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Safety and Navigational Risk Assessment for LNG-Fueled Passenger Ferry Vessels

Washington State Ferries

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Safety and Navigational Risk Assessment for LNG-Fueled Passenger Ferry Vessels	Det Norske Veritas (U.S.A), Inc. 1400 Ravello Dr Katy, TX 77449 (281) 396-1000 http://www.dnv.com
For: Washington State Ferries	

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Summary:	WSF is considering a conversion of its Issaquah class vessels to Liquefied Natural Gas (LNG) propulsion. The conversion would include retrofitting LNG tanks on the top decks of vessels between the exhaust stacks. This report documents the results of the operational and navigational portions of the Safety Assessment and the associated risk management safeguards for the operation of LNG-Fueled Passenger Ferry Vessels.	
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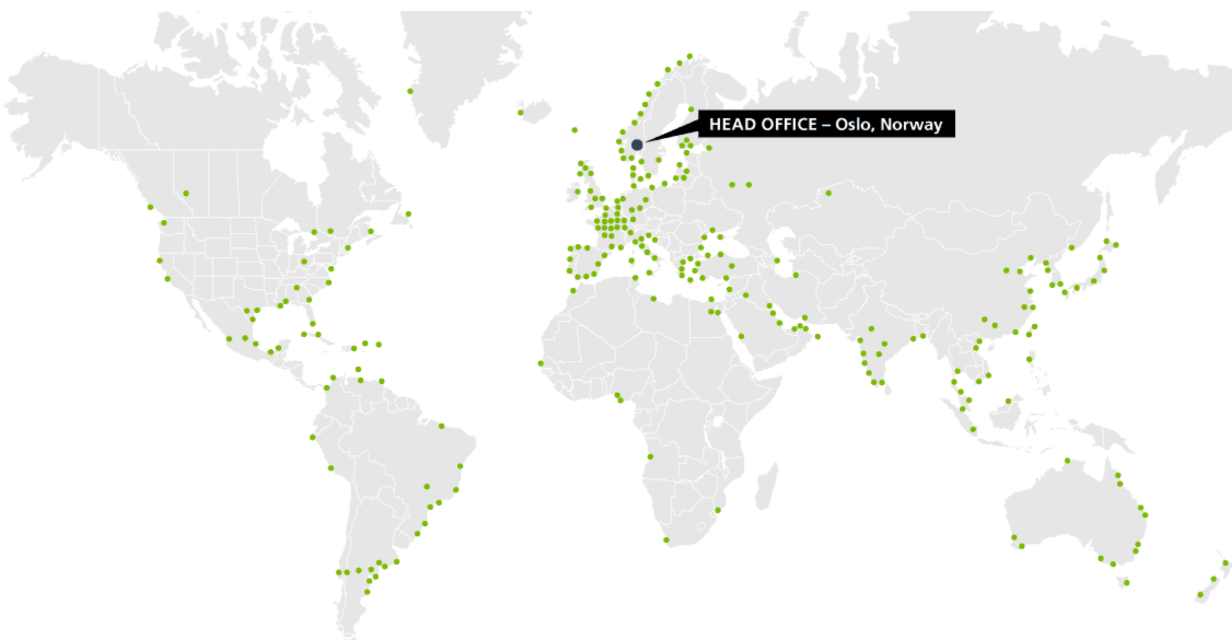
DNV IN BRIEF

DNV is a global provider of knowledge for managing risk. Today, safe and responsible business conduct is both a license to operate and a competitive advantage. Our core competence is to identify, assess, and advise on risk management, and so turn risks into rewards for our customers. From our leading position in certification, classification, verification, and training, we develop and apply standards and best practices. This helps our customers to safely and responsibly improve their business performance.

Our technology expertise, industry knowledge, and risk management approach, has been used to successfully manage numerous high-profile projects around the world.

DNV is an independent organization with dedicated risk professionals in more than 100 countries. Our purpose is to safeguard life, property and the environment. DNV serves a range of industries, with a special focus on the maritime and energy sectors. Since 1864, DNV has balanced the needs of business and society based on our independence and integrity. Today, we have a global presence with a network of 300 offices in 100 countries, with headquarters in Oslo, Norway.



Our LNG activities started almost 50 years ago when we established an LNG ship research team. Since then DNV has been at the forefront of technology development within this sector. DNV's expertise was closely associated with the development of the Moss spherical tank system and the first double corrugated membrane cargo containment system was developed by DNV's research team in 1962. DNV's services, competencies and experience cover all the links in the LNG chain.

DNV has gained significant experience with adoption of LNG as a marine fuel, both through development of gas fuel class rules, through assisting local governments with consultancy on the technical and commercial market assessment and advisory services related to LNG infrastructure and refuelling. DNV has previously worked with government bodies in, (e.g., Norway, Singapore, the Netherlands, and Sweden) as well as refuelling studies for commercial clients in Korea, Qatar, and Australia.

The relevant DNV LNG competence can be summarized as:

- Consulting competence in onshore terminals and maritime risk assessment
- Strong technical capability in assessing LNG fuelled vessels and can represent more than 100 flag administration on their regulatory regime
- Has more than 10,500 employees with a broad range of expertise
- The White Paper "Greener Shipping in the North America" is one of the leading LNG fuelled shipping reference documents prepared by DNV, http://blogs.dnv.com/lng/2011/02/lng-for-greener-shipping-in-north-america/
- Actively participated in the IMO GHG Study 2009: Prevention of Air Pollution from Ships. (http://www.imo.org/blast/blastDataHelper.asp?data_id=26046&filename=4-7.pdf)
- Extensive and global expertise in the validation and verification of projects with respect to Green House Gas emissions and other related emissions (e.g. SO_x and NO_x).
- Promoted use of LNG as a fuel with extraordinary innovation concepts, such as Triality, Quantum 6000 TEU and 9000 TEU, Oshima Eco 2020, Ecore, Catchy and Green Dolphin. LNG Ready concepts were also developed by DNV.
- First class society to develop LNG-as-fuel rules year 2000. These were issued in conjunction with the first LNG fuelled prototype vessel, Glutra, built in year 2000. In 2009, IMO interim guidelines were published with technical content similar to the DNV Rules for Gas Fuelled Ships.
- Major contributor to the development of the International Code for Gas Fuelled Ships (IGF code)
- Classed the first smallest LNG carrier "Pioneer Knutsen" - 1100 m^3 in 2004 and in 2013 the first LNG bunker vessel "Seagas" - 180 m^3 and issued an Approval in Principal for the high capacity LNG bunker barge - 4000 m^3 with type B tank
- 38 out of 41 LNG fuelled vessels in operation and another 17 on order are to DNV Class.
- Strong strategic consulting competence in onshore terminals and maritime risk assessments and evaluating LNG vessels
- Qualification of technology for navigational safety measures, loading arms, hoses, transfer systems, and cryogenic piping

As seen from above, DNV has played a leading role in the LNG industry's technological evolution due to its in-depth expertise in all aspects of the LNG value chain. We are today deeply involved in research and technology development as well as being a service provider to new project developments.

Summary

Washington State Ferries (WSF) is considering a conversion of its Issaquah class vessels to Liquefied Natural Gas (LNG) propulsion. The conversion would entail retrofitting LNG tanks on the top decks of vessels, situated on either side of the exhaust stacks and the pilot houses. The retrofit would also include installation of associated cryogenic piping. The benefits of the conversion include fuel cost savings and emissions reductions. One of the key components of WSF's decision to go ahead with such a conversion are a thorough safety and security assessment, the development of a risk management plan, and development of an LNG operations manual that can be incorporated into WSF's existing Safety Management System.

This report documents the results of the operational and navigational portions of the Safety Assessment and the associated Risk Management Plan for operation of the LNG-Fueled Passenger Ferry Vessels. The study evaluated the potential for damage to LNG systems from accidents and the subsequent safety risk. The study comprising of the operational, navigational and safety assessment took six (6) months to complete.

This study is a formal risk assessment. A formal risk assessment provides the best basis to make informed choices about uncertain future events. Risk is the combination of the likelihood and consequences of an undesirable event. Often, the objective of this process is to achieve the best balance of risks and benefits and ensure that the risks are manageable.

This study assessed:

1. Safety risk related to an accidental leak of LNG during normal ferry operations and refueling operations.
2. Safety risk related to accidental leak of LNG due to navigational incidents.

To accomplish this, the relevant portions of the system were defined and described (Sections 3 through 5). A workshop was held with key stakeholders and subject matter experts to identify the hazards, causes, consequences, and mitigations (Appendices 2 and 3). The frequencies of the events were estimated quantitatively (Sections 6 and 7) and the consequences were determined via modeling (Section 8). The risk was estimated as the product of consequences and frequency (Section 9), and the need for and potential measures to reduce risk were identified (Section 10).

In all, the frequency and consequences were studied in depth for three postulated release scenarios from a ferry and three scenarios from a truck tank. Each one was studied to estimate safe distances from flammable clouds, heat from pool fires, and explosion overpressures. In addition, the study accounted for the current population, both during the day and at night.

This study concluded that the maximum potential individual risk (that is to say, location-specific risk) is at the level of $1x10^{-6}$ (1 in 1,000,000) per year. Another way to phrase this

is that if a person stood at the location with the greatest risk, that person's risk of fatality from a studies LNG release would be 0.000001 per year.

Below follows the methodologies used to arrive at this projection.

Navigation Risk

The localization of the LNG tanks on the top deck of the ferries is an inherently safe design with regards to risk for damaging the tanks in a collision. The tanks are approximately 12 m (39 ft.) above the waterline. Tank damage would require a collision that penetrates the ferry side at least 5 m (16 ft.) deep at a height of 12 m (39 ft.) above the waterline.

During the navigational risk study, DNV drew together expertise from its three main hubs of competence within navigational risk analysis. The navigational risk study was a combined effort between the offices in Houston, London and Oslo.

Approximately eight (8) people were involved in the navigational risk analysis. The following disciplines ranged from statistical data analysis, shipping traffic data analysis, marine transport risk assessment, structural and stability analysis. The aforementioned expertise was combined and brought together in order to execute the navigational risk modeling.

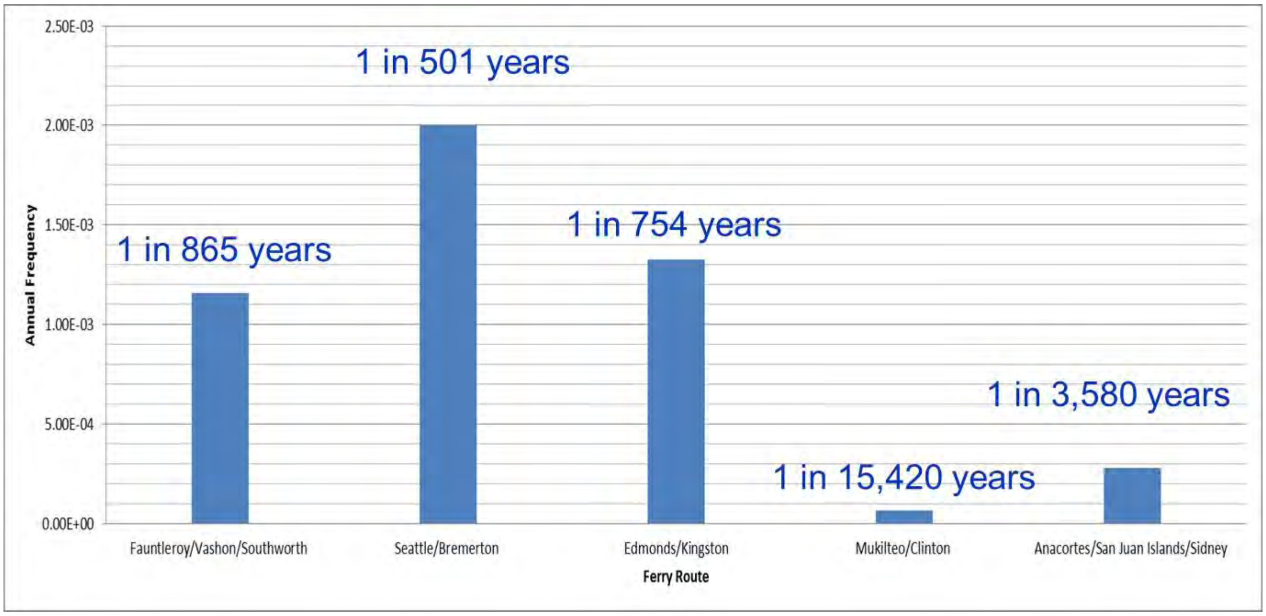
Prior to and during the navigational risk assessment a wealth of information was requested, gathered and treated. Such data comprised of metocean data (wind, visibility etc.), the sailing route characterization (draft, routes and terminal approaches) and the traffic picture with respect to the traffic and port data.

This study is a navigational risk assessment focusing on risks from grounding, collision and allision. An initial step in the risk assessment was a Hazard Identification (HAZID) workshop, in which it was concluded that the design of the terminals will prevent components of the terminal from impacting the LNG tank, should an allision occur. Similarly, grounding accidents could not lead to damage of the LNG tanks because the tanks are on the top deck. Therefore the only risk that was quantified was collision risk.

The collision risk was modeled for all ferry routes that have a potential to be sailed by LNG-fuelled passenger ferry vessels. The risk was modeled using the DNV risk assessment tool MARCS. The resulting estimated collision frequencies were in the same range as the historical average collision frequency for WSF over the last 34 years.

A closer evaluation of the historical data from the WSF accident register indicates a decline in the collision incidents over the past 20 years (and therefore demonstrates a reduction in collision risk). WSF implemented important organizational and operational procedures using advancements in knowledge, experience and technology to reduce the collision risk. The establishment of Vessel Traffic Services (VTS) and the use of AIS and electronic charts where the crossing vessels are plotted is expected to have significantly reduced the collision risk.

The collision risk results from MARCS were combined with the probability for a collision that results in a penetration of at least 5 m (16 ft.) into the ferry hull, independent of the vertical distribution of the damage (Figure 1).



Estimated Annual Frequency of a Collision that Could Result in a 5 m (16ft.) Penetration into a Ferry Side near an LNG Tank (assuming unlimited vertical damage)

The uncertainty in the vertical distribution probability of an impact from a collision is too high to make any exact calculations of the ferry routes collision frequencies that could impact an LNG tank (and thus the frequencies for a LNG spill from a collision). The estimated frequencies should be adjusted significantly lower to account for the probability of damage to an LNG tank. It is expected that the adjustment should be in the order of 10 to 100 times less than the frequencies estimated for each route in the study.

Safety Risk

The likelihood of a natural gas cloud to reach its largest potential extent and then ignite is very low, especially in a near-shore urban area. It is reasonably assumed that the cloud would be ignited by the first available ignition source and progress to a pool fire. For a gas cloud dispersion event, the hazard zone area extends from the postulated spill point and is elongated in the downwind direction, rather than spread in a uniform circle around the spill point. Pool fire and vapor dispersion hazard distances were studied, and are significantly influenced by site-specific environmental, topographical, and operational conditions.

During the safety risk study DNV drew together expertise from its two main hubs within DNV's competence of safety risk analysis. The safety risk study was a combined effort between the offices in Houston and Oslo.

Approximately eight (8) people were involved in the safety risk analysis. The following disciplines ranged from quantitative risk analysis, LNG fueling and operations, LNG ferry classification and LNG dispersion modeling. The aforementioned expertise was combined and brought together in order to execute the safety risk assessment.

Prior to and during the safety risk assessment a wealth of information was requested, gathered and treated. Such data comprised of population demography data, ferry design and operations, suggested LNG system configuration (no. of tanks, placement, system pressure etc.) and LNG fueling configuration including operations.

The estimated safety risk for a fatality from a potential LNG release is low. Safety risk was estimated in two ways: individual risk and societal risk. The maximum estimated individual fatality risk is at the level of one in a million per year or less for any individual.

Individual Risk is the risk of a fatality experienced by a single individual in a given time period. It reflects the severity of the hazards and the amount of time (usually assumed to be a year) the individual is in proximity to the hazards.

In the absence of relevant U.S. risk acceptance criteria, the United Kingdom's criteria were used to provide a basis of evaluation. Based on criteria adopted by the United Kingdom Health and Safety Executive (UK HSE), the estimated individual risk is broadly acceptable.

Societal risk is the risk experienced in a given time period by a whole group of exposed individuals. Societal risks are the relationship between the frequency and the number of people suffering a given level of harm from the realization of specified hazards, in this case, an accidental LNG release.

Societal risk is often expressed as lines on an FN curve that are graphical measures of societal risk. The lines show the relationship between frequency and size of an accident. This curve allows a measure not only for the average number of fatalities from all sizes of accidents, but also the risks of catastrophic accidents that potentially impact many people at once.

The estimated societal risk from operation of the LNG-Fueled Passenger Ferry Vessels is less than the UK HSE *maximum tolerable criteria*. The risk falls between the maximum tolerable and *broadly acceptable* risk levels (which is called the ALARP region - As Low as Reasonably Practicable), but closer to *broadly acceptable*. Based on DNV's previous experience, it is unusual for a study to estimate an FN curve below the UK HSE broadly acceptable criteria, and the societal risk estimated in the current study is less than many other industrial facilities.

Security Risk

The security assessment identified eight threat scenarios. These threat scenarios and the recommended risk mitigation measures to address these threats were in included in the report. This portion of the report has been designated as Sensitive Security Information and is only releasable by the U.S. Coast Guard.

Abbreviations

AIS	Automatic Identification System
ALARP	As Low As Reasonably Practicable
BLEVE	Boiling Liquid Expanding Vapor Explosion
CCPS	Center for Chemical Process Safety
DGPS	Differential Global Positioning System
DNV	Det Norske Veritas
DWT	Dead Weight Tons
CCTV	Closed Circuit Television
CFR	Code of Federal Regulations
COLREGS	Convention in the International Regulations for Preventing Collisions at Sea
ECDIS	Electronic Chart Display and Information System
ENC	Electronic Navigational Charts
ESD	Emergency Shut Down
ESDV	Emergency Shut Down Valves
ESI	Environmental Sensitivity Index
ETV	Emergency Towing Vessel
FN	Frequency-Fatality
GRT	Gross Register Tonnage
GRU	Gas Regulating Unit
HAZID	Hazard Identification
HCRD	Hydrocarbon Risk Database
HSC	High Speed Craft
HSE	Health and Safety Executive (of the United Kingdom)
IGF	International Code of Safety for Gas-Fuelled Ships
IMO	International Maritime Organization
IR	Individual Risk
IRPA	Individual Risk per Annum
ISO	International Organization for Standardization
LEAK	commercial software available from DNV

LNG	Liquefied Natural Gas
LSIR	Location Specific Individual Risk
MARCS	The DNV Marine Accident Risk Calculation System software
M/V	Motor Vessel
NOAA	National Oceanic and Atmospheric Administration
OPA	Oil Pollution Act
P&ID	Piping and Instrumentation Diagrams
QRA	Quantitative Risk Analysis
RCW	Revised Code of Washington
RR	Research and Rescue Vessels
SMP	Shoreline Master Program
SMS	Safety Management System
SNL	Sandia National Laboratories
SOLAS	Safety of Life at Sea
SR	State Route
SSDG	Ship Service Diesel Generators
STCW	Standards of Training, Certification and Watchkeeping for Seafarers
TOS	Traffic Organization Services
TSS	Traffic Separation Scheme
UK HSE	United Kingdom Health and Safety Executive
VHF-FM	Very High Frequency – Frequency Modulated
VMRS	Vessel Movement Reporting System
VTC	Vessel Traffic Center
VTSPS	Vessel Traffic Service Puget Sound
WAC	Washington Administrative Code
WIG	Wing In Ground Craft
WSA	Waterway Suitability Assessment
WSF	Washington State Ferries

Terminology

Event Tree Analysis	A logic model that graphically portrays the outcomes, or events that could result given a specific main failure or accident of interest
Fault Tree Analysis	A logic model that graphically portrays the combination of failures that can lead to a specific main failure or accident of interest
Frequency	The number of occurrences per unit time at which observed events occur or are predicted to occur For example a frequency of $1x10^{-6}$ per year is equivalent to 1 in 1,000,000 years
HAZID	Hazard Identification, a technique for the identification of all significant hazards associated with the particular activity under consideration
Likelihood	The expected frequency of an event's occurrence

Units of Measure

°C	degrees Celsius
°F	degrees Fahrenheit
cm	centimeters
ft.	feet
ftm	fathoms
gal	gallons
km	kilometers
kW/m^2	kilowatts per square meter
L	liters
m	meters
m^3	cubic meters
nm	nautical miles
psi	pounds per square inch

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1 INTRODUCTION

WSF is considering a conversion of its Issaquah class vessels to Liquefied Natural Gas (LNG) propulsion. The conversion would entail retrofitting LNG tanks on the top decks of vessels, situated between the exhaust stacks. The retrofit includes installation of associated cryogenic piping. The potential benefits include fuel cost savings and emissions reductions.

An integral component of WSF's decision to go ahead with such a conversion is a thorough safety and security assessment, the development of a risk management plan, and an LNG operations manual. These documents will be incorporated into WSF's existing Safety Management System (SMS) (1).

WSF is completing three related studies:

1. Safety, Security Assessment and Operational Planning for LNG Fuelled Passenger Ferry Vessels (Security Sensitive Information) (2)
2. Safety and Navigational Risk Assessment for LNG Fuelled Passenger Ferry Vessels (this report)
3. LNG Fueling Procedure for LNG Fuelled Passenger Ferry Vessels

This report documents the Safety and Navigational Risk Assessment (item no 2). Included in this study are recommended risk management safeguards for the operation of LNG-fueled passenger ferry vessels.

2 OVERALL METHODOLOGY

2.1 Key Stages of the Risk Assessment

A formal risk assessment provides the best basis to make informed choices about uncertain future events. Risk is the combination of the likelihood and consequences of an undesirable event. Often, the objective of this process is to achieve the best balance of risks and benefits. This study assessed:

1. Safety risk related to an accidental leak of LNG during normal ferry operations and Fueling operations

2. Safety risk related to accidental leak of LNG due to navigational incidents.

The process of assessing risks involved the following stages:

- **System Description**: A clear statement of the system that is subject to the risk analysis. In this case, the vessel with retrofitted LNG tanks and cryogenic piping (Section 3), the fueling operations (Section 3), the terminals and ferry routes (Section 4) and the marine traffic going through the study area (Section 5).
- **Hazard Identification**: This stage answers the question: what might go wrong within the bounds of the system description and the scope of the risk analysis, and identifies credible hazards and hazard causes. This was conducted as two separate workshops for the navigational risk (Section 6.1) and for the operational risk (Section 7.1).
- **Frequency Assessment**: The frequency assessment analyzes how often an LNG leak could occur. For the navigational risk, this will be how often a navigational accident that leads to a LNG leak could occur (Section 0). For the operational risk, this is how often an LNG leak during normal operation and fueling can occur (Section 7.3).
- **Consequence Assessment**: The consequence assessment analyzes the potential impact to people as a result of a potential LNG leak occurring, and how severe the impact is likely to be. The consequence assessment results can be found in the DNV Report "Security Assessment for LNG Fueled Passenger Ferry Vessels" (3) for the various ferry routes.
- **Risk Analysis**: The total risk for harming people because of an accidental LNG leak from the ferries is calculated based on all hazards and the potential accidents (Section 8).
- **Risk Management:** This stage answers the question: what can be done to reduce the risk? The identification of risk reduction options and coarse evaluation of their implementation (Section 9). The implementation of risk reduction options and the evaluation of the residual risks after implementing all justified risk reduction options can be considered elements of risk management. However, these elements of risk management are outside the scope of this study.

3 LNG-FUELED PASSENGER FERRY VESSEL CHARACTERISTICS

3.1 Issaquah Class Vessels

WSF currently operates five Issaquah 130 class ferries: M/V Issaquah, M/V Kittitas, M/V Chelan, M/V Kitsap, M/V Cathlamet and one Issaquah class ferry, M/V Sealth. These vessels were built and commissioned in the early 1980s. Originally all these vessels were built to carry 1,200 passengers and 100 cars. However, in the 1990s, five of the vessels were modified to carry 130 cars, leaving just the M/V Sealth unmodified. The M/V Chelan was upgraded to SOLAS standards in 2005, allowing it to be one of two WSF ferries certified to make the crossing between Washington State in the United States and British Columbia in Canada (4).

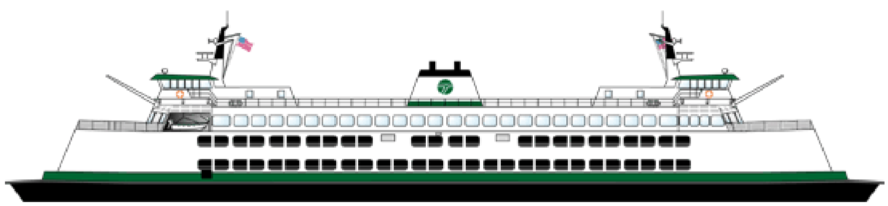

Figure 3-1 Issaquah 130 Car Class Vessel

Table 3-1 Vessel Specifics Issaquah 130 Car Class (4)

Class: Issaquah 130	Type: Auto/Passenger Ferry
Length: 328 ft	Engines: 2
Beam: 78 ft 8in.	Horsepower: 5,000
Draft: 16' 6"	Speed in Knots: 16
Max Passengers: 1,200	Propulsion: Diesel
Max Vehicles: 130	Gross Tonnage: 2,477
Tall Deck Space: 26	City Built: Seattle
Auto Deck Clearance: 1 ft 6 in.	Year Built / Re-built: 1981 / 1993

The vessels potentially run any of the Washington State Ferry routes:

- SR 304 - Seattle, Washington to Bremerton, Washington
- SR 305 - Seattle, Washington to Bainbridge Island, Washington
- SR 160 - Triangle Route:
  Southworth, Washington to Vashon Island, Washington
  Vashon Island to Fauntleroy (Seattle, Washington)
  Fauntleroy to Southworth
- SR 163 - Point Defiance, Washington to Tahlequah (southern Vashon Island, Washington)

- SR 525 - Mukilteo, Washington to Clinton , Washington
- SR 104 - Edmonds, Washington to Kingston, Washington
- Various routes - Anacortes, Washington to any or all of the following in the State of Washington: Lopez Island, Shaw Island, Orcas Island, and Friday Harbor (on San Juan Island); and Anacortes to Sidney, British Columbia.

However, these vessels normally operate on a more limited set of routes, which are: the Seattle-Bremerton Route, the Triangle Route, the Mukilteo-Clinton Route, and the San Juan Island Routes (4).

3.1.1 Proposed Changes to Issaquah Class Vessels for LNG Operations

The conversion of the Issaquah Class ferries to LNG fueled vessels will require removal of the existing propulsion diesel engines and installation of either a single fuel natural gas engine or a dual fuel engine. The existing diesel fuel tanks would remain intact on the vessel and the ship's service generators (SSDG) would use the day tank which would provide approximately 30 days of fuel for the SSDGs. The LNG tanks would be located on the upper deck which is not accessible to passengers. Two skid mounted tanks would be located on either side of the existing stack. The tanks would be an integrated assembly with a cold box and control system built in to control fueling and vaporization of the LNG to gas for use in the engines. The tanks would be manufactured using the same technology used in road-going LNG truck trailers. The capacity of each tank would be 100 m^3 (26,000 gal), resulting in a total capacity of 200 m^3 (53,000 gal) (4).

Other additions and changes would include a LNG fueling station on the No. 1 end of the car deck, two natural gas supply lines (one to each engine room in double wall piping), a vent system and vent mast approximately 9 m (30 ft.) above the deck, gas detection system integration that meets IMO regulations, control and monitoring instrumentation, and augmented fire suppression systems (deluge system for each pilothouse and dry chemical system for fueling station) (4).

3.2 LNG Storage Description

The LNG will be maintained under pressure at -160°C (-256°F) in a double walled insulated tank that consists of a stainless steel inner tank and a mild steel outer tank. The space between the tanks will be approximately 25 cm (10 in.), filled with Perlite insulation, and will be maintained at a vacuum. The tanks would be secured on the sun deck (Texas deck) fore and aft of the stacks to provide a safe location for vapor (if any) to dissipate naturally away from the vessel and passengers (4).

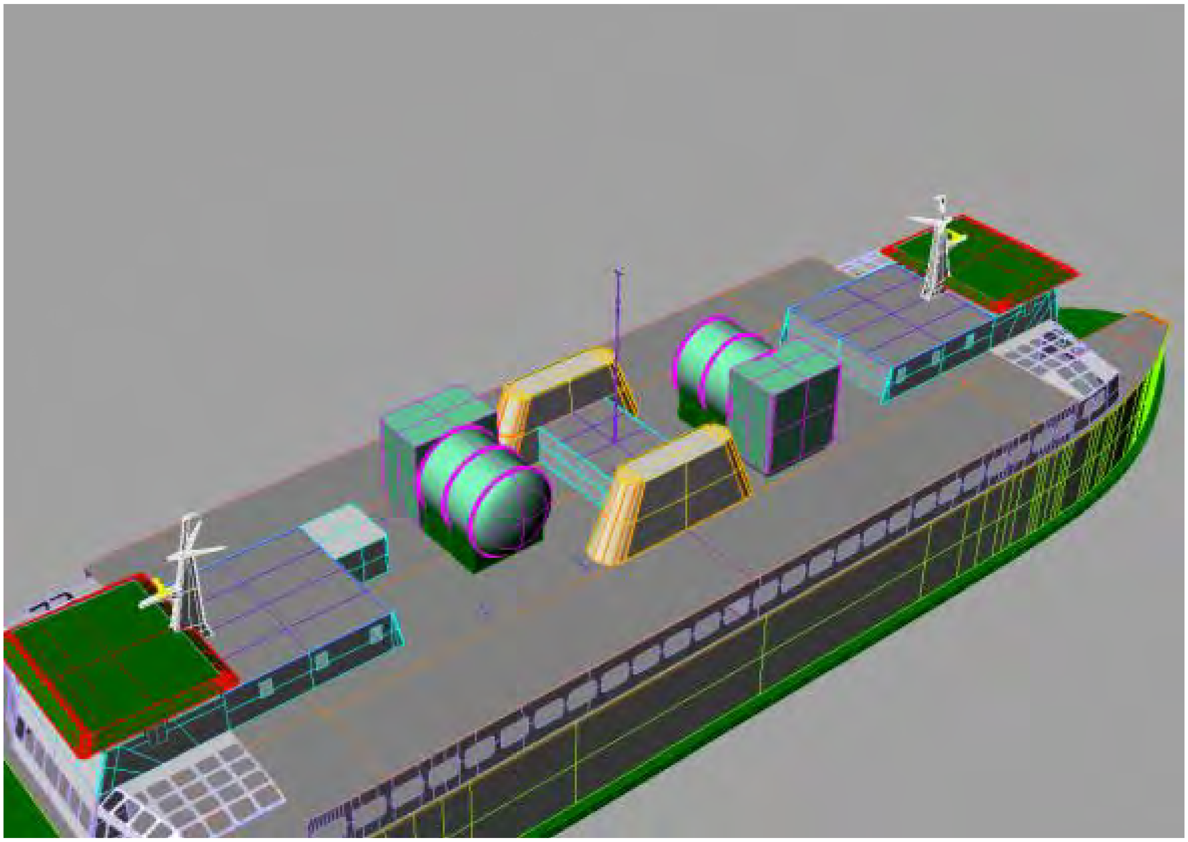

Figure 3-2 Layout Showing LNG Tanks on an Issaquah Class Vessel

3.3 LNG Fuel Description

LNG will be vaporized at the tank by two heat exchangers (Cold Box) built into each tank as a unit. The heat exchangers will be incorporated into the LNG storage system, which will be mounted on a skid supplied by a vendor. The gas from each tank will be cross-connected, with capability to supply gas to either engine room, but it is expected that during normal operations, one tank will supply each engine room. As the gas line enters the exhaust trunk, the line will transition to a double-walled pipe that will run to each engine room. In the engine room, the line will be attached to a container hung from the overhead that contains the Gas Regulating Unit (GRU) which will be within 8 m (25 ft.) of the engine. The GRU is not a double-walled unit and will be housed within a secondary barrier that is ventilated at a rate of 30 air changes per hour. The gas line exits the GRU at a double wall flange connection at the boundary of the enclosure and connects to the engine (4).

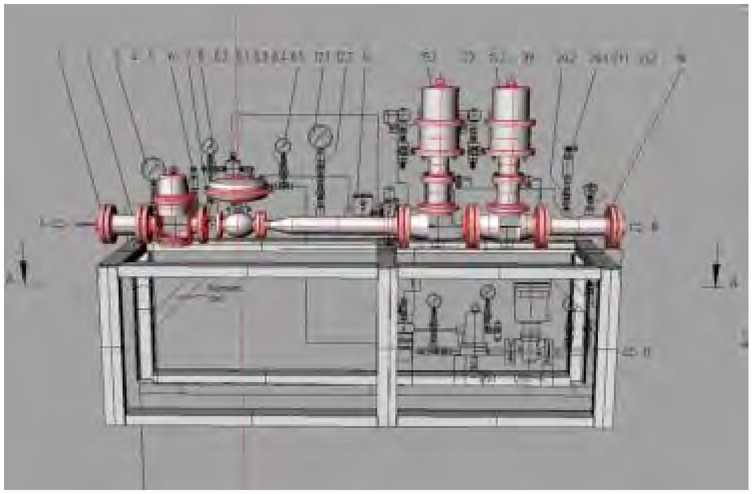

Figure 3-3 Gas Regulating Unit: (GRU)

3.4 Fuel Station Description

The Issaquah class vessels are presently fueled at night by truck during out-of-service time. LNG suppliers currently use a dedicated trailer that carries 38,000 L (10,000 gal) of LNG. After conversion to LNG, WSF plans to continue to use trucks to fuel the vessel during nightly tie-up. A hose connection would be attached at the ramp just inside the curtain plate to a manifold. The manifold would contain the necessary valving for transfer of LNG to the tank. The pressure in the storage tank would be controlled by the addition of LNG as a condensate to cool the tank which will reduce the pressure. The condensate line would connect to the fill line at the tank (4).

The truck would normally have a pump to transfer the LNG, but if the trailer is not fitted with a pump, a Mobile Fueling Unit could be used to transfer the LNG from the trailer to the storage tanks. A vapor return line will be attached to the fill tank and the trailer to equalize the pressure between the two tanks reducing the pumping head to the height and velocity head of the fluid. The piping for the Fueling system will be a double walled pipe and qualified for cryogenic use with the space between the inner and outer pipe held at a vacuum providing insulation (4).

4 ROUTE AND TERMINAL SUMMARIES

This section summarizes the routes and terminals with a focus on key inputs to the study and potential consequences. Appendices 2 and 4 provide additional detail concerning the routes and terminals.

The following key parameters were used to define the routes and terminals in this study:

- Traverse Frequency and Duration
- Weather Conditions
- Shoreline
- Population Estimates

Figure 4-1 shows the ferry routes and segments.

Five ferry routes were included in the study:
1. Anacortes/San Juan Islands/Sidney
2. Mukilteo/Clinton
3. Edmonds/Kingston
4. Seattle/Bremerton
5. Fauntleroy/Vashon/Southworth

Key data concerning each of the five routes is summarized in Section 4.1 through Section 4.5.

Figure 4-1 Route Segments Schematic

4.1 Anacortes/San Juan Islands/Sidney Route

This ferry route connects Anacortes (approximately 80 miles northwest of Seattle), the San Juan Island ferry terminals (Friday Harbor, Orcas, Shaw and Lopez) and Sidney B.C. This route consists of three separate runs:

1. Anacortes, Washington to Friday Harbor, Washington Service stopping at Orcas, Shaw and Lopez all in Washington
2. Inter-Island Service between Friday Harbor, Orcas, Shaw and Lopez in Washington State
3. International Service from Anacortes, Washington to Sidney, British Columbia, with stops at Orcas, Washington and Friday Harbor, Washington

Table 4-1 summarizes key data for the route. Additional information is available in Appendix 2 and Appendix 4.

Table 4-1 Summary of Data for Anacortes/San Juan Islands/Sidney Route

	Ferry transits (per year) and Duration	No. of slips	Shoreline Classification	Population Estimates (sq miles)
Anacortes Terminal	Anacortes – Lopez 11,902	2	Urban	368
Lopez Terminal	Lopez – Friday Harbor 5,357	1	Conservancy	72
Shaw Terminal	Orcas – Shaw 8,717	1	Rural	72
Orcas Terminal	Sidney – Orcas 196	1	Urban	118
Friday Harbor	Friday Harbor – Orcas 3,909	1	Urban	117

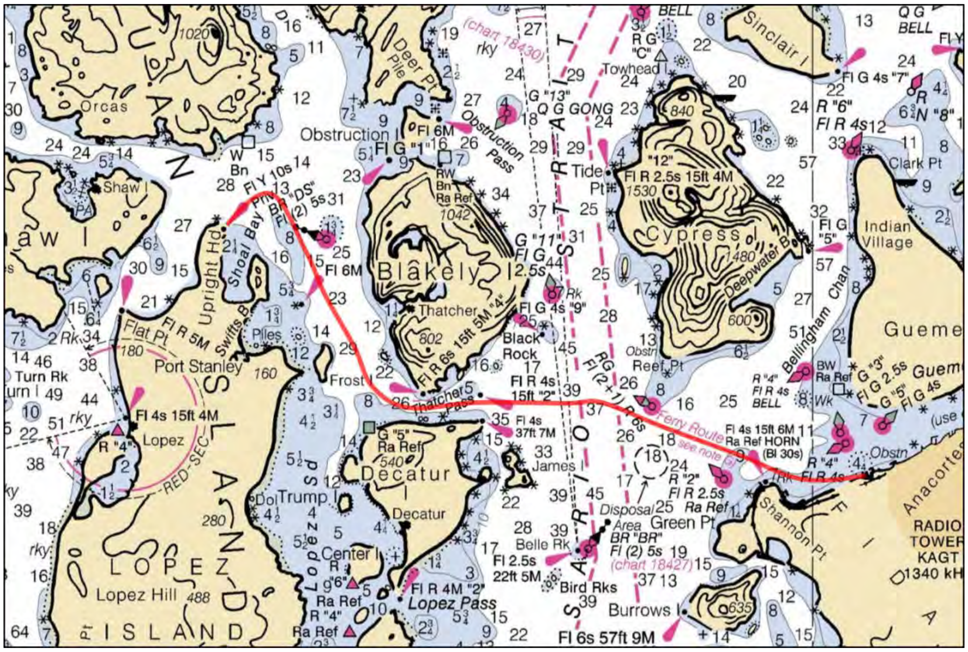

Figure 4-2 Anacortes/Lopez Route

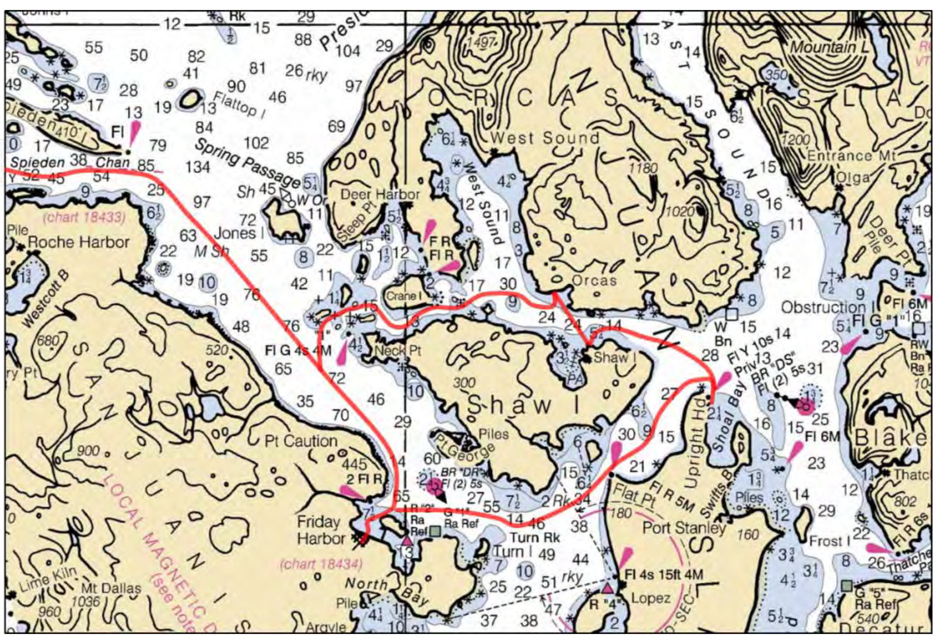

Figure 4-3 San Juan Islands Ferry Routes

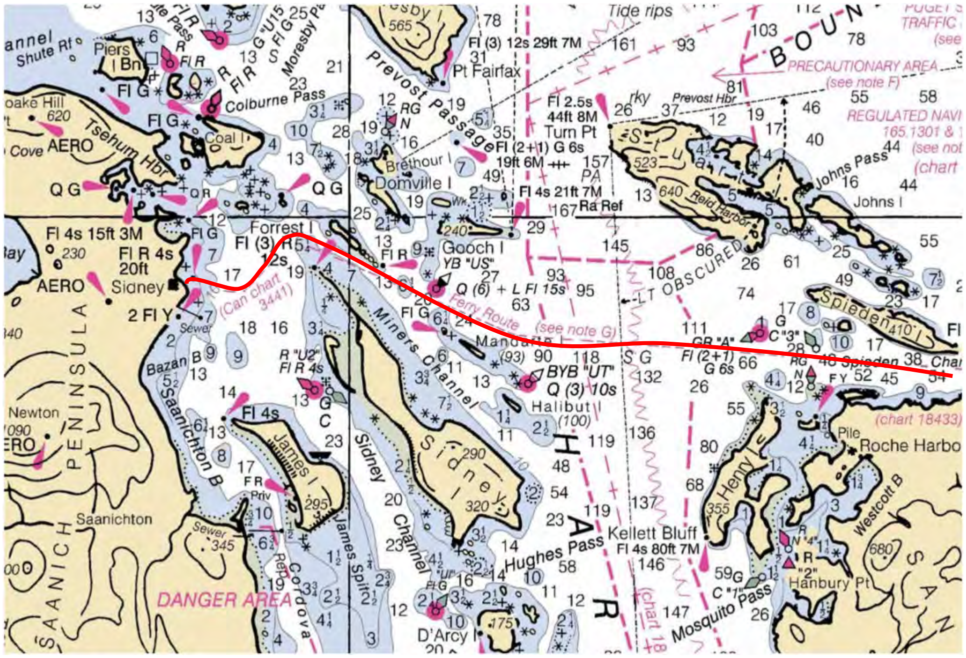

Figure 4-4 Friday Harbor/Sidney Ferry Route

4.2 Seattle/Bremerton Ferry Route

The route has two segments connecting Seattle (Colman Dock) to both Bainbridge Island and Bremerton. Only the segment connecting Seattle and Bremerton is under consideration for the LNG-fueled passenger ferry passage.

Table 4-2 summarizes key data for the route. Additional information is available in Appendix 2 and Appendix 4.

Table 4-2 Summary of Data for Seattle/Bremerton Ferry Route

	Ferry transits (per year) and Duration	No. of slips	Shoreline	Population Estimates (sq. miles)
Seattle Terminal	10,897 / 60 minutes	3	Urban Harborfront	93,500
Bremerton Terminal		2	Downtown Waterfront	8,327

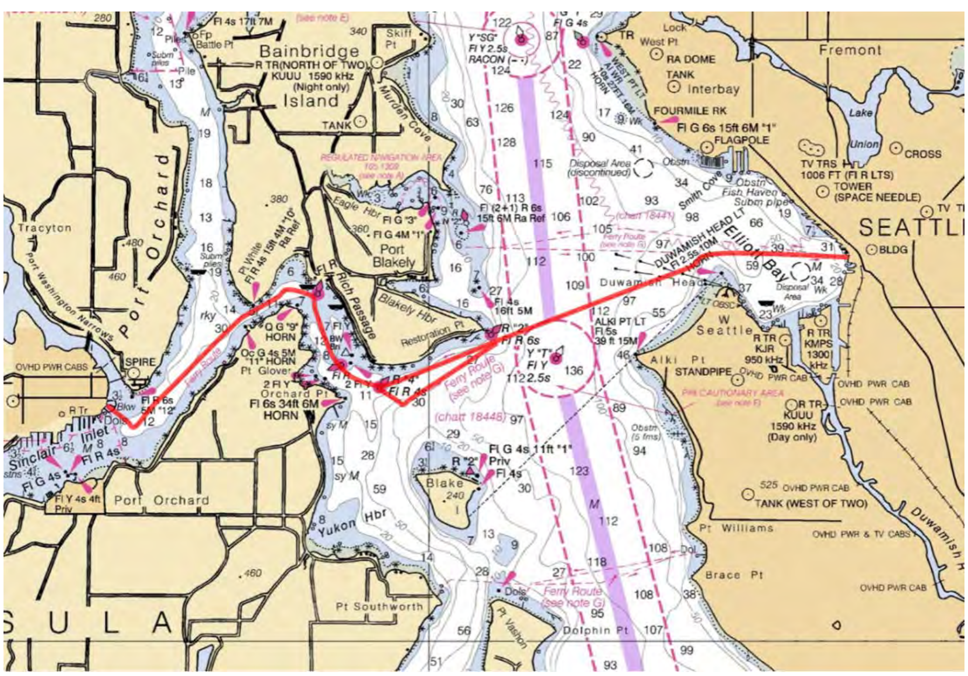

Figure 4-5 Map of Seattle/Bremerton Ferry Route

4.3 Mukilteo/Clinton Route

The route has a single segment that connects Mukilteo (approximately 25 mi north of Seattle) and Clinton (Randall Point on Whidbey Island). This run is a main route providing access for commuters from the south end of Whidbey Island to the greater Seattle/Everett metropolitan area.

Table 4-3 summarizes key data for the route. Additional information is available in Appendix 2 and Appendix 4.

Table 4-3 Summary of Data for Mukilteo/Clinton Route

	Ferry transits (per year) and Duration	No. of slips	Shoreline	Population Estimates (sq. miles)
Mukilteo Terminal	26,770 / 20minutes	1	Urban Waterfront	2,953
Clinton Terminal		2	High Intensity	181

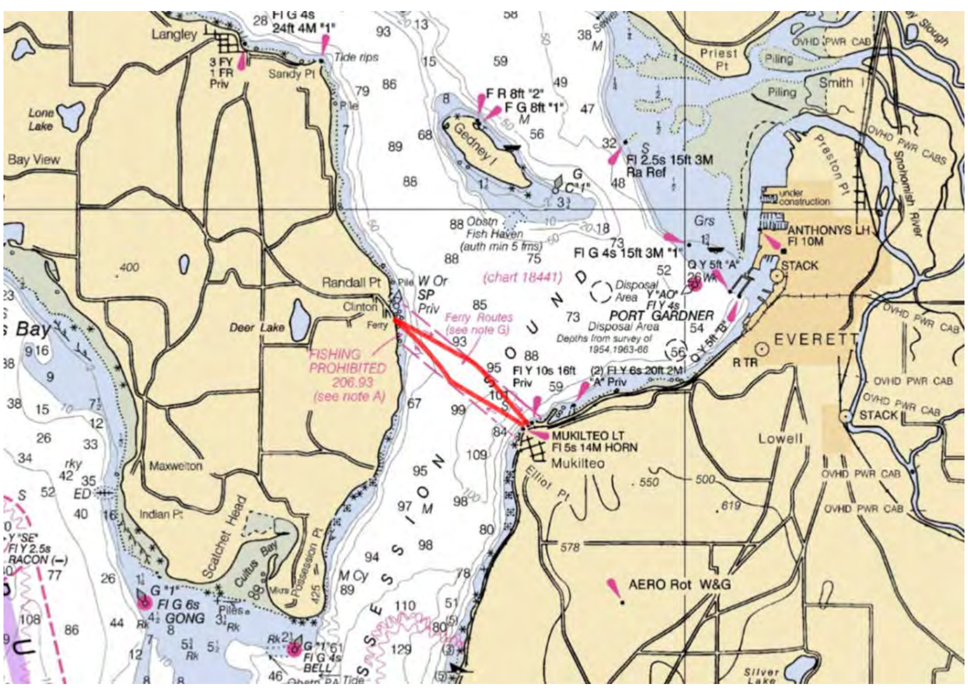

Figure 4-6 Map of Mukilteo/Clinton Ferry Route

4.4 Fauntleroy/Vashon/Southworth Ferry Route

The route contains three segments connecting Fauntleroy (approximately 8 miles south of Seattle), Vashon (on the northern end of Vashon Island) and Southworth (located on the Kitsap Peninsula). This run is a main route providing connections both from south Kitsap County via Southworth and from Vashon Island to the greater Seattle metropolitan area. The route also supplies freight and service access to Vashon Island.

Table 4-4 summarizes key data for the route. Additional information is available in Appendix 2 and Appendix 4.

Table 4-4 Summary of Data for Fauntleroy/Vashon/Southworth Ferry Route

	Ferry transits (per year) and Duration	No. of slips	Shoreline	Population Estimates (sq. miles)
Fauntleroy Terminal	Fauntleroy-Southworth 4,600 / 40 minutes	1	Urban Residential	4,481
Vashon Terminal	Fauntleroy - Vashon 22,610 / 10 minutes	2	Rural	252
Southworth Terminal	Southworth - Vashon 13,415 / 20 minutes	1	High Intensity	1,377

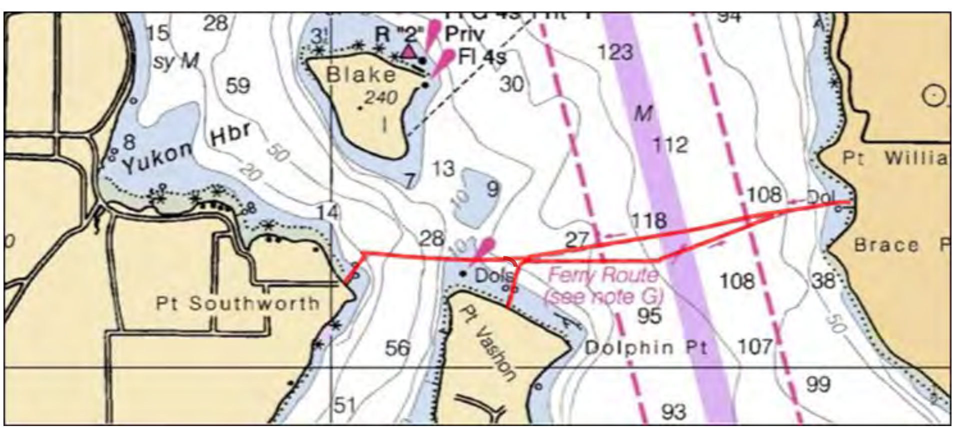

Figure 4-7 Map of Fauntleroy/Vashon/Southworth Ferry Route

4.5 Edmonds/Kingston Ferry Route

This route has a single segment that connects Edmonds (approximately 18 mi north of Seattle) and Kingston (located on the Kitsap Peninsula). This run is a main route providing commuter and recreational access from the Kitsap and Olympic Peninsulas to Edmonds and the greater Seattle area beyond. It also provides a freight route for a significant amount of trucking traffic.

Table 4-5 summarizes key data for the route. Additional information is available in Appendix 2 and Appendix 4.

Table 4-5 Summary of Data for Edmonds/Kingston Ferry Route

	Ferry transits (per year) and Duration	No. of slips	Shoreline	Population Estimates (sq mile)
Edmonds Terminal	17,052 / 30 minutes	1	Urban Mixed	2,682
Kingston Terminal		2	High Intensity	285

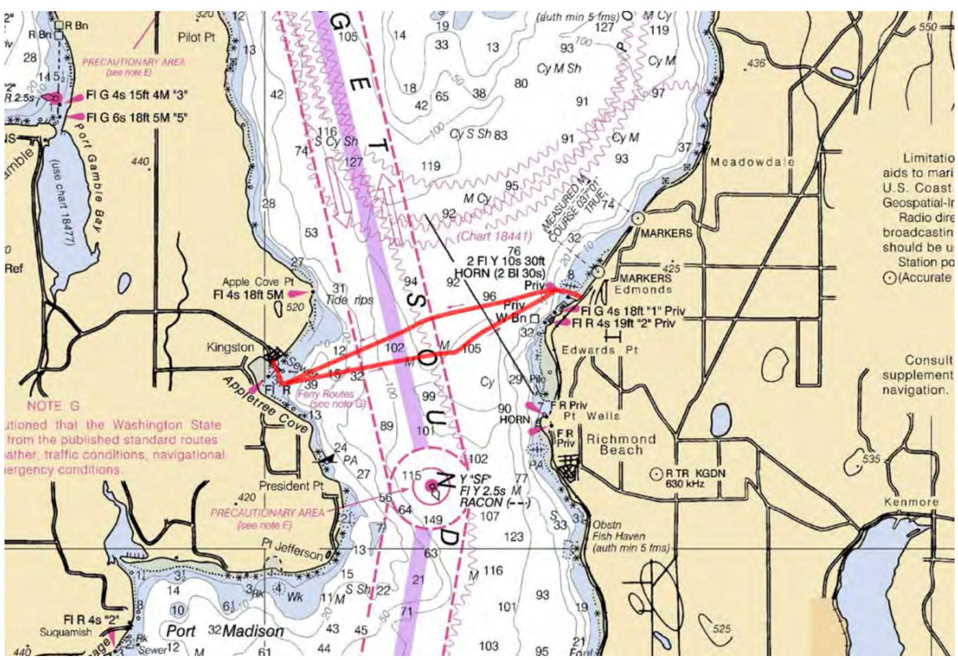

Figure 4-8 Map of Edmonds/Kingston Ferry Route

5 TRAFFIC DESCRIPTION

Description and analysis of vessel traffic was a necessary initial step in the navigational risk assessment. It was a primary input to the estimation of the risk of marine accidents. Automatic identification systems (AIS) transponders provide information about a ship to other ships and to coastal authorities automatically. For this study, AIS data was obtained for the calendar year 2012 (5) for the area within 1 km of the ferry routes.

The vessel types included in the AIS data are:

- Cargo
- Diving Operations
- Dredging Or Underwater Operations
- Fishing
- High Speed Craft
- Law Enforcement Vessels
- Medical Transports
- Military Operations
- Other*****
- Passenger
- Pilot Vessel
- Pleasure Craft
- Port Tender
- Sailing
- Search And Rescue Vessel
- Ships According To RR Resolution No.18 (Mob-83)
- Tanker
- Towing (2 Categories)
- Tug
- Undefined (3 Categories + Blank)
- Vessel With Anti-Pollution
- Wing In Ground Craft (WIG)
- Special Local Vessel

*****Note: as an example Other vessel types consisted of an Offshore Service Vessel and Research Vessel

The traffic was analyzed by type of vessel and divided into 23 categories in order to describe the maritime traffic. The traffic in the studied area consists of about 370,000 vessel trips, summarized in Table 5-1.

About 21% of the data within 1 km of the ferry routes does not attribute a type of vessel (type: Undefined). The *Passenger* type was largest single contributor to traffic, comprising 51% of the traffic. Towing vessels, Pleasure craft, Cargo vessels and Tugs each represented 3 to 6% of the traffic.

The Ferry routes lengths and number of trips from the 2012 AIS data are shown in Table 5-1.

Table 5-1 Length of Routes and Number of Trips in 2012 (5)

	Ferry Route				
	Clinton / Mukilteo	Kingston / Edmonds	Bremerton / Seattle	Southworth / Vashon / Fauntleroy	Anacortes / San Juan Islands / Sidney
Number of trips by any Type of Vessel	30,085	44,338	144,250	56,781	95,138
Length of the Route km (nm)	(2.4)	(4.8)	(14.6)	(8.9)	(67.3)

Table 5-2 Summary of Percentage of Vessel Trips from Top 5 Contributing Vessel Types - Analyzed per Ferry Route (5)

		Ferry Route				
		Clinton - Mukilteo	Kingston - Edmonds	Bremerton - Seattle	Southworth - Vashon - Fauntleroy	Sidney - Friday Harbor - Orcas-Shaw - Lopez - Anacortes
Vessel Type (only top 5 contributors included)	Passenger vessels	**89.0% (rank #1)**	**38.5% (rank #1)**	**44.7% (rank #1)**	**71.5% (rank #1)**	**41.2% (rank #1)**
	Undefined	**3.3% (rank #2)**	**33.2% (rank #2)**	**20.3% (rank #2)**	**16.0% (rank #2)**	**23.8% (rank #2)**
	Towing vessels	**2.2% (rank #4)**	**6.3% (rank #4)**	**7.8% (rank #3)**	**4.0% (rank #3)**	2.9%
	Tugs	**2.6% (rank #3)**	3.9%	4.8%	**3.3% (rank #4)**	2.4%
	Cargos	0.5%	**6.9% (rank #3)**	**5.5% (rank #5)**	**3.0% (rank #5)**	**4.6% (rank #5)**
	Tugs	**2.6% (rank #3)**	3.9%	4.8%	**3.3% (rank #4)**	2.4%
	Search & rescue vessels	0.1%	0.1%	**6.1% (rank #4)**	0.0%	0.1%
	Pleasure craft	**1.1% (rank #5)**	**6.2% (rank #5)**	2.3%	0.8%	**9.3% (rank #3)**
	Dredging/underwater operations	None	0.0%	0.0%	0.0%	**7.6% (rank #4)**

Figure 5-1 shows the density of AIS points from the 2012 data in the Puget Sound and the Strait of Juan de Fuca areas. It represents the density of presence of vessels in 2012, and indirectly the 2012 traffic density.

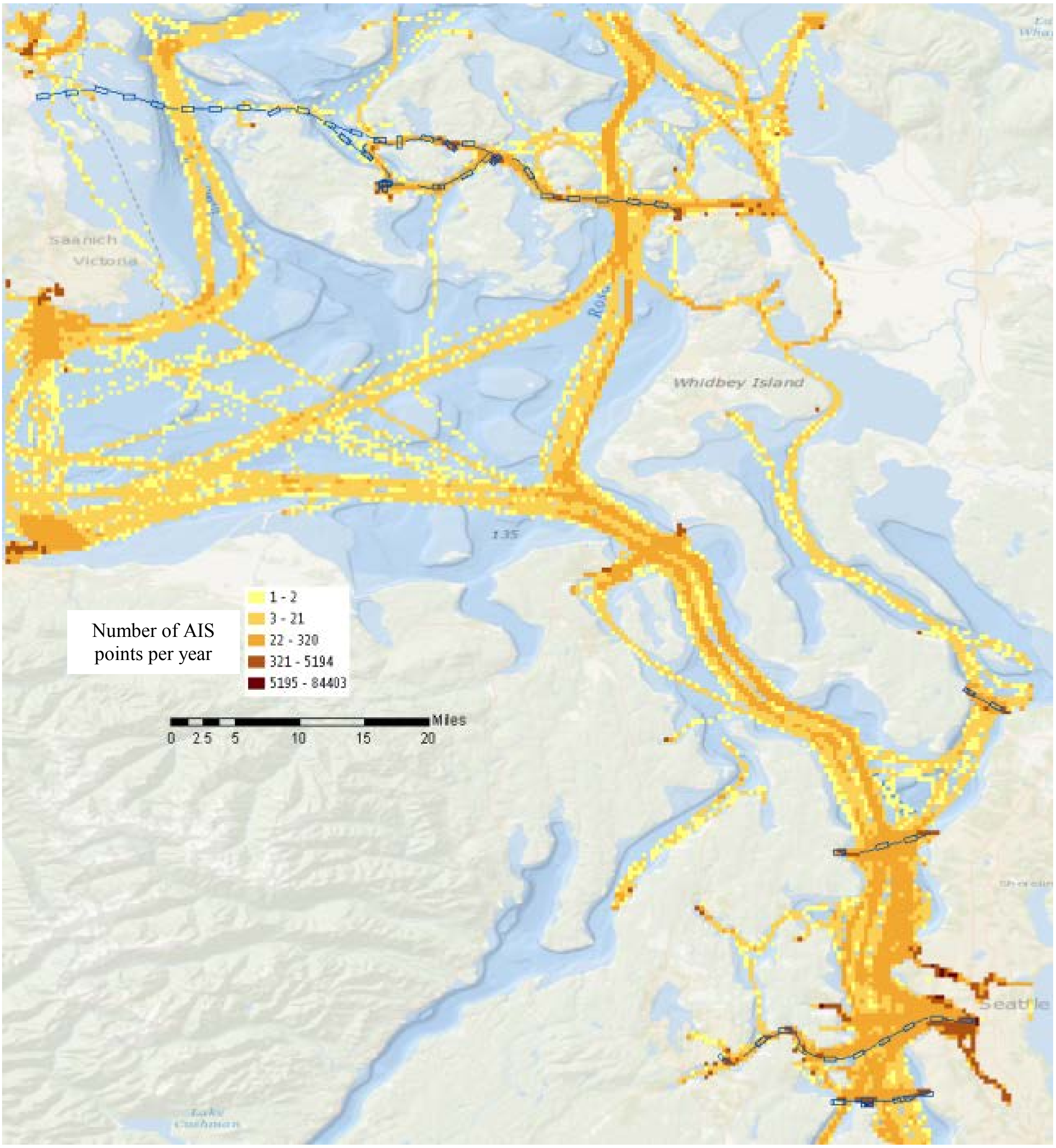

Figure 5-1 Density of Recorded AIS Points in the Puget Sound Area for 2012

The most important activity within a relatively close distance to the ferry routes in 2012 occurred in the areas around Seattle, Puget Sound, and Rosario Strait. The Puget Sound Inbound/Outbound traffic lines are easily identifiable in the figure.

A more detailed description of each route is provided in Sections 5.1 through 5.5 as relevant to the study. The information provided for each route includes:

- Number of trips
- Length of the route
- Number of vessels of each type
- Traffic density - all vessels
- Traffic density - filtered to reveal cross-traffic

5.1 Mukilteo/Clinton Route

Approximately 30,100 trips were sailed in this 2.5 nm route during 2012 (5) and majority of the traffic was the ferries (89.0%). Only 3.3% of the vessels were not defined. Other contributors to the marine traffic were the tugs (2.6%), towing vessels (2.2%) and pleasure craft (1.1%). The number of trips of all traffic types is listed in Table 5-3.

Table 5-3 Number of Trips by Vessel Type in 2012 Near Mukilteo/Clinton Ferry Route (5)

Type of vessel	Number of trips	Percentage of Total Trips
Passenger	26,770	89.0%
Undefined	1,007	3.3%
Tug	788	2.6%
Towing	669	2.2%
Pleasure Craft	315	1.0%
Cargo	155	0.5%
Fishing	128	0.4%
Military Operations	96	0.3%
Other	60	0.2%
Sailing	57	0.2%
Search and Rescue Vessel	19	0.1%
Wig	7	0.0%
Vessel with Anti-Pollution	6	0.0%
Port Tender	3	0.0%
Pilot Vessel	2	0.0%
Tanker	2	0.0%
Law Enforcement Vessels	1	0.0%
Total	**30,085**	100.0%

The density of traffic in this area is shown in Figure 5-2 and Figure 5-3. The ferry route from Mukilteo to Clinton is not crossed by many vessels. The AIS points clearly define the route sailed by the ferries.

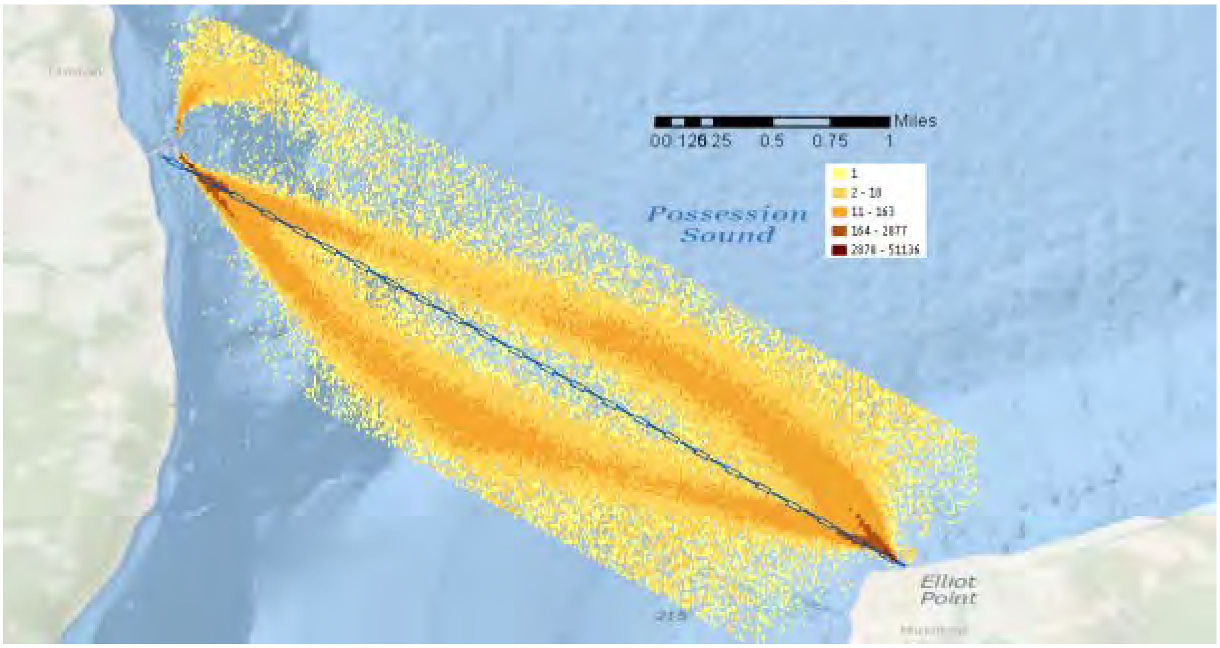

Figure 5-2 Density of Recorded AIS Points along Mukilteo/Clinton Ferry Route for 2012

Figure 5-3 shows detailed traffic density without the Passenger and Undefined types. Since the Passenger and Undefined vessel types dominate the vessel traffic (a combined 92.3%), it was necessary to remove those vessel types to gain insight on the traffic from the remaining categories (the figure appears grainy because the resolution of its grid has been decreased in order to be able to observe different ranges of AIS points density).

Figure 5-3 also shows the primary shipping lanes for the remaining vessel categories. In comparison with the other ferry routes, the crossing traffic is not important (maximum number of AIS points per grid cell is low, approximately 200 points maximum.), and is mainly originating either from or travelling to the Port of Gardner located to the East of the Gedney Island

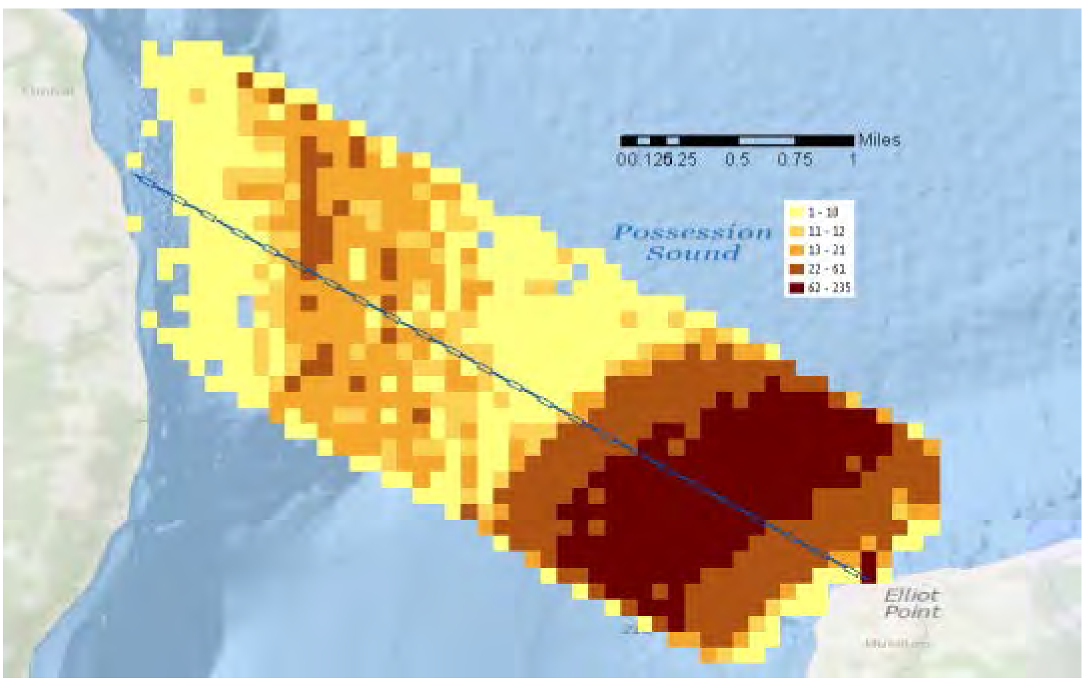

Figure 5-3 Density of Recorded AIS Points along Mukilteo/Clinton Ferry Route for 2012, without Passenger and Undefined types (to show potential cross-traffic)

5.2 Edmonds/Kingston Route

Approximately 44,400 trips were sailed near the 5-nm Edmonds/Kingston Route during 2012 (5). Approximately a third of the traffic was undefined. Ferry traffic constituted 38.5% of the traffic in 2012. Other significant contributors were cargo vessels (6.9%), towing vessels (6.3%) and pleasure craft (6.2%). The number of trips for all traffic types is listed in Table 5-4.

Table 5-4 Number of Trips by Vessel Type in 2012 near Edmonds/Kingston Route (5)

Type of vessels	Number of trips	Percentage of Total Trips
Passenger	17,052	38.5%
Undefined	14,701	33.2%
Cargo	3,042	6.9%
Towing	2,775	6.3%
Pleasure Craft	2,751	6.2%
Tug	1,713	3.9%
Fishing	1,107	2.5%
Sailing	400	0.9%
Other	355	0.8%
Military Operations	159	0.4%
Tanker	146	0.3%
Search and Rescue Vessel	39	0.1%
Pilot Vessel	26	0.1%
Dredging or Underwater Operations	18	0.0%
Vessel with Anti-Pollution	17	0.0%
WIG	10	0.0%
Diving Operations	9	0.0%
Port Tender	7	0.0%
Law Enforcement Vessels	5	0.0%
HSC	3	0.0%
Ships According to RR	3	0.0%
Total	**44,338**	100.0%

The density of traffic in this area is shown in Figure 5-4 and Figure 5-5. For this route, the largest contributors of the AIS point density are the ferries; however, less dense crossing traffic is noticeable in the middle of the route in Figure 5-4.

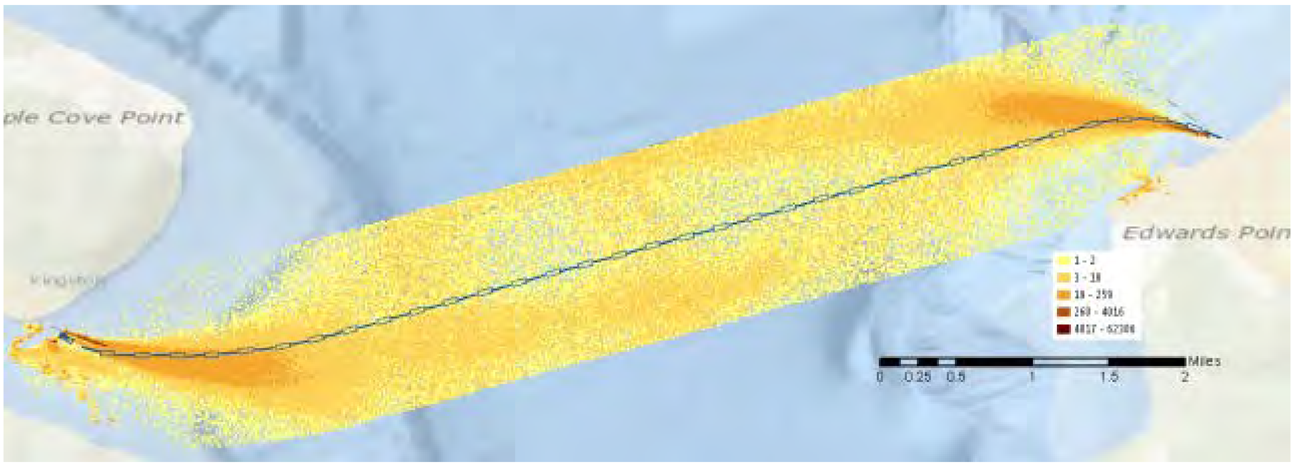

Figure 5-4 Density of Recorded AIS Points along Edmonds/Kingston Ferry Route for 2012

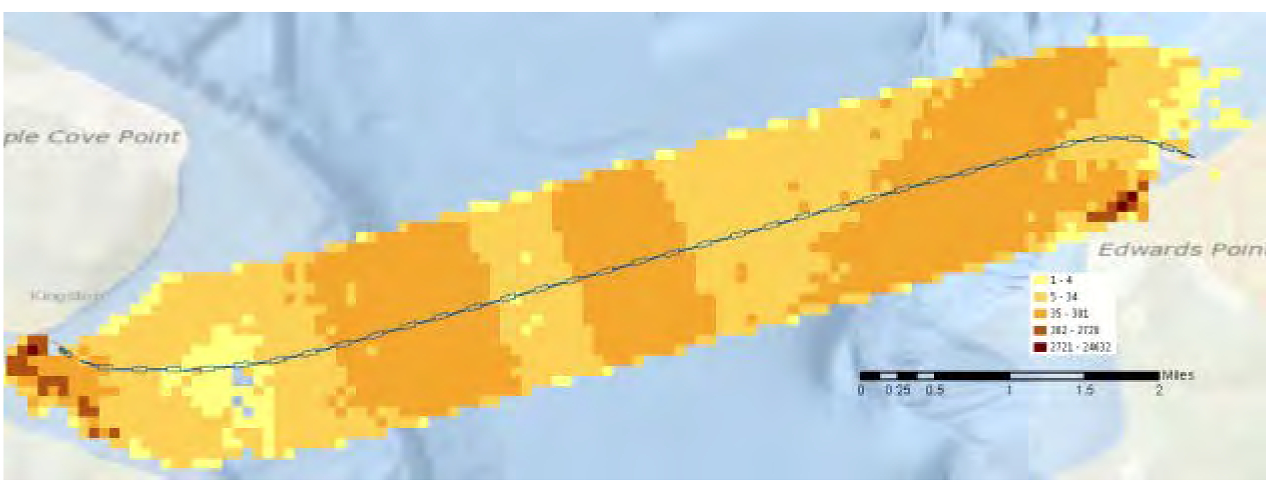

Figure 5-5 Density of Recorded AIS Points along Edmonds/Kingston Ferry Route for 2012, without Passenger and Undefined types (to show potential cross-traffic)

Since the Passenger and Undefined vessel types dominate the vessel traffic (a combined 71.7%), it was necessary to remove those vessel types to gain insight on the traffic from the remaining categories. Figure 5-5 highlights the Puget Sound inbound/outbound traffic lines and the traffic route to the Possession Sound entrance located to the north of Edwards Point. A high density of vessels is apparent south of Edwards Point and Kingston terminal, most likely due to pleasure craft (the fifth most prevalent type of vessel in the area).

5.3 Seattle/Bremerton Route

144,250 trips were sailed near the Seattle/Bremerton route during 2012 (5). This 15 nm long route had the greatest number of vessel trips compared to the other routes (43.1% of the total traffic). Approximately 80% of the vessels were categorized. Passenger vessel types (ferries) represented 44.7% of the total number of trips sailed in this area. Other contributing types were the Towing vessels (7.4%), Search and Rescue vessels (6.1%), and Cargo vessels (5.5%). The number of trips from all traffic types is listed in Table 5-5.

Table 5-5 Number of Trips by Vessel Type in 2012 near Seattle/Bremerton Route (5)

Type of vessels	Number of trips	Percentage of Total Trips
Passenger	64,406	44.7%
Undefined	29,294	20.3%
Towing	11,307	7.8%
Search and Rescue Vessel	8,824	6.1%
Cargo	7,878	5.5%
Tug	6,863	4.8%
Other	4,630	3.2%
Pleasure Craft	3,347	2.3%
Fishing	2,398	1.7%
Military Operations	2,372	1.6%
HSC	981	0.7%
Sailing	781	0.5%
Tanker	381	0.3%
Port Tender	356	0.2%
Vessel with Anti-Pollution	160	0.1%
Wig	85	0.1%
Law Enforcement Vessels	84	0.1%
Pilot Vessel	60	0.0%
Diving Operations	34	0.0%
Ships According To RRR	5	0.0%
Dredging or Underwater Operations	4	0.0%
Total	**144,250**	100.0%

Both the Seattle and Bremerton areas have substantial traffic of all types. Figure 5-6 shows the total traffic density.

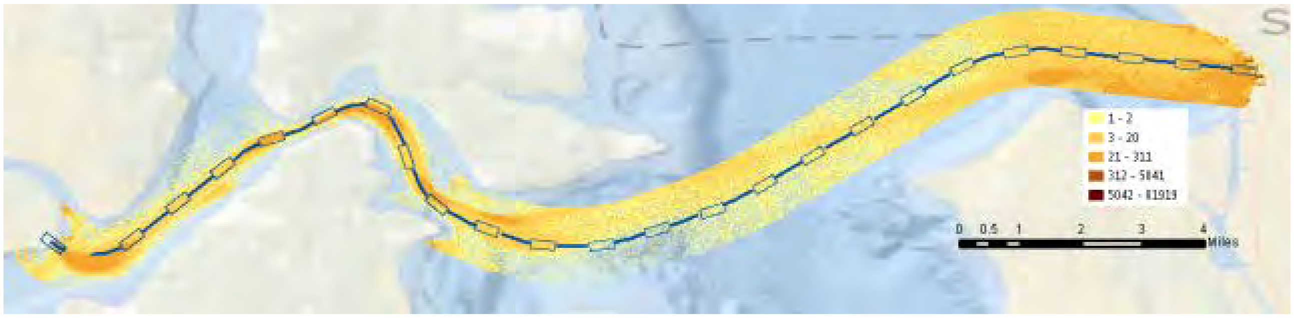

Figure 5-6 Density of Recorded AIS Points along Seattle/Bremerton Ferry Route for 2012 (to show potential cross-traffic)

Figure 5-7 shows the traffic density excluding the Passenger and Undefined types to reveal traffic paths for the remaining types of vessels. Since the Passenger and Undefined vessel types dominate the vessel traffic (a combined 64.9%), it was necessary to remove those vessel types to gain insight on the traffic from the remaining categories.

The Puget Sound inbound/outbound traffic lines are obscured in Figure 5-7 due to the volume of traffic crossing between Seattle and the Rich Passage. The density of the traffic increases through the Rich Passage due to the limited navigable area through the passage.

Figure 5-7 Density of Recorded AIS Points along Seattle/Bremerton Ferry Route for 2012, without Passenger and Undefined types

5.4 Fauntleroy/Vashon/Southworth Route

Approximately 56,800 trips were sailed near the Fauntleroy/Vashon/Southworth route during 2012 (5). This route is 9 nm long, including three different segments. Approximately 84% of the vessels were categorized. Passenger vessels represent the majority of the traffic in the area (71.5%). Other contributors were Towing vessels (4.0%), Tugs (3.3%), and Cargo vessels (3.0%). The number of trips from all traffic types is listed in Table 5-5.

Table 5-6 Number of Trips by Vessel Type in 2012 near Fauntleroy/Vashon/Southworth Route (5)

Type of vessels	Number of trips	Percentage of Total Trips
Passenger	40,625	71.5%
Undefined	9,071	16.0%
Towing	2,286	4.0%
Tug	1,846	3.3%
Cargo	1,726	3.0%
Pleasure Craft	471	0.8%
Sailing	181	0.3%
Other	171	0.3%
Fishing	153	0.3%
Vessel with Anti-Pollution	81	0.1%
Tanker	72	0.1%
Military Operations	61	0.1%
Search and Rescue Vessel	22	0.0%
Port Tender	5	0.0%
Law Enforcement Vessels	3	0.0%
Dredging or Underwater Operations	3	0.0%
Diving Operations	3	0.0%
Pilot Vessel	1	0.0%
Total	**56,781**	100.0%

The density of traffic in this area is shown in Figure 5-8, which indicates higher density areas close to the terminals and in the northern area of Vashon Island. The high density areas align with the ferry route.

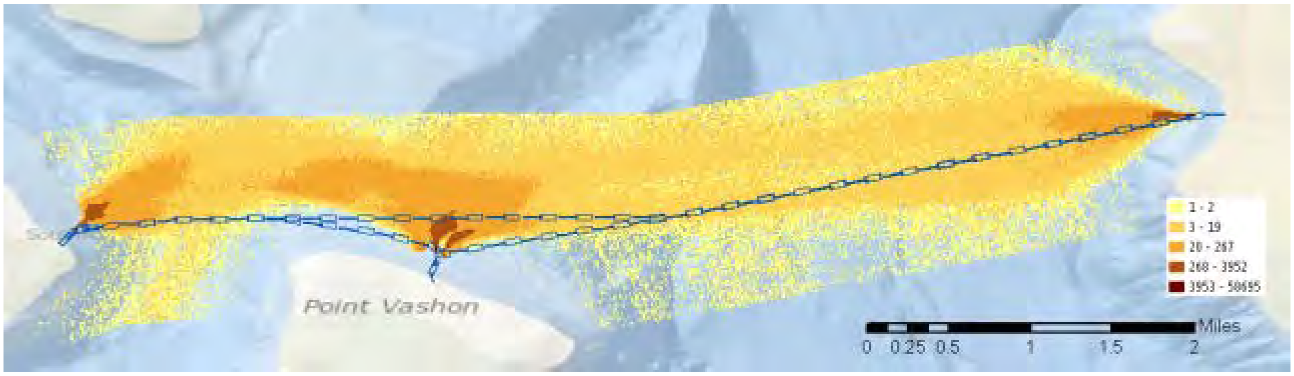

Figure 5-8 Density of Recorded AIS Points along Fauntleroy/Vashon/Southworth Ferry Route for 2012

The primary crossings with the Southworth-Vashon-Fauntleroy route are revealed by showing the AIS data without the Passenger and Undefined types (as in Figure 5-9). Since the Passenger and Undefined vessel types dominate the vessel traffic (a combined 87.5%), it was necessary to remove those vessel types to gain insight on the traffic from the remaining categories

Figure 5-9 shows three important crossing areas: the channel between Southworth and Vashon and the inbound/outbound traffic lines between Vashon and Fauntleroy. (The figure appears grainy because the maximum number of AIS points per grid cell in Figure 5-9 is low, approximately 200 points maximum.)

The traffic in the crossing lanes is not dense.

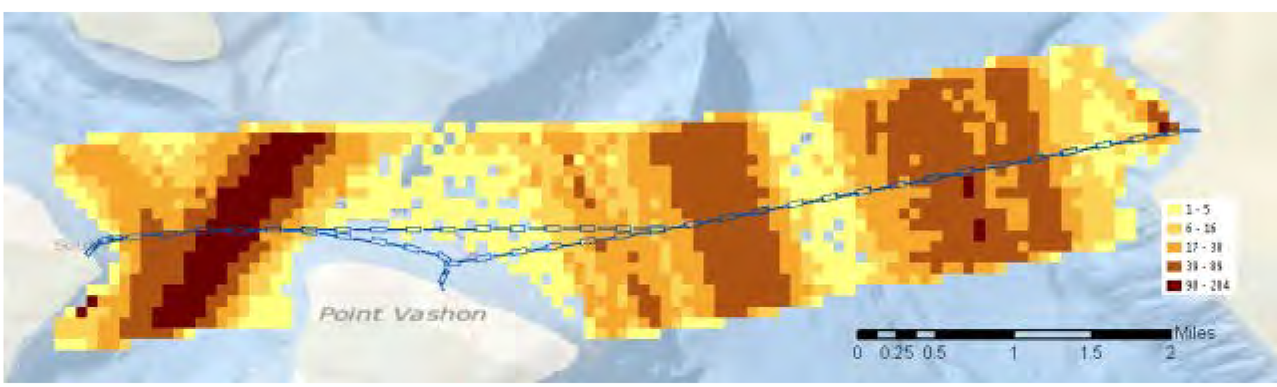

Figure 5-9 Density of Recorded AIS Points along Fauntleroy/Vashon/Southworth Ferry Route for 2012, without Passenger and Undefined Types (to show potential cross-traffic)

5.5 Anacortes/San Juan Islands/Sidney Routes

Approximately 95,200 trips were sailed near the Anacortes/San Juan Islands/Sidney routes during 2012 (5). This route is the longest of the ferry routes, and extends 67 nm. Approximately 76.2% of the vessels were categorized. The Passenger vessel type contributes 41.2% to the overall traffic in the area. Other contributors include Pleasure craft (9.3%), Dredging/Underwater Operations vessels (7.6%), and Cargo vessels (4.6%). The number of trips for all traffic types is listed in Table 5-7.

Table 5-7 Number of Trips by Vessel Type in 2012 near Anacortes/San Juan Islands/Sidney Routes

Type of vessels	Number of trips	Percentage of Total Trips
Passenger	39,236	41.2%
Undefined	22,646	23.8%
Pleasure Craft	8,878	9.3%
Dredging or Underwater Operations	7,220	7.6%
Cargo	4,384	4.6%
Sailing	3,709	3.9%
Towing	2,716	2.9%
Tug	2,244	2.4%
Military Operations	1,460	1.5%
Tanker	1,086	1.1%
Fishing	714	0.8%
Other	672	0.7%
Search and Rescue Vessel	56	0.1%
WIG	48	0.1%
Vessel with Anti-Pollution	38	0.0%
Port Tender	11	0.0%
HSC	8	0.0%
Pilot Vessel	8	0.0%
Diving Operations	2	0.0%
Spare 57	1	0.0%
Medical Transports	1	0.0%
Total	**95,138**	100.0%

The density of traffic in this area is shown in Figure 5-10 and Figure 5-11. Figure 5-10 shows 4 major crossings among the ferry routes: one is located in Sidney Channel, one in Haro Strait, another in Rosario Strait and the last in Bellingham Channel. Ferry traffic is denser in the U.S. than in Canada.

Since the Passenger and Undefined vessel types dominate the vessel traffic (a combined 64.5%), it was necessary to remove those vessel types to gain insight on the traffic from the remaining categories. Figure 5-11 reveals the four major traffic lanes crossing the ferry route. In addition, it shows Pleasure craft activity around Shaw Island. Pleasure craft were the third largest contributor to traffic in this area, after Passenger and Undefined vessel types.

Figure 5-10 Density of Recorded AIS Points along Anacortes/San Juan Islands/Sidney Ferry Routes for 2012

Figure 5-11 Density of Recorded AIS Points along Anacortes/San Juan Islands/Sidney Ferry Routes for 2012, without Passenger and Undefined Types (to show potential cross-traffic)

6 NAVIGATIONAL RISK ASSESSMENT

6.1 Approach

This navigational risk assessment is focused on navigational related accidents that can lead to an accidental spill of LNG fuel from an LNG tank.

The approach is as follows:

1. Hazard identification
2. Collision risk analysis
    a. Register all traffic interfering with each ferry route during one year (2012) (Section 5)
    b. Filter out the vessels that are too small to impact the ferry significantly in case of a collision (significant impact is a damage that potentially can lead to a LNG leak)
    c. Calculate the traffic statistics for the selected vessel types, based on 2012 data
    d. Estimate the potential collision frequency using DNV's Marine Accident Risk Calculation System (MARCS) model
3. Estimating the probability of a LNG leak from the tanks at the top deck, given a collision with a specified ship type.

6.1.1 Overview of MARCS Model

The MARCS model has been developed by DNV over the last 20+ years to support DNV's global navigational risk assessment projects.

6.1.2 Description of MARCS

The MARCS model has been implemented in two forms. One is more suitable for open water study areas and one is more suitable for linear systems like ferry routes. The latter version of MARCS was used in this study.

MARCS includes a set of models to estimate the frequencies of various types of marine accidents. MARCS also estimates the consequence of each accident type in terms of liquid cargo spill (e.g. oil and bunker spill). The consequence part of MARCS was not used in this study, as the focus here is on spillage of LNG fuel.

This study evaluated the following accident types:

- Collision (with other vessels)
- Impact with the dock

MARCS relies on a wide range of parameters to represent the marine environment and operations in the study area in order to provide realistic estimates of the risks. These parameters include study area, marine traffic, marine environment, and marine operations.

The block diagram in Figure 6-1 shows the data flow in MARCS.

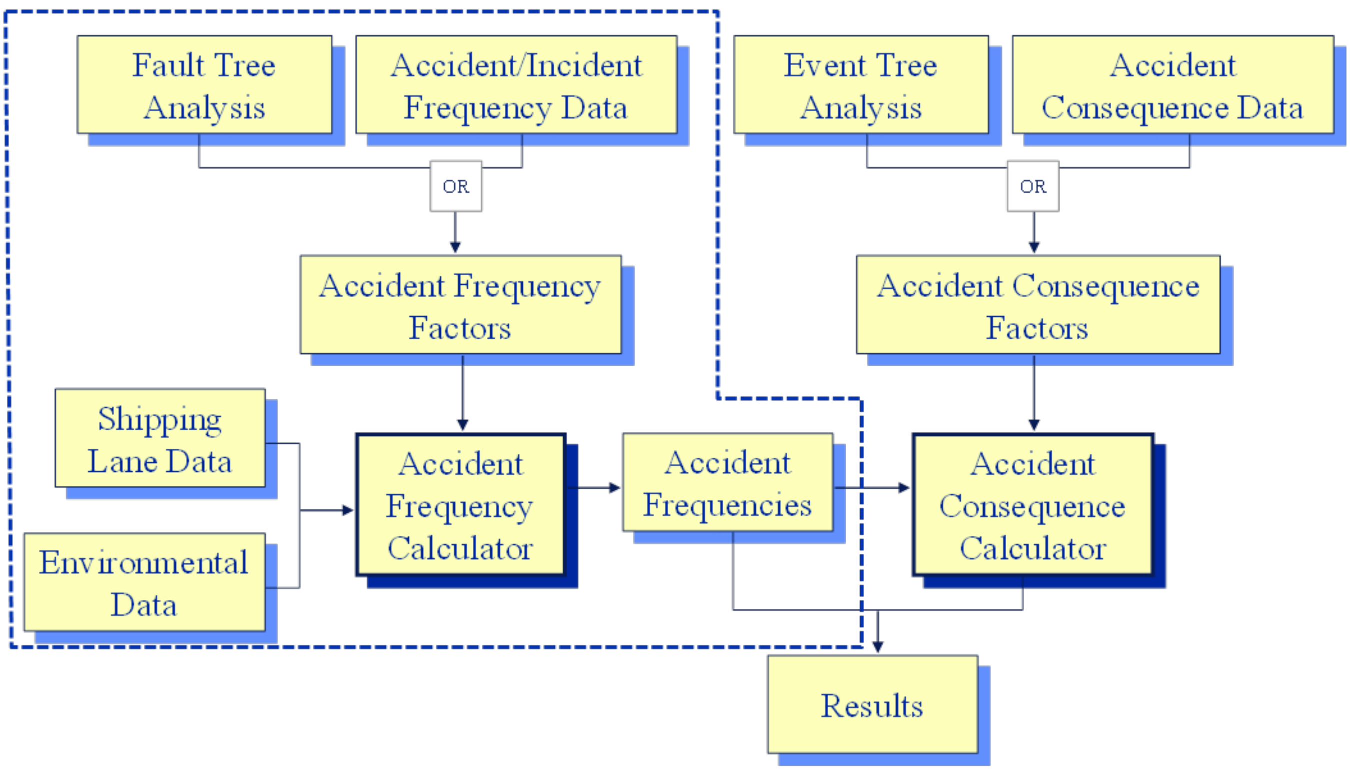

Figure 6-1 MARCS Block Diagram (The dotted boxed line portion was used to estimate the potential collision frequency)

6.1.3 Data used by MARCS

This section briefly describes the main data used by MARCS.

Study area: characteristics of the waterways, including the study area boundaries, locations of shallow water and any fixed man-made structures that could be a hazard to navigation (described in Section 4).

Marine traffic: The marine traffic in the study area is described in Section 5. The traffic that is included in the risk calculations was filtered to include only those vessels that are large enough to potentially hit LNG tanks at the upper deck should a collision occur. This is discussed in greater detail in Section 06.5.

The vessel types included in the risk calculations are:

- Passenger vessels
- Tankers
- Cargo vessels
- Bulk carriers
- Military vessels

Marine environment: Marine environment information includes data on visibility, which is used in the collision (and powered grounding) accident models.

Marine operations: Waterways management and navigational aids have an impact on accident risk estimation. The risk reducing measures considered relevant for potential collision risk in Puget Sound are shown in Table 6-1. MARCS applies shaping factors to adjust the navigational risk to reflect the implemented risk reducing factors, Table 6-1 shows the applied factors.

Table 6-1 Risk-reducing Measures Relevant to Collision and Applied "Shaping Factors" in MARCS

Risk Reduction Measures	Risk reduction factor related to collision
Port State Control (PSC)/WSF Procedures and Control	12 %
Vessel Traffic Service (VTS) with Traffic Organization Services (TOS) and AIS surveillance	20 %
Pilotage	25 %
Operational Give Way procedures for WSF ferries. (That was captured in the Navigational risk workshop) /Safety Zones	0 %*

* Note, MARCS does not have reduction factors for the give-way requirements implemented in WSF operational procedures.

6.1.3.1 Effect of the Risk Controls Applied in MARCS

The risk reduction factors applied in the MARCS model are derived from international research on the effect of various risk controls and from experience gathered in DNV. Effect of VTS was studied in a European study from 1988 (6) that estimated that radar-based VTS would produce a relative risk for collisions and groundings of 0.6 (i.e., a 40% risk reduction).

Other similar studies (7) have found relative risks of 0.5 to 0.33 (i.e. risk reduction by 50% to 67%).

The SAFECO study (8) (DNV 1998) quoted data for the Western Scheldt estuary that indicated relative risks of 0.6 for collisions and 0.8 for powered groundings. Based on this, DNV's MARCS model uses a risk reduction factor of 0.2 (i.e. a 20% reduction) for collisions (assuming both ships in the encounter participate in the VTS) and for powered grounding.

Port State Control (PSC) has been progressively adopted world-wide since the first implementation in Europe through the Paris Memorandum of Understanding (MOU) in 1982. It may account for some of the reduction in accident frequencies since then.

Figure 6-2 shows the historical trend in the frequency of all types of losses, casualties and incidents in the world-wide fleet. The frequency of total losses has declined at an average rate of approximately 5.2% per year. However, when serious casualties and non-serious incidents are included, the frequency appears to have increased between 2002 and 2007. The causes are not entirely clear, but the effect is that the historical trend does not show any clear decline that could be apportioned into its various causes, including PSC, but also including changes in operating procedures and safety management.

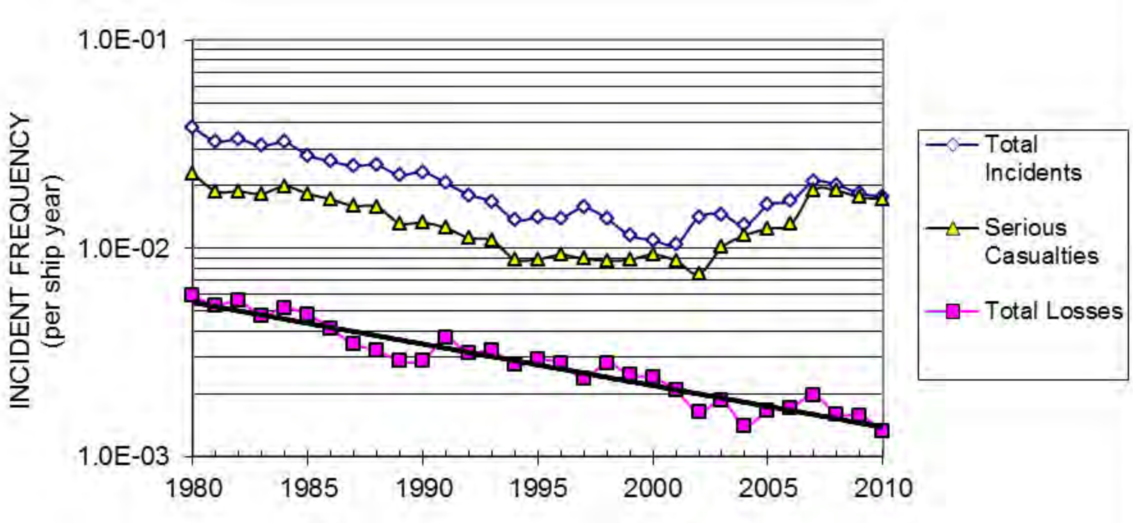

Figure 6-2 Overall ship accident frequency trends, 1980 - 2010 (global data)

Knapp et al (9) estimated the survival gains for different ship types in the years 2003 to 2007 based on individual ship loss experience and PSC inspections in Australia and the U.S. Combining the data for four cargo ship types over 5 years, the average reduction in risk for total losses was 12%. Although there is significant uncertainty, the most valid estimate available is provided by the above analysis. Based on this, DNV's MARCS model uses a risk reduction factor for PCS of 0.12 (i.e., a 12% reduction) for collisions.

Pilotage is expected to influence the frequency of collision and powered grounding. The personal accident risk from embarking/disembarking is not modeled in the study.

Where a pilot is optional, Japanese data (7) indicated that a pilot on board reduced the accident frequency by 83%.

An Australian study (10) used a relative risk of 0.51 (i.e. a 49% reduction) for "compulsory pilotage for majority of ships". Given the extension of compulsory pilotage since then, this has been re-interpreted more recently (11) as a relative risk of 0.5 for "non-compulsory pilotage".

SSPA Sweden AB (12) reports various studies of risk control efficiency, with estimated risk reductions in the range of 50% to 97%. However, no data was provided in the studies to support the risk-reducing factors.

DNV's MARCS model uses performance shaping factors (PSFs) for internal vigilance of 0.5 with respect to human performance and 0.25 with respect to incapacitation, which give an overall relative risk of 0.74, which results in a 26% reduction for collisions. The collision result assumes pilotage on one ship only.

6.2 Hazard Identification

Collaborative risk assessment is the process of engaging stakeholders, decision makers, and analysts in the design and conduct of a risk assessment. Hazard identification is usually a qualitative exercise based on expert judgment. Most HAZID techniques involve a group of experts, since few individuals have expertise on all hazards, and since group interactions stimulate consideration of hazards that even well-informed individuals might overlook.

DNV conducted a navigational HAZID workshop in Seattle on February 13, 2013. The main focus of the workshop was to identify navigational hazards that could lead to accidents with an LNG leak from a ferry's fuel tanks. The results from this workshop are detailed in Appendix 2 - Navigational Safety HAZID.

6.2.1 Navigational Issues

There are very few specific navigational issues identified in the U.S. Coast Pilot 7, chapter 13 for the ferry routes (13):

6.2.1.1 Rich Passage

Rich Passage is about 3 miles long and takes a sharp bend near the west end between Waterman Point (to the south) and Point White (to the north). The passage narrows to approximately 0.2 miles at the western outlet (13).

Current velocities increase from east to west in the Rich Passage reaching a maximum average velocity of 2.4 knots at the flood and 3.1 knots at the ebb. Extensive eddies and countercurrents occur at the ebb and extend to mid-channel midway through the Rich Passage. The eddies, countercurrents, and water velocities diminish the effective width of the channel (13).

The U.S. Coast Pilot 7 (13) describes the Rich Passage as an area with large traffic volumes due to activities at the Puget Sound Naval Shipyard, the U.S. Coast Pilot does not define the size of a "large traffic volume" and DNV has not been able to find any standard definition in the U.S. Coast Pilot that supports any size definition of a "large traffic volume". Deep-draft vessels making the turn at the western end of the Rich Passage often must pass other vessels starboard-to-starboard (13).

6.2.1.2 San Juan Islands

Freshets, strong winds, unusually high tides, and tide currents increase the navigational challenges in the San Juan Islands area. Much of the other traffic in the area (any vessel not exclusive Pacific Northwest area trade) requires pilotage. Localized magnetic disturbances can cause as much as 14° in variation (13).

6.2.2 Navigational Hazards Included in the Risk Assessment

Table 6-2 lists the identified navigational hazards that were identified during the workshop. Because of the design of the LNG fuel system with the LNG fuel tanks situated at the top deck between the stacks and pilot houses, the team agreed that most of the identified hazards do not have the potential to lead to an accident involving an LNG leak.

Table 6-2 - Main Hazards and Hazard Causes Identified in the HAZID Workshop

Hazard	Typical Hazard Causes
Collision between two navigating ships	Human error
Powered grounding	Human error
Drift grounding	Mechanical failure - Harsh weather
Allision with the ferry terminal	Human error Severe environmental conditions
Striking of ferry at the terminal by a passing ship	Human error

Powered grounding and drift grounding incidents will not lead to damage of the LNG tanks on the top deck. Allision with the ferry terminal, which is the most common incident, also does not have the potential to cause LNG tank damage. During the HAZID workshop, it was concluded that the design of the terminals and the slips will prevent components of the terminal from damaging the LNG tank area of the vessel should an allision occur.

Collision between a large vessel and a ferry and striking of a ferry at the terminal by a passing ship are estimated together in the risk assessment as a *collision*. Given sufficient energy and height of the ship bow, there is a theoretical possibility that a collision could lead to an accident with LNG tank damage and an LNG spill. However, the likelihood for such an accident is extremely low; this is discussed in more detail in Section 6.5.

The risk estimates in this navigational risk assessment are estimates of collision risk between ferries and large crossing vessels. The majority of these vessels are in the main sailing lane of Puget Sound, in the Haro Strait and the Rosario Strait.

The vessel types included in the collision risk analysis are shown in Table 6-3. DNV maritime experts have established a threshold length for various vessel types: vessels longer than the threshold are expected to have a bow height that is greater than 10 m to 15 m (32 ft to 49 ft). All vessels greater than the minimum length were included in the collision risk analysis.

Table 6-3 Vessel Types and Minimum Sizes Defined as Large Vessels and Included in the Collision Risk Analysis

Vessel type	Minimum Length Over All (LOA)
Vehicles carrier	All included
Heavy lift vessel	All included
Heavy load carrier	All included
Ro-Ro vessels	All included
Wood chips carrier	180 m (590 ft)
Cargo	200 m (656 ft)
Research/survey vessel	200 m (656 ft)
Logistics naval vessel	200 m (656 ft)
Replenishment vessel	200 m (656 ft)
Container ship	200 m (656 ft)
Bulk carrier	250 m (820 ft)
Tanker	250 m (820 ft)
VLCC	250 m (820 ft)
Military Ops	300 m (985 ft)
Aircraft Carrier	300 m (985 ft)

6.3 Traffic Statistics for Vessels that could pose a Hazard to LNG Fuel Tanks

The filtering criteria for large vessels shown in Table 6-3 were applied to the 2012 AIS data. Table 6-4 shows the traffic statistics for the “large” vessels crossing the ferry route per year (based on 2012 AIS data). The table also shows the average length and the average max speed of the large vessels.

The Seattle - Bremerton route is the route with the highest number of large vessel crossings (according to the definition in Table 6-3); 5,696 large vessels were crossing the sailing route in 2012, their average length was 276 m (905 ft) and the average maximum speed for the vessels was 18 knots.

The Mukilteo - Clinton route had the lowest number of large vessel crossings; only 69 large vessels crossed the ferry route in 2012. The average length of the vessels was 176 m (577 ft) and the average speed of the vessels was 15 knots.

Table 6-4 Number of Vessel Crossings per Ferry Route (5)

Route	Route-crossing Traffic (after applying length criteria)		
	No. of Crossings (per year)	Avg ship length	Avg max speed (knots)
Fauntleroy/Vashon/Southworth	2,984	249 m (917 ft)	19
Seattle/Bremerton	5,696	276 m (905 ft)	18
Edmonds/Kingston	2,427	262 m (860 ft)	18
Mukilteo/Clinton	69	176 m (577 ft)	15
Anacortes/San Juan Islands/Sidney	2,354	262 m (860 ft)	16

Table 6-5 shows the annual number of ferry trips of each of the WSF ferry routes that are included in this analysis. The numbers of sailings are calculated based on the WSF route table. The Fauntleroy/Vashon/Southworth route and the Anacortes/San Juan Islands/Sidney route consists of several small routes, but is handled as a common set of routes in the risk assessment.

Table 6-5 Number of Ferry Trips per Year for Each Route, based on WSF Route Table

Route	Ferry trips per year	Route	Ferry trips per year
Fauntleroy/Vashon /Southworth	-	***Anacortes/San Juan Islands/Sidney***	
Fauntleroy/Vashon	22,610	Anacortes - Lopez	11,902
Fauntleroy/Southworth	4,600	Lopez - Friday Harbor	5,357
Vashon/Southworth	13,415	Friday Harbor - Sidney	560
Seattle/Bremerton	10,897	Friday Harbor - Orcas	3,909
Edmonds - Kingston	17,052	Orcas - Sidney	196
Mukilteo - Clinton	26,770	Orcas - Shaw	8,717
		Lopez - Shaw	8,595

Names in *italics* indicates a grouping of routes

6.4 Collision Risk Analysis

The annual frequency of the ferry traffic (Table 6-5) and the number of large vessels crossing the ferry route in a year (Table 6-4) were the basis for estimating the potential collision frequency in the MARCS model. The MARCS model accounts for the effect of many existing risk controls. Table 6-1 shows the risk reducing factors applied to reflect the effect of the established risk controls.

Figure 6-3 shows the potential collision risk results. The ferry route with the lowest potential collision risk is Mukilteo/Clinton with an annual collision frequency of $7.6x10^{-4}$ per year (that is the same as the likelihood for one collision every 1,310 years). This result is easily explainable with the very low number of crossings by the large vessel traffic along the ferry route.

Seattle/Bremerton is the ferry route with the highest collision risk, with an annual frequency is $2.3x10^{-2}$ per year, which is equal to the likelihood of one collision every 42 years. The route is long and crosses the busy Elliot Bay as well as the main shipping route for North-South bound traffic so there are a high number of large vessels that cross the ferry route.

Despite the fact that the ferry route Anacortes/San Juan Islands/Sidney is crossed by approximately the same number of vessels as the Kingston/Edmonds and Fauntleroy/Vashon/ Southworth routes, Anacortes/San Juan Islands/Sidney has a lower collision frequency $3.3x10^{-3}$ per year (once every 304 years) than either of these: $1.6x10^{-2}$ per year (once every 64 years) and $1.4x10^{-2}$ per year (once every 73 years), respectively. The main reason for this is that the Anacortes/San Juan Islands/Sydney ferry route crosses densely-trafficked waters less frequently than the other two routes. The Anacortes/San Juan Islands/Sydney ferry route is not just one route, but consists of seven smaller routes. The numbers of ferry crossings vary between these routes. The ferry routes with the fewest ferry crossings are Friday Harbor/Sidney and Orcas /Sidney routes, which cross the densely trafficked Haro Strait.

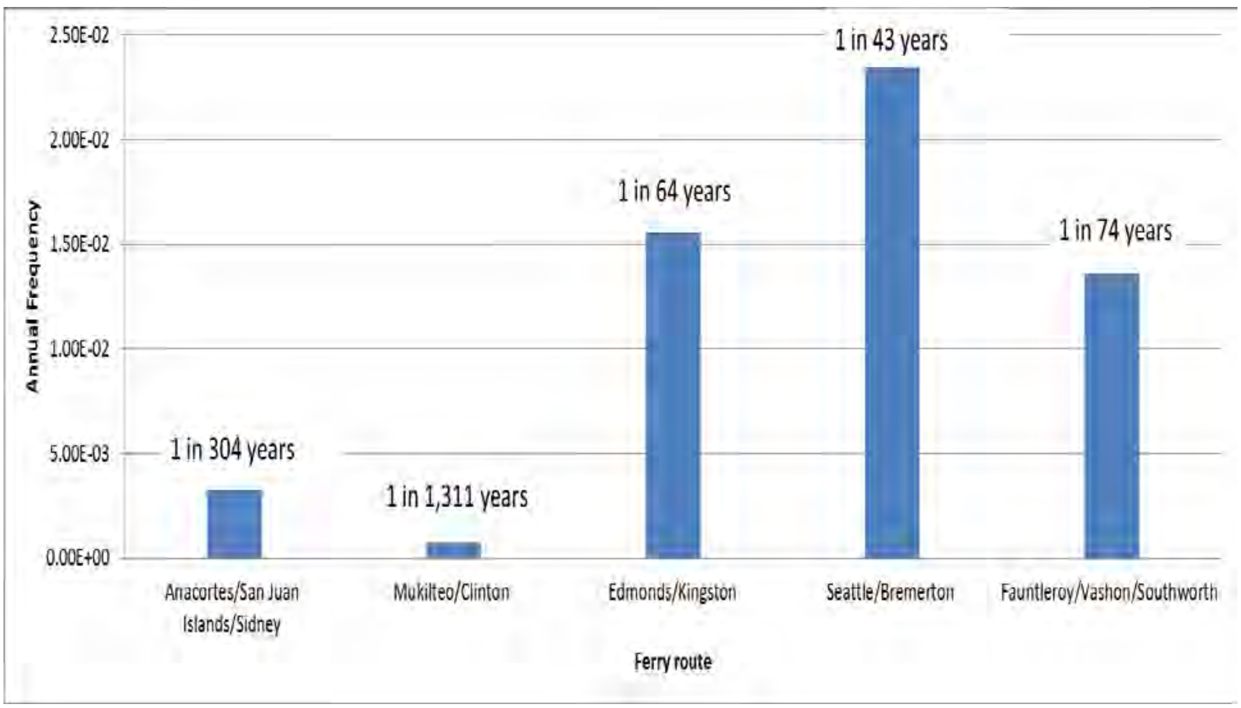

Figure 6-3 Estimated Annual Collision Frequency per Ferry Route

6.4.1 Historical WSF Ferry Incident and Accidents

This section gives an overview of the major WSF ferry incidents and accidents since the 1960s. It is clear from the overview that historically until about 1980, the level of detail and number of incident registrations was very limited. In contrast, the level of detail improved and number of incidents registered increased from around mid-2000 and onwards. This variation in registered incidents and accidents makes the data assessment less powerful in terms of understanding the historical incident picture. However, it is assumed that the major accidents are represented in the data.

The Washington State Ferries Risk Assessment of 1999 (14) showed that majority of incidents did not lead to an accident. In the 10 year period from 1988 to 1999 there were 460 incidents, while only 36 were categorized as an accident. Of the 36 accidents, there were 4 collisions, 6 groundings, and 26 allisions. An assessment of the reported registered accidents from WSF (Table 6-6) shows that there have been no collision accidents since 1994. The accidents registered since the last risk assessment consists of 8 allisions and 5 groundings. None were severe accidents. No collisions have led to major damage since the collision between M/V Nisqually and Taichung in 1963.

Table 6-6 Major Incidents from 1979 to 2012 plus the Collision in 1963 (data from WSF)

Year	Incident	Collision	Grounding	Allision	Near collision	Near grounding
1963	The M/V Nisqually collided with the 10,000-ton Chinese freighter Taichung in fog near Kingston. The bow of the freighter ripped a V-shaped gash in the port side of the ferry running from three feet above the waterline up into the dining area on the upper deck. No one was injured, but the ferry was out of commission with close to $100,000 in damage.	X				
1979	The M/V Tillikum has a hard landing at the Kingston Terminal. One passenger was injured. The Kingston terminal was out of service for a significant amount of time.			X		
1981	The Klahowya collided with a Liberian freighter in heavy fog in Elliot Bay causing minor damage.	X				
1983	1983: The M/V Elwha runs aground in the San Juan Island.		X			
1986	A freighter failed to respond to numerous attempts at passing arrangements and the ferry Chelan was forced to stop to avoid collision.				X	
1986	The Hyak ran into a reef near the Anacortes ferry terminal, forcing the evacuation of 250 passengers.		X			
1987	An inbound freighter nearly collided with the ferry Walla Walla, leaving Seattle Pier 52. The ferry turned hard right to avoid a collision.				X	
1990	The M/V Chelan had a hard landing with the terminal dock at Orcas Island. There are no injuries and little damage to the vessel. However, the terminal received more than $225,000 in damage.			X		
1990	The M/V Spokane lost propulsion and crashed into the Eagle Harbor Marina, severely damaging two recreational vessels and destroying a marina dock, estimated damage in excess of $500,000. No injuries reported.			X		
1991	The ferries Sealth and Kitsap collided in heavy fog just north of Bremerton, injuring one woman.	X				
1993	A 32-foot pleasure boat broadsided the M/V Spokane, the accident was blamed on an inattentive boat operator.	X				
1994	The ferry Nisqually went aground on Elwha Rock off of Orcas Island.		X			
1994	The ferry Kitsap collided with a pleasure craft as it was proceeding to a Bremerton dock.	X				
1994	The M/V Quinault grounded no other details available.		X			
1994	The ferry Elwha crashed into the Anacortes dock causing $500,000 in damages.			X		

Year	Incident	Collision	Grounding	Allision	Near collision	Near grounding
1995	The ferry Nisqually lost power and rammed into the Lopez Island dock. Several passengers suffered minor injuries and the dock was seriously damaged.			X		
1996	The M/V Kitsap ran aground in thick fog, three miles east of Bremerton near Point Glover. None of the 475 passengers aboard the ferry was hurt, but the accident caused $200,000 damage to the ferry.		X			
1996	The ferry Elwha nearly runs aground in the San Juan Islands when the skipper goes for an unauthorized, 15-mile detour.					X
1999	The ferry Elwha crashed into the Orcas Island dock when the engines failed to reverse, causing $2.5 million in damages and disrupting vehicle traffic for days.			X		
2001	The M/V Sealth grounded caused by human error, no one was injured. The investigation concluded that the master was negligent in his watch-standing duties while the vessel was underway.		X			
2002	The M/V Quinault grounded in Keystone Harbor. A few hundred yards from the dock and about 25 yards off the beach. Approximately 110 passengers were stranded for six hours.		X			
2004	The M/V Sealth grounded on Reid Rock near Friday Harbor was the result of "gross negligence" by the Chief Mate and Licensed Captain. Damage and cost $273,000.		X			
2005	The M/V Quinault ran aground when it backed up and hit a rock shelf damaging its rudder.		X			
2005	The M/V Wenatchee almost struck a Danish cargo ship. The M/V Wenatchee and the 1,044-foot freighter Knud Maersk were forced to veer off-course passing within a quarter mile of each other. No injuries or damage reported.				X	
2007	The M/V Klickitat encountered an exceptionally large wave that pushed four cars around the deck. The M/V Klickitat experienced a major interruption that lasted several days after the boat was pulled out of service for repairs to a crack found in its hull. Repairs cost $50,000. (categories do not apply)					
2007	The M/V Cathlamet struck the north wing wall at the Mukilteo Ferry terminal at a speed of over seven knots, causing $139,000 damage to the ferry and over $1 million to the terminal. No injuries reported.			X		
2008	The M/V Snohomish hit a breakwater yet suffered no significant damage but missed its last two scheduled runs.			X		

Year	Incident	Collision	Grounding	Allision	Near collision	Near grounding
2008	The M/V Yakima hit the breakwater near the Bremerton dock putting three cracks in the hull. The vessel hit the edge of a new breakwater being built for a new Bremerton marina, causing the cracks. The accident caused water to seep into the hull.			X		
2009	The M/V Wenatchee had a hard landing with Slip 3 at Colman dock. The landing caused damage to the vessel's bow and the slip's wing wall. One elderly person was slightly injured. Repairs and schedule delay cost $327,000.			X		
2010	The M/V Hyak, hit the outer mooring dolphin and caused damage to the frames and curtain plate of the upper car deck of the port side of the ship between Frames 36 and 44.			X		
2010	The M/V Hyak, hit the left wingwall (viewed from the shore) with the starboard bow of End No. 1 with sufficient force to cause damage and break timbers in the wingwall structure. No crew or passenger injuries were experienced.			X		
2010	The M/V Evergreen State, hit the left wing wall of the berth (viewed from land) with the stern of the ship with sufficient force to cause moderate damage to the vessel and cosmetic damage to the berth wing wall structure. No crew or passenger injuries were experienced.			X		
2010	The M/V Sealth, experienced a “hard landing” with the dock. No crew injuries were sustained. Two reported minor passenger injuries were experienced. There was no damage to the vessel.			X		
2011	February 15, 2011 the MV Chetzemoka soft grounding in Key Stone Harbor with no damage, but with service disruption for the remainder of the day and the next morning.		X			

6.4.2 Comparison of Risk Results with the Historical Data

The collision probability estimated in MARCS requires careful evaluation as it is based on modeling. All models intend to replicate what happens in reality, but no matter how well a model performs, it will have some shortcomings. That is why it is important to evaluate the risk results to verify that they are valid.

The accident statistics for significant accidents with WSF ferries appear to be reliable for the period 1979 and onward. Credible data are lacking for 1979 and earlier, except for information on major accidents such as the M/V Nisqually collision. From 1979 until the present, 2 collisions occurred between large vessels and a ferry: one ferry-to-ferry, and one bulk vessel-to-ferry. These two collisions during the course of 34 years result in an average collision frequency of **0.059** per year. This is valid for all WSF's ferry routes.

The total collision frequency calculated using MARCS is **0.057** per year (very similar to the actual average of 0.059 per year). A minor difference in the data sets is the number of routes: in this analysis, three routes were not included that are represented in the historical data. Even taking into consideration this minor difference, the collision frequency calculated by using MARCS is well in alignment with the historical collision risk picture.

It could be argued that the analysis has not taken into consideration the decreasing trend of collision frequency. There have not been any collisions since 1994. WSF implemented important organizational and operational procedures to reduce the collision risk. This together with the establishment of Vessel Traffic Services (VTS) and the use of AIS and electronic charts where the crossing vessels are plotted is expected to have significantly reduced the collision risk.

As discussed in Section 6.1.3, the collision model did not include a risk reduction factor to reflect the existing operating procedure that requires the ferries to give way in crossing situations - even if they have the right not to give way. It could be argued that this risk control would further reduce the predicted collision frequency, though DNV is unable to quantify the magnitude of the reduction. Introduction of such a factor in the model could have decreased the collision frequencies, but not as much as an order of magnitude (i.e., not as much as a 90% reduction). Thus, the collision frequencies would still have been in the same order of magnitude as the frequencies are based on the historical data.

The collision frequencies estimated in the MARCS model are valid results.

6.5 LNG Leak Probability

This section will discuss the probability of having a LNG leak from one of the two LNG tanks at the top deck due to a collision. The frequency of a collision between a ferry and a large vessel was discussed in the previous section. Three conditions would be required for a leak from a LNG tank:

1. Collision
2. 5 m (16 ft.) penetration into the hull
3. Penetration to occur at a height of 12 m (39 ft.)

Therefore, the vast majority of collisions, even with large vessels, will not have any impact on the LNG tanks.

Many previous studies have evaluated the probability for penetrating a LNG tank in a LNG carrier in case of a collision. But these studies are not relevant for a redesigned LNG fueled ferry as in this risk assessment. In this study we have to consider the likelihood that a vessel penetrates more than 5 m (16 ft) into the side of the ferry during a collision. Further we need to understand the likelihood that a 5 m (16 ft) or larger penetration occurs at the top deck where the LNG tanks are situated.

For the estimation of the probability for a 5 m (16 ft) penetration or larger (in case of a collision), the methodology and formulas contained in SOLAS Ch.II-1 have been used. These regulations are based on a probabilistic method, which includes probabilities for a damage to occur within the limits of a defined zone in the longitudinal direction as well as the penetration depth transversally into the ship.

When using this methodology, the area forward and aft of the LNG tank has been divided into zones as shown in Fig.1. The LNG tanks are located within the boundaries of zones Z3 and Z5. The probability for a damage to occur within these two zones is denoted p. Correspondingly the ship has been divided in zones forward and aft of the LNG tank areas.

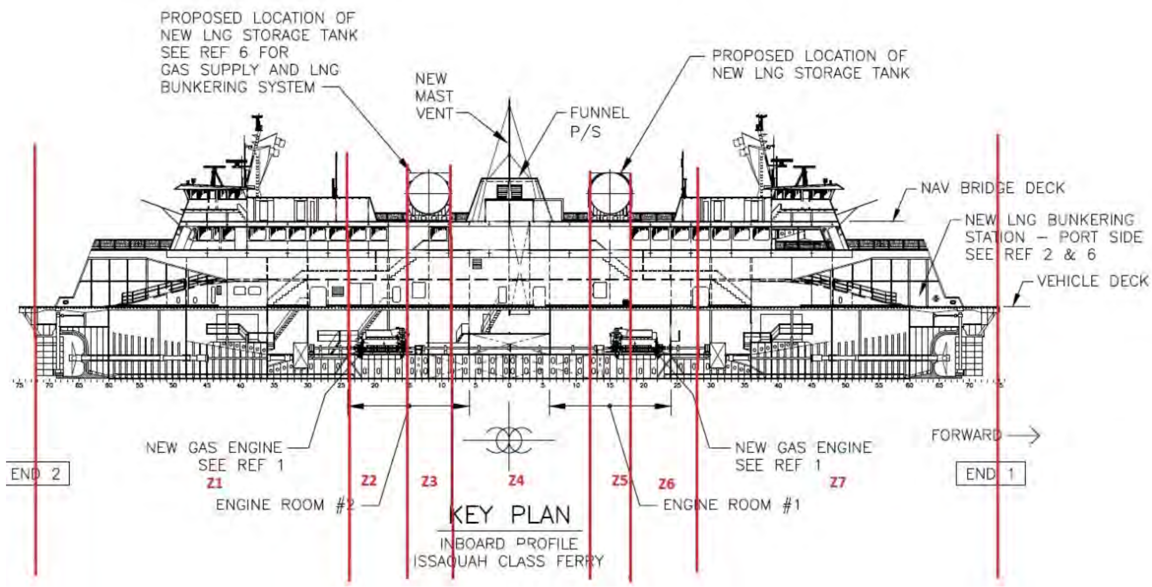

Figure 6-4 Zones Considered Regarding Probabilities for Hitting an LNG Tank

SOLAS Ch.II-1 formulations provide probabilities of potential involvement of zones Z3 and Z5 due to any damage, either solely or in combination with, adjacent zones (e.g., Z2-3 and Z5-6).

SOLAS Ch.II-1 also includes a probability distribution for transverse damage penetration. This distribution is also somewhat dependent on the length of the damage.

Based on a review of a LNG-fueled passenger vessel drawing, the tanks are located roughly 15.8 m (52 ft.) above the base line (around 12 m (39 ft.) above the waterline for deepest draft) and 5 m (16 ft.) from the gunnel.

The calculation results for the probability of penetration independent of vertical distribution are listed in Table 6-7. As the LNG tanks are located symmetrically, only starboard side damages were estimated.

Based on the estimates, it is assumed that the probability for damaging an LNG tank given a collision and being rammed by another ship is 8.5%, assuming no correction for the height of the impact on the vessel. (These results are based on a simplified model.)

Table 6-7 Probability of Penetration Exceeding 5 m (16 ft) into a Ferry Side

Number of zones affected	Zones involved	Probability of transverse penetration exceeding 5 m	Number of zones affected	Zones involved	Probability of transverse penetration exceeding 5 m
1 ZONE	Z3	0.00142	**4 ZONES**	Z1 to Z4	0.00429
	Z5	0.00142		Z2 to Z5	0.00059
2 ZONES	Z2 and Z3	0.00832		Z3 to Z6	0.00059
	Z3 and Z4	0.01219		Z4 to Z7	0.00429
	Z4 and Z5	0.01219	**5 ZONES**	Z1 to Z5	0.00009
	Z5 and Z6	0.00832		Z2 to Z6	0.00030
3 ZONES	Z1 to Z3	0.00518		Z3 to Z7	0.00009
	Z2 to Z4	0.01022	**Total Probability = 0.085**		
	Z3 to Z5	0.00063			
	Z4 to Z6	0.01022			
	Z5 to Z7	0.00518			

By combining the probability for a penetration exceeding 5 m (16 ft) with the estimated collision frequency, an estimate is obtained of the frequency for collisions that can potentially hit the LNG tank on the top deck (Figure 6-5).

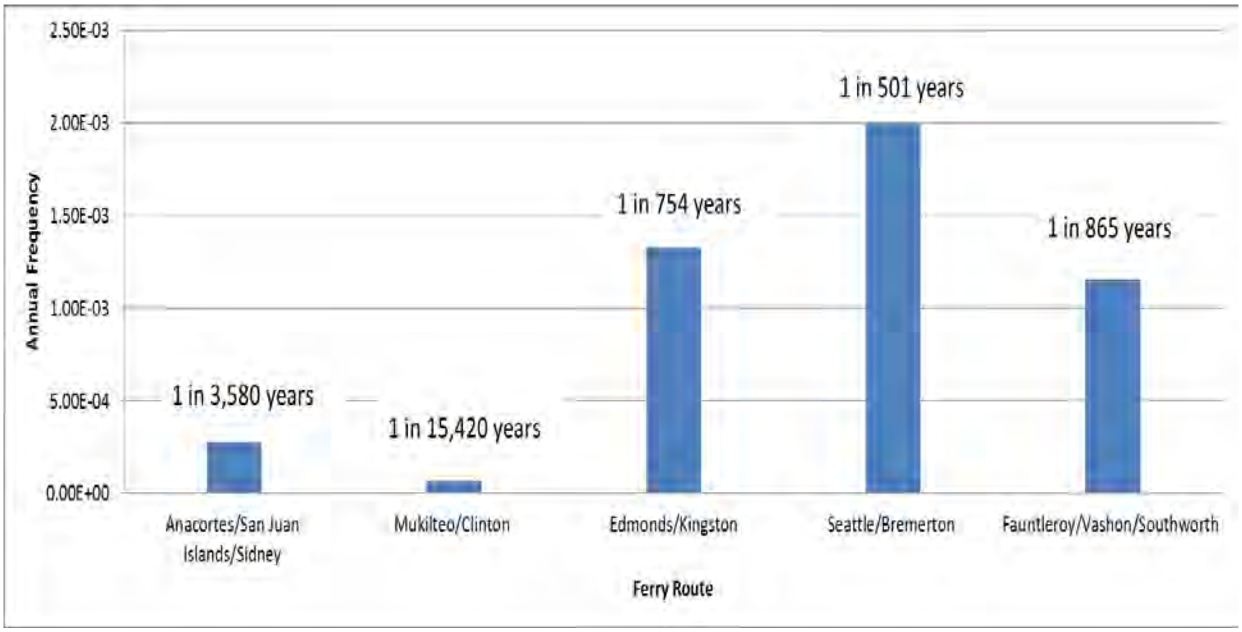

Figure 6-5 Estimated Annual Frequency of a Collision that Could Result in a 5 m (16 ft.) Penetration into a Ferry Side near an LNG Tank (assuming unlimited vertical damage)

The LNG tanks are located at the top deck more than 12 m (39 ft) above the waterline. This reduces the probability that a vessel colliding with the ferry will impact the tanks. The probability was calculated independent on the vertical distribution of the penetration. SOLAS Ch.II-1 also has a vertical distribution probability curve for collisions. The highest possible vertical area above the waterline where there is a probability to have a penetration of the ship hull from a collision is 12.5 m (41 ft). A review of the probability curve shows that the uncertainties are too high for application in this assessment, as the height of an LNG tank is at the very end of the vertical distribution of the probability curve.

The SOLAS data indicates that it is very unlikely for a vessel to collide with a ferry and penetrate 5 m (16 ft) into the top deck situated 12 m (39 ft) above the waterline. This corresponds well with the general impression that the localization of the LNG tanks has an inherently safe design against external impact from collision, striking, and allision.

As mentioned above, the uncertainty in the SOLAS probability distribution curves for vertical impact from a collision is very high. This is due to the vertical location of the LNG tanks is at a height that corresponds with the extreme far end of the probability curve (i.e. probability = 0). This can be illustrated (based on the curve), that the probability of a collision impact at 12 meters over the waterline is 0.02 while the probability of a collision impact at 12.5 meters is zero. Applying the values from the vertical impact probability curve for a collision impact at 12 meters above the waterline in combination with the estimated annual frequency for collisions that could lead to more than a 5 meter penetration (Figure 6-5) reduces the annual accident frequency with a factor of 50. The annual frequency for such an accident is shown in Figure 6-6. However, applying the probability values for a collision impact at 12.5 meters gives an insignificant annual accident frequency. It can be concluded that the annual frequency for an accident causing penetration of an LNG tank is lower than the frequencies shown in Figure 6-6. This shows that the likelihood for a collision leading to an LNG leak in the route with highest traffic (Seattle/Bremerton) is less than 1 in every 25,000 years.

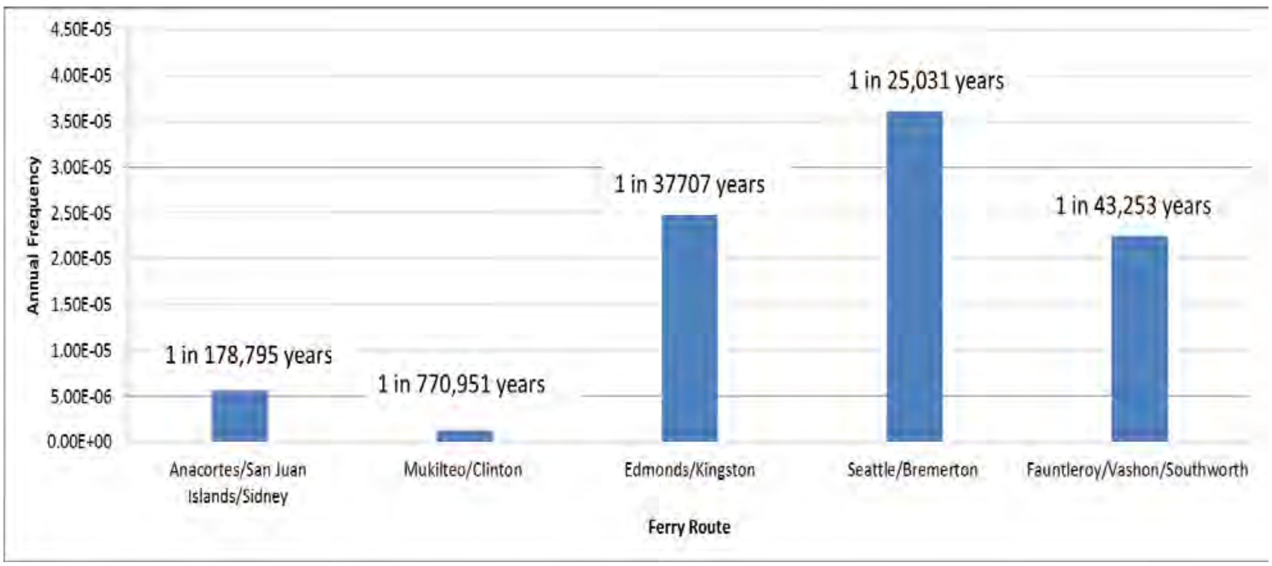

Figure 6-6 Estimated Annual Frequency of a Collision that Could Result in a 5 m (16 ft.) Penetration into a Ferry Side at a 12 meter height above waterline near an LNG Tank

6.6 Collision Risk Conclusion

The collision risk is greatest for the ferry route from Seattle to Bremerton and least for the route from Mukilteo to Clinton. The traffic in Puget Sound is well managed through the VTS and WSF has implemented a series of operational procedures to further reduce the likelihood for a navigational accident. Together with the latest developments in technological navigational aids as AIS, differential GPS and electronic navigational maps, these measures have led to an increase in the navigational safety of the WSF ferries.

The localization of the LNG tanks on the top deck of the ferries is an inherently safe design with regards to risk for damaging the tanks in a collision. The tanks are approximately 12 m (39 ft) above the waterline. Tank damage would require a collision that penetrates the ferry side at least 5 m (16 ft) deep at a height of 12 m (39 ft) above the waterline. The probability for such an accident is low.

7 OPERATIONAL RISK ASSESSMENT

The operational risk assessment was a quantitative estimate of the risk of a release from either one of the two 100 m^3 (26,000 gal) Liquefied Natural Gas (LNG) storage tanks on a ferry - or a release from a tanker truck during fueling or transit.

7.1 Hazard Identification

A risk assessment workshop was held in the Washington State Ferries headquarters in Seattle February 14^{th}, 2013. The main focus of the workshop was safety principles of concepts and operations of the current design. The results from this workshop are detailed in Appendix 3 - Operational Safety Hazard Identification (HAZID) and were used to define the operational release scenarios.

7.2 Operational Scenario Definition

Release scenarios (failure cases) were defined using a specific set of conditions to characterize a range of possible conditions of failure. It was not practicable or necessary to consider every possible permutation of release rate (or hole size) and location, exact inventory at time of failure, temperature, pressure etc., since all of these in practice can vary continuously between limits. Thus, characteristic values of each parameter necessary to model the failure are selected in such a way as to cover the spectrum of possible values. A total of 22 process release scenarios were defined.

Table 7-1 summarizes the scenarios and hole size descriptions modeled in the quantitative risk assessment (QRA). Appendix I presents detailed information for each scenario.

Table 7-1 Scenario Identification / Assumptions

Operation / Postulated Leak Location		Hole Size Description
Fueling	**LNG Truck Tank**	Catastrophic rupture
		Continuous release
	Hose	Full-bore rupture
		Leak
	Fueling Station - LNG	Large
		Medium
		Small
	Fueling Station - Vapor Return	Medium
		Small
	LNG Loading Pipe	Large
		Medium
		Small
	Vapor Return Pipe	Medium
		Small
Normal Operation - Gas Supply	**LNG Ferry Tank**	Catastrophic rupture
		Continuous release
	Gas Supply from Cold Box to Engine Room	Large
		Medium
		Small
	Supply Pipe	Large
		Medium
		Small

7.3 Operational Leak Frequency Analysis

The methodology used to estimate the leak frequency during operation is described in this section. Appendix I present the details of the frequency analysis and estimates. The frequency estimate was conducted by applying two approaches to obtain the best possible assessment of the potential for a leak of a given size.

Failure frequencies for flexible unloading hoses and tanks on moving vehicles were taken from the Purple Book (15). The "Coloured Books" are used around the world as standard reference material in safety studies. The Purple Book, *Guidelines for quantitative risk assessment* (15), documents standard methods to calculate the risks due to dangerous substances using available models and data. Data from the unloading truck was modified by the operational presence factor. The hose frequency was multiplied by the number of unloading hours per year.

Frequency of a leak from the hydrocarbon-containing equipment was assessed based on historical leak frequencies. DNV's commercial software LEAK version 3.2.1 was used to estimate leak frequencies. The program contains leak statistics from the Hydrocarbon Release Database (HCRD) published by the United Kingdom (UK) Health and Safety Executive (16). Failure frequencies were estimated based on the hole size ranges.

7.4 Operational Loss of Containment Evaluation

The consequence of interest to the Operational Risk Analysis is a loss of containment of hydrocarbons (LNG or boil-off gas).

A loss of containment has several potential subsequent outcomes: pool fire, jet fire, flash fire, or boiling liquid expanding vapor explosion (BLEVE). These are described further in Section 3 in the DNV Report "Security Assessment for LNG Fueled Passenger Ferry Vessels" (3). This portion of the report has been designated as Sensitive Security Information and is only releasable by the U.S. Coast Guard.

8 COMBINED SAFETY RISK RESULTS

Risk is the combination of likelihood and consequence of accidents. This section introduces risk as a concept, describes two measurements of risk (Individual and Societal Risk), presents commonly-used criteria for each type, and presents the study results for each type.

8.1 Risk Metrics and Criteria

Since this study was performed from a risk perspective, some general background and definitions on risk are presented here.

Risk is the combination of likelihood and consequence of accidents. More scientifically, it is defined as the probability of a specific adverse event occurring in a specific period or in specified circumstances. Although in colloquial use, *risk* and *hazard* are treated virtually as synonyms, *Risk* is distinct from *Hazard*.

Hazard is the physical situation which has the potential to cause harm. For example, a refinery is regarded as a hazardous activity, due to the toxicity of hydrogen sulfide and flammability of gases and liquids in the process. The word “hazard” does not express a view on how likely it is that the harm will actually occur.

Accident is the actual realization of a hazard. It is a sudden, unintended departure from normal conditions, in which usually some degree of harm is caused.

With every new industrial venture, there are certain inherent hazards. When planning new industrial activity, decisions have to be made about issues such as:

- What is the optimal design?
- What level of safety management is appropriate?
- Are risk reduction measures necessary?

The basis of any such decision is whether or not the activity as a whole, or the option chosen, is justifiable to the company, the regulatory authority, and ultimately the public. The risk posed by the industry is usually only one of the factors which influence the decisions. Other factors weighed in the decision making process could be operational, economic, social, political, and environmental issues.

8.1.1 Individual Risk

Individual Risk (IR) is the risk experienced by a single individual in a given time period. It reflects the severity of the hazards and the amount of time (usually assumed to be a year) the individual is in proximity to them. Thus, the total number of people present does not affect the IR. IR is defined as the frequency at which an individual may be expected to sustain a given level of harm from the realization of specified hazards. It is usually taken to be the risk of death, and is normally expressed as a risk per year.

IR is expressed in terms of geographical variations of annual risk of death, represented by isopleths, or iso-risk contour plots. The iso-risk contour indicates the extent of the area in which the facility or operation represent a potential hazard. The risk level is estimated for a hypothetical individual who is exposed to the risk at a specific location 24 hours per day, 365 days per year. This location-specific individual risk (LSIR) risk contour is thus independent of the fraction of year a person might actually be exposed to the hazards.

The individual risk for a person can be dependent upon the exposure time, as an individual does not usually remain at the same location all the time and is not exposed to the same risk all the time. The individual risk per annum (IRPA) is basically the measure of individual risk during one year's exposure. The IRPA is more difficult to estimate, as it requires knowledge of a given person's location at all times. It also can vary from person to person. As the LSIR is widely used for land-use planning and for regulatory criteria; for this study, the LSIR criterion is recommended.

Figure 8-1 is an example of an IR contour.

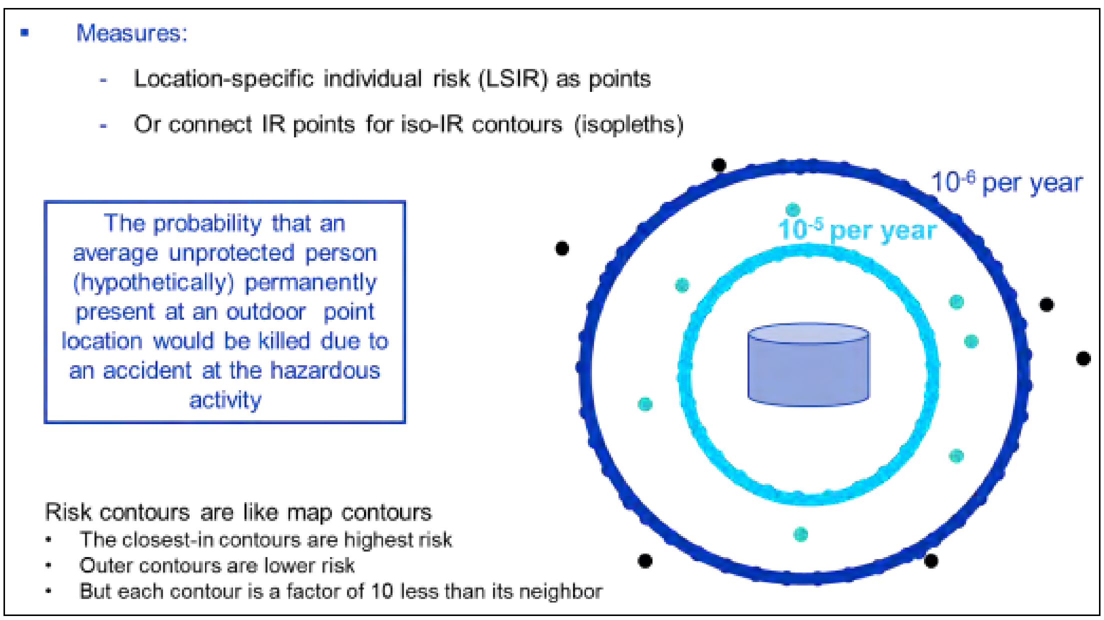

Figure 8-1 Individual Risk Presentation

8.1.2 Societal Risk

Societal risk is the risk experienced in a given time period by a whole group of exposed individuals. Societal risks are the relationship between the frequency and the number of people suffering a given level of harm from the realization of specified hazards.

Societal risk is often expressed as lines on an FN curve that are graphical measures of societal risk. The lines show the relationship between frequency and size of the accident. This curve allows a measure not only for the average number of fatalities from all sizes of accidents, but also the risks of catastrophic accidents that might impact many people at once. This analysis ensures that the public fear of a major accident is balanced by the benefits received from the hazardous activity.

FN curves are derived by sorting the frequency-fatality (FN) pairs from each outcome of each accidental event, and summing them to form cumulative frequency-fatality (FN) co-ordinates for the plot. The cumulative form is used to ensure that monotonic (steadily declining) curves are obtained even when some sizes of accident do not occur in the analysis.

For example, consider if only five events were to occur and the following frequency-fatality pairs were derived from the risk assessment:

Table 8-1 Frequency – Fatality Pairs for Five Scenarios

Scenario	Frequency (f)	Fatalities (N)
Illustrative Example 1	8.60×10^{-5}	10
Illustrative Example 2	3.50×10^{-4}	1
Illustrative Example 3	2.68×10^{-4}	5
Illustrative Example 4	6.80×10^{-6}	15
Illustrative Example 5	9.87×10^{-5}	5

The frequency-fatality pairs shown in Table 8-1 are then sorted with regards to number of fatalities and the frequencies are accumulated (Table 8-2). The cumulative form for the frequencies can be read as the frequency of 'N or more fatalities occurring'. For instance, in this example, the total frequency of fatality for 10 or more people is 9.28×10^{-5} (9.28 per 100,000) per year and the frequency of fatality impacting 5 or more people is 4.60×10^{-4} (4.6 per 10,000) per year.

Table 8-2 Frequency – Fatality Pairs Sorted by Fatality and Accumulated Frequencies

Scenario	Frequency (f)	Accumulated Frequencies (F)	Fatalities (N)
Illustrative Example 2	3.50×10^{-4}	8.10×10^{-4}	1
Illustrative Example 3	2.68×10^{-4}	4.60×10^{-4}	5
Illustrative Example 5	9.87×10^{-5}	1.92×10^{-4}	5
Illustrative Example 1	8.60×10^{-5}	9.28×10^{-5}	10

Illustrative Example 4	6.80×10^{-6}	6.80×10^{-6}	15

The cumulative frequency-fatality pairs in Table 8-2 are then plotted as an FN curve (Figure 8-2). Note that the cumulative frequency is plotted on a logarithmic scale as the frequency numbers are very low and decrease in orders of magnitude from the low impact scenarios to the high impact scenarios.

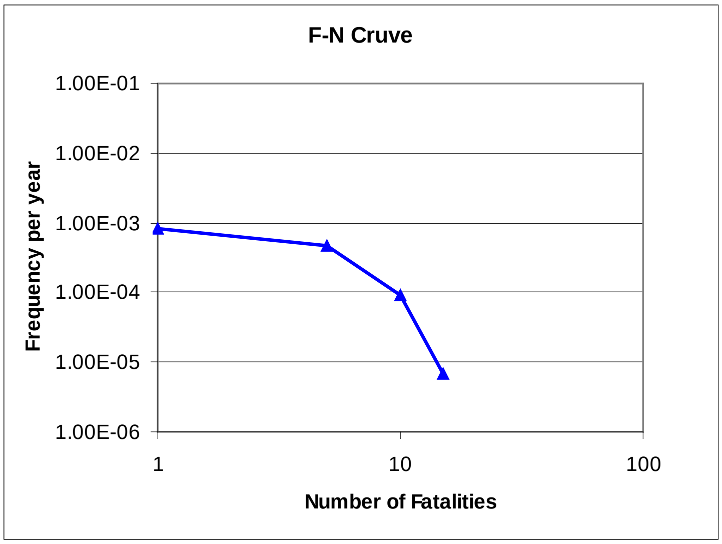

Figure 8-2 Example Overall FN Curve

8.1.3 Commonly Used Risk Criteria

Risk criteria are useful to help decision makers evaluate whether an estimated risk is acceptable as-is, unacceptable, or could be acceptable with additional mitigation measures in place.

This section discusses risk acceptance criteria that could be applied to help evaluate the estimated risk results from this study. The Center for Chemical Process Safety published Guidelines for Developing Quantitative Safety Risk Criteria, which describe risk criteria adopted. Information from CCPS (22) is summarized below for two countries' *individual* and *societal* risk criteria for processing facilities.

DNV recommends application of the UK HSE criteria to the risk estimated in this study, because of their widespread acceptance, application, and workability.

8.1.3.1 Individual Risk Criteria

Two countries' risk criteria are commonly referred and are discussed here, the United Kingdom Health and Safety Executive (UK HSE) criteria and the Dutch criteria.

The UK HSE has adopted Individual Risk Criteria for onsite using the "As Low As Reasonably Practicable" (ALARP) principle (i.e., cost-effective risk reduction would be considered), where, for workers (23):

- 1×10^{-3} (1 in 1,000) per year – maximum tolerable individual risk level.
- 1×10^{-3} to $1{\times}10^{-6}$ (1 in 1,000 to 1 in 1,000,000) per year – tolerable if (and only if) shown to be ALARP, i.e., that all risk reduction measures that are reasonably practicable have been implemented.
- $1{\times}10^{-6}$ (1 in 1,000,000) per year – tolerable individual risk level, below which risks are deemed to be broadly acceptable.

The suggested maximum tolerable individual risk level with respect to the public is recommended to be an order of magnitude less than it is for workers (i.e., 10^{-4} per year), and where the target criterion for the public should be the tolerable individual risk level of 10^{-6} per year.

The Dutch have a slightly different approach, and in their criteria make a distinction between "vulnerable" and "less vulnerable" objects (24). Vulnerable objects are residential objects, hospitals, schools and objects of high strategic value. Less vulnerable objects are shops, department stores, hotels, restaurants, commercial and industrial buildings, office buildings, and recreational facilities.

For risk to *vulnerable* objects (from both new and existing establishments), the IR limit is 10^{-6} per year. The maximum risk to *less vulnerable* objects is also 10^{-6} per year; however, this is a "target value" that is to be achieved as far as possible by a specified date and maintained so far as possible thereafter (i.e. it is not a hard limit).

The Netherlands does not have an individual risk criterion for workers, nor does it differentiate risks to the public versus industrial populations.

8.1.3.2 Societal Risk Criteria (Offsite)

The UK HSE adopted an FN anchor point for maximum tolerable public societal risk (N = 50, f=2×10^{-4}) and proposes a -1 slope for the societal risk FN curve. The *maximum tolerable* curve defines the region of maximum tolerable risk for a single major industrial activity, while a second curve, below and parallel to it, defines the *broadly acceptable* (negligible) risk as two orders of magnitude less.

Figure 8-3 displays this UK HSE criterion. The use of UK HSE risk criteria is recommended since they have widespread acceptance, application, and workability.

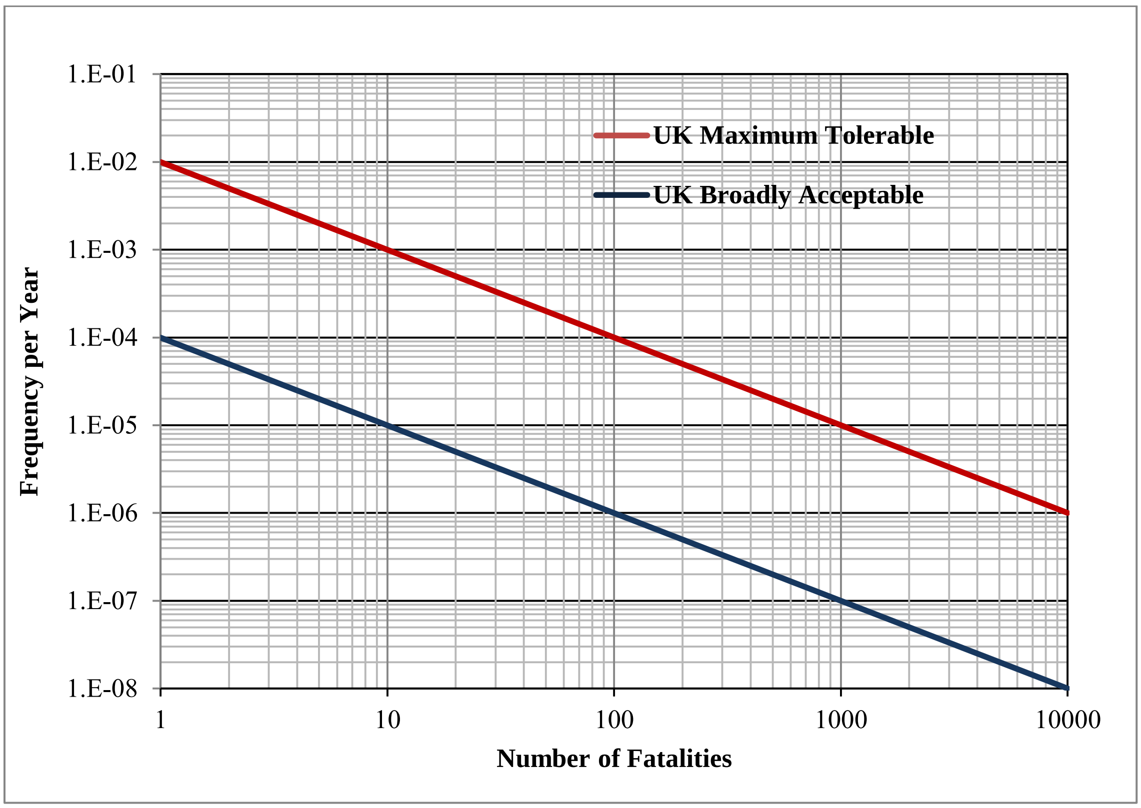

Figure 8-3: UK Societal Risk Criteria

8.2 Individual Risk Results

The individual risk (IR) is expressed in terms of geographical variations of annual risk of death, represented by iso-risk contour plots. The iso-risk contour indicates the extent of the area in which the facility or operation represent a potential hazard. The risk level is estimated for a hypothetical individual who is exposed to the risk at a specific location 24 hours per day, 365 days per year. This risk contour is thus independent of the time a person might actually be exposed to the hazards. IR is typically displayed in decreasing orders of magnitude.

Figure 8-4 and Figure 8-5 show the overall individual risk contours at the two terminals, for purposes of clarity, at Seattle and Bremerton respectively. As identified in this figure, the maximum risk level is at the level of 1×10^{-6} (1 in 1,000,000) per year, which is the UK HSE broadly acceptable criterion. Therefore, the individual risk is deemed to be broadly acceptable.

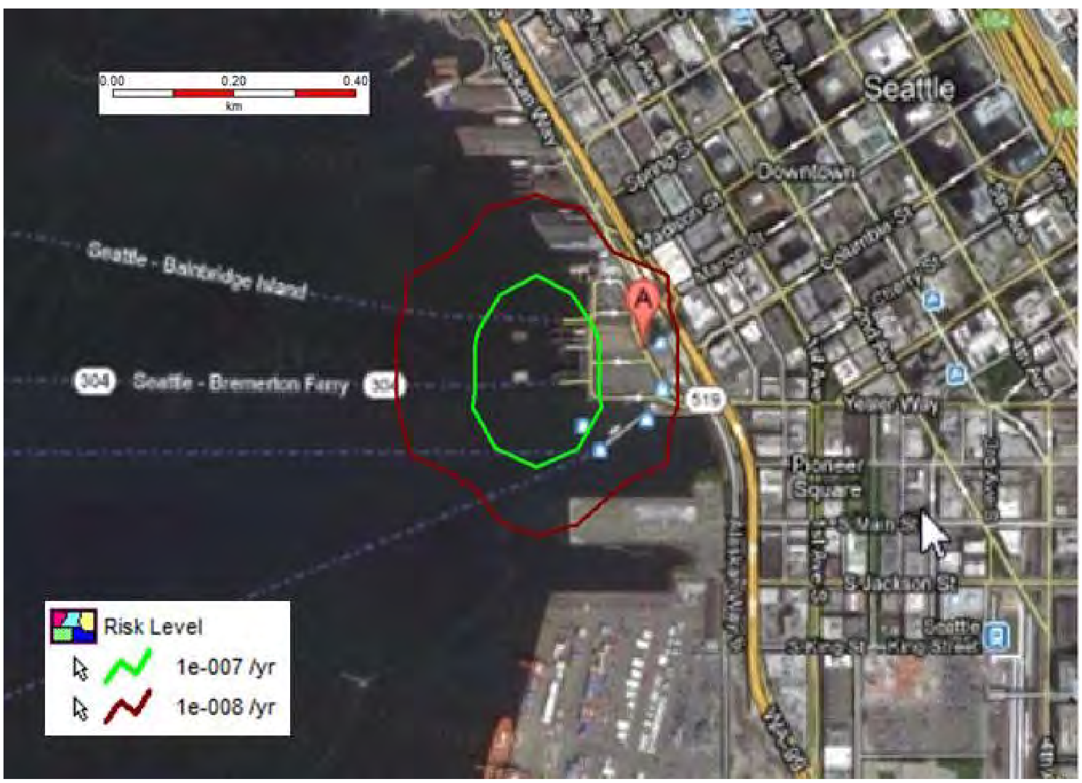

Figure 8-4 Individual Risk Contours at the Seattle Terminal

Figure 8-5 Individual Risk Contours at the Bremerton Terminal

8.3 Societal Risk Results

The societal risk FN curve is shown in Figure 8-6. The risk from the ferry sailing is not included in generating the FN curve shown in the figure (i.e., only the risk when the ferry is at berth or fueling is included).

The FN curve shows that the curve is below the UK maximum tolerable criteria. When the fatality number (N) is less than 2 or greater than 800, the societal risk is below the UK broadly acceptable criteria, and when the fatality number is from 2 to 800, the societal risk is at the lower end of the ALARP region and very close to the broadly acceptable criteria.

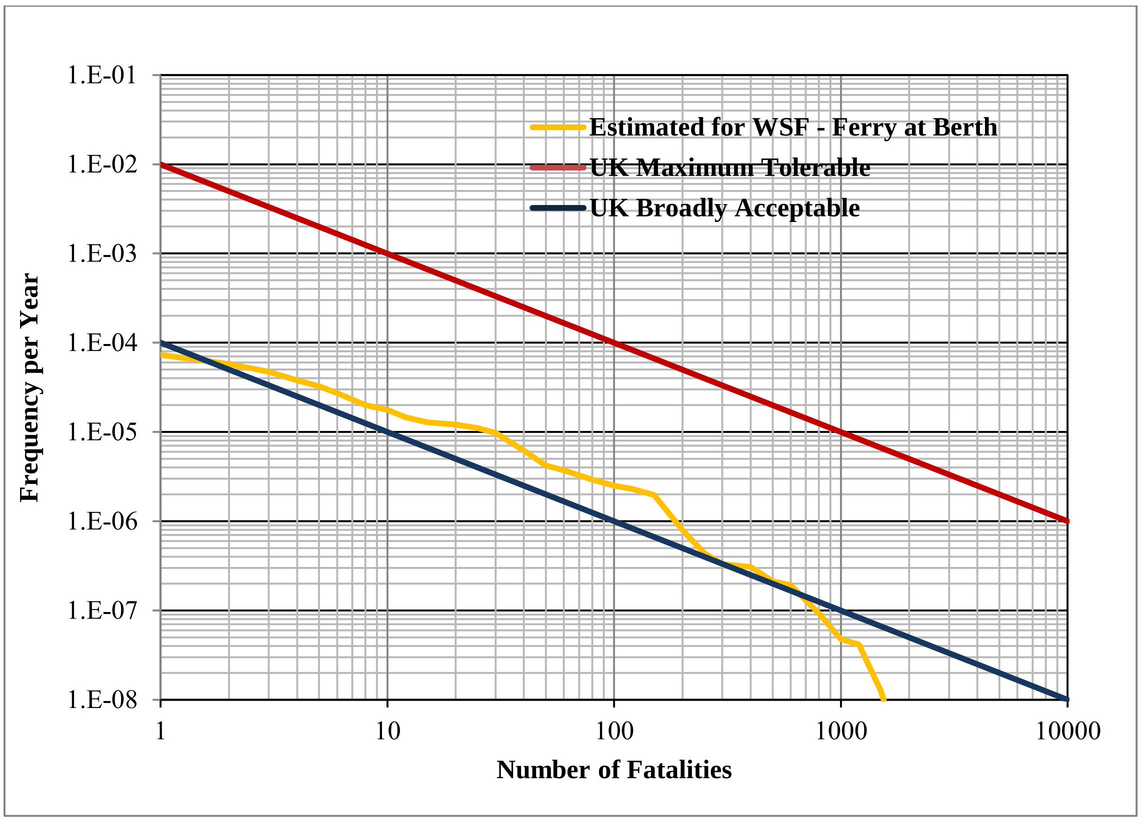

Figure 8-6 Societal Risk (FN) Curve

8.4 Safety Risk Analysis Conclusion

This study evaluated the potential for damage to LNG and supply gas containment systems that could result from accidents. A summary of the safety analysis conclusions is presented in this section.

The safety risk from the potential LNG release is low in general. Section 8.2 shows that the individual risk is at the level of 10^{-6} per year or below. Based on UK HSE criteria, the risk is broadly acceptable. The FN curve is below the UK HSE maximum tolerable criteria, and is at the lower end of the ALARP region in general, as presented in Section 8.3. Based on DNV previous experience, it is rare to have the FN curve below the UK HSE broadly acceptable criteria, and the societal risk estimated in the current study is lower than many other facilities.

For the most extreme possibility (i.e. people impacted onshore by a LNG fire and or explosion) of an LNG leak three minimum conditions would be necessary:

1. Release occurs near the shore adjacent to an urban area
2. Wind direction is toward the urban area
3. The vapor cloud is within its flammable limit and passes over an ignition source

Because the above three conditions must be concurrent, the likelihood of a natural gas cloud fully extending, especially in a near-shore urban area, and then igniting is very low. If ignition occurs in the near-shore area this would most likely cause a slow moving flame front instead of a detonation. A vary unlikely event such as vapor cloud explosion could occur in the near-shore urban area, but would require the cloud to form in a confined space, with particular air flow conditions present. A cloud would most likely ignite from the first available ignition source and progress to a pool fire instead of extending as the theoretical models would convey. Pool fire and vapor dispersion hazard distances are significantly influenced by site-specific environmental and operational conditions. For a dispersion event, the hazard zone area is elongated in the downwind direction from the spill point, rather than spread over a uniform circle.

9 RISK MANAGEMENT PLAN

Based on the findings from the navigational and safety assessments, risk management plans have been developed. Risk management plans identify best methods to prevent an accident that could lead to a Liquefied Natural Gas (LNG) release and measures that can mitigate the consequences should a breach on the LNG-fueled passenger ferry occur.

9.1 Navigational Risk Management Plan

This section describes risk management measures for navigation in Puget Sound in the form of safeguards to prevent and respond to a navigational incident. Some safeguards are already implemented, including those from Washington State Ferries' (WSF's) own Risk Management Plan. Other safeguards are new and were identified during the HAZID workshops or extracted from DNV's knowledge from other navigational risk studies.

9.1.1 Prevention Safeguards

The following prevention safeguards, listed in Table 9-1, are applicable to LNG-fueled passenger ferry vessels during transit on the proposed routes. During the follow-up WSA that WSF will undertake, decisions will be made regarding the implementation of the safeguards identified.

Table 9-1 Navigational Prevention Safeguards

Prevention	Description
1. Standards of Training, Certification and Watchkeeping (STCW)	The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) is an international initiative that establishes basic requirements for comprehensive training, assessment, and certification of commercial mariners. Both the U.S. and Canada are signatory to these standards.
2. Port and Flag State Control	Port and Flag State Control are key elements in fulfilling the revisions of the STCW Code. Port State Control is the authority an administration has over vessels operating within their waters (jurisdiction) regardless of Flag. Port State Control includes the oversight and inspections conducted by the administration of the port on a vessel entering their port. Flag State Control is the authority an administration has over vessels with their own registration (flag) regardless of where they are operating.

Prevention	Description
3. Differential Global Positioning Systems (DGPS)	Differential Global Positioning System (DGPS) is an enhancement to Global Positioning System that provides improved location accuracy, from the 15-meter nominal GPS accuracy to less than a meter for the best implementations.
4. Electronic Chart Display and Information System (ECDIS) and Electronic Navigation Charts (ENC)	An Electronic Chart Display and Information System (ECDIS) is a navigation aid that can be used instead of paper charts and publications to plan and display a ship's route, and to plot and monitor its position throughout the voyage. Electronic Navigational Charts (ENC) are a standardized database of chart information, including supplementary information considered necessary for safe navigation, issued by ECDIS.
5. Vessel Traffic Service (VTS) with Traffic Organization Services (TOS) and Automatic Identification Systems (AIS)	U.S. Coast Guard operates the Vessel Traffic Service Puget Sound (VTSPS). VTSPS is comprised of three major components: (1) a Vessel Movement Reporting System (VMRS); (2) a Traffic Separation Scheme (TSS); and (3) Surveillance systems including radar, Automatic Identification System (AIS), and closed circuit television (CCTV). The VMRS is based upon a VHF-FM communications network maintained continuously by the Vessel Traffic Center (VTC) in Seattle. This network consists of 14 variable power sites. The location of these communication sites throughout the VTSPS area allows mariners to contact the VTC while normally only using low power on their radio. The VTC processes all information received and disseminates navigational safety information to those vessels asking for or requiring it. The TSS in the VTSPS area has been adopted by the International Maritime Organization (IMO). Therefore, the TSS is subject to the provisions of Rule 10 of the 1972 Collision Regulations. The traffic lanes and separation zone that comprise the TSS are depicted on nautical charts. Throughout the VTSPS area, International Collision Regulations apply. The VTC receives radar signals from 12 strategically located radar sites throughout the VTSPS area. Radar provides approximately 2,900 square miles of coverage including the Strait of Juan de Fuca, Rosario Strait, Admiralty Inlet, and Puget Sound south to Commencement Bay. Additionally, closed circuit TV provides coverage of various critical waterways. The AIS system is a shipboard broadcast system that acts like a continuous and autonomous transponder, operating in the VHF maritime band. It allows ships and shore personnel to easily track, identify, and exchange pertinent navigation information from one another and ashore for collision avoidance, security and Vessel Traffic System reporting. Use of AIS is compulsory in the U.S. for self-propelled vessels 65 ft or more in length.

Prevention	Description
6. Pilotage	All commercial traffic of a size that could potentially hit the LNG tanks in a collision with LNG-fueled passenger ferry vessels are required to have a pilot on board in the Puget Sound area.
7. Waterways Aids to Navigation	Refers to buoys, daymarkers, ranges or many other types of marks federally maintained by United States and Canadian agencies that provide mariners with a "sense of direction", mark deep draft navigable channels and identify hazards in the navigable waterways. The term *aids to navigation* also refers to privately maintained navigation aids.
8. Operational Give Way procedures for WSF Ferries	The WSF ferries have a standing order to avoid a potential collision situation by sailing aft of any ship which they cannot pass more than one nautical mile ahead of, even if the ferry has the right-of-way.
9. Navigational Rules (COLREGS)	Also known as the nautical "Rules of the Road". Refers to the International Regulations for Avoiding Collisions at Sea. These rules are applicable on waters outside of established navigational lines of demarcation. The lines delineate those waters upon which mariners shall comply with the Inland and International Rules.
10. Traffic Separation Scheme and Puget Sound Vessel Traffic Service	A Traffic Separation Scheme (TSS) exists for the Strait of Juan de Fuca and Puget Sound and is recognized by the International Maritime Organization (IMO). Puget Sound Vessel Traffic Service (PSVTS) provides timely information to participating vessels regarding traffic movement, weather, and hazards to navigation.

9.1.2 Mitigation Safeguards

Table 9-2 lists mitigation procedures that are applicable to reducing the consequences if an event were to occur involving an LNG-fueled passenger ferry vessel during transit. During the follow-up WSA that WSF will undertake, decisions will be made regarding the implementation of the safeguards identified.

Table 9-2 Navigational Mitigation Safeguards

Mitigation	Description
1. Vessel Emergency Contingency Plans	Refer to vessel contingency plans required by regulators that provide information and procedures to assist crew members to rapidly and successfully respond to a myriad of contingencies addressed in the plans. For the WSF ferries, this would be the Washington State Maritime Cooperative Oil Spill Contingency Plan http://wsmcoop.org/contingency_plan.
2. Terminal Emergency Contingency Plans	Refer to facility contingency plans required by regulators that provide information and procedures to assist facility personnel to rapidly and successfully respond to a myriad of contingencies addressed in the plans.
3. Nation/Regional/Local Emergency Contingency Plans	Refer to plans required by local, state and/or federal regulations that provide information, processes and procedures to assist local, state, and federal emergency response agencies to rapidly and successfully respond to a myriad of contingencies addressed in the plans.
4. Vessel/Facility Personnel Emergency Response Training	Refers to level of preparedness crewmembers and facility personnel are skilled to respond to a myriad of contingencies. Emergency response training and drills are required by Port State Control authorities and documentation of the drills is required by vessel classification standards.
5. Local/Regional Emergency Response Preparedness and Training	Refers to level of preparedness local/state and federal emergency response agencies are skilled to respond to a myriad of contingencies from classroom or hands on training and exercises.
6. LNG Tank Design	Two independent LNG tanks are placed on the Texas (top) deck, precluding direct contact by smaller vessels.
7. Local/Regional Incident Management Response System	Refers to coordination efforts from local, state and federal responders from various jurisdictions and disciplines to work in harmony while responding to a variety of emergency contingencies, including actual or perceived acts of terrorism.
8. Marine Firefighting Capabilities	Refers to trained personnel and equipment, including vessels, capable of responding to a fire on a LNG fueled ferry.

9.2 Safety Risk Management Plan

This section describes proposed risk management measures in the form of safeguards to prevent and respond to an accidental release of LNG. These safeguards were developed during the HAZID workshops for this purpose. In addition, safeguards were extracted from DNV's knowledge from other risk studies focusing on LNG-fueled ships, navigational risk studies and onshore/offshore LNG facilities.

It shall be noted that the preventative and mitigation safeguards identified in this section are more of a general nature as the type of LNG gas engine, fueling system or tank configuration has not yet been finalized. Once the design of the LNG configuration has been selected it is suggested that the preventative and mitigation safeguards are revisited.

9.2.1 Prevention Safeguards

The following suggested prevention safeguards, listed in Table 9-3 have been identified during the course of the study and are applicable in preventing an accidental release of LNG from happening

Table 9-3 Accidental Release Prevention Safeguards

Prevention	Description
1. Vessel Emergency Contingency Plans	Refer to vessel contingency plans required by regulators that provide information and procedures to assist crew members to rapidly and successfully respond to a myriad of contingencies addressed in the plans.
2. National and International Design codes for Gas Fueled Ship Installations	Refer to national (USCG) and international IGF Code, classification societies, etc.) design codes for arrangement and installation of LNG fuel fueling station and equipment, LNG fuel tanks, equipment, piping and arrangements, hazardous areas and spaces, control, monitoring and safety systems for gas installations.
3. Preventative Maintenance	Refers to overview of classification of hazardous areas, with information about gas groups and temperature class, records sufficient to enable the certified safe equipment to be maintained in accordance with its type of protection (list and location of equipment, technical information, manufacturer's instructions, spares etc.). Updated documentation and maintenance manual shall be kept onboard, with records of date and names of companies and persons who have carried out inspections and maintenance of components and systems. Duplicates of the preventive maintenance records are kept at WSF headquarters. Inspection and maintenance of installations shall be carried out only by experienced personnel whose training has included instruction on the various types of protection of apparatus and installation practices to be found on the vessel. Appropriate refresher training shall be given to such personnel on a regular basis.

Prevention	Description
4. Inspection Routines	Refers to inspection routines with information about level of detail and time intervals between the inspections, acceptance/rejection criteria, register of inspections, with information about date of inspections and name(s) of person(s) who carried out the inspection and maintenance work.
5. Third Party Inspections	Refer to an inspection carried out by an independent competent person, who is not involved in the maintenance of the LNG fueled ferry. This could comprise of reviewing past service history of the ferry, carry out an extensive inspection on all parts of the ferry from mechanical, electrical and structural components and after the inspection a full report with recommendations will be given to the client that indicates what areas of the LNG fueled ferry do not comply with current standards or regulations.
6. Fueling procedures	Refer to procedures aiming at establishing safe truck to ship fueling procedures for LNG, encompassing the entire fueling operation, both the operational fueling process and the technical solutions needed.
7. Operating Procedures	Refer to procedures aiming at establishing safe operating procedures of the LNG system and interface systems, encompassing all operational aspects, including the technical solutions needed. An updated version of the Operations Manual to the finalized design must be available at all times including emergency procedures.

In addition, internal and external safety management system audits help prevent degradation of the above safeguards.

9.2.2 Mitigation Safeguards

The following suggested mitigation safeguards, listed in Table 9-4 have been identified during the course of the study and are applicable in mitigating the consequences associated with an accidental release of LNG.

Table 9-4 Accidental Release Mitigation Safeguards

Mitigation	Description
1. LNG Automatic Fire and Gas Detection Systems and Fire Protection Systems	Refer to quick activation systems which detect and suppress potential fires from an LNG release.
2. Vessel Safety Alarm Systems	Refer to existing safety and security alarm and response systems required by vessel construction standards that give vessel crew members notice and locations where contingencies may need to be addressed.
3. Vessel Emergency Contingency Plans	Refer to vessel contingency plans required by regulators that provide information and procedures to assist crew members to rapidly and successfully respond to a myriad of contingencies addressed in the plans.
4. Nation/Regional/Local Emergency Contingency Plans	Refer to plans required by local, state and/or federal regulations that provide information, processes and procedures to assist local/state and federal emergency response agencies to rapidly and successfully respond to a myriad of contingencies addressed in the plans
5. Vessel/Terminal Personnel Emergency Response Training	Refers to the level of preparedness crewmembers and terminal personnel maintain in responding to a myriad of contingencies. Emergency response training and drills are required by Port State Control authorities and documentation of the drills is required by vessel classification standards.
6. Local/Regional Emergency Response Preparedness and Training	Refers to level of preparedness local/state and federal emergency response agencies are skilled to respond to a myriad of contingencies from classroom or hands on training and exercises.
7. Cryogenic Spillage Control	Cryogenic spillage design requirements for containing and isolating spills at or close to the LNG tanks, piping and LNG tanker transfer hoses.
8. Local/Regional Incident Management Response System	Refers to coordination efforts from local, state and federal responders from various jurisdictions and disciplines to work in harmony while responding to a variety of emergency contingencies, including actual or perceived acts of terrorism.

Mitigation	Description
9. Marine Firefighting Capabilities	Refer to trained personnel and equipment, including vessels, capable of responding to an LNG fire
10. Emergency Shutdown (ESD)	In the case that a hazardous situation (e.g. operation mal-function or security violations) occurs, appropriate safeguards shall be implemented in order to detect that a release has occurred, reduce immediate consequences and prevent escalation. All functional requirements according to safety standards (ISO and IGF) for equipment and detectors shall be followed and maintained.
11. Area Classification in Fueling Area	Area classification is a method of analyzing and classifying the areas where explosive gas atmospheres may occur. The object of the classification is to allow the selection of electrical apparatus able to be operated safely in these areas.
12. LNG Automatic Fire and Gas Detection Systems and Fire Protection Systems	Refer to quick activation systems which detect and suppress potential fires from an LNG release.

9.3 Maritime Safety, Security and Response Resource Needs

In accordance with 33 CFR 127.007(f)(2)(v) the following is an indication of resource needs for maritime safety, security, and response:

Maritime Safety	
WSF	
1.	Will need to provide its employees with increased levels of training that are commensurate with roles and responsibilities as they relate to LNG (see LNG Operations Manual, Appendix 1 attached to the Preliminary WSA)
2.	Will need to provide employees with specific firefighting training that addresses the unique qualities of LNG
3.	Will need to install additional firefighting equipment for vessels and terminals that is specifically designed to extinguish LNG fires
4.	Will need to fully integrate LNG operations in to its existing Safety Management System
Local First Responders	
1.	Fire Departments where LNG operations or fueling will occur will need specific firefighting training that addresses the unique qualities of LNG
2.	Fire Departments where LNG operations or fueling will occur will need vessel and fueling operations orientations prior to the commencement of WSF operations
U.S. Coast Guard	
1.	Will need to develop a cadre of Marine Inspectors with increased levels of training that are commensurate with roles and responsibilities as they relate to LNG

Security	
WSF	
1.	Will need to provide appropriate barriers, enclosures or redundant security measures that will ensure that systems with LNG or natural gas are protected
2.	Will need to review and update its security procedures as related to fueling and operation of LNG vessels
Local First Responders	
1.	Local police departments and the Washington State Patrol where LNG operations or fueling will occur will need vessel and fueling operations orientations prior to the commencement of WSF operations
U.S. Coast Guard	
1.	At heightened MARSEC Levels Sector Puget Sound may elect to conduct vessel escorts of LNG fueled vessels
2.	At heightened MARSEC Levels Sector Puget Sound may elect to provided armed and visible presence aboard LNG fueled vessels

Response	
WSF	
1.	Will need to developed detailed procedures to address major emergency events such as: liquid leaks (small, medium, and large), vapor leaks (small, medium, and large), fire, attempted or successful terrorist attacks. The procedures will need to incorporate the most effective use of installed firefighting and security systems
Local First Responders	
1.	Will need to be incorporated into detailed response procedures and trained on those procedures
U.S. Coast Guard	
1.	Will need to be incorporated into detailed response procedures and trained on those procedures

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