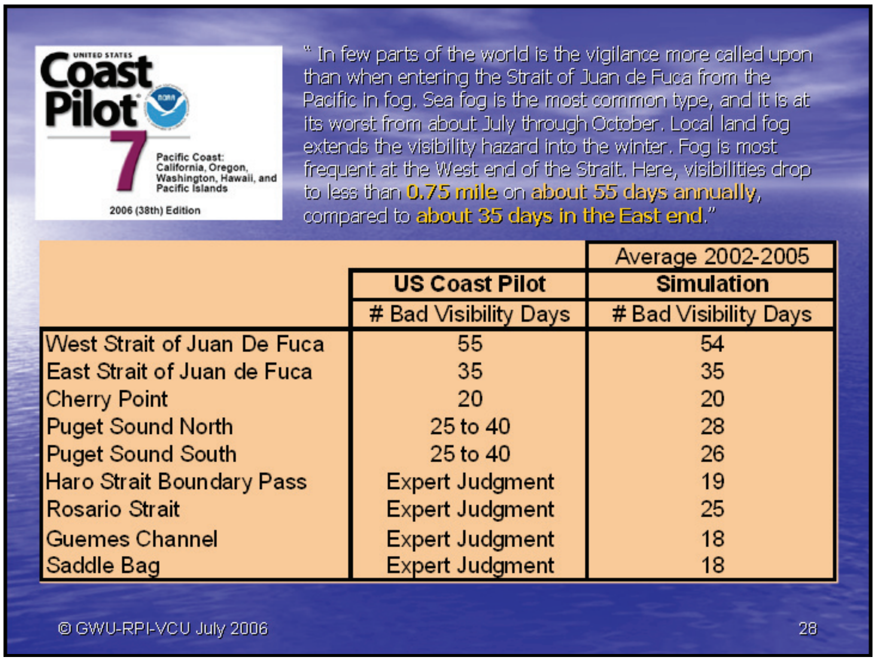
Figure C-33. Modeling a channel fog phenomenon in the Strait of Juan de Fuca West.

We observe from Figure C-32 a less pronounces see channel fog phenomenon for the East Strait of Juan de Fuca (most pronounced in the month of July).

Given the large geographical area that the modeled West Strait of Juan de Fuca location in Figure C-17 encompasses, we have modeled a more smooth transition between the 54 and 35 days for the West Strait of Juan de Fuca and East Strait of Juan de Fuca as specified by the US Coast Pilot. Given that we obtained water temperature data to the extreme west end of the Strait of Juan de Fuca we added a visibility location "Buoy J" as depicted in Figure C-33, we applied the 55 days of bad visibility from the US Coast Pilot to this location. To further model a channel fog phenomenon, we sample with a 50-50 chance bad visibility with the visibility location Strait of Juan de Fuca West (as displayed in Figure C-33) if the wind is eastward into the West Strait of Juan de Fuca (as depicted in Figure C-33) and bad visibility is present in the Buoy J location depicted in Figure C-33.

The US Coast Pilot (2006 edition) also provided a range for the number of bad visibility days experiences typically experienced in the Puget Sound North and South. Since it also states that visibility in the Puget Sound North and South is less prevalent as in the Strait of Juan de

Fuca, it was decided to calibrate our visibility models for these locations towards the lower bounds of the specified range from the US Coast Pilot. Unfortunately, no anecdotal information in terms of number of annual bad visibility days was provided by the US Coast Pilot for the location definitions Haro-Strait-Boundary pass, Rosario Strait, Guemes Channel, and Saddle Bag in Figure C-17. To arrive at the number of days to which the visibility model was calibrated we utilized expert judgment elicitation. Figure C-34 provides the number of bad visibility days that followed after calibration to the expert judgment. This process is described in more detail in the next section.



	US Coast Pilot	Average 2002-2005 Simulation
	# Bad Visibility Days	# Bad Visibility Days
West Strait of Juan De Fuca	55	54
East Strait of Juan de Fuca	35	35
Cherry Point	20	20
Puget Sound North	25 to 40	28
Puget Sound South	25 to 40	26
Haro Strait Boundary Pass	Expert Judgment	19
Rosario Strait	Expert Judgment	25
Guemes Channel	Expert Judgment	18
Saddle Bag	Expert Judgment	18

Figure C-34. Anecdotal data from the US Coast Pilot (2006 edition) regarding the average number of bad visibility days for the Puget Sound South and North.

C-6.3.2. Calibrating the visibility model with expert judgments.

We were extremely fortunate that in November 2006 the Puget Sound Harbor Safety committee agreed to provide us a platform to present interim results of the VTRA study and ask for feedback from the Puget Sound maritime community. This platform and the close relationship between the Puget Sound maritime community, were instrumental in obtaining access to experts and the expert participation that we received. We were able to hold our first expert judgment elicitation session one month after the introduction to the Puget Sound

Harbor Safety committee. Invitations to the expert judgment elicitation sessions were sent out initially by the US Coast Guard and later on by the Puget Sound Harbor Safety committee. None of the experts personally benefited from participating in the expert judgment elicitation. They donated their time for the enhancement of the safety levels in their maritime domain and they should be commended for it. Each expert judgment elicitation session consisted of a morning and afternoon session.

Two elicitation sessions were held that included visibility questionnaires; one in December 2006 and one in February 2007. The elicitation sessions were held at the US Coast Guard Seattle Sector VTS building. In total 20 experts responded to these questionnaires. The cumulative years of experience within the VTRA study area of these experts equals 513. Table C-10 further describes the experience by the type of expert.

As part of our Institutional Review Board procedure regarding research involving human subjects, it is a requirement that the expert remains anonymous. However, the experts were asked to provide their job title and number of years of sailing experience (see Figure D-1) in the VTRA area (although they were not forced to provide this information to participate in the survey). It was explained to the experts that every effort will be made to keep their provided information confidential. There were instructed that if any of the questions they were asked as part of this study made them feel uncomfortable they could refuse to answer that question.

Table C-10. Experience of experts in the VTRA Study area that participated in the visibility expert judgment elicitation sessions.

5 QUESTIONNAIRES	EXPERTS - Numbers indicate years sailing experience in VTRA Study area	CUMULATIVE EXPERIENCE (YRS)	SESSIONS
Visibility Pair Wise Comparison	7 PILOTS (42,34,32,25,16,16)	186	Dec-06
	6 TUG OPERATORS (39, 30, 30, 30, 15, 12)	156	Feb-07
	4 FERRY OPERATORS (31, 30, 25, 8)	94	
	2 PORT CAPTAINS (27, 25)	52	
	1 VTS WATCH (25)	25	
TOTAL	20 Experts	513	2 Sessions

The objective of the visibility elicitation sessions is to obtain relative percentages of time that mariners have to operate their fog signals in the locations: East Strait of Juan de Fuca, Haro-

Stait/Boundary Pass, Rosario Strait, Guemes Channel and Saddle Bag as per the location definitions in Figure C-17. Figure C-17 was provided to the experts as an explanation of the locations in the introduction of the visibility questionnaires. The location East –Strait of Juan de Fuca was included within the visibility questions to allow for calibration between the visibility modeling in the previous sections and the expert judgment results.

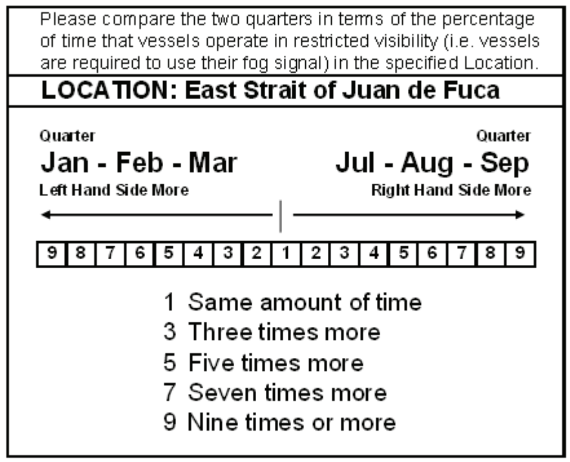


Figure C-35. Example question from East Strait of Juan de Fuca visibility pair wise comparison questionnaire.

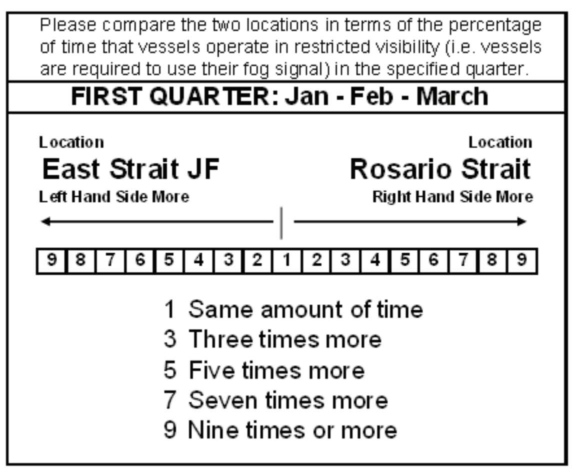


Figure C-36. Example question from Location visibility pair wise comparison questionnaire by quarter.

During one visibility questionnaire elicitation session and expert responded to 5 separate questionnaires. One questionnaire consisted of 6 pair wise comparison question wherein an expert was asked to compare one quarter of the year to another quarter of the year for the East Strait of Juan de Fuca location. Figure C-35 above displays one of the questions in this questionnaire. The four other questionnaires involved pair wise comparisons of locations, one for each quarter. Since these questionnaires involved a total of five locations each questionnaire consisted of 10 questions. Figure C-36 above displays an example question of such a questionnaire for the first quarter of the year.

From the responses of the East Strait of Juan de Fuca questionnaires we can evaluate for each expert the relative multiplier that one quarter of the year for the East Strait of Juan de Fuca has more or less frequent bad visibility than another quarter. From the location questionnaires we can evaluate for each expert the relative multiplier that one location has more of less frequency bad visibility than another location. The responses of an individual expert are compared to an individual expert at random. A statistical hypothesis test involving a consistency index (similar to the Analytical Hierarchy Process (AHP) methodology; see Foreman and Selly (2002)) was formulated such that there was only a 5% chance that a random responding expert would have a lower consistency index. Lower consistency index values are better than higher ones. An expert's response was discarded if a random responding expert had a higher than 5% chance of obtaining a consistency index lower than that of the individual expert. Expert that were retained by applying the rule above were deemed consistent relative to a random responding expert.

The multiplicative weights amongst the remaining consistent expert were averaged using the geometric mean. Summary results of the by quarter questionnaire for the East Strait of Juan de Fuca location are displayed in Figure C-37. The green line represents the results that followed for the East Strait of Juan de Fuca location from the sea/land visibility model discussed in more detail in the previous section. The red line indicates the results for the experts that participated in the December 2006 elicitation session and the blue one indicates the results of those experts that participated in the February 2007 elicitation session, after calibrating the overall average of the expert responses to the overall average of the sea/land visibility model. Please note, the remarkable agreement of both groups of experts relative to the results of our sea/land visibility model discussed in the previous sections. Also note remarkable agreement between both groups of experts. Both display an over estimation in the first and third quarters of the year and an under estimation during the fourth quarter of the year (relative to our sea/land visibility model).

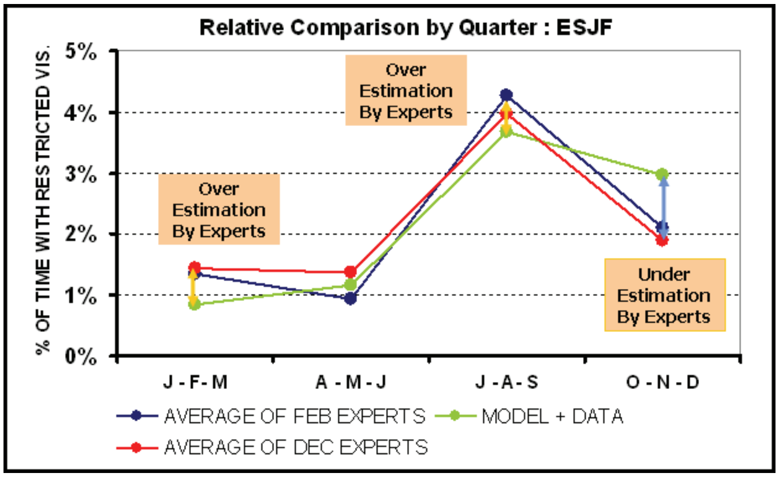


Figure C-37. Expert judgment visibility elicitation results by quarter for the East Strait of Juan de Fuca

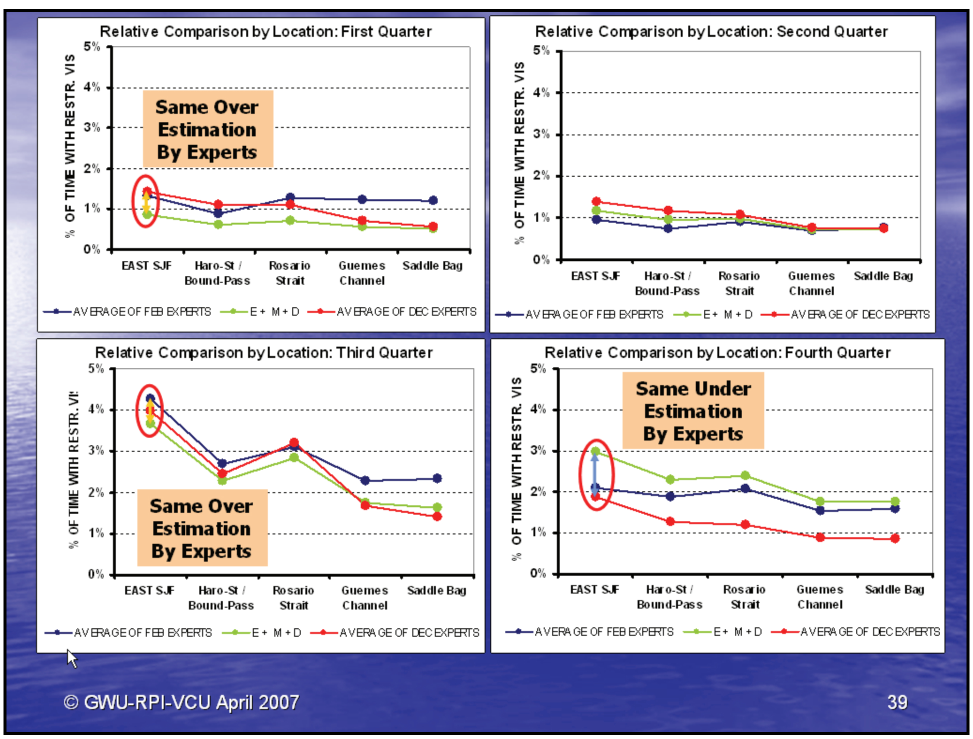


Figure C-38. Expert judgment visibility elicitation results by Location

Figure C-38 summarized the results of the four pair wise comparison questionnaires by location. The red line indicates the results for the experts that participated in the December 2006 elicitation session and the blue one indicates the results of those experts that participated in the February 2007 elicitation session. Please note again the agreement amongst the December experts and the February experts, especially during the third quarter of the year. To arrive at the percentage of time of bad visibility for the locations Haro-Strait/Boundary Pass, Rosario Strait, Guemes Channel and Saddle Bag we used the percentages time of bad visibility for the East Strait of Juan De Fuca and extrapolated to the other locations following the trend lines that we obtained from the December 2006 and February 2007 expert judgment results. The green lines in Figure C-38 summarize these results by quarter and are thus obtained though a combination of modeling, data and expert judgment.

The percentages from Figure C-38 in turn are used to calibrate the sea/land visibility model discussed in the previous section to arrive an hourly time series of bad/good visibility for the locations Haro-Strait/Boundary Pass, Rosario Strait, Guemes Channel and Saddle Bag. The resulting number of bad visibility days per year (defined as a day with at least two hours of bad visibility) for each of these locations are provided in Figure C-34; 25 for Rosario Strait, 19 for Haro-Strait/Boundary Pass, and 18 for both Guemes Chanel and Saddle Bag.

C-6.3.3. Summary results of visibility in the VTRA maritime simulation.

Figure C-39 and Figure C-40 summarize the results of our bad visibility modeling by the different locations as defined by Figures C-17 and C-33. A histogram in these figures provides the number of bad visibility days (defined as one day with at least two hours of bad visibility) by month for a specific location. The locations Buoy J, East and West Strait of Juan de Fuca and Rosario Strait summarized in Figure C-19 display primarily a sea fog phenomenon during the months of June, July and August. The other locations summarized in Figure C-40 display primarily a land fog phenomenon primarily during the months of September through January. Overall a lesser number of bad visibility days seems to be observed during the months of February through.

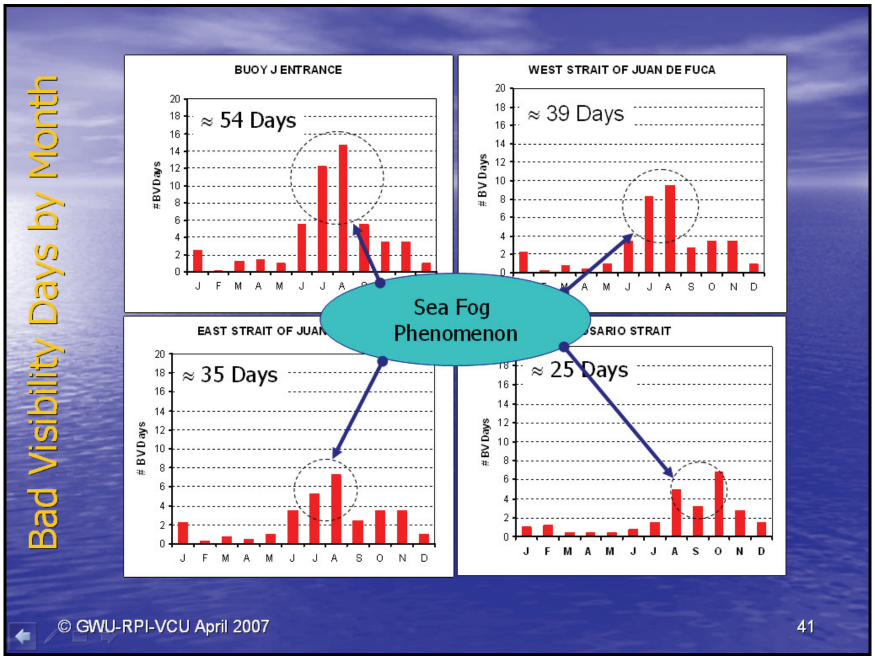


Figure C-39. Summary bad visibility results by month for: Buoy J entrance, West Strait of Juan de Fuca, East Strait of Juan de Fuca and Rosario Strait as defined by Figures C-33 and Figure C-17 for Rosario Strait.

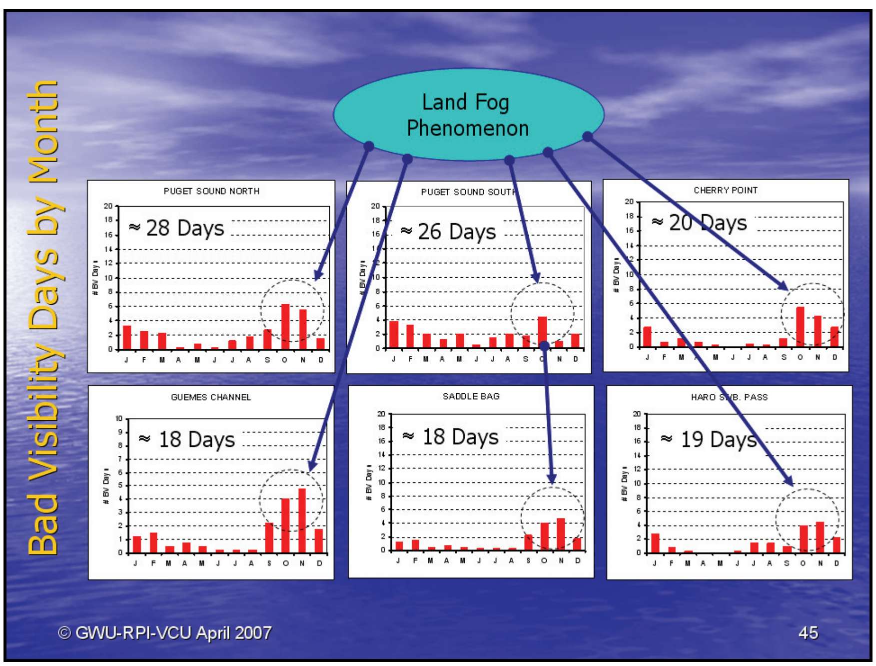


Figure C-40. Summary bad visibility results by month for: Puget Sound North and South, Cherry Point, Guemes Channel, Saddle Bag and Haro-Strait/Boundary Pass as defined by Figure C-17.

References

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