GUEMES ISLAND FERRY REPLACEMENT

TRANSPORTATION SYSTEM ASSESSMENT

PREPARED FOR

SKAGIT COUNTY PUBLIC WORKS
MOUNT VERNON, WASHINGTON

14 DECEMBER 2017
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Revision History

Section	Rev	Description	Date	Approved
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References

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Executive Summary

The purpose of this report is to analyze all aspects of the Guemes Island ferry system not covered by the *Concept Design Report* (Reference 1) and the *Vessel Capacity Study* (Reference 2). This report analyzes shoreside infrastructure, ferry terminal operations, total system throughput, ferry system alternatives, emergency services provided by the ferry system, and environmental considerations.

While the design of the replacement ferry will have the biggest impact on the future performance of the ferry system, this report investigates other opportunities for improvement, and provides feedback to the replacement ferry design, to ensure that all aspects of the system that impact its stakeholders have been considered. The objective of this study is to ensure the Guemes Island ferry system is optimized as a whole.

In Section 1, ferry terminal infrastructure is investigated, starting with how the terminals constrain the principal dimensions of the new ferry. Maximum recommended length and beam are 180' and 54', respectively. Increasing freeboard generally improves ADA accessibility and reduces the percent of time the grade break between the transfer span and the vessel would cause vehicles to bottom out. However, at high tides, the existing wing walls and dolphin fenders are not tall enough to accommodate significantly higher freeboard than the existing ferry. Therefore, the optimal freeboard with the existing infrastructure is approximately 6'-0". Increasing the height of the wing walls and possibly the dolphin fenders would further reduce the slope of the transfer span at extreme tides, improving ADA accessibility and reducing or eliminating the risk of vehicles bottoming out at low tides.

Widening the transfer span aprons at both terminals to allow for concurrent loading of vehicles and passengers is recommended. Without this modification, the throughput of the replacement ferry will be constrained by loading operations, resulting in schedule delays, long vehicle queues, and a lower overall level of service than would otherwise be possible.

Figure 1 Transfer span components

The replacement ferry will be larger and heavier than the existing ferry. Reinforcing the dolphin fenders is recommended to protect the equipment and prevent potential out-of-service time.

In Section 2, ferry terminal operations are investigated. Additional parking capacity will be required at both terminals to accommodate future traffic unless demand-reducing changes are made to the parking and ferry ticket fare structure, as well as enforcement of parking rules. In the absence of such changes, the estimated 2060 Anacortes terminal parking demand can be mostly satisfied by reconfiguring the existing parking facilities. Skagit County is already planning to reconfigure the Guemes Island lot. To meet the full 2060 demand, it may be possible to acquire adjacent land and build a new lot.

Vehicle queues are expected to increase slightly in Anacortes by 2060 and decrease on Guemes Island. This calculation assumes the ferry will be replaced by that described in the *Concept Design Report*, modifications will be made to the transfer span, and improvements will be made to the ticketing system. These three changes will significantly improve the service rate of the ferry system (the maximum number of vehicles and passengers per hour the system is capable of carrying).

The ticketing process is the bottleneck in the current system, due in large part to inefficient credit card transactions, but also for several other secondary reasons. The most critical improvements recommended are the addition of ticketing kiosks, online ticketing sales, and the ability for the ticketing agent to process credit card transactions on a mobile device from anywhere on premises.

In Section 3, system throughput is analyzed. Without improvements to the ticketing system and modification of the transfer spans to allow for concurrent vehicle and walk-on passenger loading, throughput will be limited to about 22 vehicles per half-hour round-trip crossing, or 44 vehicles per hour, in each direction. With these improvements, throughput could be improved to about 33 vehicles per half-hour round-trip crossing, or 66 vehicles per hour, in each direction.

In Section 4, the basic design options for a replacement ferry are discussed, and a two-ferry system is compared with a one-ferry system. It is concluded that the replacement ferry should be a steel, double-ended, displacement monohull. A two-ferry system has some advantages, including greater redundancy and schedule flexibility, but the result of the analysis is a recommendation to pursue a one-ferry system, based on the limited upside of a two-ferry system and the significant cost advantages of a one-ferry system.

In Section 5, emergency services to the island are investigated. Like the existing ferry, the replacement ferry will be a primary lifeline for residents of Guemes island, as well as provide life-saving support to Guemes Channel. This should be considered when designing the replacement ferry.

In Section 6, environmental considerations are investigated. Air pollution was analyzed by estimating diesel engine particulate matter emissions for each of five possible propulsion types.

It is recommended that upland noise and underwater noise be minimized during the design of the replacement ferry. Underwater noise, which is mostly emitted from the propellers, should be minimized. Wake wash is not anticipated to be an issue. Environmental permitting will likely be required if modifications to the terminals are made, as recommended in Section 1 and Section 2.

Section 1 Ferry Terminal Infrastructure

Ferry terminal infrastructure was analyzed to understand the constraints imposed on a replacement ferry and areas for improvement. Maximum dimensions of a replacement ferry are investigated in Section 1.1. Recommended improvements to transfer spans and other structural elements of the terminals are discussed in Sections 1.2 and 1.3, respectively. Overnight berthing requirements, shore power capabilities, and consumables and waste requirements are presented in Sections 1.4, 1.5, and 1.6, respectively.

1.1 Compatible Ferry Principal Dimensions

1.1.1 Length

As-built plan view drawings of the Anacortes and Guemes Island terminals were provided by PND Engineers (PND). Figure 3 shows a 178' x 53' replacement ferry concept at each terminal, with complete as-built plan view drawings of the terminals provided in Appendix A.

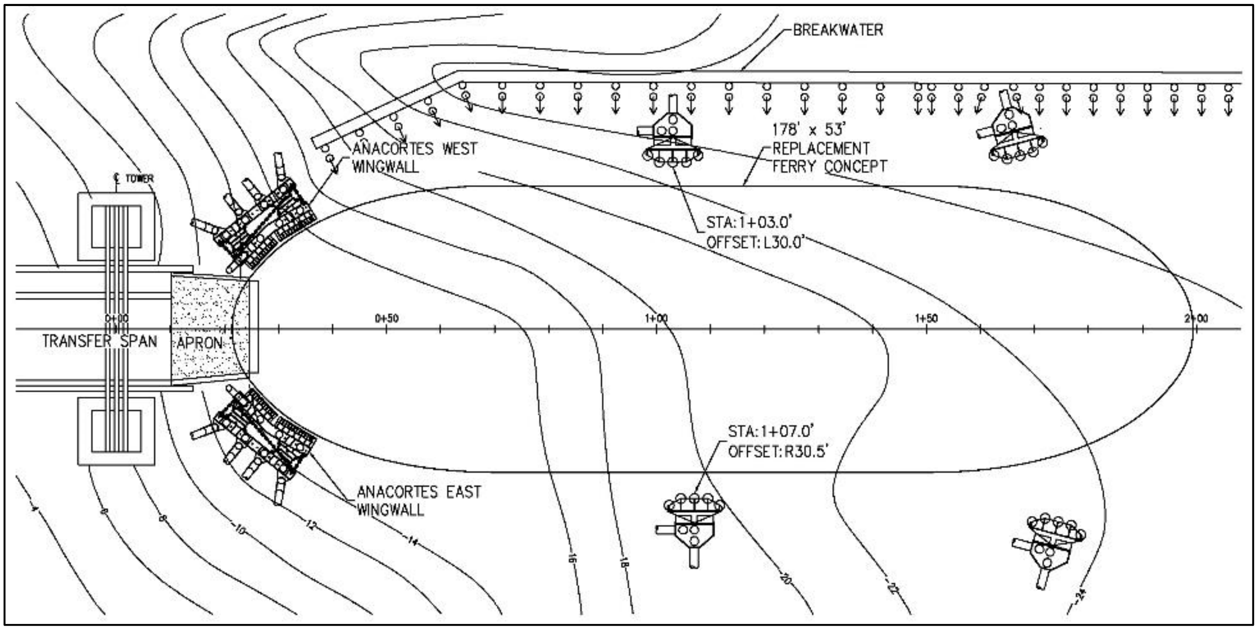


Figure 2 Anacortes terminal: as-built plan view and outline of 178' x 53' replacement ferry concept

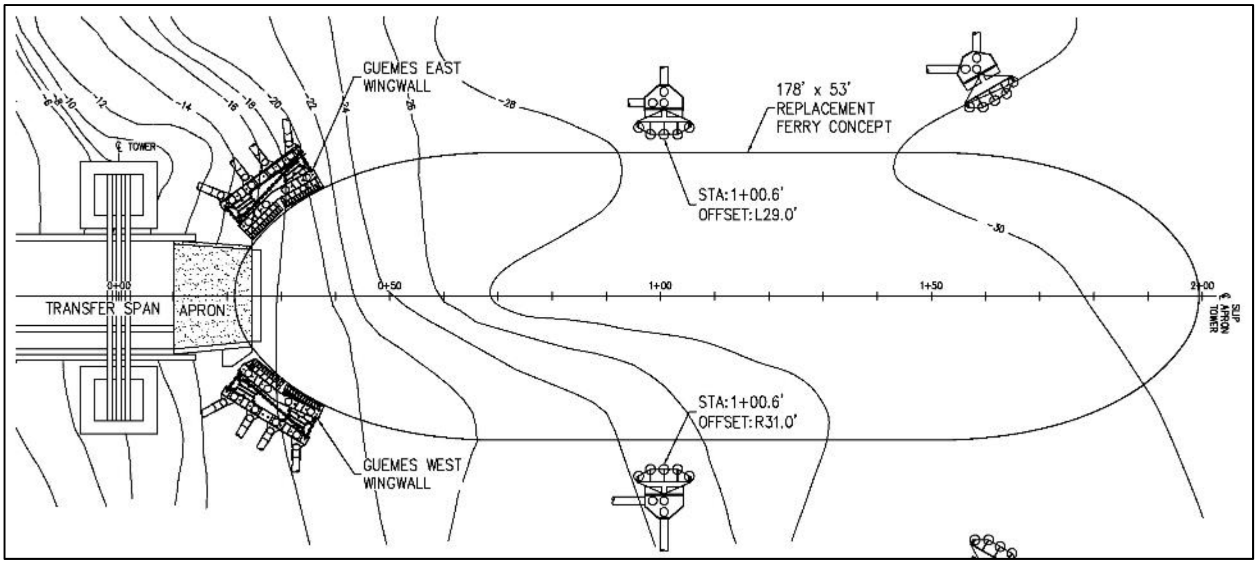


Figure 3 Guemes Island terminal: as-built plan view and outline of 178' x 53' replacement ferry concept (Source: PND Report; see Appendix A for complete as-built drawings)

The length of the replacement ferry concept was primarily based on the necessary length to accommodate forecasted ferry demand (see the Glosten *Concept Design Report* for more information, Reference 1). At 178 feet, the middle of the vessel (amidships) is on the channel side of the first pair of dolphin fenders. Substantial tidal side-current occurs at both terminals, which often results in the vessel resting on the down-current dolphin fender. This imparts a load on the down-current dolphin fender, the magnitude of which increases with length when amidships is on the channel side of the dolphin fender, as is expected of the replacement ferry. The magnitude of this load could become a limiting factor for design length of a replacement ferry if the length much exceeds that of the concept design shown in Figure 3.

1.1.2 Beam

As-built plan view drawings of the Anacortes and Guemes Island terminals show that there are several fenders located approximately 30 feet from the center plane of the two terminals, with the closest being 29 feet from the center plane (see Figure 3). Unless these fenders are moved, their location limits the maximum beam of the new ferry to 58 feet, minus required room for maneuvering.

The required room for maneuvering depends on the maneuverability of the vessel. The existing ferry, M/V *Guemes*, has a beam of 50 feet. The operators of *Guemes* stated that about 3 to 4 feet of beam could be added safely. Assuming the replacement ferry has similar maneuverability to *Guemes*, breadth is limited to 54 feet.

1.1.3 Draft

Water depth is at least 60 feet for a majority of the ferry route (Figure 4, Reference 3) and at least 14 feet at the terminals (Reference 4), as measured from Mean Lower Low Water (MLLW). Water depth is not anticipated to be a limiting factor for the replacement ferry, in terms of draft limitations or shallow water effects on speed and maneuverability. The lowest observed tide from 2007-2016 was 3.9 feet below MLLW, or a water depth of approximately 10 feet underneath the transfer span apron at the Anacortes terminal.

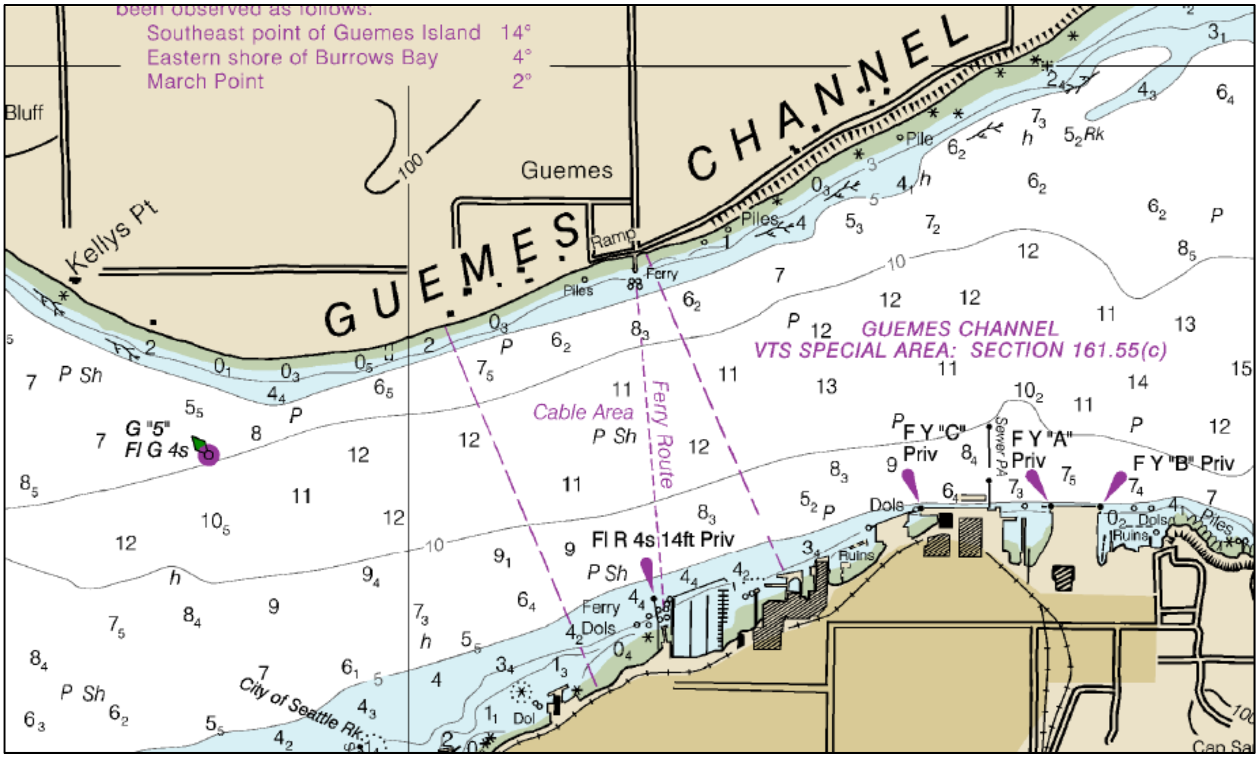


Figure 4 Water depths in fathoms and feet at MLLW, from NOAA Chart 18427 (Reference 3)

1.1.4 Freeboard

A study was conducted to provide a recommended minimum and maximum freeboard for a replacement ferry designed to call at the Anacortes and Guemes terminals.

1.1.4.1 Terminal Ramp Compatibility

Ramp Height Compatibility and ADA Compliance

A freeboard model was developed to understand the relationship between the freeboard of the ferry and the percentage of time the ferry would be compatible and ADA compliant with the adjustable-height terminal ramps. Compatibility in this section refers to the ability for the ramp to rest on the ferry, allowing for passengers and vehicles to load and unload. ADA compliance is defined as meeting the ADA ramp slope limit of less than or equal to 1:12 (noting, however, that the transfer spans may be exempt from regulatory requirements, Reference 5). The inputs to the model are:

1. The maximum angles at which the ramps at the terminals can be raised and lowered.
2. The sea level at the terminals based on tidal variation.

Maximum ramp angles were verified by PND Engineers (Appendix A). Figure 5 shows the basic composition of the adjustable height ramps located at each terminal.

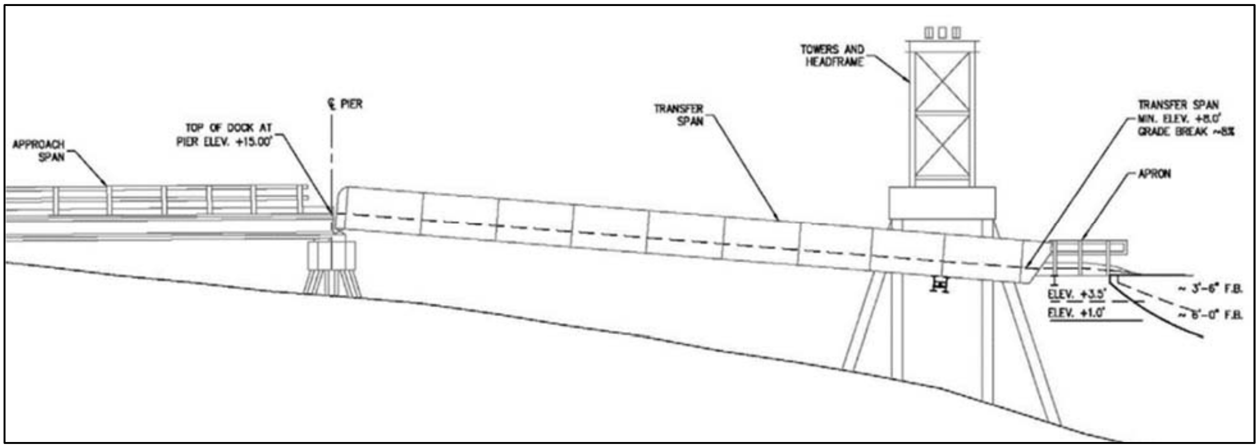


Figure 5 Adjustable-height ramp components (MLLW datum)

Figure 6 illustrates the probability distribution of sea level at the terminals. Table 1 shows the percentage of time a ferry would be compatible and ADA compliant at various freeboards.

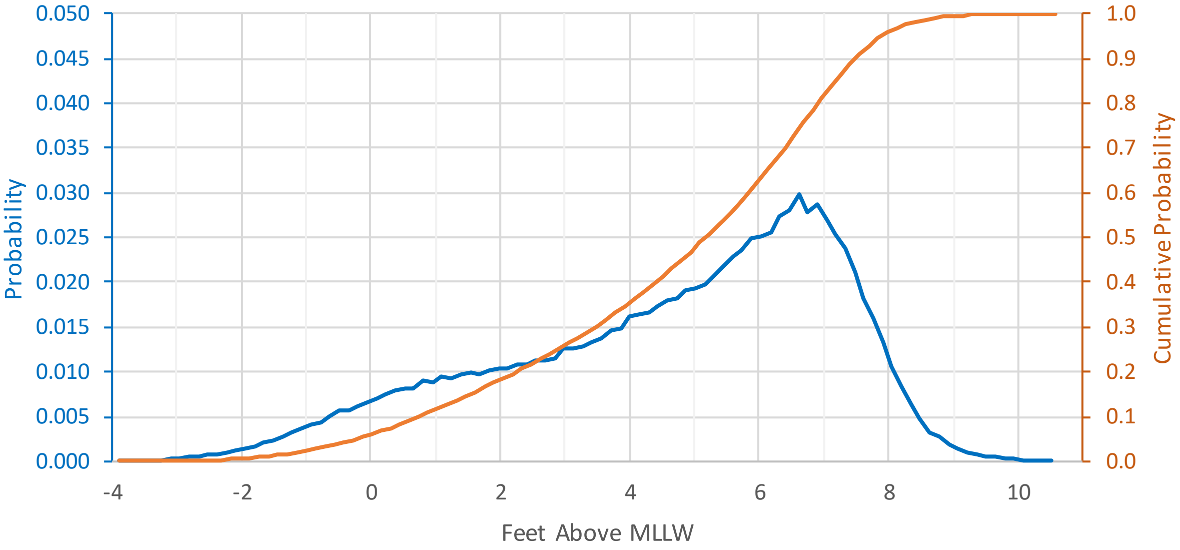


Figure 6 Water level probability distribution (tidal level data from Reference 6)

As illustrated, limitations of the terminal infrastructure prevent the system from ever being 100% ADA compliant, at least within the practical limits of the replacement ferry freeboard. However, a freeboard of 5.75 feet or more would allow for compatibility 100% of the time. Therefore, it is recommended that the minimum freeboard of the replacement ferry is 5.75 feet. The ferry terminal infrastructure is unlikely to drive the maximum freeboard of the replacement ferry.

Table 1 Freeboard compatibility with terminal ramps

Freeboard (ft)	% of time compatible	% of time ADA compliant
4.00	98.40%	80.40%
4.25	98.80%	82.20%
4.50	99.20%	83.90%
4.75	99.50%	85.60%
5.00	99.70%	87.30%
5.25	99.80%	88.90%
5.50	99.90%	90.40%
5.75	100.00%	91.80%
6.00	100.00%	93.10%
6.25	100.00%	94.30%
6.50	100.00%	95.40%
6.75	100.00%	96.40%
7.00	100.00%	97.20%
7.25	100.00%	97.90%
7.50	100.00%	98.50%
7.75	100.00%	98.90%
8.00	100.00%	99.30%

Grade Break

Another factor that was considered in the freeboard study was the abrupt changes in angle, or grade breaks, between different parts of the terminal ramps. Too abrupt a change can result in a vehicle bottoming out when traveling across the ramp, as illustrated in Figure 7. It was reported to Glosten that at extreme tides, some vehicles cannot be loaded on the existing ferry for this reason.

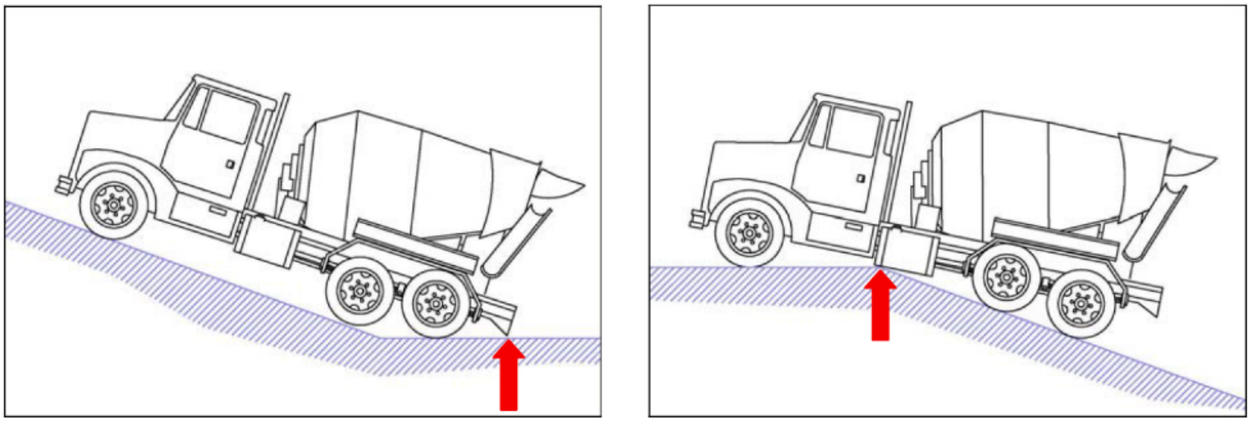


Figure 7 Negative grade break (left) and positive grade break (right) (Source: PND Report; see Appendix A)

PND Engineers investigated this issue and found that, for a vessel with a freeboard of 6 feet, the negative grade break limit is exceeded at a tide of +1.0 foot above MLLW (see Appendix A for more details). Such a tidal condition exists 11.5% of the time. The positive grade break limit is never exceeded. Increasing freeboard reduces the percentage of time the negative grade break limit is exceeded.

1.1.4.2 Wing Wall and Dolphin Fender Compatibility

Freeboard compatibility with the existing wing walls and dolphin fenders was examined. Specifically, the maximum height of vessel guards above the water without exceeding the height of the wing walls and dolphin fenders was calculated. The wing walls have a maximum height of 19'-8" above mean lower lower water (MLLW). The dolphin fenders have a maximum fender height of 20'-6" above MLLW. Extreme high water (EHW) is 11'-0" above MLLW, so the maximum guard height to be compatible with both wing walls and dolphin fenders in all tidal conditions is 8'-8". Using the replacement ferry concept design (Reference 1) as a reference vessel, and assuming 1 degree of trim and 3 degrees of list, the maximum rub rail height is 6'-1", limited by the height of the wing walls. In this scenario, almost half of the guard's 18" height is above the outermost section of the wing wall. Depending on the final replacement vessel design, it may be necessary to increase the height of the wing walls, and possibly the dolphin fenders, to ensure that the height of the replacement vessel guards never exceeds the wing wall and dolphin fender heights.

At the very least, it will be necessary to increase the height of the fender liner material on the wing walls (the black material shown in Figure 8 below). Although the wing walls are designed to accommodate the design impact load along the full height of the structural timber section (Reference 7), the wing walls currently only have fender liner material extending to roughly 11'-0" above MLLW.

Figure 8 Wing walls at Anacortes terminal

If the fender liners are replaced, it also may be desirable to change the material. The existing fender liner material is ultra-high molecular weight polyethylene (UHMWPE), which is strong, long-lasting, and has a low coefficient of friction (it is slippery). Operators of the existing ferry report that a higher friction coefficient may be desirable to help restrict vessel motion when the ferry is actively pushing on the wing walls.

1.2 Transfer Span Apron Improvements

Analysis of ferry loading and unloading operations revealed that the greatest single improvement to reduce round-trip time would be enabling vehicles and walk-on passengers to load at the same time. Current ferry procedures prohibit concurrent loading, because the apron that connects the transfer span to the ferry is too narrow. There are separated vehicle and walk-on passenger lanes from their respective waiting areas all the way to the end of the transfer span, but they merge on the apron (Figure 9). An analysis of the time that could be saved by widening the transfer span apron to allow for concurrent vehicle and walk-on passenger loading is described in Section 3.4.3. This section describes the feasibility and cost of doing so.

Figure 9 Transfer span components

PND Engineers performed the apron improvement feasibility and cost analysis. It was determined that widening the transfer span aprons is feasible, but it would require modification of the wing walls at both terminals. On the Anacortes side, it would also require modification to the overnight mooring line system, which is attached to the wing walls. Total modification costs were estimated to be $380,000. Given the significant throughput improvement it would enable, this modification is recommended. More details on the feasibility and cost of transfer span improvements are provided in the PND report, Appendix A.

In certain wave conditions, the vessel rolls to the degree that some of the transfer span apron fingers lift off the deck of the vessel. Lengthening the fingers may mitigate this potential safety hazard.

1.3 Design Loads of Ferry on Terminals

The replacement ferry is likely to be heavier and have more propulsive thrust than the existing ferry. For both these reasons, the loads the replacement ferry will impart to the terminals will be greater. Design loads on the dolphin fenders and wing walls and the allowable approach speeds of the replacement ferry were investigated by PND Engineers.

Assuming a replacement vessel mass of 475-675 long tons, the maximum approach speed where minor damage is possible, compared to the existing ferry, decreases from about 1.6 knots to as little as 1.2 knots. Modifications could be made for about $1.2 million, which would increase the maximum approach speed to the original capacity of at least 1.6 knots. This improvement is recommended to protect the dolphin fender equipment and minimize potential out-of-service time.

The wing walls can withstand an approach speed of at least 1.0 knots, compared to 1.40 knots for the existing ferry.

Additional details of the design loads analysis are presented in the PND report, Appendix A.

1.4 Overnight Berthing

The replacement ferry will be berthed overnight at the Anacortes dock, similar to the existing ferry. Modifications to the aprons will necessitate changes to the overnight mooring system at the Anacortes terminal. The replacement ferry will need to include a mooring plan to ensure safe and reliable overnight berthing at the Anacortes terminal.

1.5 Shore Power

The existing shore power connection available at both terminals is 480V, 60A, 3-phase. This connection should be sufficient for a diesel-powered replacement vessel.

In the event of a power outage, the generator onboard the existing ferry provides power to the terminal transfer span lifting system with a power cable that connects to transformers located on the dock and the vessel (Reference 8). Similar functionality is required for the replacement vessel.

1.6 Consumables and Waste

1.6.1 Fresh Water

The existing ferry has a small fresh water tank (approximately 20 gallons) that is filled with a garden hose at the Anacortes terminal. The water is not for drinking, only due to the aged condition of the tank and piping. There is one sink located in the crew day room that provides water for window washing and hand washing. The existing terminal infrastructure in place at the Anacortes terminal will be sufficient for the replacement vessel.

1.6.2 Refueling

The existing ferry is refueled by truck every two weeks during the midday lunch break. The fuel truck drives onboard M/V *Guemes* and usually transfers between 2,000 and 2,500 gallons of diesel fuel. There are no dock-side refueling options at the Anacortes or Guemes Island terminals. This fueling procedure will be sufficient for the replacement vessel.

1.6.3 Waste Removal

The Anacortes and Guemes Island terminals are not outfitted with connections for offloading sewage, waste oil, and oily water. Waste oil and oily water are pumped out via a vacuum pump-out truck when required. Future sewage pump-out, if required for the replacement vessel, could be accommodated via vacuum pump-out truck. The existing waste removal operations are anticipated to be adequate for the replacement ferry.

Section 2 Ferry Terminals Operations

Ferry terminal operations were analyzed to understand how future increases in traffic and the acquisition of a replacement ferry will impact shoreside operations, and vice versa.

All cost data presented in this section is in 2017 dollars.

2.1 Vehicles

2.1.1 Parking Capacity

Parking capacity at the Anacortes and Guemes Island terminals was investigated by DN Traffic Consultants (DN) in their Land Facilities Impact Study (Reference 9). The following section summarizes DN's findings.

2.1.1.1 Anacortes

DN determined that 59 additional parking stalls are required at the Anacortes terminal to meet the forecasted 2060 demand. Most of this increased capacity requirement, 42 stalls, could be realized by modifying existing parking lots 4 and 5 (Reference 9). Reconfiguring these lots could add 12 stalls to Lot 4 and 30 stalls to Lot 5, for approximately $138,000. Alternatively, DN estimated that a new 59-stall parking lot could be constructed for $1.9 million, including the cost of acquiring land. A third alternative that could be investigated is to add a single elevated deck above Lot 5 to increase capacity without requiring additional land to be purchased.

Figure 10 Anacortes Terminal parking lots

2.1.1.2 Guemes Island

DN determined that 96 additional parking stalls are required at the Guemes Island terminal to meet forecasted 2060 demand. About 20% of this increased capacity requirement, 20 stalls, could be realized by modifying the existing parking lot (Figure 11). Reconfiguring this lot would cost approximately $650,000.

Skagit County is planning to pave and delineate parking spaces in the existing lot, increasing the total capacity from 80 to 90 (Reference 10).

DN estimated that a new 96-stall parking lot could be constructed for $1.3 million, including the cost of acquiring land.

Figure 11 Guemes Island parking lots (Source: Google)

2.1.1.3 Alternative Parking Solutions

DN also discussed options for reducing parking demand so that larger lots may not be necessary. Alternative parking solutions are listed below:

1. **Implement and enforce parking policies.** Currently, there is a three-day parking limit at both terminals, and it is not well enforced. This increases demand as people may be leaving their cars parked in the lots for more than three days without fear of penalty. Additionally, the parking lots are currently being used by people who are not patronizing the Guemes Island ferry. For example, it was revealed that patrons of the nearby Washington State Ferry terminal sometimes park at the Guemes Island Ferry Anacortes parking lot to avoid paying fees imposed at the Washington State Ferry terminal.
2. **Institute a parking fee.** Currently, it is free to park at both terminals. Implementing a parking fee will reduce parking demand. However, this will likely increase vehicle

demand on the ferry, since the marginal cost of driving aboard the ferry, versus parking and walking aboard, will effectively be reduced.

3. **Decrease the ferry ticket price for vehicles.** Decreasing the ferry ticket price for vehicles will increase vehicle demand and reduce parking demand. Of course, the replacement ferry will have a limited capacity, and a collateral effect of reducing ticket prices or instituting a parking fee will be longer vehicle queues at peak times.

Currently, parking is adequate at both terminals, and the parking demands cited in the above sections are estimates for 2060. If alternative parking solutions 2 and 3 (above) are implemented, they can be slowly adjusted to establish an optimal balance of vehicle demand for the available parking spots and vehicle capacity of the replacement ferry.

2.1.2 Vehicle Queues

Queue lengths were estimated for a specified design hour, defined as the peak hourly demand on a typical summer weekend. Glosten determined demand was greatest at the Anacortes terminal on Fridays and at the Guemes Island terminal on Sundays, for a typical summer weekend. Based on historical vehicle ridership levels and observed queue lengths, Glosten developed forecasts for vehicle demand in 2060, as illustrated in Figure 12.

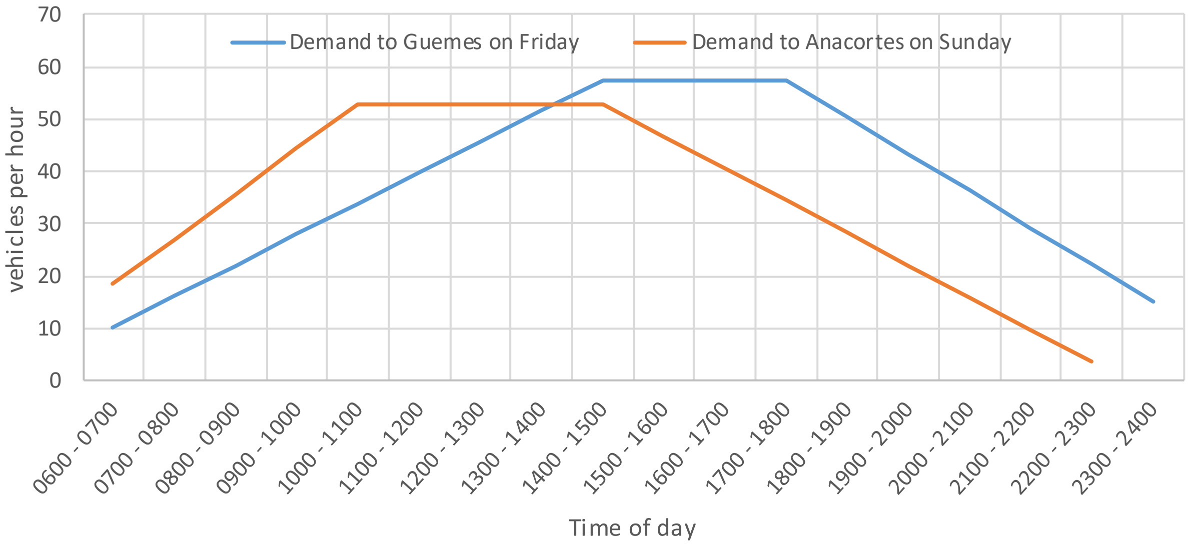


Figure 12 Forecasted hourly vehicle demand, typical summer weekend in 2060

Vehicle queue lengths at the Anacortes and Guemes Island terminals were estimated by DN in their Land Facilities Impact Study (Reference 9) under the following assumptions:

1. Year 2060 forecast vehicle demand, as shown in Figure 12.
2. Replacement vehicle capacity of 32 vehicles (Reference 1).
3. A ferry schedule of two round-trip transits per hour (30-minute round-trips).
4. Upgraded ticketing system such that ticketing is not a bottleneck.
5. Concurrent vehicle and walk-on passenger loading (see Section 3.4.3 for more information).

2.1.2.1 Anacortes Queue

DN estimated that the queue length during the design hour at the Anacortes terminal will be 1,573 feet, which is 523 feet longer than the existing delineated queue lane. Extending the delineated queue lane from existing terminus at K Avenue to M Avenue, as illustrated in Figure 13, would accommodate the estimated design hour demand in 2060. DN estimated that the cost of restriping 6th Street to extend the delineated queue lane would cost $3,000.

Figure 13 Existing Anacortes terminal delineated queue lane (blue) and additional length required to accommodate 2060 forecast (orange)

An alternative to extending the queue length would be to institute a reservation system for vehicles. This would help to balance the demand throughout the day, reducing peak demand.

2.1.2.2 Guemes Island Queue

DN estimated that the queue length during the design hour at the Guemes Island terminal will be 403 feet, which is less than the existing delineated queue lane. The reason for this reduction in queue length is that the improvements to service rate are forecasted to outweigh the increase in design hour demand on Guemes Island due to assumptions 2, 3, and 5 above (Section 2.1.2).

Figure 14 Existing Guemes Island terminal delineated queue lane (blue) and estimated 2060 queue length (orange)

2.2 Walk-On Passengers

Impacts to walk-on passengers at the Anacortes and Guemes Island terminals were investigated by DN in their Land Facilities Impact Study (Reference 9). DN determined that the Anacortes waiting area is large enough to accommodate forecasted 2060 demand. The Guemes Island side does not have a waiting area, although a small passenger shelter may be added as part of the ongoing parking lot improvement project (Reference 10).

Anacortes walk-on passengers who park at lot number five are currently required to walk through the middle of lot number 4. Segregating pedestrians and vehicles by providing a sidewalk along the north property line fence would be a significant improvement in pedestrian safety. If modifications are made to the Anacortes terminal parking lot number four (Figure 10), a pedestrian walkway should be investigated. If restriping of I Avenue at the terminal is performed, the pedestrian crosswalk should be aligned with the new walkway.

2.3 ADA Accessibility

A report by Art Anderson Associates (AAA) investigates compliance of the existing terminals with the American Disabilities Act (ADA) and related codes and standards, and makes recommendations for remedying any non-compliant findings (Reference 5). Their report finds that there are a few minor deficiencies, but nothing that must be immediately remedied to ensure equal access by disabled persons. A sensible time to make improvements to address the minor deficiencies is during future new construction or modifications to terminal infrastructure.

Their findings are summarized below:

- The Anacortes terminal is in compliance.
- The Guemes Island parking area likely qualifies as meeting the "maximum extent feasible" compliance criterion, but the slope of the paving leading from the old bus shelter to the transfer span should be reduced if there is a practical opportunity. Such an opportunity may exist during the upcoming modifications discussed in Section 2.1.1.2 (also see Reference 10).
- The Guemes Island pedestrian walkway has a railing with a gap that is out of compliance (Figure 15). Installing a safety mesh would resolve the issue.

Figure 15 Non-compliant gap at Guemes Island terminal (Source: Reference 5)

- The transfer spans and aprons are exempt from walkway rise and slope requirements (Section 1.1.4.1 of this report also presents the relationship between vessel freeboard and meeting a hypothetical 1:12 slope requirement).
- Several minor handrail additions are recommended at both the Anacortes and Guemes Island terminals to improve general safety and ensure the County is meeting the "maximum extent feasible" compliance criterion.
- Notices at the terminals and on the website providing information to those with special needs or requiring special assistance are recommended.

2.4 Ticketing System

In the existing system, tickets are sold at the Anacortes terminal by a single ticketing agent. The agent accepts cash and credit cards, although both customer and agent must walk to the terminal building to conduct credit card transactions. All tickets are sold as round-trip.

If improvements are not made to the existing ticketing system, and the replacement ferry is larger than the existing ferry, the ticketing system will become a major source of schedule delays. DN quantified the performance of the existing system and investigated opportunities for improving the system in the future in their Land Facilities Impact Study (Reference 9). The following section summarizes DN's findings.

2.4.1 Causes of Delays

The ticketing system currently does not always have a significant detrimental effect on throughput, because the rate at which the existing ferry can be loaded is usually the bottleneck, not the ticketing system. However, a key assumption to ensuring the ticketing system will not inhibit throughput in the future is that it will not become the bottleneck. DN found that it almost certainly will become the bottleneck if improvements are not made, based on the causes of delays described below, and the assumption that the existing bottleneck, the loading rate of vehicles and walk-on passengers, will be improved by enabling concurrent vehicle and walk-on passenger loading.

Causes of the delays due to the existing ticketing system were mostly due to patrons who did not have pre-purchased tickets. On the day of DN's site visit, this accounted for 47% of all patrons. Delays were observed to be caused by the following primary factors:

- **Credit card transactions.** Credit card transactions were observed to take an average of approximately six minutes per vehicle! This is because the patron must exit their vehicle, walk to the terminal building with ticketing agent, conduct the transaction inside the terminal building, and walk back to their vehicle.
- **Cash transactions.** Cash transactions were observed to take an average of 21 seconds per vehicle (versus 6 seconds per vehicle for those patrons holding pre-purchased tickets).
- **Walk-on passengers.** It was observed that ticketing of vehicles was interrupted whenever a walk-on passenger purchased a ticket. This was because the same ticketing agent sells tickets to the vehicles and the walk-on passengers.
- **Staging of large vehicles.** This does not have to do with ticket purchasing, but is another significant factor causing delays. There are often large commercial vehicles that need to fit onto the ferry with smaller cars. Especially towards the end of loading, the crew must carefully select vehicles that fit on the ferry and maximize its load. DN observed that delays were caused by small and large vehicles mixed together in one queue.

2.4.2 Proposed Improvements

DN investigated available ticketing system options and formulated recommendations based around the ideas of separating ticket sales from the loading operation, incentivizing patrons to purchase tickets ahead of time, and eliminating lengthy transactions, especially those requiring the patron and ticketing agent to walk to the terminal building and back. The following improvements were recommended:

- **Ticketing kiosks.** Install unmanned ticketing kiosks at the head of the ferry loading lane(s) for vehicles, and at the terminal waiting area for walk-on passengers.
- **Online ticket sales system.** Implement an online ticket sales system (combined with ticket kiosks in previous bullet).

- **Separate small and large vehicles.** DN observed that there is sufficient width on I Avenue at the Anacortes terminal for four traffic lanes. If two lanes were designated for loading, the two loading lanes could be split into large vehicles and small vehicles, improving the efficiency with which the vessel crew could load the vessel. The estimated cost to re-stripe these lanes is $5,000.
- **Reservations.** Require reservations for large commercial vehicles (dump trucks, 18-wheelers, etc.). Such reservation systems are utilized by other vehicle ferry systems, and could be combined with the previous bullet to institute a priority reservation line, separate from the general boarding lane.

An interim, cost-effective solution would be for allowing credit card transactions to be processed in the vehicle queue. This would drastically reduce the time required to conduct credit card transactions.

DN also observed that cash transactions are a security concern, as they often require the ticketing agent to carry a large sum of money. This security risk could be mitigated by requiring exact change (the ticketing agent would not have to carry change), by removing the cash option altogether, or by making it easier to purchase tickets by other means, thereby reducing the number of patrons paying with cash.

Section 3 Throughput Assessment

3.1 Overview

A throughput model was developed to understand the operational characteristics of the ferry system necessary to meet the forecasted traffic demand in 2060, the approximate end date of a replacement ferry's service life. The throughput model outputs key performance characteristics of the ferry system, such as the time it takes to complete a round-trip transit. The throughput model utilizes the Monte Carlo method to randomly sample the time it takes to complete each segment of a round-trip journey, from the time the first passenger or vehicle loads in Anacortes, to the time the last passenger or vehicle unloads from the return trip back to Anacortes. It sums all the time segments that make up a round-trip, resulting in one possible total round-trip time. This calculation is repeated thousands of times to return a probability distribution of total round-trip time.

The probability distribution of total round-trip time that the model calculates represents the likelihood that each run of the ferry will exceed a given amount of time. For example, it reveals the probability that, fully loaded with vehicles, the ferry will perform a round-trip to Guemes and back in 30 minutes or less. Thus, the throughput model may be used to determine working combinations of ferry system inputs that satisfy the schedule and throughput requirements of the replacement ferry.

To build the model, probability distributions of each time segment were developed by analyzing GPS data and video recordings of the existing Guemes Island ferry.

Assumptions on which the model is based are described in Section 3.2. Validation of the model via comparison with known operational characteristics of the existing ferry system is described in Section 3.3. Results are presented in Section 3.4.

3.2 Assumptions

The following key assumptions were held constant unless otherwise noted:

- It was assumed that the ticketing system and vehicle and passenger queues do not have any effects on the ferry schedule. See Section 2 for more discussion on these aspects of the ferry system.
- The rates at which walk-on passengers and vehicles embarked and disembarked were assumed to follow the probability distribution observed over the course of nine round trips during typical busy crossings on the 2017 Labor Day weekend.
- For peak load scenarios, the number of walk-on passengers was assumed to be 33. This corresponds to our estimate for the 95th percentile number of walk-on passengers at the end of the replacement ferry's service life.
- The number of vehicles was assumed to be 100% of total vehicle capacity in both directions. This follows from the assumption that the ferry will be designed to be 100% utilized by vehicles at peak times at the end of its service life.
- The distribution of vehicle sizes utilizing the ferry system is assumed to remain constant between now and the end of the replacement ferry's service life. The assumed vehicle capacity is based on this size distribution.

- Based on GPS data of typical crossings, the distance over ground covered by a transit was assumed to be the straight-line distance between the Anacortes terminal and the Guemes Island terminal plus a 5% maneuvering margin.
- Current was assumed to travel perpendicular to the direction of transit. A probability distribution of the current speed was developed using NOAA buoy data from the west entrance of Guemes Channel (Reference 11).

3.3 Validation

The throughput model was validated by comparing the actual performance of the existing system to its modeled performance. Figure 16 shows the throughput model distance and elapsed time calculated for the existing ferry's average transit (transit time is defined as the time between the ferry breaking contact with one terminal and contacting the opposite terminal). The blue and red curves are actual recorded transits, and the bold black curve is the average time versus distance calculated by the throughput model. The result shows that the throughput model is slightly conservative, with an average calculated transit time of six seconds (2.2%) greater than the average recorded transit time.

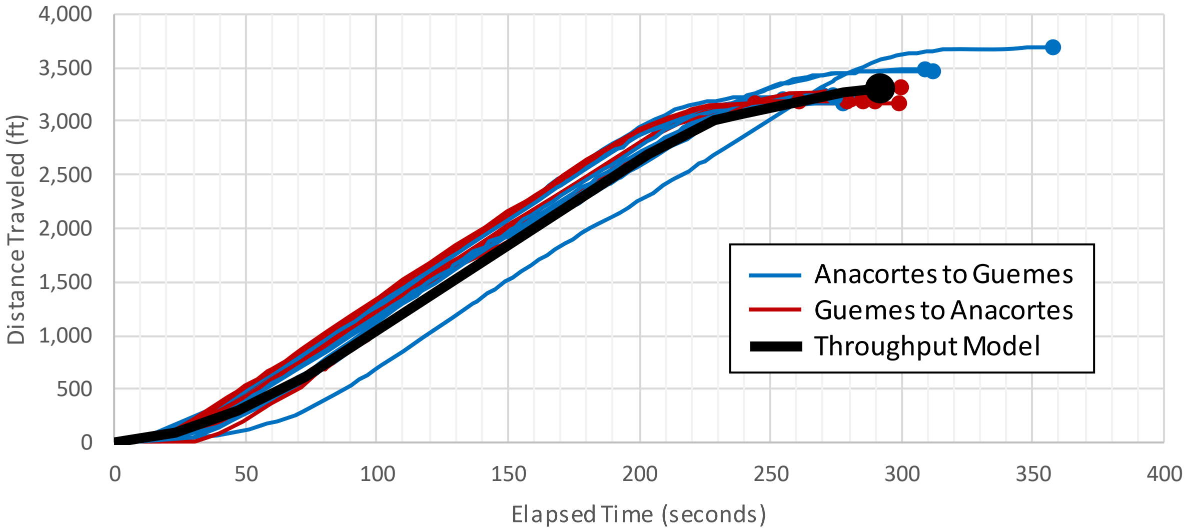


Figure 16 Comparison of throughput model transit calculation with actual transits from 2 July 2017

Empirical probability distributions of additional time segments were developed by parsing video recordings of nine round-trip crossings on the 2017 Labor Day weekend. The existing ferry was modeled, and it was calculated that, at the design load of 100% vehicle capacity and 18 walk-on passengers per transit, the average round trip takes less than 30 minutes 91% of the time. This corresponds well with historical observations that on busy weekends, M/V *Guemes* is generally on time, but occasionally late. Figure 17 shows the throughput model results for total round-trip time for the existing ferry (M/V *Guemes*) in the design scenario: fully loaded with vehicles, and 18 walk-on passengers. As can be seen, the model predicts that 91% of the time, the ferry will complete the round trip in under 30 minutes (1800 seconds). The predicted median round-trip time is 28:14.

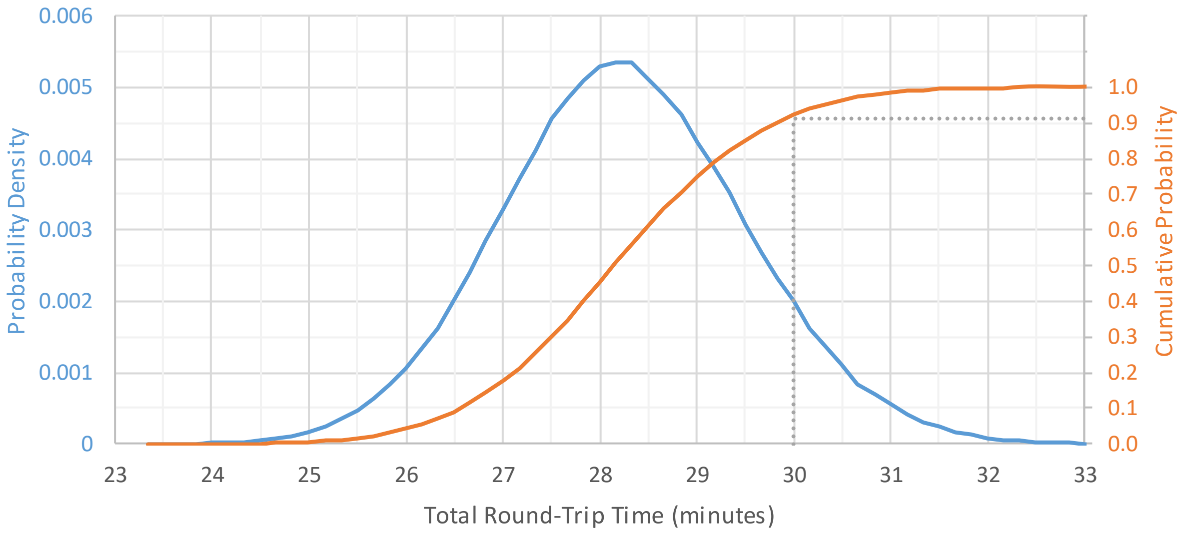


Figure 17 Throughput model results: total round-trip time for existing ferry (M/V *Guemes*), fully loaded with vehicles

3.4 Results

The results presented below assume the input parameters for the replacement ferry as presented in Table 2. These inputs reflect the concept design at the time of this writing, however, later iterations of the concept design will likely result in updates to these assumptions. Indeed, the throughput model will be used as a design tool for the replacement ferry, to estimate combinations of these parameters that achieve the desired throughput and schedule.

Table 2 Assumed replacement ferry parameters

Length overall	178 ft
Cruising speed	11.5 knots
Acceleration (> 5 knots)	8.25 knots/minute
Acceleration (≤ 5 knots)	9.90 knots/minute
Walk-on passenger load, both directions	33 passengers
Vehicle load, both directions	100% of capacity

3.4.1 Maximum Vehicle Capacity

The throughput model was used to estimate the maximum vehicle capacity of the ferry at which the ferry system can reliably meet the schedule requirement of two round trips per hour. It was assumed the maximum vehicle capacity was that capacity at which a round trip will take, on average, 30 minutes or less. Given this assumption, the assumptions in Section 3.2, and the input parameters in Table 2, it was estimated that the maximum vehicle capacity is 22 vehicles. Figure 18 shows the maximum hourly vehicle throughput (left vertical axis) and average round trips per hour (right vertical axis) predicted by the throughput model, given the vehicle capacity (horizontal axis).

This result shows that the existing ferry is sized appropriately given the existing operating regime. However, two key areas for improvement were identified which would increase the vehicle capacity of the replacement ferry while still allowing for two round trips per hour:

minimizing the time spent clearing the ramp (see Section 3.4.2) and allowing for simultaneous passenger/vehicle loading (see Section 3.4.3).

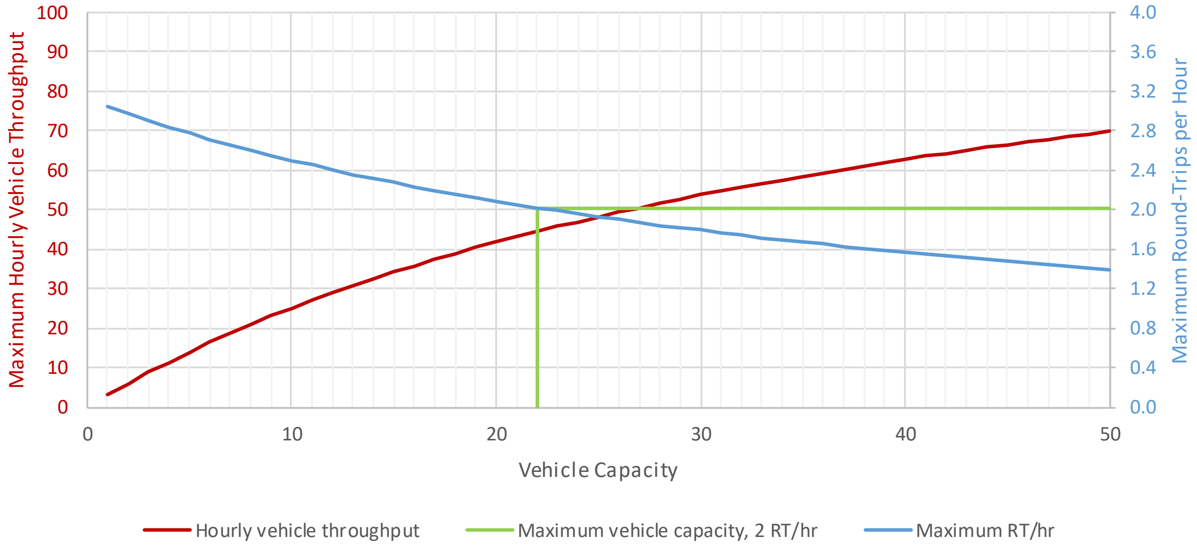
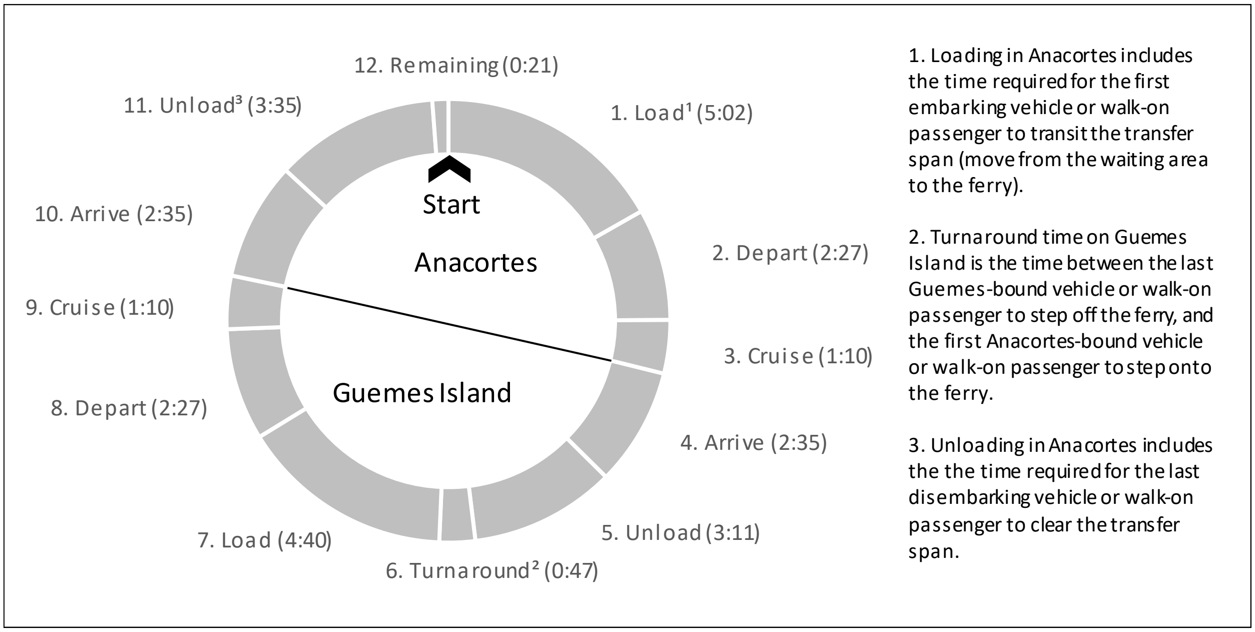


Figure 18 Average vehicle throughput versus vehicle capacity, assuming existing loading operations

Figure 19 shows how the time segments of the average round trip are predicted by the throughput model for a 22-vehicle ferry.



1. Loading in Anacortes includes the time required for the first embarking vehicle or walk-on passenger to transit the transfer span (move from the waiting area to the ferry).

2. Turnaround time on Guemes Island is the time between the last Guemes-bound vehicle or walk-on passenger to step off the ferry, and the first Anacortes-bound vehicle or walk-on passenger to step onto the ferry.

3. Unloading in Anacortes includes the the time required for the last disembarking vehicle or walk-on passenger to clear the transfer span.

Figure 19 Typical round-trip transit: 22 vehicle ferry, existing loading operations

3.4.2 Ramp Clearing Time

The above Section 3.4.1 analysis assumes that the current practice of alternating repeatedly between loading vehicles and loading walk-on passengers persists. Since vehicles and walk-on passengers are not allowed on the transfer span apron (the ramp) at the same time, time is lost while the ramp is cleared. The time spent clearing the ramp is illustrated in Figure 20.

Figure 20 **Example of ramp clearing time: time spent waiting for vehicles and walk-on passengers to clear the apron while switching between the loading of each. In this example, eight seconds were added to the total loading time due to the vehicle being instructed to stay clear of the ramp while the passenger embarked.**

This ramp clearing time adds up to about 42 seconds per round trip, which reduces the maximum vehicle capacity that could meet the two round-trips per hour schedule requirement. Ramp clearing time could be minimized by loading all vehicles, followed by loading all passengers (or vice versa).

The throughput model was used to estimate that the vehicle capacity would be increased to 24 if ramp clearing time was minimized.

3.4.3 Concurrent Vehicle/Walk-On Passenger Loading

Analysis of ferry loading and unloading operations revealed that the greatest single improvement to reduce round-trip time would be to enable vehicles and walk-on passengers to load at the same time. Currently this is prohibited, because the apron that connects the transfer span to the ferry is too narrow. There are separated vehicle and walk-on passenger lanes from their respective waiting areas all the way to the end of the transfer span, but they merge on the apron.

The throughput model was used to estimate the improvement that could be achieved if concurrent vehicle and walk-on passenger loading was enabled. As illustrated in Figure 21, maximum vehicle capacity that could meet the two round-trips per hour schedule requirement would be increased to 33 vehicles.

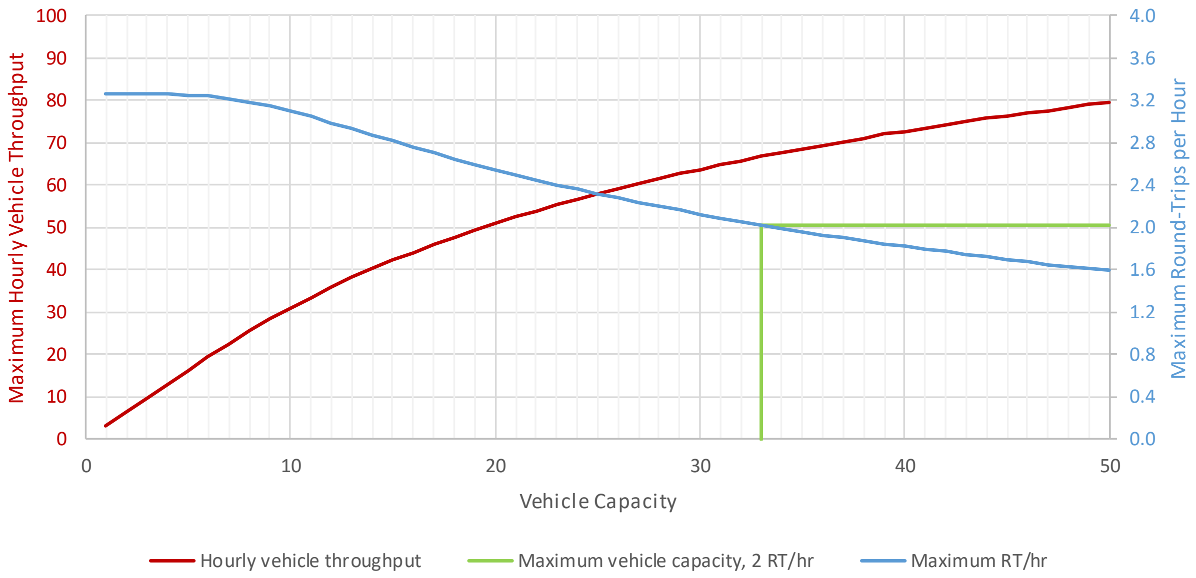
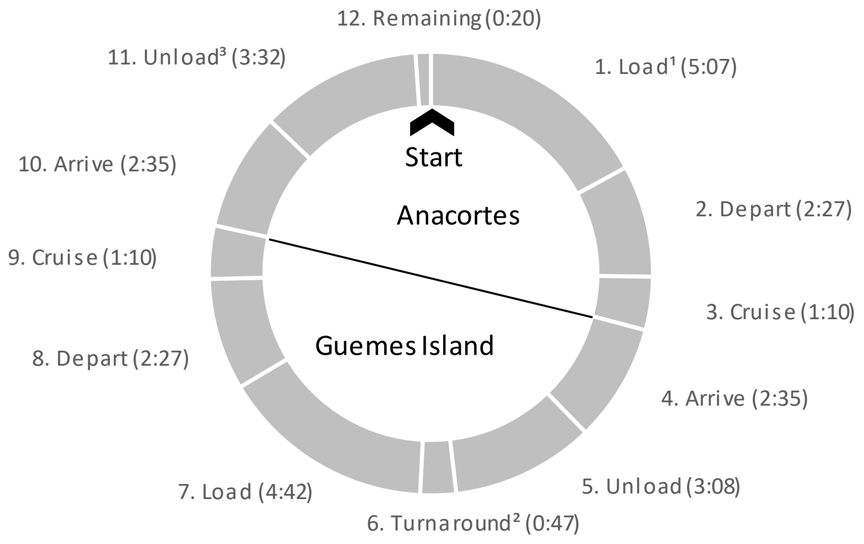


Figure 21 Average vehicle throughput versus vehicle capacity, assuming concurrent vehicle and walk-on passenger loading

Figure 22 shows how the time segments of the average round trip are predicted by the throughput model for a 33-vehicle ferry, assuming concurrent vehicle and walk-on passenger loading is enabled.



1. Loading in Anacortes includes the time required for the first embarking vehicle or walk-on passenger to transit the transfer span (move from the waiting area to the ferry).

2. Turnaround time on Guemes Island is the time between the last Guemes-bound vehicle or walk-on passenger to step off the ferry, and the first Anacortes-bound vehicle or walk-on passenger to step onto the ferry.

3. Unloading in Anacortes includes the the time required for the last disembarking vehicle or walk-on passenger to clear the transfer span.

Figure 22 Typical round-trip transit – 33 vehicle ferry, concurrent passenger and vehicle loading

Section 1.2 analyzes the feasibility of widening the apron as a means of enabling concurrent vehicle and walk-on passenger loading.

Section 4 Ferry Design Alternatives

4.1 Basic Design Options

The replacement ferry will be a steel, double-ended, displacement monohull. The following subsections describe the logic behind these basic design options for the replacement ferry. Replacing the existing ferry with a similar but larger vessel is then compared with an alternative two-ferry system, to analyze the tradeoffs and verify that a single replacement ferry is advisable, in terms of system performance and costs (Sections 4.2).

4.1.1 Single-Ended versus Double-Ended

The route, operating schedule, and vehicle and walk-on passenger operations are all properties of the Guemes Island ferry system for which a double-ended ferry is better suited than a single-ended ferry. All else being equal, a double-ended ferry has both higher initial costs and higher operating costs than a single-ended ferry, but the benefits summarized below outweigh the costs.

- **Vehicle and walk-on passenger operations**. A double-ended ferry allows vehicles to flow through the vessel in one direction, simplifying vehicle maneuvering and reducing congestion at the bow during loading and unloading. This reduces the time and improves the safety of vehicle loading and unloading, compared to a single-ended ferry.
- **Transit and maneuvering time**. A double-ended ferry can accelerate to full speed immediately upon exiting the slip. A single-ended ferry must back out slowly, due to limitations in backing speed and limited visibility when backing into a channel containing other vessel traffic. A single-ended vessel must turn around before it can accelerate to full speed ahead. These downsides are exacerbated on very short routes. In addition to reduced operational performance, a single-ended ferry also faces greater fuel efficiency penalties on shorter routes due to the extra transit distance traveled, at an inefficient operating speed, with each crossing.
- **Safety**. Double-ended ferries never operate in “reverse.” A single-ended ferry must back out of a slip, a maneuver that is typically accompanied by poor maneuverability. A double-ended ferry is designed to operate with equal visibility and maneuverability in both directions. This reduces the risk of collision with other waterborne objects, such as debris and other marine traffic.

The cost of a double-ended ferry typically exceeds that of a single-ended ferry for the reasons summarized below:

- **Propulsion requirements**. It is most efficient for a double-ended vessel to generate most of its propulsion from the aft propulsion unit. In other words, it is more efficient to “push” than to “pull” due to hull/propeller hydrodynamics, to the extent that the forward propeller on most double-ended ferries is only spun at a rate sufficient to mitigate the drag that would otherwise be caused by not spinning the propeller at all. This typically increases the capital cost, because a double-ended ferry must either be a conventionally-shafted geared diesel with up to 100% greater engine size than a comparable single-ended ferry, or have a more complex and expensive drive train to deliver the required power from multiple engines to the aft propeller, such as diesel-electric propulsion or a high-speed connecting shaft. Operating costs are less affected since the approximately the same overall power must be delivered to the driving propeller(s).

- **Hull complexity**. The bow of a ship typically costs more to construct than the stern, due to greater complexity of shape. A single-ended vessel has one bow and one stern while a double-ended vessel essentially has two bows and no stern.
- **Pilothouse redundancies**. The pilothouse (or pilothouses) on a double-ended ferry is usually symmetric about amidships. This is accomplished by having one pilothouse with controls facing both directions, or two identical pilothouses, mirrored about amidships. A single pilothouse is generally less costly and less operationally complex, but may place undue constraints on the overall general arrangement of the ferry. In either case control systems and windows may have to be symmetric to allow for operation in either direction. A single-ended ferry only requires one pilothouse.

4.1.2 Displacement Hull versus Semi-Planing Hull

The replacement ferry will be a displacement hull (as opposed to a fast semi-planing hull).

The hull form of a double-ended ferry is not compatible with a fast semi-planing hull, nor is a fast hull feasible for this application. As can be seen in Figure 22, only 2:20 of the total 29:40 round-trip time is spent at cruising speed for the concept design. The route is so short that it is highly unlikely that a fast semi-planing hull would even be able to achieve cruising speed before having to decelerate. This would be extremely inefficient and is not recommended.

4.1.3 Monohull versus Catamaran

The replacement ferry will be a monohull, although a catamaran hull form was considered. The primary tradeoffs are summarized below:

- **Stability**. If transverse stability is found to be a design driver, a catamaran design may be favorable. On the other hand, a monohull tends to have a larger waterplane area than a catamaran, resulting in less change to draft as cargo is loaded and unloaded, and less change in trim as cargo is shifted fore and aft. Monohulls are advantageous for small vehicle ferries, on which large, heavy vehicles move from one end of the vessel to the other.
- **Maneuverability**. While also highly dependent on other factors, such as the propulsion system, maneuverability can vary largely between monohulls and catamarans. A steel monohull fitted with azimuthing propulsors will generally provide the best maneuverability (as reflected by the excellent maneuverability of the existing Guemes Island ferry).
- **Powering**. Catamarans tend to have less ahead resistance but more side resistance. The replacement ferry must have the ability to counter the significant side current that occurs at both terminals. Ahead speed is less important due to the short route.

4.1.4 Steel versus Aluminum

Steel and aluminum are the practical hull material options to consider for the replacement Guemes Island ferry. Composites such as fiberglass and carbon fiber are lightweight but expensive. The primary tradeoffs between steel and aluminum are summarized below:

- **Initial capital cost**. All else being equal, aluminum vessels are lighter than steel vessels, as aluminum is about one third the weight but half the strength of steel. For shipbuilding, aluminum is approximately four times more expensive than steel, in terms of raw material and labor required to fabricate a similarly sized hull. However, steel requires hull coating (painting) for corrosion resistance, whereas aluminum generally does not.

Taking all these factors into consideration, the hull structure of an aluminum vessel can typically be expected to cost about three times as much as the hull structure of a similarly sized steel vessel.

- **Operating costs**. Aluminum vessels tend to be less costly to maintain than steel vessels due to their corrosion resistance. Because aluminum vessels are lighter, they also require less power, which can reduce fuel consumption and maintenance costs. However, aluminum is more easily damaged.
- **Service life**. Aluminum vessels typically have shorter service lives than steel vessels, due to their susceptibility to fatigue cracking. In applications with high loads, such as a vehicle deck with large trucks, steel would provide a more deformation-tolerant and fatigue-resistant design, while maintaining reasonable thicknesses.

A steel hull is recommended for the reasons noted above. A steel hull with an aluminum deckhouse can provide a compromise between the benefits of the two materials.

4.2 Two Small Ferry Alternative

The obvious ferry replacement strategy is to replace the existing ferry with a single new ferry of adequate capacity to meet the forecasted traffic demand at the end of its design life (40 years). However, for some ferry systems, multiple smaller ferries may be a better solution than one larger ferry. This section investigates the tradeoffs between a single larger ferry and two smaller ferries. Although there are advantages to the two-ferry solution, the investigation concludes that the single ferry solution is recommended in terms of overall costs and benefits.

4.2.1 Operational Tradeoffs

The following is a list of operational advantages and disadvantages of replacing M/V *Guemes* with two smaller ferries instead of one larger ferry.

Table 3 Advantages and disadvantages of a two-ferry system

Advantages of Two-Ferry System	Disadvantages of Two-Ferry System
Redundancy – if one ferry is down for maintenance, the other ferry can continue running. Vehicle capacity will be limited during these times, but the system will always have at least 50% of its total vehicle capacity. This also likely obviates the need for a charter ferry.	Higher overall maintenance costs – two smaller ferries will generally be more expensive to maintain than one larger ferry (see Economic Tradeoffs, Section 4.2.2).
Higher utilization - with two smaller ferries, there is an increased flexibility to match overall system throughput capacity (maximum vehicles and passengers per hour) with demand. This increases overall utilization, potentially reducing overall operational costs.	For the Guemes Island ferry system, there are not large spikes in demand at certain times of day (see Figure 23 and Figure 24). Nor are there days of the week that are substantially busier than others (see Figure 25). The possible gains in utilization are modest as a result. Furthermore, staffing a ferry schedule that matches demand is challenging and may not be feasible. Additionally, both options require the same number of crew per ferry. Crew costs will be higher overall for the two-ferry option.

Advantages of Two-Ferry System	Disadvantages of Two-Ferry System
More frequent runs – when both ferries are running, there will be a ferry departing every 15 minutes rather than every 30 minutes. Walk-on passengers will especially benefit from the increased run frequency. The ferry capacities are determined by the maximum vehicle demand, whereas walk-on passenger space is almost always underutilized. At peak times, the two-ferry system will be designed to carry the same number of vehicles per hour as the one-ferry system, meaning that in the two-ferry system at peak times, the typical vehicle will have to wait in the queue for one run (15 minutes). Due to ample walk-on passenger capacity, walk-on passengers will typically be able to show up and board the next ferry.	Because the fleet throughput capacity is designed to meet peak vehicle demand, and both ferries will only be running at peak times, vehicles will not often benefit from the increased frequency of runs. Additionally, there is only one slip at each terminal, so if one ferry is delayed significantly, it could delay the other ferry.
Simpler machinery – Halving the size of the ferries means simpler machinery for the two-ferry option. For example, the single ferry option likely requires EPA certified Tier IV engines, which require exhaust gas after treatment and the associated equipment and consumables. The two-ferry option likely only requires EPA Tier III engines, which do not require exhaust gas after treatment.	The machinery may be simpler, but there will be twice as much of it.

Figure 23 shows the average number of vehicles per trip, Monday through Thursday (weekday traffic). From 0600 to 1800, average number of runs going in one direction or the other is at least 16. Only after this time span, from 1600 to close, does average runs in both directions decline, indicating that there is only a small window of opportunity for a two-ferry system to benefit from only running one ferry during off-peak times.

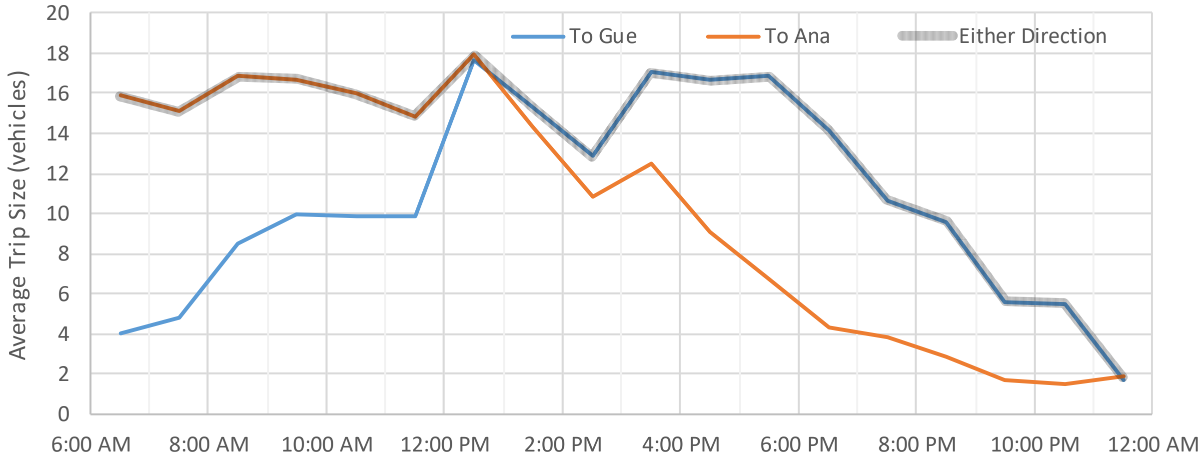


Figure 23 Average number of vehicles per trip by time of day, Monday through Thursday, 2001-2017

Figure 24 illustrates a similar conclusion for weekend traffic (Friday through Sunday). There is only a modest benefit from the enhanced peak traffic-matching ability of the two-ferry system.

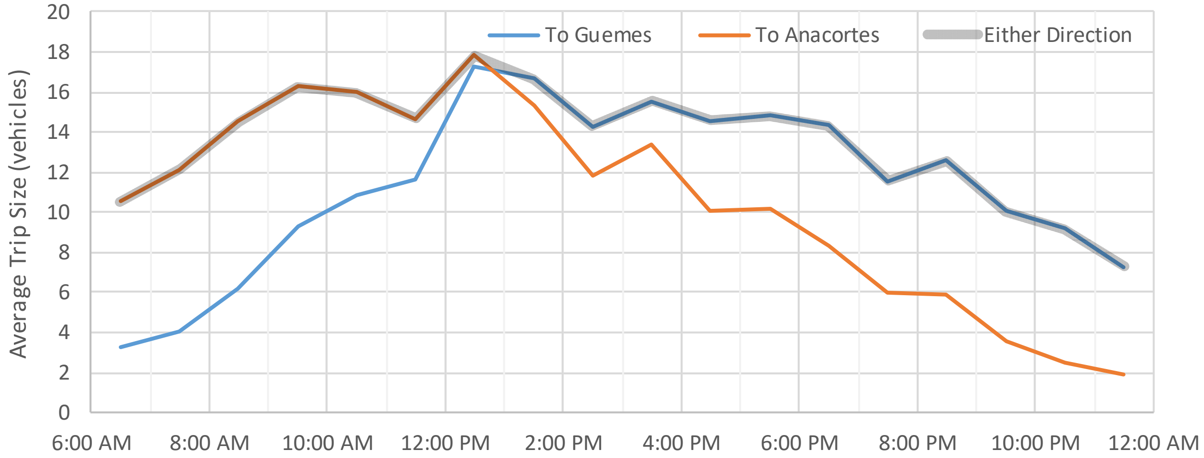


Figure 24 Average number of vehicles per trip, Friday through Sunday 2001-2017

Figure 25 illustrates that the daily vehicle traffic is relatively constant. If it varied substantially on certain days of the week (for example, if there was substantially different traffic on the weekdays than on the weekends), then it might be possible to run one small ferry during the low traffic days, and two ferries during the high traffic days. Because the traffic is approximately constant all seven days of the week, the benefit of having two small ferries would be modest, at best.

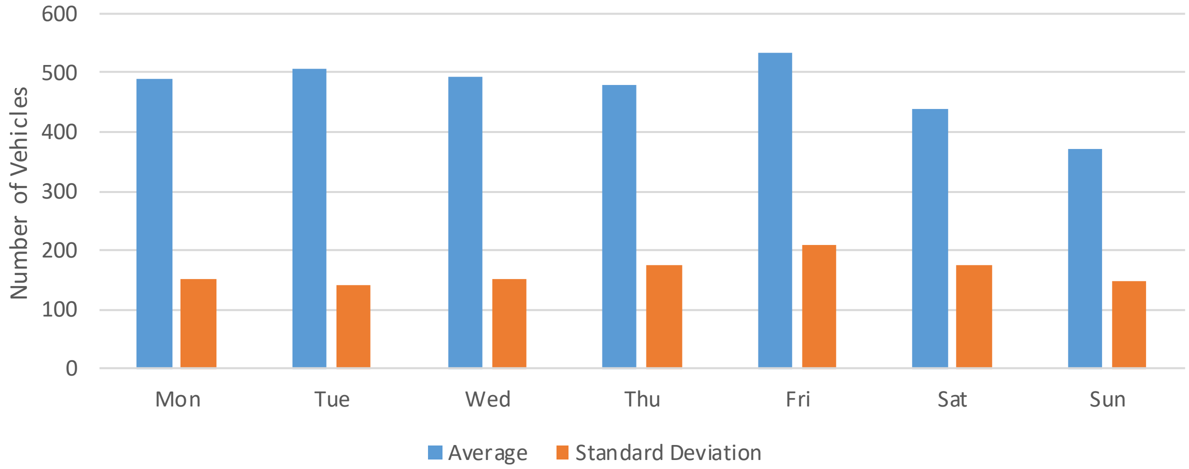


Figure 25 Daily vehicle traffic, 2009-2016

4.2.2 Cost Tradeoffs

A total life cycle cost estimation model was developed to compare the costs of the one ferry option with the two-ferry option. In the two-ferry option, it was assumed that both ferries are acquired at the same time. All ferries are assumed to have a 40-year service life. Summary results are presented in Table 4. Detailed results are provided in Appendix B.

Table 4 Total lifecycle (40-year) cost summary results

	One Ferry Option	Two Ferry Option	% Increase for Two-Ferry Option
Ferry Description	32 vehicles 150 passengers 1,000 HP Tier IV engines	16 vehicles 150 passengers 600 HP Tier III engines	-
Total Lifecycle Cost	$ 56,618,723	$ 74,528,397	32%
Initial Capital Cost	$ 12,215,000	$ 16,400,000	34%
Estimated Annual OpEx*	$ 1,707,236	$ 2,091,118	22%
Maintenance	$ 371,784	$ 364,900	-2%
Fuel	$ 231,452	$ 277,218	20%
Salaries/Wages	$ 1,104,000	$ 1,449,000	31%

*This reported value is the estimated average cost over first ten years of operation (2020-2029). See Appendix B for more details.

Sensitivity Study

The sensitivity of the lifecycle cost model to average utilization of the two-ferry option was studied. One of the primary advantages of having two ferries instead of one is that peak loads can be matched, so that during off-peak times only one ferry is operating, and during peak times, both ferries are operating. Based on historical ridership data, it was assumed that a two-ferry option would have total ferry utilization of 87.5%: one ferry operating 100% of the time, and one ferry operating 75% of the time (the average of which is 87.5%). Table 5 shows the lifecycle cost model results for total ferry utilization of 75%, 87.5%, 100%. Even at 75% average ferry utilization, the two-ferry option is more expensive, by every measure, than the one ferry option for this transportation system.

Table 5 Percent increase in costs from one ferry option to two ferry option

Two Ferry Average Ferry Utilization	75%	87.5%	100%
Total Lifecycle Cost	21%	32%	43%
Initial Capital Cost	34%	34%	34%
Estimated Annual Operating Costs*	8%	22%	37%
Maintenance*	-2%	-2%	-2%
Fuel	3%	20%	37%
Salaries/Wages	13%	31%	50%

*Includes replacement ferry charter costs

In terms of cost, a single ferry is recommended.

Section 5 Emergency Services

The existing Guemes Island ferry provides a critical emergency service link to the mainland for the residents and visitors of Guemes Island.

The most recent large fire response on Guemes Island, in 2012, resulted in continual ferry service from 3:00 pm until 3:10 am on May 20th, for a total of 17 unplanned trips (Reference 12). The response involved approximately 100 emergency responders and 23 emergency vehicles coming from 13 fire districts (Reference 13). Although this was a rare event, the ferry played a crucial role in enabling emergency service vehicles to access the island.

Calls for transport of an ambulance are a much more common occurrence, but no less critical as life depends on response time. A rustic emergency heliport exists on the island, but in most situations, helicopter travel is neither the fastest nor the most practical means of transporting patients to the care they need.

The existing Guemes Island ferry has set a standard of emergency response for the community, to which the replacement ferry will be compared.

The largest sea evacuation in modern history took place on September 11, 2001. Ferries and vessels around Manhattan responded to the terrorist attack by evacuating a half million people from the island in approximately 9 hours. This scenario, documented in a short film called Boatlift (Reference 14), highlights the importance of ferries during emergency evacuations. Guemes Island is a dramatically different setting, but, like Manhattan, a mass evacuation would rely extensively on marine transportation, and the Guemes Island ferry would be called upon as a first responder. The Cascadia Rising exercise conducted in 2016 (Reference 15) highlights a relevant catastrophic event that could involve Guemes Island.

Figure 26 New York Waterway Ferries and other vessels evacuate Manhattan Island on September 11, 2001 (Reference 14)

The availability of the replacement ferry as an emergency supply vessel should be considered, although all ferries are periodically unavailable for a variety of reasons, including vessel maintenance, crew availability, and extreme weather. The existing ferry is available approximately 98% of the year. Emergency preparedness plans must also have contingencies for when the ferry is unavailable.

5.1 Rendering Assistance at Sea

The existing ferry has responded to distress calls from other vessels, rendered assistance to personal watercraft, and performed man-overboard operations for persons in the water.

All vessels are required to render assistance at sea, per the United States Code (Reference 16):

> *A master or individual in charge of a vessel shall render assistance to any individual found at sea in danger of being lost, so far as the master or individual in charge can do so without serious danger to the master's or individual's vessel or individuals on board.*

Given that the ferry is on a fixed ferry route and operates in waters with a significant amount of other commercial marine traffic, the typical response distance is relatively short. Prior assistance has been provided as far away as Bellingham Channel, which is approximately 2nm west of the ferry route.

5.2 Diesel versus All-Electric

If the vessel is fitted with any variety of diesel propulsion, the ability to render assistance at sea and to provide long duration emergency vehicle shuttling will be similar to that of the existing ferry. Unfortunately, equipping an all-electric ferry with a battery bank that provides the same operating range between charges as a diesel-powered vessel between refuelings is cost prohibitive.

For example, the existing Guemes Island ferry consumes approximately 164 gallons of diesel fuel per day. This volume of fuel is about 22 cubic feet and weighs approximately 1,170 lbs.

To achieve the same daily operating range with an all-electric ferry would require a 6,000-kWh battery bank, assuming an 80% depth of discharge and overnight recharging. A lithium-ion energy storage system (battery bank) of this size would require 2,100 cubic feet of space, weigh approximately 112,000 lbs, and cost approximately $4M.

To overcome these challenges, all-electric ferries rely on charging between runs to reduce the necessary battery size. However, this reduces the energy reserve available for emergency response or other unscheduled events.

To respond to an emergency such as the 2012 fire, an energy reserve of 50-100% above that required for a normal one day of operation would be necessary. This is easily achieved on a diesel-powered ferry, as they typically carry several days if not weeks' worth of fuel. An all-electric ferry must either be charged between runs, reducing the frequency and/or total number of back to back sailings, or have an extremely large and expensive battery, as illustrated above.

If the replacement vessel is all-electric, an on-shore generator and battery bank could be installed to allow for rapid charging of the vessel even in the event of a power grid failure. Alternatively, an onboard generator(s) could be installed to provide propulsion power.

5.2.1 Response Scenarios

Several emergency scenarios in which the ferry would be called upon to respond are outlined below. The existing ferry can complete each of these response scenarios, and it is assumed that the replacement vessel must also be able to do so.

1. A catastrophic event requires evacuation of the island and the electrical grid is disabled. The island population varies seasonally, ranging from approximately 750 to 2,750. This could significantly increase in the next 40 years. The duration of continuous operation would be up to 24 hours. The ferry would have to provide power to the ramp and apron on each side.
2. Significant fire/emergency on the island requiring continuous operation of the ferry for up to 24 hours. The vessel must be able to complete two round trips without charging.
3. Rendering assistance to a distressed vessel or person in Bellingham Channel. Approximately 2-nm distance from ferry route to site of assistance. On station for 1 hour in 18 knots of wind (95th percentile), with associated waves, and 1 knot of current.
4. Man overboard recovery of a ferry passenger. On station for ½ hour in 32 knots of wind (99.9th percentile), with associated waves, and 2 knots of current. Man overboard recovery is a required operation of all USCG inspected ferries.

In terms of risk, the probability of the above response scenarios are low (less than once per year), but the consequence of not being able to perform the service is high (potential loss of life). The high value placed on life typically results in the categorization of the above response scenarios as high-risk. It is recommended that either the propulsion system of the replacement ferry is designed such that the vessel can mitigate these risks, or an alternative system is put in place to mitigate the risks.

How the replacement vessel is able to accomplish the above response scenarios is discussed further in the Concept Design Report (Reference 1).

Section 6 Environmental Considerations

6.1 Air Pollution

Air pollution is a concern to the future stakeholders of a replacement Guemes Island ferry. Diesel particulate matter (DPM) was used as a proxy for local vessel air emissions as it presents greater localized health risks than other diesel exhaust pollutants such as nitrogen oxides (NOx) and sulfur oxides (SOx). The tradeoffs of DPM emissions from different propulsion systems are discussed in the Concept Design Report (Reference 1), a summary of which is presented in Table 6.

Table 6 Engine diesel particulate matter (DPM) emissions, annually

	Gear Diesel	Diesel Electric	Series Hybrid	All-Electric	Plug-in Hybrid
Engine DPM - 1000hp (g/bkWh)	0.04	-	-	-	-
Generator DPM - 550 kW (g/bkWh)	-	0.27	0.27	-	0.27
Generator DPM - 66 kW (g/bkWh)	0.27	-	-	-	-
Total DPM (kg/yr)	107.5	339.6	124.7	-	5.6

6.2 Noise

6.2.1 Upland Noise

There are no city ordinances limiting the noise produced by the replacement ferry. However, it was reported to Glosten that noise complaints have been reported. It is recommended that the noise produced by the replacement ferry be reduced from the current level for this reason.

It is reasonable to expect that the replacement ferry can meet this goal, given the likelihood that the engines will be placed below the main deck (the main engines of M/V *Guemes* are located on the main deck), and that new engines can be outfitted with higher attenuation (i.e. quieter) silencers.

6.2.2 Underwater Noise

Underwater noise emitted by ferries and other marine vessels has received increased attention in recent years due growing scientific evidence of the harm that underwater noise can cause to marine wildlife. Effort should therefore be made to minimize the underwater radiated noise of the replacement ferry, to the extent possible.

Most underwater noise emitted by marine vessels is from propellers, especially from the cavitation that can occur with highly loaded propellers and the pressure pulses from passing propeller blades. Propellers and the associated thruster components can be designed to minimize excess noise. This approach is recommended for the replacement ferry.

6.3 Wake Wash

Wake wash, or the effect of waves caused by a marine vessel on the shoreline surrounding its route, is a problematic issue for some ferry routes. For example, attempts in the 1980s to establish fast ferry service between Seattle and Bremerton failed, at great expense, due to complaints from residents about the damaging effects of wake wash from the new ferries in the narrowest part of the route, Rich Passage (Reference 17).

Wake wash should be considered during the design of a replacement Guemes Island ferry, however it is not considered to be a serious risk or design driver. The route runs perpendicular to both shore lines, and the waves associated with wake wash damage, the diverging waves, propagate at a shallow angle from the direction of travel, as illustrated in Figure 27. This means that most of the wave energy produced from the ferry will travel far down the channel and mostly dissipate before striking the shore.

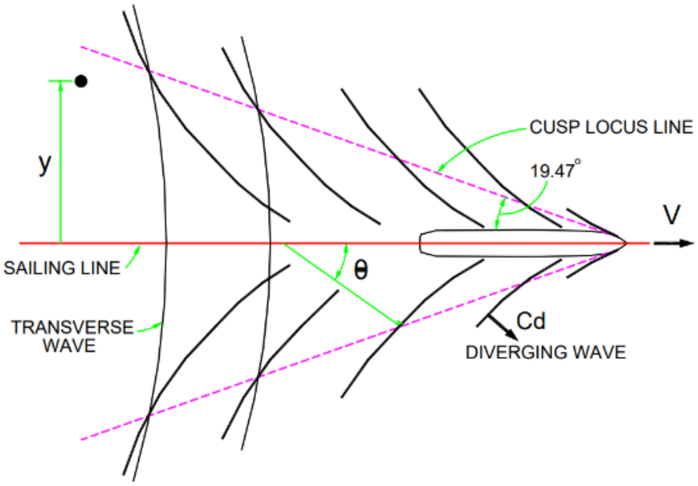


Figure 27 Wake wash (Reference 18)

6.4 Permitting

It was reported by the City of Anacortes Planning, Community & Economic Development Department that no permits for the replacement ferry would be required unless it included any dock revisions or dredging (Reference 19). Permits may also be required if modifications are made to land-based assets, such as parking lots.

Appendix A Marine Terminals Evaluation

PND ENGINEERS, INC.

MEMORANDUM

To: Matthew Lankowski, Glosten

Date: November 28, 2017

From: John Olson, PND Engineers, Inc.

File: 174082.01

Subject: Guemes Island Ferry Boat Replacement – Design Studies
Transportation System Analysis – Marine Terminals Evaluation

INTRODUCTION

Skagit County Public Works has determined that the existing Guemes Island Ferry vessel has exceeded its economically useful life and needs to be replaced. Glosten is under contract with the County to support this effort, from the performance of design studies through vessel design and procurement assistance.

An important consideration in selection of design parameters for a new vessel is the evaluation of the existing terminal facilities and any potential operational limits. PND is tasked with assisting Glosten in the Transportation System Analysis portion of the Design Studies task for the overall project. Our goal in this design study is to provide sufficient background information and help identify any limitations imposed by the existing facilities to assist Glosten in their work.

SITE VISIT / FACILITY EVALUATION

Field Measurements:

On October 6, 2017, a two person PND team made a site visit to both ferry terminals to collect field measurements and assess the general condition of dolphins, wingwalls, transfer spans and apron ramps. Equipment used for the assessment included, shop drawings, as-builts and other background documents, 35-ft steel tape measure, 100-ft cloth tape with weight for soundings, bubble level, cameras, and standard PPE for crew safety. The deck of the MV Guemes was used as a working platform for measurements and observations at both terminals.

Field measurements were used to verify and/or update as-built drawings. Attached to this report are the updated site plan drawings for each terminal, ***Appendix A*** and ***Appendix B***, showing the as-built locations and orientation of each dolphin (11 total) and wingwall (4 total). In summary, the minimum clear spacing between adjacent dolphins is about 60-ft across at both slips. Stations and offsets are used to identify relevant layout points. Control for horizontal measurements is set as follows:

- A station line is set up oriented along centerline of ramp.
- Station point 0+00 is at the intersection of centerline of ramp and centerline of lift tower piers and runs offshore.
- Offsets, to left and right of station line, are provided for each layout point oriented along the station line moving offshore.

The transfer span and apron ramp at each terminal are mirror images of each other, with the only difference being the side of the ramp that the pedestrian way is located. The pedestrian way is located on the West side of both ramps. Ramp width, length, deck layout and component sizing were spot checked and verified to match the shop drawings. The apron and apron lip assembly dimensions and components were spot checked and verified to match shop drawings. No significant variations from the existing shop drawings were noted.

The vertical lift limits of the transfer span were checked at the Anacortes terminal by raising the ramp to its highest extent, at the highest pin hole in the live load hanger bars. It was determined that the end of the transfer span could be raised to an elevation of about +21-ft, MLLW at deck surface. See ***Figure 1***, below for a graphical illustration of the ramp components. The lowest ramp elevation was not physically measured due to tidal levels at the time of evaluation. However, the shop drawings for the transfer spans and overhead hoist mechanisms indicate a lower stop on the live load hanger bar that restricts the ramp lowering to elevation +3-ft, MLLW at deck surface. A review of the lifting procedure with the crew was used to confirm that similar limits control maximum vertical lift for the Guemes terminal ramp. Both ramps are routinely raised and stowed at their full height overnight.

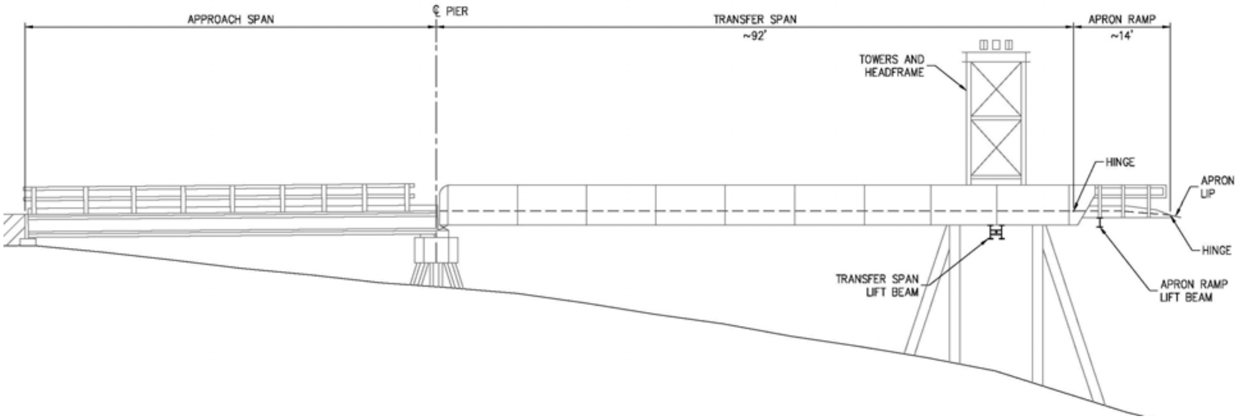


Figure 1: Terminal Ramp Anatomy

We also verified mudline depths at the end of each apron ramp, at centerline of slip. Soundings were taken and compared with a known fixed elevation at top of transfer span of elevation +15.0’ MLLW. The field measurements confirm the bathymetry shown in the existing drawings within about one foot of elevation, which is a reasonable tolerance for bathymetric soundings. It is recommended that the bathymetry be considered when determining the draft of a new vessel.

Vertical Limits Analysis:

The apron ramp is about 1.0-ft tall from the deck bearing edge to the top traction surface of the ramp where it connects to the transfer span. The full load freeboard of the existing ferry is about 3.5-ft. This results in an operational water elevation range for the existing boat from a high of about +16.5-ft down to a maximum low of -1.5-ft. A new vessel will likely have a full load freeboard closer to 6-ft. This would result in an operational water elevation range for the new vessel from a high of +14.0-ft down to a low of -4.0-ft elevation. Additionally, the end of the apron ramp can be raised higher with the apron hydraulic lift system, effectively increasing the possible serviceable water depth for operations. See ***Appendices C, D*** and ***E*** for schematic representations of the operational vertical ramp limits.

A review of historical tidal data for the Guemes Channel provides the following important water elevations, ***Figure 2*** below, for use in evaluation of any operational limits due to tidal fluctuation:

Datum Plane	**Elevation (referred to MLLW)**
Highest Estimated Tide:	+11.00-ft
Mean Higher High Water (MHHW):	+8.20-ft
Mean Lower Low Water (MLLW):	0.00-ft
Lowest Estimated Tide:	-4.50-ft

Figure 2: Tidal Datum Plane: Anacortes, Guemes Channel, Skagit County
Reference: Washington State Tidal and Terrestrial Datum Planes, September 1994,
Compiled by Douglas J. Canning, Shorelands and Water Resources Program,
Washington Department of Ecology, Olympia, WA 98504-7600

Based on the above tidal data and the anticipated higher freeboard characteristics of a new vessel, the existing ramp vertical range will be suitable for all tides. This same analysis indicates that the existing ferry is probably also fully operational through all tides. It must be noted however, that this analysis is limited to the ability of the apron ramp to rest on the deck of the ferry, but neglects to consider the limits of vehicles travelling across the ramp. A discussion of permissible grade break, or abrupt change in vertical slope, is needed. Excessive grade breaks can cause damage to vehicles and/or the ramp from a vehicle's bumper or hitch scraping on a negative grade break, illustrated in ***Figure 3***, and/or high centering on a positive grade break, as shown in ***Figure 4***.

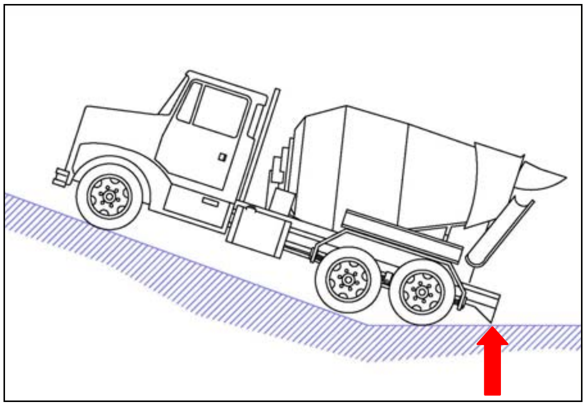


Figure 3: Negative Grade Break

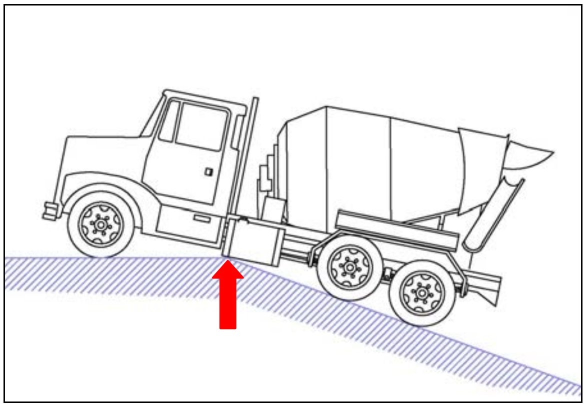


Figure 4: Positive Grade Break

In the absence of vertical curves to ease the transition between different grades, a sharp grade break will occur during certain ramp slopes. There will be grade breaks at three different interfaces:

- Between approach and transfer span,
- Between transfer span and apron ramp, and
- At the apron ramp, apron lip and ferry deck interface.

Permissible grade breaks vary by vehicle type and size but as a general rule should be limited to no greater than 8%. Limiting grade breaks to 8% at all three interfaces yields an allowable low ramp elevation of +8.0-ft. Applying this metric to our allowable operational water level calculation yields an operational low water elevation of +3.5-ft for the existing boat and +1.0-ft for a proposed new vessel with assumed freeboard of 6-ft. The high tide condition does not result in large grade breaks, so is not analyzed further. ***Appendix E*** illustrates the grade break controlled minimum ramp elevation.

According to one of the Captains interviewed during our site visit, Skagit County does operate the ferry at lower tides than those calculated in this analysis, by limiting loading of some vehicles. Large trucks, RV's, etc. are prohibited from loading at negative tides due to increased grade break issues. (Heavy trucks push the vessel down as they load, which increases the grade break, for example). Grade breaks greater than 8% are permissible for smaller vehicles (passenger cars and trucks) so the ferry is able to operate throughout all but the most extreme tides, with some operational limits in place.

Observed Damage/Wear:

Generally, the condition of the dolphins appears to be good, with incidents of surface rust evident in the intertidal zone on the older dolphins that were constructed in 2004 (Dolphins 'A' and 'C' at both terminals). The wingwalls exhibit signs of significant coating failure and corrosion, but seem to be holding up and functioning adequately for now.

One fender pile on Guemes Dolphin 'C' was found to be damaged. The southernmost fender pile has been struck and plastic yielding is visible at about elevation +9' MLLW. The HDPE plastic sleeve pipe is split around the full circumference of the pipe at the same elevation as the steel pipe damage. See ***Figure 5*** and ***Figure 6*** for photos of the observed damage.

Figure 5: Damage to Guemes Dolphin 'C'

Figure 6: Close up of damage

The transfer spans, apron ramps, towers and hoist mechanisms appear to be in fair condition, although it has been reported that ongoing maintenance efforts on these structures have become a significant expense. The cables, motors, sheaves, bearings, etc. have started to require more extensive and frequent repairs and the risk of failure and/or loss of use for down time will only increase with time. Other similar hoist systems in use around Puget Sound have experienced major shut downs and disruption of service in recent years as these systems age and require attention that outpaces maintenance efforts. It is recommended that the County explore options for replacement of ramps and mechanical systems for vessel boarding in conjunction with the vessel replacement project.

DESIGN LOADS

Having designed all of the new dolphins and the modifications and repairs to the wingwalls, PND has a unique understanding of the design criteria, and performance characteristics of these structures. Following is a discussion on design load calculations for use in evaluating the performance of the existing structures when larger vessels are considered.

Dolphin Performance:

All of the dolphins were replaced in three phases over three construction seasons between 2004 and 2014. The dolphins were designed specifically for the existing ferry vessel to provide multi-stage energy absorption through progressive performance modes. The performance modes are:

Stage	Absorbed Energy	Performance Characteristics
Stage 1:	E = 25 kip-ft	Typical Berthing (no damage)
Stage 2:	E = 50 kip-ft	Moderate Berthing (minor damage possible)
Stage 3:	E = 100 kip-ft	Hard Berthing (damage expected)
Stage 4:	E = 200 kip-ft	Loss of Control (significant damage)

Stage 1 performance mode is the level of energy that stresses the fender piles to the allowable stress of the steel fender pile, within the elastic range of the material. This includes all typical berthing activities and results in no damage. Stage 2 represents the point at which the fender piles reach the yield point of the material, without going plastic. At this point the dolphin fender piles will spring back to their original configuration and continue to function without need for repairs. Stage 3 energy will form a plastic hinge in the fender piles, absorbing energy and slowing the vessel while the piles deform. A hard berthing event that causes this level of damage may require repairs in order to continue to function correctly. However, depending on the severity and type of damage, repairs could be deferred as needed. Note, the damaged fender pile on Guemes Dolphin 'C' as reported in the previous chapter suffered a stage 3 event. This is an example of stage 3 damage that has been deferred as the function of the dolphin has not been significantly impacted. The final stage is an estimated level of energy to completely fail the fender piles, and begin pushing over the dolphin cap and start tension pile pullout. This would be a significant, loss of control type failure that will require emergency replacement in order to safely continue to service the ferry route.

The energy absorbed by the dolphins is a direct relation to the kinetic energy of the moving vessel when it comes in contact with the fenders. Generally, the kinetic energy of a vessel moving through the water is a function of the vessel's mass, velocity, and several variable factors. The equation is as follows:

$$E = 1/2 \times m \times v^2 \times C_m \times C_e \times C_c \times C_s$$

Where:
E = berthing energy (kip-ft)
m = vessel mass = (kip-sec^2/ft)
v = approach velocity (ft/sec)
C_m = virtual mass factor (assumes water mass is moving in addition to the vessel)
C_e = eccentricity factor (accounts for the approach angle of the vessel to the fenders)
C_c = berth configuration factor (accounts for any cushion effect from water squeezed between the vessel and the berth)
C_s = softness factor (relation between energy absorbed by the vessel hull versus the fender)

By applying this equation and solving for v, the velocity at which various size vessels (m) reach the energy absorption (E) at each stage was calculated and plotted. Our task for this exercise was to help define how the existing dolphins would perform for larger vessels. The chart in ***Figure 7***, below, shows the anticipated acceptable approach velocities for each stage, for a range of vessel sizes. The existing ferry has a dead weight tonnage (DWT) of approximately 300 long tons. We understand that a new vessel could be as large as 550 to 700 long tons. From the chart, it is clear that improved vessel speed and steering control, or other operational limits, would need to be established to maintain safe berthing for larger vessels at the existing dolphin structures.

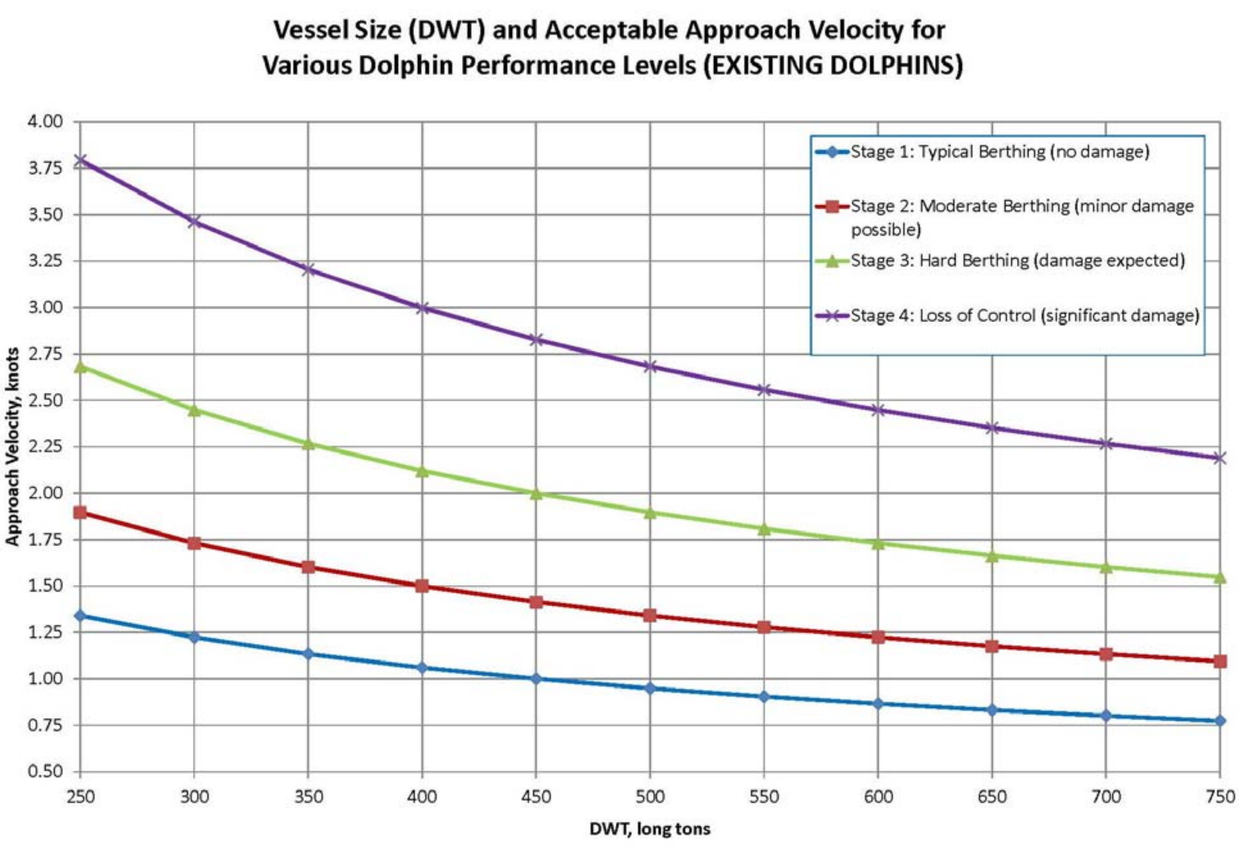


Figure 7: Existing Dolphin Performance Chart

It may not be possible or realistic to place operational (speed) limits on the ferry and captain(s) in order to maintain an operationally safe berthing facility. We were asked to supplement our analysis to consider what modifications to the existing dolphins might be possible in order to accommodate larger vessels (550 to 700 long tons) without significantly reducing acceptable approach velocity. Following is a brief description of this evaluation.

To establish reasonable approach velocity criteria for ferry operations at these terminals, we considered a number of sources, from WSF studies to PIANC guidelines. None of these resources seemed to converge on a definitive answer. Nor did they consider performance stages in their guidelines, with speeds ranging from 0.3 knots to 5.0 knots. Instead, we decided to start with our original performance stage approach velocities as our target for the evaluation. See table below for the estimated energy absorption required to meet the original target velocity criteria. The table shows the drastic reduction in performance capability of the existing dolphins with increased vessel mass.

	Original Design	Energy Absorption		
Stage	**Approach Velocity**	**300 LT vessel**	**550 LT vessel**	**700 LT vessel**
Stage 1:	2.0 ft/sec = 1.2 knts	25 kip-ft	46 kip-ft	58 kip-ft
Stage 2:	3.0 ft/sec = 1.8 knts	50 kip-ft	92 kip-ft	117 kip-ft
Stage 3:	4.0 ft/sec = 2.4 knts	100 kip-ft	183 kip-ft	233 kip-ft
Stage 4:	6.0 ft/sec = 3.6 knts	200 kip-ft	367 kip-ft	467 kip-ft

It is unlikely that the existing dolphins can be ‘modified’ to achieve these same criteria through all four stages, but we will explore some options that could meet some of the criteria without requiring full replacement. For purposes of describing our analysis and options, refer to the dolphin anatomy photo in ***Figure 8***, below.

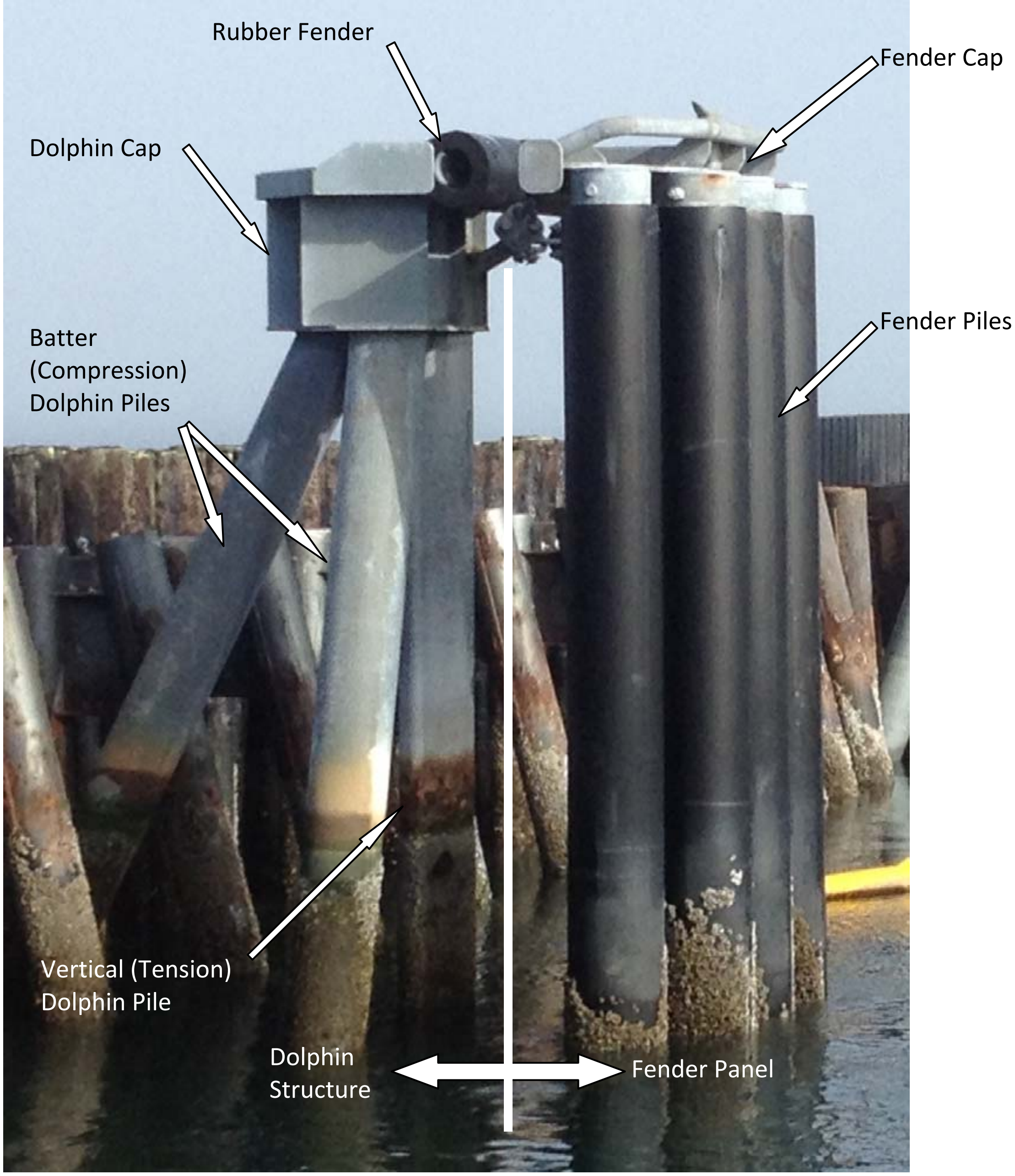


Figure 8: Dolphin Anatomy

The dolphins are constructed of two principal components: dolphin structure and fender panel. The dolphin structure is made of one vertical tension pile and two batter compression piles, topped with a dolphin cap. The dolphin cap has two rubber energy absorbers (fenders) bolted to it. The fender panel is made of five vertical steel pipe piles with plastic sleeves, capped with a fender cap.

We have assumed that any modifications to the dolphins would be limited to the fender panel portion, maintaining the dolphin structure as is. The dolphin piles are all equipped with SPIN FIN™ pile tips, which generate tension and compression capacities 2.5 to 5 times that of a smooth pipe pile and while it is possible to extract these piles, we have assumed that replacing them would effectively exceed ‘modification’ criteria and extend into a ‘full replacement’ level of effort. Assuming that the structural capacity of the existing dolphin structure piles and cap represents the maximum ability of the dolphin to resist berthing forces, we calculate a maximum energy absorption capability of just about 200 kip-ft.

The fender panel could be upgraded to increase efficiency for larger vessels by adding fender piles, replacing the fender cap (to accommodate the added fender piles), and replacing the rubber fenders with larger units. It is conceivable that energy absorption levels up to 60 kip-ft and 110 kip-ft within the level 1 and 2 performance criteria (no/minor damage) could be achieved. Additionally, energy absorption of about 150 kip-ft, corresponding to level 3 (sustaining repairable damage) could be reached. The maximum energy absorption, as stated earlier, would top out at about 200 kip-ft (causing significant dolphin damage, but sparing the vessel and passengers).

The chart in ***Figure 9***, below, shows the potential improved performance of the dolphins with modified fender panels as described.

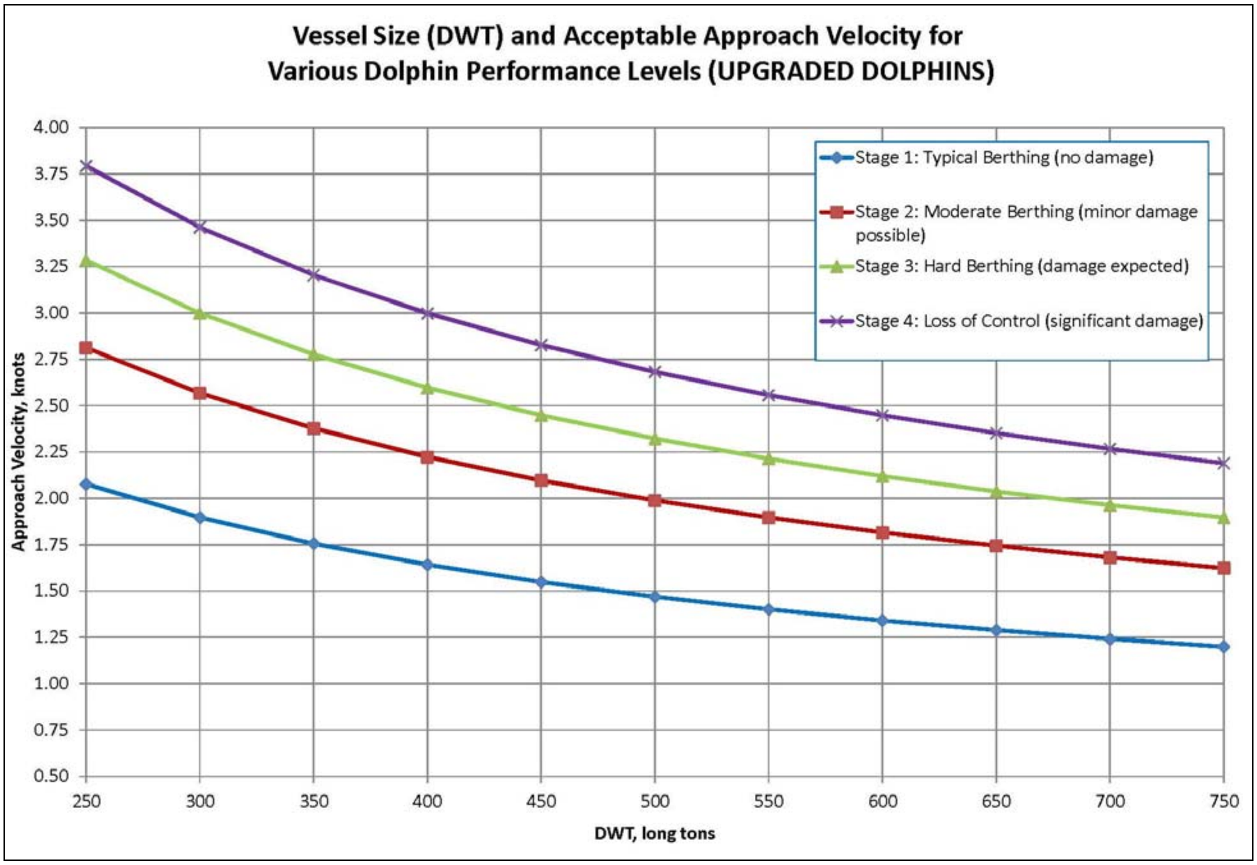


Figure 9: Modified Dolphin Performance Chart

It should be noted that the stage 4 energy absorption does not improve with the described upgrades. Only stages 1, 2 and 3 show performance improvements. The table below highlights the potential improved capacity of the dolphins after modification.

	Possible	**Approach Velocity**		
Stage	**Energy Absorption**	**550 LT vessel**	**700 LT vessel**	**Performance**
Stage 1:	60 kip-ft	2.4 ft/sec = 1.4 knts	2.1 ft/sec = 1.2 knts	Typical (no damage)
Stage 2:	110 kip-ft	3.2 ft/sec = 1.9 knts	2.8 ft/sec = 1.7 knts	Operational (minor)
Stage 3:	150 kip-ft	3.7 ft/sec = 2.2 knts	3.3 ft/sec = 2.0 knts	Repairable Damage
Stage 4:	200 kip-ft	4.3 ft/sec = 2.6 knts	3.8 ft/sec = 2.2 knts	Replacement Event

Rough order of magnitude costs to make the described modifications to the dolphins, including contingency, taxes and engineering, are estimated at about $1.2 million. The ROM estimate is presented in ***Appendix F***. New, replacement dolphins, designed specifically for larger vessels could cost $5 to $8 million, based on similar WSF designs. New structures would be much larger, consisting of a greater number of larger diameter piles, and would require removal of the existing dolphins. Another option would be to install additional new dolphins, immediately adjacent to the existing dolphins to split berthing loads, at an estimated cost of $3 to $4 million, based on previous bid tabulations.

Wingwall Performance:

The existing wingwalls were rehabilitated in 2008. The modifications were limited to replacing the face timbers and the rubber energy absorbing fenders to maintain the same performance of the original design. The wingwalls were originally installed about 37 years ago when the existing MV Guemes was acquired. The wingwall face profile and placement was specifically configured to fit the hull profile of the existing vessel. The old rubber profile fenders between fender panel and reaction structure, were replaced as part of the 2008 renovation, with new cylindrical rubber fenders. The new fenders were furnished with manufacturer performance test results. Each wingwall has two 3.5-ft long x 28-in O.D. x 14-in I.D. rubber cylinders. The energy absorption capacity of the fenders when compressed to 50% deflection is about 50 kip-ft with a reaction of about 100 kips.

Taking into consideration the orientation of the wingwalls to the bow of the ferry, and assuming even distribution of force between the two opposing wingwalls, we calculated a maximum push force against the walls. A steady ferry push force of about 140 kips will elastically deflect the four steel pipe piles and compress the cylindrical fender units to 50% deflection.

Another consideration regarding the wingwalls is the berthing velocity of the approaching ferry. For this, the design energy absorption of the wingwalls is estimated and, using similar calculations and methods as employed in the dolphin analysis, approach velocity and vessel mass are compared. The design energy absorption of each wingwall of approximately 50 kip-ft, translates to a ferry kinetic energy of about 70 kip-ft. The chart in ***Figure 10***, below, shows the anticipated acceptable approach velocities for full compression of the wingwall fenders, for a range of vessel sizes.

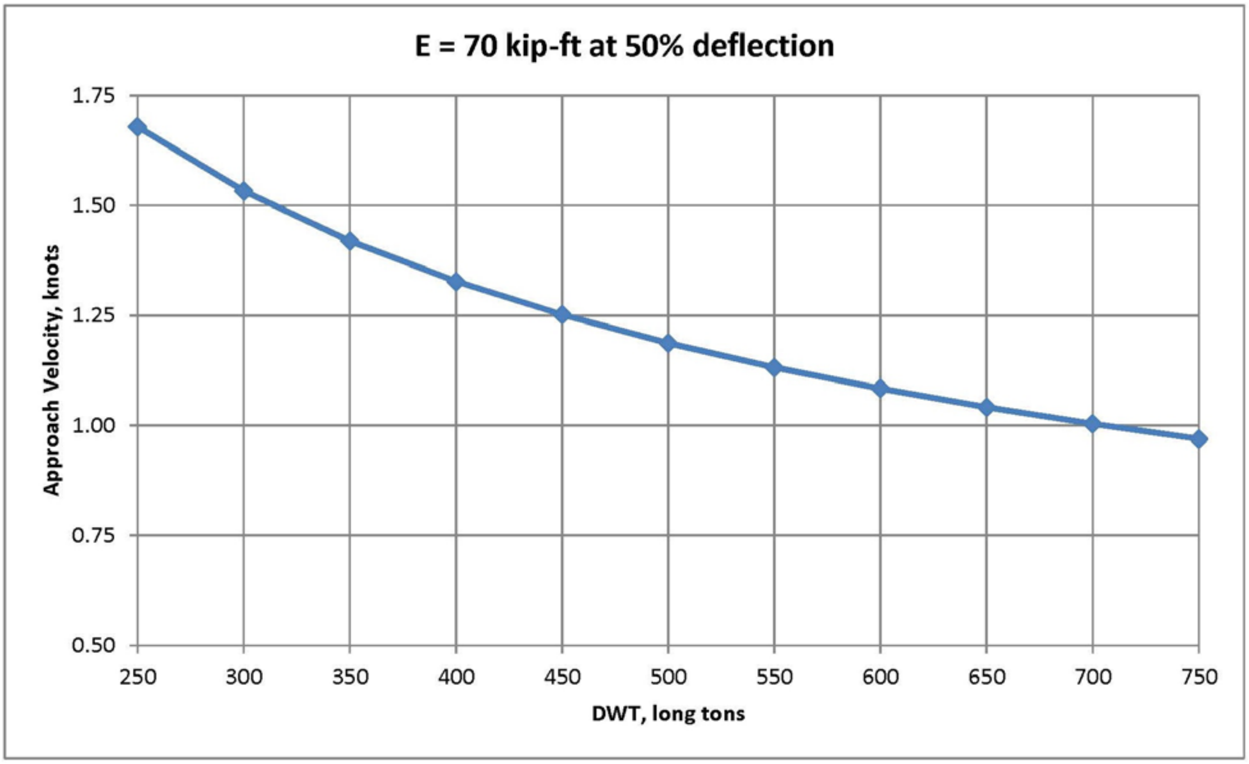


Figure 10: Wingwall Performance Chart

APRON RAMP LIMITATIONS

The apron ramp and lip plates that span from the transfer span to ferry deck taper in width from 20’-8” at the transfer span down to 17’-5” at the ferry deck. Because of this taper, the dedicated pedestrian path that exists along the full length of the approach and transfer spans is not continuous onto the ferry. As a result, foot and vehicle traffic cannot occupy the ramp at the same time, which slows ferry load and unload operations. PND was asked to evaluate and investigate the feasibility of widening the aprons to provide a dedicated pedestrian path, isolated from vehicles.

The three components that must be considered when contemplating modification to the aprons are: 1) ferry layout and configuration, 2) spacing of the wingwalls, and 3) attachment details to the transition ramp. A new ferry could be designed specifically to allow dedicated pedestrian loading, so existing ferry layout would be considered a non-issue. The current issues with insufficient clear width between the bulwarks and the lack of pedestrian path continuity when boarding the vessel can be resolved in vessel design.

The configuration of the wingwalls however is a concern. Currently the gap between the wingwalls at the Anacortes terminal is too tight to allow replacement with a wider apron. These wingwalls were recently modified to add a mooring line system for overnight moorage of the ferry while the ramp is hoisted to its upper limit. The existing gap between mooring pipes is about 20’-9”, excluding the mooring lines that are permanently attached to the pipes. ***Figure 11*** is a photo of the apron ramp, wingwalls and referenced mooring pipes.

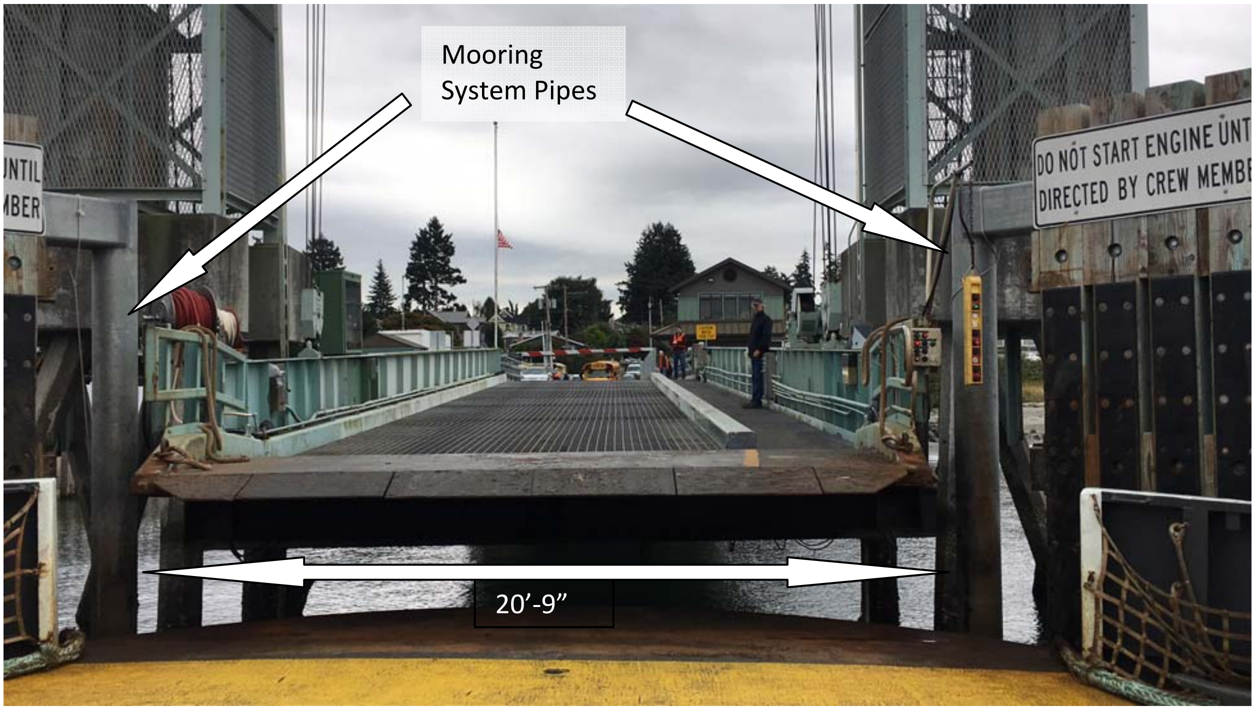


Figure 11: Photo of Anacortes Ramp and Wingwalls

The wingwalls at the Guemes side are slightly wider apart, which would provide adequate space for a wider apron without modification to the wingwalls. Modifications to the Anacortes wingwalls to accommodate a wider apron would require development of a new overnight moorage system. ***Figure 12*** is a photo of one of the existing pipes in the mooring system.

Figure 12: Photo of Mooring System

Design, fabrication and installation of new apron ramps could be done by matching the existing hinges and making some modifications for the hydraulic lifts. Rough order of magnitude costs for fabrication and installation of new apron ramps and lip plates, including necessary modifications to the wingwalls at the Anacortes terminal, and install a new moorage system, are estimated at about $380,000. The ROM estimate for this work, including contingency, taxes and engineering, are presented in ***Appendix G***.

SUMMARY

In summary, the existing facilities could accommodate a new ferry vessel. The dolphins at both terminals are in good structural condition, and could serve larger vessels, with upgrades and/or implementation of operational controls to reduce vessel approach speed. The clear distance between dolphins is about 60-ft, slightly wider than the existing ferry, and may accommodate a wider vessel.

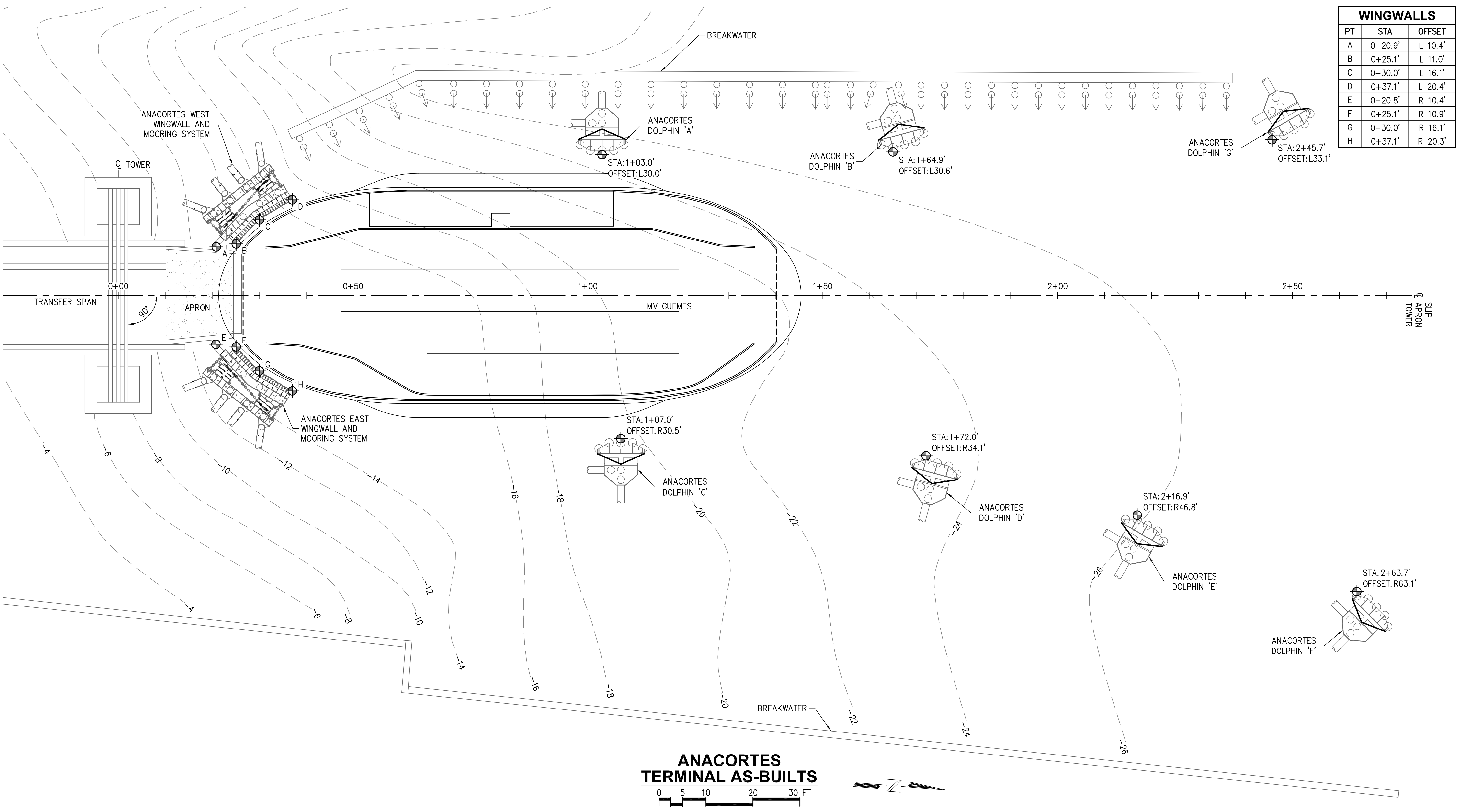
The wingwalls, though starting to show signs of significant corrosion, are still functional and have sufficient capacity to accommodate a larger vessel. The placement of the existing wingwalls limits the clear space available for any ramp or apron modifications. It is recommended, if the existing wingwalls are to remain, that gunwale profile on a new vessel would match that of the existing boat, to avoid having to change the profile of the wingwall face. If new wingwalls were included in this effort, it would open up more options for the design of a new vessel and any desired modifications to ramps or aprons.

The vertical limits of the transfer span and apron do not appear to place any significant operational limits on loading, particularly with a higher freeboard vessel. There could be some improvements with vertical grade breaks by making some modifications to the ramps, though these changes would likely mean replacement of significant components of the ramp and hoist system.

It would be possible to widen the aprons somewhat to create a continuous, separate pedestrian path onto the vessel. It may require some minor modifications to the West wingwall at both terminals however. The mooring pipe system at the Anacortes terminal would also need to be revised.

After review of the existing facilities and conversations with the ferry crew, maintenance and management, it may be time to start thinking about concepts for replacement ramps and mechanical systems. If addressed concurrently with vessel design, the entire system could be optimized for operations and maintenance improvements.

LIST OF APPENDICES



WINGWALLS		
PT	STA	OFFSET
A	0+20.9'	L 10.4'
B	0+25.1'	L 11.0'
C	0+30.0'	L 16.1'
D	0+37.1'	L 20.4'
E	0+20.8'	R 10.4'
F	0+25.1'	R 10.9'
G	0+30.0'	R 16.1'
H	0+37.1'	R 20.3'

ANACORTES TERMINAL AS-BUILTS

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REVISIONS

REV	DATE	DESCRIPTION

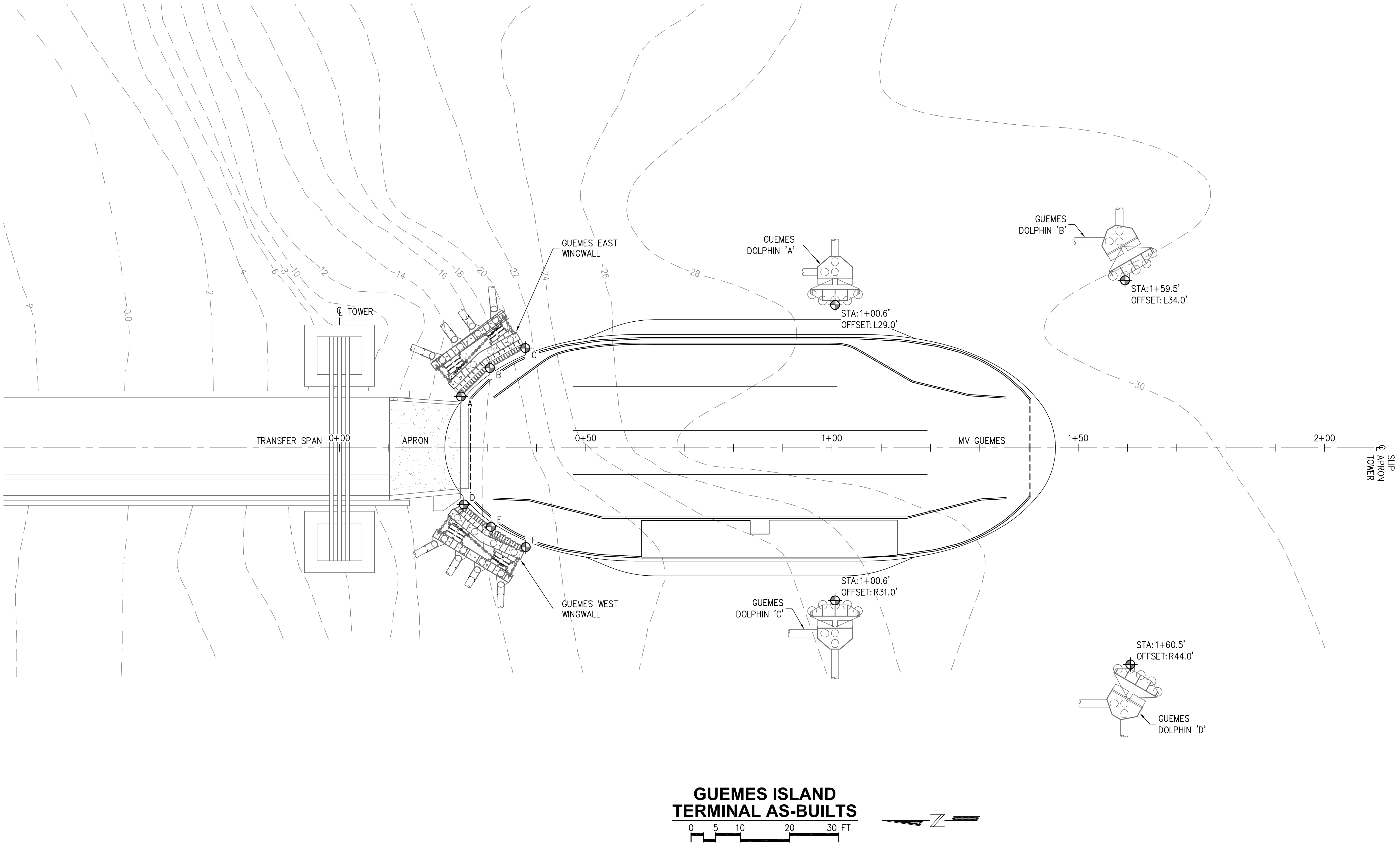
PROJECT:
SKAGIT COUNTY
ANACORTES/GUEMES ISLAND FERRY

TITLE:
TERMINAL AS-BUILTS
ANACORTES

DESIGNED BY: JO	PROJECT NO: 174082	SHEET NO:
DRAWN BY: DM	DATE: OCTOBER 2017	1 OF 2
CHECKED BY:	SCALE: NOTED	

Appendix A: Anacortes Terminal Plan View As-Built

WINGWALLS		
PT	STA	OFFSET
A	0+24.7'	L 10.4'
B	0+30.5'	L 16.2'
C	0+37.7'	L 20.3'
D	0+25.3'	R 11.5'
E	0+30.8'	R 16.0'
F	0+37.8'	R 20.2'



GUEMES ISLAND TERMINAL AS-BUILTS

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PROJECT:
SKAGIT COUNTY
ANACORTES/GUEMES ISLAND FERRY

TITLE:
TERMINAL AS-BUILTS
GUEMES ISLAND

DESIGNED BY: JO	PROJECT NO: 174082	SHEET NO: 2 OF 2
DRAWN BY: DM	DATE: OCTOBER 2017	
CHECKED BY:	SCALE: NOTED	

Appendix B: Guemes Terminal Plan View As-Built

11/3/17 GDEAN
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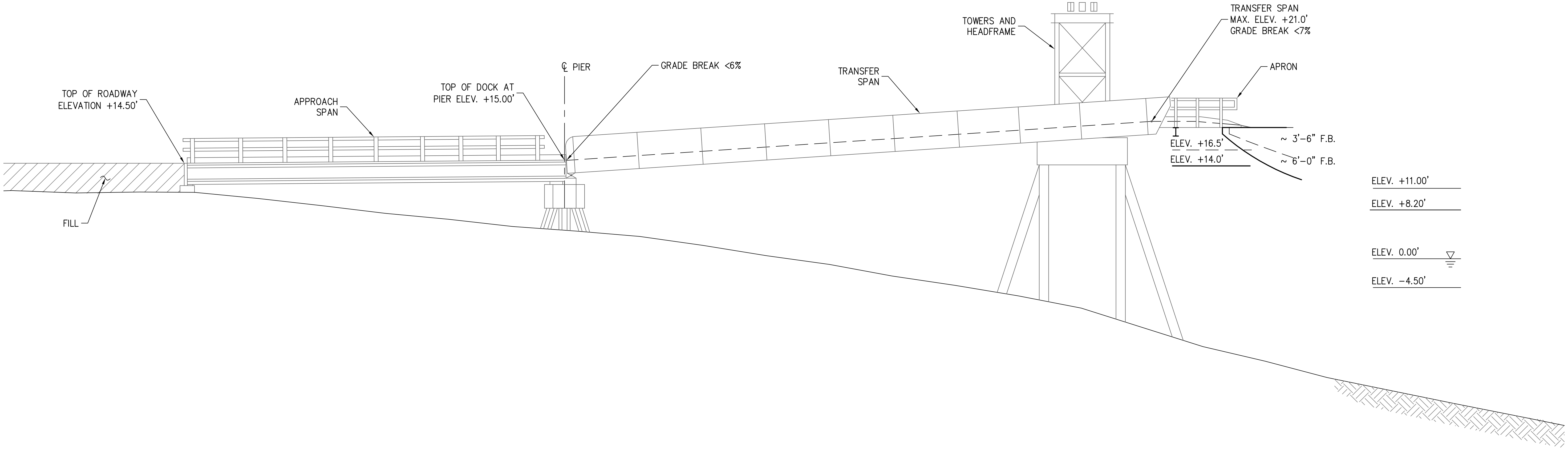

ELEVATION

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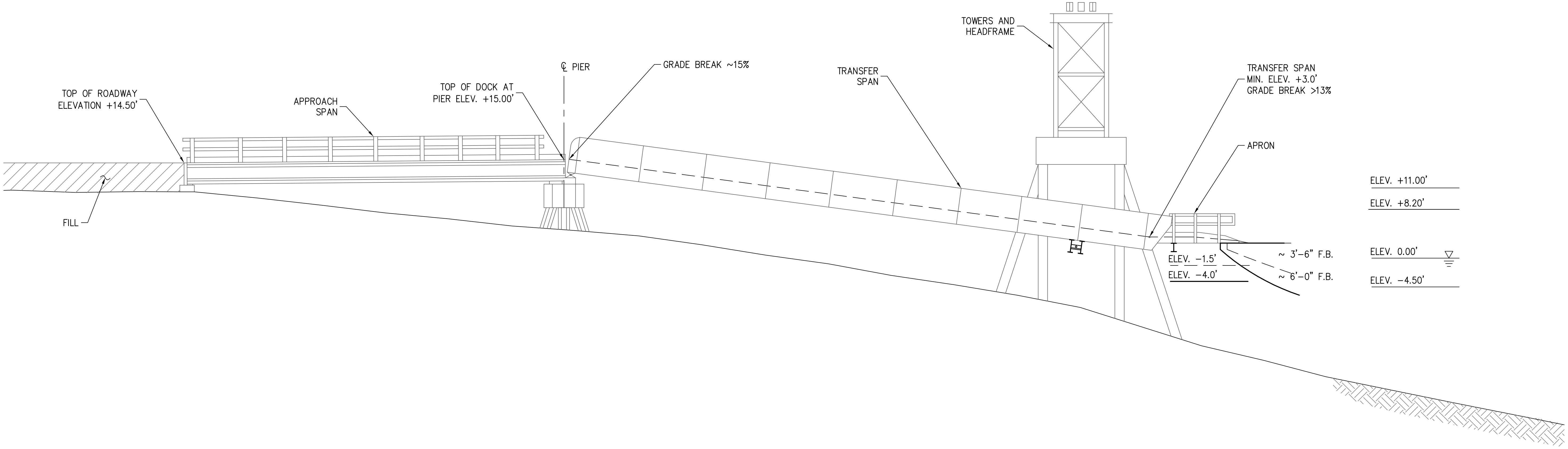
REVISIONS

REV	DATE	DESCRIPTION

PROJECT:
SKAGIT COUNTY
ANACORTES/GUEMES ISLAND FERRY

TITLE:
TRANSFER SPAN
HIGHEST VERTICAL LIMIT

DESIGNED BY:	JO	PROJECT NO:	174082	SHEET NO:
DRAWN BY:	GRD	DATE:	NOVEMBER 2017	1 OF 3
CHECKED BY:		SCALE:	NOTED	



ELEVATION

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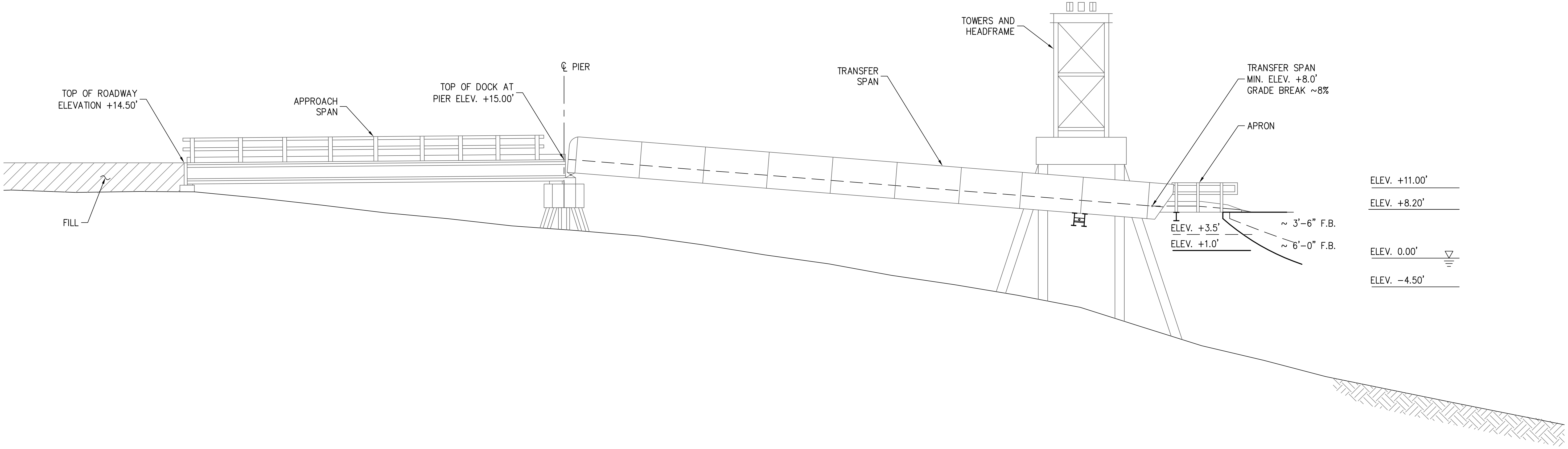
REVISIONS

REV	DATE	DESCRIPTION

PROJECT:
SKAGIT COUNTY
ANACORTES/GUEMES ISLAND FERRY

TITLE:
TRANSFER SPAN
LOWEST VERTICAL LIMIT

DESIGNED BY: JO
DRAWN BY: GRD
CHECKED BY:
PROJECT NO: 174082
DATE: NOVEMBER 2017
SCALE: NOTED
SHEET NO: 2 OF 3



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REVISIONS

REV	DATE	DESCRIPTION

PROJECT:
SKAGIT COUNTY
ANACORTES/GUEMES ISLAND FERRY

TITLE:
TRANSFER SPAN
VERTICAL LIMIT-GRADE BREAK CONTROLLED

DESIGNED BY: JO
DRAWN BY: GRD
CHECKED BY:
PROJECT NO: 174082
DATE: NOVEMBER 2017
SCALE: NOTED
SHEET NO: 3 OF 3

11/3/17 GDEAN
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Appendix E: Transfer Span Low Vertical Limit – Based on Grade Break

Item	Unit	Quantity	Unit Cost	Cost
Mob/Demob (10%)	LS	1	$ 77,000.00	$ 77,000.00
Demo/remove fender cap	EA	11	$ 8,000.00	$ 88,000.00
Demo/remove rubber fenders	EA	22	$ 500.00	$ 11,000.00
Furnish new steel pile piles	EA	22	$ 7,000.00	$ 154,000.00
Install new steel pipe piles	EA	22	$ 10,000.00	$ 220,000.00
Furnish new fender cap	EA	11	$ 10,000.00	$ 110,000.00
Install new fender cap	EA	11	$ 5,000.00	$ 55,000.00
Furnish new rubber fenders	EA	11	$ 10,000.00	$ 110,000.00
Furnish/install new chains and hardware	EA	11	$ 2,000.00	$ 22,000.00
			Subtotal	**$ 847,000.00**
			20% Contingency	$ 169,000.00
			Total (before tax)	$ 1,016,000.00
			Total (incl. 8.5% tax)	**$ 1,102,000.00**
			Engineering (Est. 10%)	$ 110,000.00
			Total Project Cost	**$ 1,212,000.00**

Appendix F: ROM Cost Estimate – Dolphin Upgrades

Item	Unit	Quantity	Unit Cost	Cost
Mob/Demob (10%)	LS	1	$ 24,000.00	$ 24,000.00
Demo/remove aprons, lip plates, etc.	LS	1	$ 10,000.00	$ 10,000.00
Furnish new apron ramp and lip plates	EA	2	$ 74,000.00	$ 148,000.00
Modify hydraulic lifts and controls, as req'd	EA	2	$ 10,000.00	$ 20,000.00
Install new apron ramps and lip plates, etc.	EA	2	$ 10,000.00	$ 20,000.00
Demo/remove mooring pipes	LS	1	$ 5,000.00	$ 5,000.00
Furnish new mooring system piles	EA	4	$ 3,500.00	$ 14,000.00
Install new mooring system piles	EA	4	$ 3,500.00	$ 14,000.00
Furnish/install new mooring system caps, lines	LS	1	$ 10,000.00	$ 10,000.00
			Subtotal	**$ 265,000.00**
			20% Contingency	$ 53,000.00
			Total (before tax)	$ 318,000.00
			Total (incl. 8.5% tax)	**$ 345,000.00**
			Engineering (Est. 10%)	$ 35,000.00
			Total Project Cost	**$ 380,000.00**

Appendix G: ROM Cost Estimate – Apron Ramp Replacement

Appendix B Total Lifecycle Cost Model

ONE FERRY		All costs in 2017 USD
Ferry Description	32 vehicles, 150	pax
CAPEX	$ 12,215,000	from new ferry estimate in 2017 14-yr plan.
Midlife refit factor	33.3%	assume 1/3 CAPEX cost to refit
Midlife refit	$ 4,071,667	calculated
Maintenance		
Base factor	2.00%	rule of thumb
Escalator factor	0.05%	rule of thumb
charter cost	$ 100,000	from 2017 14-yr plan
Fuel cost ($/gal)	$ 1.91	The most recent price paid
Engine power (HP)	2,000	estimated size of each engine for vessel this size
SFC (lb/HP-hr)	0.36	based on assumed weighted average % MCR and engine size/type
diesel lb/gal	6.943	
Avg. % MCR	21%	weighted average %MCR throughout day of operation
Average fleet utilization	100%	for one ferry option, one ferry is always operating
hr/day	12	typical operating hours based on current schedule
weeks/ferry/yr	51	assume one week of downtime per year
Fuel cost/ferry/yr	$ 180,313	calculated
Annual crew cost/ferry	$ 1,104,000	includes 4 FT, 5 regular PT, 2 PT, 5 on-call
Real discount rate	3%	for municipalities. includes inflation. matches NIST fuel forecast assumed DR.

TLCC	**$ 56,618,723**	**CAPEX**	**$ 12,215,000**	**Annual OPEX***	**$ 1,707,236**

*average opex over first 10 years of operation

Year	**Year #**	**CAPEX**	**Maint. Yr**	**Maintenance**	**Charter**	**Fuel**	**Salaries**	**Discounted FCF**
2020	0	$ 12,215,000	0	$ 244,300		$ 211,380	$ 1,104,000	$ 13,774,680
2021	1		1	$ 250,408		$ 211,380	$ 1,104,000	$ 1,520,182
2022	2		2	$ 256,515		$ 218,050	$ 1,104,000	$ 1,487,949
2023	3		3	$ 262,623		$ 223,746	$ 1,104,000	$ 1,455,412
2024	4		4	$ 268,730		$ 229,099	$ 1,104,000	$ 1,423,205
2025	5		5	$ 274,838	$ 100,000	$ 230,167	$ 1,104,000	$ 1,474,203
2026	6		6	$ 280,945		$ 240,137	$ 1,104,000	$ 1,360,980
2027	7		7	$ 287,053		$ 245,832	$ 1,104,000	$ 1,330,937
2028	8		8	$ 293,160	$ 100,000	$ 246,895	$ 1,104,000	$ 1,376,773
2029	9		9	$ 299,268		$ 257,834	$ 1,104,000	$ 1,273,096
2030	10		10	$ 305,375	$ 100,000	$ 258,593	$ 1,104,000	$ 1,315,534
2031	11		11	$ 311,483		$ 269,723	$ 1,104,000	$ 1,217,428
2032	12		12	$ 317,590		$ 275,795	$ 1,104,000	$ 1,190,512
2033	13		13	$ 323,698	$ 100,000	$ 276,857	$ 1,104,000	$ 1,228,814
2034	14		14	$ 329,805		$ 288,788	$ 1,104,000	$ 1,138,837
2035	15		15	$ 335,913	$ 100,000	$ 289,638	$ 1,104,000	$ 1,174,319
2036	16		16	$ 342,020		$ 302,062	$ 1,104,000	$ 1,089,347
2037	17		17	$ 348,128		$ 308,676	$ 1,104,000	$ 1,065,315
2038	18		18	$ 354,235	$ 100,000	$ 309,447	$ 1,104,000	$ 1,097,066
2039	19		19	$ 360,343		$ 322,572	$ 1,104,000	$ 1,019,052
2040	20	$ 4,071,667	0	$ 244,300	$ 100,000	$ 323,188	$ 1,104,000	$ 3,235,213
2041	21		1	$ 250,408		$ 336,704	$ 1,104,000	$ 909,056
2042	22		2	$ 256,515		$ 343,950	$ 1,104,000	$ 889,547
2043	23		3	$ 262,623	$ 100,000	$ 344,512	$ 1,104,000	$ 917,687
2044	24		4	$ 268,730		$ 358,659	$ 1,104,000	$ 851,728
2045	25		5	$ 274,838	$ 100,000	$ 359,087	$ 1,104,000	$ 877,803
2046	26		6	$ 280,945		$ 373,677	$ 1,104,000	$ 815,464
2047	27		7	$ 287,053		$ 381,308	$ 1,104,000	$ 797,897
2048	28		8	$ 293,160	$ 100,000	$ 381,540	$ 1,104,000	$ 821,136
2049	29		9	$ 299,268		$ 396,964	$ 1,104,000	$ 763,922
2050	30		10	$ 305,375	$ 100,000	$ 417,520	$ 1,104,000	$ 793,855
2051	31		11	$ 311,483		$ 437,889	$ 1,104,000	$ 741,325
2052	32		12	$ 317,590		$ 450,457	$ 1,104,000	$ 726,985
2053	33		13	$ 323,698	$ 100,000	$ 454,508	$ 1,104,000	$ 747,343
2054	34		14	$ 329,805		$ 476,787	$ 1,104,000	$ 699,362
2055	35		15	$ 335,913	$ 100,000	$ 481,135	$ 1,104,000	$ 718,247
2056	36		16	$ 342,020		$ 504,779	$ 1,104,000	$ 673,089
2057	37		17	$ 348,128		$ 519,427	$ 1,104,000	$ 660,437
2058	38		18	$ 354,235	$ 100,000	$ 524,246	$ 1,104,000	$ 677,277
2059	39		19	$ 360,343		$ 550,088	$ 1,104,000	$ 636,063
2060	40		20	$ 366,450	$ 100,000	$ 555,239	$ 1,104,000	$ 651,645

TWO FERRIES		All costs in 2017 USD
Ferry Description	16 vehicles, 150	pax
CAPEX	$ 8,200,000	scaled by cubic # and regression analysis.
Midlife refit factor	33.3%	assume 1/3 CAPEX cost to refit
Midlife refit	$ 2,733,333	calculated
Maintenance		
Base factor	2.00%	rule of thumb
Escalator factor	0.05%	rule of thumb
charter cost	$ -	assume no charter req'd for two ferries.
Fuel cost ($/gal)	$ 1.91	The most recent price paid
Engine power (HP)	1,200	estimate based on M/V Guemes powering
SFC (lb/HP-hr)	0.4	based on assumed weighted average % MCR and engine size/type
diesel lb/gal	6.943	
Avg. % MCR	21%	weighted average %MCR throughout day of operation
Average fleet utilization	87.5%	assume one ferry 100%, the other ferry 75%. (100% + 75%)/2 = 87.5% per ferry, on average.
hr/day	12	typical operating hours based on current schedule
weeks/ferry/yr	51	assume one week of downtime per ferry per year
Fuel cost/ferry/yr	$ 105,183	calculated
Annual crew cost/ferry	$ 828,000	assume each ferry costs 75% cost to operate one ferry due to some redundancies
Real discount rate	3%	for municipalities. includes inflation. matches NIST fuel forecast assumed DR.

TLCC	**$ 74,528,397**		**CAPEX**	**$ 8,200,000**		**Annual OPEX***	**$ 2,091,118**	
						*average opex over first 10 years of operation		
Year	**Year #**	**CAPEX**	**Maint. Yr**	**Maintenance**	**Charter**	**Fuel**	**Salaries**	**Discounted FCF**
2020	0	$ 16,400,000	0	$ 328,000		$ 246,610	$ 1,449,000	$ 18,423,610
2021	1		1	$ 336,200		$ 254,391	$ 1,449,000	$ 1,980,186
2022	2		2	$ 344,400		$ 261,037	$ 1,449,000	$ 1,936,504
2023	3		3	$ 352,600		$ 267,283	$ 1,449,000	$ 1,893,321
2024	4		4	$ 360,800		$ 273,794	$ 1,449,000	$ 1,851,246
2025	5		5	$ 369,000		$ 280,160	$ 1,449,000	$ 1,809,891
2026	6		6	$ 377,200		$ 286,804	$ 1,449,000	$ 1,769,607
2027	7		7	$ 385,400		$ 293,692	$ 1,449,000	$ 1,730,334
2028	8		8	$ 393,600		$ 300,807	$ 1,449,000	$ 1,692,025
2029	9		9	$ 401,800		$ 307,607	$ 1,449,000	$ 1,654,240
2030	10		10	$ 410,000		$ 314,677	$ 1,449,000	$ 1,617,420
2031	11		11	$ 418,200		$ 321,761	$ 1,449,000	$ 1,581,352
2032	12		12	$ 426,400		$ 329,333	$ 1,449,000	$ 1,546,355
2033	13		13	$ 434,600		$ 336,919	$ 1,449,000	$ 1,512,065
2034	14		14	$ 442,800		$ 344,537	$ 1,449,000	$ 1,478,482
2035	15		15	$ 451,000		$ 352,406	$ 1,449,000	$ 1,445,734
2036	16		16	$ 459,200		$ 360,122	$ 1,449,000	$ 1,413,543
2037	17		17	$ 467,400		$ 368,100	$ 1,449,000	$ 1,382,160
2038	18		18	$ 475,600		$ 376,333	$ 1,449,000	$ 1,351,556
2039	19		19	$ 483,800		$ 384,446	$ 1,449,000	$ 1,321,493
2040	20	$ 5,466,667	20	$ 492,000		$ 392,821	$ 1,449,000	$ 4,318,941
2041	21		21	$ 500,200		$ 401,275	$ 1,449,000	$ 1,263,496
2042	22		22	$ 508,400		$ 409,811	$ 1,449,000	$ 1,235,430
2043	23		23	$ 516,600		$ 418,435	$ 1,449,000	$ 1,207,971
2044	24		24	$ 524,800		$ 427,149	$ 1,449,000	$ 1,181,108
2045	25		25	$ 533,000		$ 435,957	$ 1,449,000	$ 1,154,830
2046	26		26	$ 541,200		$ 444,859	$ 1,449,000	$ 1,129,124
2047	27		27	$ 549,400		$ 453,858	$ 1,449,000	$ 1,103,980
2048	28		28	$ 557,600		$ 463,125	$ 1,449,000	$ 1,079,459
2049	29		29	$ 565,800		$ 496,657	$ 1,449,000	$ 1,065,728
2050	30		30	$ 574,000		$ 510,871	$ 1,449,000	$ 1,043,921
2051	31		31	$ 582,200		$ 525,533	$ 1,449,000	$ 1,022,661
2052	32		32	$ 590,400		$ 540,656	$ 1,449,000	$ 1,001,931
2053	33		33	$ 598,600		$ 556,251	$ 1,449,000	$ 981,720
2054	34		34	$ 606,800		$ 572,331	$ 1,449,000	$ 962,014
2055	35		35	$ 615,000		$ 588,908	$ 1,449,000	$ 942,800
2056	36		36	$ 623,200		$ 605,998	$ 1,449,000	$ 924,065
2057	37		37	$ 631,400		$ 623,613	$ 1,449,000	$ 905,798
2058	38		38	$ 639,600		$ 641,769	$ 1,449,000	$ 887,987
2059	39		39	$ 647,800		$ 660,481	$ 1,449,000	$ 870,621
2060	40		40	$ 656,000		$ 679,764	$ 1,449,000	$ 853,688