DAVID EVANS AND ASSOCIATES INC.

MEMORANDUM

Date: June 15, 2010
Client: Anchor Environmental
Subject: East Waterway Supplemental Remedial Investigation & Feasibility Study, Port of Seattle Multibeam Bathymetry

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Project Parameters
Horizontal Datum: *NAD 83/91*
Vertical Datum: *MLLW (1983 -2001 epoch)*
Coordinate System: *Washington State Plane – North Zone*
Units: *US Survey Feet*

Primary Survey Dates (multibeam and jetski)
January 13, 14 & 15, 2010

Supplemental Survey Dates (under bridge tag-line)
April 16, 2010

Survey Crew
Ben Hocker – Lead Hydrographer
Josh Sampey – Hydrographer II
Travis Brennan – Hydrographer III
Nicholas Lesnikowski – Lead Hydrographer, Project Manager, ACSM* Hydrographer

Supplemental Survey Crew
Gabe Swartz – Land survey technician
Matt Pybas – Land survey technician
Josh Sampey – Hydrographer II
Nicholas Lesnikowski – Lead Hydrographer, Project Manager, ACSM* Hydrographer

Equipment
Vessels – DEA's 33-foot *John B Preston,* Hydrographic survey jetski, 11' Livingston
Multibeam – Reson 8101 240 kHz, 101 beam, 150° swath with 15° roll bias to starboard.
Singlebeam – Odom CV100 on jetski with 200kHz narrow beam transducer, Odom MkIII with 200 kHz narrowbeam transducer for tag-line survey.
Motion Sensor – Applanix POS-MV
Heading Sensor – Applanix POS-MV
Positioning – Trimble MS750 RTK GPS rover on vessel with a base station setup on temporary site at north end of Olympic Tug & Barge facility. Jetski positioning under West Seattle overpass was accomplished with a Trimble automated total station (range-azimuth system). Tag line survey positioning based on DEA land survey reference points and taped distances.
Navigation and data logging – HypackMax - Hysweep Ver. 2009a & Trito ISIS
Sound Speed - AML-SV Plus, Sound Velocity Profiler

Field Procedures

Position Check

Each day after base station setup, a confidence check was made on a secondary control point DEA #2000 (S end of Harbor Island) by decoupling the RTK antenna from the vessel, placing it on a fixed length staff and occupying the control point. Comparisons for the RTK system, utilized for the multibeam aspects of this survey, are displayed in the following table.

	Easting (X) US Feet	**Northing (Y) US Feet**	**Elevation (Z) FT**
Actual DEA 2000	*1266932.88*	*211485.40*	*17.11*
Obs. 01/14/10	1266932.95	211485.41	17.16
Obs. 01/15/10	1266932.96	211485.35	17.26

Position checks for the range-azimuth system used to position the jet ski under the ramp to the West Seattle Bridge, consisted of back-sighting the EHI control point (provided by Anchor Environmental) and checking both the opposite side range-azimuth station location, as well as, a secondary point established close to the waters edge. The hydrographer on the jet ski decoupled the tracking prism and held it on the check point while logging the data with the vessel's onboard Hypack navigation system. This procedure was used on both sides of the waterway.

Patch Test

Prior to the start of multibeam survey operations, data was collected along a series of controlled transects to be used for checking the alignment and system latency of the survey equipment. After analysis during data processing the following correction values were determined and applied during data processing.

Roll	Pitch	Yaw	Latency
0.52°	1.037°	0.55°	0.00 sec

Sound Velocity Casts

Detailed measurements of the sound velocity profile through the water column are crucial in multibeam surveys. Changes in the velocity profile will 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 with different velocities. An AML SV-Plus was used to measure the speed of sound of the water column. A total of nine sound speed casts were made during survey operations. The casts showed a freshwater lens in the upper 5-6 feet of the water column, especially toward the head of the waterway; consisting of a slower velocity of approximately 4773 ft/sec. Deeper depths within the waterway were very consistent showing speeds of approximately 4855 ft/sec to the maximum depth of all the casts (62 feet).

Bar Check and Draft Readings
A flat bar target was held below the single-beam transducer installed on the jetski to verify the system draft. On the multi-beam, vessel draft readings were made off draft markings established on the multibeam mount.

Data Acquisition (primary survey)
In the open portions of the survey area, soundings were acquired with a Reson SeaBat 8101 multibeam bathymetric sonar using a frequency of 240 kiloHertz (kHz). The system records 101 soundings in a single sonar ping. Additionally, DEA's 8101 includes options such as a stick projector for enhanced shallow water performance and the ability to output side scan sonar imagery. The stick projector option on the Reson SeaBat 8101 improves the system performance in shallow water (depths less than
150 ft).

Multibeam data was conducted by running lines both parallel and perpendicular with the waterway for the length of the project. For this survey, the sonar head was mounted with 15° starboard angle to allow for maximum coverage of side slope areas. This enabled coverage over a range of 90° from nadir (straight down) to starboard and 60° from nadir to port with a recorded depth every 1.5°. Sonar swaths were recorded at a rate of 14 Hz as the vessel transited along the survey track lines. Multibeam data were clipped at 45° (90° total swath width) during processing to improve data quality for the main waterway, the accepted angles were opened up along the slopes (50° port/90° stbd) and to reach under obstructions. The total swath width of full coverage mapping in a single pass varied with the water depth.

The most vital measurements in a multibeam survey are heading and roll angles. To account for vessel heading, heave (vertical movement), pitch and roll, an Applanix POS/MV motion reference sensor was utilized. By utilizing vessel speed over ground and heading data provided by GPS, the POS/MV can isolate horizontal accelerations from vessel turns and provide highly accurate motion data. The POS/MV system was also used to record vessel heading (yaw) from which the sonar beam orientation was derived. The POS/MV provides a higher degree of accuracy for heading measurements than a conventional gyrocompass.

The navigation and survey control system was a personal computer running Hypack MAX software. Hypack Hysweep software and Triton ISIS were used for multibeam and sensor data acquisition. Hypack MAX software allowed the swath bathymetric data to be displayed as a painted color image in a "matrix" on the navigation screen. The matrix cell size on was set to 3-ft during operations and nearly all cells were filled with sounding data. This real-time display gave the hydrographers immediate indications of data quality and coverage.

Under the West Seattle freeway, where no GPS signals could be obtained and the larger survey vessel could not enter, soundings were acquired with a customized personal watercraft (i.e. jetski) which was tracked with a range-azimuth system setup on the banks on local control established for this survey. The jetski ran transects within the small basin between the railraoad bridge to the south and the Spokane street bridge to the North. The large bridge supports for the freeway partially blocked the tracking of the vessel which required a second setup of the range azimuth system on the opposite bank of the basin. The jetski was equipped with an ODOM CV-

100 singlebeam system with a 200 kHz narrow beam transducer and the data was logged to an onboard computer running Hypack acquisition software.

Data Acquisition (tag-line survey)
Additional survey data was needed in the area under the Spokane Street bridge which could not be accessed during the January field effort due to high tides limiting clearance. In April, DEA brought a small boat and single beam system and ran transects between accessible pile bents under the Spokane Street roadway. Due to difficult logistics the vessel could only be positioned relative to stretched out lines which were pre-marked in 5-foot intervals (tag-lines). A DEA land crew was also on site to provide reference points for the tag line setups and to shoot the survey vessel when possible. In addition, the land survey team was able to take wading "topo" shots for cross checking the hydro data, as well as, in-filling some hard to reach areas.

Processing Procedures

Tides
The elevation data obtained from the RTK GPS system during multi-beam acquisition was stripped out and averaged at a 30-second sliding window. In addition, tide data from the NOAA gauge in Seattle (9447130) was downloaded for the survey period for comparison, as well as, readings from a tape set on DEA BM #1 which had been established at the south end of Harbor Island during the 2003 Lower Duwamish Working Group survey. The readings at BM #1 were useful in establishing any phase differences that may occur between the south end of the survey area and the NOAA site in Elliott Bay. No significant phase difference was noticed; with the tape, RTK and NOAA values generally agreeing to with 0.1 to 0.2 ft. The RTK-30 sec tide was used for processing the multibeam data and the single beam data was corrected using NOAA observations.

The tagline data was corrected for tide based on observations from the NOAA gauge in Elliott Bay.

Data Editing
Post-processing of multibeam data was conducted utilizing Caris HIPS multibeam analysis and processing software version 6.1/SP2/HF 7. Patch test data was analyzed and alignment corrections were applied. Water-level data was applied to adjust all depth measurements to project datum from the RTK GPS processed data. Velocity profiles were used to correct slant range measurements and compensate for any ray path bending.

Applanix POSPAC-MMS software was used to refine and improve the final vessel navigation and attitude solution. This software post-processes the raw GNSS (Global Navigation Satellite System) and IMU (Inertial Motion Unit) data to produce a "smoothed best estimate of trajectory" (SBET) using advanced forward and backward filtering algorithms. These navigation solutions are considered more accurate than stand-alone RTK (real-time kinematic) positions.

Processing began with review of each survey line using Caris swath editor. Verified water surface correctors were applied to the data set at this time. Position and sensor data was reviewed and accepted. Sounding data was reviewed and edited for data flyers. Sounding data, including sonar beams reflecting from sediment in the water column or noise in the water column, were carefully reviewed before flagged as rejected. In each case, data was not eliminated and can be re-accepted in the future if required. Also during editing, real features not associated with bottom elevations but of possible interest, pilings and bridge footings, etc., were designated as examined. This designation allows these features to be included in the hillshade images which add references points to aid in interpretation. The “examined” soundings were not included in the final data exported for difference modeling or contouring.

After swath editing, all data was reviewed through the Caris HIPS subset editing program to ensure no flyers remained in the data set, or to re-accept data previously flagged in the swath editor. In the Caris subset editor, a set of lines was reviewed together for line-to-line comparison to ensure agreement to one another in a Caris session.

Single-beam bathymetric data acquired near the Spokane Street bridge, was processed using CARIS-HIPS software. Navigation data was reviewed for flyers, latency adjustments applied and NOAA tide corrections made, on a line-by-line basis. Exported data was thinned using Hypack’s sort routine to a 3-foot density and imported into Terramodel for final contouring.

For the tag-line survey the processing involved creating a file of XY points based on the idealized tagline positions for each line. These 5-foot interval points were brought into an excel spreadsheet where the digitized raw sounding values, stamped on the hardcopy record, were entered for each point. The raw soundings were adjusted to MLLW by applying the NOAA tided value associated with the time of each line. The corrected files were then exported in XYZ format and brought in to Terramodel where the points were compared to any land shots acquired to help adjust the idealized tag-line positions closer to the actual track of the vessel. The final adjusted points were exported from Terramodel in XYZ format and merged in with the survey data previously acquired.

Data Export

To take advantage of the level of detail the multibeam bathymetric survey provided for the waterway, a 3.28 foot (1.0-meter) grid of the survey area was created by the HIPS processing software and exported to an ASCII XYZ file. This process created a 1.0-meter grid over the survey coverage area and then assigned values to each grid node with an inverse distance weighted algorithm. The ASCII XYZ points file uses the North American Datum of 1983 (NAD83), State Plane Coordinate System (SPCS), Washington North Zone with units in US Survey feet.

Data Images

The 1.0-meter database was rendered in CARIS to produce a hillshade image of the bottom bathymetry. The hillshade image is a colored rendering of the surface with shadows created by a artificial sun to help draw out features and make the image more interpretable. For the East Waterway a 3x3 interpolation was applied to the 1.0-meter surface to reduce the distracting effects of empty pixels. The interpolation was only applied to the hillshade image and not to any other products. The parameters used for creating the hillshade image were:

Sun Azimuth	Sun Elevation	Vertical Exaggeration
345°	45°	2X

Various multibeam datasets from the East Waterway, conducted by DEA in ’02, ’03 and ‘05, were imported into Trimble TerraModel for comparison. The surveys agreed well (i.e. better than +/- 0.25 ft in most areas). In addition, the junction with the LDWG data at the south end of Harbor Island also agreed well, however apparent changes in the bottom have occurred over the more than six years which has transpired between the surveys.

Data Contours

A set of 2-foot contours were produced and delivered as .pdf files. In addition, ASCII XYZ data at a 3.28 foot (1-meter) grid was exported for use in digital models. The data is in NAD83/91 WA-N, US feet and corrected to the ‘83-‘01 MLLW tidal epoch.

Data Files

Copies of the contour drawings and exported ASCII xyz data files were delivered along with this memorandum.