FINAL

Appendix E
PDI Bathymetric Survey Data Report

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1 Introduction and Survey Design

The 2021 *Quality Assurance Project Plan: Pre-Design Surveys of the Lower Duwamish Waterway Middle Reach* (QAPP) described required bathymetric surveying coverage, methods, and quality control (QC) for the Lower Duwamish Waterway (LDW) middle reach (Anchor QEA and Windward 2021). The 2021 bathymetric survey of the middle reach collected precision bathymetry data between river mile (RM) 1.35 and RM 3.05; water depths within the middle reach survey area allowed all bathymetry data to be collected with a R2Sonic™ high-resolution multibeam bathymetric sonar. The 2021 bathymetric survey results were reported in Appendix B of the *Pre-design Investigation Work Plan for the Lower Duwamish Waterway - Middle Reach* (Windward and Anchor QEA 2023). In that document, it was noted that there were limited data gaps in the 2021 survey coverage, due to the presence of large barges or vessels, and that these gaps would be surveyed in 2023.

This appendix to the data evaluation report summarizes the 2023 bathymetric survey, which was conducted during the Phase I Pre-Design Investigation to fill data gaps in survey coverage. Data from the 2023 report supplement those from the 2021 report by providing additional details on surveying methods, QC, and data processing methods that were used for both the 2021 and 2023 surveys. There were no deviations from the survey QAPP during the 2023 bathymetric survey (Anchor QEA and Windward 2021). Bathymetric survey coverage in the middle reach is now complete and no additional coverage data gaps exist. The final combined bathymetric data were used to create a digital terrain model of seafloor morphology, from which contours and sun-illuminated images were generated.

Both the 2021 and 2023 surveys were conducted on an established coordinate system. All bathymetry data are referenced to monuments established by the Anchor QEA project team prior to bathymetry data acquisition. The horizontal datum for this survey is North American Datum of 1983, 1991 adjustment (NAD83/91), State Plane Coordinate System, Washington North Zone, measured in U.S. Survey Feet; the vertical datum for this survey is mean lower low water (MLLW). The 2021 bathymetric survey began on October 20, 2021, and was completed on November 18, 2021. For the 2023 bathymetric survey, hydrographic survey operations were conducted between January and June 2023. Results are presented on Map E-1a and Map E-1b. Data acquisition was performed during higher daylight tides to maximize bathymetry coverage within the shallow intertidal zone. Prior to bathymetric surveying activities, True North Land Surveying, Inc. established a control network along the LDW at upland locations. These survey control points were installed on October 15, 2021.

2 Survey Vessel and Crew

The Survey Vessel *Soundwave*—a 26-foot custom aluminum survey boat, owned and operated by Northwest Hydro Inc. (NWH)—was deployed for both the 2021 and 2023 bathymetric surveys. This vessel is equipped with an integrated navigation/data acquisition system and a custom mount for

the R2Sonic™ 2022 high-resolution multibeam bathymetric sonar. This hydrographic survey system is ideal for shallow-water survey operations in constrained areas, such as the LDW.

3 Positioning

Horizontal positions were acquired using an Applanix© POS MV combined inertial real-time kinematic global positioning system (RTK GPS) navigation system. This system integrates two GPS receivers with a motion reference unit. RTK GPS corrections were input to improve horizontal positioning accuracy to less than 0.5 meters (1.6 feet). The advantage of this navigation system is that it not only provides motion information (i.e., heading, roll, pitch, and heave) to compute X, Y, Z data from the multibeam sonar measurements, but it also provides accurate inertial navigation through GPS outages for up to 30 seconds. Position data were used in real time to provide navigation information to the vessel operator. To check the accuracy of the positioning system and confirm the RTK corrections, a position check was conducted daily on an established monument with a known position. Water level measurements were obtained by RTK GPS during data acquisition. Water surface elevations obtained by RTK GPS were verified against gauges positioned within the project area, as well as using an automated water level gauge deployed by NWH within the project area for the duration of data collection. All soundings were reduced to MLLW elevations in the delivered dataset.

4 Multibeam Data Acquisition

Soundings were acquired using a R2Sonic™ 2022 high-resolution multibeam bathymetric sonar. Using a frequency of 450 kHz, the R2Sonic™ sonar illuminates up to a 160° (80° to starboard and 80° to port) by 1.0° swath along the riverbed, perpendicular to the ship's track, and resolves a slant-range measurement to the riverbed every 1.0° along the swath. Sonar ping rates vary, depending on the depth of the water and sonar range settings. In the LDW, ping rates were generally at least 17 Hz as the vessel surveyed along each track line.

Multibeam data were collected by running lines parallel with the shorelines and dock structures. During survey operations, all lines offshore of the shoreline were run using a sonar swath limited in width to 60° on both starboard and port beams during processing.

To account for survey vessel heave (vertical movement), pitch, and roll, an Applanix© POS MV motion reference sensor was utilized. The POS MV system was also used to record the vessel heading (yaw) from which the sonar beam orientation was derived. Multibeam data were gathered with Hypack Hysweep® data acquisition software, which acquired and time-tagged all sensor data, including multibeam sonar, position, heading, heave, pitch, and roll. The navigation system provided navigation output to the vessel operator's monitor and managed survey data collection.

Detailed measurements of the sound-velocity profile (SVP) through the water column are critical in multibeam surveys. Changes in the SVP not only affect acoustic distance measurements but can also cause refraction, or bending of, the sonar path as it passes through layers in the water column at different velocities. Because the velocity of sound is directly related to the density and temperature of water, changes in the SVP are expected to occur in the LDW due to the mixing of fresh water and saltwater during tidal changes. In the LDW survey area, SVPs were measured at 0.5-meter depth intervals, from the water surface to the mudline, in the deepest part of the survey area. An AML BaseX2 sound-velocity profiler was used to directly measure SVPs of the water column. To account for SVP spatial and temporal variations, the LDW survey area was divided into subsections. The size of a survey subsection was determined at the time of surveying by collecting SVP data and adjusting the length of the subsection so that similar results were obtained at each end. Temporal change was addressed by taking SVP measurements as each section was mapped.

Data acquisition involves setting the motion sensor to the survey conditions and running slow, uniform lines in a systematic pattern. Adjustments were made to scale and gain settings, as required, to maximize the resolution of the survey. During the survey, preliminary multibeam bathymetric data were displayed in real time on the Hypack Hysweep® computer. A real-time color matrix was drawn on the vessel's computer screens to show data coverage. Bathymetry data acquisition was strategically planned to collect shallow-water data during daily high tide events, thereby maximizing the high-resolution multibeam sonar coverage of the project area.

5 Single-beam Data Acquisition

No single-beam bathymetry was collected during the middle reach data collection. Each survey was timed to coincide with daylight high tides, and water was deep enough at all locations to allow for high-resolution multibeam sonar data collection.

6 Data Processing Methods

Post-processing of multibeam data in 2021 and 2023 was completed using Hypack Hysweep® multibeam editing and analysis software. Patch test data were analyzed and any alignment corrections were applied. Water level data were verified and applied to adjust all depth measurements to MLLW. SVPs were generated from the AML BaseX2 sound-velocity profiler measurements taken in the field and used to correct slant range measurements and compensate for ray path bending.

Processing began with a review of each survey line using the Hypack Hysweep® swath editor. Verified water surface correctors were applied to the dataset at this time. Position and sensor data were reviewed by qualified surveyors and accepted or removed if erroneous data were observed. Sounding data were reviewed and edited to remove bad data points, such as bottom multiples or

sonar returns from pilings. After swath editing, all data were reviewed using the Hypack Hysweep® area-based editing tools to ensure no erroneous data points remained.

To take advantage of the level of detail provided by a multibeam survey, a 1-foot-resolution sun-illuminated model and 1-foot gridded dataset were exported from Hypack Hysweep®. The gridding process uses an inverse-weighted mean of all soundings within a 1-foot by 1-foot cell. The 1-foot grid size allows for comparisons with previous bathymetric surveys that were conducted with similar high-resolution methods. The final accepted bathymetry data were imported into Autodesk Civil 3D® to generate a project digital terrain model and 1-foot contours.

7 Quality Control and Survey Accuracy

The acquisition system and survey protocols were designed with some redundancy to demonstrate achievement of the required accuracy during data acquisition. The following control methods and survey accuracies were used for both the 2021 and 2023 bathymetric surveys, in compliance with the Survey QAPP (Anchor QEA and Windward 2021):

- **Positioning:** Positions were logged in WGS84 geographic coordinates and projected onto the NAD83/91 Washington North Zone coordinate system. A geodetic control survey was conducted to provide positions for monuments within the study area. A position confidence check was conducted daily on a monument that was accessible from the water. Measured positions recorded during these checks were compared to the surveyed value to ensure the target horizontal and vertical accuracies were being obtained.
- **Tides and Water Elevations:** RTK GPS-derived water levels were checked twice daily by observing NWH staff gauges that had been installed in the project area. Backup tidal observations were gathered from NWH-deployed automated gauges that were used to confirm RTK GPS tidal values.
- **Patch Test:** To confirm alignment of the sensor data with the sonar swath and verify delay times applied to the time-tagged sensor data, a patch test was conducted. A patch test is a series of lines run in a specific pattern that are used in pairs to analyze roll, pitch, and heading alignment angles with the sonar swath, as well as latency (time delays) in the time tagging of sensor data. A bar check and lead line check were conducted to confirm draft of the sonar head. These tests were conducted at the beginning and end of the survey and any time there were changes in the instrument configuration.
- **Sonar Draft:** A bar check was conducted at the beginning and end of the project to confirm multibeam and single-beam sonar transducer draft below the water line. Using calibrated marks on an attached chain, a bar was lowered below the sonar to specific intervals beneath the water surface. Onboard sonar depth measurements were confirmed to match the known depth of the bar.

- **Survey Accuracies:** Bathymetry data were acquired in conformance with the U.S. Army Corps of Engineers specification for soft-bottom dredge surveys (USACE 2013), which states an accuracy of +/- 0.5 feet vertically and 3 feet horizontally for 95% of all data points. These accuracies meet the approved Survey QAPP requirements (Anchor QEA and Windward 2021). Quality assurance/QC checks during data collection indicated better accuracies were achieved.

8 References

Anchor QEA, Windward. 2021. Quality assurance project plan: pre-design surveys of the Lower Duwamish Waterway middle reach. Final. Submitted to EPA October 19, 2021. Anchor QEA and Windward Environmental LLC, Seattle, WA.

USACE. 2013. Engineering and design. Hydrographic surveying. EM 1110-2-1003. US Arny Corps of Engineers.

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