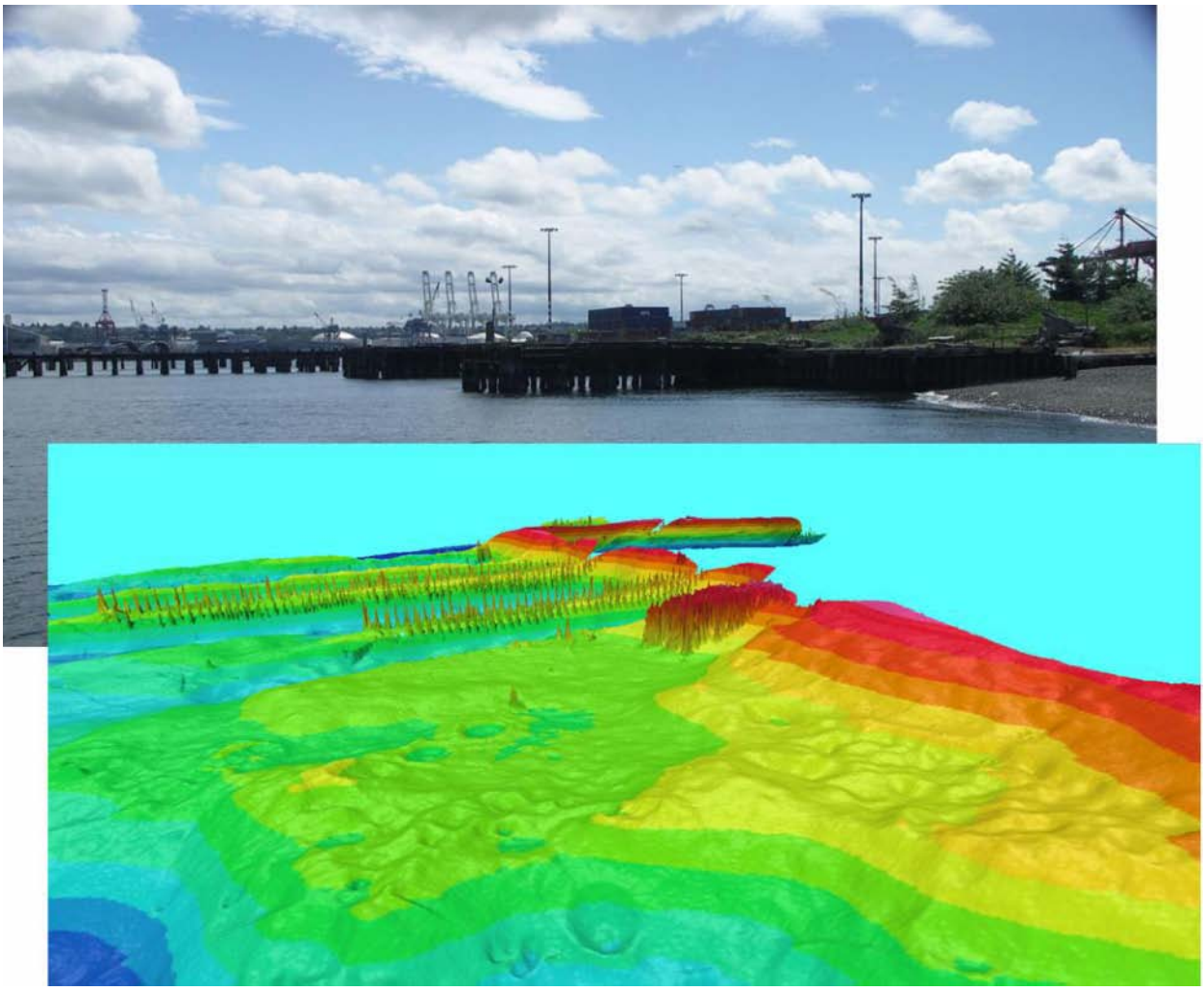
APPENDIX B

LOCKHEED BATHYMETRY SURVEY REPORT

Lockheed
Lockheed Shipyard 2



Bathymetry Survey Report
May 2006

Prepared by:
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1 Introduction

The following document describes a high resolution multibeam sonar bathymetric survey which was conducted for Lockheed, by TetraTech, Inc, on May 20, 2006. The multibeam sonar system provided a high resolution, full bottom coverage, bathymetry of the area in the vicinity of the Lockheed Shipyard 2 project site, from which contour lines and hill-shade maps (hard copy and electronic) digital terrain models where created.

The survey data was collected to chart bottom features and provide detailed bathymetric data to: 1) support future site characterization activities; 2) determine bathymetric anomalies; and 3) provide data for potential remedial designs. Additionally, the collected data may also be used to: 1) analyze bottom substrate composition; and 2) evaluate sediment transportation.

The survey was conducted in accordance with the procedures in the US Army Corps of Engineers Manual 1101-2-1003, Engineering and Design Hydrographic Surveying.

Table 1 lists the personnel and their roles in the survey.

Table 1 – Survey team

Company	Personnel
TetraTech EC, Inc.	Robert Feldpausch - Hydrographer Burton Bridge - Hydrographer
Sound Vessels, Inc.	Lou Schwartz – Vessel Captain

2 System Setup

The survey systems were installed on the R/V Brendan D, a 32 foot research vessel owned by Sound Vessels, Inc., of Port Townsend, WA The equipment used for the survey is shown in Table 2. Data sheets for the main survey systems are included in Appendix C.

Table 2 - Survey Equipment

Sensor Type	Manufacturer/Model
Multibeam Sonar	RESON SeaBat 8125
Motion Sensor	Applanix WaveMaster
Heading	Applanix WaveMaster
Position	Leica 1230 RTK GPS
Sound Speed Profiler	SeaBird SBE-19
Tide Corrections	Leica 1230 RTK GPS

Data collection and navigation software for the bathymetry survey was Hypack®/Hysweep®. The data were processed and data products generated using a combination of Hysweep, IVS 3D Fledermaus, and ESRI ArcGIS.

Software settings for bathymetry data acquisition include the serial I/O configuration and sensor offsets in Hypack, and Hypack Navigation device offsets in the Hysweep hardware configuration.

Figure 1 - R/V Brendan D

2.1 Interconnections

Figure 2 shows the data flow and communications setup for the devices which make up the survey system. Table 3 lists the settings for each of the data communication links.

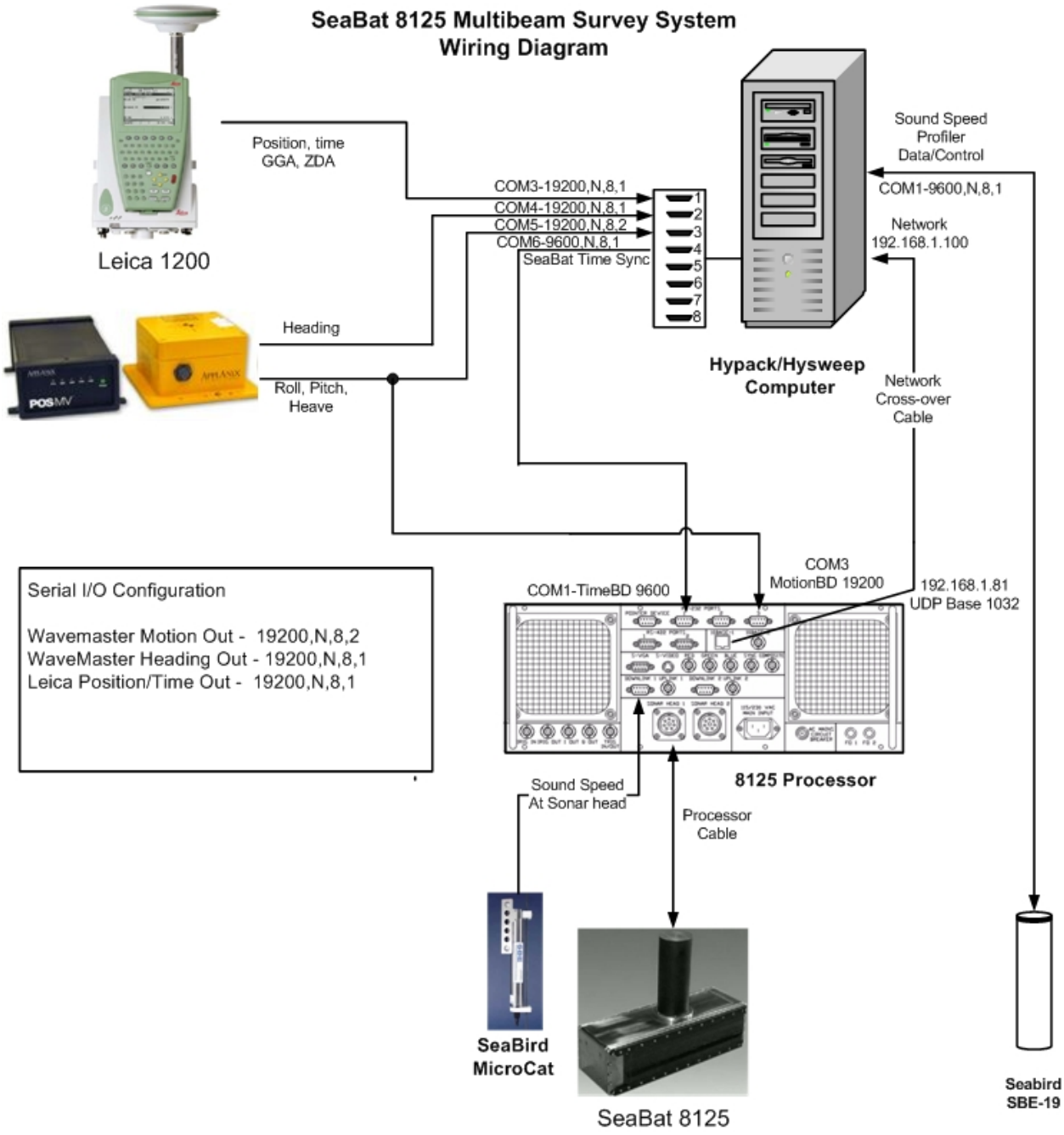


Figure 2 – 8125 Multibeam Survey System

Table 3 - Communications Settings

Device	Communications link	Settings
8125 SeaBat	Network imagery data out	Local IP 192.168.1.25 Remote IP 192.168.1.100 UDP base port 1032
8125 SeaBat	UTC time sync in	COM 1 – 9600, N, 8, 1
Applanix WaveMaster	TSS1 roll, pitch, heave out	19200, N, 8, 2, 50 Hz update
Applanix WaveMaster	NMEA HDT heading	19200, N, 8, 1, 5 Hz update
Leica position	NMEA GGA position	19200, N, 8, 1, 10 Hz update
Leica time	NMEA ZDA time	19200, N, 8, 1, 1 Hz update

2.2 Device Offsets

Device offsets are precisely defined for the multibeam sonar, attitude sensor and GPS antenna, so that the Hypack/HySweep acquisition software can accurately convert the input sonar and support sensor data into XYZ soundings on the earth.

2.2.1 Hypack/Hysweep Offsets

The following offsets, in feet, were used for the Hysweep sensors:

Table 4 - Sensor Offsets (feet)

Sensor	Across	Along	Vertical
SeaBat 8125	1.84	0.00	3.08
Motion Sensor (Applanix WaveMaster)	0.00	0.00	-4.50
Hypack Navigation (Leica RTK antenna)	1.84	0.00	-11.78

2.3 Sonar Mount

The sonar head was mounted to the vessel using a side mount pole, shown in Figure 1. The mount is rigidly attached to the side of the vessel, with the Leica GPS antenna mounted on an extension pole, directly above the sonar.

2.4 Geodesy Settings

The geodesy settings shown in Table 5 were used for the project.

Table 5 - Survey Geodesy Settings

Parameter	Setting
Grids	State Plane NAD-83
Zone	WA-4601 Washington North
Distance Unit	US Survey Feet
Depth Unit	US Survey Feet
Ellipsoid	NAD-83
Geoid	NAVD 88
Vertical Datum	Port of Seattle MLLW (geoid height – 2.59 ft)
Horizontal Control	WA DOT Duwamish SY4595 – ID 6242
Vertical Control	WA DOT Duwamish SY4595 – ID 6242

The elevations output by the Leica RTK were referenced to the NAVD88 geoid. Corrections to the Port of Seattle MLLW datum were made in the Hypack Max® sensor offsets.

2.5 GPS Reference Station

The RTK base station was set up over Washington Department of Transportation (DOT) benchmark SY4595, as shown in Figure 3. The agency provided description of the control point is shown in Appendix D.

3 Survey Procedures

This was a project condition survey to assess the bottom topography and the presence of man-made debris in the area of the shipyard. To provide the highest possible resolution, a RESON SeaBat 8125 multibeam sonar was used. This system is currently the highest resolution commercial multibeam sonar on the market. It has an along-track beamwidth of 1.0 degrees and an across-track beamwidth of 0.5 degrees normal to the array, increasing to 1.0 degrees at +/- 60 degrees. The support sensors, used to measure vessel attitude (roll, pitch, heave), position, heading, and sound speed through the water column, were selected to ensure that the associated accuracies commensurate with the accuracy and resolution of the sonar.

Figure 3 - RTK GPS Base Station - Duwamish Benchmark

3.1 Position/height

To compensate for tides, vessel squat and settlement and varying draft due to vessel loading, RTK GPS was used for both position and height. Tetra Tech staff set up a RTK base station on the WA DOT monument shown in Table 5 and Appendix D. The rover unit was then taken to monument GP17099-241 and the position compared to that of the monument. In the comparison between the position reported by the rover GPS and the published position of the monument, all X, Y and Z values matched to within 5 cm. The locations of the base station (Duwamish monument) and the monument used for QC are shown in Figure 4.

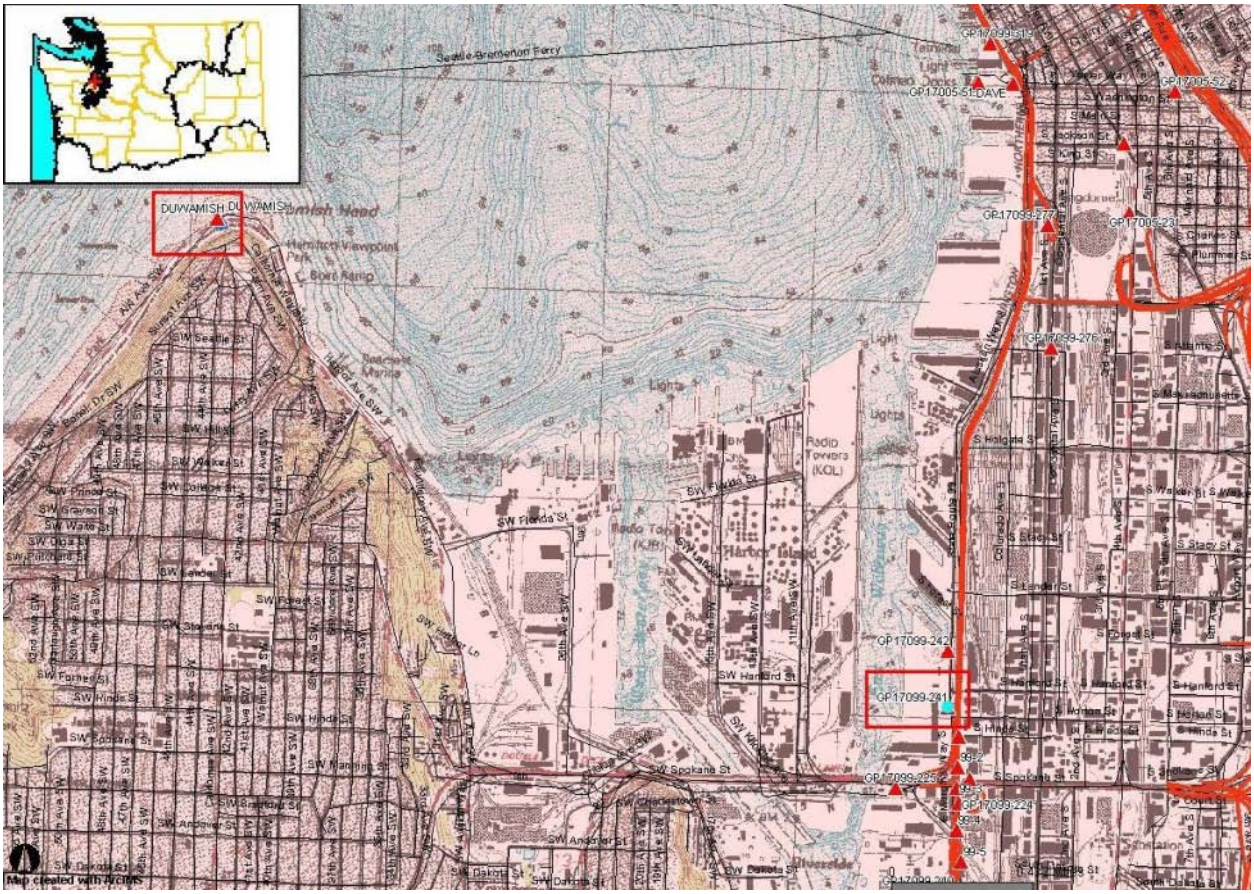


Figure 4 - Monument Locations

3.2 Sensor Offset Measurements

All sensor offsets were measured relative to the XY position of the Inertial Measurement Unit (IMU), with the waterline as the vertical reference. All measurements were done at the dock, in calm water, using a tape measure.

The measured offsets were compared to those done for the preceding survey, and matched, except for small changes in the draft of the multibeam sonar head, due using a different model sonar, with different brackets and size, and the height of the GPS antenna above the waterline. The latter is expected to change with changes in vessel loading. The vertical offset between the GPS antenna and the acoustic center of the sonar is a critical measurement, and was checked by two of the survey staff.

3.3 WaveMaster GAMS Calibration

Prior to performing the patch test, an alignment test was performed on the Applanix WaveMaster motion and heading sensor. This procedure, called a GAMS calibration by Applanix, uses software built into the WaveMaster, while the vessel is maneuvering, to calculate the offsets between the system's two GPS antennas. This allows the system to align the heading with the vessel and provide the full specification measurement accuracies (see Appendix B).

3.4 Patch Test Results

A standard patch test was carried out within the survey area to determine the calibration offsets between the multibeam echosounder and the motion reference unit. The offsets shown in Table 6 were calculated from the patch test which was conducted on 20 May 2006. These offsets were applied in the data processing software to correct residual misalignments in the mechanical installation of the sensors, and to compensate for any latency in the positioning system.

Figure 5 shows the site, the survey lines and data collected for the patch test calibration. This location provided multiple distinct features, with significant changes in depth over very short distances along track. This in turn provided very consistent results fromt eh processing.

The data collection software was time synchronized to GPS UTC time, and the time stamp from the GPS position messages was used for the position data, which should provide a latency value of zero. This had been verified with this same hardware and software configuration multiple times in the past, so a latency test was not specifically done for this survey. Review of the full survey data set showed none of the position offsets that would result from a latency error.

Table 6 - Patch Test Results

Parameter	Value (deg.)
Roll	-0.3
Pitch	0.0
Yaw	4.0
Latency	0.0 sec

The data were processed using the Patch Test toolkit in the Hypack MB Max processing software, using the procedures defined in the Hypack documentation. Collections were performed so that at least two independent data sets were used to derive each measurement. No significant differences were observed in the results for each measurement.

Figure 6 shows a check of the calculated yaw offset, with four patch test survey lines input. This a cross section taken between the two parallel pairs of lines.

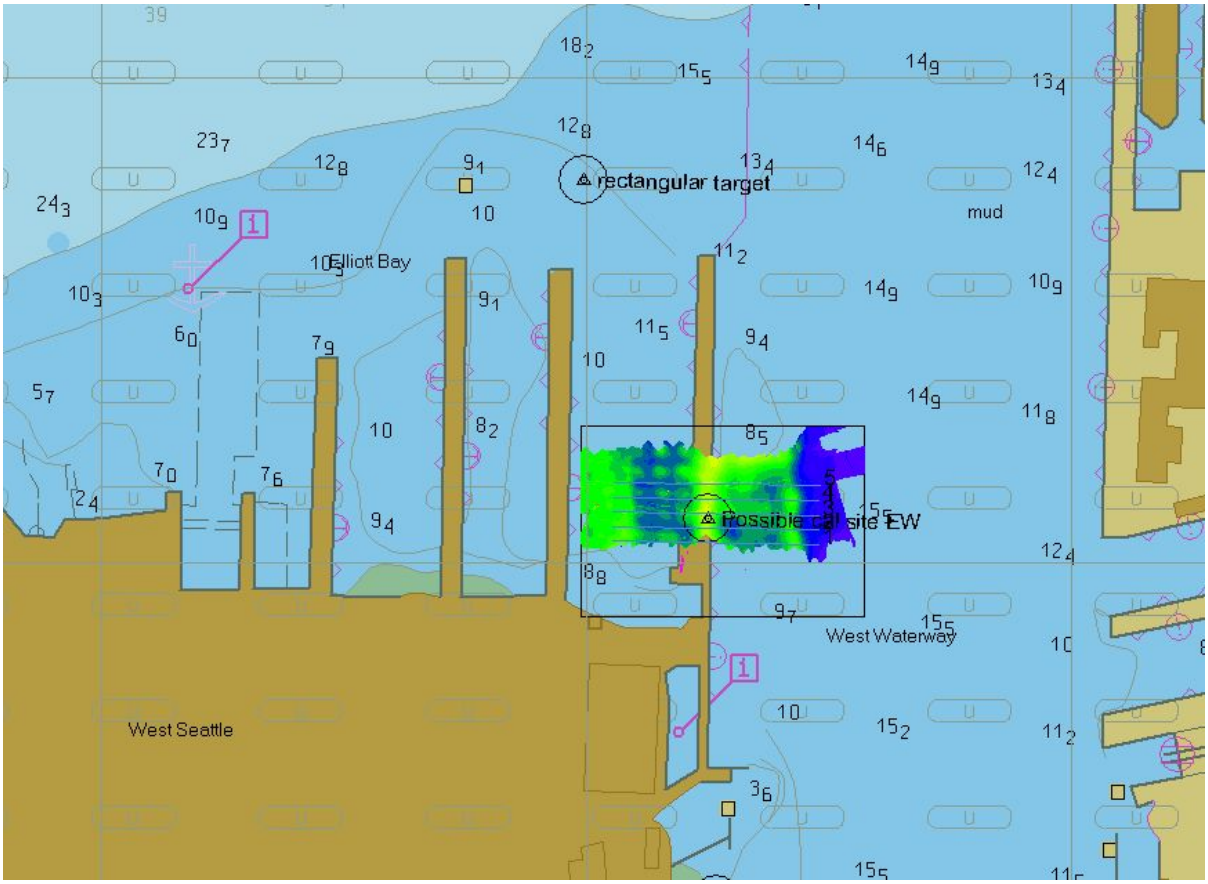


Figure 5 - Patch Test Site

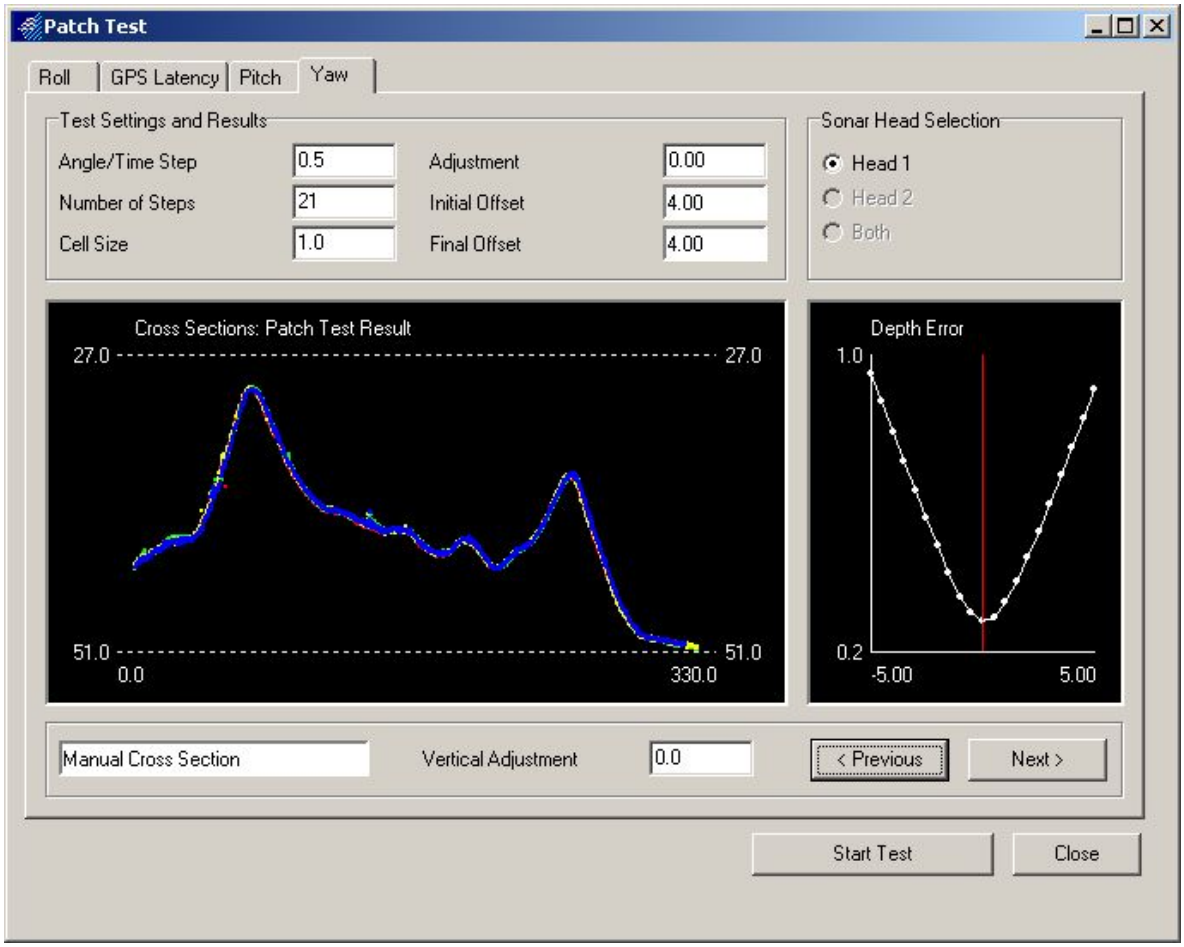


Figure 6 - Yaw Calibration Check (4 survey lines)

3.5 Sound Speed Casts

Sound speed casts were performed at the beginning and end of the survey. A comparison of the cast data showed no significant differences in the induced depth offsets out to the +/- 60 degree swath coverage of the sonar.

4 Bathymetry Results

The following is a description of the processing used to convert the raw collected data to depths and positions, and to remove invalid soundings from the processed data set.

4.1 Bathymetry Processing

The collected data were processed in Hypack MB Max to generate the XYZ soundings, in the survey coordinate system and units. The preliminary data cleaning was also done in MB Max, to eliminate any gross outliers induced by noise in the sensor systems or the acoustic environment. A subsequent area based cleaning, using the merged data from all the survey lines, was then conducted using Fledermaus, an advanced 3D editing application. The results of this processing were then exported back to the Hypack HS2 files.

As this was intended as a condition survey, and one of the objectives was to locate and identify debris in the project area, the data were binned in a one (1) foot grid, and the minimum depth value within each grid cell was used for the final data presentations.

4.2 Bathymetry Results

The results from the multibeam bathymetry survey are shown in Figure 7 and in Appendix A. Appendix C contains the survey collection logs. Bathymetry data extended from near shore to approximately 192 ft below MLLW off shore.

The high resolution bathymetry data shows extensive man-made debris in the area around the shipyard, mostly what appear to be timber pilings, lying on the seafloor. Areas previously dredged, as well as deposition under existing and former piers, are clearly visible in the data.

Figure 8 shows a set of 3D soundings from an area near the northeast corner of the shipyard, color coded for survey line. The data clearly show a set of fully submerged, but standing pilings, the tops of which are as little as 3.6 feet below MLLW. Many other pilings, some lying on the bottom and some tilted up are also visible. A review of the data in this and other areas also shows very good correlation between the data from overlapping survey lines, another QC check used in processing the data.

Figure 9 shows two 10 foot square blocks that were found near the north end of one of the former piers. The tops of the blocks are about five (southern) and 4 (northern) feet above the surrounding bottom. More piles lying on the bottom are also visible in the same area.

Figure 10 shows the Digital Terrain Model (DTM) of the data around the northeast corner of the shipyard. The objects sticking up near the center of the image are the same pilings shown in Figure 8. They appear distorted since the DTM provides a less than perfect representation of vertical features. Large numbers of piles lying on the bottom, the pattern of mounds where the former dry docks were located, and the mounds at the former pier locations are clearly visible.

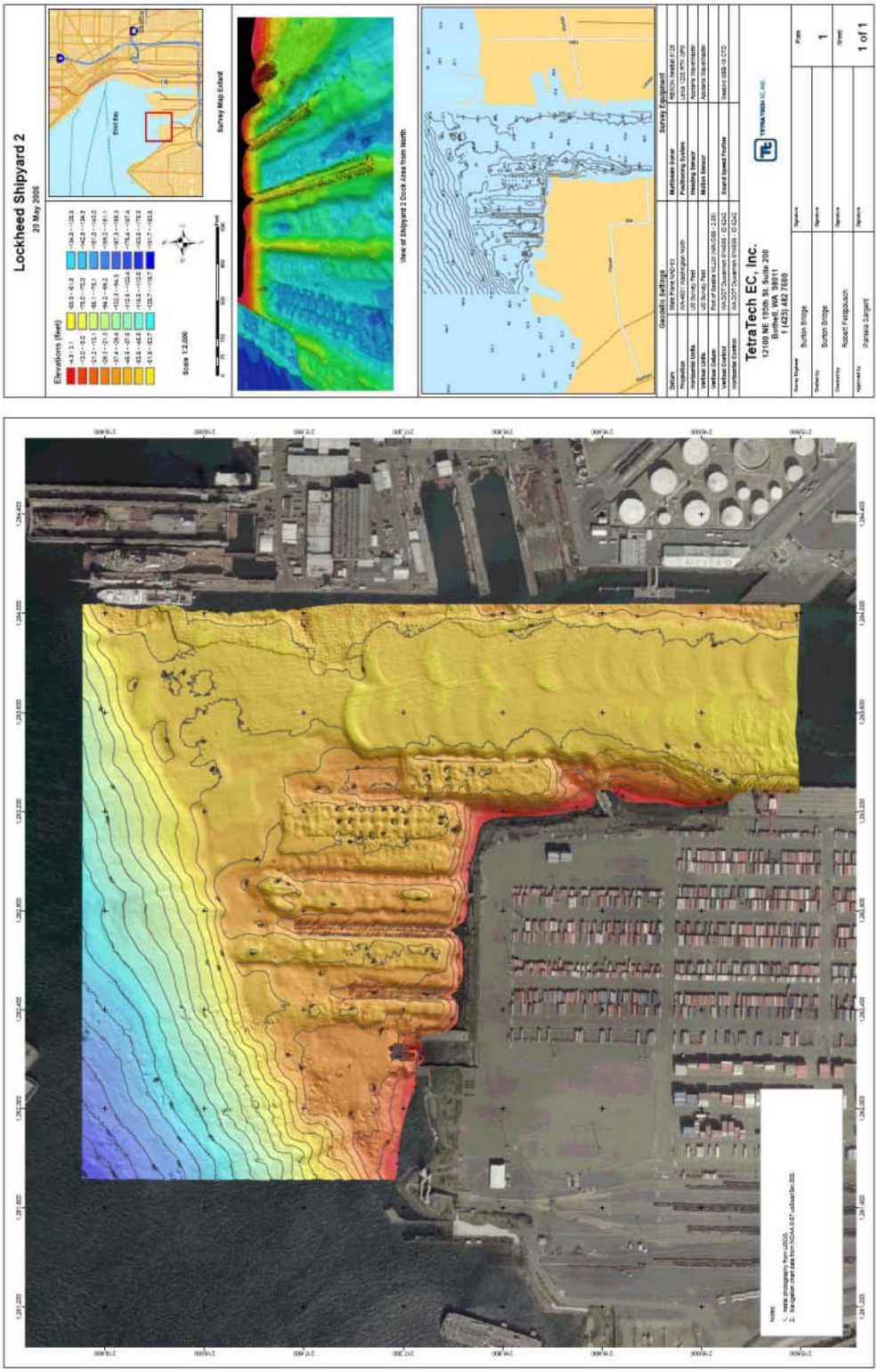


Figure 7 – Lockheed Shipyard 2 Bathymetry – May 2006

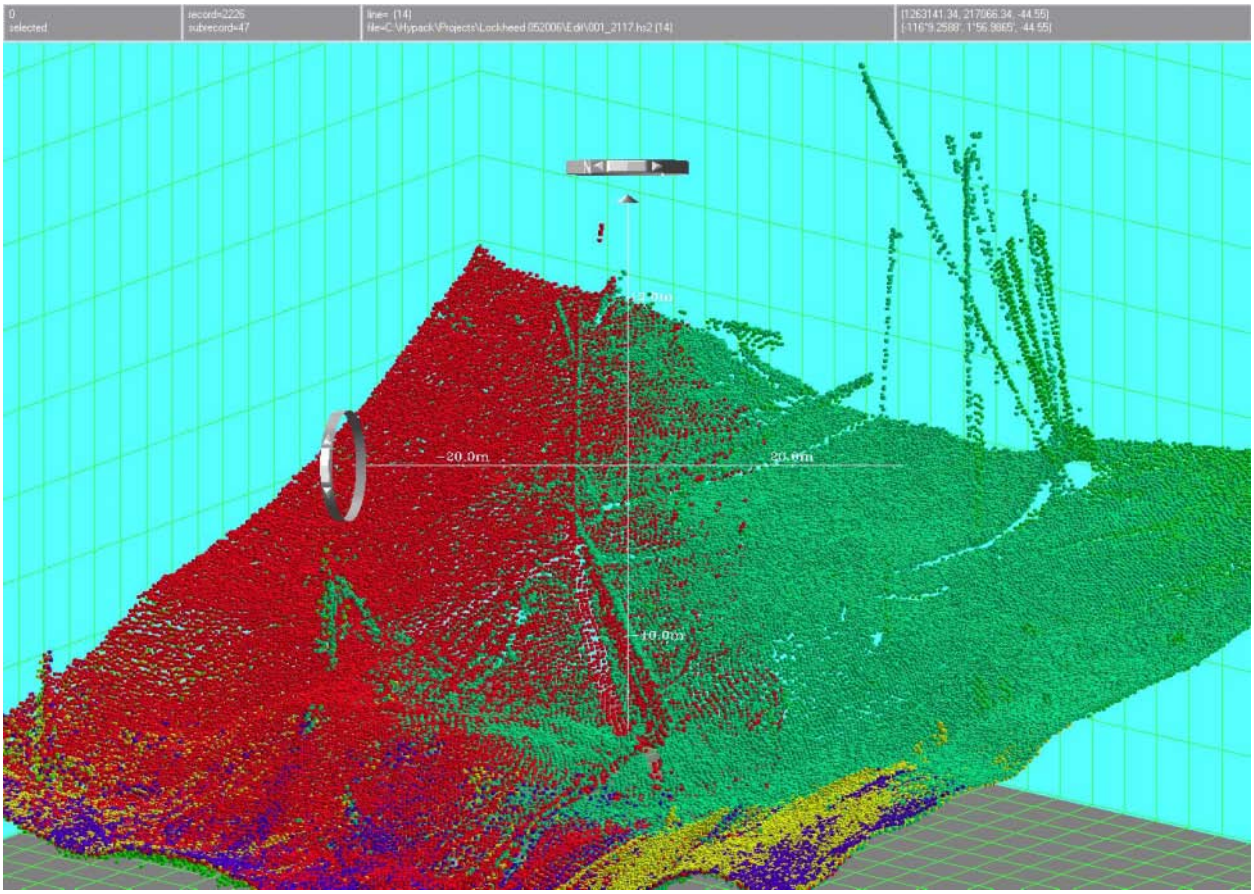


Figure 8 - 3D Sounding Display - Multiple Piles

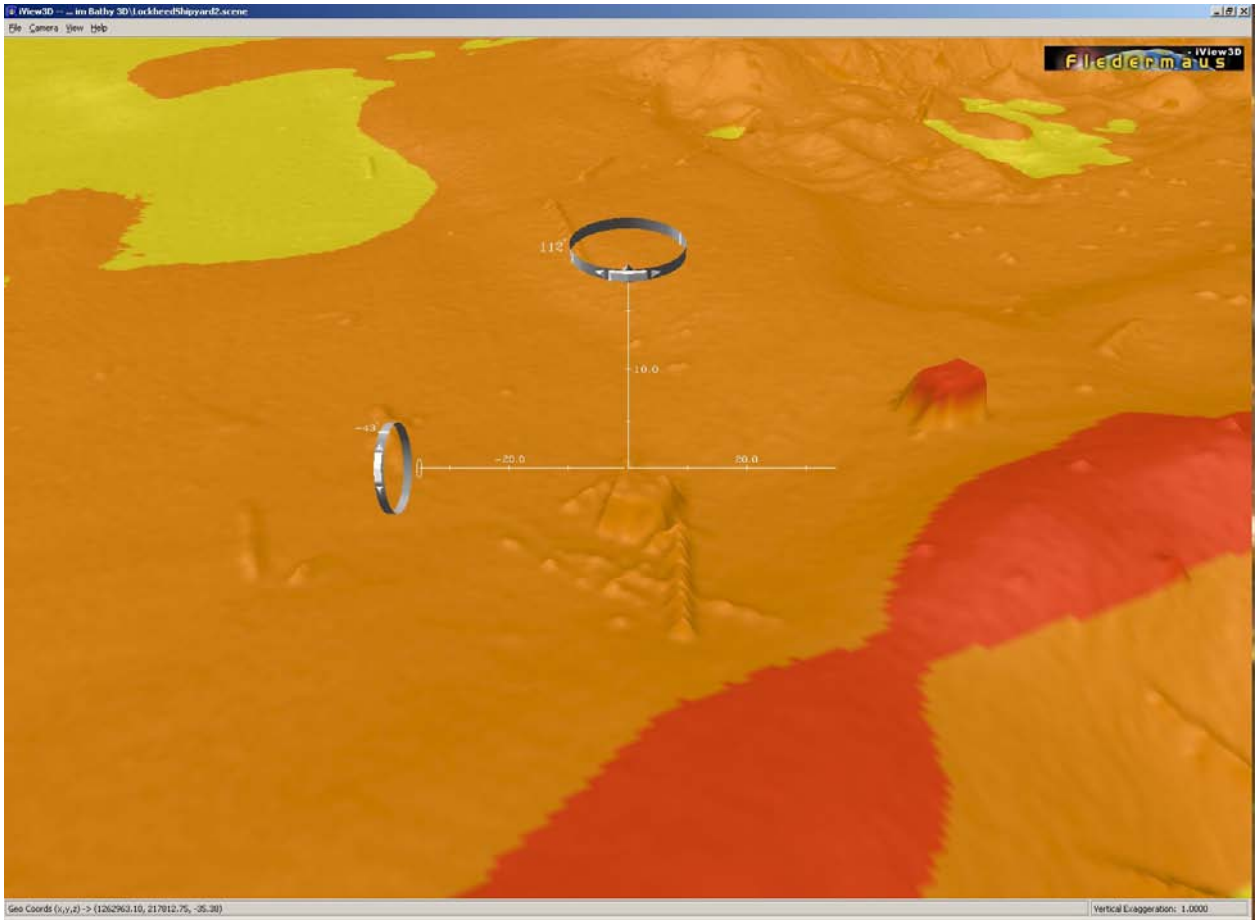


Figure 9 - DTM of Blocks and Piles

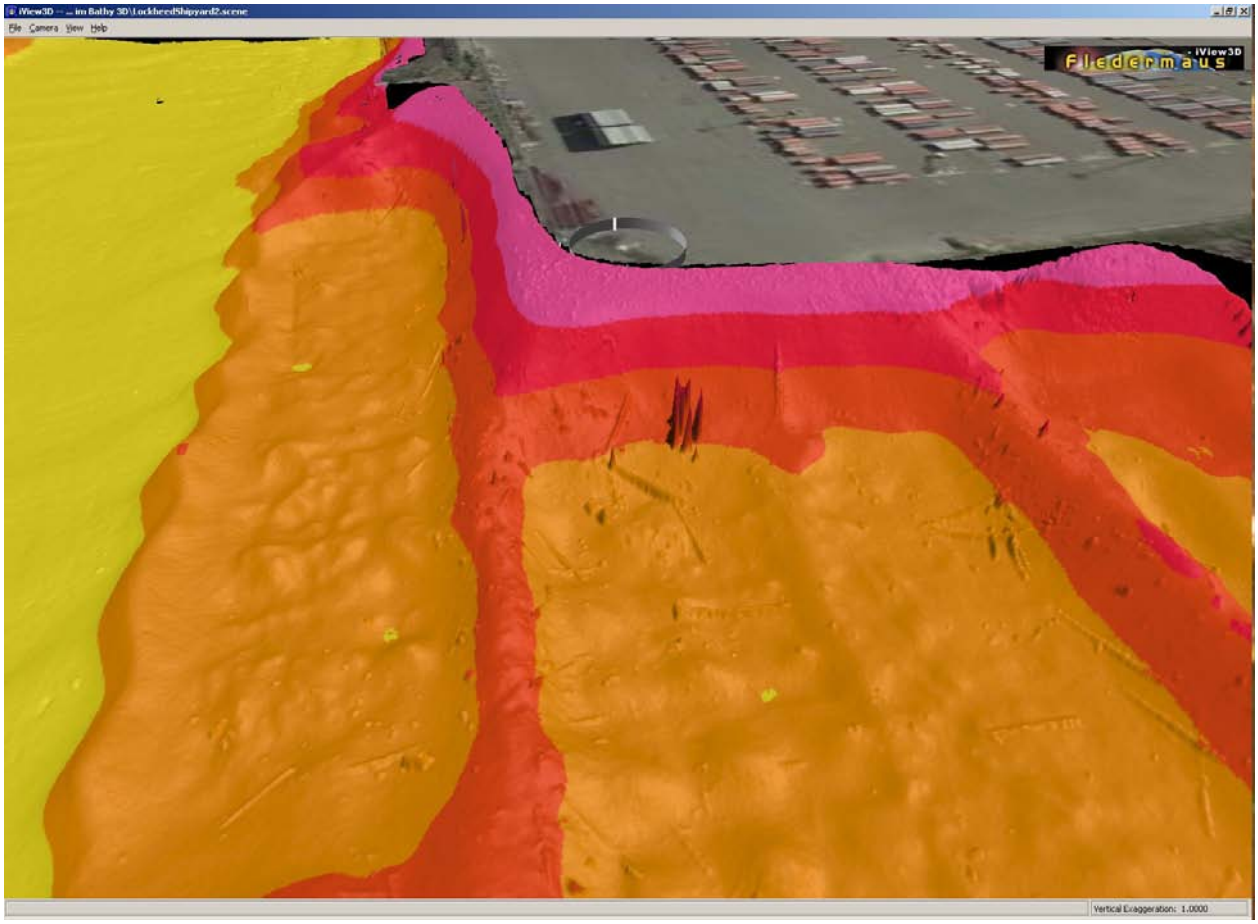


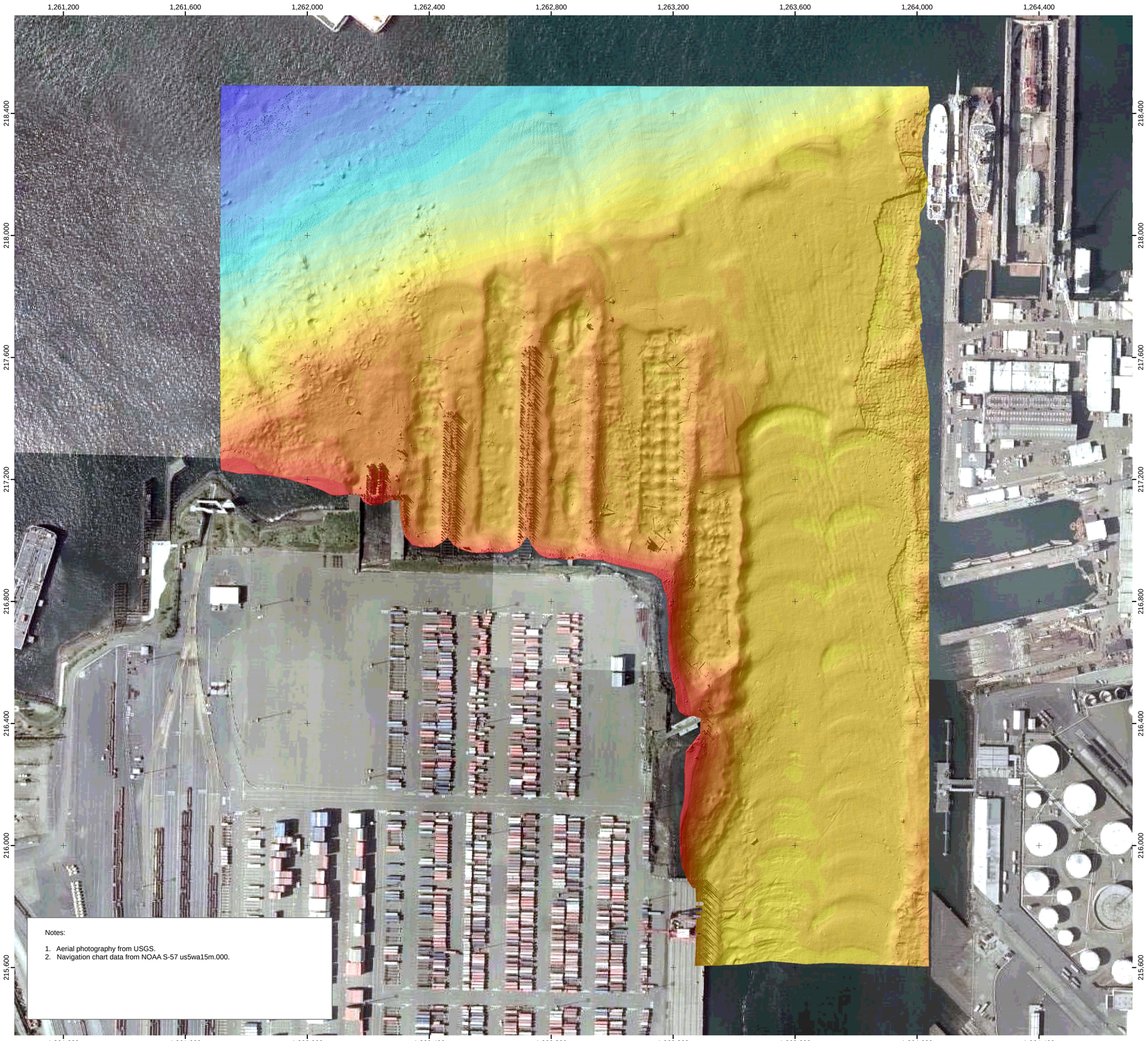
Figure 10 - DTM Around NE Corner of Shipyard

5 Summary

This data set provides a high resolution view of the topography in the vicinity of the shipyard that can be used for planning further tests, such as sediment sampling, and for locating debris.

Previously unknown features, such as the pattern of mounds in the former locations of the dry docks have been found, and can be used in planning remediation work.

The high resolution bathymetry clearly shows features 0.5 feet or less above the surrounding bottom. These data can be used to locate and identify the great majority of the man made debris that will need to be removed from the site.



Notes:

1. Aerial photography from USGS.
2. Navigation chart data from NOAA S-57 us5wa15m.000.

Lockheed Shipyard 2

20 May 2006

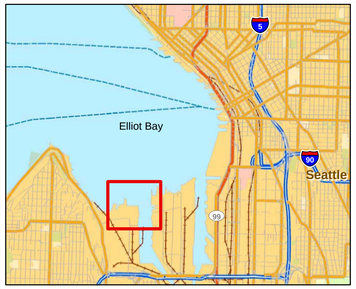
Elevations (feet)

-4.9 - 3.1	-69.9 - -61.9	-134.8 - -126.8
-13.0 - -5.0	-78.0 - -70.0	-142.9 - -134.9
-21.2 - -13.1	-86.1 - -78.1	-151.0 - -143.0
-29.3 - -21.3	-94.2 - -86.2	-159.2 - -151.1
-37.4 - -29.4	-102.3 - -94.3	-167.3 - -159.3
-45.5 - -37.5	-110.5 - -102.4	-175.4 - -167.4
-53.6 - -45.6	-118.6 - -110.6	-183.5 - -175.5
-61.8 - -53.7	-126.7 - -118.7	-191.7 - -183.6

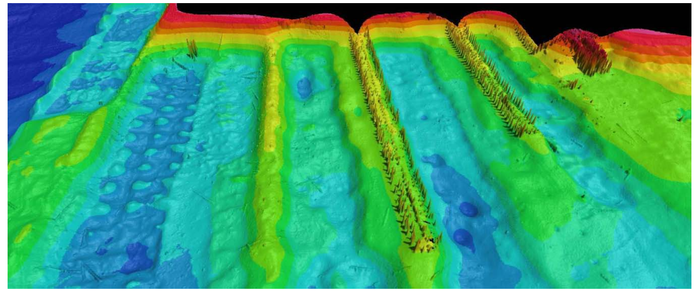
Scale 1:2,000

N W E S

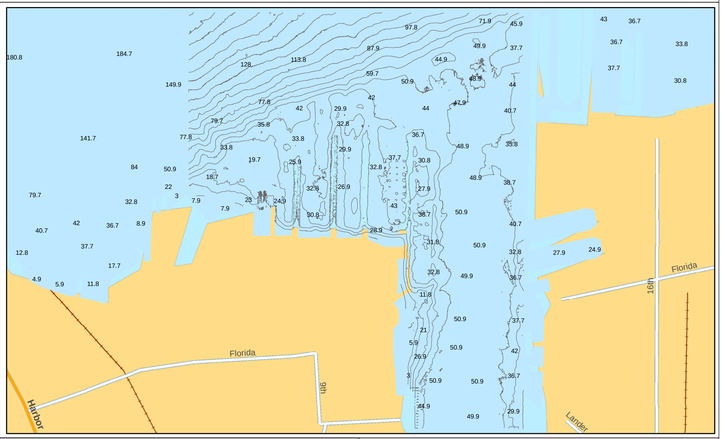
0 75 150 300 450 600 Feet



Survey Map Extent



View of Shipyard 2 Dock Area from North



Geodetic Settings		Survey Equipment	
Datum	State Plane NAD-83	**Multibeam Sonar**	RESON SeaBat 8125
Projection	WA-4601 Washington North	**Positioning System**	Leica 1230 RTK GPS
Horizontal Units	US Survey Feet	**Heading Sensor**	Applanix WaveMaster
Vertical Units	US Survey Feet	**Motion Sensor**	Applanix WaveMaster
Vertical Datum	Port of Seattle MLLW (NAVD88 - 2.59)		
Vertical Control	WA DOT Duwamish SY4595 - ID 6242	**Sound Speed Profiler**	Seabird SBE-19 CTD
Horizontal Control	WA DOT Duwamish SY4595 - ID 6242		

TetraTech EC, Inc.

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Survey Engineer: Burton Bridge	Signature	Plate: **1**
Drafted by: Burton Bridge	Signature	
Checked by: Robert Feldpausch	Signature	Sheet: **1 of 1**
Approved by: Pamela Sargent	Signature	

P:\projects_2006\Lockheed_Bathymetry\maps\LockheedShipyard2.mxd

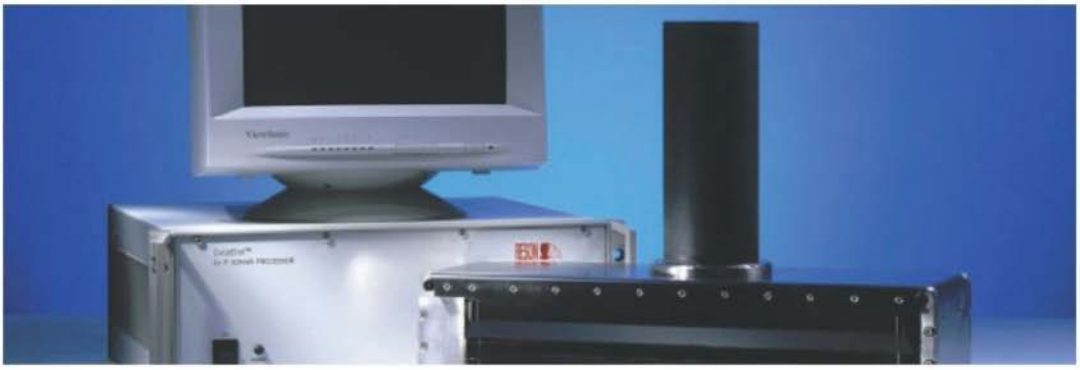
Appendix B. Equipment Data Sheets

The following are copies of the equipment data sheets provided by the manufacturers of some of the systems used in the survey.

RESON

SeaBat 8125

ULTRA HIGH RESOLUTION FOCUSED MULTIBEAM ECHOSOUNDER SYSTEM



SeaBat 8125

- **Focused 0.5° beams**
- **240 beams**
- **2.5cm near field resolution**
- **6mm depth resolution**
- **120° swath**

The SeaBat 8125 is the first wide-sector, wide-band, focused multibeam sonar ever to be deployed. Utilizing 240 dynamically focused receive beams, the system measures a 120° swath across the seafloor, detects the bottom, and delivers the measured ranges at a depth resolution of 6mm. The backscatter intensity image is displayed in real time on the sonar display.

The 8125 can be controlled through its native graphical user interface, or through an external control data collection and navigation software package.

The system can be mounted on a survey vessel or deployed on an ROV at depths down to 1500m. The high-speed data uplink is carried on a standard SeaBat copper cable for surface installation. A fiber-optical interface is available for ROV deployment.

www.reson.com

RESON

SeaBat 8125

ULTRA HIGH RESOLUTION FOCUSED MULTIBEAM ECHOSOUNDER SYSTEM

SYSTEM PERFORMANCE

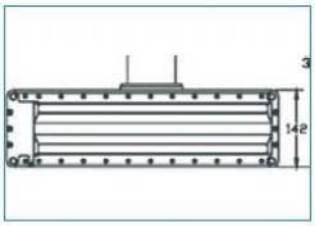
Frequency:	455kHz
Depth Resolution:	6mm
Swath Coverage:	120°
Max Range:	120m
Number of Beams:	240
Along-Track Beamwidth:	1°
Across-Track Beamwidth:	0.5°
Accuracy:	• IHO Special Order • U.S. Army Corps of Engineers Special Order
Operational Speed:	Up to 12 knots
Max. Update Rate:	40
Transducer Depth Rating:	600m (Standard) 1500m (Optional)

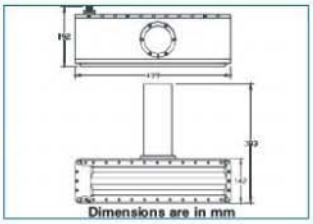
INTERFACE

System Supply:	115V/230V 50/60Hz, 350W max	
Video Display:	SVGA, 800 x 600, 72Hz	
System Control:	Trackball	
Data Output:	10MB Ethernet or serial RS232C	
Data Uplink:	High-speed digital coax with fiber-optic option	
Sonar Head Supply:	24VDC, 5.6A Peak, 2A Average (May be supplied from sonar processor)	
Temperature:	Operating:	0° to +40°C
	Storage:	-30° to +55°C

MECHANICAL INTERFACE

Power Requirements:	24VDC, 5.6A Peak, 2A Average (May be supplied from sonar processor)	
Operating Depth:	600m/1500m	
Dimensions:	266 x 320mm (W / D) excluding projector	
Temperature:	Operating:	-5° to +40°C
	Storage	-30° to +55°C
Weight (aluminum):	Dry:	26.8kg (59lbs.)
	Wet:	4.8kg (10.6lbs.)
Weight (titanium):	Dry:	40kg (88lbs.)
	Wet:	18kg (39.6lbs.)





Dimensions are in mm

RESON reserves the right to change specifications without notice. © 2006 RESON A/S
For Acoustical Measurement Accuracy please refer to www.reson.com or contact sales.

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www.reson.com

Version: B023 051103 / US

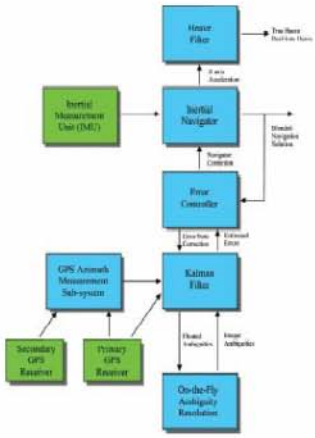
POS MV™ WaveMaster

Providing Survey Launch Marine Industry with robust, reliable, and repeatable position and orientation solutions in all dynamics

Accurate Position and Orientation Solution
POS MV WaveMaster designed for survey launch vessels, maintains positioning accuracy under the most demanding conditions. With its high data update rate, the system delivers a full six degree-of-freedom position and orientation solution to provide the following:

- Position (latitude, longitude and elevation)
- Velocity (north, east and vertical)
- Attitude (roll, pitch and true heading)
- Heave (real-time, delayed)
- Acceleration Vectors
- Angular Rate Vectors

The new POS MV WaveMaster generates a tightly-integrated solution for smaller vessels, which means the system's Inertial Navigator will provide continuous positioning information while surveying in areas where GPS reception is compromised by multipath effect and signal loss. Raw GPS data from as few as one satellite can now be processed directly within the WaveMaster.



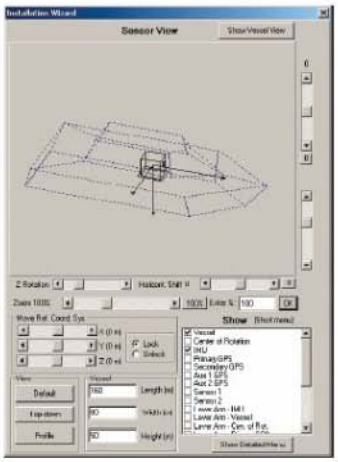
Tightly Coupled POS MV WaveMaster

Tightly-coupled integration offers the following advantages:

Advantage – Strengthens the system's ability to provide continuous, accurate data in areas with intermittent GPS reception
Advantage – Reduces position drift
Advantage – Enables almost instantaneous RTK re-acquisition (with internal RTK option)

WaveMaster Features and Benefits:

- Uses the latest GPS receiver technology from Trimble:
  - Maxwell™ chip technology
  - Everest™ multipath elimination technology
  - 10Hz raw observables for post-processing
  - Outstanding positioning performance and low elevation satellite tracking accuracy
- TrueHeave - **Applanix's ground breaking delayed time** heave processor
  - Removes processing artifacts but not real motion
  - No tuning required for varying sea conditions
  - Provides online quality measurement
- Faster CPU (700Mhz)
  - Low system loading allows for enhanced capabilities in the future
  - Runs at less than 10% of its total capacity to allow for upgrades and additional features
- TCP/IP protocol for raw data logging
  - Reliable logging of all raw data with microsecond-accurate time stamping
  - POSPac ready (for post-mission analysis)
- Firmware migration path
  - Access to new releases with new features as they become available
- New small, compact form-factor
- New Graphical User Interface
  - Makes installation and setup intuitive
  - Reduces operator error



POS MV WaveMaster Graphical User Interface

SYSTEM COMPONENTS

POS Computer System (PCS)
A rugged, compact computer system contains the core POS processor and IMU interface electronics, plus two GPS receivers. The PCS **provides** all motion variables and timing data at high rate and/or provides motion compensation and georeferenceing data to all multibeam systems.

POS Inertial Measurement Unit
The system's primary sensor is a Ring Laser Gyro (RLG) manufactured by one of the world's experts in inertial technology. This **high performance**, low drift rate gyro ensures that the attitude data remains robust as the dynamics increase.

Primary and Secondary GPS Antennas
Dual frequency antennas for use with GAMS and/or RTK.

APPLANIX
A TRIMBLE COMPANY

POSMV™ WaveMaster

POS MV WAVEMASTER MAIN SPECIFICATIONS (with Differential Corrections)

Roll, Pitch accuracy:	0.03° (1 sigma with GPS or DGPS) 0.02° (1 sigma with RTK)
Heave Accuracy:	5 cm or 5% (whichever is greater) for periods of 20 seconds or less
Heading Accuracy:	0.06° (1 sigma) with 1 m antenna baseline, 0.03 (1 sigma) with 2 m baseline, 0.015 (1 sigma) with 4 m baseline
Position Accuracy:	0.5 - 2 m (1 sigma) depending on quality of differential corrections 0.02 - 0.10 m (RTK) with input from auxiliary RTK or optional internal RTK receiver
Velocity Accuracy:	0.05 m/s horizontal

POS MV WAVEMASTER DURING GPS OUTAGES

Roll, Pitch accuracy:	0.04° (1 sigma)
Heave accuracy:	5 cm or 5% (whichever is greater) for wave periods of 18s or less
Heading accuracy:	Drift less than 2° per hour
Position accuracy degradation:	3 m (1 sigma) for 30 s outages <10 m (1 sigma) for 60 s outages

PHYSICAL CHARACTERISTICS

Size

IMU	160mm x 160mm x 102mm
PCS	281mm x 165mm x 90mm
GPS Antenna (2)	187mm x 53mm

Weight

IMU	3.6kg
PCS	3.0kg
GPS Antenna	<0.5kg

Power

IMU	Power provided by PCS
PCS	24vdc, 50 W (peak)
GPS Antenna	Power provided by PCS

ENVIRONMENTAL

Temperature Range (Operating)

IMU	-40 °C to +60 °C
PCS	-20 °C to +60 °C
GPS Antenna	-40 °C to +70 °C

Temperature Range (Storage)

IMU	-40 °C to +60 °C
PCS	-20 °C to +60 °C
GPS Antenna	-40 °C to +70 °C

Humidity

IMU	10-80% RH, Ingress Protection of 65
PCS	5-90% RH, non-condensing
GPS Antenna	0-100% RH

Ethernet (100 base-T)

Parameters	Time tag, status, position, attitude, heave, velocity, track and speed, dynamics, performance metrics, raw IMU data, raw GPS data
Display Port	Low rate (1 Hz) UDP protocol output
Control Port	TCP/IP input for system commands
Data Port 1	Real-time (up to 200 Hz) UDP protocol output
Data Port 2	Buffered TCP/IP protocol output for data logging to external device

Serial RS232 I/O

5 COM Ports	User assignable to: NMEA output, Binary output, Auxiliary GPS input (2), Base GPS correction input (2)

NMEA ASCII Output

Parameters	NMEA Standard ASCII messages: Position ($INGGA, $INGGK), Heading ($INHDT), Track and Speed ($INVTG), Statistics ($INGST), Attitude ($PASHR, $PRDID), Time and Date ($INZDA, $UTC).
Rate	Up to 50 Hz (user selectable)

High Rate Attitude Output

Parameters	User selectable binary messages: attitude, heading, speed
Rate	Up to 100 Hz (user selectable)

Auxiliary GPS Inputs

Parameter	NMEA Standard ASCII messages: $GPGGA, $GPGST, $GPGSA, $GPGSV. Uses Aux input with best quality.
Rate	1 Hz

Base GPS Correction Inputs

Parameter	RTCM 1, 9, 18, 19, CMR and CMR+ input formats accepted. Combined with raw GPS observables in tightly-coupled navigation solution.
Rate	1 Hz

Digital I/O

1PPS Output	1 pulse-per-second Time Sync output, normally high, active low pulse
Event Input (2)	Time mark of external events. TTL pulses > 1 msec width, rising or falling edge, max rate 200 Hz.

Applanix Marine Offices

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APPLANIX
A TRIMBLE COMPANY

TETRA TECH, INC.

LOCKHEED MARTIN
We never forget who we're working for™

Leica GPS1200
Technical specifications and system features

GPS1200 receivers	GX1230 GG/ATX1230 GG	GX1230/ATX1230	GX1220	GX1210
GNSS technology	SmartTrack+	SmartTrack	SmartTrack	SmartTrack
Type	Dual frequency	Dual frequency	Dual frequency	Single frequency
Channels	14 L1 + 14 L2 GPS 2 SBAS 12 L1 + 12 L2 GLONASS 72 Channels	12 L1 + 12 L2 GPS 2 SBAS	12 L1 + 12 L2 GPS 2 SBAS (with DGPS option)	12 L1 2 SBAS (with DGPS option)
RTK	SmartCheck+	SmartCheck	No	No
Status indicators	3 LED indicators: for power, tracking, memory			

GPS1200 receivers	GX1230 GG/GX1230/GX1220	GX1210	ATX1230 GG/ATX1230
Ports	1 power port, 3 serial ports, 1 controller port, 1 antenna port		1 power/controller port, Bluetooth® port
Supply voltage,	Nominal 12 VDC		Nominal 12 VDC
Consumption	4.6 W receiver + controller + antenna		1.8 W
Event input and PPS	Optional:	Optional:	
	1 PPS output port	1 PPS output port	
	2 event input ports	2 event input ports	
Standard antenna	SmartTrack+ AX1202 GG	SmartTrack AX1201	SmartTrack+ ATX1230 GG
Built-in groundplane	Built-in groundplane	Built-in groundplane	Built-in groundplane

The following apply to all receivers except where stated.

Power supply	Two Li-Ion 3.8 Ah/7.2 V plug into receiver. One Li-Ion 1.9 Ah/7.2 V plugs into ATX1230 and RX1250.
Plug-in Li-Ion batteries Same for GPS and TPS	Power receiver + controller + SmartTrack antenna for about 15 hours (for data logging).
	Power receiver + controller + SmartTrack antenna + low power radio modem or phone for about 10 hours (for RTK/DGPS). Power SmartAntenna + RX1250 controller for about 5 hours (for RTK/DGPS)
External power	External power input 10.5 V to 28 V.
Weights	Receiver 1.20 kg. Controller 0.48 kg (RX1210) and 0.75 kg (RX1250). SmartTrack antenna 0.44 kg. SmartAntenna 1.12 kg. Plug-in Li-Ion battery 0.09 kg (1.9 Ah) and 0.19 kg (1.9 Ah).
	Carbon fiber pole with SmartTrack antenna and RX1210 controller: 1.80 kg.
	All on pole: carbon fiber pole with SmartAntenna, RX1250 controller and plug-in batteries: 2.84 kg.

Temperature ISO9022 MIL-STD-810F	Operation:	Receiver	−40° C to +65° C
	Antennas		−40° C to +70° C
	Controllers		−30° C to +65° C
	Storage:	Receiver	−40° C to +80° C
	Antennas		−55° C to +85° C
	Controllers		−40° C to +80° C
Humidity ISO9022, MIL-STD-810F	Receiver, antennas and controllers Up to 100 % humidity.		
Protection against water, dust and sand IP67, MIL-STD-810F	Receiver, antennas and controllers: Waterpoof to 1 m temporary submersion. Dust tight		
Shock/drop onto hard surface	Receiver: withstands 1 m drop onto hard surface. Antennas: withstand 1.5 m drop onto hard surface.		
Topple over on pole	Receiver, antennas and controllers: withstand fall if pole topples over.		
Vibrations ISO9022 MIL-STD-810F	Receiver, antennas and controllers: withstand vibrations on large construction machines. No loss of lock.		

MicroCAT C-T Recorder (Serial interface & Memory)

SBE 37-SM

The SBE 37-SM MicroCAT is a high-accuracy conductivity and temperature (pressure optional) recorder with internal battery and memory. Designed for moorings or other long duration, fixed-site deployments, the MicroCAT includes a standard serial interface and non-volatile FLASH memory. Construction is of titanium and other non-corroding materials to ensure long life with minimum maintenance, and depth capability is 7000 meters (23,000 feet).

Calibration coefficients are stored in EEPROM, and uploaded data is presented in ASCII engineering units. The data always includes Conductivity, Temperature, and Pressure (if optional pressure sensor is installed). If desired, time can be added to each scan, and the MicroCAT can calculate and output salinity and sound velocity (Chen-Millero). The MicroCAT retains the temperature and conductivity sensors used in our time-proven SEACAT products; however, new acquisition techniques provide increased accuracy and resolution while reducing power consumption. Electrical isolation of the conductivity electronics eliminates any possibility of ground-loop noise.

The MicroCAT's unique internal-field conductivity cell permits the use of expendable anti-foulant devices. The aged and pressure-protected thermistor has a long history of exceptional accuracy and stability.

The MicroCAT's optional pressure sensor, developed by Druck, Inc., has a superior new design that is entirely different from conventional 'silicon' types in which the deflection of a metallic diaphragm is detected by epoxy-bonded silicon strain gauges. The Druck sensor employs a micro-machined *silicon diaphragm* into which the strain elements are implanted using semiconductor fabrication techniques. Unlike metal diaphragms, silicon's crystal structure is perfectly elastic, so the sensor is essentially free of pressure hysteresis. Compensation of the temperature influence on pressure offset and scale is performed by the MicroCAT's CPU.

SENSOR INTERFACE ELECTRONICS

Temperature is acquired by applying an AC excitation to a hermetically-sealed VISHAY reference resistor and an ultra-stable aged thermistor (drift rate typically less than 0.002 °C per year). The ratio of thermistor resistance to reference resistance is determined by a 24-bit A/D converter; this A/D also processes the pressure sensor signal. Conductivity is acquired using an ultra-precision Wien-Bridge oscillator. A high-stability reference crystal with a drift rate of less than 2 ppm/year is used to count the frequency from the oscillator.

COMMUNICATIONS AND INTERFACING

The MicroCAT communicates directly with a computer via standard RS-232 interface. Data can be uploaded at up to 38.4K baud. Real-time data can be transmitted at distances of up to 1600 meters (5200 feet) at 600 baud, simultaneously with recording. An optional RS-485 interface allows multiple MicroCATs to share a common 2-wire cable, minimizing cable complexity for C-T chains.

User-selectable operating modes include:

- **Autonomous Sampling** – At pre-programmed intervals of 5 seconds to 9.1 hours, the MicroCAT wakes up, samples, stores the data in its FLASH memory, and goes to sleep.
- **Polled Sampling** – On command from a computer or satellite, radio, or wire telemetry equipment, the MicroCAT takes a sample and transmits the data.
- **Serial Line Sync** – In response to a pulse on the serial line, the MicroCAT wakes up, samples, stores the data in its FLASH memory, transmits real-time data, and goes to sleep.

SOFTWARE

The MicroCAT is supplied with a powerful Windows 95/98/NT/2000/XP software package, SEASOFT®-Win32, which includes:

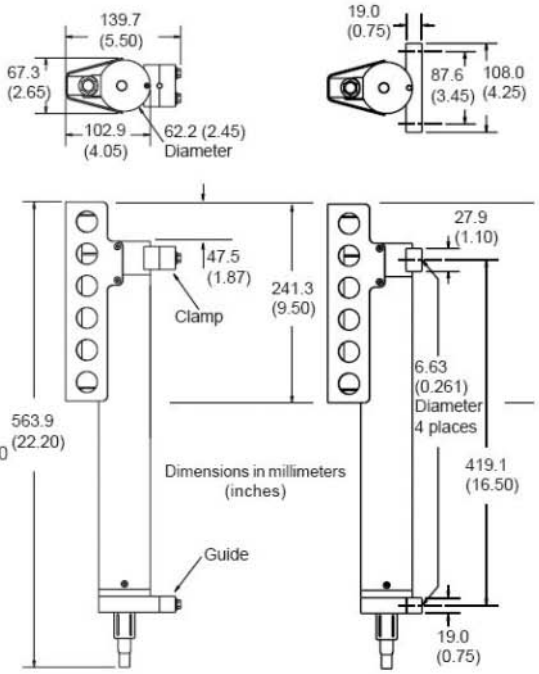
- SEATERM® – terminal program for easy communication and data retrieval.
- SBE Data Processing® – programs for calculation, display, and plotting of conductivity, temperature, pressure (optional), and derived variables such as salinity and sound velocity.

Sea-Bird Electronics, Inc.
1808 136th Place NE, Bellevue, Washington 98005 USA
Website: http://www.seabird.com
E-mail: seabird@seabird.com
Telephone: (425) 643-9866
Fax: (425) 643-9954

MicroCAT C-T Recorder (Serial interface and Memory) SBE 37-SM

DATA STORAGE AND BATTERY ENDURANCE

Converted temperature and conductivity are stored 5 bytes per sample, time 4 bytes per sample, and optional pressure 2 bytes per sample; memory capacity is in excess of 185,000 samples. The MicroCAT is powered by a 7.2 Ampere-Hour (nominal) battery pack consisting of six 9-volt lithium batteries which, when removed from the MicroCAT, can be shipped without hazardous material restrictions. The pack provides sufficient internal battery capacity for more than 300,000 samples. *



SPECIFICATIONS

Measurement Range
Conductivity: 0 - 7 S/m (0 - 70 mS/cm)
Temperature: -5 to 35 °C
Optional Pressure: 20/100/350/600/1000/2000/3500/7000 (meters of deployment depth capability)

Initial Accuracy
Conductivity: 0.0003 S/m (0.003 mS/cm)
Temperature: 0.002 °C
Optional Pressure: 0.1% of full scale range

Typical Stability *(per month)*
Conductivity: 0.0003 S/m (0.003 mS/cm)
Temperature: 0.0002 °C
Optional Pressure: 0.004% of full scale range

Resolution
Conductivity: 0.00001 S/m (0.0001 mS/cm)
Temperature: 0.0001 °C
Optional Pressure: 0.002% of full scale range

Time Resolution 1 second

Clock Accuracy 13 seconds/month

Quiescent Current * 10 microamps

Sampling and Communication Current *
Without external power option
Communication 38 milliamps
Sampling 20 milliamps for autonomous or serial line sync sampling; 39 milliamps for polled sampling
With external power option
Communication 35 milliamps
Sampling 35 milliamps

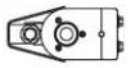
Acquisition Time 1 - 3 seconds/sample (for 1 measurement/sample), *dependent on sampling mode and inclusion of pressure sensor*

Optional External Input Power 0.5 Amps at 9-24 VDC

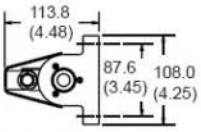
Housing Titanium

Depth Capability 7000 m (23,000 feet)

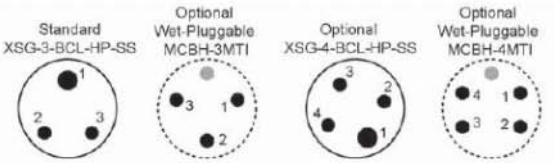
Weight
in air: 3.8 kg (8.3 lbs)
in water: 2.3 kg (5.1 lbs)



Standard Wire Mounting Clamp and Guide



Alternate Flat Surface Mounting Brackets



3-pin Connector

Pin	Signal
1	Common
2	RS-232 data receive
3	RS-232 data transmit

Optional 4-pin Connector

Pin	Signal
1	Common
2	RS-232 data receive
3	RS-232 data transmit
4	9-24 VDC (optional external power)

* Power consumption / battery endurance values are for standard RS-232 interface; for optional RS-485 interface, see RS-485 manual

05/05

Sea-Bird Electronics, Inc.
1808 136th Place NE, Bellevue, Washington 98005 USA
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E-mail: seabird@seabird.com
Telephone: (425) 643-9866
Fax: (425) 643-9954

Appendix C. Survey Log Sheets

TetraTech EC

Date:	5/20/2006	**Survey Area:**	Lockheed	**Page 1 / Pages:**	
Survey Name:	Thea Foss	**Surveyors:**	Bridge, Feldpausch	**TimeZone:**	GMT
Survey Vessel:	R/V Brendan D	**Client:**	Tetra Tech EC		

Offset Information

	X	Y	Z	Latency	Roll	Pitch	Yaw
Sounder	1.84	0.00	3.08	0.00	-0.30	0.00	4.00
RTK GPS	1.84	0.00	-11.78	0.00			
Motion Sensor	0.00	0.00	-4.50				
Other							

SVP File:

Tide File:

Date of Patch Test 5/10/2006

Total Pole	14.86
minus Dry Pole	11.78
Draft (Z)	3.08

Start	Stop	Line (.raw)	Dir.	Speed	COMMENTS
1748	1810	001_1748	108	2	Bad sound speed at head - don't use
1829	1857	001_1829	86	2	1480 m/sec from cast - check headings (possible C1911
1904	1911	001_1904	345	2.5	
1911	1933	001_1911	28	2	
1934	1941	001_1934	95	2	
1942	1949	001_1942	124	2	
1950	2008	001_1950	115	2	
2011	2017	001_2011	348	3	
2018	2028	001_2018	192	2	still seeing CMG in heading
2033	2039	001_2033	340	4	changed setup to put gyro in Hysweep
2040	2048	001_2040	173	2.7	
2117	2033	001_2117	285	2	
2134	2046	001_2134	85	2.5	chk headings for variations
2147	2157	001_2147	300	2.5	
2158	2208	001_2158	40	2	
2208	2218	001_2208	310	3	
2222	2233	001_2222	80	3.6	
2233	2237	001_2233	352	3.8	
2237	2241	001_2237	140	3	

Survey Manager: _____ Client Representative: _____

Signature: _____ Signature: _____

TetraTech EC

Date:	5/20/2006	**Survey Area:**	Lockheed	**Page 1 / Pages:**	
Survey Name:	Thea Foss	**Surveyors:**	Bridge, Feldpausch	**TimeZone:**	GMT
Survey Vessel:	R/V Brendan D	**Client:**	Tetra Tech EC		

Offset Information

	X	Y	Z	Latency	Roll	Pitch	Yaw
Sounder	1.84	0.00	3.08	0.00	-0.30	0.00	4.00
RTK GPS	1.84	0.00	-11.78	0.00			
Motion Sensor	0.00	0.00	-4.50				
Other							

Date of Patch Test 5/20/2006

SVP File: Lockheed 052006 16

Tide File: RTK GPS

Total Pole	14.86
minus Dry Pole	11.78
Draft (Z)	3.08

Start	Stop	Line (.raw)	Dir.	Speed	COMMENTS
2254	2256	003_2254	250	3.8	pitch/yaw cal
2257	2259	003_2257	86	3.5	
2300	2301	005_2300	252	4.3	
2302	2304	005_2302	88	3.6	end cal
2327	2341	001_2327	73	3.5	re-start survey data collection
2341	2349	001_2341	249	3.1	
2350	2352	003_2350	29	2.7	

Survey Manager: _____ Client Representative: _____

Signature: _____ Signature: _____

Appendix D. Base Station Benchmark Description

WSDOT Survey Mark Report http://www.wsdot.wa.gov/monument/report.cfm?monumentid=6242

Washington State Department of Transportation **Geographic Services**

SURVEY INFORMATION SYSTEM **Report of Survey Mark**

GENERAL MONUMENT INFORMATION

Designation:	DUWAMISH	**T.R.S:**	24N, 3E , 2	
Monument ID:	6242	**Corner Code:**		
Ngs Pid:	SY4595	**State Route:**		
State:	WASHINGTON	**Mile Post:**		
County:	KING	**Station:**		
Region:	NW	**Offset:**		
Nearest Town:	SEATTLE	**Owner:**	GS	
Usgs Quad:	DUWAMISH HEAD	**Bearing:**	M	

ACCOUNTS INFORMATION

BOOK	PROJECT	INVOICE
253	MS4466	23-04006
264	XL2219	23-04021
296	XL2219	23-06020

Description

TO REACH THE STATION FROM THE JUNCTION OF SR 005 AND SPOKANE STREET IN SEATTLE, GO WEST 2.3 MILES ALONG SPOKANE STREET TO THE HARBOR AVENUE EXIT. BEAR RIGHT AND FOLLOW THE EXIT RAMP 0.2 MILES TO A 'T' INTERSECTION. TURN RIGHT AND GO NORTHWEST 2.0 MILES ALONG HARBOR AVENUE TO MARK ON RIGHT. IT IS LOCATED IN AN OLD CONCRETE SEA WALL SOUTH OF A SIDEWALK AND A SMALL PARK, 5.8 METERS EASTERLY OF TOP OF STAIRS, 4.9 METERS NORTH OF THE NORTH EDGE OF A SIDEWALK ADJACENT TO ALKI AVE, 15.2 METERS NORTHWEST OF THE CENTER OF HARBOR AVE SW, 9.1 METERS NORTHWEST OF A LIGHT POLE AND 7.0 METERS EAST OF A 1.5-INCH IRON PIPE. THE MARK IS A USC&GS TRIANGULATION STATION DISK SET IN A DRILL HOLE AND LEVEL WITH THE CONCRETE SEA WALL SURFACE.

CURRENT SURVEY CONTROL

DATUM	LATITUDE	UNIT	LONGTITUDE	UNIT	NETWORK	METHOD	ACCURACY
NAD 83/91	47 35 42.537420	N	122 23 14.845970	W	PRIMARY	GPS	2 CM
	ELLIP HGT						
NAD 83	-18.180	M				GPS	5 CM
	ORTHO HGT						
NAVD 88	5.244	M			PRIMARY	DIFF LEVELS	1 CM
SPC ZONE	**NORTHING**	**UNIT**	**EASTING**	**UNIT**	**SCALE**	**CONV.ANGLE**	**COMB.FACTOR**
N	67350.036	M	383128.343	M	0.99998361	-1 09 25.5	

MONUMENTATION HISTORY

DATE	RECOVERED BY	CONDITION

01/01/1933	USC&GS	MONUMENTED
01/01/1955	USC&GS	GOOD
01/01/1973	NGS	GOOD
05/17/1994	NOS	GOOD
02/26/2004	GEOGRAPHIC SERVICES	GOOD
08/06/2004	GEOGRAPHIC SERVICES	UPDATED
07/10/2006	GEOGRAPHIC SERVICES	GOOD

SUPERSEDED CONTROL

DATUM	LATITUDE	UNIT	LONGTITUDE	UNIT	NETWORK	METHOD	ACCURACY
	ORTHO HGT						
NAVD 88	5.2	M			PRIMARY	GPS	5 CM

Traffic & Roads | Site Index | Contact WSDOT | WSDOT Business | WSDOT Home

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WSDOT Survey Mark Report http://www.wsdot.wa.gov/monument/report.cfm?monumentid=3296

Washington State Department of Transportation **Geographic Services**

SURVEY INFORMATION SYSTEM **Report of Survey Mark**

GENERAL MONUMENT INFORMATION

Designation:	GP17099-241	**T.R.S:**	24N, 4E , 18	
Monument ID:	3296	**Corner Code:**		
State:	WASHINGTON	**State Route:**	099	
County:	KING	**Mile Post:**	29.070	
Region:	NW	**Station:**		
Nearest Town:	SEATTLE	**Offset:**		
Usgs Quad:	SEATTLE SOUTH	**Owner:**	GS	
		Bearing:	M	

ACCOUNTS INFORMATION

BOOK	PROJECT	INVOICE
152	0L3414	23-98015

Description

TO REACH THE STATION FROM THE JUNCTION OF SR 099 AND SR 509 IN SOUTH SEATTLE, GO NORTHERLY 2.10 MILES ALONG SR 099 TO THE EAST MARGINAL WAY OFF-RAMP, TAKE THE OFF-RAMP AND GO NORTHERLY 0.53 MILES ALONG EAST MARGINAL WAY TO MARK ON LEFT. IT IS LOCATED IN THE WESTERLY SIDEWALK OF EAST MARGINAL WAY, APPROXIMATELY 60 METERS NORTH OF THE 'T' INTERSECTION WITH HORTON STREET, 6.3 METERS @ 55 DEGREES FROM A ELECTRICAL RISER BOX, 6.5 METERS @ 160 DEGREES FROM A MANHOLE COVER IN SIDEWALK, 2.1 METERS @ 240 DEGREES FROM THE EAST FACE OF THE WEST SIDEWALK AND 12.9 METERS @ 335 DEGREES FROM THE SOUTHEAST CORNER OF THE SIDEWALK. MARK IS A WSDOT BRASS DISK CEMENTED INTO A DRILL HOLE AND SET LEVEL WITH THE CONCRETE SURFACE. NOTE: THIS STATION SIGHTS GP17099-242.

CURRENT SURVEY CONTROL

DATUM	LATITUDE	UNIT	LONGTITUDE	UNIT	NETWORK	METHOD	ACCURACY
NAD 83/91	47 34 29.040571	N	122 20 24.431981	W	PRIMARY	GPS	2 CM
NAD 83	ELLIP HGT -18.657	M				GPS	5 CM
NAVD 88	ORTHO HGT 4.669	M			PRIMARY	DIFF LEVELS	1 CM
SPC ZONE	**NORTHING**	**UNIT**	**EASTING**	**UNIT**	**SCALE**	**CONV.ANGLE**	**COMB.FACTOR**
N	65009.837	M	386643.247	M	0.99998690	-1 07 18.6	

MONUMENTATION HISTORY

DATE	RECOVERED BY	CONDITION

03/03/1998	GEOGRAPHIC SERVICES	MONUMENTED

SUPERSEDED CONTROL

DATUM	LATITUDE	UNIT	LONGTITUDE	UNIT	NETWORK	METHOD	ACCURACY
	ORTHO HGT						
NAVD 88	4.708	M			PRIMARY	DIFF LEVELS	1 CM

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