Inshore Feeder Barge Conceptual Feasibility Study for Offshore Wind Farms

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Inshore Feeder Barge
Conceptual Feasibility Study for Offshore Wind Farms

Summary Report

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Abstract

This study supplements a collection of studies prepared on behalf of the New York State Energy Research and Development Authority (NYSERDA) to provide information related to a variety of environmental, social, economic, regulatory, and infrastructure-related issues implicated in planning for future offshore wind energy development off the coast of New York State. This study builds on the Assessment of Ports and Infrastructure, referred to as the "Ports Study" (COWI, 2017), to assess the feasibility of using an inshore feeder barge system to augment the capacity of offshore wind staging ports in New York Harbor. As a result of the Ports Study, a limited number of waterfront facilities were identified as potential installation and staging ports, primarily due to air draft limitations associated with area bridges. Many latest-generation Wind Turbine Installation Vessels (WTIVs) may be unable to pass below the bridges in order to reach those port facilities. The inshore feeder barge concept presents an alternative solution to air draft limitations that will enable existing waterfront facilities in New York Harbor and up the Hudson River to more readily support the implementation of offshore wind along the New York Bight. This study provides the framework necessary to advance the floating feeder barge concept as a means of transporting and staging offshore wind components. NYSERDA's intent is to facilitate the principled planning of future offshore development, to provide a resource for the various stakeholders, and to support the achievement of the State's offshore wind energy goals.

Keywords

offshore wind, feeder barge, vessel, ports study, bridge restriction, wind turbine installation vessel

Table of Contents

Figures

List of Tables

Acronyms and Abbreviations

AoA	Area of Analysis
BOEM	Bureau of Ocean Energy Management
BMP	Best Management Practices
CES	Clean Energy Standard (New York State)
GIS	Geographic Information System
H3	Significant Wave Height
JFK	John F. Kennedy (Airport)
M&F	Manufacturing and Fabrication
MHW	Mean High Water
mph	Miles per hour
MT	Metric Ton
NOAA	National Oceanic and Atmospheric Administration
NYS DEC	New York State Department of Environmental Conservation
NYSDOS	New York State Department of State
NYSERDA	New York State Energy Research and Development Authority
O&M	Operations and Maintenance
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act
OPC	Opinion of Probable Cost
OSA	Offshore Study Area
OSW	Offshore Wind
OTM	Offshore Transformer Module
OWA	Offshore Wind Area
psf	Pounds per Square Foot
RNA	Rotor-Nacelle Assembly
USACE	United States Army Corps of Engineers
WEA	Wind Energy Area
WTIV	Wind Turbine Installation Vessel
W	watts

Summary

This Inshore Feeder Barge Conceptual Feasibility Study is one in a collection of Offshore Wind studies being prepared on behalf of New York State. The study builds on the Assessment of Ports and Infrastructure, referred to as "Ports Study" (COWI, 2017), to assess the feasibility of using an inshore feeder barge system to augment the capacity of offshore wind staging ports in New York Harbor. As a result of the Ports Study, many sites were identified as showing promise for manufacturing and fabrication as well as operations and maintenance facilities. A limited number of waterfront facilities were identified as potential installation and staging ports, primarily due to air draft limitations associated with area bridges. Many latest-generation Wind Turbine Installation Vessels (WTIVs), whose jack-up legs can reach 84 m (276 ft.) above water level, are unable to pass below the bridges in order to reach those port facilities. The inshore feeder barge concept presents an alternative solution to air draft limitations that will enable existing waterfront facilities to more readily support the implementation of offshore wind (OSW) along the New York Bight. This study leverages the U.S. Jones Act Compliant Offshore Wind Turbine Installation Vessel Study (GustoMSC, 2017) as a source of information for Wind Installation Vessel (WTIV) and jack-up feeder barge operations.

The Inshore Feeder Barge Concept entails transporting offshore wind superstructure components, including nacelles, blades, and towers by floating barges from a staging port in New York Harbor, underneath the Verrazano-Narrows Bridge, to a component transfer area located in the more sheltered waters of Lower New York Harbor (Gravesend, Sandy Hook or Raritan Bays). The Verrazano-Narrows Bridge has an air draft (vertical clearance under the bridge) of 60 m (198 ft.) for the center 610 m (2,000 ft.) of the main span and a maximum clearance of 65.5 m (215 ft.) at the center of the bridge as per the NOAA Navigation Charts of the area. At the component transfer area, a WTIV-mounted crane lifts components from the floating barge and loads them on to the WTIV. The WTIV then proceeds to the offshore installation site. This concept yields a number of distinct advantages, including reduced transit time for the WTIV, the ability to use New York's existing port facilities without major infrastructure improvements to area bridges, and component transfer in relatively calm waters, reducing the risk of damaging critical components. All vessels in this study are assumed to be compliant with the Merchant Marine Act of 1920, also known as the "Jones Act."

The Vessel Study investigates two component transportation scenarios, including WTIV self-carry and the use of jack-up feeder barges. These methods may be challenging to implement in New York Harbor due to their air draft requirements. The inshore feeder barge study is unique in that it provides proof of concept for a floating barge as a means of transporting OSW components in New York's sheltered waters, in order to operate within New York Harbor's existing air draft constraints. The inshore feeder barge, when fully loaded with current generation OSW components, will have a maximum air draft of 52.6 m (173 ft.), leaving a sailing clearance of approximately 12.9 m (42 ft.) when transiting under the Verrazano-Narrows Bridge.

In order to provide a proof of concept for an inshore feeder barge as a means of transporting and staging OSW components, key design inputs were first explored and defined. These inputs include identifying characteristics of wind turbine components, potential transfer areas, and the environmental characterization associated with each potential transfer area. This study sought to identify a barge capable of transporting a similar number of components as the WTIV, specifically: four nacelles, 12 blades, and eight tower sections (including four tower bottom and four tower top sections). Five potential transfer areas (locations A–E) were identified within New York Harbor's Lower Bay, Sandy Hook Bay, and Raritan Bay in order to begin a discussion among waterway stakeholders to locate a suitable transfer area. A high-level GIS analysis of the areas was completed using publicly available information on factors that may influence use of certain areas (water depth, obstructions, anchorages, pipelines, etc.). A DHI Mike21 Spectral Wave model was created and simulated for the Area of Analysis (AoA), using the area's bathymetry and wind data, which was extracted from John F. Kennedy (JFK) Airport. Wind and wave results were obtained for each of the potential transfer locations. These results were later used to obtain total availability of the feeder barge system in each transfer area and to verify stability of the inshore feeder barge.

Since the use of floating barges to transport OSW components is well known in the industry, the characteristics of vessels available in the New York market were used for the first order analyses to understand the viability associated with transferring components, including loading conditions, availability, and stability. Two representative barges were identified and used as a basis for the inshore feeder barge concept due to their size, load capacity, and ability to meet the design basis requirements as per the defined inputs. Both barges were evaluated in order to investigate the difference in response to environmental conditions for a barge that is 100.6 m (330 ft.) in length (to be referred to as the "330-foot barge") versus 122 m (400 ft.) in length (to be referred to as the "400-foot barge"). Table S-1 summarizes the principle characteristics of both barges.

Table S-1. Inshore Feeder Barge Principle Characteristics Basis

Parameter	330-foot Barge[a]	400-foot Barge[b]
Length Overall	100.6m (330 ft.)	122m (400 ft.)
Hull Width	30.5m (100 ft.)	36.6m (120 ft.)
Hull Depth	6.1m (20 ft.)	7.6m (25 ft.)
Deck Loading	20MT/sq. m (4,096 psf)	25MT/sq. m (5,120 psf)
Transit Speed	4 knots (5 mph)	4 knots (5 mph)

Note(s):

[a] Based on the *JMC 3341* vessel, information provided on the Cashman Equipment Corp. website.

[b] Based on the *Miss Hannah* vessel provided on the Cashman Equipment Corp website.

Hydrodynamic analyses were performed for both barges in each transfer location using both ANSYS Aqwa and Orcina Ocraflex software in order to assess the barges' response to environmental conditions. Both barges were analyzed using a conventional spread mooring system. Stability was assessed by examining two stability dimensions pertaining to the center of gravity of the vessel as well as the restoring force when subject to wind and waves—which were found to be satisfactory for both barges. The availability is limited by the barge response to waves and wind as well as wind speed limitations for performing lifts during the barge-to-WTIV transfer process. It was found that the total operational availability for the three southward transfer locations (Areas B, C, D) and the northeast transfer location (Area E) was 95% for both barges, due to wind. Whereas the northward location (Area A) has a total availability of 94% and 93% for the 330-foot barge and 400-foot barge, respectively, due to wave conditions at the site. These results confirm the major operational goal to have the inshore feeder barge available at virtually all times to ensure that the WTIV has no downtime.

In order to estimate cost and schedule impacts associated with an inshore feeder barge, three scenarios were explored for installing turbines at the offshore wind area (OWA). At the time the study was initiated, the OWA used the New York Wind Energy Area (NY WEA) for the purposes of performing calculations; while this study was performed, Equinor executed a lease of the NY WEA for their Empire Wind Offshore Wind Farm (EWOWF). The first two of the three scenarios are based on the installation methods detailed in the Vessel Study; these scenarios serve as a baseline for comparison to the inshore feeder barge concept. The scenarios include using the following: (1) a WTIV only with the New Bedford Terminal in Massachusetts serving as a staging port; (2) a WTIV and two jack-up feeder barges (with jack-ups), with the WTIV staying on site at the OWA, while the feeder barges transport components from New Bedford Terminal to the WTIV continuously; and (3) a WTIV and inshore feeder barge (floating), in which the feeder barge transports components from a waterfront terminal in New York Harbor to an inshore area and then transfers them to the WTIV which then transits to the OWA. For the third scenario, the South Brooklyn Marine Terminal was selected as a representative waterfront facility. It should be noted that the selection of specific OWAs and terminals is not intended to be an endorsement or selection by New York State. Rather they were selected for the purposes of preparing representative cost and schedule comparisons. A high-level schedule was completed for each scenario. The total durations were further used to understand the associated costs. Table S-2 summarizes the findings. An important consideration that goes beyond the cost numbers is the economic benefits associated with each alternative. Unlike scenarios 1 and 2, the inshore feeder barge scenario 3 may be implemented in New York Harbor, potentially resulting in greater economic benefits for New York State than some alternatives.

Table S-2. Duration and Cost Summary for Scenarios 1-3

Scenario	1 Turbine		% Change from Scenario 1	
	Days	Cost	Days	Cost
Scenario 1 - WTIV Only	2.7	$590,150		
Scenario 2 - WTIV & 2 Jack-Up Feeder Barges	2.1	$817,375	-29% Decrease	+28% Increase
Scenario 3 - WTIV & Inshore Floating Barge	2.5	$631,841	-8% Decrease	+7% Increase

This study provides the framework necessary to advance the floating feeder barge concept as a means of transporting and staging OSW components. Although in the scenarios analyzed the inshore feeder barge concept is anticipated to cost 7% more than using only a WTIV, it costs 29% less than the use of a WTIV and jack-up feeder barges and opens up access to multiple facilities in New York Harbor and up the Hudson River that may result in further economies such as lower labor and land costs. Additionally, the schedule savings associated with the inshore feeder barge (8% more time effective than using only a WTIV) may allow the wind farm to be commissioned earlier, therefore potentially resulting in earlier revenues. Note that the cost comparison is a direct comparison of installation vessel strategies for turbine components only; costs are not inclusive of other impacts to cost of energy, including cost of materials, installation of other components or operations and maintenance costs. As a result of this study, the inshore feeder barge concept was proven to be a technically viable and potentially economically efficient solution to the air draft restrictions in New York State.

1 Introduction

This Inshore Feeder Barge Conceptual Feasibility Study (Feeder Barge Study) is one of a collection of studies prepared on behalf of New York State that provide information on a variety of potential environmental, social, economic, regulatory, and infrastructure-related issues associated with the planning for future offshore wind energy development off the coast of the State. When the State embarked on these studies, the initial focus was on a study area identified by the New York State Department of State (DOS) in its two-year Offshore Atlantic Ocean Study (DOS 2013). This original offshore study area (OSA) is a 16,740-square-mile (43,356-square-kilometer) area of the Atlantic Ocean extending from New York City and the south shore of Long Island, to beyond the continental shelf break and slopes into oceanic waters to an approximate maximum depth of 2,500 meters. While the location of future offshore wind development is planned in an area encompassing much of the original OSA, each of the State's individual studies ultimately focused on a geographic Area of Analysis (AoA) that was unique to that respective study. The AoA for this study is described below in Section 1.1.

The State envisions that its collection of studies will form a knowledge base for the area off the coast of New York that serves a number of purposes, including (1) informing the Bureau of Ocean Energy Management (BOEM) Call for Information and Nominations process about the New York Bight Call Areas; (2) providing current information about potential environmental and social sensitivities, economic and practical considerations, and regulatory requirements associated with any future offshore wind energy development; and (3) identifying measures that could be considered or implemented with offshore wind projects to avoid or mitigate potential risks involving other uses and/or resources. NYSERDA released a Master Plan in January of 2018, which articulated New York State's vision of future offshore wind development. The Master Plan identifies potential future wind energy areas for BOEM's consideration, discusses the State's goal of encouraging the development of 2,400 megawatts (MW) of wind energy off the New York coast by 2030, and sets forth suggested guidelines and best management practices (BMPs) that the State will encourage to be incorporated into future offshore wind energy development. This report is supplemental to the Master Plan and has been provided to aid decision making by federal agencies, project sponsors, and the entire offshore wind supply chain.

This Inshore Feeder Barge Conceptual Feasibility Study builds on the Ports Study (COWI, 2017), which identifies a number of waterfront sites that showed notable potential to be used or developed into facilities capable of supporting offshore wind development. Many of these sites were identified for their potential to serve as manufacturing and fabrication facilities as well as operations and maintenance facilities. The

Ports Study identified few waterfront facilities in New York State with unrestricted air draft, which poses challenges to their use as staging and installation facilities. In order to access the majority of identified facilities, a vessel must be capable of transiting beneath the Verrazano-Narrows Bridge, which has an air draft (vertical clearance under the bridge) of 60 m (198 ft.) for the center 610 m (2,000 ft.) of the main span and a maximum clearance of 65.5 m (215 ft.) at the center of the bridge. Per the U.S. Army Corps of Engineers Controlling Depth Report for the Ambrose Channel (September 1, 2017), the water depth below the bridge ranges from approximately 22.9 m (75 ft.) at the west edge of the channel to 29 m (95 ft.) at the east edge of the channel with a maximum depth of approximately 29.9 m (98 ft.) just east of the centerline. The air draft for the center 610 m (2,000 ft.) of the bridge over the navigation channel, the available water depth below the span, and the tidal range, provides approximately 84.7 m (278 ft.) clearance between the bottom of the navigation channel and the bottom of the bridge. Many latest-generation Wind Turbine Installation Vessels (WTIVs), whose jack-up legs can reach 84m (276 ft.) above water level, are unable to pass below the bridges in order to reach those port facilities. It is not favorable from a maneuverability stand point for a WTIV to transit with its legs jacked down beneath its hull. However, even with the jack-up legs in a partially down position, many WTIVs would be unable to transit below the Verrazano-Narrows Bridge.

The inshore feeder barge concept presents an alternative solution to New York's challenging air draft restrictions. In this concept, offshore wind superstructure components, including nacelles, blades, and towers are transported by a floating barge from a staging port in New York Harbor (the South Brooklyn Marine Terminal was used as a reference facility), underneath the Verrazano-Narrows Bridge, to a component transfer area located in the sheltered waters of Lower New York Harbor, Sandy Hook Bay or Raritan Bay. The inshore feeder barge, when fully loaded with components, will have a maximum air draft of 52.6 m (173 ft.), leaving a sailing clearance of approximately 12.9 m (42 ft.) when transiting under the Verrazano-Narrows Bridge. Once the feeder barge is in the transfer location, it secures itself in position and waits for the WTIV. Once the WTIV is at the transfer location, it jacks-up in order to secure its position, loads the components from the barge onto itself, and then jacks-down to refloat and transit to the installation site. From there, the WTIV continues the transit to the offshore installation site while the inshore feeder barge returns to the staging area to load the next components. This cycle is repeated until turbine installation is complete. The activities of the inshore feeder barge and WTIV are sequenced to minimize downtime for the WTIV.

This concept yields a number of distinct advantages, including reduced transit time for the WTIV, the ability to use New York's port facilities without major infrastructure improvements to area bridges, and component transfer in a relatively protected environment, reducing the risk of damaging critical components. This study provides proof of concept that a floating barge may be used as a means of transporting OSW components from existing waterfront facilities to a transfer area in New York's sheltered waters, in order to operate within New York Harbor's existing air draft constraints.

1.1 Scope of Study

This study focuses primarily within New York Harbor, specifically on the waters south of the Verrazano-Narrows Bridge and west of Sandy Hook, New Jersey, and Breezy Point, NY. This AoA is relatively sheltered and offers calmer weather conditions, which will help to limit motions of the floating barge during component transfer operations. In order to investigate the viability of using a floating barge to transport and stage OSW components, the following tasks were completed:

1.1.1 Investigate Transport and Transfer Scenarios

The study investigated three turbine installation scenarios. The first two scenarios leverage information presented in the U.S. Jones Act Compliant Offshore Wind Turbine Installation Vessel Study, referred to as the Vessel Study in this report, completed by GustoMSC in October 2017, and to serve as a baseline for comparison. The third scenario uses the inshore feeder barge concept. The scenarios include turbine installation using the following:

Scenario 1: A WTIV only, self-transporting components from the New Bedford Terminal in Massachusetts (staging port) to the offshore wind area (OWA).

Scenario 2: A WTIV and two jack-up feeder barges (with jack-ups); the WTIV remains at the OWA while the feeder barges transport components from New Bedford Terminal to the WTIV continuously.

Scenario 3: A WTIV and one inshore feeder barge (floating), in which the feeder barge transports components from South Brooklyn Marine Terminal (reference staging facility) to an inshore transfer area; components are transferred to the WTIV, which then completes the transit and installation at the OWA.

1.1.2 Identify Design Inputs

Inputs investigated and defined include the OSW component dimensions and weights, potential inshore transfer areas, and the met-ocean characteristics associated with these areas. To identify transfer areas, a high-level, GIS-based analysis of Lower New York Harbor, Sandy Hook Bay, and Raritan Bay was completed in order to identify potential transfer areas. Publicly available information on fairways, water depth, and different forms of obstructions, easements, and critical environments were gathered in order to depict the five potential areas explored. Wave characteristics were defined using DHI's MIKE21 Spectral Wave model, and wind data was obtained from John F. Kennedy (JFK) Airport. Wind and wave results were then correlated and analyzed for each transfer area.

1.1.3 Specify Inshore Feeder Barge Characteristics

Using the necessary inputs investigated, principle characteristics for the feeder barge design were defined based on vessels already available in the New York State Typical barges used in the U.S. were also briefly discussed.

1.1.4 Analyze Barge Station Keeping Alternatives

A station keeping methods alternatives analysis was completed in order to investigate several ways to maintain the inshore feeder barge's position during the transfer of components to the WTIV.

1.1.5 Define Inshore Feeder Barge Operations

Barge deck layouts were defined in order to provide the number of OSW components to be accommodated. An outline for the overall inshore feeder barge transfer process was also laid out, based on the most fitting station keeping method.

1.1.6 Analyze Inshore Feeder Barge Buoyancy, Stability, and Availability

Availability of the inshore feeder barge in the AoA was determined by analyzing barge motions based on wave and wind conditions. Wind and wave thresholds were defined, as they dictate lifting limitations. Stability was also analyzed in the loaded condition to confirm that the stability criteria as per the barges' Stability Booklets were met. Analyses were performed in the hydrodynamic analysis software ANSYS Aqwa and Orcina Orcaflex.

1.1.7 Project Schedules and Opinions of Probable Cost

High-level schedules were created for each of the three scenarios. These schedules were then used to complete Opinions of Probable Cost (OPCs) for each scenario, based on vessel day rates provided in the Vessel Study as well as pricing information obtained from marine contractors active in the New York market.

2 Inshore Feeder Barge Operation

The following sections further outline the inshore feeder barge concept. The vessels and procedures required for the transfer of OSW components from the feeder barge to WTIV are described. Variations and alterations of the described operations are possible, depending on a number of factors, including project capacity, available equipment, regulatory considerations and more. However, this series of operations has been developed to illustrate the potential of the inshore feeder barge concept.

Descriptions are provided for potential methods of towing the inshore feeder barge from the land-based staging facility to the transfer area, mooring setup in the transfer area, mooring the feeder barge in the transfer area, and transferring components onto the WTIV.

2.1 Onshore Staging Facility

Offshore wind components are gathered at an onshore staging facility, prior to being loaded onto the inshore feeder barge. This analysis uses the South Brooklyn Marine Terminal, in Brooklyn, NY as the reference facility. However, results of the analysis are generally similar for other terminals in New York Harbor (e.g., South Brooklyn Marine Terminal, Global Container Terminal—Staten Island, etc…). Component staging may also take place at facilities located on the Hudson River (e.g., Port of Coeymans and Port of Albany), which typically have lower facility and labor costs. However, analyzing the trade-offs of using different onshore port facilities was beyond the scope of this report, which is intended to evaluate potential solutions to air-draft constraints.

2.2 Towing Tugs

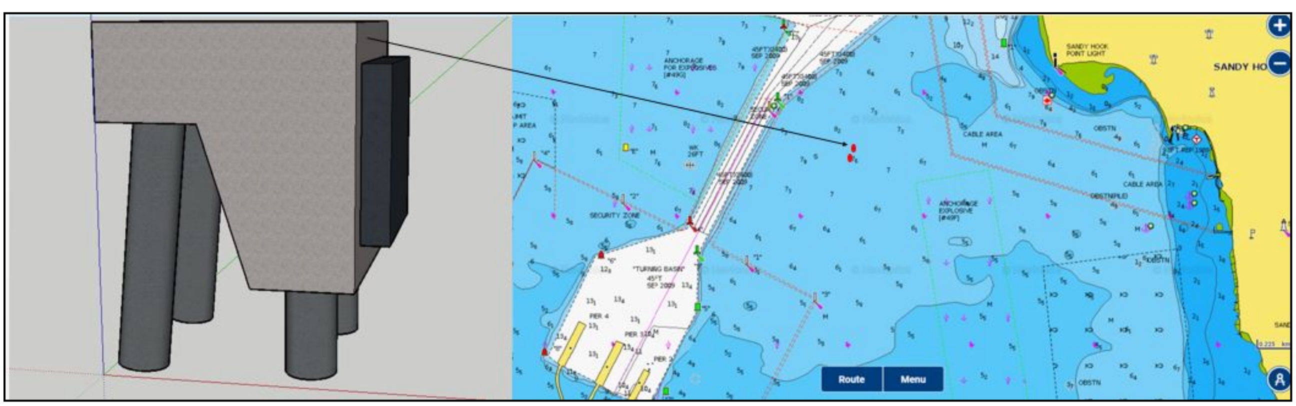
To tow and maneuver the inshore feeder barge, two tugs are recommended. Tug 1 should have towing capacity (bollard pull) of approximately 50 metric tons (MT) while tug 2 should have approximately 30–40 MT bollard pull. In addition to the towing tugs, a mooring vessel will be required on the transfer location to connect the mooring lines to the barge. The types of tugs with the required capacities are commonly available in the New York area.

Figure 1. Representative 46 MT Bollard Pull Tug for Barge Transport

2.3 Transfer Location and Mooring Setup

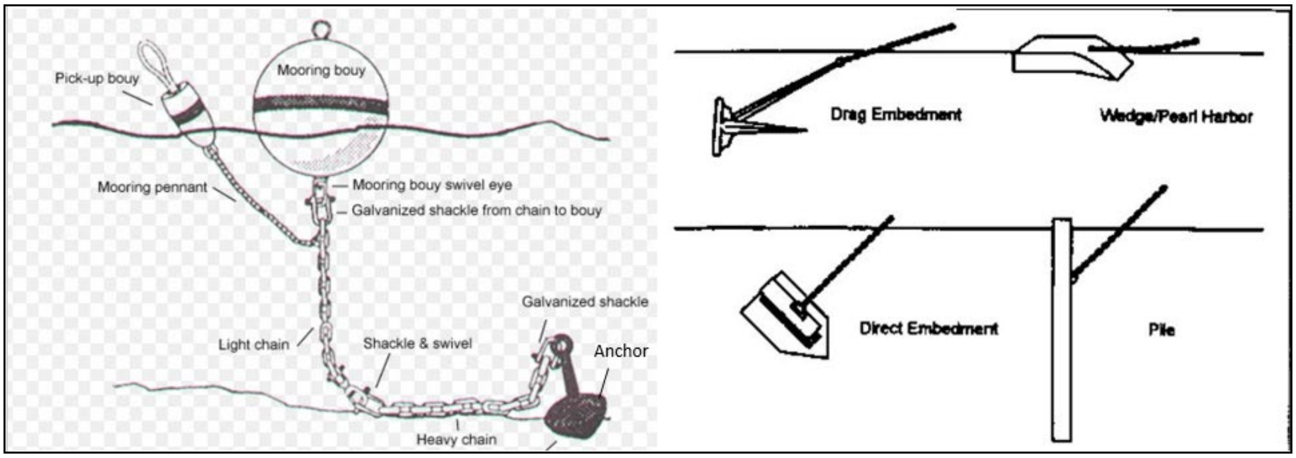
A number of potential transfer areas were identified and are discussed in further detail in Section 4.2. The transfer location used for the schedule and OPC estimates is in the sheltered waters of Sandy Hook Bay. The station keeping method chosen for this analysis is a combined system consisting of two breasting dolphins and four spread mooring lines. An image of the breasting dolphin design and the location of the dolphins is shown in Figure 2.

Figure 2. Transfer Location with Breasting Dolphins



The mooring system consists of a mooring buoy connected to an anchor with a chain or combined wire and chain; the system occupies an area of approximately 22.7 hectares (56 acres). A mooring pennant on the chain beneath the buoy is recommended for ease of pick up and connection to the barge. The mooring system and various anchors alternatives are illustrated in the Figure 3.

Figure 3. Mooring System Setup and Anchor Options

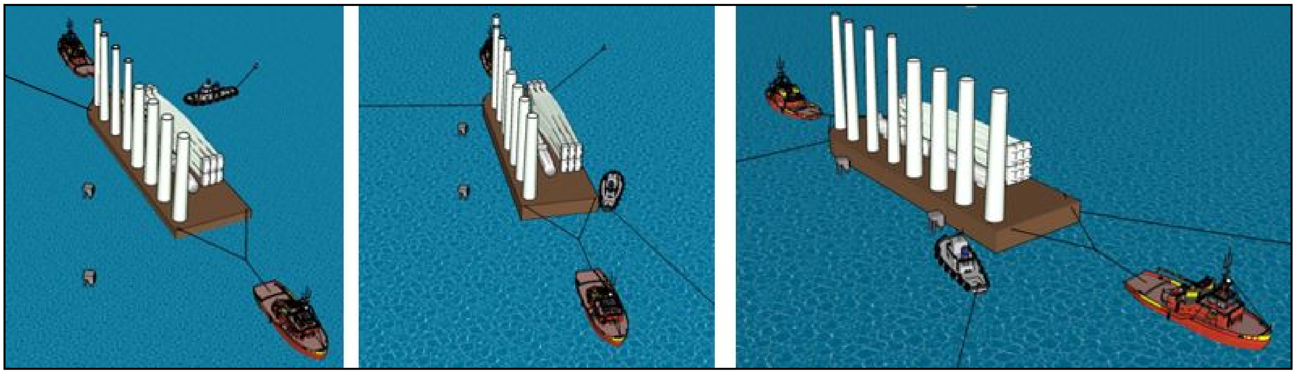


2.4 Component Transfer Outline

The offshore wind component transfer process from the inshore feeder barge to the WTIV at the transfer location is shown in the following figures. After the four sets of components are transported approximately 14 nautical miles (26 km) by the inshore feeder barge from the staging facility to the transfer location, the barge is moored to the breasting dolphins and mooring lines. Once the barge is positioned with the moorings, the WTIV takes position next to the barge, jacks up and transfers the OSW components from the barge onto the WTIV.

In the envisioned concept, two tugs are used to the tow the inshore feeder barge from the staging facility to the transfer location. Once the inshore feeder barge is at the transfer site, the two tugs hold the barge in position while a third, smaller, mooring vessel connects the preinstalled mooring lines to the winches on the barge. The breasting dolphins at the transfer site will be used to keep the barge in position during lifting operations. The mooring process is shown in Figure 4.

Figure 4. Mooring Process for the Barge at the Transfer Location

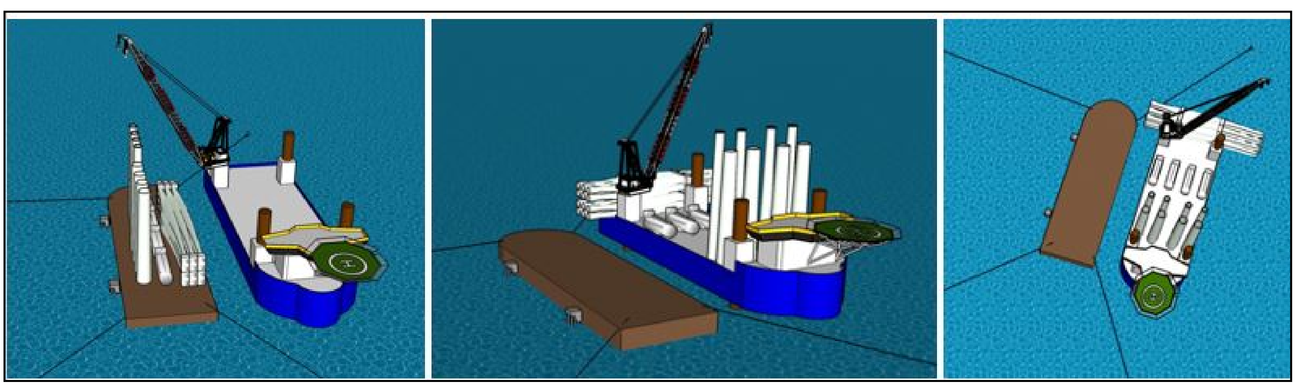


When the barge is moored and ready to transfer components, the WTIV will come in and jack-up next to the barge in order to lift the components from the barge to itself. The blades will be lifted on first, in sets of two or four, then the nacelles will be transferred, followed by the tower sections. Figure 5 and 6 show the component transfer process.

Figure 5. Wind Turbine Blades during Lifting Operations

Figure 6. WTIV Deck Loaded with OSW Components

Figure 7. Sketches of Components Transferred from the Barge to WTIV

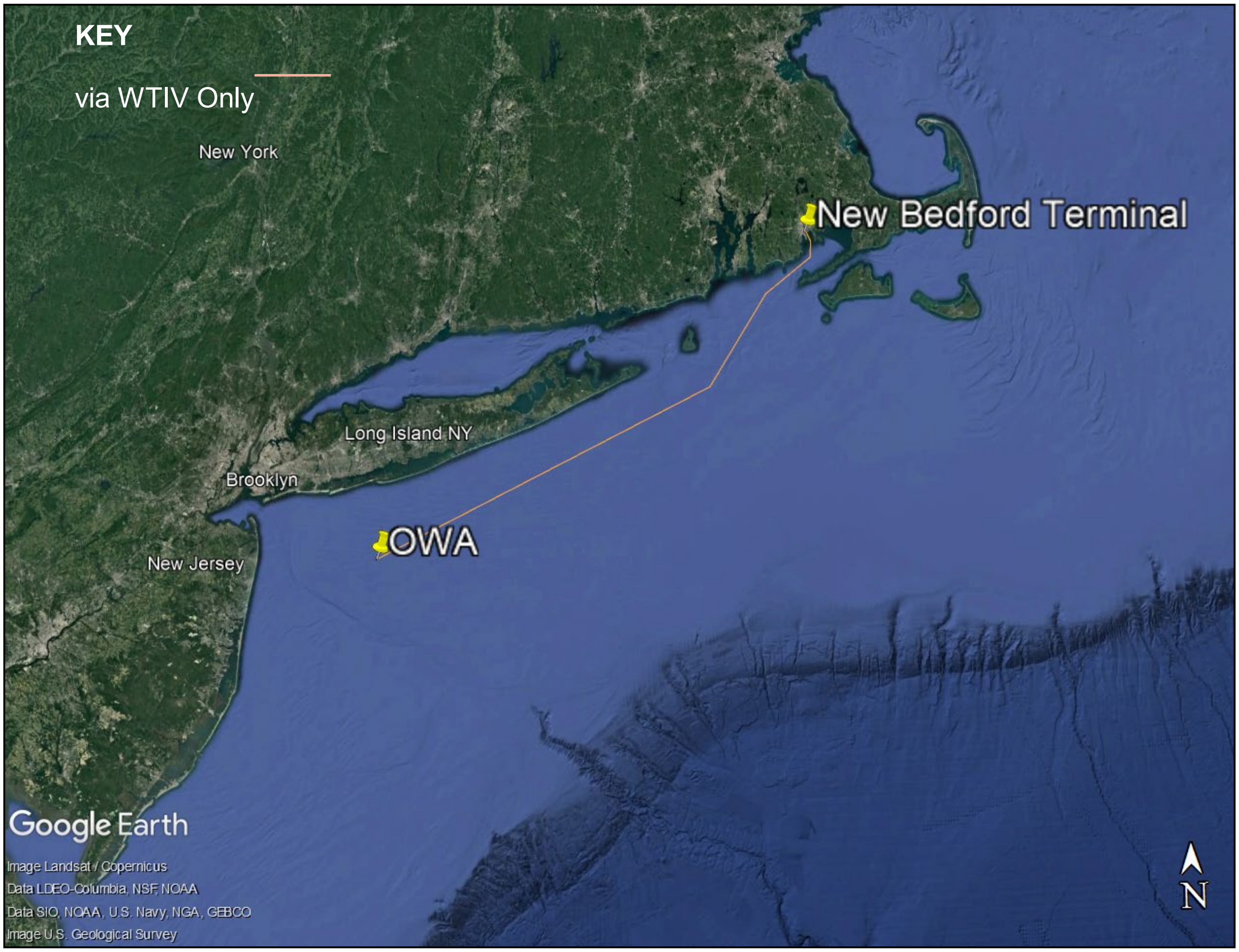


3 Transport and Transfer Scenarios

In order to understand the viability and logistics associated with the inshore feeder barge concept, this study compares the inshore feeder barge with two baseline scenarios for a total of three transport and transfer scenarios. Each scenario uses a different staging, transport, and transfer methodology. This study leverages the work of the Vessel Study for the two baseline scenarios. Since New York State has limited land-based options that could serve as a staging facility without air draft restrictions, the baseline comparison scenarios use the New Bedford Terminal in Massachusetts as a staging port, in which the WTIV and/or jack-up feeder barges would transit to/from New Bedford in order to deliver components to the Empire Wind project site. The inshore feeder barge concept uses South Brooklyn Marine Terminal as an intermediary staging port to load components on to the inshore feeder barge and uses an area in the sheltered waters of New York Harbor (including the Lower, Raritan, and Sandy Hook Bays) to transfer components from inshore feeder barge to WTIV. Each scenario is a basis of comparison for turbine installation duration and cost to be further discussed in Section 8. The scenarios investigated are defined along with an aerial view of barge routes:

Scenario 1. WTIV only as seen in Figure 8: The WTIV performs self-carry, transporting components from the New Bedford Terminal (staging port) to the OWA, where it then installs the turbines and returns to the staging port. The steaming distance for scenario 1 is approximately 222 km (120 nautical miles). Scenario parameters are based on the Vessel Study.

Figure 8. Scenario 1—WTIV Only from New Bedford Terminal to OWA



Scenario 2. WTIV and two jack-up feeder barges as seen in Figure 9: The feeder barges complete continuous round-trips from the New Bedford Terminal to the OWA, a steaming distance of approximately 222 km (120 nautical miles). On arrival at the OWA, the components are installed directly from the feeder barge by the WTIV, which stays on the project site at all times. Scenario parameters are based on the Vessel Study.

Figure 9. Scenario 2—Feeder Barge from New Bedford Terminal to OWA/WTIV

Scenario 3. WTIV and inshore feeder (floating) barge as seen in Figure 10: The feeder barge transports components from South Brooklyn Marine Terminal (reference land-based staging facility) to the inshore transfer area (in the Lower New York Harbor area), a steaming distance of approximately 26.5 km (14.3 nautical miles). At the inshore transfer area, the components are transferred onto the WTIV, which then transits the approximate 71.1 km (38.4 nautical miles) to the OWA to install the turbines.

Figure 10. Scenario 3—Inshore Feeder Barge from South Brooklyn Marine Terminal to Transfer Area to WTIV, then WTIV to OWA

The three scenarios are referenced throughout this Study and were used to create the schedule and cost estimates discussed further in Section 8.

3.1 Overview of Comparison Scenario Vessels

Typical operational parameters associated with a latest generation WTIV and jack-up feeder barges have been defined based on the Vessel Study. The study examines the required functionality, financial considerations, and design of a Jones Act compliant WTIV and jack-up feeder barge for input into a vessel owner's risk assessment. This information was used as a basis for the comparison scenarios, as discussed above, and was also used to build out the inshore feeder barge concept as it requires the transferring of components onto a WTIV. Table 3-1 summarizes the operational parameters associated with the GustoMSC's NG-9800C WTIV and NG-3750C Feeder Barge.

Table 3-1. GustoMSC's NG-9800C WTIV and NG-3750C Feeder Barge Operational Parameters

Parameter	Vessel	
	WTIV	Jack-Up Feeder Barge
Representative Vessel Class	NG-9800C	NG-3750C
Hull Length (main deck)	127.8m (419 ft.)	70.5m (231 ft.)
Hull Width	42m (138 ft.)	38m (125 ft.)
Hull Depth	10m (33 ft.)	6.5m (21 ft.)
Hull Draft	5.8m (19 ft.)	0m (0 ft.)
Leg Length [incl spudcan]	92m (302 ft.)	86m (282 ft.)
Leg Length under hull [max]	69m (226 ft.)	68m (223 ft.)
Transit Speed	11 knots	6-7 knots
Variable Load	6400 MT	3400 MT
Main Crane Capacity	1500 MT	N/A
Transit Draft	7.9m (26 ft.)	N/A
Max Water Depth Accommodation	55m (180 ft.)	55m (180 ft.)
PoB: Minimum Crew Accommodation	90 people	12 people

4 Inshore Feeder Barge Design Basis

To inform the design of the inshore feeder barge, several inputs were investigated. These inputs include definition of the OSW components (nacelles, blades, and towers) dimensions and weights, potential transfer areas in the sheltered waters of New York Harbor, and the environmental conditions (wind and waves) associated with these potential locations.

4.1 Wind Turbine Components

The goal was to identify and/or design a suitable inshore feeder barge that could transport the same type and quantity of OSW components as the WTIV. For this study, each vessel is capable of transporting four nacelles, 12 blades, and eight tower sections (four tower bottom and four tower top sections). The wind turbine components defined were used as a basis to understand the necessary size and load capacity of the inshore feeder barge. The component definitions presented are intended to be representative of the 8-MW turbines anticipated to be installed in the OWA. The parameters are combined from the Ports Study and the Vessel Study. In addition to the OSW components, the feeder barge needs to have deck space available for four mooring winches with hydraulic power units in each corner, as well as towing bridles at both ends of the barge. Deck layouts and transport and transfer specifics are further discussed in Section 5.

Table 4-1. 8-MW Wind Turbine Component Characterization

	Blade	Nacelle	RNA	Tower
Length	85m (290 ft.)	21m (69 ft.)	---	6.75m (22 ft.)
Width	5.5m (18 ft.)	9.6m (32 ft.)	---	6.75m (22 ft.)
Height	4.5m (14.8 ft.)	7m (23 ft.)	---	94m (308 ft.)
Mass/Weight	40t (44 tons)	450t (496 tons)	495t (545 tons)	500t (551 tons)

Note(s): Wind component characteristics were obtained primarily from the Vessel Study; where necessary, additional characteristics were obtainedfrom the Ports Study.

4.2 Potential Transfer Areas

The inshore feeder barge concept relies on the calm waters in New York Harbor, rather than the offshore project site (OWA) to transfer the components to the WTIV. Specifically, this study evaluates the areas of Lower New York Harbor south of the Verrazano Bridge. It is necessary to identify a regular area in which transfer can occur due to the nature of repeated operations and the requirements of the WTIV during transfer.

The intent of this section is to begin the discussion between relevant stakeholders to identify a viable transfer area. This report does not recommend any particular transfer area. A high-level, GIS-based analysis of New York Harbor's Lower Bay, Sandy Hook Bay and Raritan Bay was performed to identify possible transfer areas. Publicly available data, including water depth, obstructions, anchorages, pipeline areas, fairways, submerged cable areas, and critical environmental areas was compiled. By considering these existing exclusionary uses, five potential locations for the feeder barge transfer area were identified. Advantages and challenges associated with each area are discussed below. Authors of this study acknowledge that additional coordination and review will be required to advance any of the potential transfer areas.

Note that the actual area occupied by the mooring system described in Section 2.3 is approximately 22.7 hectares (56 acres) to account for the spread of the anchors. The actual area occupied by the vessels during transfer is significantly less.

4.3 Exclusionary Uses

Water Depth

Water depth was obtained from NOAA Navigation Charts. Based on parameters from the GustoMSC NG-9800C-US WTIV, the fully-loaded WTIV requires a navigational draft (minimum water depth while moving) of 8 m (26 ft.). The fully-loaded inshore feeder barge also requires a minimum water depth of 8 m (26 ft.) to navigate. Therefore, selection of the transfer area will be based on the navigational draft of the WTIV. Depths that do not meet this criterion will require dredging. Although it may be possible to use shallower areas, the use of shallower areas will prevent the WTIV and barge from being fully loaded, reducing the number of components carried by the WTIV and decreasing the installation efficiency.

Obstructions

Obstructions were obtained from NOAA Electronic Navigation Chart GIS data. For this analysis, obstructions did not preclude consideration of a transfer area; however, areas with significant or multiple obstructions were avoided.

Anchorages

Anchorages were obtained from NOAA Electronic Navigation Chart GIS data. A buffer of 100m (328 ft.) was used between existing anchorages and potential transfer locations (excluding location D).

Pipeline Areas

Pipeline areas were obtained from NOAA Electronic Navigation Chart GIS data. A buffer of 200 m (656 ft.) was used between existing pipeline areas and potential transfer locations.

Fairways

Fairway areas were obtained from NOAA Electronic Navigation Chart GIS data. A buffer of 100m (328 ft.) was used between existing fairways and potential transfer locations.

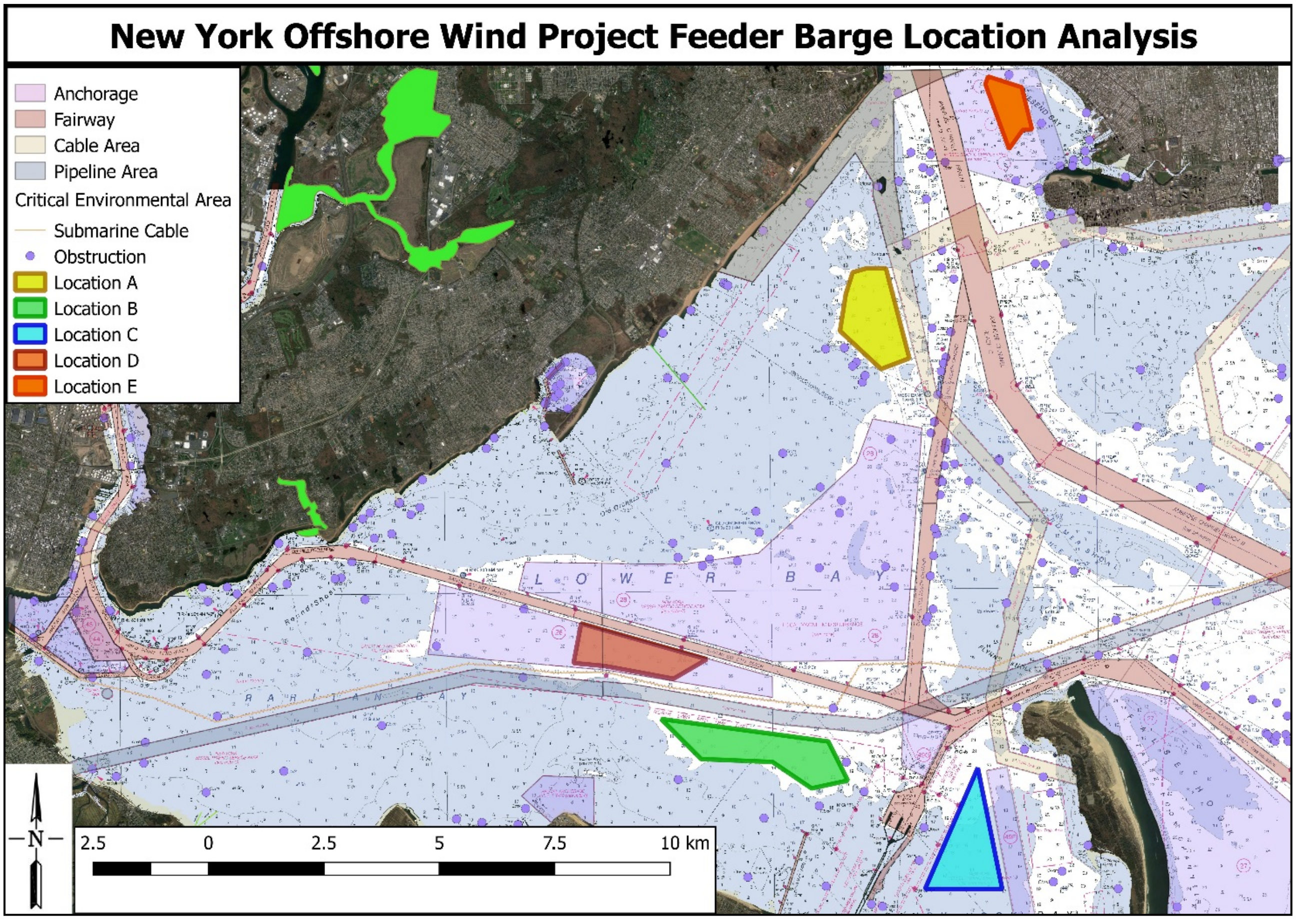
Submerged Cable Areas

Submerged cable areas were obtained from NOAA Electronic Navigation Chart GIS data. A buffer of 100 m (328 ft.) was used between existing submerged cable areas and potential transfer locations.

Critical Environmental Areas

Critical environmental areas were obtained from the New York State Department of Environmental Conservation (DEC). No potential transfer locations were within 6 km (3.7 miles) of a critical environmental area.

Figure 11. Potential Inshore Feeder Barge Transfer Locations



4.3.1 Location A

Location A encompasses an area of approximately 216 hectares (534 acres), located approximately 5.5 km (3.4 miles) south of the Verrazano Bridge directly west of the shipping lane. The primary benefits of this location include its relative proximity to New York Harbor and water depths of 6.4m to 7.9m (21 ft. to 26 ft.), requiring a moderate amount of dredging relative to the other potential locations. However, its proximity to Staten Island may present temporary view shed issues for local residents, and the directly adjacent cable areas and obstructions may present navigational hazards. Unlike locations B–E, location A is relatively unsheltered and subject to ocean waves entering New York Harbor from the southeast.

4.3.2 Location B

Location B encompasses an area of approximately 262 hectares (647 acres), located approximately 5.7 km (3.6 miles) directly west of Sandy Hook Point. Location B is not directly adjacent to either a navigation fairway or a cable area and contains water depths of 5.8 m to 6.7 m (19 ft. to 22 ft.), requiring a moderate amount of dredging relative to the other locations.

4.3.3 Location C

Location C encompasses an area of approximately 219 hectares (541 acres), located approximately 3.4 km (2.2 miles) north of Atlantic Highlands, New Jersey, between Sandy Hook and the Navy Piers at the Naval Weapons Station Earle. Shallow water depths as low as 4.3 m (14 ft.) would likely require the most significant dredging effort in comparison to the other four locations. Proximity to the Navy Piers and the New Jersey coastline may present a navigation hazard.

4.3.4 Location D

Location D encompasses an area of approximately 177 hectares (437 acres), located approximately 2 km (1.2 miles) northwest of location B, directly south of the Raritan Bay East Reach channel. Location D contains water depths of 6.7 m to 9.1 m (22 ft. to 30 ft.). It is directly adjacent to a submerged cable area and occupies part of an existing anchorage.

4.3.5 Location E

Location E encompasses an area of approximately 85 hectares (210 acres), located approximately 1.8 km (1.1 miles) southeast of the Verrazano Bridge in the Gravesend Bay Anchorage area. Water depths between approximately 7.3 m and 9.1 m (24 ft. and 30 ft.) would require minimal dredging efforts to reach the required depth for safe WTIV operations. Location E's proximity to the Upper Bay results in the shortest transit from the Upper New York Harbor.

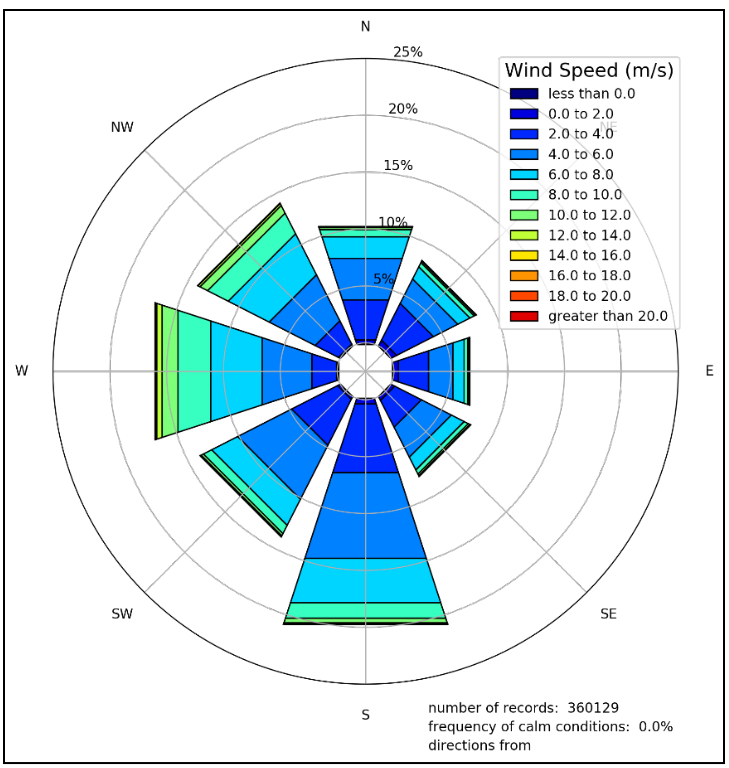
4.4 Meteorological Characterization

In order to analyze the behavior of the feeder barge during component transfer, the met-ocean characteristics within each potential transfer area were defined. The goal was to determine the most frequent wind and wave conditions in order to define barge availability once the hydrodynamic and stability analyses (as discussed in Section 7) were completed. This information was further used to identify the optimal location for the transfers to occur. The investigation included the collection of actual wind data and creation of a Spectral Wave model in the MIKE21 software package as published by the Danish Hydraulic Institute (DHI). Wind and wave results were then correlated and analyzed for each potential transfer area.

4.4.1 Wind

Wind data was collected from JFK Airport. JFK is located approximately 25–36 km (16–22 miles) northeast of the potential transfer areas and has a long record of wind speeds and directions. The record of collected wind data spans from 1973 to 2017 and is summarized in Figure 12 in the form of a wind rose. These winds were correlated with the winds used in the MIKE21 model in order to obtain the simulated wave heights associated with the AoA.

Figure 12. JFK Wind Rose



4.4.1 Waves

A Spectral Wave model in DHI MIKE21 was set up in order to simulate wave conditions at each of the potential transfer locations, as there are no buoys with site specific wave data at each of these locations. The model's primary inputs include a range of wind speeds coming from 16 compass point directions, bathymetry of the AoA, and boundary conditions. The boundary conditions include the forcing of offshore wave data (height, period, and direction), which provides the swell component to the wind waves as they propagate from the offshore boundary towards the shore. The model output included significant wave height (Hs), mean wave direction (WDir), and wave period (Tp) at locations A–E.

Once the waves simulated in the MIKE21 model using the range of wind speeds and directions were obtained, the results were correlated with the wind speeds collected from JFK. These results were then further analyzed to obtain the site-specific wave heights, wave directions, and wave periods. Table 5 summarizes the most frequently observed conditions in each of the five locations, which were used to define barge availability in waves per each location.

Table 4-2. Summary of Most Frequently Observed Wave Conditions

Potential Transfer Area	Hs (m)	WDIR (deg)	Tp (sec)
A	0-0.5	125-170	1-2
B	0-0.5	70	1-2
C	0-0.5	0	1-2
D	0-0.5	270	1-2
E	0-0.5	170-190	1-2

A picture of the wave conditions per site, including the frequency of wave height per compass point, can be represented through wave rose diagrams, as seen in Figures 13–16. Amongst other conclusions, this information allows for the inference of optimal vessel orientation. For example, location A has the largest and most frequent waves coming from the southeast; therefore, the vessel's bow should be oriented southeast when moored.

Figure 13. Location A Wave Rose

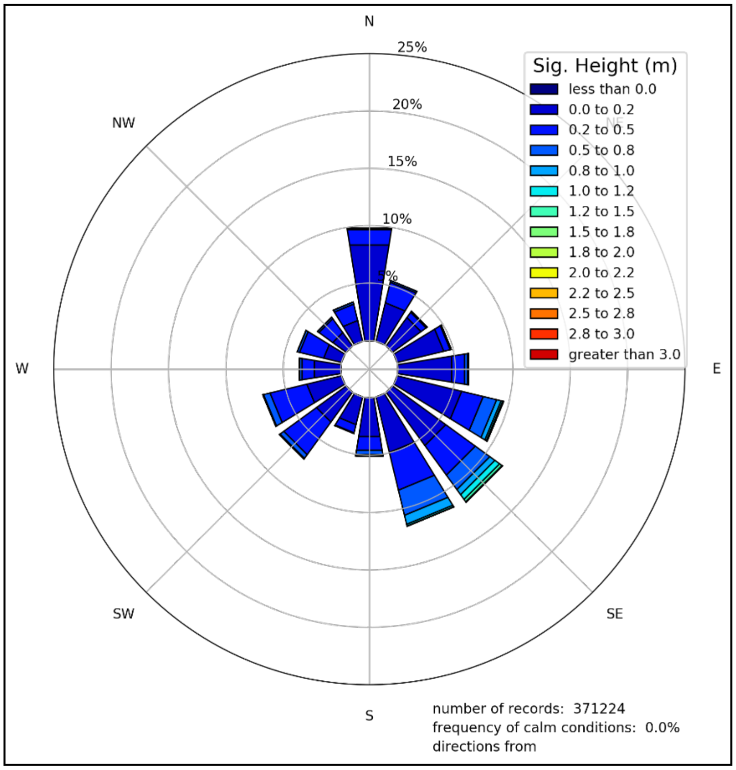


Figure 14. Location B Wave Rose

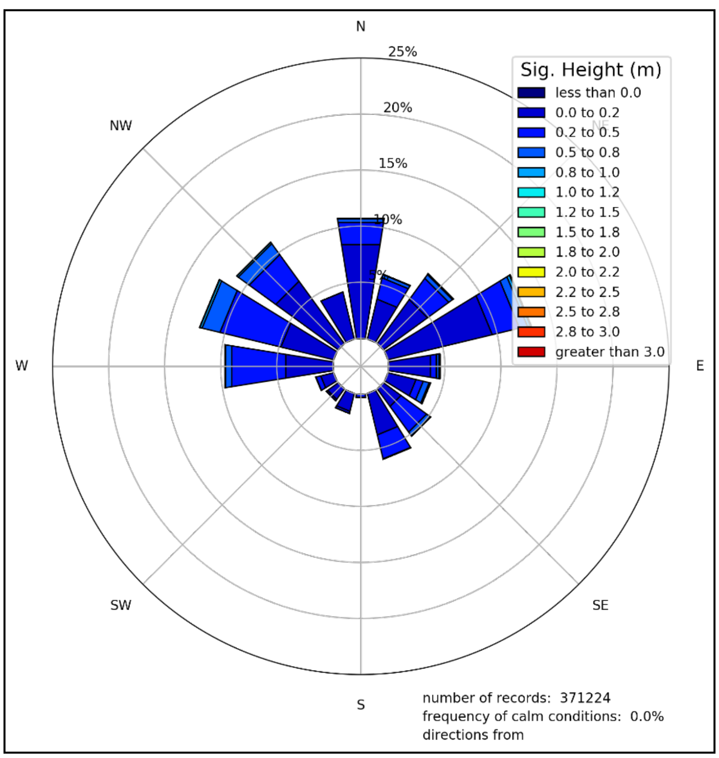


Figure 15. Location C Wave Rose

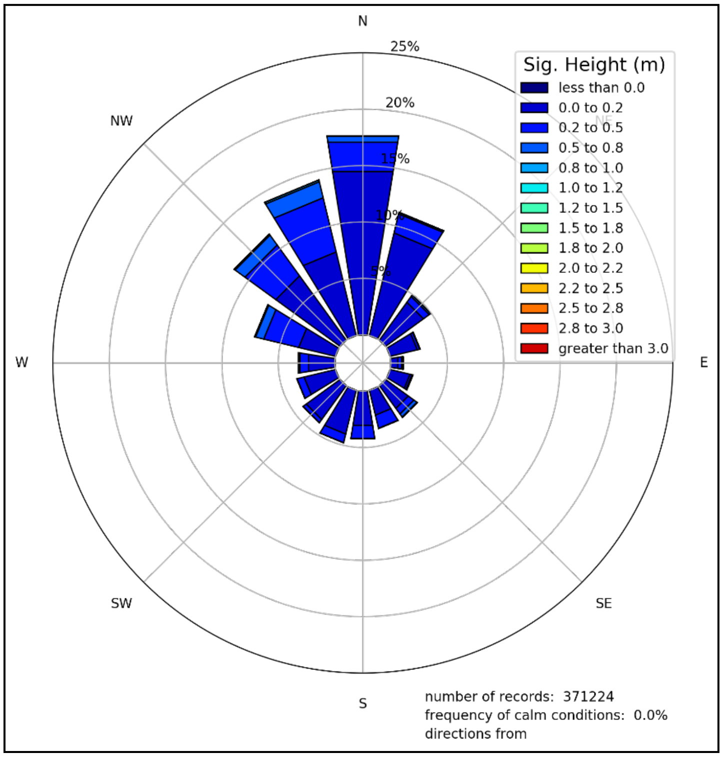


Figure 16. Location D Wave Rose

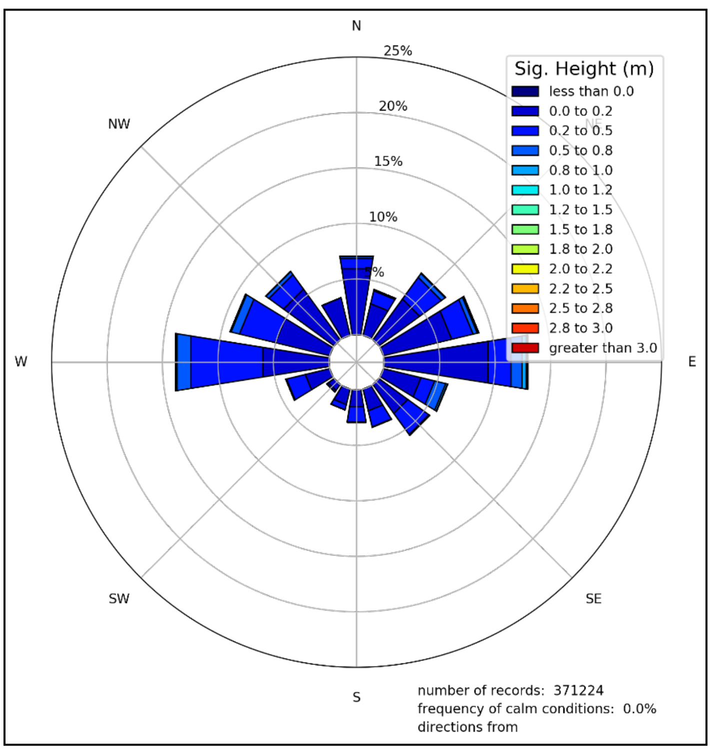
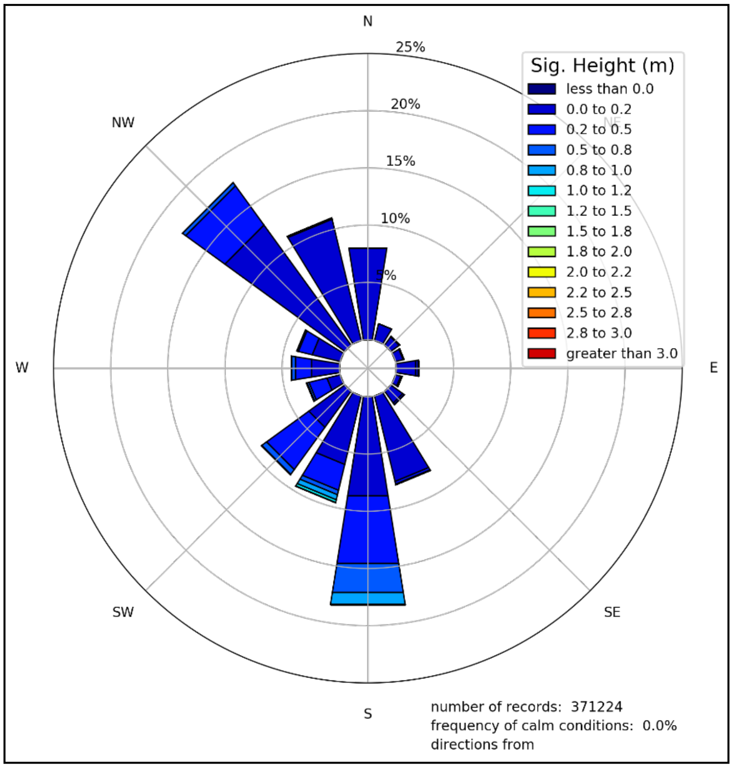


Figure 17. Location E Wave Rose



4.5 Operational Criteria

Typically, the WTIV is the most expensive equipment involved in the installation of offshore turbines; therefore, construction methodology should be planned to optimize the use of the WTIV. Moreover, the inshore feeder barge(s) must be able to transport and deliver the turbine components at a sufficient rate to ensure that downtime for the WTIV is minimized. This means that the barge should be designed in a manner that meets the environmental and operational criteria to ensure that it is operable whenever the WTIV is ready.

The primary activities of the inshore feeder barge can be split into three sub-operations: loadout from staging facility to barge, transit to and from loading site, and transfer operations from barge to WTIV. The operational criteria are based on environmental conditions. Wind speed criteria of 10–15 m/s (22–36 mph) is common in offshore operations. Although, due to the fragility of many components to be handled, a maximum wind speed of 10 m/s (22 mph) was applied for loadout operations from staging port to barge. Considering the relatively short distance between the WTIV installation site and the loadout site, it is reasonable to assume that the same wind conditions occur at both locations at the same time. This means that waiting on weather due to wind will occur both at the installation site and at the loadout location at the same time, and hence the barge will not delay the operation in such an event.

Loading operations from feeder barge to WTIV are affected by both wind and wave conditions. To provide a stable foundation for performing lift operations, a maximum horizontal offset amplitude of 0.3 m (1 ft.), and a maximum vertical motion amplitude of 0.2 m (0.7 ft.), is therefore applied. This is much stricter than the typical offshore vessel-to-vessel lift maximum relative motion criteria of 2 m (7 ft.), but is applied due to the shape, size, and delicateness of the structures to be handled. As stated previously, a maximum wind speed of 10 m/s (22 mph) is applied for the phase when the objects are being lifted during loadout operations.

The barge is intended to maintain a minimum level of stability during all phases of barge operations in all environmental conditions encountered in the AoA.

5 Inshore Feeder Barge Design

5.1 Barge Types

Large, heavy cargo, such as offshore wind superstructure components, are typically transported by either heavy-lift project cargo ships, or barges. In the United States, barges are commonly used for the transport of project cargo and break-bulk items. Federal vessel regulations typically separate barges into two primary classes: inland/intra-coastal and offshore/international (load line) barges based on the areas each class is permitted to operate. The areas are separated by demarcation lines set along the U.S. coast, which delineate those waters in which mariners must comply with international regulations versus inland navigational rules. Inland barges are subject to less stringent requirements (health and safety, inspections, licensure, etc.) and are therefore more economically efficient. This study encompasses waters inland of the demarcation line drawn between Sandy Hook, New Jersey and Long Beach, New York, and therefore the inshore feeder barge would only be subject to inland rules and requirements.

5.2 Barge Characteristics

The primary goal of this study was to determine if a floating barge could be used to transport OSW components to an inshore transfer area in order to address the air draft challenges posed in New York. Floating barge suitability was investigated through defining the required barge dimensions and capacity in order for barge motions to remain within acceptable limits for the specified environmental and loading conditions. As determined by the motion analyses completed in the study (further detailed in Section 7), existing barges capable of serving this role are available in the New York area. Therefore, it was not necessary to prepare the design of a unique vessel.

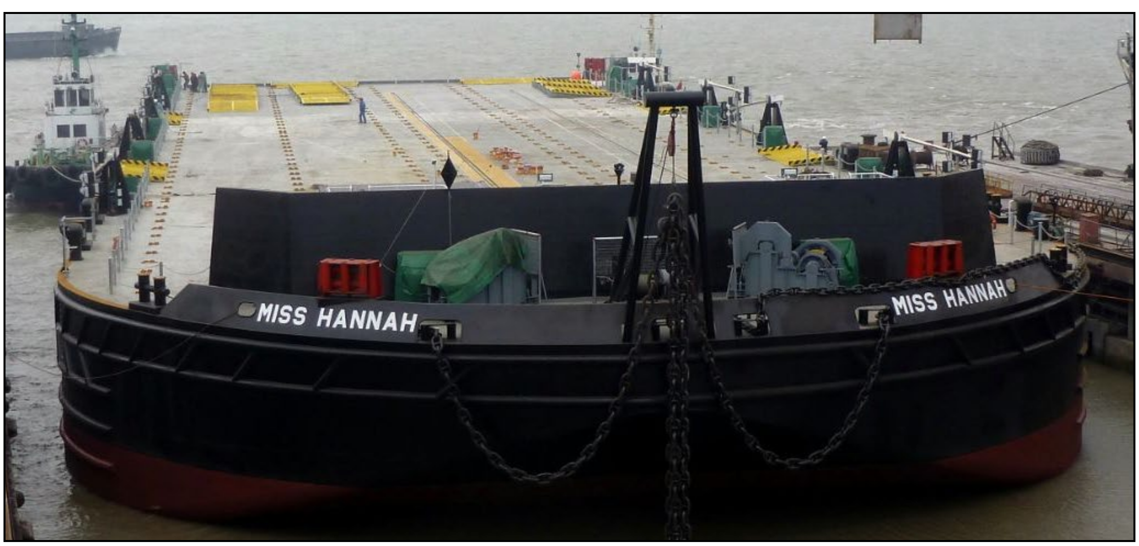
Two barges operating within New York Harbor were identified as being representative of barges available in the northeast United States (including New York Harbor) and were therefore used for the analyses in this study. These barges were used in order to investigate the response to environmental conditions for a barge that is 100.6 m (330 ft.) in length (to be referred to as the "330-foot barge") versus 122m (400 ft.) in length (to be referred to as the "400-foot barge"). These barges were chosen based on their size, load capacity, and ability to meet the design basis requirements discussed in the previous section. The vessels selected for the analysis are operated by Cashman Equipment; however, barges of similar dimensions and capacity (as the 330-foot and 400-foot barges) are available in the New York area. It should be noted that the regional availability of barges similar to the 400-foot barge will be more limited due to their larger size.

The 330-foot barge is based on the Cashman *JMC 3341* vessel and has dimensions (l x b x d): 100.6 m x 30.5 m x 6.1 m (330 ft. x 100 ft. x 20 ft.) with deck capacity of 20 MT/m² (4,096 psf). The specification sheet for the *JMC 3341* barge is included in the appendix. Figure 18 is a picture of a barge similar to the 330-foot barge.

Figure 18. Representative Vessel Similar to the 330-Foot Barge

The 400-foot barge is based on the Cashman *Miss Hannah* vessel and has dimensions (l x b x d): 121.9 m x 36.6 m x 7.6 m (400 ft. x 120 ft. x 25 ft.) with deck capacity of 25 MT/m² (5,120 psf). The specification sheet for the *Miss Hannah* barge is included in the appendix. Figure 19 is a picture of the *Miss Hannah* barge.

Figure 19. Cashman Miss Hannah Vessel as a Basis for the 400-Foot Barge



After outlining the concept of using the 330- and 400-foot barges to transport and transfer components to a WTIV and running through the initial availability and stability analyses, it was proven that these barges satisfy the defined requirements, making the need to design a new barge unnecessary. Instead, the 330-foot and 400-foot barges were used for the further assessment of station keeping methods, schedules, and Opinions of Probable Cost. This approach simplifies the implementation of this concept and requires less investment, as it would not require the creation of a new type of barge.

Table 5-1 summarizes the principle characteristics of the 330- and 400-foot barges, as a basis for the inshore feeder barge design. The barge would require winches at each corner for connection to on-site moorings. Descriptions of the deck layouts, availability, and stability per each barge is described in the sections to follow.

Table 5-1. Inshore Feeder Barge Principle Characteristics Basis

Parameter	330-foot Barge[a]	400-foot Barge[b]
Length Overall	100.6m (330 ft.)	122m (400 ft.)
Hull Width	30.5m (100 ft.)	36.6m (120 ft.)
Hull Depth	6.1m (20 ft.)	7.6m (25 ft.)
Deck Loading	20MT/sq. m (4096 psf)	25MT/sq. m (5120 psf)
Transit Speed	4 knots (5 mph)	4 knots (5 mph)

Note(s):

a Based on the *JMC 3341* vessel provided on the Cashman website.

b Based on the *Miss Hannah* vessel provided on the Cashman website.

6 Station Keeping Alternatives

In order to transfer components between the inshore feeder barge and the WTIV, both vessels need to be capable of remaining relatively stationary; this is called station keeping. It is assumed that the WTIV will be jacked-up during the transfer of components in order to provide a safe lifting platform. Since the feeder barge will be a floating vessel without jack-up capability, it must use another method to maintain its position. There are a number of commonly used methods for station keeping, each alternative having associated advantages and challenges as seen in Tables 6-1 to 6-4.

6.1 Fixed Structure

A fixed structure solution consists of two to four pile supported dolphins at the transfer area. This effectively creates a vessel berth at the offshore area. A four-point mooring system secures the inshore feeding barge against the dolphins for the transfer of components to the WTIV. In this mooring system, two tugs aid the barge in mooring to four separate mooring anchors, approximately at each corner of the barge.

Table 6-1. Fixed Structure Station Keeping Method, Advantages and Disadvantages

Advantages	Challenges
Restrained movement of Inshore Feeder Barge; and Reduced risk of drifting or losing station.	May be seen as obstructions in waterway; Navigation lights may be necessary; and Significant decommissioning effort required.

6.2 Spud Barge

A spud barge is a barge with steel pipes (commonly called legs or spuds) which are lowered through holes in the deck to the seabed to set the barge in place. Unlike a jack-up vessel, the spuds rest passively on the seafloor and the barge itself is not lifted out of the water. This type of barge is prevalent in the U.S., although it is typically utilized for smaller vessels in more protected conditions than expected in the AoA. Additional analysis will be required to ensure the safety and validity of this solution.

Table 6-2. Spud Barge Station Keeping Method, Advantages and Disadvantages

Advantages	Challenges
Highly restrained movement of Feeder Barge; Does not require anchors/mooring system; and No permanent obstructions.	Requires competent seabed; Typically utilized for smaller vessels in more protected conditions; Potential high loads acting on the spuds; and Capacity of spud to seabed connection requires further analysis, may results in decreased availability.

6.3 Self-Carry Anchor System

A self-carry anchor solution consists of an anchor system that is carried on the inshore feeder barge or support tug during transit. In addition to the tug used to move and position the feeder barge, a support tug is required to set the anchors as the feeder barge is incapable of doing so unassisted. This solution may be appropriate for a single project or for demonstration purposes due to its simplified installation process relative to the previous methods. However, serial production of multiple turbines and projects requires a more permanent approach.

Table 6-3. Self-Carry Anchor System Station Keeping Method, Advantages and Disadvantages

Advantages	Challenges
No permanent obstructions; Ability to move or turn station for differing wind and wave conditions; and Less robust anchors – simplifies anchoring process.	Risk of drifting, difficult to preload the anchors sufficiently; Anchors and line occupy deck space; Additional relative movement of floating Feeder Barge complicates component transfer; Additional anchor handling tug required (preloading); and Less robust anchors – smaller weather window.

6.4 Fixed Anchor System

A fixed anchor solution consists of an anchor and mooring system that remains on station. The anchors are connected to pennant lines which float from buoys. On arriving on site, the inshore feeder barge retrieves the anchor lines from the pennants and secures permanent anchors to the barge for the transfer of components to the WTIV.

Table 6-4. Fixed Anchor System Station Keeping Method, Advantages and Disadvantages

Advantages	Challenges
Minimal permanent obstruction; Preloading anchors is only required once; and Anchor installation performed off the critical path.	Similar risk of drifting as self-carry anchors; and Additional relative movement of floating Feeder Barge during transfer of components complicates component transfer.

7 Availability and Stability Analyses

Availability and stability analyses were performed in order to confirm the suitability of both inshore feeder barges for the environmental conditions associated with the potential transfer areas. The barges should be capable of operating with minimal downtime so as to avoid negatively impacting the critical path installation schedule. The availability assessment considers the movements of the vessel during component transfer and the time available for operations to proceed. The stability analysis considers the rotational stability (pitch and roll) of the vessel and the barge's ability to navigate from the land-based staging site to the transfer area and return safely. In order to inform both of these analyses, deck layouts for each barge were configured to determine the position of the turbine components and the associated loads applied to the barges.

7.1 Barge Deck Layouts

Barges were selected based on their ability to carry a similar number of components as the WTIV. In this case, the barges were required to carry four complete turbine superstructures (nacelle, blades, and towers) for a representative 8-MW turbine. The placement of OSW components on each barge was determined based on the barges' allotted space and capacity. The location of components affects the barges' stability and ballast. Deck layouts were drawn to scale in order to visually understand the configuration of the components per each barge type—as seen in Figure 20 and 21 four nacelles, four blade sets, and eight tower sections (broken into lower and upper). For both the 330- and 400-foot barges, the deck layout figure number labels (1–4) alongside of the major components have the following definitions:

1 = nacelles, 2 = blades, 3 = upper tower sections, 4 = lower tower sections.

Figure 20. Typical 330-Foot Barge Deck Layout for OSW Components

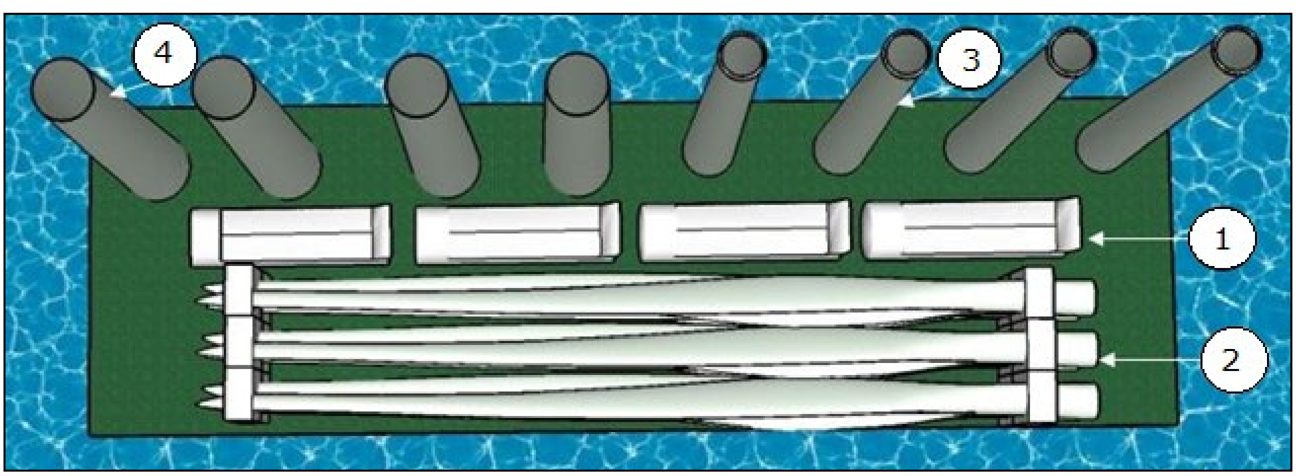
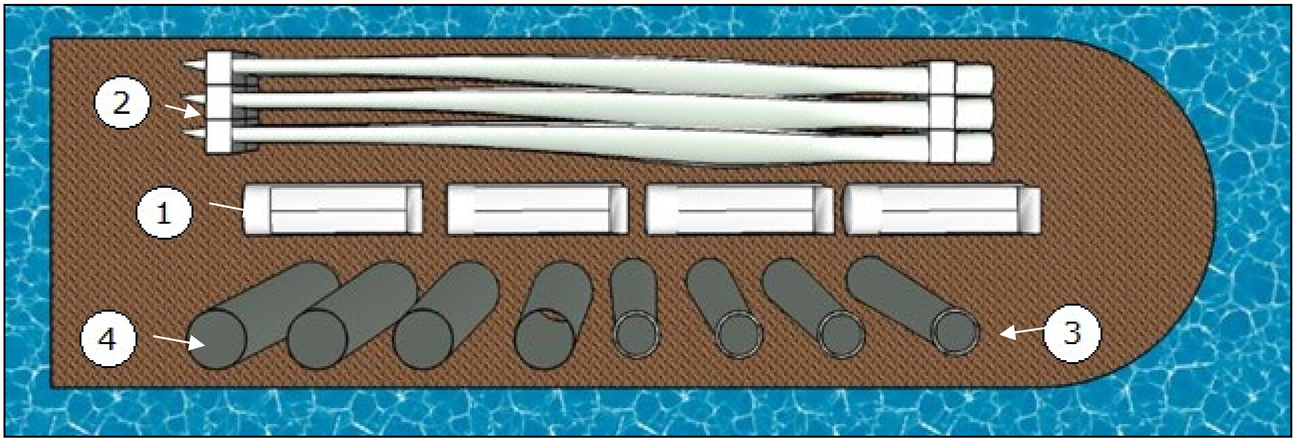


Figure 21. Typical 400-Foot Barge Deck Layout for OSW Components



7.2 Availability Analysis

The availability of the feeder barge is most limited at the offshore transfer area during the period when components are being transferred from the barge to the WTIV. During this period, the availability is limited by two factors: the barge motion due to waves and wind and the wind speed limitations for performing lifts. The criteria for this is given in Section 4.5 and included below:

- Maximum barge horizontal offset (surge and sway): 0.3 m (1 ft.) amplitude
- Maximum barge vertical heave: 0.2 m (0.7 ft.) amplitude
- Maximum wind speed: 10 m/s (22 mph)

The barge movement response criteria are very strict, considering that the barge needs to serve as a stable platform for performing lifts. The maximum wind speed during lift operations is 10 m/s (22 mph). This is lower than typical crane limitations but is justified due to the size and shape of the components to be handled.

The availability analysis is performed by first conducting a hydrodynamic analysis of the barge motions when subject to the wave and wind conditions at the transfer location. The resulting acceptable environmental conditions are then combined with the environmental data for each location to determine the total availability.

The hydrodynamic analyses were performed for the 330- and 400-foot barges. Both barges were analyzed with a conventional spread mooring system, and in the case of the 400-foot barge, a combined mooring system with fixed breasting dolphins was also analyzed. Screenshots from the analysis model for the 400-foot barge during the mooring process with and without breasting dolphins is given in Figure 22 and 23, respectively. Note that the wind turbine components that should be on the deck are not graphically shown in the model but are included in the weight and wind load calculations of the analyses completed.

Figure 22. 400-Foot Barge—Spread Mooring Combined with Breasting Dolphins

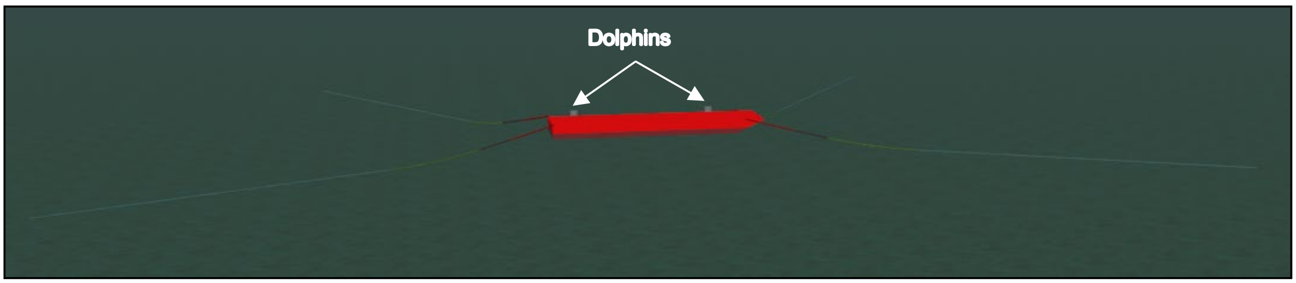
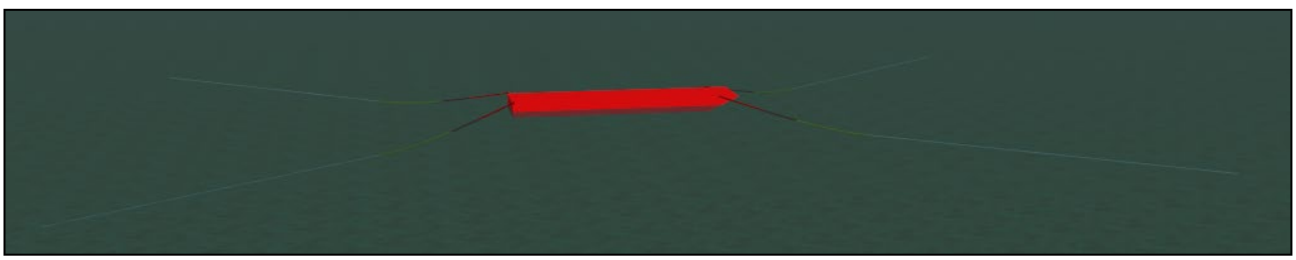


Figure 23. 400-Foot Barge—Conventional Spread Mooring



In all analyses, a 10 m/s (22 mph) wind speed was applied and combined with a wave height and wave period to be investigated. If the horizontal or vertical motions obtained exceeded operational maximums, then the wave height and period were adjusted to reanalyze the motions until satisfactory results were obtained. This was repeated for all headings in order to obtain directional wave limitations. The maximum significant wave heights that resulted in acceptable movements are given in Figure 24 and further detailed in Table 7-1 and Table 7-2. These are considered the limiting wave heights to continue operations.

Figure 24. Maximum Acceptable Hs for Loading Operations from Feeder Barge to WTIV

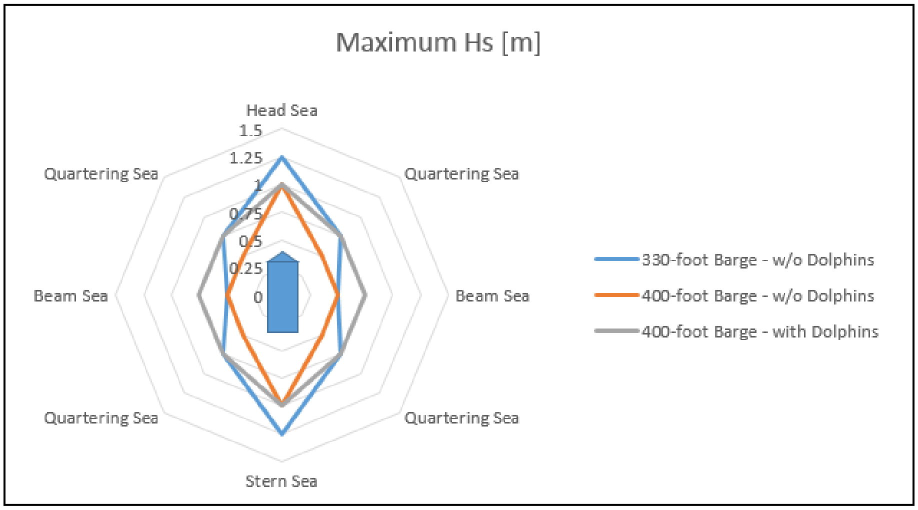


Table 7-1. 330-Foot Barge—Hydrodynamic Analysis Results

330-foot Barge	Without Breasting Dolphins		
	Head/Stern Sea	Quartering Sea	Beam Sea
Wave Height	1.25m (4.1 ft.)	0.75m (2.5 ft.)	0.5m (1.6 ft.)
Wave Period	4.5 sec	3.5 sec	3 sec
Wind Speed	10 m/s		
Offset	0.2m (0.7 ft.)	0.27 (0.9 ft.)	0.24 (0.8 ft.)
Heave	0.2m (0.7 ft.)	0.05 (0.2 ft.)	0.04 (0.1 ft.)

Table 7-2. 400-Foot Barge—Hydrodynamic Analysis Results

400-foot Barge	Without Breasting Dolphins			With Breasting Dolphins			
	Head/Stern Sea	Quartering Sea	Beam Sea	Head/Stern Sea	Quartering Sea	Beam Sea – towards Dolphins	Beam Sea – from Dolphins
Wave Height	1m (3.3 ft.)	0.5m (1.6 ft.)	0.5m (1.6 ft.)	1.25m (4.1 ft.)	1m (3.3 ft.)	0.75m (2.5 ft.)	0.75m (2.5 ft.)
Wave Period	4 sec	3 sec	3 sec	4.5 sec	4 sec	3.5 sec	3.5 sec
Wind Speed	10 m/s						
Offset	0.27m (0.9 ft.)	0.17m (0.6 ft.)	0.25m (0.8 ft.)	0.19m (0.6 ft.)	0.19m (0.6 ft.)	0.15m (0.5 ft.)	0.3m (0.9 ft.)
Heave	0.06m (0.2 ft.)	0.01m (0.03 ft.)	0.02m (0.07 ft.)	0.12 (0.4 ft.)	0.04 (0.1 ft.)	0.05m (1.6 ft.)	0.05m (1.6 ft.)

The total annual availability resulting from the defined wind and wave limitations in comparison to actual wind and waves at each location is given in Table 7-3. It is noted that for locations B, C, and D the availability is the same for both barges—with and without breasting dolphins due to the set wind limitation. The wind alone gives a total availability of 95% for all potential transfer areas. These results therefore show that the wave conditions are not limiting, as the wind imposes a lower availability than the waves. A slightly lower availability is obtained without breasting dolphins at location A, indicating that at this location the wave conditions impose a slightly lower availability than the wind alone. The same is observed at location E for the 400-foot barge.

Table 7-3. Availability for Loading Operations from Feeder Barge to WTIV

Availability					
Location	**A**	**B**	**C**	**D**	**E**
330-Foot Barge – Without Breasting Dolphins	94%	95%	95%	95%	95%
400-Foot Barge – Without Breasting Dolphins	93%	95%	95%	95%	94%
400-Foot Barge – With Breasting Dolphins	95%	95%	95%	95%	95%

The results of the availability assessment also show that it is not required to analyze the 330-foot barge with breasting dolphins, as the wind availability will govern the total availability and hence breasting dolphins will not improve the results.

From the analyses, it is found that locations B, C, D and E are nearly equal with respect to availability. The analysis shows the use of breasting dolphins does not significantly improve the availability, although a slight increase in acceptable wave heights is achieved. Dolphins may be advantageous from other perspectives, such as line handling during operations and when subject to effects from passing vessels. The transfer areas are located in proximity to federal navigation channels, meaning that moored vessels are susceptible to passing vessel effects (PVE), such as surge, sway and yaw. PVE are not considered in this analysis as PVE are highly sensitive to the relative vessel speed, position, and displacement. Fixed structures, such as the breasting dolphins, may also help to restrain the moored feeder barge during PVE. A refined availability analysis, inclusive of PVE, is recommended on selection of the transfer area.

Currents are not taken into consideration for these analyses since they would mainly contribute to static forces on the barge and would therefore not differentiate the dynamic response. However, currents could play a role in the maneuvering and handling of the barge. Further details of the availability analyses are given in appendix B.

7.3 Stability Analysis

For the feeder barge alternatives considered in this report, the 330- and 400-foot barges, stability criteria and pre-accepted loading conditions are defined in Stability Booklets that come with the barges. Stability analyses are therefore performed based on the criteria applicable to each of the barges and are reported separately.

The analyses are performed for the barges in a fully-loaded condition, assuming a draft of 3 m (10 ft.). This draft results from the lightweight of the barge, deadweight of the turbine components, and ballast required to obtain the desired draft while maintaining the barge on even keel. Analyses are performed for small heel angles only. For large heel angles, the results provided in the stability booklets are used.

The principal parameters required to assess the stability is the initial stability dimension "GM" and the restoring arm "GZ." GM is a measure of the stability at even keel in which a positive GM means that the center of gravity is not too high above the keel of the barge. GZ is a measure of the restoring arm when the vessel starts to heel, in which a positive GZ means that the forces acting on the barge are working to bring it back to even keel. In addition to criteria specific to these parameters, the stability booklet criteria require a check of static heel angle when subject to 30m/s (67 mph) wind conditions, accounting for wind loading both on the barge itself and on the turbine components.

The results of the stability check are given in Tables 7-4 and 7-5. It is found that both barges have satisfactory stability for the considered load conditions. For reference, a plot of the restoring arm GZ is also given in Figure 25.

Table 7-4. 330-Foot Barge—Stability Check

330-foot Barge - Stability Check			
Parameter	**Result**	**Criteria**	**Comment**
Vertical Center of Gravity (VCG)	6.0m (20 ft.)	<22m (72 ft.) above deck	Criteria met. Criteria applies to a draft of 3m (10 ft.).
GM	17m (56 ft.)		No criteria in Stability Booklet. GM is accounted for in VCG criteria (above)
Area under GZ curve up to maximum GZ*	0.25 meter-radians (0.8 feet-radians)	>0.08 meter-radians (0.3 feet-radians)	Criteria met. Note that true area is higher, as these analyses are based on small angels only, hence not including the angle of maximum GZ.
Minimum Range of Stability (positive GZ)	>20.9 deg	>19.9 deg	Criteria confirmed based on data given in Stability Booklet, which covers loading conditions more severe than considered for the feeder barge. A minimum range of stability >20.9 deg is reported.
Static Angle of Heel due to 30m/s (67 mph) Winds	1.5 deg	<5.7 deg	Criteria met. The criteria is set based on the angle where half the freeboard to the deck is immersed.

Note(s):

* The "Area under GZ curve up to maximum GZ" is found as the area under the restoring arm (GZ) curve from even keel and up to the point where the restoring arm is at its maximum value. This value is a measure of the dynamic stability of the barge.

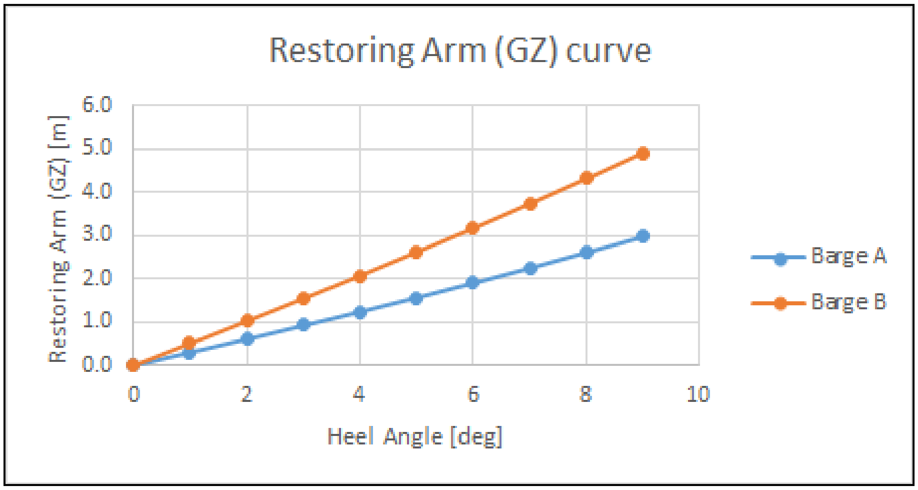
Table 7-5. 400-Foot Barge—Stability Check

400-foot Barge - Stability Check			
Parameter	**Result**	**Criteria**	**Comment**
Vertical Center of Gravity	10.6m (35 ft.)	<32.6m (107 ft.) above keel	Criteria met. Criteria applies to a draft of 3m (10 ft.).
GM	28.8m (94 ft.)	>7.5m (25 ft.)	Criteria met. Criteria applies to a draught of 3m (10 ft.).
Area under GZ curve up to maximum GZ*	0.42 meter-radians (1.4 feet-radians)	>0.08 meter-radians (0.3 feet-radians)	Criteria met. Note that true area is higher, as these analyses are based on small angels only, hence not including the angle of maximum GZ.
Minimum range of stability (positive GZ)	>42.6 deg	>17.8 deg	Criteria confirmed based on data given in Stability Booklet, which covers loading conditions more severe than considered for the feeder barge. A minimum range of stability >42.6 deg is reported.
Static angle of heel due to 30m/s (67 mph) wind	0.7 deg	<7.1 deg	Criteria met. The criteria is set based on the angle where half the freeboard to the deck is immersed.

Note(s):

* The "Area under GZ curve up to maximum GZ" is found as the area under the restoring arm (GZ) curve from even keel and up to the point where the restoring arm is at its maximum value. This value is a measure of the dynamic stability of the barge.

Figure 25. Barge Stability Assessment Results—Restoring Arm GZ



8 Schedules and Opinions of Probable Cost

Project schedules were developed to determine an estimated production rate and Opinion of Probable Cost (OPC) for each of the three scenarios. The Vessel Study provides estimates for the duration of certain tasks performed by either a WTIV or a jack-up feeder vessel. These tasks include but are not limited to: loading and securing turbine components (nacelles, blades, and tower sections) at port; positioning, preloading and jacking-up the WTIV; lifting and installing the turbine components; and integration activities. The majority of information for baseline scenarios 1 and 2 were obtained from the Vessel Study. Information from industry and previous expertise were leveraged to extrapolate the data in the Vessel Study in order to develop schedule estimates for scenario 3.

The OPCs were derived using the scheduled production rates multiplied by vessel costs. Vessel cost rates were determined based on pricing information published in the Vessel Study and augmented by rates obtained from marine contractors in the New York Area. The three installation scenarios and their associated costs are detailed in the following sections.

Note that the cost comparison is a direct comparison of installation vessel strategies for turbine components only; costs are not inclusive of other impacts to cost of energy, including cost of materials, installation of other components, or operations and maintenance costs. All costs are presented in 2017 U.S. dollars.

8.1 Exclusions

The intent of this comparative analysis is to determine the schedule and cost of each scenario and the relative differences between each scenario on a "per turbine basis" during industry-scale deployment of OSW. Therefore, results are presented for each scenario as if set in continuous operation and are summarized using a "start-to-start" methodology in order to compare each scenario equally.

8.2 Mobilization and Demobilization

Mobilization and demobilization activities, including but not limited to welding and installing the grillages and sea fastenings to secure the components, are detailed in each scenario's schedule, but are not included in the comparative duration and cost. This study acknowledges that mobilization activities will increase the total duration and absolute cost of vessel charter(s) on an individual project level. However, mobilization activities are relatively independent of the number of turbines; and therefore, by omitting mobilization activities, the cost per turbine varies based on the number of units installed.

8.2.1 Waiting on Weather

Calm seas and weather conditions are required to safely lift, position, and install offshore wind turbine components. Due to the precise and delicate nature of the installation process, turbine installation activity is expected to be restricted to the summer and fall months. However, time spent waiting on weather is not entirely unavoidable. In order to be consistent with the Vessel Study, waiting on weather (WoW) time is excluded from the project schedules. Instead, an availability analysis was outlined in Section 7.2 and detailed in appendix B, which predicts the amount of time that wind and wave conditions are suitable for component transfer as a percentage for each type of barge at each potential transfer location. Using the values provided in the Vessel Study, Table 8-1 defines WoW time as a percentage for each month. These values encompass "waiting for lower sea-states to go on location, weather induced delays in tug operations, or lower wind speeds for lifting operations" (GustoMSC, 2017).

Table 8-1. Waiting on Weather, Time per Month

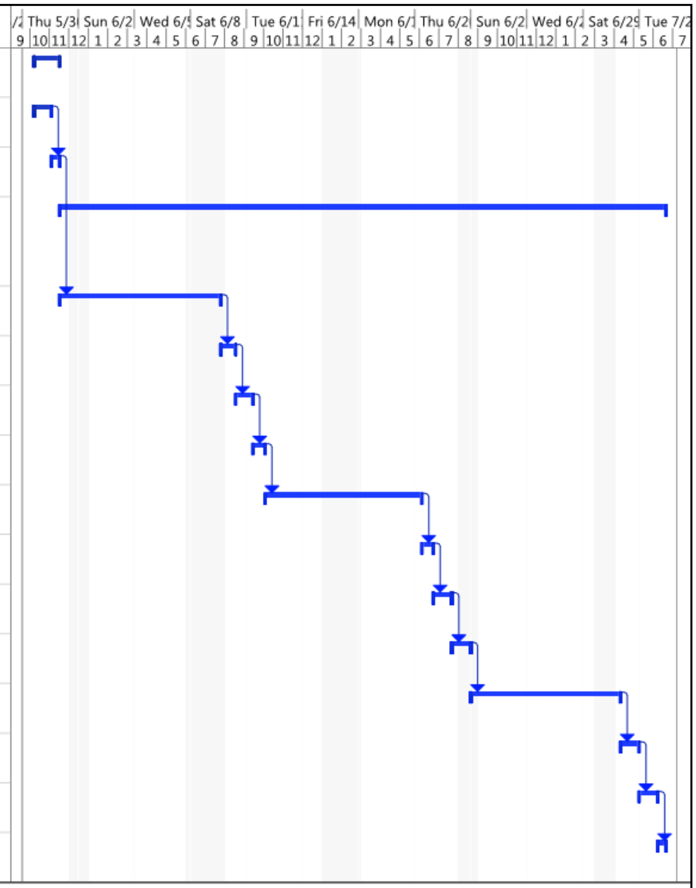
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
WoW Percentage	40%	40%	35%	25%	15%	15%	15%	15%	15%	15%	35%	50%

8.3 Scenario 1: WTIV Only

In scenario 1, the WTIV is loaded with turbine components at the New Bedford Terminal (staging port) before transiting to the New York WEA project site. On completing the installation of the turbines, the WTIV returns to the staging port to be loaded with the next round of turbine components.
Figure 26 shows the schedule created for this scenario.

Figure 26. WTIV Only Schedule

Task Name	Duration
WTIV - MOBILIZATION ACTIVITIES	38.3 hrs
WTIV - LOAD COMPONENTS	22 hrs
TRANSIT TO WEA	16.3 hrs
INSTALLATION OF 12 TURBINES	772.5 hrs
WTIV - INSTALL FIRST 4 TURBINES	200.9 hrs
RETURN TO PORT	19.3 hrs
WTIV - LOAD COMPONENTS	22 hrs
TRANSIT TO WEA	16.3 hrs
WTIV - INSTALL NEXT 4 TURBINES	200.9 hrs
RETURN TO PORT	19.3 hrs
WTIV - LOAD COMPONENTS	22 hrs
TRANSIT TO WEA	16.3 hrs
WTIV - INSTALL NEXT 4 TURBINES	200.9 hrs
RETURN TO PORT	19.3 hrs
WTIV - LOAD COMPONENTS	22 hrs
TRANSIT TO WEA	13.3 hrs

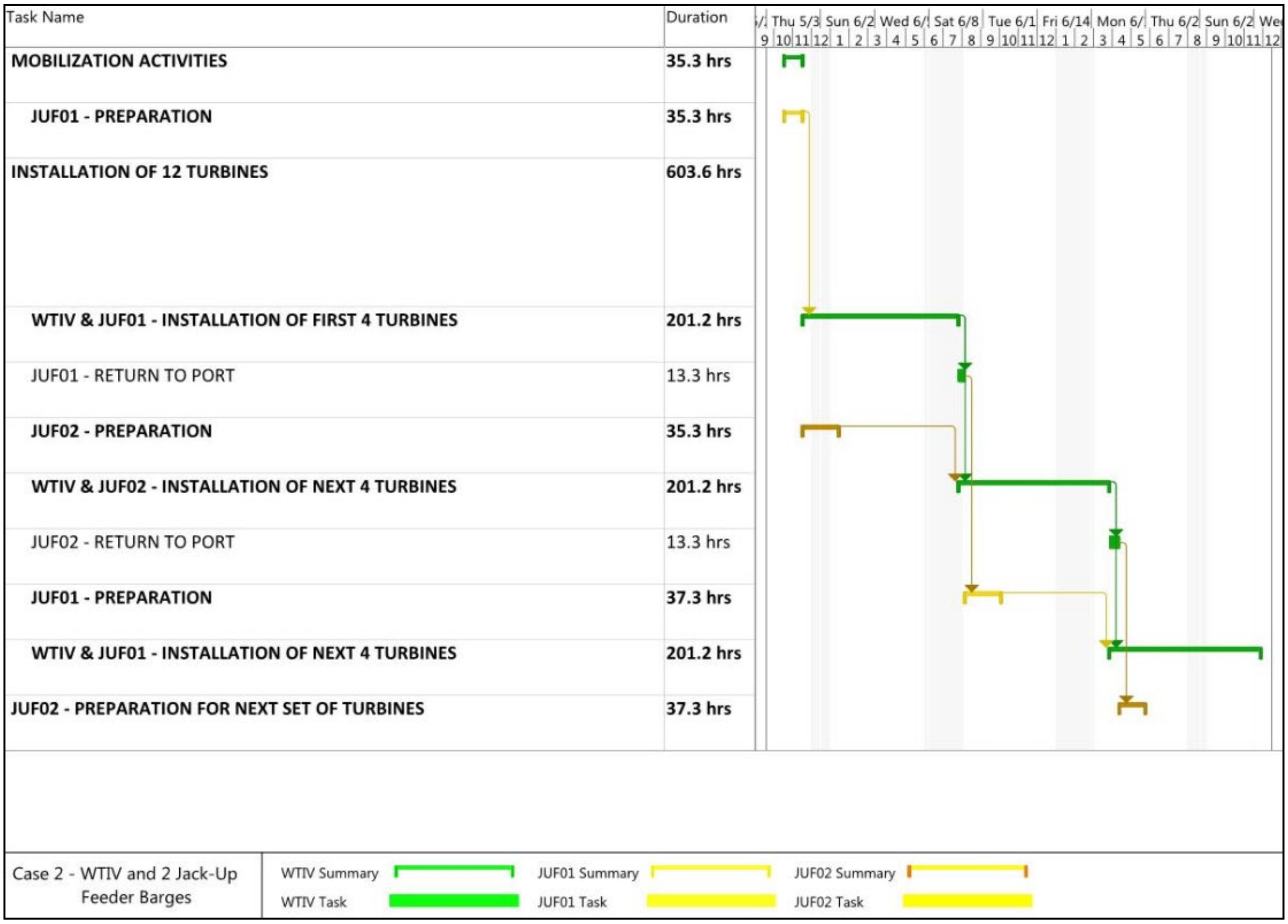


Case 1 - WTIV Only | Task | Summary | Project Summary

8.4 Scenario 2: WTIV and Jack-Up Feeder Barges

In scenario 2, the WTIV is supported by two jack-up feeder barges. The jack-up feeder barge transports the turbine components from the staging site (New Bedford Terminal) to the offshore installation site. The WTIV is responsible for transferring components from the jack-up feeder and installing them directly at the offshore site. The jack-up feeder transits between the New Bedford Terminal and the New York WEA while the WTIV remains at the installation site. Two feeder barges are utilized in rotation to minimize wait time for the WTIV. Figure 27 shows the schedule for this scenario.

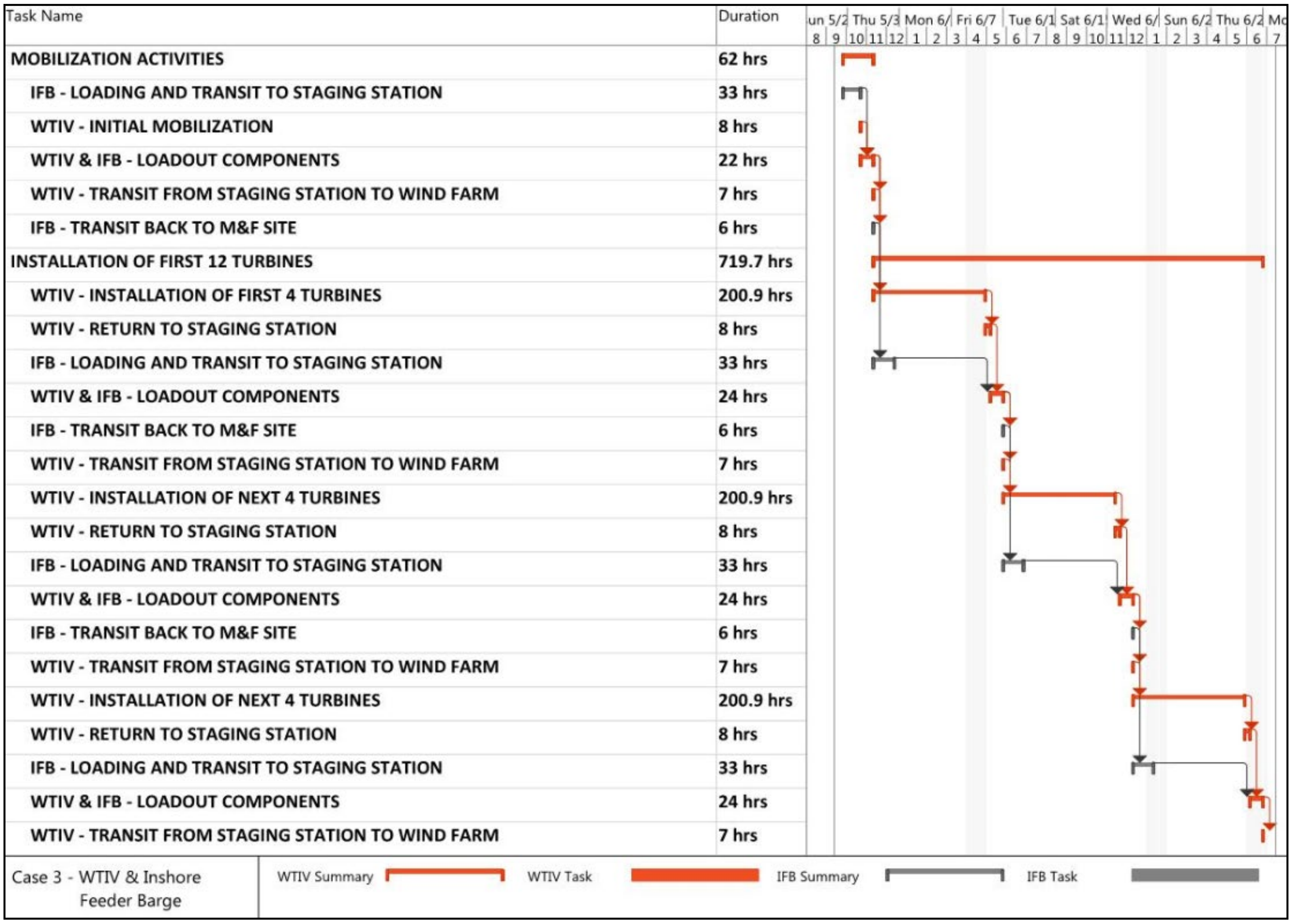
Figure 27. WTIV and Jack-Up Feeder Barge Schedule



8.5 Scenario 3: WTIV and Inshore Floating Barge

In scenario 3, the WTIV is supported by an inshore feeder barge. The Inshore Feeder Barge is loaded with turbine components at South Brooklyn Marine Terminal. The barge then transits to the inshore transfer area where the components are loaded onto the WTIV. After transfer, the WTIV transits to the New York WEA while the inshore feeder barge returns to New York Harbor to receive the next round of turbine components.

Figure 28. WTIV and Inshore Floating Barge Schedule



8.6 Comparison

The estimated duration(s) associated with each scenario is summarized in Table 8-2. To compare methods equally, the durations associated with each scenario assume the start of the project to begin with the task "WTIV – Position, Preload, and Jack-Up" at Turbine Site 1 at 0600 on June 1, 2024; the end point for all three scenarios was designed to be the beginning of the same task "WTIV—Position, Preload, and Jack-Up" at Turbine Site 12 (following three complete installation cycles). Projected durations were interpolated or extrapolated linearly to determine the duration for 1 Turbine and 100 Turbines, respectively.

Table 8-2. Durations Summary for Scenarios 1-3

Scenario	Installation of 1 Turbine		Installation of 12 Turbines		Installation of 100 Turbines	
	Hours	Days	Hours	Days	Hours	Days
Scenario 1 - WTIV Only	64.4	2.7	772.5	32.2	6,437.5	268.2
Scenario 2 - WTIV & 2 Jack-Up Feeder Barges	50.3	2.1	603.6	25.2	5,030.0	209.6
Scenario 3 - WTIV & Inshore Floating Barge	60.0	2.5	719.7	30.0	5,997.5	249.9

OPCs for each scenario were created based on the summarized duration information provided in Table 8-2 as well as the day rates provided in the Vessel Study and collected from marine contractors in the New York Area. Table 8-3 summarizes the costs per scenario, breaking down the individual costs associated with each vessel type per scenario. Table 8-4 summarizes the day rates used for the cost estimates.

Table 8-3. Cost Summary for Scenarios 1-3

Scenario	Installation of 1 Turbine	Installation of 12 Turbines	Installation of 100 Turbines
Scenario 1: WTIV Only[a]	**$590,150**	**$7,081,250**	**$59,010,417**
Scenario 2 - WTIV & 2 Jack-Up Feeder Barges	**$817,375**	**$9,808,500**	**$81,737,500**
WTIV[1]	$461,083	$5,533,000	$46,108,333
Jack-Up Feeder Barges (2)[a]	$356,292	$4,275,500	$35,629,167
Scenario 3 - WTIV & Inshore Floating Barge	**$631,841**	**$7,581,462**	**$62,655,850**
WTIV[a]	$549,817	$6,597,250	$54,518,750
Inshore Feeder Barge[b]	$29,990	$359,850	$2,973,750
Tugs (2 50T BP) and Mooring Tug[b]	$47,584	$570,962	$4,718,350
Fuel for Tugs (2) and Mooring Tug[c]	$4,450	$53,400	$445,000

Note(s):

[a] Hourly rates were derived from the daily rates for the WTIV and Jack-Up Feeder Barge provided in the Vessel Study.

[b] Hourly rates were derived from the daily rates for barges and tugs of the same magnitude/capacity provided by marine contractors in the New York area.

[c] Fuel for the tugs was calculated using the high-level schedule created for scenario 3 and is based on the percentage of hours the tugs are in use versus the total overall hours for rental.

Table 8-4. Day Rate Summary

	Day Rates	
	Vessel Study	**Survey of NY Marine Contractors**
WTIV[1]	$220,000	
Jack-Up Feeder Barge[a]	$85,000	
Inshore Feeder Barge[b]		$12,000
Tug[c]		$6,800
Tug Fuel[d]		$7,200

Note(s):

[a] Day rate includes the cost of crew: 12 people at $125,000 salary; this daily cost is derived from the pricing model (to achieve a specific Internal Rate of Return) based on the cost of building the vessel, as investigated by GustoMSC.

[b] Approximate mid-range day rate for a barge ranging between 330 ft. and 400 ft. in length, as provided by marine contractors in the New York area.

[c] Day rate for the base cost of a 40-55t bollard pull tug, without the cost of fuel included, as provided by marine contractors in the New York area.

[d] Day rate for fuel of a 40-55t bollard pull tug, assuming the tug runs for 24 hours, as provided by marine contractors in the New York area.

As seen in the summary of costs, scenarios 1 and 3 result in relatively similar costs, because they are the most economically efficient solutions to the staging solutions posed in the New York area.

8.7 Conclusion and Next Steps

This study provides the framework necessary to prove the feasibility of the floating inshore feeder barge concept as a means of transporting OSW components. This framework includes the identification of required barge dimensions and load capacity to accommodate four nacelles, 12 blades, and eight tower sections (four tower top and four tower bottom sections). Five potential transfer locations (locations A–E) have been identified in the shelter waters of Lower New York Harbor, including Gravesend, Sandy Hook and Raritan Bays; with environmental conditions characterized in each location. Station keeping alternatives have been analyzed, and the envisioned transfer outline described. Through the analyses of barge availability and stability, this study has verified that the 330- and 400-foot barges are viable inshore feeder barge options.

Beyond proving that the inshore feeder barge concept is technically feasible, the associated schedule and cost for the inshore feeder barge and WTIV have been approximated. In comparison to scenario 1 (in which only a WTIV is used, as discussed in Section 8.3), scenario 3 (the inshore feeder barge concept) is anticipated to require 8% less time per installation cycle. Although scenario 3 is anticipated to cost approximately seven 7% more than scenario 1, the use of the inshore feeder barge allows access to multiple facilities in New York Harbor and up the Hudson River that may result in further economies which are outside the scope of this report.

A number of activities are proposed to further develop the inshore feeder barge concept, including the following:

- Coordination with Stakeholder groups. The inshore feeder barge may potentially impact a number of existing waterway users, including federal (USACE, U.S. Coast Guard, U.S. Navy) and state (NYS DOS, NYS DEC, NJ DEP) agencies, maritime user groups (MAPONY), harbor pilots, commercial shipping, recreational users, and environmental interests in the area. Input from all of these groups will be necessary to select the most beneficial transfer area with the least adverse effects.
- Meteorological Measurements. The availability analysis may be refined based on site-specific measurements. A wave buoy is recommended to gather data at potential sites, in order to inform site selection and further development of the station keeping method.
- Regulatory Coordination. Use of the waterway, especially considering the installation of any fixed or floating structures (e.g., breasting dolphins, buoys, etc.) will require approvals at the Federal, State and possibly local levels. A pre-application meeting is recommended to better define regulators' concerns and data needs to evaluate potential future regulatory application.
- Transfer Area Basis of Design. A Basis of Design (BOD) would compile all of the relevant statement of need, project description, federal, state and local regulations, operational considerations (e.g., vessel routes, lighting and marking requirements), and other parameters which may influence the selection of a transfer area or design of the station keeping system. The BOD could be used as a consistent reference when coordinating with the various stakeholder groups.

While a number of additional actions are necessary to further develop the inshore feeder barge concept prior to use as a process to assist in the installation of offshore wind facilities, this study demonstrates technical feasibility and potential economic efficiency for the inshore feeder barge concept as a possible solution to the staging challenges posed in New York State.

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Appendix A. Feeder Barge Hydrodynamic Analyses Details

Hydrodynamic analyses are performed to assess the motions of the feeder barge when subject to wind and wave loading. The motions of the feeder barge are especially critical during load transfer from feeder barge to WTIV. The analyses are divided into frequency domain analyses and time domain analyses.

The frequency domain analyses provide general hydrodynamic properties of the barges, describing how the barge behaves when subject to dynamic loading at single frequencies. Results from these analyses are used both in the stability assessment and in the time domain analyses.

Time domain analyses are performed to determine the dynamic response of the barges when subject to the operational wave and wind conditions on site. These analyses account for dynamic loading within a frequency interval, where the response at each frequency in the interval is determined based on the frequency domain results. The time domain analysis models the mooring system, and also includes the breasting dolphins where applicable.

Frequency domain analyses are linear analyses, as opposed to time domain analyses which are non-linear. Linear analyses are often sufficient to determine the dynamic response of structures such as barges. However, when analyzing the barge response with the additional mooring restraint of breasting dolphins, the non-linear model is required to capture the non-linear restoring effect between barge and breasting dolphins. Time domain analyses were therefore chosen to analyze the barge response when moored at the mooring dolphins.

A.1 Frequency Domain Analyses

Frequency domain analyses are performed in the ANSYS Aqwa software, published by ANSYS, Inc. Aqwa is a 3D boundary element method diffraction radiation code. For each barge, a panel model was generated and analyzed to obtain the load and response transfer functions, drift force transfer functions, frequency dependent added mass and damping, and vertical restoring properties. In addition, basic stability parameters are obtained.

The barge and load data given in Table A-1 is applied in the analyses.

Table A-1: Frequency Domain—Barge Model Data

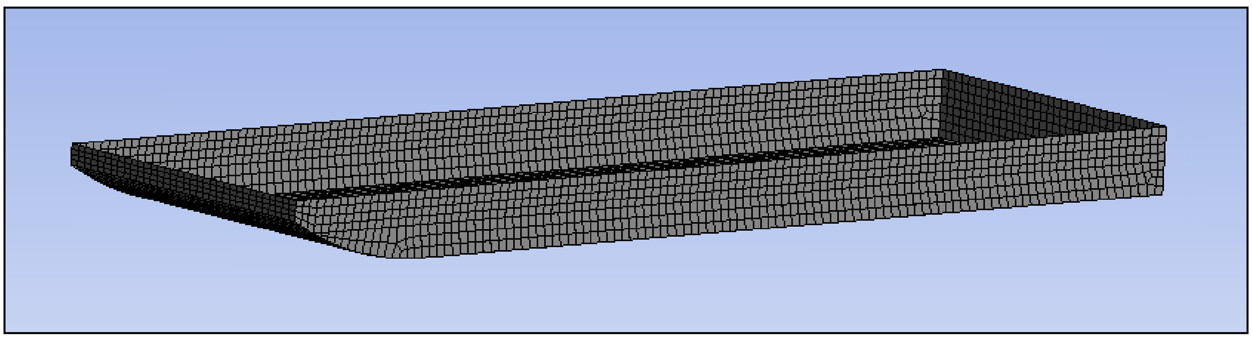
Frequency Domain Model Data	330-foot Barge	400-foot Barge
Length	100.6m (330 ft.)	122m (400 ft.)
Width	30.5m (100 ft.)	36.6m (120 ft.)
Depth Moulded	6.1m (20 ft.)	7.6m (25 ft.)
Draught Moulded	3m (10 ft.)	3m (10 ft.)
Mass (incl deck load)	8,826 MT (19,458,000 lbs.)	12,551 MT (27,670,220 lbs.)
Center of Gravity (COG)* (X / Y / Z incl deck load)	47.1m / 0m / 12.08m (155 ft. / 0 ft. / 40 ft.)	55.8m / 0m / 10.58m (183 ft. / 0 ft. / 131 ft.)

Note(s):

* COG with reference to X at aft perpendicular, Y at barge centerline and Z at keel.

A screenshot of the 330-foot barge model applied in ANSYS Aqwa is shown in Figure A-1.

Figure A-1: 330-Foot Barge Analysis Model



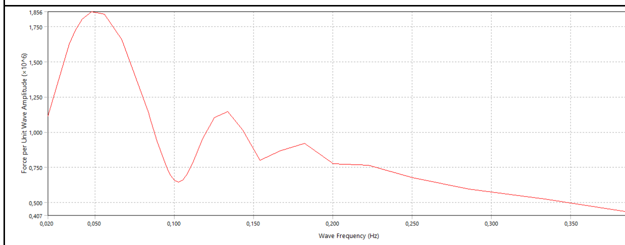
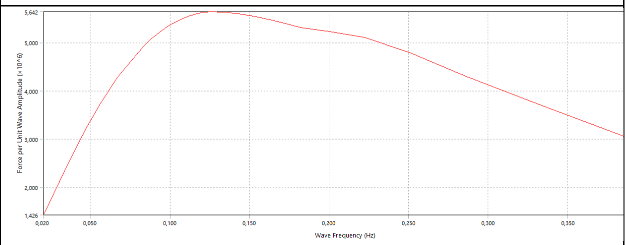
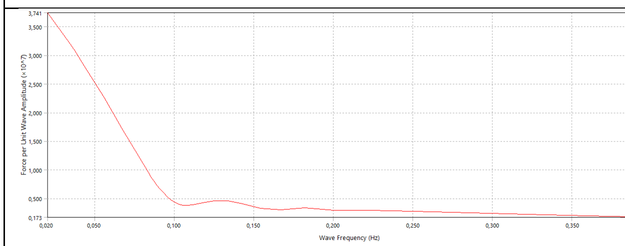
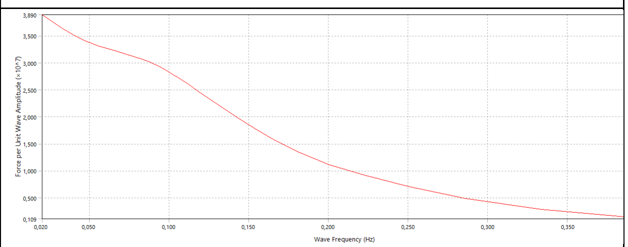
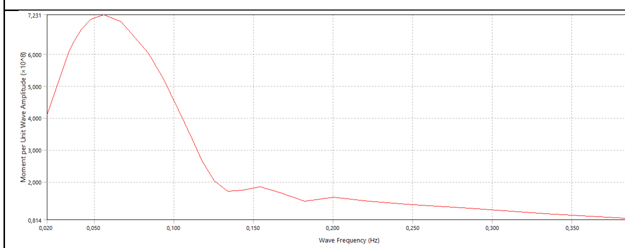
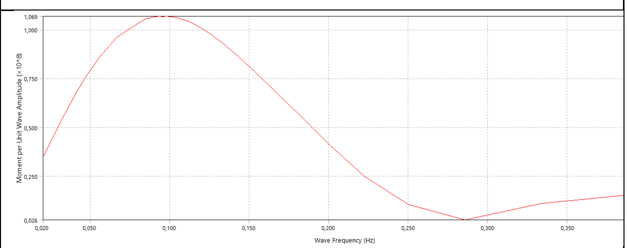
The analysis parameters defined in Table B-2 were applied in the analyses.

Table A-2: Frequency Domain Analysis Parameters

For reference, results for linear load and moment response amplitude operators (RAOs) are given in Figure A-2. The results of these analyses are transferred to the time domain analysis model for further analyses.

Frequency Domain Analysis Parameters	Applied Values
Analysis Frequencies	33 frequencies, from 0.02 Hz to 0.4 Hz (corresponds with wave periods from 50s to 2.5s)
Analysis Directions	8 headings with 45 degrees separation
Wave Drift Quadratic Transfer Functions (QTFs)	Newman’s approximation
Sum Frequency QTFs	Not calculated

Figure A-2: Linear Load and Moment RAOs

Surge Load RAO – 0 deg [N/m]	Sway Load RAO – 90 deg [N/m]
	
Heave Load RAO – 0 deg [N/m]	Heave Load RAO – 90 deg [N/m]
	
Pitch Moment RAO – 0 deg [Nm/m]	Roll Moment RAO – 90 deg [Nm/m]
	

A.2 Time Domain Analyses

Time domain analyses are performed in analysis software Orcaflex published by Orcina, Ltd. These analyses combine the results of the frequency domain analysis with the mooring system and wind loading and are used to obtain barge responses.

Data applied in the barge model is given in Table A-3.

Table A-3: Time Domain—Barge Model Data

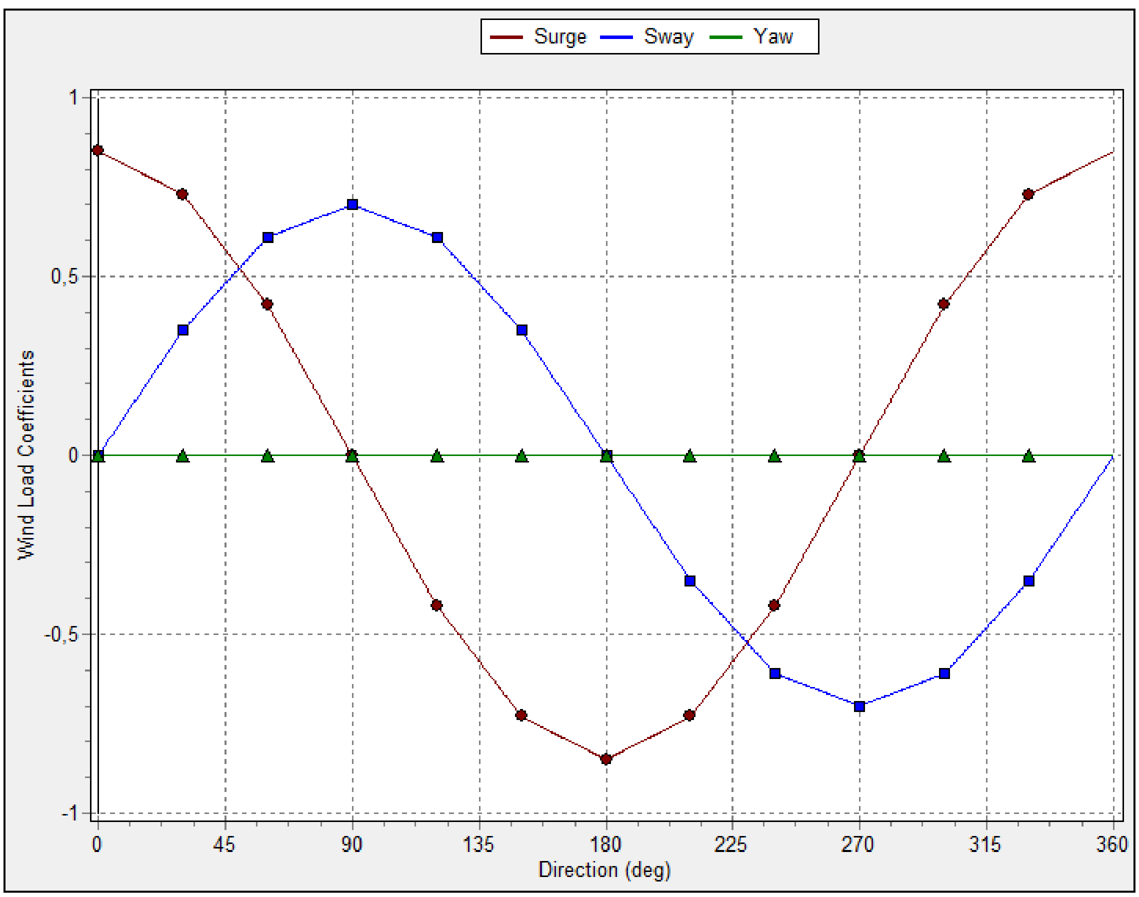
Time Domain Barge Model Data	330-foot Barge	400-foot Barge
Mass and Inertia	From Frequency Domain analyses	From Frequency Domain analyses
Load RAOs		
Wave Drift QTFs		
Vertical Stiffness		
Added Mass and Damping		
Wind Coefficients (Surge / Sway / Yaw)* [-]	0.834 / 0.682 / 0	0.85 / 0.7 / 0
Wind Areas (Surge / Sway / Yaw)*	628m^2 / 3,290 m^2 / 0 m^2 (6,760 ft^2 / 35,413 ft^2 / 0 ft^2)	702.8 m^2 / 3,504.9 m^2 / 0 m^2 (7,565 ft^2 / 37,726 ft^2 / 0 ft^2)

Note(s):

* The following procedure is used to obtain wind coefficients and areas:

1. Obtain the projected area of each component (barge/towers/nacelles/blade racks) based on component size and orientation on the barge.
2. Apply shape dependent drag coefficient (Cd) and calculate distributed load for each component, based on Cd, area and wind profile. Summarize loads to obtain total load.
3. Combine the total load and total projected area and derive corresponding drag coefficient of total system. A screenshot of the directional wind coefficients applied in the analysis of the 400-foot barge is shown in Figure B-3.

Figure A-3: Barge B—Wind Coefficients



The mooring system consist of four (4) lines, where each line has a 50m (164 ft.) wire segment connected to the barge, and a 233.7m (767 ft.) chain segment along seabed, giving a total length of 283.7m (931 ft.) for each mooring line. Note that the length and dimensions of the mooring system have not been optimized, but rather defined sufficiently large to achieve the required stiffness properties.

Table A-4: Time Domain—Mooring System Data

Time Domain Mooring System Data	330-foot Barge	400-foot Barge
Number of Lines [-]	4	4
Line Segment 1 – Wire – Length	50m (164 ft.)	50m (164 ft.)
Line Segment 1 – Wire – Diameter	70mm (2.8 in.)	70 mm (2.8 in.)
Line Segment 2 – Chain – Length	233.7m (767 ft.)	233.7 m (767 ft.)
Line Segment 2 – Chain – Diameter	76mm (3 in.)	76mm (3 in.)
Barge Hang-off Coordinates (X/Y/Z)	+/-45m / +/-15m / 5m (+/-148 ft. / +/-49 ft. / 16 ft.)	+/-55m / +/-18m / 5m (+/-180 ft. / +/-59 ft. / 16 ft.)
Anchor Coordinates (X/Y/Z)	+/-245m / +/-215m / -8m (+/-804 ft. / +/-705 ft. / 26 ft.)	+/-255m / +/-285m / -8m (+/-837 ft. / +/-935 ft. / 26 ft.)
Pretension Level	30MT (66,138 lbs.)	30MT (66,138 lbs.)

For analyses with breasting dolphins, the following data applies.

Table A-5: Time Domain—Mooring System Data including Breasting Dolphins

Time Domain Mooring System Data	400-foot Barge
Number of Lines [-]	4
Line Segment 1 – Wire – Length	50m (164 ft.)
Line Segment 1 – Wire – Diameter	70mm (2.8 in.)
Line Segment 2 – Chain – Length	233.7m (767 ft.)
Line Segment 2 – Chain – Diameter	76mm (3 in.)
Barge Hangoff Coordinates (X/Y/Z)	+/-55m / +/-18m / 5m (+/-180 ft. / +/-59 ft. / 16 ft.)
Anchor Coordinates (X/Y/Z) – Line 1 and 4	+/-196.4m / 263m / -8m (+/-644 ft. / +/-863 ft. / 26 ft.)
Anchor Coordinates (X/Y/Z) – Line 2 and 3	+/-300m / -159.4m / -8m (+/-984 ft. / +/-523 ft. / 26 ft.)
Pretension Level	30MT (66,138 lbs.)
Breasting Dolphin Coordinates (X/Y)	+/- 40m / 18.3m (+/-131 ft. / +/-60 ft.)
Breasting Dolphin Stiffness	842 kN/m (621,027 lb./ft.)

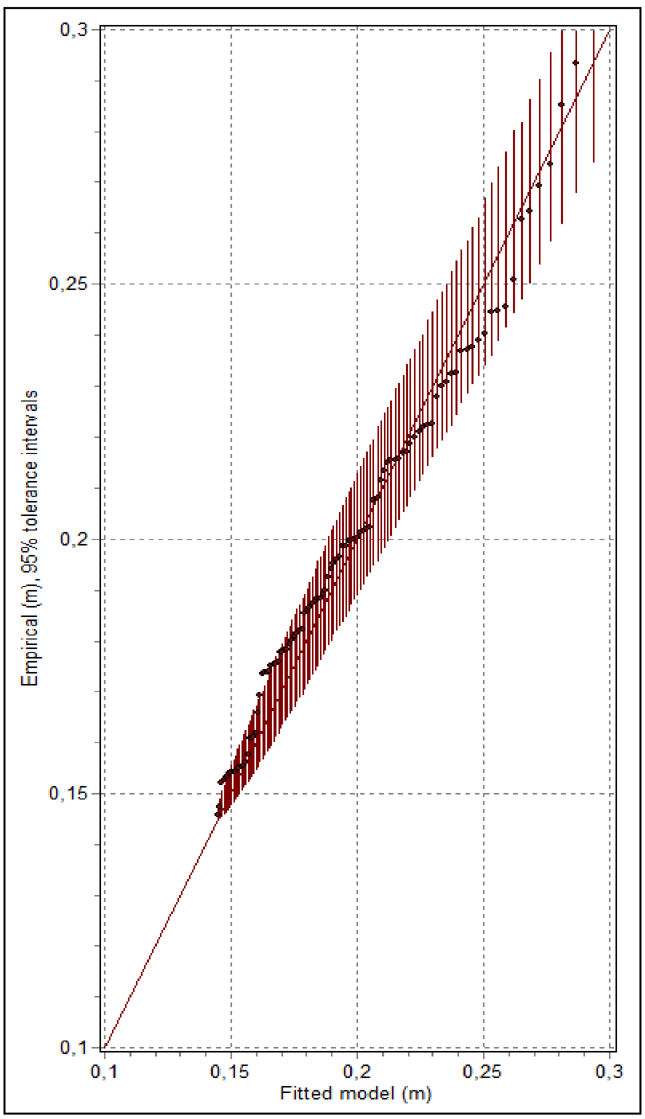
The analysis parameters defined in Table B-6 were applied in the analyses.

Table A-6: Time Domain—Analysis Parameters

Time Domain Analysis Parameters	Applied Values
Analysis Duration [hours]	3
Wave Spectrum	JONSWAP with gamma 1
Wind Spectrum	NPD
Post Processing Method	Generalized Pareto, 3 hour return period

For reference, a probability plot of maximum surge motion using the Generalized Pareto distribution is shown in Figure A-4. The distribution is seen to fit the data points well, and within the 95% confidence intervals at the upper tail.

Figure A-4: Probability Plot of Maximum Surge Motion—Generalized Pareto Distribution



The results of the time domain analyses are provided in the report.

A.3 Availability Assessment

Total availability is determined by first obtaining the directional availability in wave conditions only, and thereafter by comparing these to the directional availability based on wind limitations.

Table A-7 shows the assessment of directional availability based on waves only for the 330-foot barge at location A. The green cells indicate where acceptable wave conditions are found, based on the wave conditions previously presented, and also given in Table A-8. For this location a barge heading of 135 degrees is used.

Table A-7: Directional Availability in Waves Only—330-Foot Barge—Location A

Hs/Dir Scatter	HDir (from deg T)															
Hs (m)	349 - 11	11 - 34	34 - 56	56 - 79	79 - 101	101 - 124	124 - 146	146 - 169	169 - 191	191 - 214	214 - 236	236 - 259	259 - 281	281 - 304	304 - 326	326 - 349
Greater Than 3.00																
2.75 - 3.00																
2.50 - 2.75																
2.25 - 2.50								1								
2.00 - 2.25						1	1									
1.75 - 2.00						2	5	1								
1.50 - 1.75					2	32	210	16								
1.25 - 1.50			2	3	19	258	947	50	3	1	3	1				
1.00 - 1.25			7	19	59	542	1888	580	39	4	47	17	1	1		
0.75 - 1.00	14	11	42	44	185	1488	2037	2999	403	30	211	213	57	36	29	29
0.50 - 0.75	414	572	388	313	927	4456	5783	8363	1423	173	1483	2162	786	747	581	669
0.25 - 0.50	5095	6812	2082	2135	4254	7169	11829	12564	4466	2735	13060	12240	4062	8031	5514	5470
0.00 - 0.25	31345	12792	11356	15468	17656	21422	21255	18414	12793	9178	11858	11521	8694	5898	5335	6891
Total Observations	36868	20187	13877	17982	23102	35370	43955	42988	19127	12121	26662	26154	13600	14713	11459	13059
Occurences with Acceptable Hs	36854	19604	13438	17603	22837	33047	42792	39341	18682	11913	24918	23761	13542	14676	11459	13030
Availability [%]	100.0 %	97.1 %	96.8 %	97.9 %	98.9 %	93.4 %	97.4 %	91.5 %	97.7 %	98.3 %	93.5 %	90.9 %	99.6 %	99.7 %	100.0 %	99.8 %

Table A-8: Acceptable Environmental Conditions—330-Foot Barge

Barge A	Head/Aft Sea	Quartering Sea	Beam Sea
Wave Height	1.25m (4.1 ft.)	0.75m (2.5 ft.)	0.5m (1.6 ft.)
Wave Period	4.5 sec	3.5 sec	3 sec
Wind Speed	10 m/s (22 mph)		

The results in Table A-8 are thereafter converted to the same heading sectors as used in the wind scatter.

Table A-9: Availability Converted to Wind Sectors

Availability Converted to Wind Sectors								
Heading [deg]	0-45	45-90	90-135	135-180	180-225	225-270	270-315	315-360
Availability [%]	98.2 %	98.0 %	95.6 %	94.0 %	96.3 %	92.9 %	99.8 %	99.9 %

Table A-10: Directional Availability in Wind Only

Wind/Dir Scatter	UDir (from deg T)							
U (m/s)	0 - 45	45 - 90	90 - 135	135 - 180	180 - 225	225 - 270	270 - 315	315 - 360
Greater Than 20.0	2		4	2	1	1	3	
18.0 - 20.0	2	4	2	1	2	4	11	1
16.0 - 18.0	6	31	9	16	15	49	147	21
14.0 - 16.0	28	52	23	56	44	75	378	127
12.0 - 14.0	187	164	114	172	388	230	1787	710
10.0 - 12.0	713	518	427	562	1533	797	5298	2692
8.0 - 10.0	2387	1480	1213	1475	5162	2950	10906	7345
6.0 - 8.0	7172	4315	3735	4535	14728	9252	17106	14561
4.0 - 6.0	13836	8653	8130	10633	28537	19164	16590	16348
2.0 - 4.0	13328	13074	9986	9497	22882	16351	8275	8312
0.0 - 2.0	1417	2057	1963	1361	1850	943	602	609
Total	39078	30348	25606	28310	75142	49816	61103	50726
Occurences with Acceptable Wind	38140	29579	25027	27501	73159	48660	53479	47175
Availability [%]	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %

The combined availability is then finally obtained by combining the wind and wave results, and selecting the lowest availability of the two. By selecting the minimum, it is assumed that the occurrence of wind and waves is correlated, meaning that the limiting wave conditions occur at the same time as high wind. This is assumed to be a good assumption, as the wave conditions are primarily wind driven in New York Harbor.

Table A-11: Combined Availability—330-Foot Barge—Location A

Location A	0 - 45	45 - 90	90 - 135	135 - 180	180 - 225	225 - 270	270 - 315	315 - 360
Availability Wind	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Availability Waves	98.2 %	98.0 %	95.6 %	94.0 %	96.3 %	92.9 %	99.8 %	99.9 %
Combined Availability	97.6 %	97.5 %	95.6 %	94.0 %	96.3 %	92.9 %	87.5 %	93.0 %

By combining these results with the weight of each sector, a total availability of 94% is found.

Full results for the 330-foot barge at each location are given in Table A-12, and for the 400-ft barge in Table A-13.

Table A- 11: Directional Availability – 330-foot Barge – All Locations

Location A	0 - 45	45 - 90	90 - 135	135 - 180	180 - 225	225 - 270	270 - 315	315 - 360
Availability Wind	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Availability Waves	98.2 %	98.0 %	95.6 %	94.0 %	96.3 %	92.9 %	99.8 %	99.9 %
Combined Availability	97.6 %	97.5 %	95.6 %	94.0 %	96.3 %	92.9 %	87.5 %	93.0 %
Sector weight	11.1 %	8.6 %	7.3 %	8.0 %	21.3 %	14.2 %	15.6 %	13.8 %
Total Availability	94 %							
Location B	0 - 45	45 - 90	90 - 135	135 - 180	180 - 225	225 - 270	270 - 315	315 - 360
Availability Wind	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Availability Waves	98.3 %	99.4 %	95.6 %	97.1 %	100.0 %	99.5 %	95.8 %	94.4 %
Combined Availability	97.6 %	97.5 %	95.6 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Sector weight	11.1 %	8.6 %	7.3 %	8.0 %	21.3 %	14.2 %	15.6 %	13.8 %
Total Availability	95 %							
Location C	0 - 45	45 - 90	90 - 135	135 - 180	180 - 225	225 - 270	270 - 315	315 - 360
Availability Wind	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Availability Waves	99.9 %	98.3 %	96.4 %	99.6 %	100.0 %	99.0 %	93.6 %	99.2 %
Combined Availability	97.6 %	97.5 %	96.4 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Sector weight	11.1 %	8.6 %	7.3 %	8.0 %	21.3 %	14.2 %	15.6 %	13.8 %
Total Availability	95 %							
Location D	0 - 45	45 - 90	90 - 135	135 - 180	180 - 225	225 - 270	270 - 315	315 - 360
Availability Wind	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Availability Waves	98.0 %	99.1 %	98.6 %	99.5 %	99.8 %	99.9 %	99.5 %	99.1 %
Combined Availability	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Sector weight	11.1 %	8.6 %	7.3 %	8.0 %	21.3 %	14.2 %	15.6 %	13.8 %
Total Availability	95 %							
Location E	0 - 45	45 - 90	90 - 135	135 - 180	180 - 225	225 - 270	270 - 315	315 - 360
Availability Wind	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Availability Waves	100.0 %	99.5 %	98.6 %	100.0 %	96.7 %	95.4 %	97.6 %	99.8 %
Combined Availability	97.6 %	97.5 %	97.7 %	97.1 %	96.7 %	95.4 %	87.5 %	93.0 %
Sector weight	11.1 %	8.6 %	7.3 %	8.0 %	21.3 %	14.2 %	15.6 %	13.8 %
Total Availability	95 %							

Table A- 12: Directional Availability – 400-foot Barge – All Locations

Location A	0 - 45	45 - 90	90 - 135	135 - 180	180 - 225	225 - 270	270 - 315	315 - 360
Availability Wind	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Availability Waves	97.8 %	96.7 %	93.5 %	91.8 %	94.2 %	92.0 %	98.3 %	99.3 %
Availability Waves incl. Dolphins	99.9 %	99.6 %	97.9 %	98.3 %	99.5 %	99.2 %	100.0 %	100.0 %
Combined Availability w/o Dolphins	97.6 %	96.7 %	93.5 %	91.8 %	94.2 %	92.0 %	87.5 %	93.0 %
Combined Availability incl. Dolphins	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Sector weight	11.1 %	8.6 %	7.3 %	8.0 %	21.3 %	14.2 %	15.6 %	13.8 %
Total Availability w/o Dolphins	93 %							
Total Availability incl. Dolphins	95 %							
Location B	0 - 45	45 - 90	90 - 135	135 - 180	180 - 225	225 - 270	270 - 315	315 - 360
Availability Wind	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Availability Waves	96.3 %	99.1 %	89.4 %	97.1 %	99.7 %	99.5 %	88.6 %	94.4 %
Availability Waves incl. Dolphins	99.8 %	99.9 %	99.6 %	99.8 %	100.0 %	100.0 %	99.5 %	99.4 %
Combined Availability w/o Dolphins	96.3 %	97.5 %	89.4 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Combined Availability incl. Dolphins	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Sector weight	11.1 %	8.6 %	7.3 %	8.0 %	21.3 %	14.2 %	15.6 %	13.8 %
Total Availability w/o Dolphins	95 %							
Total Availability incl. Dolphins	95 %							
Location C	0 - 45	45 - 90	90 - 135	135 - 180	180 - 225	225 - 270	270 - 315	315 - 360
Availability Wind	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Availability Waves	99.6 %	96.9 %	92.6 %	97.4 %	100.0 %	98.9 %	89.9 %	97.3 %
Availability Waves incl. Dolphins	100.0 %	99.8 %	99.6 %	100.0 %	100.0 %	99.9 %	99.3 %	99.9 %
Combined Availability w/o Dolphins	97.6 %	96.9 %	92.6 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Combined Availability incl. Dolphins	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Sector weight	11.1 %	8.6 %	7.3 %	8.0 %	21.3 %	14.2 %	15.6 %	13.8 %
Total Availability w/o Dolphins	95 %							
Total Availability incl. Dolphins	95 %							
Location D	0 - 45	45 - 90	90 - 135	135 - 180	180 - 225	225 - 270	270 - 315	315 - 360
Availability Wind	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Availability Waves	96.2 %	97.7 %	98.0 %	99.0 %	99.7 %	99.9 %	98.6 %	97.6 %
Availability Waves incl. Dolphins	99.9 %	99.8 %	99.7 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Combined Availability w/o Dolphins	96.2 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Combined Availability incl. Dolphins	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Sector weight	11.1 %	8.6 %	7.3 %	8.0 %	21.3 %	14.2 %	15.6 %	13.8 %
Total Availability w/o Dolphins	95 %							
Total Availability incl. Dolphins	95 %							
Location E	0 - 45	45 - 90	90 - 135	135 - 180	180 - 225	225 - 270	270 - 315	315 - 360
Availability Wind	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Availability Waves	100.0 %	99.4 %	98.6 %	99.9 %	95.5 %	92.7 %	96.5 %	99.1 %
Availability Waves incl. Dolphins	100.0 %	100.0 %	99.8 %	100.0 %	98.7 %	99.0 %	99.6 %	99.8 %
Combined Availability w/o Dolphins	97.6 %	97.5 %	97.7 %	97.1 %	95.5 %	92.7 %	87.5 %	93.0 %
Combined Availability incl. Dolphins	97.6 %	97.5 %	97.7 %	97.1 %	97.4 %	97.7 %	87.5 %	93.0 %
Sector weight	11.1 %	8.6 %	7.3 %	8.0 %	21.3 %	14.2 %	15.6 %	13.8 %
Total Availability w/o Dolphins	94 %							
Total Availability incl. Dolphins	95 %							

Summary and discussion of availability results is given in the report.

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