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Delaware River (Reach B) Probing Project: Drillboat Apache Horizontal & Vertical Positioning Quality Control Procedures

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Horizontal and Vertical controls for the probing project were based off of three monuments: JU0786 served as the primary, JU4112 as a horizontal check and JU0832 as vertical check.

Primary: “PRINTZ” / PID: JU0786 in New Castle County Delaware

39d 47’ 45.21714” (N) 075d 27’ 27.67300” (W) Elev: 17.5ft (NAVD88)

Horizontal Check: “HAR 2” / PID: JU4112 in New Castle County Delaware

39d 48’ 12.02442” (N) 075d 28’ 48.97020” (W)

Vertical Check: “Q 276” / PID: JU0832 in Delaware County Pennsylvania

39d 49’ 12.0” (N) 075d 25’ 49.8” (W) Elev: 47.69ft (NAVD88)

Horizontal checks with a Trimble R8 GNSS System on the upper deck of the drillboat were performed twice a week and more often when operating near cable or pipeline crossings. Vertical checks with a Trimble SPS 855/Zephyr system on the crewboat “Swift Runner” were performed at least two times per 12-hour shift. Exact procedure for these checks is described below:

Horizontal QC Checks

Before startup, two QC points were marked on the upper deck of the drillboat at known offsets from the two GPS antennas. The location of these QC points were selected for their distance from the tallest vertical structures on the Apache (drill frames, spuds and GPS towers) to improve line of sight to satellites and allow for fixed RTK quality survey.

The Apache’s positioning software displays the Northing/Easting of these two points at all times. Whenever a surveyor performed a check with the rover GPS system, the values

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were checked against each other. Each time this was performed, the rover was shown to be within 2.0 feet of the theoretical value shown by the positioning software on the drillboat. As the Northings/Eastings of the drill frames are determined by an analogous procedure, this procedure serves as a reliable check on horizontal control.

Vertical QC Checks

Given the importance associated with vertical control on this project, the bulk of the QC efforts were directed at maintaining an accurate accounting of tidal values at the location of the drillboat over the course of the project. The following summary was produced at the conclusion of the Test Phase of drilling operations and distributed to and accepted by the client on April 20th. It covers how live tides were tracked for the drillers' use from multiple sources, and how regular checks were performed between the Swift Runner, the R8 Rover and our Differential NOAA-based Tide Program.

This is a summary of the four sources of vertical control for this project. The goal is to provide accuracy within at most 3" of the true tide at the Drillboat's location. The remaining 3" of our 1/2 foot error budget is available for operator error. The primary anticipated source of user-error will be if the drillbit is not positioned at the exact water level when "zeroed out" at the start of each hole.

Hazen Tide Gauge @ Anchorage Marina

When working in Areas A-D, the Anchorage Marina is less than 2.0 miles from the drillboat. Tests in this area of the river before startup showed that during maximum tidal currents, tide values can be off by up to 0.2' between two locations 2 miles apart. The tide gauge is to be checked and standardized by site engineers at the start of each shift (every 8 hours) and not to be used when working any farther south than Area D. This tide value is automatically projected onto the LED screen on the top deck. The helper on frame B observes this tide and shares it with the other frames.

NOAA Tides Corrected based on Work Area

When working in Areas E-Q, the primary source of tides will be the NOAA tides corrected for the drillboat's position. Two NOAA gauges broadcast tide values via the internet from locations at Marcus Hook and Philadelphia. These values are broadcast in MLLW and have been verified against RTK tide readings on a GLDD survey boat. The drillboat tide is corrected off of the NOAA gauges based on the distance from each, assuming a linear slope between the two. This system has proven to provide accurate readings within 0.25' for Work Areas E-I and 0.15' for Work Areas J-Q. This value is provided on the Widescreen Monitor on

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the Upper Deck and broadcast to the small monitor on Frame B. The Helper on Frame B shares it with the other frames.

RTK Tides from the Swift Runner

The backup/QC source of tide values will be the RTK tides broadcasted from the crew boat "Swift Runner". The boat's GPS antenna is mounted 13.5' above the water level and the RTK correction radio signal reaches throughout Work Areas A-Q. This tide will be broadcasted by a wireless LAN network from the boat to the operator's cab in B Frame. These tides will be available to QC check the tide gauge and NOAA program whenever the boat is within a quarter mile of the drillboat, is receiving RTK fix and is not moving. Accuracy of these values are within 0.1'. Precision is maintained using a 1-minute moving average of the readings.

RTK Rover Tides off the side of the Apache

Three times daily, at the start of each Site Engineer's shift, all the above values will be checked against an RTK Tide Value collected using a Rover GPS unit at the edge of the drillboat. Freeboard is subtracted from the reading using a survey rod. If these values are seen to match the other sources within the allowed tolerances described above, then these other sources will continue to be used. If a clear RTK tide reading with the Rover provides a reading outside of the allowed tolerance, then the NOAA or GLDD gauges will not be relied upon and the Site Engineer (or Swift Runner) will provide RTK Tide Readings until the gauge or gauges are back in working order.

The following additional correspondence (May 9th e-mail to GBA representative Jonathan Barker) covers how we retroactively adjusted all the operators' tide values to reflect the best tidal information we have for the time the drilling was performed:

Over the course of the project we recorded many RTK tidal checks that we checked against Ed's program (NOAA tides corrected for horizontal offset) as we went. At the end of the project we back-generated all of the same tides to better precision (within 3 minutes) than we were able to keep live (usually within 20 minutes, always lagging in the same direction). This log of tidal values was offset correctly according to where the drillboat was at the time of each hole. The RTK checks have been plotted against this archived set of tides and are shown to land overwhelmingly within the 0.25' tolerance we set out to meet (a couple of exceptions out of more than a hundred checks were off by 0.3 or 0.4—could be explained by the boat underway, not actually having RTK on the boat, the boat being out of range, etc)

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This gives us the confidence we wanted to be able to apply tides from this log throughout the project. Our program pulls the timestamp that each hole was started and applies the corresponding tide value to that hole. The vast majority of the holes show a difference between operator tide and this archived tide value of less than 0.2'. These adjustments make sense given the time window for applied tide going from ~20 minutes to less than 3.

End of Project Corrections for Horizontal Control

In addition to the end-of-project vertical corrections discussed above, there was also a need for horizontal corrections based on lower quality GPS signal or dropped communication between the GLDD positioning and the Thunderbird computers on about 5% of the holes.

When the issue was one of reduced GPS signal quality, we used the known "feet-on-deck" offset between the frames (usually 75' when all three frames were in use) and the known azimuth of the drillboat (based on the relative position of the other two holes on that range) and measured the appropriate location for the inaccurately logged hole. In these cases, horizontal precision was improved from within 20' to within 5' of the actually drilled hole.

In the events that the GLDD positioning was not live-sharing position with the Thunderbird computer, we relied upon the GLDD Surveyor's notes for the actual location. These were kept for every hole over the course of the project. Precision for these corrected horizontal coordinates are as accurate as those of the holes that were logged correctly.