Addendum 1 of Appendix D, Economics – Attachment 1: Lock Capacity Analysis

Inner Harbor Navigation Canal (IHNC) Lock – Lock Replacement, Orleans Parish, Louisiana

General Reevaluation Report

Planning Center of Expertise for Inland Navigation and Risk-Informed Economics Division (PCXIN-RED)

U.S. Army Corps of Engineers – Huntington District

Attachment 1 - Lock Capacity Analysis

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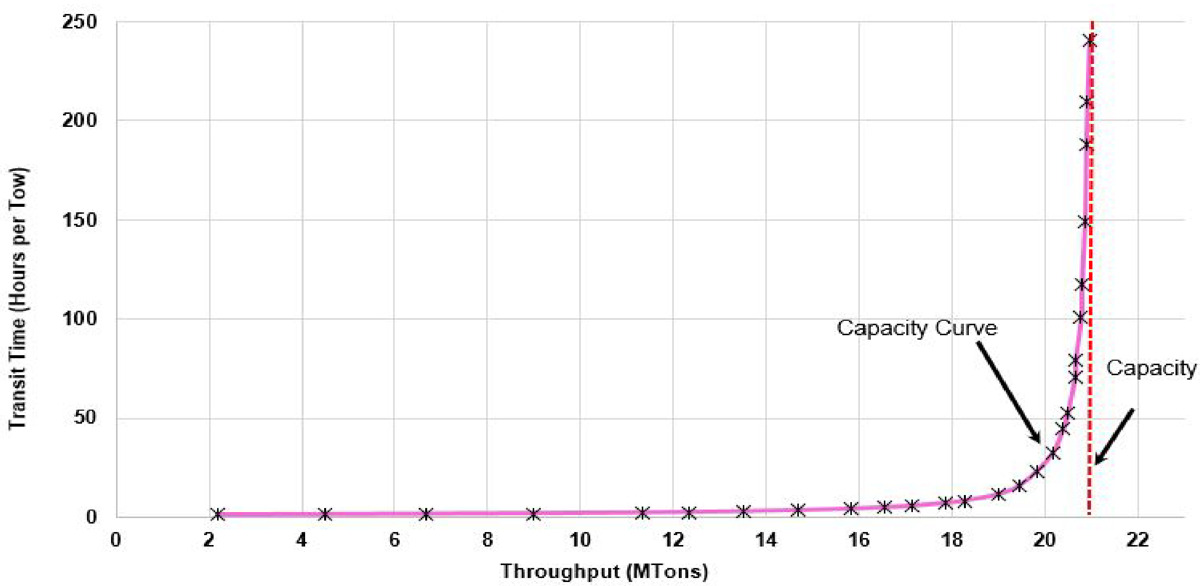
1. Summary

The ARNOLT model, like the shallow draft WAM model, is an annual simulation model used to evaluate the capacity of lock projects on the inland system. Capacity in this context is defined as the relationship between the volume of traffic that desires to transit the project in a given year and the average transit time, the time to navigate fully from arrival at one end to departure at the other, of all such traffic that can successfully complete a transit in that year. This capacity estimate ordinarily takes the form of what is known as a 'tonnage transit curve', the average transit time (on the y axis) displayed as a function of the annual tonnage (x axis) that attempts to transit the project. These curves typically have a set of common properties; they exhibit exponential growth, and eventually at a given tonnage level become asymptotic. This tonnage level, or its approximate location on the curve at least, is referred to as 'capacity' for the evaluated project, the point at which no more traffic can viably use the project.

Figure 1 – Tonnage Transit Curve (Capacity Curve) Example



A tonnage/transit time relationship, or tonnage transit curve, can be generated by a capacity simulation model for a range of scenarios which may through various mechanisms alter a projects capacity, both in the sense of its capacity threshold and its capability to pass a set tonnage volume. These scenarios could include a period of closure of one or more chambers at the project, slower or quicker processing of tows, changes in the composition and characteristics of traffic, etc. Normally these scenarios describe a range of lock closure or other disruptions to service that can result from routine or catastrophic failure of lock components. These scenarios comprise what is known as a 'family of curves', which together describe the locks capacity across as series of hypothetical current and future scenarios. The ultimate use of these tonnage transit relationships is in system equilibrium modeling, normally performed by the Navigation Investment Model (NIM).

2. Discrete Event Simulation

ARNOLT produces these tonnage-transit curves by simulating the operation of the lock over the course of a year. It is a stochastic model; in that it performs this simulation over the course of numerous iterations. Within each iteration uncertain parameters are sampled from probability distributions, resulting in a distribution of outputs, the mean of which can be considered the 'expected' output. This simulation of lock operation includes the physical characteristics and operation of the lock itself, as well as the characteristics of the traffic that transits it.

The physical lock characteristics and operation include the size and number of chambers, the rules or operating policies implemented at the project, the fill and spill times for the chambers, the availability of helper boats or tow haulage system, etc. The characterization of traffic includes the volume and seasonality of traffic, the composition of traffic (commercial tows vs recreation vessels), the traits of individual vessels or flotillas, and so on.

During a simulation traffic, will arrive at the project, enter a queue, eventually process through the project with its processing time being a function of tow or vessel characteristics, characteristics of the transited chamber, and uncertainty distributions, and its ultimate transit time computed as the sum of processing time and delay (time spent in queue roughly speaking). The average transit time (y axis of the tonnage transit curve) at the conclusion of a simulated year then would be computed as the average total transit time of all vessels or flotillas that completed a transit during the simulated year, while the tonnage (x axis) computed as the sum of all commodity tons carried by these flotillas. The details of capacity analysis will be described in greater detail below.

This simulation is applied over each analyzed scenario, and as such the model is a discrete event simulation. It does not associate probabilities to the occurrence of these scenarios, nor randomly sample them in individual iterations, but rather directly simulates a series of discrete events, or scenarios, and returns their output distributions separately.

3. Capacity Analysis Overview

As previously stated, a lock's 'capacity' is typically described as a relationship between tonnage throughput and average processing time per user. This relationship is a function of the lock's design, the condition/performance of the lock's primary components, the fleet utilizing the lock, and the distribution of arrivals of that fleet.

A lock's design is the leading indicator of the lock's capacity to process traffic in an efficient manner. The number and size of the chambers, and to a lesser extent the lift and the target filling and emptying times are, for the most part, fixed variables that largely set the bounds of a lock's potential capacity. For example, a single chamber project with a chamber 1200 feet long by 110 feet wide will have significantly more capacity than a single chamber project with a chamber 600 feet long by 110 feet wide. Likewise, adding an additional chamber at a project will significantly increase the capacity of that project to process traffic, as there is a second chamber available to process traffic when needed during times of congestion or a chamber outage. The design lift of the chamber, and the design of the ports that fill and empty the chamber, largely dictate how fast the water elevation can be safely changed when a vessel is utilizing the project. This effectively bounds the time a vessel will spend in the chamber, with larger lifts or inefficient port designs leading to less available capacity than smaller lifts or well-designed filling and emptying systems.

The condition and performance of the lock's primary components, such as the gates, the ports, the valves, and the hydraulics, also influence the ability of the lock to process traffic efficiently. These components can generally function as intended throughout the majority of their lives. Even when the components are old and beginning to degrade, they can still generally function per their design up until the point of a major failure. However, the maintenance needs of these components in order to keep them functioning well beyond their design life continues to grow throughout time. As maintenance becomes more frequent, the outages associated with the maintenance also becomes more frequent and thus degrades the lock's capacity.

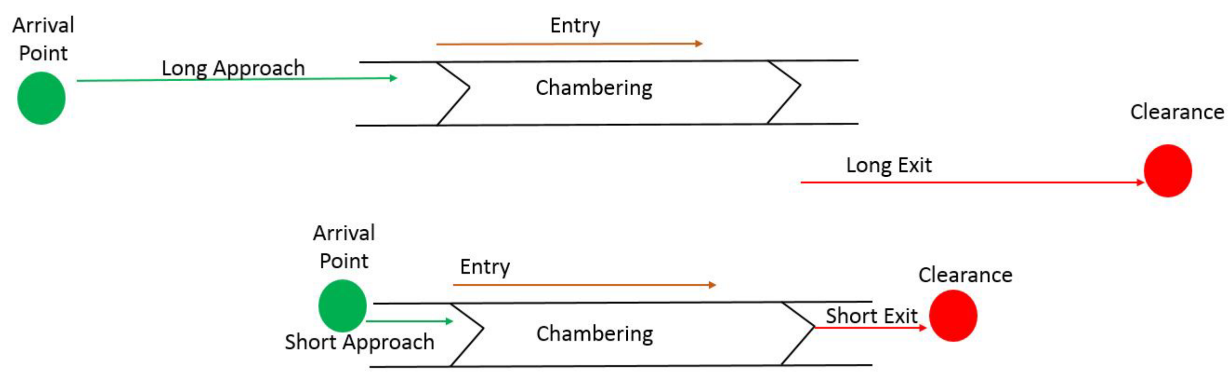
The fleet that utilizes a lock is a significant factor in a lock's capacity. The size of the barges, the size of the towboat, and the configuration of the overall tow package all play a role in determining how long the flotilla spends at the lock. The characteristics of the fleet at a project are typically reflective of the position of the lock within the context of the overall inland marine transportation network. If a project is closer to the middle of the system, such as the Middle Mississippi River or the Lower Ohio River, then the fleet is going to trend larger, regardless of the size of the lock. If the project is towards the outer limits of the system, then the project dimensions are going to have a larger impact on the overall fleet size as less through traffic is going to be featured at the project.

A capacity analysis is generally a reflection of the performance of a lock, system, or river's performance in allowing for the movement of traffic along its extent. For a lock, this performance is measured in terms of transit time. Transit time is the measured as the time period between when a vessel arrives at a lock and the time it sufficiently clears the lock area so that another lockage can occur. Transit time is broken down into two elements, delay time and processing time.

Delay time is the time period between when a vessel arrives at the lock and when the lock is ready to begin processing that vessel. Delay can occur because another vessel is utilizing the chamber or the chamber is out of operation.

Processing time is the time related to the actual lockage process. A simplified visual representation can be found in Figure 2. Processing time is further broken down into the five components of processing time: approach, entry, chambering, exit, and turnback. These times are tracked by direction and can be further broken down according to the type of approach or exit, which are determined by their interactions with other vessels in the system. A long approach signifies a vessel approaching the lock from the beginning of the arrival point, which means that the vessel had to wait for a different vessel traveling in the opposite direction to clear the project area or the vessel arrived in the absence of another vessel. Likewise, a long exit means that the vessel exiting the chamber is interfering with another vessel entering the chamber from the opposite direction, and thus must clear the area completely for the other vessel to begin its approach. A short approach usually signifies that the vessel has arrived as another vessel traveling in the same direction is utilizing the lock chamber. This allows the vessel to make its approach and wait immediately below the chamber gates as no interference is caused by the exiting vessel. Similarly, a short exit signifies the lack of another vessel traveling in the opposite direction, meaning the exiting vessel is not interfering with another vessel and the lockage can be considered complete when the vessel has left the vicinity of the project gates. Entry time is the time period between when the bow of the vessel crosses the lock sill and the vessel is ready for the chambering process. The chambering process is the time it takes for the lock to change the elevation within the chamber. Turnback is the time period between when a vessel exits the chamber and the chamber's elevation can be changed to serve another vessel traveling in the same direction.

Figure 2 – Lockage Overview



4. IHNC Model Setup

To perform capacity analysis for a project or series of projects, the model must first be set up to reflect the characteristics of those projects and the traffic that transits them. This setup process consists of loading data into the model from datasets such as the Lock Performance Monitoring System (LPMS) and Waterborne Commerce Statistics Center (WCSC), as well as specifying input parameters. Historical data from LPMS and WCSC are used to characterize the traffic and usage patterns of the project or projects. These two datasets, as well as the other input parameters and assumptions required to set up an ARNOLT model are summarized below.

4.1. LPMS

To successfully evaluate the role of an individual project to the larger inland waterways system, standardized data needs to be collected in a uniform manner across all USACE lock projects. This insures not only that a standard suite of system planning models are able to be deployed, but that evaluation of projects is done on an apples-to-apples basis. The Lock Performance Monitoring System (LPMS) was established by an Office of the Chief of Engineers (OCE) Task Group for Inland Waterways Systems Analysis to collect and display the required data to support such analyses. LPMS data tracks a vast array of data relating lock traffic and operation, including records of each lock transit, barge and vessel characteristics, et cetera. Table 1 below summarizes the LPMS data used in setting up an ARNOLT model.

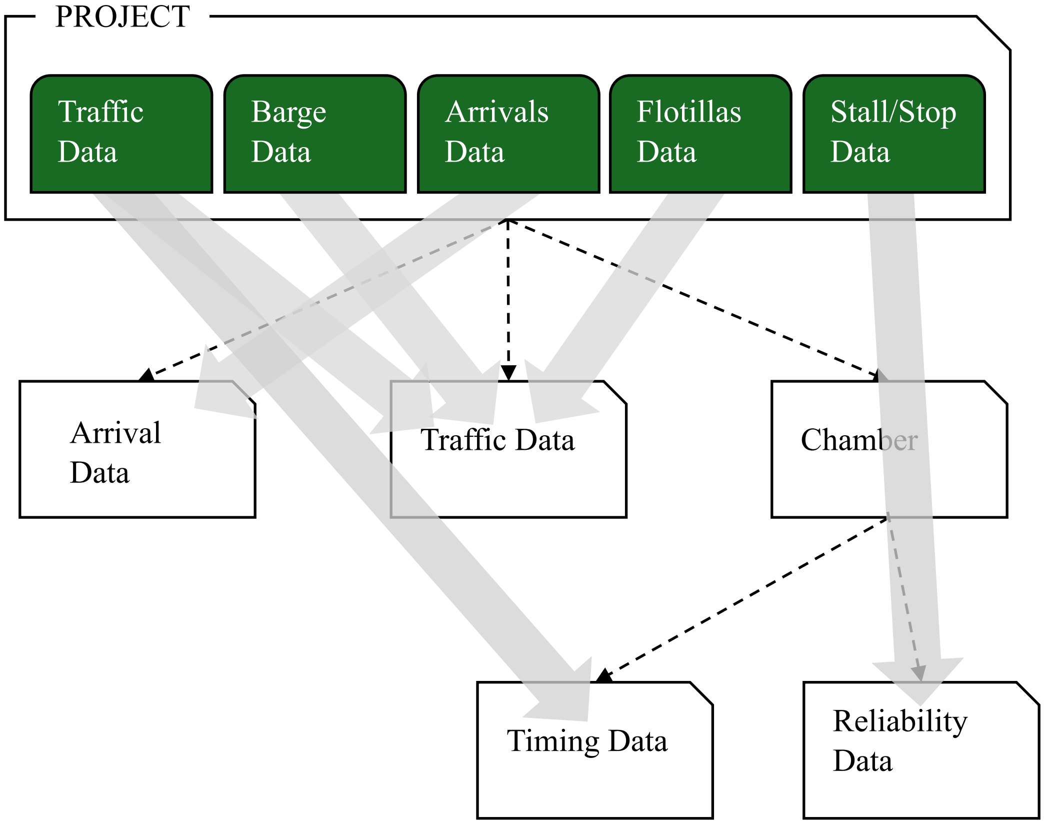
Table 1 – Input Data Tables

Description	Used For	Server Path
Traffic Data	Processing time distributions, lockage type data, flotilla characteristics	[LPMS_DATA_RAW].[dbo].[TRAFFIC] [LPMS_DATA_RAW].[dbo].[OPERATIONS]
Barge Data	Barge dimensions, commodity and tonnage information, flotilla characteristics	[LPMS_DATA_RAW].[dbo].[BARGES] [LPMS_DATA_RAW].[dbo].[BARGE_COMMODITIES] [LPMS_DATA_RAW].[dbo].[TRAFFIC]
Arrivals Data	Arrival patterns	[LPMS_DATA_RAW].[dbo].[TRAFFIC] [LPMS_DATA_RAW].[dbo].[OPERATIONS]
Flotilla Data	Flotilla characteristics	[LPMS_DATA_RAW].[dbo].[FLOTILLAS] [LPMS_DATA_RAW].[dbo].[TRAFFIC]
Stall/Stop Data	Random minor outages	[LPMS_DATA_RAW].[dbo].[STALL_STOPPAGE]

In addition to these tables, a number of additional referential tables are retrieved, which are used to join or translate data in the tables listed above.

When these data are loaded, they are used to define characteristics of the project. This includes arrival data, containing information related to arrival patterns at the project, traffic data, containing information describing historic and expected future traffic at the Project, timing data, which describes the processing times through the Chamber, and reliability data, which describes the frequency of random minor outages. The ways in which these input datasets are used to define these sub-components is illustrated in Figure 3 below.

Figure 3 – Input Data Use Flow Chart



In the previously modeling using the Waterway Analysis Model (WAM) WAM , LPMS data for the period 2000-2013 was used to characterize lock traffic, with a primary. In this update, the ARNOLT model was setup using LPMS data for the years 2015, and 2017-2019. Other recent years were omitted due to events, including the COVID 19 pandemic, that would lead to these data years being non-representative.

In addition to modeling differences previously discussed, differences in lock operation between the period of LPMS data used to load the WAM model and those used in the ARNOLT model will also have an impact on how traffic conditions are simulated and thus model results. The following figures present a comparison between LPMS data in the period used in the WAM model, and that used in the ARNOLT model. In general, recent traffic years have been characterized by greater delay times, lower traffic volumes, and an increase in the number of cuts per tow to transit (likely the primary contributor to the higher average delays). Tow-sizes, in terms of linear dimensions as well as barge counts, have remained mostly constant.

Figure 4 - Transit Time Comparison by Data Year

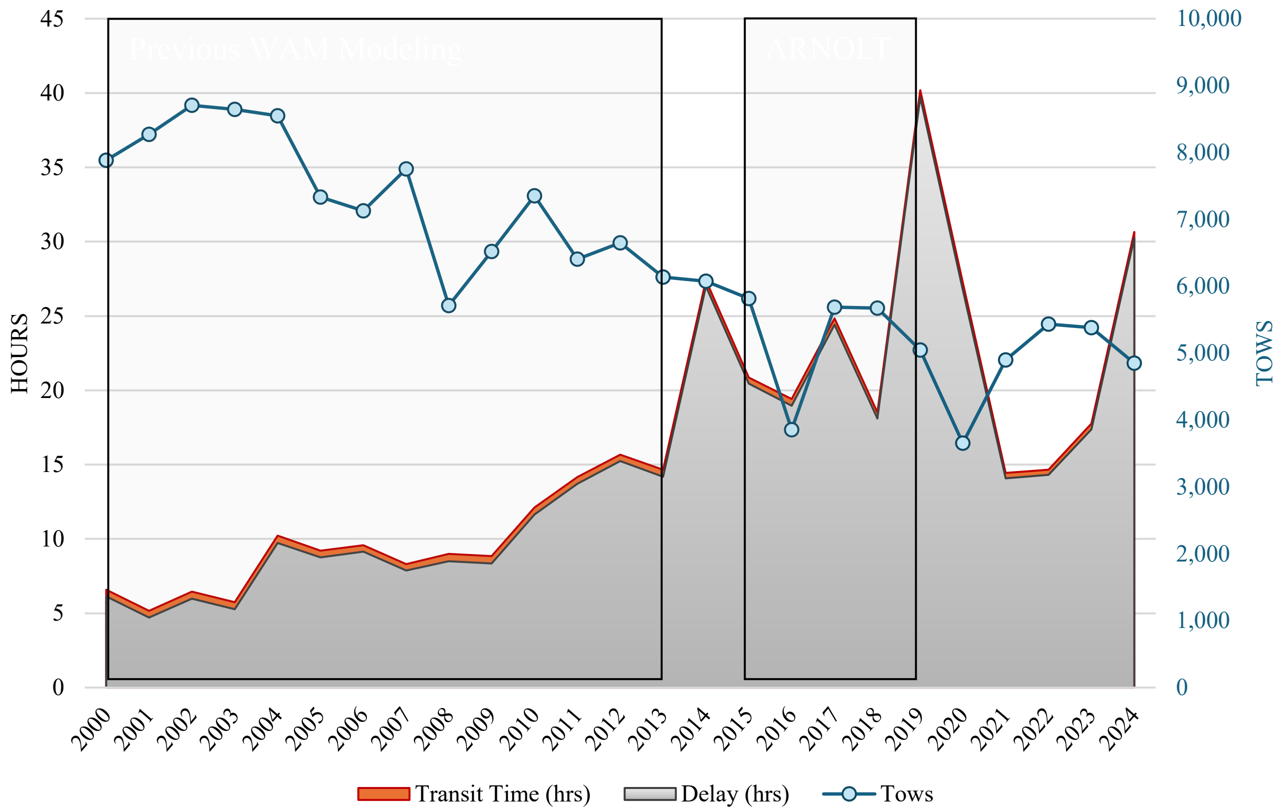


Figure 5 – Average Cuts Per Tow Comparison by Data Year

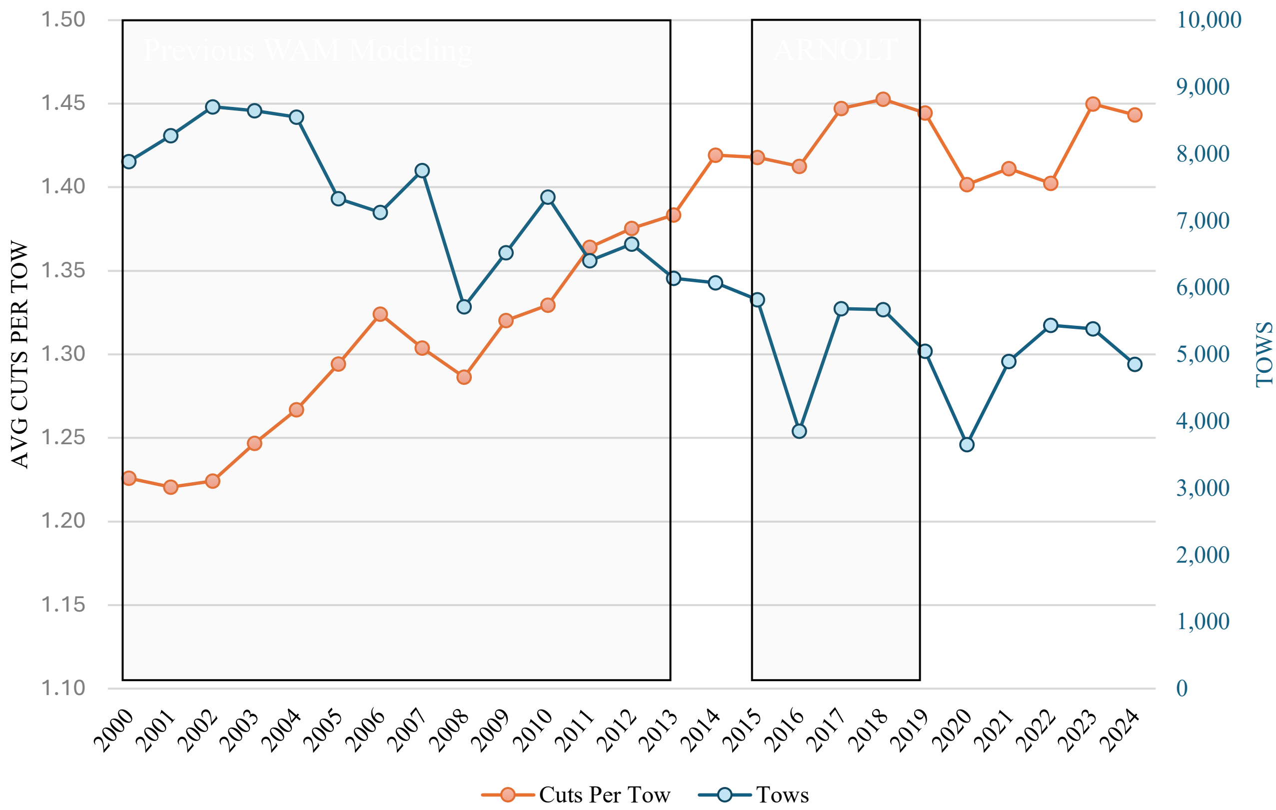
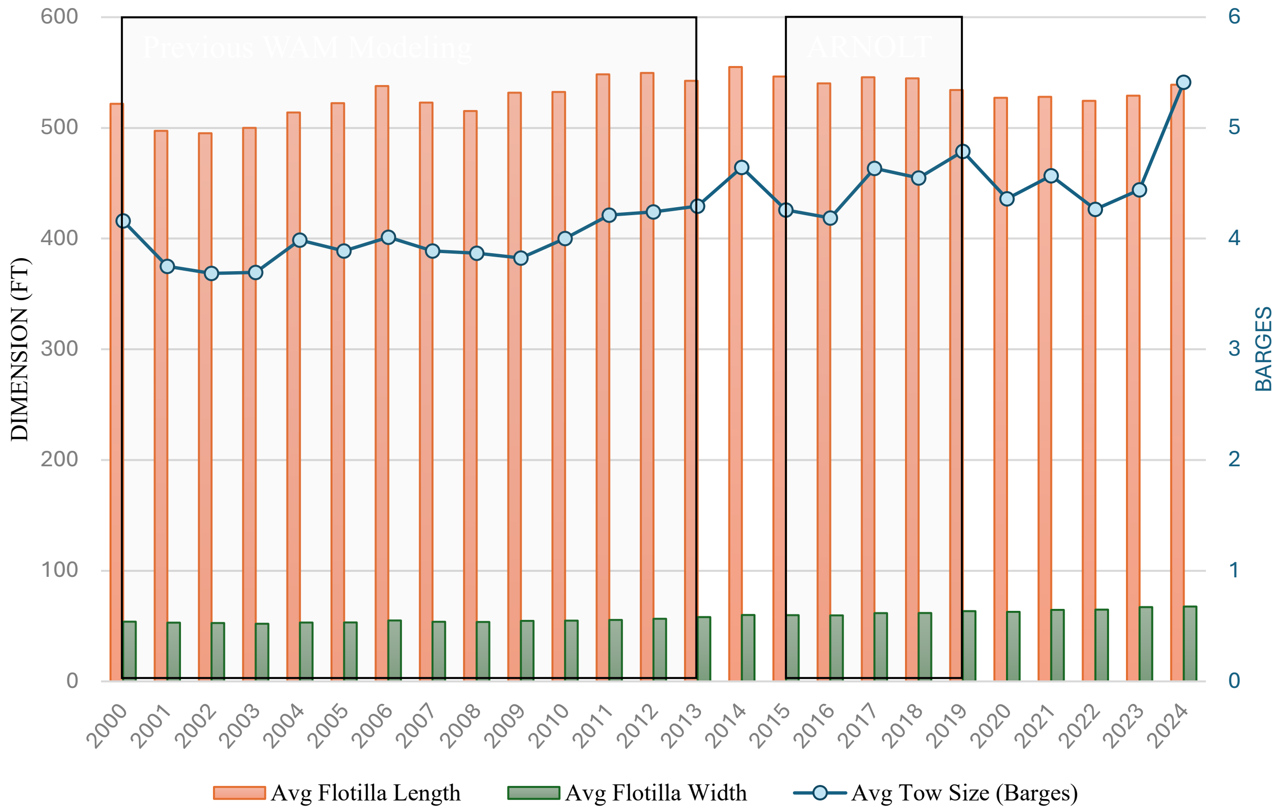


Figure 6 – Average Tow Size Comparison by Data Year



For IHNC, LPMS data presented a unique problem due to how individual lockages and arriving flotillas are recorded in the database. In a typical project, flotillas that transit the project are recorded with unique identifiers that persist across all entries (cuts) for that flotilla. If for example a flotilla arrives with 12 barges, 8 of which transit the lock in the first cut, and the remaining 4 in a subsequent cut, this would be recorded as two separate transit entries in the LPMS Traffic data table, each with the unique identifier denoting that both arrived as part of the same flotilla, with the same powered vessel. Because of how IHNC operates however, with flotillas typically breaking before arrival at the project, often pushed by a powered vessel other than the one they arrived with, transits are recorded without this unique identifier (or at least an incomplete version of it). As a consequence, each cut is essentially treated as a separate flotilla. For the purposes of ARNOLT simulation, this would lead to incorrect characterization of traffic, as a far greater number of flotillas, each able to transit the project in a single cut. It would also lead to incorrect fitting of lockage timing distributions, as every lockage type is reported as a 'straight' or single cut lockage.

To address these issues, LPMS data was retrieved and pre-processed before being loaded into the ARNOLT model. The pre-processing attempted to both re-combine flotillas that had arrived with the same powered vessel, and to adjust their lockage types, where appropriate, to a multi-cut type. This process effectively transforms the LPMS data back to the format expected by the ARNOLT model.

4.2. Waterborne Commerce Data

The Waterborne Commerce Statistics Center collects data monthly from commercial vessel operators on the vessels used, commodities and tonnages moved, and origins and destinations. These data provide a more accurate picture of commodities and tonnages (as they are user reported instead of approximated by lock operators) and are used in ARNOLT primarily to refine LPMS tonnage and commodity estimates.

4.3. User Input Parameters

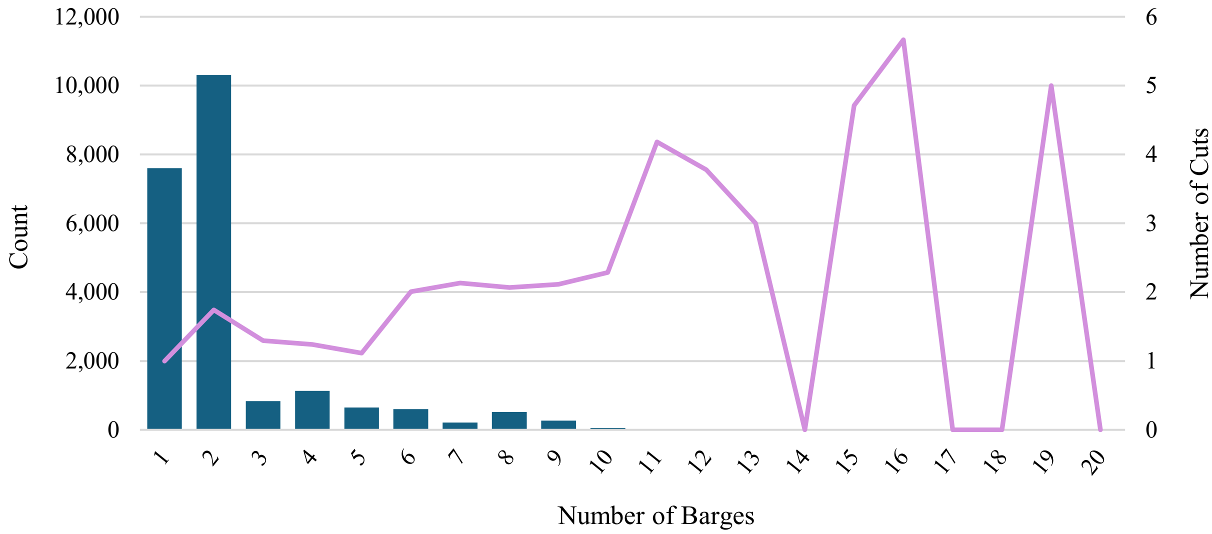
An ARNOLT study is defined by the data loaded from the input datasets described above, as well as a series of user input parameters which describe how the project is assumed to operate, which scenarios are to be evaluated, and how the simulation is to be performed. Significant input parameters are summarized below.

For project operating policies and conditions, the ARNOLT model for IHNC was set up to process traffic in a 5 up/5 down operating pattern. A minimum clearance of one foot was assumed to be required between all separable tow elements (multiple tow packets or vessels in the chamber concurrently), and multi-vessel lockages were set to be restricted only to users without hazardous flagged cargo. The curfews observed at the project between 6:30 and 8:30, and 15:30 and 17:45 on weekdays only were also set in the project operating inputs. For these periods, every weekday of the simulation the project will be assumed closed to traffic, and any vessels or flotillas at the project will remain in queue for those periods.

The combined LPMS and WSCS data described above was then used to generate a series of flotilla "archetypes", each based off of tows that have historically transited the project and used to represent the characteristics of likely future traffic. The characteristics of these generated flotilla archetypes greatly impact the simulated capacity of the lock, just as do the corresponding characteristics of the traffic they represent. This is via a combination of processing times and number of cuts required to transit the project, both of which influenced by the configuration and size of the flotilla, its number of barges and their respective dimensions, the characteristics of the powered vessel, etc. In general, it is the number of cuts per flotilla that most greatly impacts the overall capacity of the lock.

7,977 flotilla archetypes were generated in this way, 4,149 upstream, and 3,828 downstream. These were generated from the pre-processed LPMS dataset. A genetic algorithm optimization is used to fill in missing data an ensure these generated archetypes best reflect actual traffic at the IHNC project. Significant characteristics are summarized in the following figures.

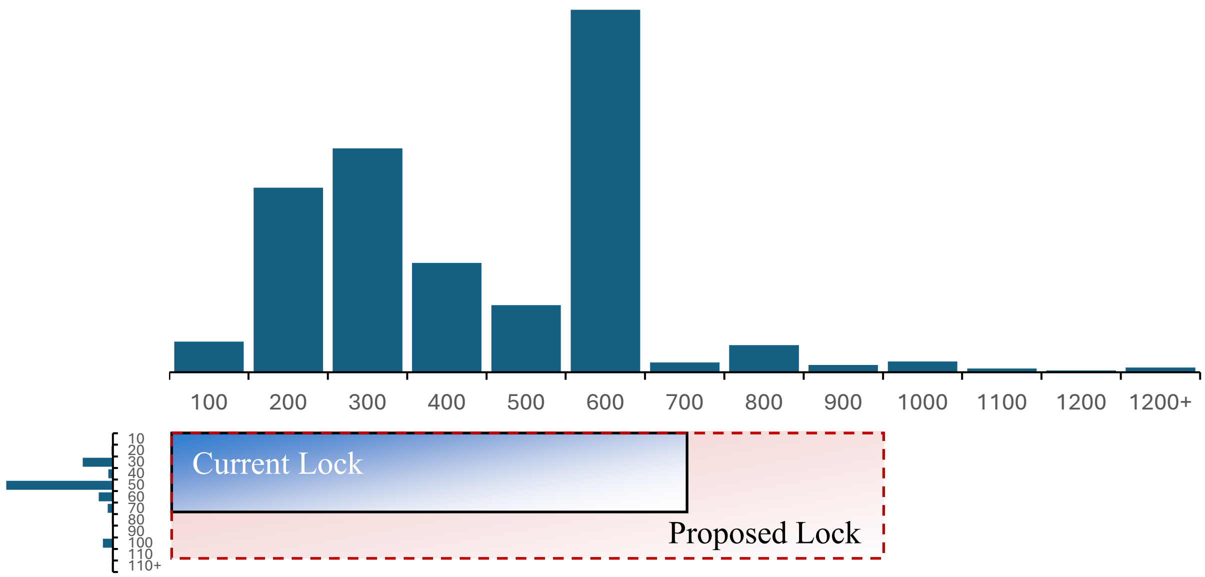
Figure 7 - Flotilla Archetypes, Barge Sizes/Number of Cuts



The figure above shows the relationship between the number of barges per flotilla and number of cuts required to transit the project, as well as the frequency across all flotilla archetypes of each barge count. The majority of flotillas that transit IHNC are pushing either one or two barges, which largely transit in 1 or 2 cuts. At six barges or more, the average number of cuts required increased to 2 or more. Overall, the average number of cuts required in the existing condition is 1.46 cuts per tow.

In the proposed WPC lock configuration, a larger chamber size will result in increased capacity, as fewer cuts on average will be required to process each flotilla. Overall flotilla lengths and widths for IHNC traffic are shown in the figure below relative to the current and proposed chamber dimensions.

Figure 8 - Flotilla Dimension Distributions Relative to Chamber Size



Note however that in the figure above, no correlation is shown between flotilla widths and lengths, and also that existing flotilla dimensions are, in part, a function of the size of the IHNC chamber.

5. Model Calibration

After this process is complete, the model must also be calibrated to ensure that, as set up, it accurately represents the operation of the project or projects. This is done by running the simulation for set scenarios for which historically observed data exists, and comparing metrics generated by the simulation with those computed from the historical data. If the model results mirror those historically observed within a reasonable margin of error, the model set up can be said to be well calibrated. If it cannot reproduce these historical metrics, input parameters may need to be corrected or problems may be present in the historic data (LPMS) used in the setup process (as well as in calibration).

Calibration is typically an iterative process, whereby an initial run is performed and compared against its historic baseline, issues and discrepancies logged, and potential causes of these identified in input data and corrected, after which the process is repeated until good calibration is achieved. The full set of input parameters and assumptions and the calibration process is documented in Attachment 2.

6. Scenarios

Multiple scenarios were run for both the Future Without-Project (FWOP) and Future With-Project (FWP) conditions. These scenarios represent all the substantially distinct circumstances of project operation that could exist for a given year or series of years during the analysis period in either project condition. The primary scenarios in both conditions would be the baseline or full operation scenarios, which represent a "normal" year of traffic, devoid of any prolonged outages or other service disruptions (only including ‘random minor’ closures, typically less than 24 hours in length). Other scenarios capture different durations, timings, and schedules of closures or other disruptions that may arise due to scheduled OMRR&R activities, impacts during construction, or other causes.

For each scenario a tonnage transit curve was produced via simulation in the ARNOLT model of project operation given the conditions defined in that scenario. To generate a tonnage transit curve, 25 separate simulations are performed at a range of traffic volumes, ranging from 20% of baseline (current) traffic, to 1.5x baseline traffic in the FWOP condition, and 3x baseline traffic in the FWP condition. For each traffic volume, 1,000 iterations are performed (or until convergence is reached).

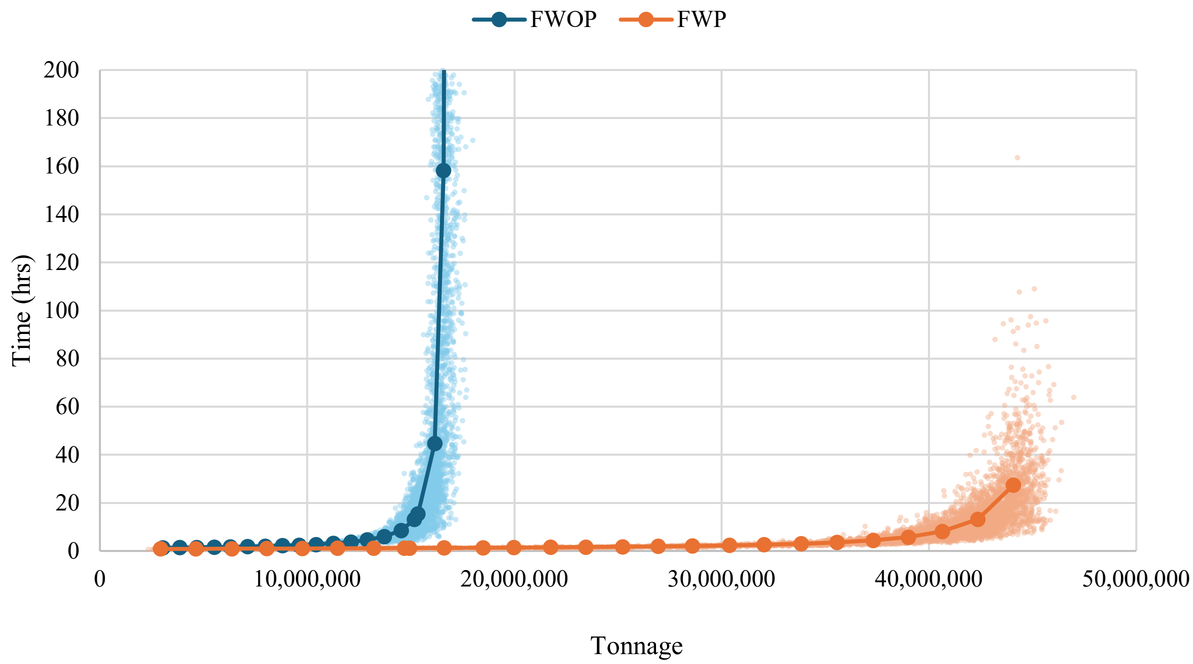
The following sections will present the results of each scenario. For many scenarios, FWOP and FWP curves were created, as these scenarios would occur in both project conditions. However, some scenarios are unique to a single project condition. In cases where scenario results exist for both the FWOP and FWP condition, these results will be presented together for comparison.

7. Lock Capacity Results

7.1. Full Operation

The full operation, or ‘full-op’ scenario represents the project operating without any prolonged service disruptions. This scenario will reflect the tonnage to average transit time relationship for the majority of the analysis period. While full operation curves typically reflect normal project operation with only ‘random minor’ service disruptions, IHNC is unique in that normal project operation includes over 45 days of closure, split amongst curfew closures for bridge operation. These curfew closures occur twice per weekday; from 6:30 am to 8:30 am, and again from 3:30 pm to 5:45 pm. While each individual closure is short, the cumulative effect on capacity is significant.

Figure 9 - Full Op/Curfews Capacity Curves



As seen in the Figure above, the FWP condition results in a more than doubling of project capacity.

7.2. Rehab/Maintenance Closures

Over the analysis period in both the FWOP and FWP conditions a number of scheduled rehab or maintenance closures will occur. The durations of these closures vary by which scheduled maintenance or rehab action is to be performed. All closures are assumed to be scheduled for their duration to occur over 12 hour shifts, on weekdays only. There were seven such scenarios simulation in the ARNOLT model, ranging in duration from 50 hours to 720 hours.

Figure 10 - 50hr Rehab Capacity Curves

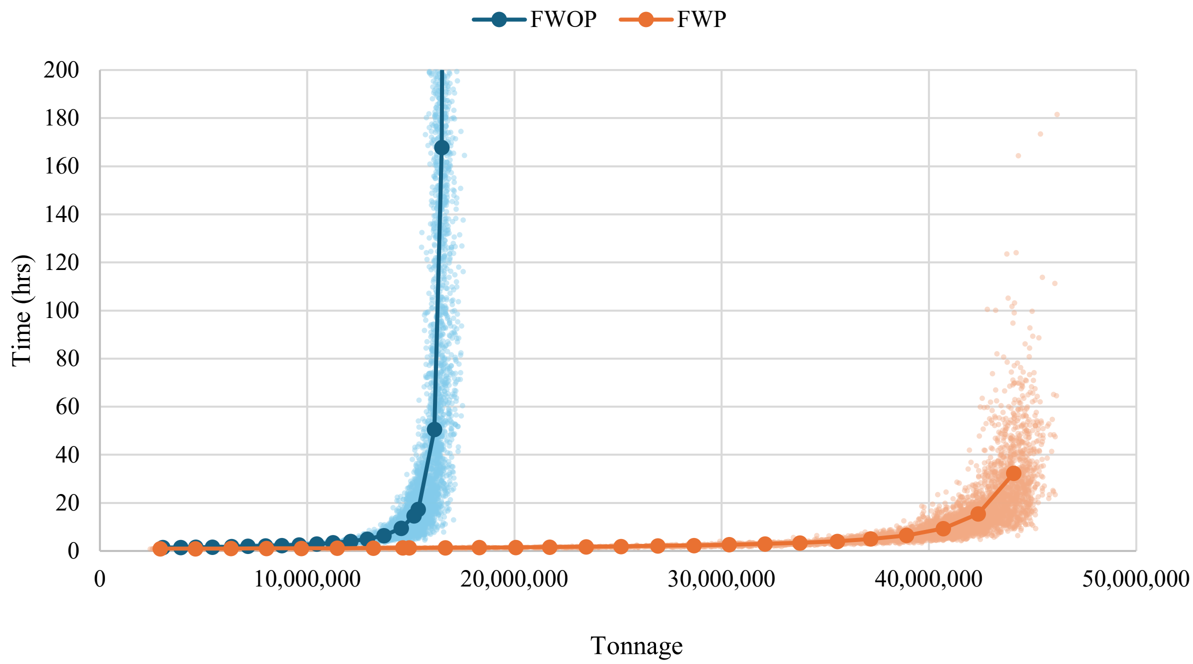


Figure 11 - 75hr Rehab Capacity Curves

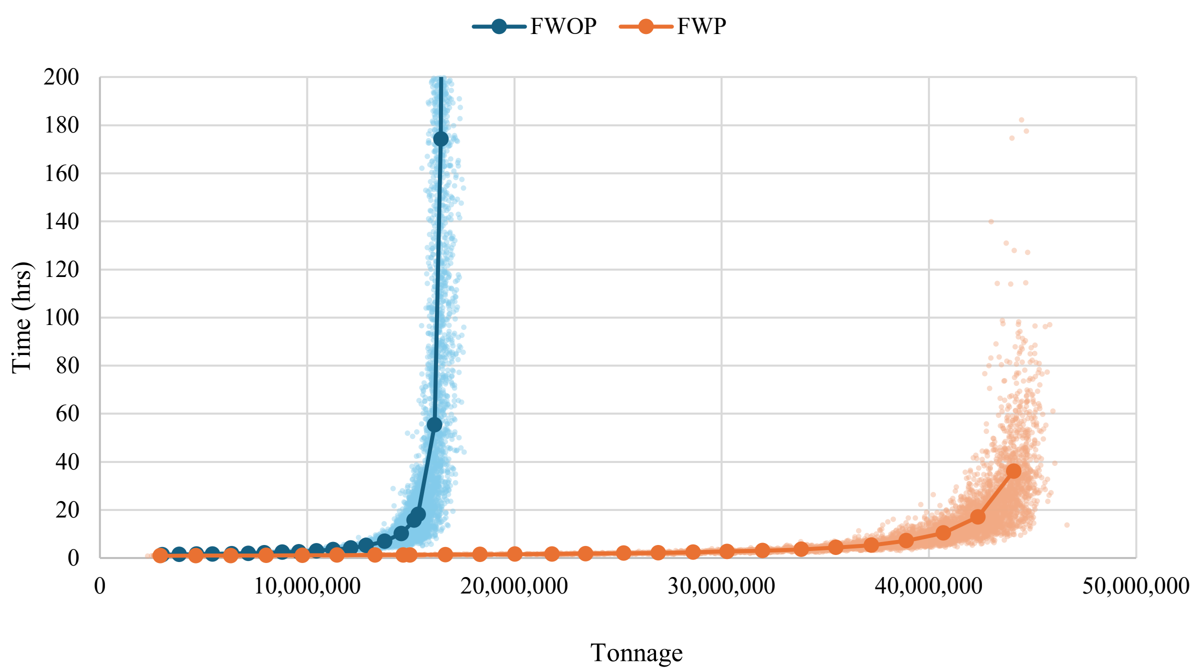


Figure 12 - 100hr Rehab Capacity Curves

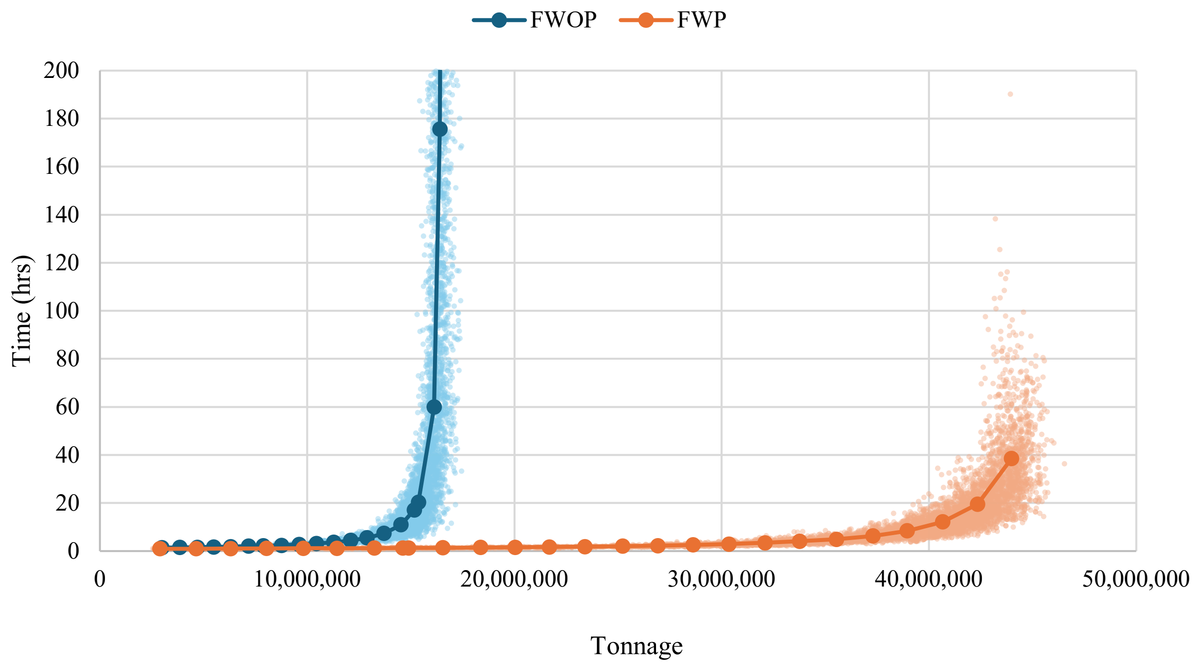


Figure 13 - 150hr Maintenance Capacity Curves

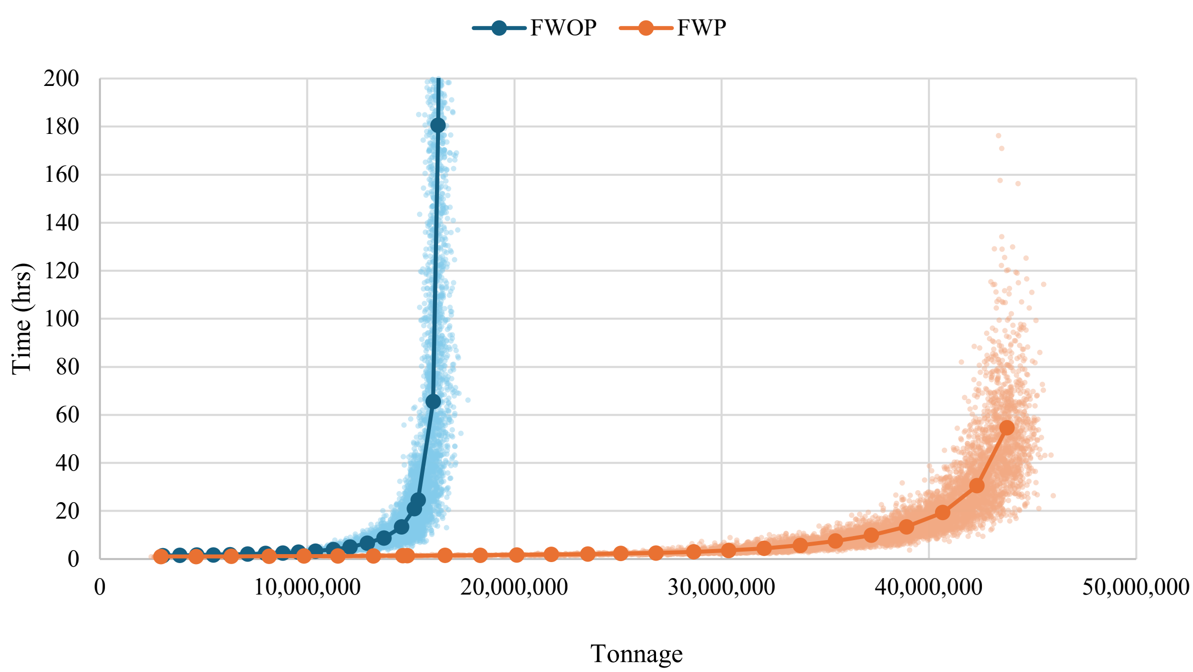


Figure 14 - 175hr Rehab Capacity Curves

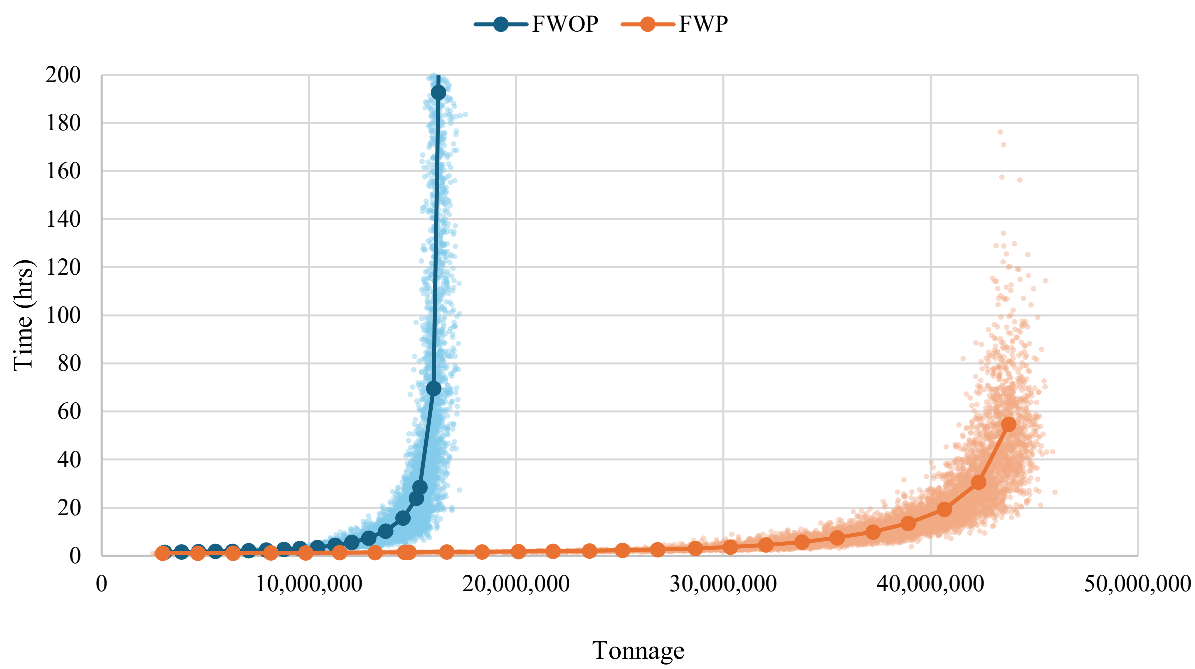
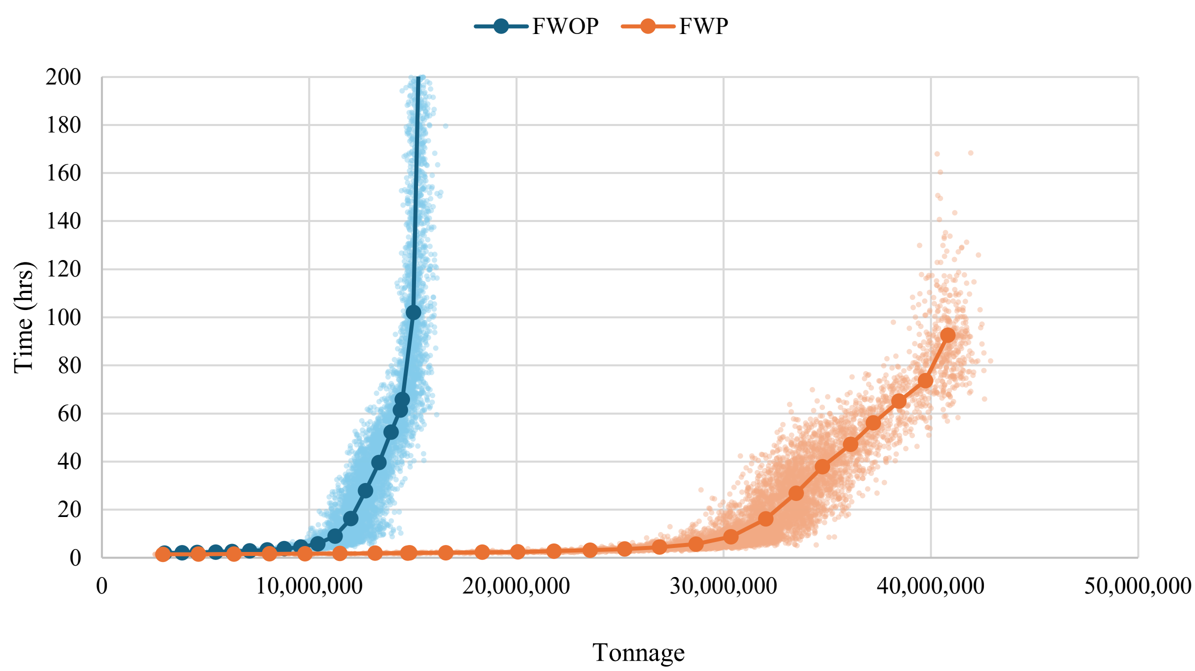


Figure 15 - 720hr Rehab Capacity Curves



7.3. FWOP Only Rehab Closures

In addition to the six rehab and maintenance related scheduled closure scenarios outlined above, there are three rehab closure scenarios that apply only to the FWOP condition, as these would be avoided in the FWP due to the replacement of the existing lock. These are for 250 hours, 400 hours, and 630 hours, again in 12-hour shifts, Monday through Friday.

Figure 16 - 250hr Rehab Capacity Curve (FWOP)

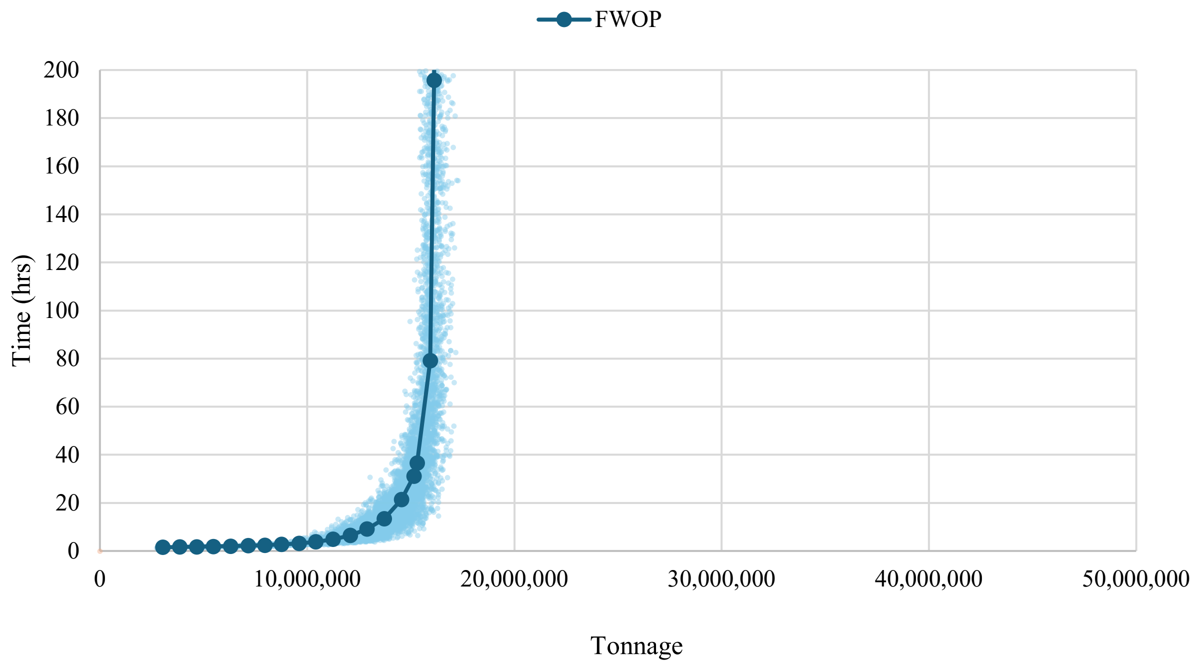


Figure 17 - 400hr Rehab Capacity Curve (FWOP)

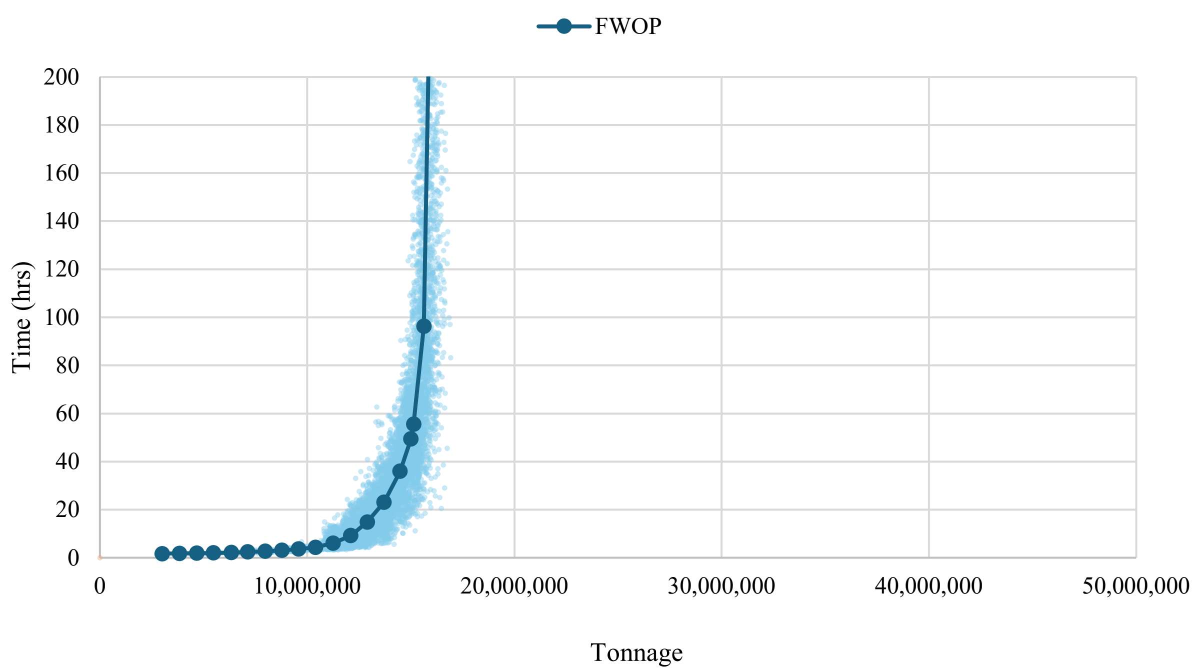
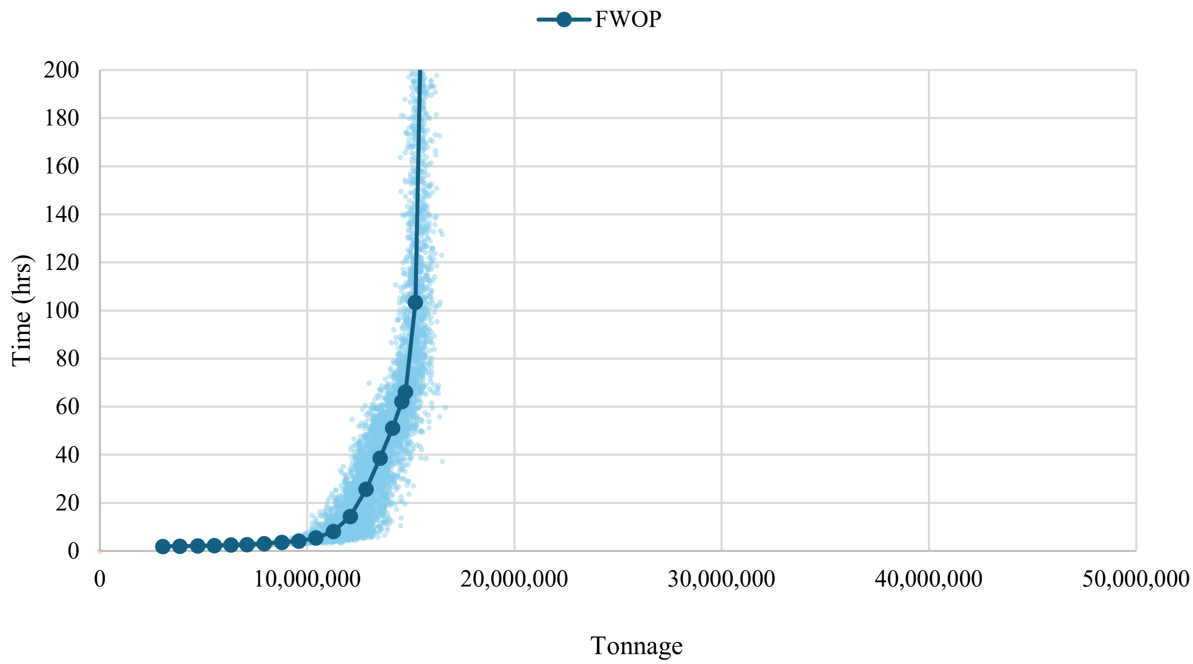


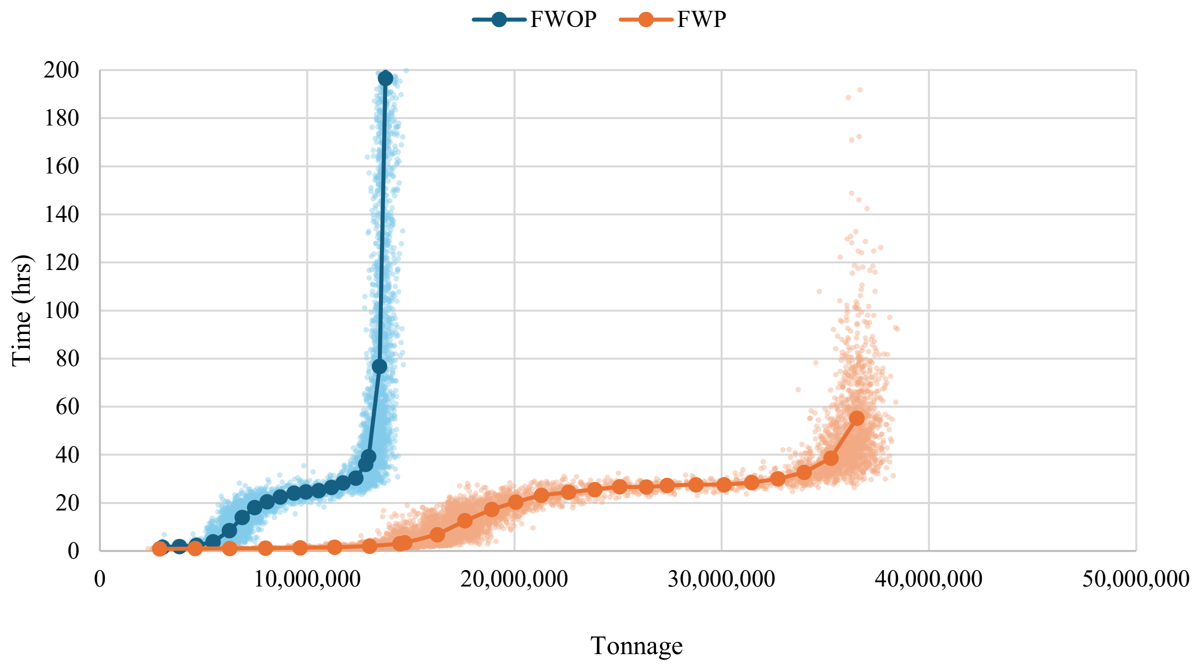
Figure 18 - 630hr Rehab Capacity Curve (FWOP)



7.4. Dewatering Closure

One dewatered scenario, a scheduled closure with a 1440 hour or 60-day duration, was simulated for both the FWOP and FWP conditions. This closure scenario, in contrast to those previously described, is a sustained 60-day closure, 24 hours a day.

Figure 19 - 1,440hr Dewatering Closure Capacity Curves



7.5. Impacts During Construction

The current implementation plan features bypass channels around the construction site of the new lock which limits the impacts to navigation during construction. Deconstruction of the existing lock and construction of the new St. Claude Avenue Bridge will impede navigation however, resulting in closure scenarios.. The first will be in 2043 where construction will result in two sustained seven-day closures, staggered with enough time in between to clear the queue, followed by a three-day closure, for twelve hours each of the three days. The second is assumed to occur in 2045, during which the project will be closed for 200 days, twelve hours each day.

For both of these construction impacts scenarios, the width restriction of 75 feet of the FWOP lock was imposed, even though the new lock is largely constructed as the existing structure would not have been completed demoed. This impacts the maximum tow-sizes capable of transiting, but also restricts any FWP adjustments to traffic configurations. Additionally, each of these construction impact curves were evaluated coincident with a tropical cyclone event, leading to an additional seven days of closure. This additional seven-day closure would be an unscheduled closure and could occur at any time during the year.

Figure 20 - 7 Day/7 Day/3 Day Construction Impacts Capacity Curve (FWP)

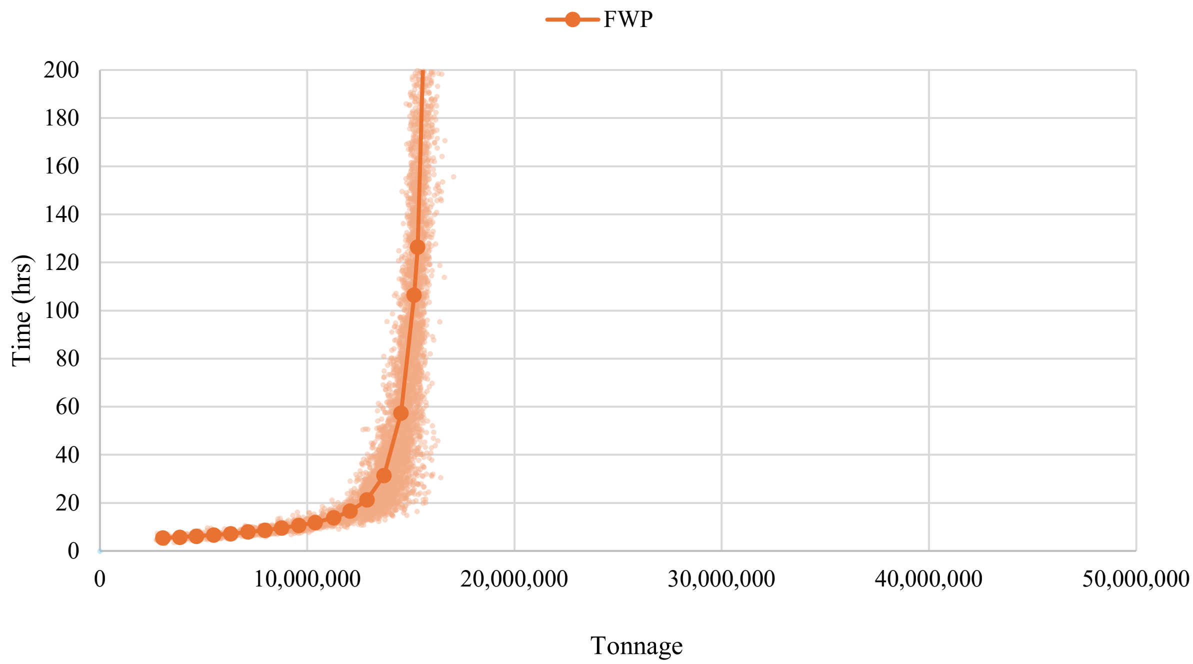


Figure 21 - 7 Day/7 Day/3 Day Construction Impacts, with Tropical Cyclone Capacity Curve (FWP)

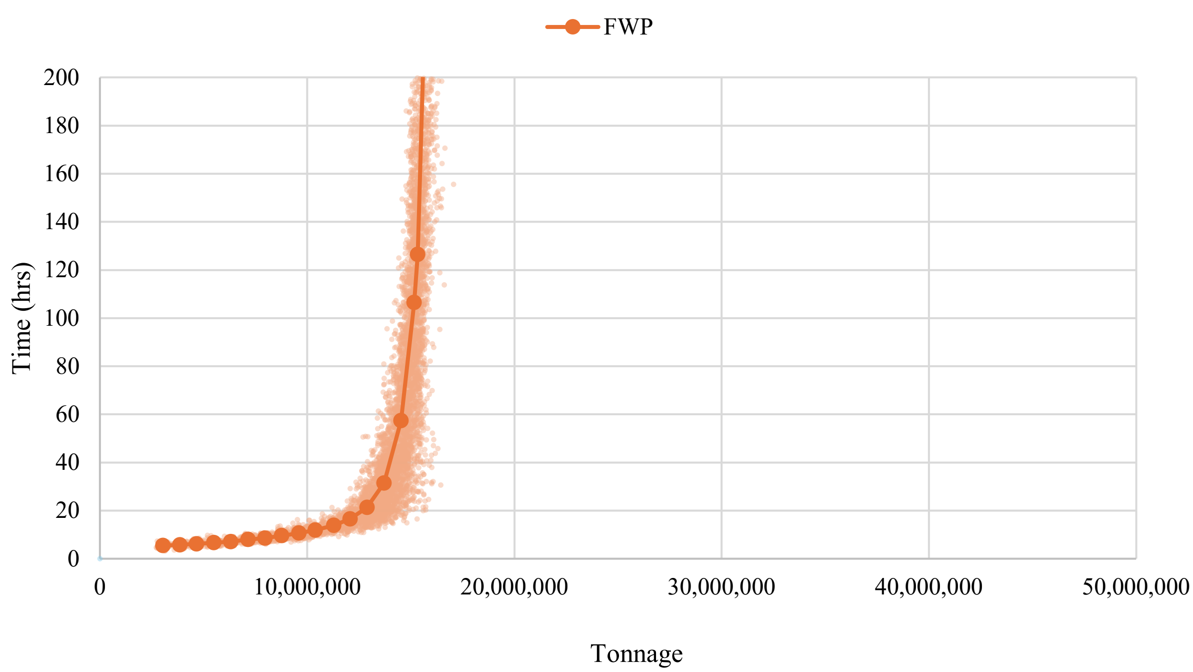


Figure 22 - 200 Day Construction Impacts Capacity Curve (FWP)

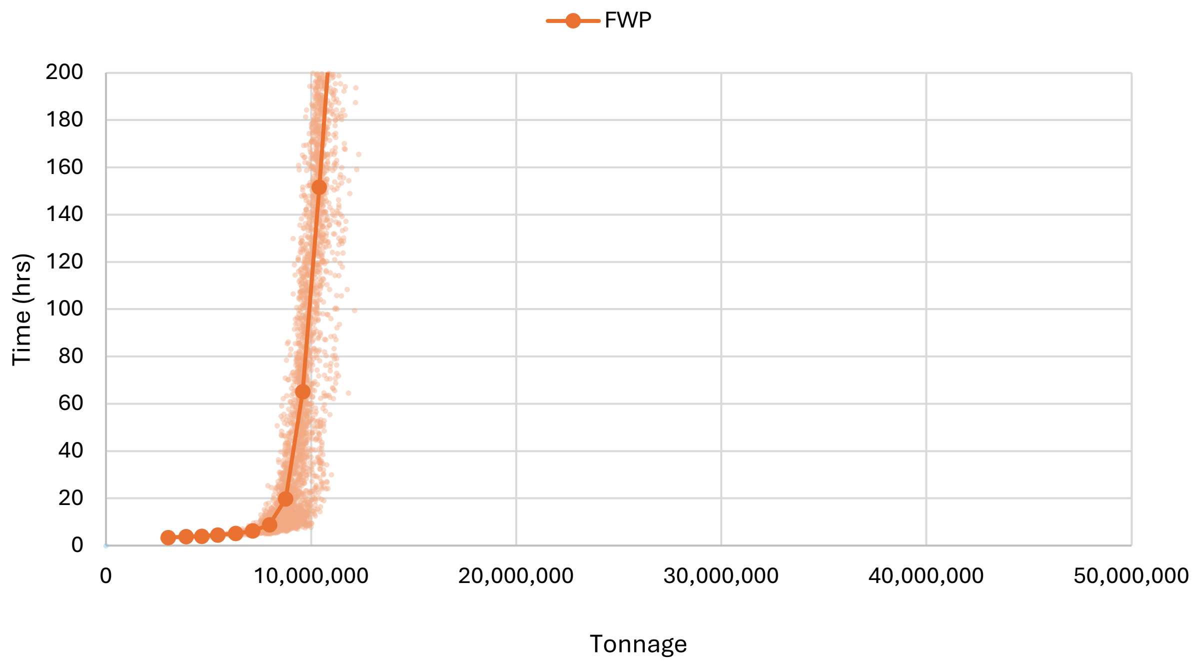
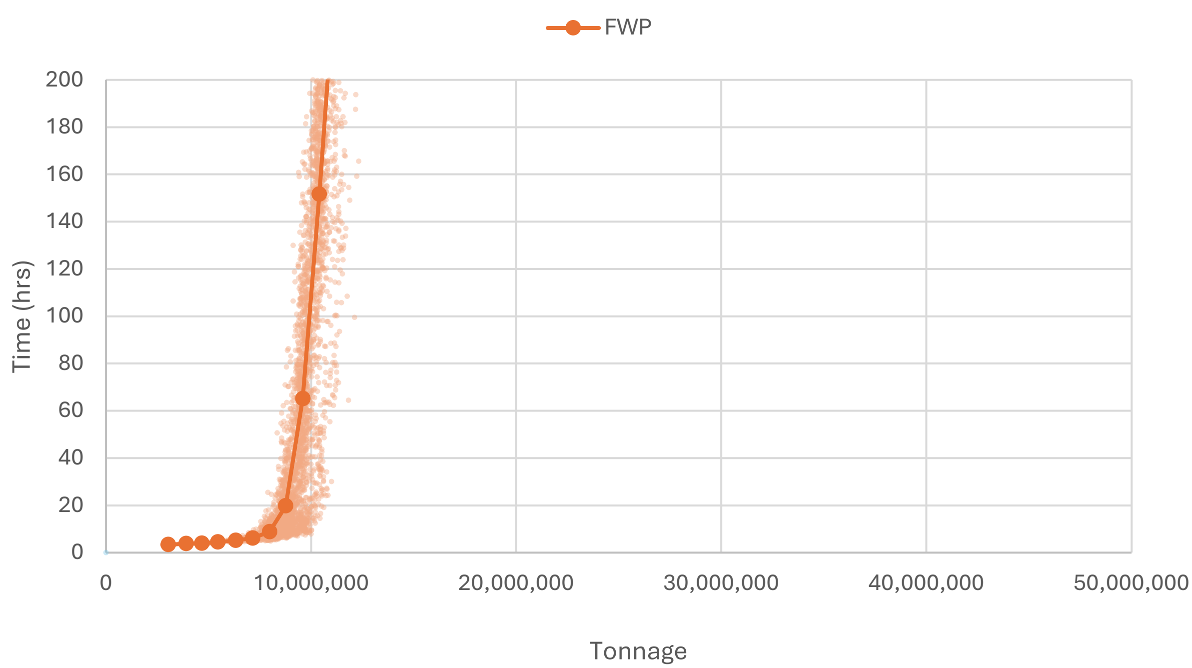


Figure 23 - 200 Day Construction Impacts, with Tropical Cyclone Capacity Curve (FWP)



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