RECLAMATION
Managing Water in the West

Manuals and Standards Report

Best Practices in Hydrographic Surveying

Living Quick Users Guide for Hydrographic Survey Equipment, Version 1.0

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

September 2019

Mission Statements

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Disclaimer

This users guide describes procedures and methods to operate certain equipment for the measurement of position, depth, and velocity in rivers and reservoirs. Product names are sometimes mentioned to describe specific equipment for which the procedures and methods apply. Nothing in this users guide constitutes endorsement by the Bureau of Reclamation of a particular product or method.

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Acronyms and Abbreviations

>	greater than
<	less than
%	percent
3D	three-dimensional
ADCP	Acoustic Doppler Current Profiler
ADQA	automated data quality assessment
amp	ampere
APC	antenna phase center
ARP	antenna reference point
ASCII	American Standard Code for Information Interchange
BT Filters	bottom track filters
BT Frequency	bottom track frequency
CDMA	Code-Division Multiple Access
cm	centimeter/centimeters
CMR+	Compact Measurement Record
CORS	Continuously Operating Reference Station
COV	coefficient of variation
DC	direct current
ENU	East, North, Up
ft	foot/feet
ft/s	foot/feet per second
GB	gigabyte
GGA	fix data NMEA string
GIS	Geographic Information System
GLONASS	Russian Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System

GPRS	General Packet Radio Service
GUI	graphical user interface
HD	horizontal distance
HI	Height of Instrument
HTDP	Horizontal Time-Dependent Positioning
Hz	hertz
ID	identity/identifier/identification
IMU	Inertial Measurement Unit
INTG	interpolate geoid
i/o	input/output
IP address	Internet Protocol address
LAN	Local Area Network
LED	light-emitting diode
m	meter/meters
m/s	meter/meters per second
MB	megabytes
MCR	Matlab Compiler Runtime
MEX	Matlab executable
MHz	megahertz
MRU	Motion Reference Unit
NAD83	North American Datum of 1983
NASA	National Aeronautics and Space Administration
NGA	National Geospatial-Intelligence Agency
NGS	National Oceanic and Atmospheric Administration's National Geodetic Survey
NMEA	National Marine Electronics Association
NWWA	northwest network
OPUS	National Oceanic and Atmospheric Administration's Online Positioning User Service
PC	personal computer

PCM	Power & Communications Module
PDL	Positioning Data Link
PPM	parts per million
QRev	U.S. Geological Survey-developed software program
RAM	random access memory
Reclamation	Bureau of Reclamation
RINEX	Receiver Independent Exchange Format
RMS	root mean square
RTCM	Radio Technical Commission for Maritime Services
RTK	Real-Time Kinematic
RTN	Real-Time Network
SIM	subscriber identity module/subscriber identification module
SPC	State Plane Coordinates
SPCS	State Plane Coordinate System
SRH	Sedimentation and River Hydraulics Group in Reclamation’s Technical Service Center
SRH-HAPS	Sedimentation and River Hydraulics–Hydro-Acoustics Processing Software
TBC	Trimble Business Center
TM	transom mount
TRDI	Teledyne RD Instruments
UHF	ultra high frequency
USACE	U.S. Army Corps of Engineers
USB	Universal Serial Bus
USGS	U.S. Geological Survey
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
VD	vertical distance
VRN	Virtual Reference Network
VRS	virtual reference station

VTG	vector track and speed over the ground
WSE	water surface elevation
WSRN	Washington State Reference Network
WT Filters	water track filters
WT Frequency	water track frequency

Introduction

This users guide has been prepared as a reference to help engineers and scientists in the field while conducting measurements in rivers and reservoirs. A variety of topics are covered including surveying, depth sounding, velocity measurements, hydro-acoustics data processing, and discharge measurements.

Surveying topics include Global Positioning System with Real-Time Kinematic corrections, use of real-time networks, and robotic total stations. Depth sounding topics include the use of single beam and multibeam depth sounders. Velocity measurement topics include varying types of equipment setup and instrument operation. The use of in-house hydro-acoustics processing software is described for multiple data collection methods. Stream discharge measurements are described using either an Acoustic Doppler Current Profiler or velocity meter.

One of the primary intents of this living reference is use as a field guide, and is written so that a user does not have to read from beginning to end.

Real-Time Kinematic Global Positioning System Surveying

By Michael Sixta, M.S., P.E.

Introduction

Real-Time Kinematic (RTK) Global Positioning System (GPS) surveying is a technique that uses carrier-based ranging and provides ranges (and therefore positions) that are orders of magnitude more precise than those available through code-based positioning. The basic concept behind RTK GPS surveying is to reduce and remove errors common to a base station and rover pair, as illustrated in figure 1.

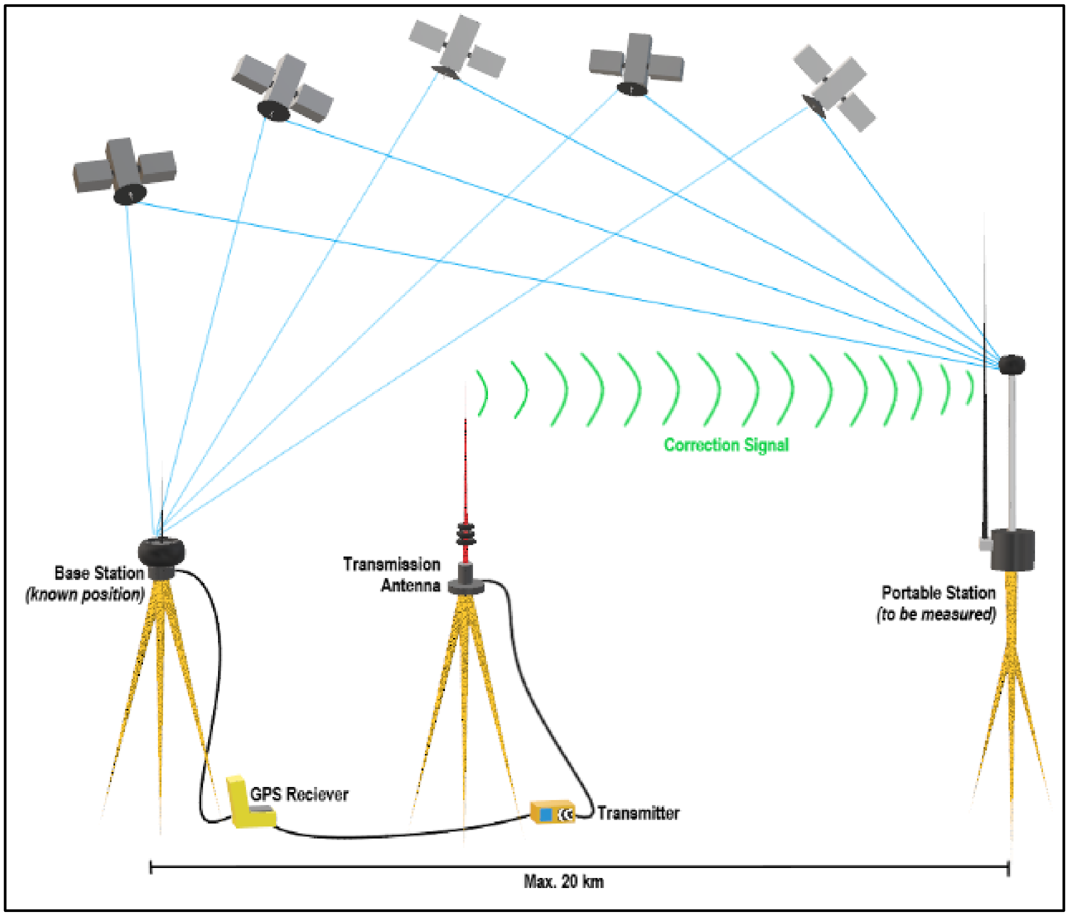

Figure 1.—RTK GPS basic concept.

RTK GPS calculates horizontal coordinates in real-time relative to a known base point and orthometric elevations based on the ellipsoid and geoid models selected. The GPS base receiver is set up over a point with known coordinates. Position corrections are transmitted to the GPS rover receiver using an external GPS radio and UHF antenna. The base station is typically powered by a 12-volt battery. Figure 2 shows a typical RTK GPS base station setup.

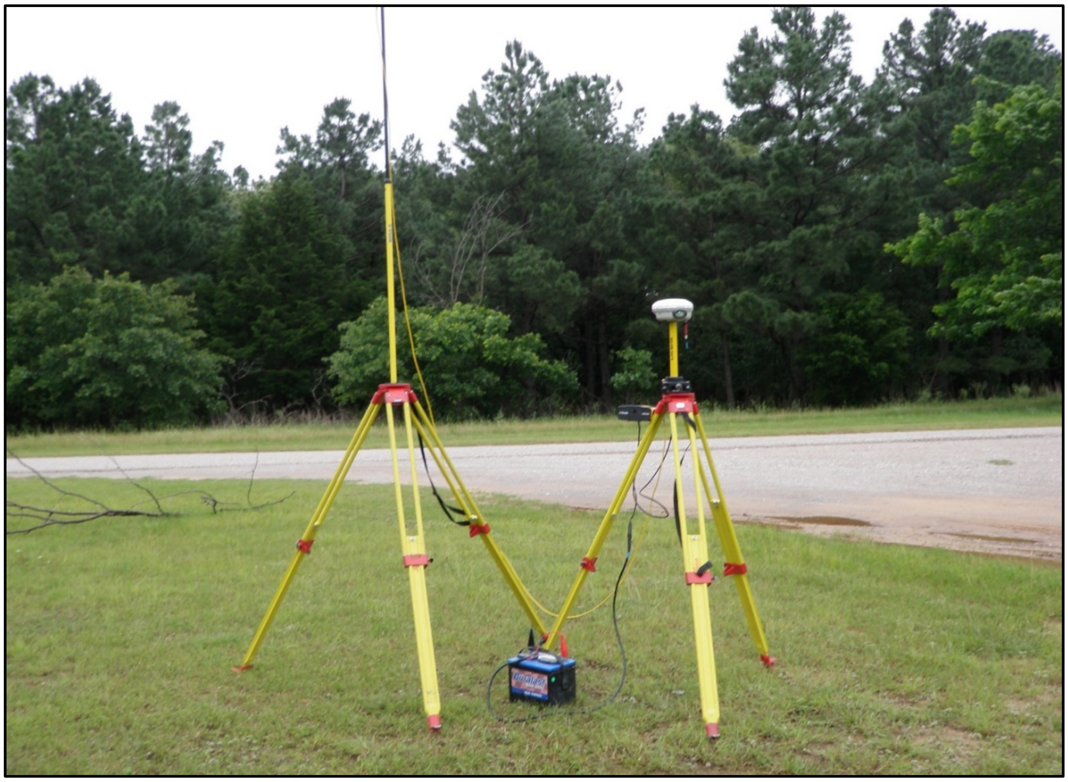

Figure 2.—Typical RTK GPS base station setup, Thunderbird Reservoir, Oklahoma.

The rover component consists of a second GPS receiver with internal radio and external antenna mounted on a range pole (ground survey) or survey vessel (bathymetric survey). The rover receiver, reading the same satellites at the same time as the base station, receives the corrected positions from the base receiver. This results in real-time positions with accuracies on the order of 2 centimeters horizontally and 3 centimeters vertically over relatively large survey areas.

Equipment

As of September 2019, the Sedimentation and River Hydraulics Group (SRH) in Reclamation’s Technical Service Center has the following RTK GPS equipment:

- Seven R8 GPS receivers
- Three R10 GPS receivers
- Three HPB450 radios
- Three TDL450 radios
- Seven TSC3 controllers
- Six antenna kits

RTK Base Station Setup Procedure

The R8 and R10 receivers have a slightly different setup, but both base station setups follow the same general steps:

1. Put battery in base receiver.

2. Set GPS base receiver over point of interest on first tripod (e.g., rebar, stake [hub], PK nail, survey cap, etc.); accurately level with tribrach before turning on receiver.

3. Set external (base) radio and radio antenna on second tripod in close proximity to base receiver; coarse level with tripod legs.

    - R8 base receivers are typically used with HPB450 radios (yellow).
    - R10 base receivers are typically used with TDL450 radios (gray).

4. Connect radio antenna cable to external radio.

5. Connect external radio to base receiver using data end of super cable.

6. Connect base battery using power end of super cable **(ALWAYS CONNECT THIS LAST!)**.

    - HPB450 radios require larger (car) 12-volt batteries.
    - TDL450 radios can be powered using smaller (amp/hour) 12-volt batteries.

7. Measure the Height of Instrument (HI) from the established base point to base receiver using collapsible black measurement rod.

    - For R8 base receivers, measure to the center of bumper.
    - For R10 base receivers, measure to the bottom of the lever arm extension.

8. Power on survey controller and start new job using the appropriate settings (General Survey→ Jobs→ New job).

9. Connect to base receiver via Bluetooth (General Survey→ Instrument→ GNSS functions→ Bluetooth).

    - Under "Connect to GNSS base," select receiver type and serial number corresponding to base receiver using the drop-down list.

    - Once the Bluetooth setting is accepted ("Accept"), select "Base Mode" under "GNSS functions." The user can then "Esc" back to the general survey screen, which should have the job name listed at the top.

10. Start base receiver (Measure→ select appropriate survey style template→ Start base receiver).

    - Enter pertinent base measurements and site information:

        - Point name is point number

        - Can "List" a pre-loaded point or "Key in" a new point by selecting menu to the right of the point name field

        - If keying in a point, can enter known coordinates and elevation or establish an autonomous position through the "Here" button near the lower left corner of the screen

        - Code is point descriptor

        - "Store" the point, which will bring the user back to the "Start base" screen

    - Enter the antenna height (followed by "m"), which will automatically convert the measurement into the coordinate system units.

    - Enter "Measured to" from drop-down menu:

        - Center of bumper for R8
        - Lever of R10 extension for R10
        - "Station index" can be any integer
        - "Transmit Delay" should be set to 0 millisecond

    - "Start" base receiver in the lower right corner.

11. Verify the external radio is on the appropriate power setting, is transmitting ("TX" light is blinking), and is set to the appropriate channel before leaving the base station.

Field Book Notes

While in the field, the user should log the following notes for each base station setup:

- Survey team member names
- Date
- Survey job file name and datum (TSC controller)
- Estimated project height
- Receiver serial number (last three digits)
- Controller number
- Radio frequency and channel
- HI measurement (and what it is measured to)
- Base station point number and coordinates (note datum and source of base point coordinates, or if needs to be post-processed with OPUS)
- Point description
- General location
- Survey style
- Start time
- End time
- Position of base station relative to local landmarks and address, or nearby cross streets
- Photograph of the base station setup from at least two vantage points

RTK Rover Setup Procedure

1. Put battery in rover receiver.

2. Power on survey controller and start new job using appropriate settings (General Survey→ Jobs→ New job).

   Note: This step is not necessary if using the same controller that was used for the base station setup.

3. Connect to rover receiver via Bluetooth (General Survey→ Instrument→ GNSS functions→ Bluetooth).

   - Under “Connect to GNSS rover,” select receiver type and serial number corresponding to rover receiver using the drop-down list.

   - Once the Bluetooth setting is accepted (“Accept”), select “Rover Mode” under “GNSS functions.” The user can then “Esc” back to the general survey screen, which should have the job name listed at the top.

4. Start survey (Measure→ select appropriate survey style template→ Measure points or Continuous topo).

    - Enter pertinent rover measurements and site information:

        - Point name is point number
        - Point code is point descriptor
        - Rod height (normally measured to "bottom of antenna mount")
        - "Station index" can be any integer
        - "Transmit Delay" should be set to 0 millisecond

Downloading and Processing Data

1. Download the ".T02" (base) file from the base receiver to a TSC3 controller via Bluetooth.

2. Transfer both the ".T02" and ".job" files from the TSC3 controller to a flash drive (hard disk) for import into Trimble Business Center (TBC).

3. Convert ".T02" file.

    a. Install the "RINEX" utility from the Trimble "Support Products A-Z" Web page (https://www.trimble.com/Support/Support_AZ.aspx).

    b. Open the ".T02" file in the "Convert to RINEX" software (Ctrl + O).

    c. Make note of the antenna offset in meters (this antenna reference point [ARP] measurement is what will be used when submitting to OPUS).

    d. Convert the ".T02" file to RINEX (File→ Convert Files).

Note: The utility will store three output files (.XXo, .XXn, and .XXg) in the same directory as the ".T02" file:

- .XXo = observation (this is the file the user submits to OPUS)
- .XXn = navigation
- .XXg = Glonass

4. Submit to OPUS (https://www.ngs.noaa.gov/OPUS/).

    a. Attach data file; use the ".XXo" file from the RINEX converter utility where XX are the last two digits of calendar year (e.g., 19o if collected in 2019).

    b. Choose antenna type, e.g., TRMR8_GNSS.

    c. Enter ARP in meters, e.g., 1.783 meters.

d. Select “Options.”

- Change standard format to standard + XML.

- Dictate which Continuously Operating Reference Station (CORS) to use. Can pull up map of CORS stations by clicking on “—find site IDs” to see if there are better geometric solutions. Ideally, the base station should be in center of three CORS stations. If all CORS stations are in one direction, this is not a good solution as the base station will be outside of center.

e. Upload to “Static” if more than 2 hours of data are available. Upload to “Rapid-Static” if less than 2 hours of data are available, or if needing a quick solution while in the field (best static solution occurs after at least 2½ weeks from collection date).

Note: OPUS will send the user a “.xml” file via email, which can be dragged directly into TBC, with the high-quality OPUS Solution Report that contains (from OPUS Web site):

- Orbit Used = precise or rapid
- Over 90% observations used
- Over 50% ambiguities fixed
- Correct antenna and antenna height
- Static: overall RMS < 3 cm, peak to peak errors < 5 cm
- Rapid Static: no warning messages
- Quality indicators that are suspiciously low
- Normalized RMS that is suspiciously high
- Coordinate standard deviations that are suspiciously high

The user should check the OPUS solution against the “HERE” X,Y,Z values:

- Document X,Y,Z while in field, or pull from controller
- Convert OPUS solution from meters to survey datum, such as U.S. Survey Feet, using Corpscon and appropriate datum (e.g., Washington State Plane North)

Global Versus Local Coordinates

In TBC, global latitude/longitude heights are in terms of a “global coordinate datum” which, in most modern cases, is synonymous with the WGS84 datum. A global coordinate datum is an approximation of the shape of the entire globe.

Local latitude/longitude heights are in terms of a “local coordinate datum,” which is a datum that is a regional best fit, rather than a global best fit.

When users import NGS datasheets or OPUS solutions to use in a site calibration, they can easily convert the Global Navigation Satellite System (GNSS) local coordinates used in those solutions to global coordinates, which are required when performing the site calibration. To do so, expand the base point node in "Project Explorer," right-click the local coordinate, and select "Change Local to Global." Another solution is to disable the grid/local coordinates or terrestrial stations for these base points.

Import Corrected Base Point Into Trimble Business Center

1. Set up a new file with a name different than field project to note post-processing.

    a. Start new project in U.S. Survey Feet (or unit of project).

    b. Import ".job" file (controller file) and choose coordinate system of imported file.

2. Import the ".xml" file from OPUS.

    a. Select File→ import, then navigate to path where file is stored and double-click.

3. Adjust quality.

    a. Zoom into control points.

    b. Select View→ Project Explorer→ Points→ Select field base point.

        - Select "Properties" (right-click), then change elevation *and* latitude/longitude from control (triangle) to "unknown quality."

    c. Select View→ Project Explorer→ Points→ Select OPUS point.

        - Select "Properties" (right-click), then change OPUS elevation *and* latitude/longitude to control quality (will show as local).

    d. Click red ball at bottom to recompute.

    e. Repeat for ".job" files for global and grid coordinates.

4. See how far OPUS solution and original HERE point differ.

    a. Select Survey (tab)→ Measure Distance (drop-down menu)→ Inverse.

    b. Use mouse to measure distance (it will show elevation and distance difference between the two points).

5. Check for red flags and investigate any major issues.

6. Merge base points.

    a. Zoom into two base points (field and OPUS solutions).

    b. Select Edit→ Merge Points.

    c. Select OPUS point first, then use control (Ctrl) key and select field base point (HERE point).

    d. Expand “Selected Points” box and check first and second box to include both OPUS and field base points; verify OPUS point is checked as final.

    e. Click “Apply” at bottom of right panel screen (points should be merged now and user should only see OPUS point label).

    f. Reselect new merged control point (OPUS) and right-click to select “properties” and change point ID to new name, similar to “CP-OPUSdate.”

    g. Go to Project Explorer→ Points, and then click on new merged control point.

        - Change height and horizontal (latitude/longitude) to control quality in local coordinates (user’s .XML OPUS point).

    h. Click red ball to recompute (watch that no red flag shows up; if it does, something is wrong).

        - Local and global coordinates should be the same.
        - Should match OPUS solution latitude/longitude and height in meters.
        - Turn “.job” back on and verify vectors are now originating from OPUS point.

Troubleshooting Common Issues

- Rover data link settings
    - Change rover radio frequency
    - Change data string
    - Change baud rate

- R10 data cable input/output (i/o) port
  - Verify the data cable going into the R10 receiver is in the i/o port (see black arrow) and *not* the USB port
- Rubber ducky antenna
  - Verify the antenna is connected to the rover receiver to help with radio connection
- Antenna mast connection
  - Verify there is a good connection at the base of the antenna mast (sometimes the metal tab gets pushed up into the mast base resulting in a bad connection)

Survey Styles Nomenclature

- R8B – R8 receiver as base
- R10B – R10 receiver as base
- R8R – R8 receiver as rover
- R10R – R10 receiver as rover

Radio Setup Notes

Important information to know before getting started:

- GPS radios communicate using two different baud rates:
  - The data exchange/serial baud rate is the rate at which data are exchanged between the radio and the receiver. For SRH's GPS radios (HPB or TDL), this is always "38400." **THE USER SHOULD NEVER NEED TO CHANGE THIS!**
  - The radio link/over-the-air baud rate is the rate at which the GPS base radio communicates with the GPS rover receiver. This rate can be different for the TDL radios than for the HPB radios.
- SRH's HPB450 radios only operate at 4800 over-the-air baud rate. *This cannot be changed on SRH's HPB radios.*
  - The 4800 over-the-air baud rate consumes an excessive amount of power. A full-size 12-volt battery (car-size or larger) is required to operate a base radio at 4800 over-the-air baud rate for more than 4 hours, approximately.

- An over-the-air baud rate of 4800 can only be repeated once. This means the user can only set up one base radio and one repeater radio when operating at 4800 over-the-air baud rate.

- TDL radios have a variable over-the-air baud rate that can be changed directly on the face plate of the radio.

    - The over-the-air baud rate of the TDL450 radios must be changed *before* starting a survey. If a survey has already been started, it must be ended before changing the over-the-air baud rate.

    - In order for a TDL radio to communicate with one of SRH's HPB radios, the over-the-air baud rate of the TDL radio will have to be changed to 4800.

    - When operating at 9600 over-the-air baud rate, the TDL radios (base or repeater) should be able to run for a full day on a smaller 12-volt battery (motorcycle or lawn mower size).

    - An over-the-air baud rate of 9600 can be repeated twice. To increase range, the user can set up a base operating at 9600 baud and two repeaters (also at 9600 baud).

Table 1.—List of Channel IDs and Corresponding Frequencies Programmed Into GPS Radios

Channel	Frequency (MHz)
0 and 1	410.6
2	411.975
3	414.875
4	415.075
5	417.575

Step 1: Select base radio type.

TSC3: Select Trimble Access→ Settings→ Survey Styles→ select style to edit→ Base data link

- Set up per table 2; accept and exit

Table 2.—TSC3 Controller Settings for TDL450 and HPB450 Radios

Setting	TDL450 as Base Radio	HPB450 as Base Radio
Type	Radio	Radio
Radio	Trimble TDL450	Trimble HPB450
Controller and Receiver Ports	COM1 and Port 1	COM1 and Port 1
Baud Rate and Parity	38,400 and none	38,400 and none

Step 2: Set up new project and "start" base receiver.

Step 3: Set up TDL450 base and/or repeater radio (radio screen).

- Right and left arrows scroll through menu items; up and down arrows scroll through setting options for a given menu item

- Use center button to select and accept a new setting

Table 3.—TDL450 Radio Faceplate Settings

Setting	Set Base TDL450 With Repeater TDL450	Set Base TDL450 With Repeater HPB450	Set Repeater TDL450 With Base TDL450	Set Repeater TDL450 With Base HPB450
Channel Frequency	410.6, etc.	410.6, etc.	Match to base	Match to base
Data Protocol	Trimark3	Trimtalk450s	Trimark3	Trimtalk450s
Radio Link Rate (Over air baud rate)	9600	4800	9600	4800
Serial Baud Rate	38,400	38,400	38,400	38,400
Operation Mode	Base/Rover	Base/Rover	Repeater 1	Repeater 1
Transmit Power	2W (1 to 2 miles) up to 16W (5 miles)	Hand select low or high switch		

Note: For HPB450, change setting between base/repeater mode by connecting to the base radio using a controller (Configuration→ Survey Style→ Base Radio→ Connect) and go through an R8 receiver (cannot change radio link rate or data protocol of HPB450).

Step 4: Set up rover radio to match base.

TSC3: Select Trimble Access→ General Survey→ Instrument→ GNSS functions→ Select Rover Mode→ Select Data link

- Select Rover data link/Type: Radio/Radio: Receiver internal

- Click "Connect" hot key
  - Radio operating mode: Rover
  - Frequency: Match to selection at base (table 1)

- Select Base Radio Mode
  - Older HPB450 radio at base or repeater: Trimtalkv1 at 4800 bits per second
  - Newer TDL450 radio as base and repeater: Trimtalkv1 at 9600 bits per second

- Click "Accept"

Changing HPB450 Radio to Repeater or Vice Versa

1. Connect radio to battery and laptop using grey serial port cable.
2. Connect yellow cord to battery to disperse power.
3. Open PDL configurator on laptop.
4. Click “load,” then turn radio off and on.
5. Go to “Serial Interface” tab.
    - Check on repeater box (or off if changing from a repeater to an emitter).
6. Go to “Radio Link” tab.
    - Change digisquelch to “high” for repeater mode (or to “low” for non-repeater mode).
7. Go to “Program” tab.
    - Click “YES” (applies settings).

Real-Time Network Surveying

By Jennifer Bountry, M.E., P.E.

Introduction

Real-Time Network (RTN) surveying is becoming an efficient and common method of surveying that eliminates the need for establishing base control. RTN surveying is similar in concept to Real-Time Kinematic (RTK) surveying in that corrections are sent from a base station to improve rover positional accuracy in real-time (figure 1). The primary difference is that unlike RTK surveying, where the reference station is physically located at a permanent or semi-permanent location, RTN surveying computes a "virtual" reference station (VRS) about 1 meter (m) from the rover.

RTN is capable of operating over inter-receiver distances up to many miles with performance equivalent to a current single-base RTK system operating over much shorter baselines. With RTN surveying, a permanent network of reference stations (Virtual Reference Network or VRN) is established with typical spacing between stations of 10 to 50 miles (https://water.usgs.gov/osw/gps/real-time_network.html). The reference station network continuously streams data (using LAN, Internet, or radio links) to a central location (server) established for each network. The server stores the transmitted RINEX data, performs quality assurance checks on the data, accomplishes network modeling and estimation of systematic errors, calculates and converts correction data to a user format of either Radio Technical Commission for Maritime Services (RTCM) or Compact Measurement Record (CMR+), and communicates the data to the users.

When performing a survey, the dataflow is as follows:

1. User's rover connects to the VRN using LAN, Internet, radio links, or a cellular modem.

2. Rover sends a NMEA[1] string (GGA[2]) to the RTN server.

3. Server uses NMEA data to establish a VRS position ±1 m from the user's rover position.

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[1] NMEA is an acronym for "National Marine Electronics Association" and, in RTN/RTK Global Positioning System (GPS), it indicates a standard data format supported by all GPS manufacturers.

[2] NMEA GGA sentence example contains information about 3D location and accuracy data.

4. Using input from the closest surrounding reference stations, the RTN server computes and sends corrections back to the rover as if a real base station were broadcasting from the location of the VRS.

5. Rover receives and applies the corrections in real-time and functions like a normal RTK survey, but essentially receives data as if coming from the VRS, thereby eliminating PPM error that normally occurs.

The accuracy of RTN surveying depends on many factors, including the reference station distances, equipment and its settings, survey procedures, and the survey environment. Accuracy typically is in the range of and, in some cases, can exceed that of traditional RTK surveying.

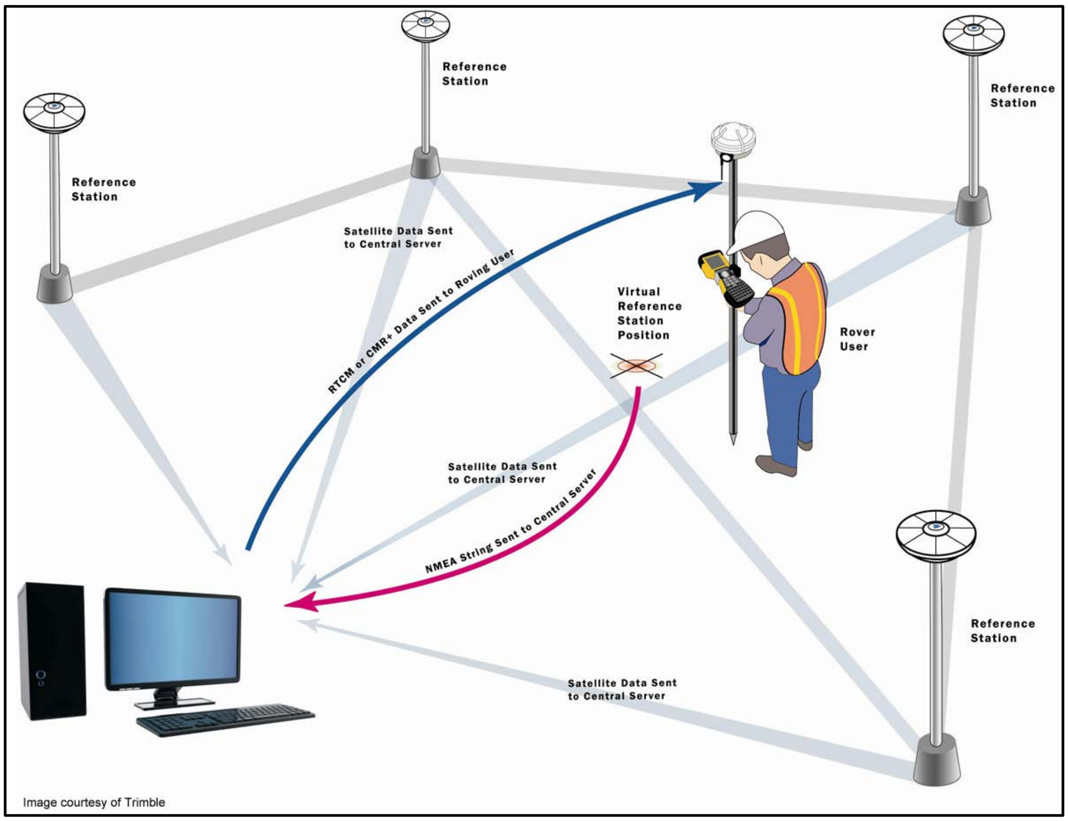


Figure 1.—Configuration of a VRN (image courtesy of Trimble).

Benefits and Limitations of RTN Surveying

The U.S. Geological Survey (USGS) lists the following benefits of RTN surveying over traditional RTK surveying (https://water.usgs.gov/osw/gps/real-time_network.html):

1. "The need for a user to establish a permanent/semi-permanent base station is eliminated. This eliminates the time for initial site selection and (daily) setup, any issues of security and power supply, and the possibility of setup errors."

2. "The RTN can monitor its own integrity and can detect if there is a problem with a particular reference station. With a single-base RTK setup it can be difficult to tell if a problem exists or occurs with a base station while conducting a survey."

3. "Since the reference stations are part of a network, a loss of one station does not result in failure of the entire network or the resulting survey. Whereas the loss of a reference station with single-base RTK setup results in the end of data collection, with RTN surveying the system accuracy degrades gradually."

4. "A sufficiently dense reference station network can result in shorter baselines. As with any other style of GPS surveying, shorter baselines result in improved accuracy because of reduced effects of atmospheric interference."

5. "The RTN reference stations allow for network atmospheric modeling resulting in improved accuracy. With RTK, atmospheric effects are computed using (usually) one location."

6. Common reference coordinate frame.

Limitations of RTN surveying include the following items as noted by USGS (https://water.usgs.gov/osw/gps/real-time_network.html):

1. High cost to establish, maintain, and manage an RTN.

2. Use and accuracy of an RTN can be limited by cellular phone coverage, network extent, and network density.

Connection Options From Rover to RTN

A cellular connection is required to accomplish an RTN survey. Many survey equipment setups are now sold with an internal modem included. The Trimble TSC2 and TSC3 devices can be installed with SIM cards. However, they are only compatible with AT&T at this time. Thus, the user should investigate cellular phone coverage at the worksite to determine which carrier has coverage.

Note: AT&T uses General Packet Radio Service (GPRS) bandwidth and Verizon uses Code-Division Multiple Access (CDMA).

Alternatives to an internal SIM card include:

1. MiFi device (e.g., Verizon jetpack)
2. Wi-Fi from a work vehicle
3. Cellular phone that is Bluetooth compatible
4. Commercial RTK bridge or repeater
5. RTK bridge system created with a laptop that has Internet access

Planning for Virtual Reference Network Surveying

The following steps can be followed to plan for VRN survey:

1. Ensure RTK methods are applicable to site.

2. Select VRN.

    a. Check VRN coverage for survey area.

    - Will the survey be inside or within 5 miles of boundary?

    - If only part of the survey area is covered by VRN, can it be used to establish the base control network?

    b. Verify quality assurance and control of VRN.

    - Who runs it?

    - How long has it been up and running?

    - How often is VRN updated?

    - What kind of technical support is provided?

    - How does VRN communicate outages and check if any are planned during field work?

    c. Sign up for an account.

    - Sometimes VRN will give discounts or free accounts to government/research efforts.

    - Note user name, password, IP address, and port.

    - Test account is active by logging into Web site.

   d. Document contact for VRN to take in the field.

   e. Look for support information on the VRN Web site that may help with setup in the field.

   f. Determine broadcast format; RTCM3 normally works well.

3. Check for cellular phone coverage relative to the provider option setup in the equipment.

   a. Be careful with carrier Web posting maps and talk to locals.

   b. Data transfer needs are less than voice transfer, but still need decent signal.

4. Select cellular connection device.

   a. Choose reliability over speed; data stream is small so speed is not as important as reliability.

   b. Consider spare batteries for cellular device as VRN is draining.

   c. Bring waterproof case if using an external modem.

5. Survey schedule.

   a. Talk with local operator of network about the application and ensure system will be running during the survey; check that no planned maintenance (downtime) of base stations is scheduled.

   b. Ensure that the base stations that encompass the survey area will be running.

   c. Plan for times of day with best satellite coverage, particularly if establishing a base station (https://www.gnssplanning.com/#/settings).

   d. Check the space weather forecast and use caution when working during increased ionospheric activity.

6. Determine what projection the selected RTN broadcasts in and if there is a need to post-process to a different projection.

7. Determine if RTN will be used for base control only, or the entire survey.

   a. Limited cellular coverage may warrant using VRN only for base setup.

8. Check into which base stations (single vs. network) will be selected when establishing connection.

    a. Some VRNs have multiple networks to represent specific geographic regions; for example, Washington State has five “VRNs” to choose from.

9. Document nearby published benchmarks that can be used as checks in the field.

    a. May need to convert coordinates to those used by RTN.

In the Field

The basic scenario for RTN surveying is a follows:

1. Due to difficulty in testing prior to survey, have some contingency time at beginning of survey trip to get connections set up and tested.

2. Consider a field reconnaissance along boundaries and within survey extent to test cellular coverage. This can be done during reconnaissance for establishing base control and access points.

3. Set up cellular connection and VRN survey style.

4. Verify quality assurance and control.

    a. Stay within the RTN.

    b. If a base station is set up, collect at least 2 hours of data to allow comparison to OPUS.

    c. Check accuracy of field survey results against known control points (benchmarks) that surround the work area(s) utilizing similar reference frames.

    d. Perform in-field calibration of survey job if necessary, and take redundant, independent readings of a selected number of survey points.

    e. Perform normal quality assurance and control steps such as checking multipath and distance from base.

    f. Recheck same point at beginning and end of day.

    g. For important survey points, conduct two separate time-windowed observations of at least 1 minute with unique initializations.

5. Whenever the user moves a set distance (3 to 5 miles) within a set of reference stations, or moves into a new area surrounded by a different set of reference stations, a new VRS and corrections are computed. This ensures that small baseline distances are maintained. The user will notice in the output files that a new VRN base is listed. Typically, only the closest base station is listed in the output file from the controller, even when surveying in a network.

Post-Processing

1. Download job file like normal RTK survey and pull into Trimble Business Center software.

2. If a base station is set up, download the ".T02" file and also pull it into Trimble Business Center software.

3. Check solution at base station against OPUS solution (may need to convert OPUS solution to same projection and datum as VRN). Expect a small amount of discrepancy from published benchmarks or OPUS; are you within published tolerance/accuracy?

4. Review RTN Web site for any noted issues or downtimes during the survey.

5. Download RINEX files from VRS Web site and import and compare against topo solution for base point or a series of ground shots, control points, etc.

Example Applications

Elwha River, Washington

Reclamation has utilized the Washington State VRN (WSRN) to survey the Elwha River since 2012, and has an established research account that is free. Reclamation staff used the VRN with a Verizon network to establish base points for RTK surveys, including topo points and bathymetric surveys in continuous topo mode without a base control setup. Reclamation was able to Bluetooth from TSC2 and TSC3 controllers simultaneously to a depth sounder and the cellular device and R8 receiver.

Contact: Jennifer Bountry, 303-445-3614, jbountry@usbr.gov.

Siletz River, Oregon

Reclamation accomplished a survey of the Siletz River using the Oregon VRN to establish base control. Reclamation staff used TSC2 controllers linked with R8 receivers and a Verizon cellular connection, and collected in the native broadcast projection of NAD83(2011) Epoch 2010. When Reclamation used the Oregon RTN in 2013, it only broadcast GPS without GLONASS capability, although this may have been updated.

Contact: Jennifer Bountry, 303-445-3614, jbountry@usbr.gov.

Helpful Web Links

For a general explanation of RTN, see the U.S. Geological Survey's "Real-Time Network (RTN) Surveying" Web site at: https://water.usgs.gov/osw/gps/real-time_network.html.

For a general explanation of the Global Navigation Satellite System (GNSS), see the U.S. Geological Survey's "USGS Global Positioning Application and Practice" Web site at: https://water.usgs.gov/osw/gps/.

Robotic Total Station Surveying

By Caroline Ubing, M.S., P.E.

Introduction

Total station surveying is a technique that measures angles and distances from a known central point to compute horizontal coordinates and elevations. All measurements are made from the total station (or base station), which is an electronic/optical instrument that measures slope distances from the instrument to a particular point.

Data can be collected using a base and rover setup or by collecting point clouds, depending on the capabilities of the instrument. Surveying can be conducted in a similar manner to Real-Time Kinematic (RTK) Global Positioning System (GPS) surveying, where one base station is established and a rover (prism) is used to measure points. Robotic total stations allow the operator to control the base instrument from a distance. Many models will automatically track the rover prism, potentially eliminating the need for additional staff to help operate the total station. Newer total stations may also have scanning capabilities, which allows a single user to collect point clouds of a designated area. The scanning function is best applied to unvegetated surfaces (ground, concrete, gravel bars, etc.) and does not work well in areas with vegetation or inundated by water.

Unlike RTK GPS surveying, total station surveying does not rely on satellite coverage to operate. Therefore, this surveying technique can be very useful at locations where satellite coverage is limited (e.g., narrow canyon). The optical nature of the instrument requires:

- A direct line of sight and radio connection between the total station and prism.
- A recommended distance of approximately 1,000 feet (ft) between the total station and prism (may go further in ideal conditions). Multiple base station setups may be required to survey a large site.
- The need to re-level and adjust the temperature of the total station throughout the day. Survey accuracy is highly dependent on these two factors.

Equipment

As of September 2019, the Sedimentation and River Hydraulics Group (SRH) in Reclamation’s Technical Service Center does not have any equipment for robotic total station surveying. All equipment can be rented from Vectors, Inc. (Phil Woodcock, 303-283-0343, PhilW@VectorsInc.com). Recommended equipment for this type of surveying includes:

- Trimble S7 or S5 total station (only the S7 has scanning capabilities)
- Multiple TSC3 controllers with robotic total station antennae mounts (while SRH does own TSC3 controllers, they do not have the appropriate antennae mount and cannot be used during robotic total station surveying)
- Multiple robotic prisms plus adjustable survey rods (VX/S series multitrack, equal to the number of surveyors)
- One or two backsight prisms
- All necessary batteries:
    - Total station batteries last 2 to 6 hours
    - Robotic prism batteries last 4 to 5 hours (same as R8 batteries)
- Air thermometer
- Hand-held radios
- Rebar/wooden stake and flagging for base location(s)
- Field book

Total Station Setup Procedure

The following steps detail how to set up the total station. Note that the greatest error during total station surveying is from human error. For an instructive step-by-step demonstration, see the “Station Setup for Total Stations in Trimble Access” video at: https://www.youtube.com/watch?v=6KRKD8fFdLY.

1. Establish known control point (rebar, stake, NGS point, etc.).

    a. This coordinate should be a known point, or the user will need to survey it with a GPS rover. If that is not possible, the final survey will be in local coordinates, relative to the total station.

    b. All points of the total station survey will be tied to this point. The data can then be shifted during the post-processing to an OPUS solution obtained for the base.

    c. Record control point number and coordinates (if known).

2. Set up total station (figure 1).

Figure 1.—Total station final setup.

a. Set up and level the tripod using a wide stance to increase stability. The Trimble S7 and S5 units are heavy. Dual clamp tripods are recommended.

b. Insert battery into total station.

c. Mount total station on tripod for further leveling.

d. Pull out lower site knob and gently turn to coarsely focus total station over control point. Push in site knob.

e. Continue leveling. Turn the backface of the total station (with the Trimble plate; figure 2) and center over two of the tripod legs. Adjust the bubble laterally, moving two leveling screws. Then, adjust the last screw to move the bubble up and down.

Figure 2.—Backface of Trimble S7 total station should be centered over two tripod legs for efficient leveling.

f. Turn on total station. Record the Radio Channel and Network ID in field book. This information is key to communicating with the TSC3.

3. Set up the TSC3.

a. Start new job.

- Name the job. SRH typically includes the location, date, and controller number in the name (e.g., SMR_20190519.C8).

- Select coordinate system under properties. If coordinate system is unknown (local), select the "Scale factor only" radio button. Set scale factor to "1."

- Select coordinate geometry settings ("Cogo Settings") under the "Distances:" drop-down menu, then select "Ground." Leave all other settings as default unless instructed to do otherwise.

b. Connect to radio.

- Go to Settings, press "Connect," and select "Radio Settings."
- Select the "VX/S Series" from the "Model:" drop-down menu.
- Match the Radio Channel and Network ID to total station output.

c. Set up station and fine leveling.

- Go to General Survey, select "Measure," and then press the "VX/S Series" button. Select "Station setup" to connect to total station.

- Use *very* small adjustments to the three level screws on the tribrach to achieve a sighting of "0." Remember survey accuracy is *highly* dependent on level instrument.

- Measure temperature (watch units) and enter. Make sure pressure set "from instrument." Do not change pressure; it will automatically populate based on temperature. Record the time and temperature in field book. Update temperature measurement during day and reset total station if more than 10 degrees increase or decrease.

- Press "Accept."

d. Enter base coordinates (right-click arrow and select point from list if already entered, or key in new GPS point).

e. Measure antennae height of base station from control point to bottom of black notch (figure 3). Enter antennae height in the TSC3 and record in field book. Set to "bottom notch" on the TSC3.

Figures 3 and 4.—Bottom of black notch used to measure antennae height (left) and backsight prism black line used to measure prism height (right).

4. Set up backsight.

   a. Set up backsight over a rebar/stake. Backsight locations should be placed at a distance equal to, or longer than, the longest foresight shot (prism/rover shot). If possible, survey the location of the backsight as a means to check the survey in the office. Record point number in field book.

   b. Measure backsight prism height from control point to center of prism black line (figure 4), or at 6-ft mark setting if using rover rod. Record in field book.

   c. Click the prism icon in the right side bar of the TSC3 screen (below total station icon). Select the correct prism type used for the backsight.

   d. Enter the backsight information into the TSC3. An Azimuth angle of “0” is sufficient without known information. This can be corrected during post-processing. Under “Method:” select “Angles and distance” from the drop-down menu. If the backsight and control point from RTK GPS is known, the TSC3 will compute the Azimuth angle automatically.

5. Set up prism/robot (rover).

   a. Insert battery and turn on prism.

   b. Adjust dial (1 through 7) to match prism ID displayed on the prism icon in the right side bar of the TSC3 screen.

   c. Record rod height in field book (measured to the bottom of the mount; figure 5).

   d. Point the total station in the general direction of the prism (use the joystick buttons on the TSC3 to move the instrument).

   e. Select the instrument icon on the right side bar of the TSC3.

      Note: The user can press “Autolock” if they want the total station to automatically follow the prism.

   f. Select semi-active tracking mode.

   g. Select the instrument icon on the right side bar of the TSC3, then press the “Search” button. The total station should find the robot, stating “Target locked” in the lower banner.

Figure 5.—Robotic prism mounted on rod. End of pen is pointing to the “bottom of mount” where rod height is measured.

   h. Record the first measurement point number in field book.

Field Book Notes to Record for Each Base Setup

- Channel
- Network ID
- Temperature and Time
- Base station point number and location
- Base station height
- Backsight point number (do not reuse the same point number) and height
- Rod height and starting point number

Measurement Procedures

The three measurement procedures outlined in this section include: topo measurements using the prism, scanning to collect a point cloud, and panoramic photographs of the site. Keep in mind that direct line of sight is required for all measurements, and the total station will need to be re-leveled and temperature adjusted throughout the day.

1. Topo measurements (using the prism).

   a. Go to General Survey and select "Measure Topo."

   b. Under the Measure Topo menu, select a starting point number under "Point name:" and type in an appropriate code and "Method." Choose "Angles and distance" from the drop-down menu. Key in target height, which equals rod height (figure 5).

      Note: It is helpful to set it to a default fixed rod height of 6 ft when possible.

   c. If measuring a ground shot such as edge of building or rock near edge of water, the user can select "DR" at 0 ft height and 0 millimeter (e.g., reflection shot).

2. Scanning (to collect a point cloud).

   Note: This is only effective in bare earth scenarios. In areas with vegetation or tall grass, the laser will not return and data will be erroneous or non-existent.

   a. Go to General Survey and select "Measure" then "Scanning."

   b. Select "Scan method:" using the drop-down menu. The default recommendation is "HA VA interval."

   c. Use the drop-down menu under "Framing:" to select how to outline the scanning area. Click "Next" to frame the scanning area.

      - To scan a rectangle area, simply tap the upper left and lower right area to be scanned.

      - To scan a polygon area, press the polygon icon→ up arrow → select polygon.

d. Define scan parameters.

- Press arrow to right of distance to update.

- Select “Method grid interval spacing:” using the drop-down menu. Recommend “HD VD interval.” HD equals horizontal distance; VD equals vertical distance. Select an appropriate “Scanning mode:” using the drop-down menu.

e. Check scanning area of the photograph in the TSC3. Press “Start.”

f. After each scan, the prior grid points will be visible on the photograph with a different color for each scan. Adjust scanning grid pixel size if difficult to see, using options.

3. Panoramic photographs (of the site, which helps inform post-processing).

a. Go to General Survey and select “Measure” then “Panorama” (first button in second column).

b. Select an image overlay of 10 percent, which is an appropriate default in most cases.

c. Select rectangle in video.

d. Press “Start” (it will take photographs of the framed area).

At the end of each day, download all controller files from the rover receiver (including “.job” and “.tsf” files, plus any image folders).

Post-Processing Total Station and Scanning Data (Trimble S7 Total Station)

Vectors, Inc., recommends the following computing capabilities:

- Number-crunching quadro video card
- Zion processor
- 32 gigabyte (GB) RAM
- Solid-state hard drive

Post-processing total station surveying data will be done in Trimble Business Center (TBC) software. The user will need a separate key or 30-day code from Trimble to unlock the scanning/total station module. The code will not work with SRH’s hardware locks. The code will also access all of the tools needed to post-process GPS data. Vectors, Inc., includes the 30-day software code with the price of renting their equipment. Before post-processing the total station data, it is recommended to process RTK GPS survey data first.

To register the key/code, click "License Manager" under "Common tasks" on the "Welcome to Trimble Business Center!" start page (figure 6).

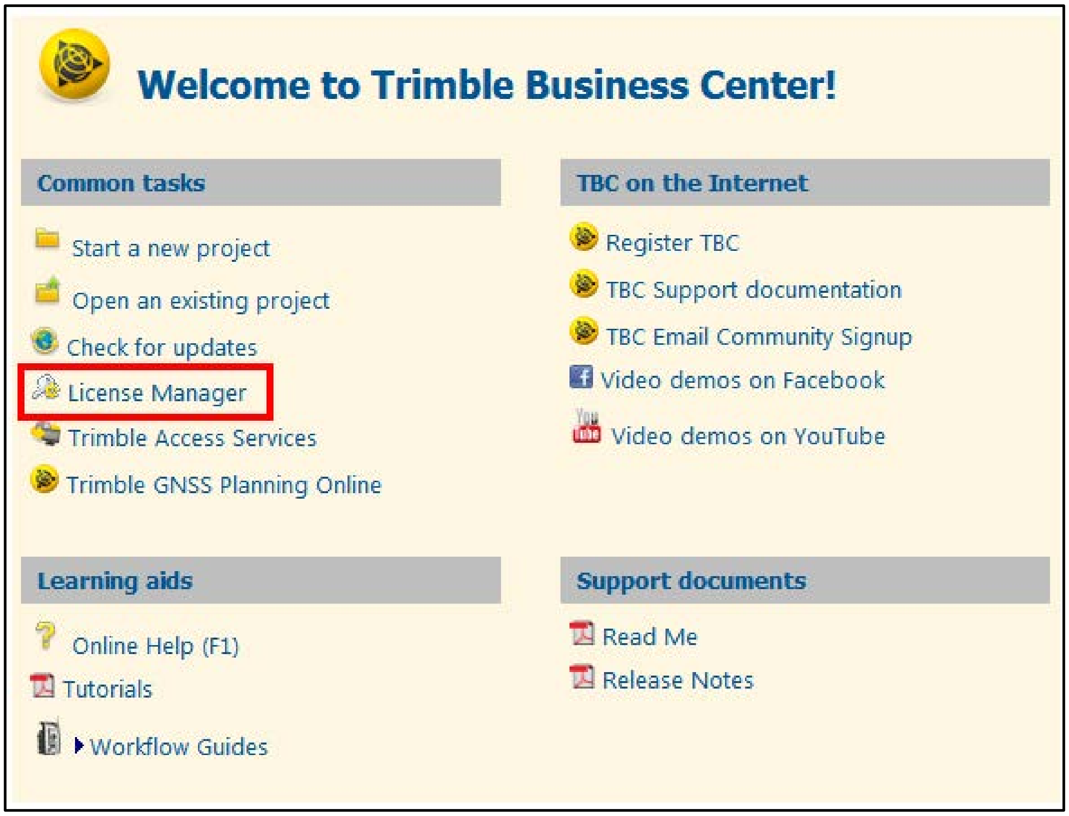


Figure 6.—Trimble Business Center start page.

Then, under “License,” click “Upgrade” and enter 19-digit code (figure 7).

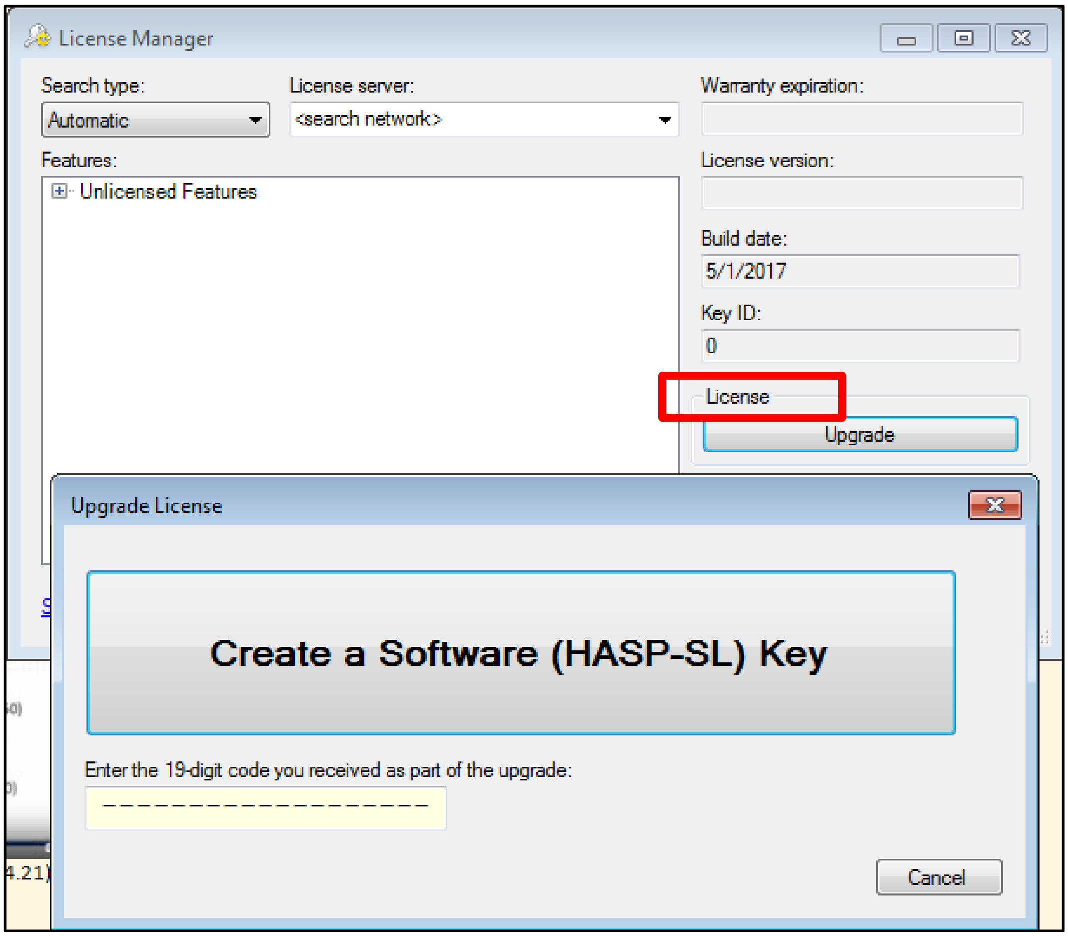


Figure 7.—License registration screen.

The following steps outline how to view, rectify, and export the total station data once the software is activated. These steps assume that the total station was set up over a known point.

1. Start and save a new project in TBC. Select the appropriate units and coordinate system. The coordinate system can be assigned using the “Coordinate System Manager” on the “Home” tab on the ribbon, within the Geodetic menu.

2. Import the “.job” file. The import button is located on the “Home” tab on the ribbon, within the “Import/Export” menu.

3. Identify base, occupation, and backsight points.

   a. If the control point was measured with an RTK GPS surveying rover, post-process the RTK GPS data first. Then, open the post-processed RTK GPS survey job file (.vce). Verify the coordinate system and point elevation by comparing grid distance to ellipsoid distance (they will be the same if using a State Plane Coordinate System [SPCS]). If the control point was known, verify its location within TBC. Select occupation and backsight points in survey project file. This set of points will be referred to as "control points."

   b. Export those points as a ".jxl" file (under the survey tab). Export the points with global coordinates (latitude, longitude, and height information). The ".jxl" file will upload the project information and accurate X,Y,Z values. The latitude, longitude, and height positions are the closest to the original data and will have the least amount of rounding.

   c. Start a new project file. Import the newly created ".jxl" file. Verify that the project coordinate system changed.

   d. Lock in the coordinates for the control points by exporting the points as a ".csv" file as northing and easting coordinates. (Click the "Export" button to open the export toolbar. Select the "Custom" tab, choose the appropriate format from the list, and save as ".csv".)

      Note: This seems redundant, but this is the best way to make it work. The northing and easting coordinates will set it as a higher priority, allowing the user to easily select the correct file in the next step.

   e. Import the control points ".csv" file into the existing project (can drag and drop file from Windows Explorer). Select the correct definition name with "(Control Quality)." This should change all of the control points from survey quality (circles) to control quality (triangles).

4. Import scan files.

   a. Verify the ".job" file is in the same folder as the scans.

   b. Import the ".job" file. A conflict will arise between the control points in the existing file and the control points in the newly imported ".job" file. Merge points and keep the existing points (select "keep existing definition"). Red flags will appear on the merged points.

5. Resolve conflict.

    a. Expand the “Imported Files” folder under “Project Explorer.” Continue to expand the “.job” file, station view, and “Single Backsight (#).” There the user will find the two merged points (figure 8).

    b. Delete both of the field-entered single backsight points. This is the crucial step to shift all of the scanned data to the OPUS Solution.

    c. Recompute and **SAVE!**

    d. View filter manager and uncheck the box next to “total station.”

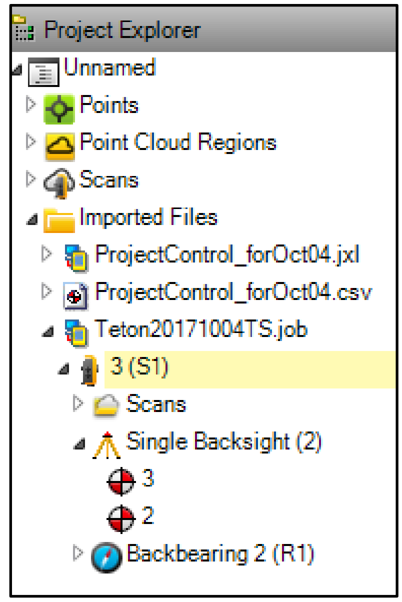


Figure 8.—Project Explorer window.

6. Three-dimensional (3D) view.

    a. **SAVE AGAIN!** This is the point where most projects crash.

    b. Select “3D View” under the “Home” tab (figure 9). This will open a new window within the project where the user can scroll, pan, and rotate data.

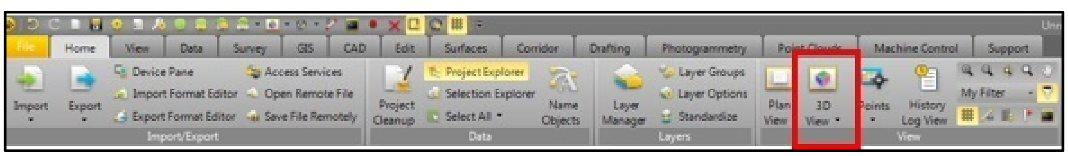
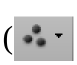


Figure 9.—Trimble Business Center ribbon highlighting the 3D View tool.

    c. Select “Rendering” under the “Points Clouds” tab. This will provide the user with options to view their data.

        - Scan color allows the user to change the color of the points based on intensity, scan, region, elevation, etc.

        - Point size can be increased or decreased ().

    d. Scan to “CAD.” This allows the user to switch the scan from a scan file with multiple points to multiple individual point files. This will be used in later instructions.

Data Export Options

There are three options to export the data into a useful format that can be used in either Geographic Information System (GIS) or CAD:

1. Select LAS (file type) format to export.

   a. Open the "View Filter Manager." Turn off raw data, photogrammetry, flags, and layers.

   b. Select "Export" and choose "Point Cloud" and "LAS exporter." Manually select all of the data in the "3D View" window, making sure to first turn off the items previously listed). Click "Export." (The number selected will reflect the number of scan files. The ellipsis after the file name will allow the user to select the export location. The default location is in the folder with the same name as the project ".vce" file.)

   Note: If the total station rover data are combined with the scanning data, it is recommended that the user keep them separate and export them as two different files.

2. Select points to export. (This option allows the user to select different hard points to export.)

   Note: Corners of structures, top of banks, etc., are recommended.

   a. Turn on points under View Filter Manager→ Raw Data to see the points as they are delineated.

   b. "Create Point" under the "CAD" tab. This setting snaps to the nearest node from the scan. In the newly opened toolbar, select point ID, layer, and feature code. It is recommended to create a new layer with the created points. It is also recommended to pick the first point ID number as one that will not overlap other project points.

   c. Click inside the "Northing" box to activate the curser. The default setting is to only create points over an existing scan point. To extrapolate a point based on the existing data, select the point cloud smart picking mode (). The "face of curb" is intended to extrapolate a point at a corner. "Gutter" is intended to extrapolate a flow path. (Note that these two tools are still in development.)

   d. Click in the "3D View" window to delineate the points.

   e. Export points as a ".csv" file when complete.

3. Create breaklines to export. (This option allows the user to create breaklines to then export into GIS/CAD.)

   a. Select "Linestring" under the "CAD" tab. Pick a name (optional) and layer. Again, it is recommended to create a new layer file. Click "OK."

   b. Select the segment type: straight, curved, etc.

   c. Select the first point. Keep selecting points until the breakline is completed. To go back and edit the breakline, scroll through the "Current segment" in the toolbar. This allows the user to delete or move previously delineated points (figure 10).

   d. Select "new" to create next linestring.

   e. Export as a ".dwg" or ".shp" file once the lines are completed.

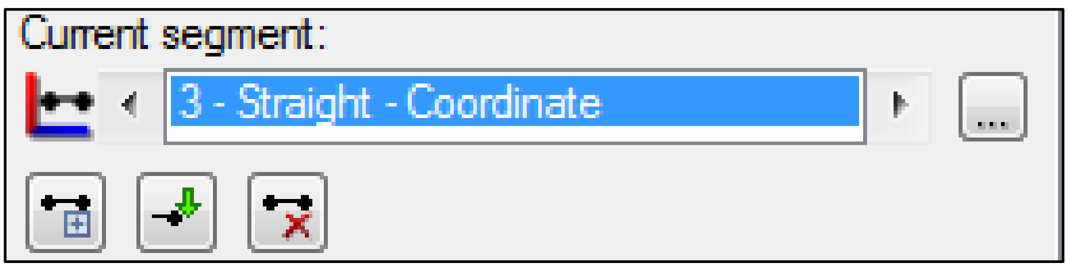


Figure 10.—Toolbar allowing the user to delete or move previously delineated points in each breakline.

If the point cloud is too dense, the user can coarsen the data by converting points to CAD. A small area, points of interest, or the entire dataset can be selected.

1. Select the scan points of interest.

2. Select "Scan to CAD" under the "Point Clouds" tab.

3. Choose between "spatial" or "random" sampling. Choose the layer. Close the "Scan to CAD" toolbar.

   Note: Vectors, Inc., recommends spatial sampling. If "spatial" is chosen, also select the "sampling distance."

4. Turn off the scan data and all other layers (uncheck "grid-only points," "survey quality," etc.). Select the new CAD points. Then, right-click and select "Convert CAD Points."

5. Check “Delete CAD points when done.” Continue and choose “Survey Quality” under the “Point quality” drop-down, then assign the “Feature code” and “Starting ID for survey point” (Point ID; figure 11).

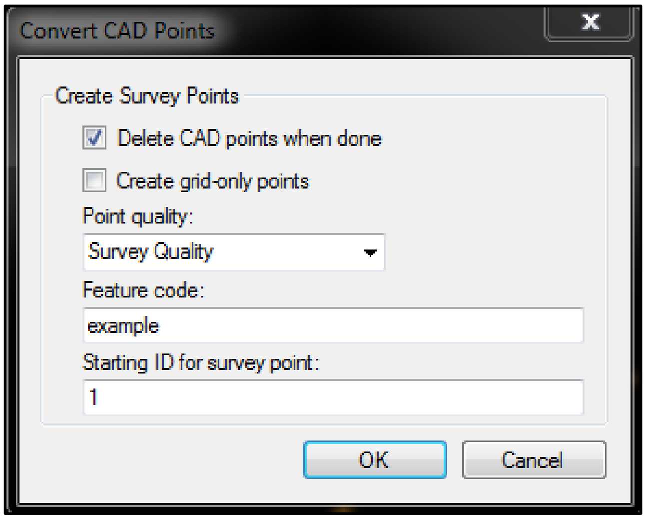


Figure 11.—Convert CAD Points tool window.

Other Useful Tips and Tricks

- If any panorama photographs were taken while in the field, they can be displayed under the “Station View” button in the “Graphic Views” toolbar within the “View” tab on the ribbon (figure 12). While it is presumed that further capabilities exist with the panoramic photographs, they are unknown at this time.

- Users can view their data in Google Earth while post-processing it (figure 12).

- If processing large point cloud files in AutoCAD, may need to separately install the “Recap” (.rcp) tool within AutoCAD.

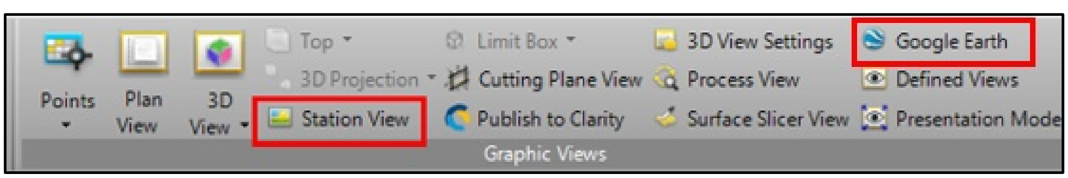


Figure 12.—Graphic Views toolbar within the “View” tab on the ribbon.

Single Beam Measurements With SonarMite

By Jennifer Bountry, M.S., P.E.

Introduction

The SonarMite MILSpec echosounder (SonarMite) is a single beam depth sounder designed to be ruggedized, portable, and economical (see the "Ohmex Instruments" Web site at: http://www.ohmex.com/sonarmite.html). The SonarMite was designed to have a large number of pings with as minimal processing of raw data to define the bottom in as fine of detail as possible. The sounder has a beam width of 4 degrees and a ping rate of 6 hertz that operates from 0.3 to 75 meters (m) (1 to 246 feet [ft]).

Equipment

The SonarMite equipment package owned by the Sedimentation and River Hydraulics Group (SRH) in Reclamation's Technical Service Center includes (figure 1):

- The SonarMite MILSpec echosounder with Bluetooth antenna (processor box SMIL120316)
- A 12-volt power supply with velcro pouch to mount on survey pole and charger (battery)
- A 200 kilohertz echosounder transducer with cable (depth sounder)
- A serial interface cable to connect to computer for changing settings or data transfer
- The HydroLite-TM (transom mount)
    - Aluminum shoe to mount on survey pole
    - Three 2-ft yellow survey poles with 5/8-inch antenna mount for Trimble receiver and one survey point (for topo shots)
    - Black transom mount to attach unit to boat
- A rugged shipping case

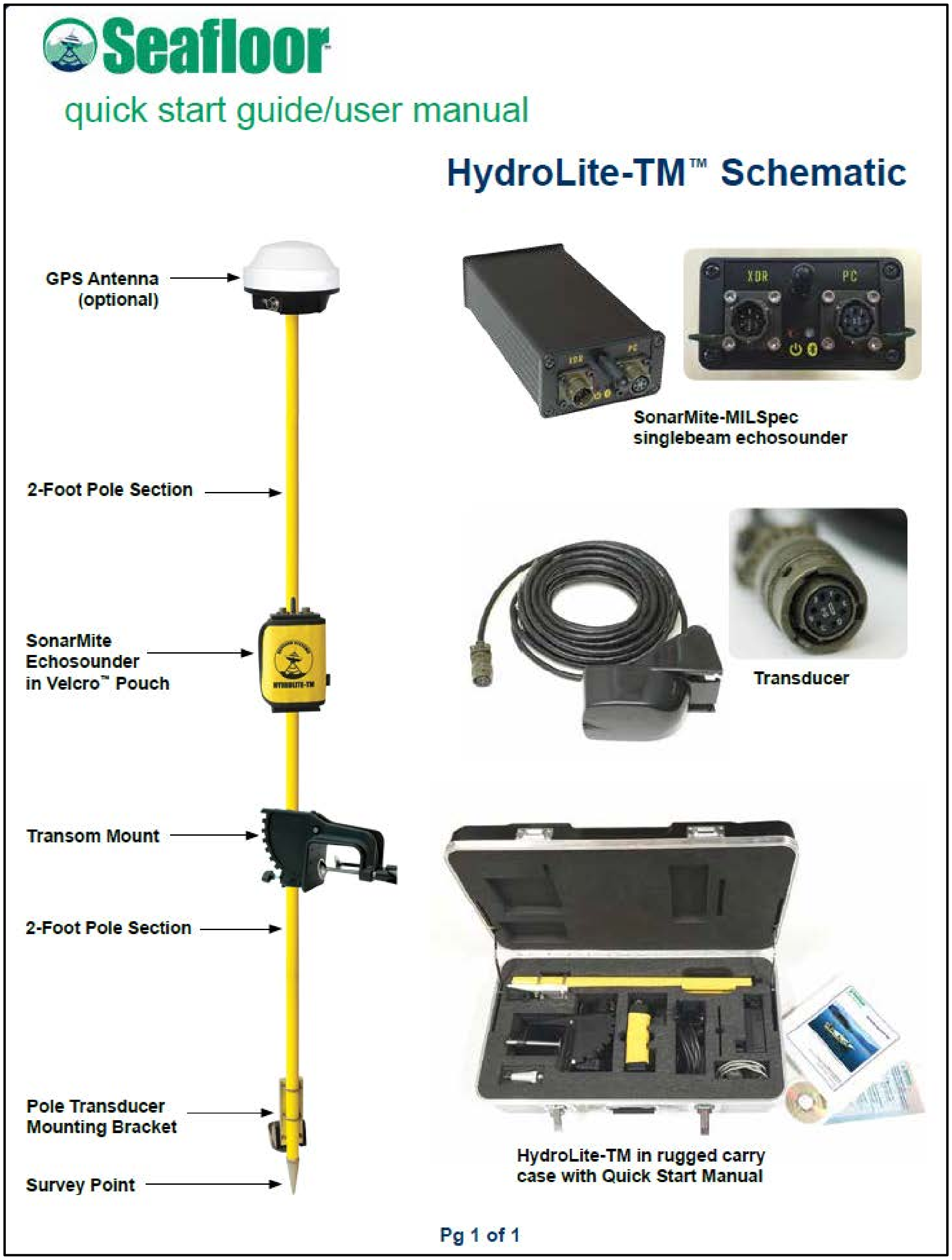


Figure 1.—SonarMite equipment package components (Seafloor Systems, Inc., 2017).

Technical Components

There are three standard configurations in which the SonarMite can be used for hydrographic surveying applications:

1. As a “Dumb” sounder connected via a serial cable/Bluetooth link to a computer running data logging and display software.

2. As a “Logging” sounder in which all depths are internally time-tagged and stored.

3. Using both modes where the serial output data are processed in real-time and the stored data are post-processed.

The connecting cable to the transducer carries only low direct current (DC) voltage and digital stream data. The device has two connectors—one that connects the device to a computer port and a second return pin with cable connection pin that connects the device to the battery and powers the depth sounder.

The accuracy of the current SonarMite is 1 centimeter or approximately 0.1 percent of the measured depth.

Planning

The basis on which all data correlation is achieved is internal time base, so particularly when using the SonarMite with Global Positioning System (GPS) data the clocks should be synchronized to GPS time (UTC). SonarMite WinCE software or SonarMite WinXP software can be used to set up the depth sounder. There is a new Android app that can also be used in the field to change SonarMite settings via Bluetooth to another Bluetooth-enabled device (cellular phone, tablet, etc.) (https://seafloorsystems.com/support/software-support).

Battery Charging

The SonarMite battery charge display on the power adapter (wall plug) is shown in figure 2.

1. Fully charge equipment prior to use in field by plugging in to wall charger.

2. Avoid using the SonarMite until the batteries are completely charged as there will be a high risk of both data loss and permanent damage to the batteries.

3. Charger will illuminate constant red when bulk charging and flashing yellow when charged.

4. Trouble Shooting: The SonarMite is protected from reverse connection or direct short circuit by an internal 1.0 amp thermal fuse. If the fuse is tripped, then the system will need to be disconnected for 1 minute for the fuse to cool down and reset itself.

5. Should last 12 hours in field.

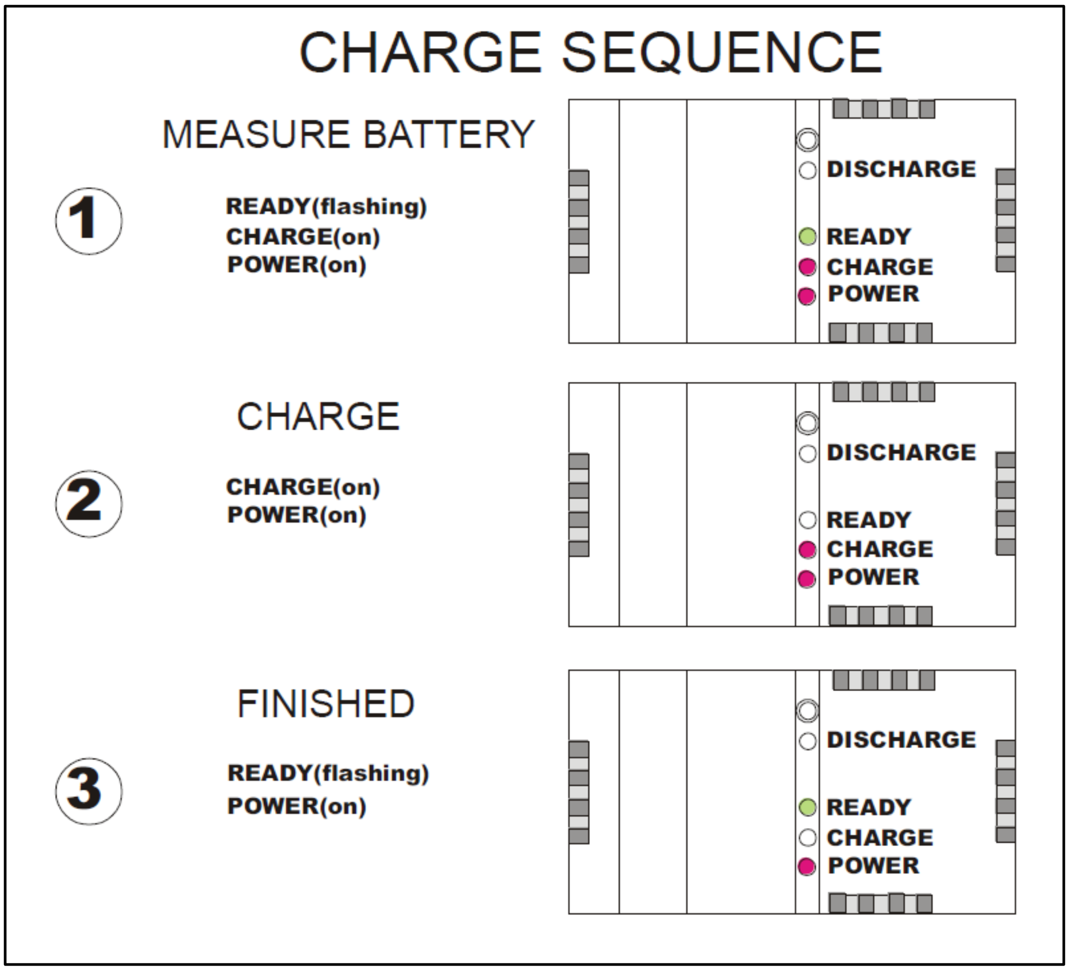


Figure 2.—SonarMite battery charge display information.

Speed of Sound

1. The depth sounder computes depth based on the time it takes a pulse of ultrasound in water to travel from the transducer face to the channel bottom and back. Pulse travel time return signal is affected by the "Speed of Sound" setting.

2. The default “Speed of Sound” is set at “1500 m/s (4921 ft/s),” but can be adjusted based on water density that is affected primarily by water temperature, salinity, and turbidity.

3. The user can measure the speed of sound through the water column by collecting velocity profiles using a dedicated velocity measuring device. The speed of sound through the water column can also be calibrated using the SonarMite at a static position in a known depth over a flat, firm base. SonarMite-measured depths can be compared to the known depth and speed of sound adjusted until the measured and known depths match.

4. To adjust the speed of sound:

   a. Connect SonarMite to computer and charger (if not charged)

   b. Press “^H” (Ctrl H) to display the following help information: “^Help,Format,Version,Id,Save,[Reset,Load,U/Dsos]”

   c. Press (^U)p

      - Increase the sound velocity setting for dense cold water (only available in the “SYS>” output mode)

      - This will change calibration values if saved

   d. Press (^D)own

      - Decrease the sound velocity setting for less dense fresh/warm water (only available in the “SYS>” output mode)

      - This will change calibration values if saved

Bluetooth Specifications

1. SonarMite uses BluWAVE PCB serial compatible with UART or RS232 interfaces.

2. Ranges up to 100 m (330 ft).

3. If the Bluetooth interface requires a password to pair devices, typically “1234” will work, or for older devices (if borrowed or rented), “0000” or “1111.”

4. Supports baud rates from 2400 to 115200 baud.

5. When connected to another device, the green/blue LED illuminates continuously.

In the Field

Equipment

- SonarMite transducer, processor box, and battery (figure 1)
- SonarMite mount
- Tools to set up mount and transducer
- Extra cam straps to secure to boat
- Tape measure to record transducer draft and GPS antenna height
- Probing rod with 0.15 m (0.5 ft) increments marked off (with permanent marker) to calibrate depth sounder
    - Can use wooden probing rod from items such as wheelbarrow handles or group leveling rods
    - Aim for about 1.8 m (6 ft) long, any shorter is not usable and any longer is too hard to manage in swift water
    - If rod has pointed end, account for that in markings
- GPS equipment (receiver, controller, radio antenna, and mounting pole)
- Writing utensil and field book

Mount

1. Set up transducer mount on boat.
    a. Normal shoe mount has angles up to 30 degrees with 12 millimeters of vertical adjustment.
    b. Reversible wedge allows transom mounting at angles ranging from 2 to 22 degrees.
    c. Transducer cable length is approximately 3 m (10 ft).
    d. Consider mounting near center of boat and adjust so beam angle is perpendicular to channel bed.
    e. Minimum draft in slow, quiet water is around 0.2 ft, but should be increased to typically 0.5 to 1 ft in deeper more turbulent river conditions.

2. Check transducer mount on boat.
    a. Avoid mounting near turbulence field generated from motor propellers or oars.
    b. Check that mount is secure and can raise quickly if transducer hits a rock.
    c. Consider strapping on counter weight if mounted on side of boat.
3. Use aluminum rings to mark desired draft location or permanent marker in case mounting poles slip during survey.
4. Use cam straps to secure equipment.

Power Depth Sounder

1. Connect the transducer to the TXR connector on the front panel.
2. The red LED alongside the connector will flash, indicating connection and battery charge status.

Connecting to Trimble Equipment

1. Mount GPS receiver directly above transducer on mounting pole if possible, otherwise record the X/Y offset.
2. Consider at least two yellow mounting poles or use an extended radio antenna to increase radio antenna range or improve sky/satellite visibility of GPS receiver.
3. Open survey style on rover controller.
    a. Select depth sounder at bottom of list.
    b. Select SonarMite from drop-down menu (each SonarMite is identified by a unique serial number on processor box).
    c. Accept/store to save updated survey style.
4. Establish Bluetooth connection to SonarMite.
    a. Verify “enable Bluetooth” and “discoverable” are selected on Trimble controller.
    b. Go to Trimble Access→ settings→ connect→ Bluetooth→ config→ add new or select unit if connected previously:

- Type: SonarMite
- Controller Port: Bluetooth
- Latency: 0
- Draft: Leave as "0" and post-process

5. Start survey.

    a. Use continuous topo setting, which needs to be used to record depths.

    b. Set data spacing typically by distance between points (e.g., X ft) depending on density of data needed.

    c. Set point name (number) and code (description) as desired.

Measurements Before Launching

1. Measure draft from water surface to bottom of transducer with all people and equipment in boat (figure 3).

2. Measure distance from bottom of transducer to bottom of Trimble receiver to use as antenna height.

3. Note offset of GPS pole (X and Y) if not mounted directly on top of transducer pole.

Quality Assurance Before Launching

Use measurement rod to take sample measurements in backwater location ideally at launch to validate initial readings before launching. Note the depth sounder has to be in the water to record depths and should be at least 0.3 m (1 ft) above channel bottom. Depth displayed on controller is distance from transducer face to river/reservoir bed (draft is incorporated during post-processing).

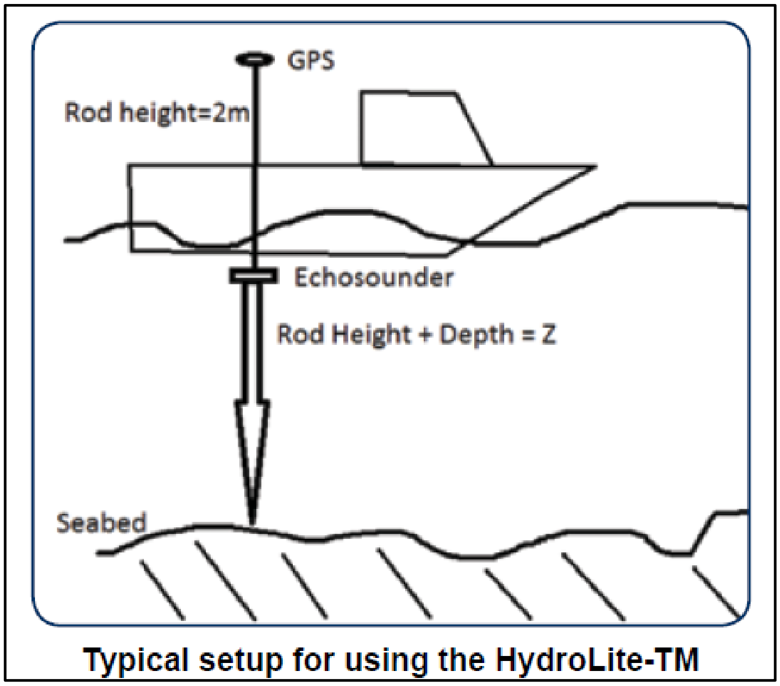


Figure 3.—Measurements required for HydroLite-TM setup.

Quality Assurance During Launching

1. If turbulence is generated around or in front of transducer when moving, lower transducer further down into water column.

2. Raise depth sounder up when at risk of hitting bottom, typically in depths less than 0.5 m (1.5 ft).

3. During survey, have one person periodically use probing rod to measure and record depths and another to document SonarMite depth and associated GPS point number that will be used in post-processing.

4. Note in field book using probing rod:

    a. Areas of shallow depths less than 0.5 m (1.5 ft); these areas often produce depth readings that are inaccurate and can be inaccurately recorded at 2 to 3 times the actual depth.

    b. Turbulence in deep scour holes where readings may be bad such as near bedrock, bottom of rapid, or base of infrastructure (dam or low-head weirs).

    c. Portage locations or where rowing along channel edge that may temporarily read shallow and deviate from actual deeper thalweg.

d. Depths and locations with shallow riffles; manually measure depths and record with Real-Time Kinematic (RTK) GPS point in locations with shallow riffles.

e. Periodic Trimble depths; visually monitor depth readings in Trimble controller and manually measure periodic depths and record to allow checking accuracy in post-processing.

Troubleshooting During Survey if Depth Sounder Stops Working

1. Check survey style. Was SonarMite option turned on and saved?
2. Ensure Bluetooth connection to SonarMite is active (blue light illuminated on processor box).
3. Verify continuous topo setting is in use.
4. Check power cord is plugged in and did not come loose.
5. Stop survey; try unplugging power to SonarMite, replugging back in, and starting new survey (sometimes it locks up and this often fixes issue).
6. Check depth sounder is still mounted securely and has not come loose causing it to make improper readings.

Removing Depth Sounder

At the end of the survey, place mount at 45 degree angle and press firmly to release depth sounder as shown in figure 4.

Figure 4.—Removal of transducer at completion of survey (Seafloor Systems, Inc., 2017).

Process Hydrolite Depth Sounder Data

1. Output depth data.

   a. Open Trimble Business Center.

   b. Start new job and save project in desired coordinates/units.

   c. Import ".job" file from Trimble controller that contains bathymetric data.

   d. Select file→ tools→ job report generator.

   e. Select ".job" file.

   f. Select stylesheet (comma delimited with depths.csv) with elevations and depths.

      - Can be downloaded from: https://www.trimble.com/globalTRLTAB.asp?nav=Collection-32914

   g. Identify output location.

   h. Select draft zero (in past, draft tool has not worked).

   i. Select apply (may give code error, but ignore and should work fine).

2. Update X,Y,Z values for cases with post-processing of coordinates.

   a. If any updates are made to X,Y,Z coordinates in Trimble Business Center, such as changing projection or post-processing with OPUS data, note that the Trimble export file with depths does *not* apply the updated information.

   b. To apply updated X,Y,Z coordinates, export the processed X,Y,Z coordinates.

   c. Align with same point numbers of exported depth data.

   d. Delete the original X,Y,Z points associated with depth data and use the updated values.

   e. Use formula in spreadsheet to verify point numbers are aligned correctly before deleting duplicate point numbers associated with depth data.

3. Review and edit depth data.

    a. Type in notes from field that correlate to GPS points to review depth readings indicating areas of potentially bad readings, or to validate shallow or deep locations.

    b. Plot points in Geographic Information System (GIS) and pan through aerial photograph to check for erroneous values.

    c. Plot points on longitudinal profile in GIS and export to spreadsheet to review.

        - Generate centerline along middle of channel
        - Create a route of centerline
        - Use “near” function to determine distance of raw survey points to routed line
        - Use “locate features along route” to compute station along centerline (be sure to type in search tolerance in tool)
        - Plot in spreadsheet

    d. Plot points in ArcScene and use three-dimensional view to look for outliers.

    e. In spreadsheet, look for points less or equal to 0.5 m (1.5 ft) and review for legitimacy.

    f. Interpolate or delete depth readings that are not valid.

    g. Add draft back to depth and compute total depth.

4. Review and edit water surface elevations.

    a. Compute approximate stationing between sequential points with distance formula.

    b. Highlight distances greater than X to denote there may be legitimate reasons for jump in water stage reading.

    c. Look for outliers by plotting in sequence in spreadsheet with approximate stationing between points.

    d. Use “IF/THEN” formula to check for deviations between sequential points of more than 0.3 m (1 ft) if in turbulent water, or perhaps more than 0.5 m (1.5 ft) if in calmer water.

e. Plot in GIS and manually pan to look for outliers.

f. Consider averaging every 3 to 10 water surface elevations (amount depends on distance between recorded points, slope of river, and profile tracks).

- Do *not* average across gaps with large distances between recorded points, such as where satellite coverage is poor and loses RTK fix

g. Interpolate or delete bad water surface elevation data.

5. Compute channel bottom elevations.

a. Average water surface elevation minus total depth.

b. Use spatial join tool in ArcMap to merge depths to nearest water surface elevations. Compute depths in attribute table using field calculator.

6. Final check.

a. Delineate channel centerline in GIS.

b. Pull data into GIS and route along centerline.

c. Export to spreadsheet and replot longitudinal profile of water surface elevation and channel bottom.

d. Look for any outliers and perform final edits as needed.

Multibeam Surveying

By Kent Collins, P.E.

Multibeam technology was originally developed in the 1960s for deep water ocean mapping. In the 1990s, multibeam technology was further advanced for application to shallow water conditions, primarily the detection of navigational obstacles. An increasing number of companies manufacture multibeam systems and develop the software required for both data collection and processing. Numerous vendors demonstrate, sell, install, and train users on multibeam systems in the United States and around the world. Manufacturers and vendors typically provide training for users on proper data collection and processing techniques.

Multibeam systems are fan-beam array, acoustic sounding systems comprised of multiple narrow-beam transducers mounted in close proximity, typically within a single transducer head, each emitting beams at equally spaced angles or equal distances from one location under the survey vessel (figure 1).

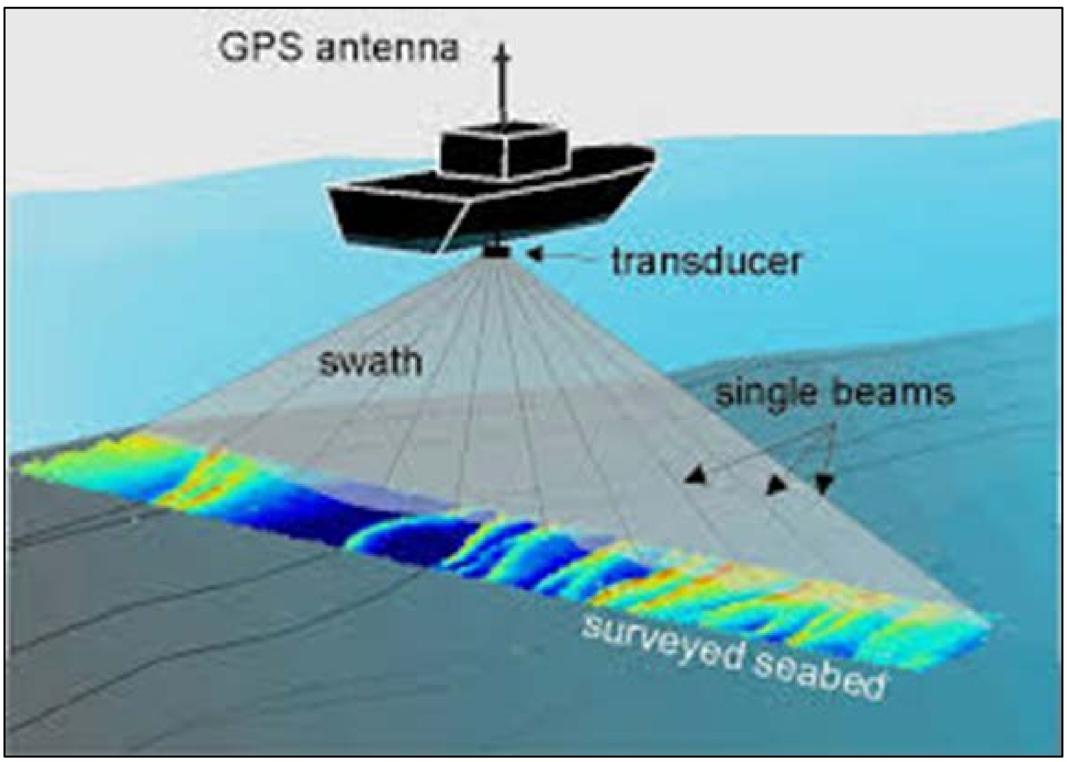


Figure 1.—Typical multibeam (swath) system for bathymetric surveying. Source: Submerged Prehistoric Archaeology and Landscapes of the Continental Shelf (https://www.splashcos.org/sites/splashcos.org/files/downloads/2_Multibeam.pdf).

Each transducer acts as a separate acoustic-distance measuring unit, emitting beams at a given angle with respect to the transducer head mounted to the survey vessel. Real-time computations determine the depth of each beam from the slant-distance signal, adjusted to account for the orientation and motion of the survey vessel and changes in sound velocity at the transducer face and throughout the entire depth of the water column.

An integrated Motion Reference Unit (MRU) or Inertial Measurement Unit (IMU) allows multibeam systems to collect accurate data in rough water while providing full bottom coverage within the survey swath. Typical swath coverage angles for current multibeam systems range from 120 degrees to over 200 degrees. The coverage area is primarily dependent on the water depth. For example, a fan array of 120 degrees results in a bottom swath approximately 3.5 times the water depth. In water 20 feet deep, a 120-degree multibeam system will produce approximately 70 feet of swath coverage along the bottom (figure 2). Multibeam manufacturers have recently developed transducers capable of full coverage over a swath angle of 210 degrees, providing complete coverage up to the water's edge in a single pass and eliminating the need to tilt the transducer head for mapping vertical features. Curved transmission and receiver arrays provide the most accurate and precise distance measurement up to the water's edge and are limited only by the power of the transmission signal and the distance to the bottom, banks, or other features. Dual head multibeam systems mounted at opposite angles can achieve similar swath coverage. Figure 3 represents the relative difference in bottom coverage that surveyors might expect from the various types of bathymetric data collection methods. The figure demonstrates the additional bottom detail provided by a multibeam system while traversing similar survey patterns.

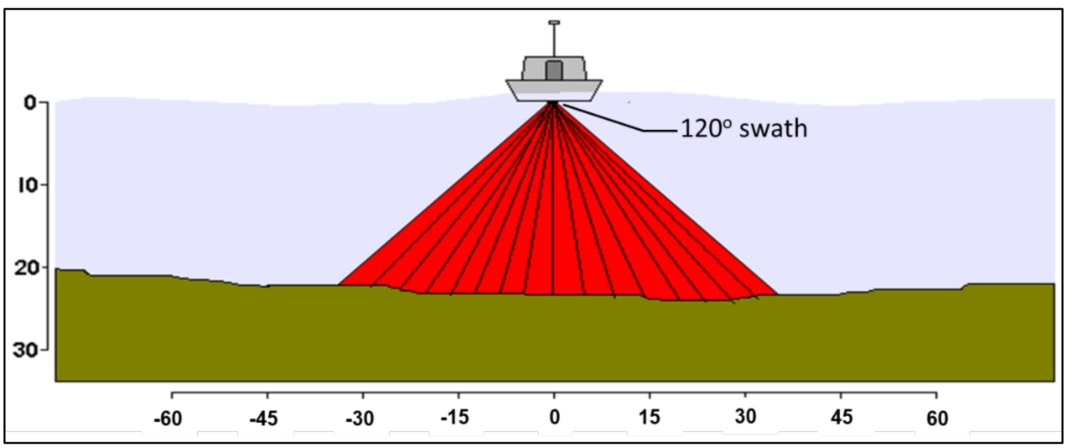


Figure 2.—Multibeam swath/beam pattern emitted from typical multibeam transducer demonstrating bottom swath coverage for a 120-degree system. Source: HYPACK - A Xylem Brand (HYPACK / Xylem, Inc.).

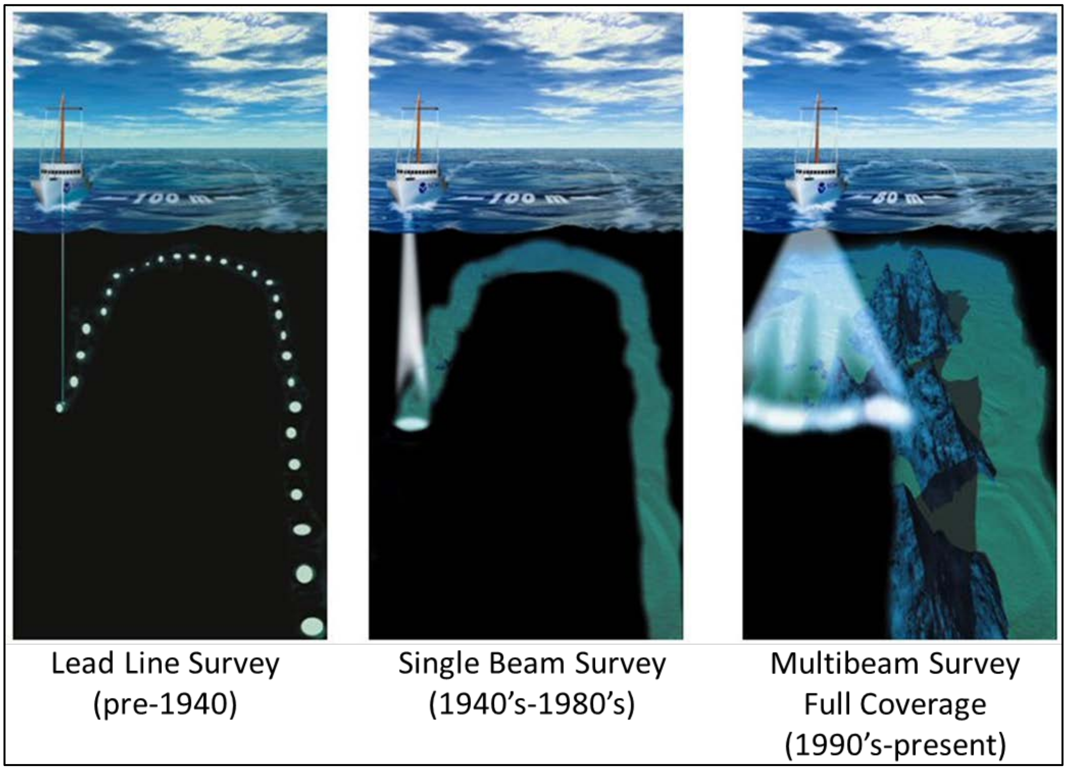


Figure 3.—Relative bottom coverage provided by various bathymetric survey methods. Source: National Oceanic and Atmospheric Administration (https://noaateacheratsea.blog/tag/multi-beam-sonar/).

It is recommended, and must be noted for navigation-type surveys, that a 50-percent overlap of the survey swaths should be maintained for quality control. Most Reclamation surveys, though, are not performed for navigational purposes, so the percentage of swath overlap can be reduced. Overlap between successive passes should be enough to ensure complete coverage once outer beams are filtered out. The outer beams produce the most measurement error because they travel the furthest distance to and from the transducer head and strike the bottom at more of an oblique angle (referred to as the grazing angle), introducing more measurement uncertainty. Depending on the characteristics of the multibeam system and the bathymetric survey conditions (both water and bottom conditions), a portion of the outer beam depth measurements will be eliminated to reduce errors. For example, when processing data collected using a 120-degree multibeam system, it is common to filter the outer 5 degrees from each side of the swath, eliminating the largest sources of error.

The horizontal and vertical accuracy of the collected multibeam data relies on many vital system components. These components include a computer with hydrographic surveying software; sensors to measure the heave, pitch, roll, yaw, and heading of the transducer and survey vessel; a surface sound velocity probe; a positioning system (typically, Global Positioning System [GPS]); and a vertical sound velocity profiler for calibration. Figure 4 shows some of the important multibeam system components mounted to a survey vessel belonging to the Sedimentation and River Hydraulics Group (SRH) in Reclamation's Technical Service Center.

Figure 4.—Multibeam bathymetry system mounted to an SRH survey vessel.

An MRU or IMU integrates with the other system components to measure and correct position and depth errors introduced due the heave, pitch, and roll of the transducer head. On newer systems, the MRU or IMU are often mounted to the outside or inside of the transducer head itself to provide a more accurate measurement of transducer head motion. A surface sound velocity probe (usually mounted to the transducer head) is required to compute the correct angle that each beam is received into the transducer. GPS instruments provide accurate horizontal and vertical positioning in real-time, as well as calculating the heading and yaw of the transducer head relative to the survey vessel. The vertical sound velocity profiler is separate from the integrated multibeam system, but is necessary to measure the properties of the water column that affect the speed of sound of the sonar beams (primarily water temperature and salinity).

Multibeam systems have very high data acquisition rates, typically thousands of depth points per second. To minimize measurement errors and reduce post-processing times, an extensive calibration is necessary prior to data collection. The calibration is necessary to determine the magnitude of error sources such as the roll, pitch, and yaw mounting angles of the transducer head relative to the MRU or IMU and GPS antennas. Field calibration of multibeam systems is more critical and complicated than what is required for single beam systems. Periodic, precise calibration is essential to ensure that the multibeam positions and elevations are accurate. The horizontal positioning accuracy is dependent upon the ability of the system to compensate for pointing errors caused by vessel roll, pitch, and yaw, where a small degree of roll can cause large errors in the outer beams. For high-accuracy surveys, restrictions are typically placed on the use of the outer beam data. Manufacturer recommendations and experience should be used to determine the appropriate use of the outer beams. Accurate and efficient multibeam system operation requires an experienced crew and good calibration practice. Multibeam calibration is achieved by performing patch tests and by collecting multiple vertical velocity profiles.

The purpose of a calibration patch test is to measure the position and orientation of the MRU or IMU relative to the acoustic center of the multibeam transducer and survey vessel heading system. A patch test should be performed after initial installation, after any system component modification, and prior to each survey to confirm previous system alignment. This comprehensive patch test includes a latency test to measure any delay between the positions and depth inputs and checks to determine the pitch, roll, and yaw or azimuth offsets. The appendices in this users guide contain two documents[1]—appendix A describes the collection and analysis requirements for performing a typical multibeam patch test and appendix B explains the method of processing patch test data in the HYPACK® MBMAX64 Multibeam Editor.

Velocity profile corrections are required for proper calibration of any multibeam hydrographic survey system and should be performed periodically throughout the area being surveyed each day. It is recommended that the velocity profile correction be completed at least twice per day and more frequent in locations where physical changes in the water column are suspected, measured, or observed. A traditional bar test can be used to verify the settings and corrections of the measured multibeam depths. The bar test can also be used to check some of the outer beam depths and is an excellent method to confirm the draft settings of the system. Manufacturer and software vendors usually recommend patch and performance tests to ensure the quality of the survey data. The performance test may compare overlapping bathymetry collected using different survey methods, such as multibeam overlapping a single beam data.

Most multibeam sonar beams are not projected perpendicular to the water surface and encounter changes in sound velocity resulting in deflection as they travel through the water column. Increases in sound velocity deflect sonar beams upward towards the water surface. Decreases in the speed of sound deflect sonar beams downward towards the bed (figure 5). Correction for these sounding refractions requires an actual velocity variation with depth table of values that are

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[1]Published by HYPACK - A Xylem Brand (HYPACK / Xylem, Inc.).

used in post-processing of the depth data. The outer beams travel the greatest distance through the water column at the most oblique angles and are, therefore, subject to the greatest deflection caused by changes in water properties.

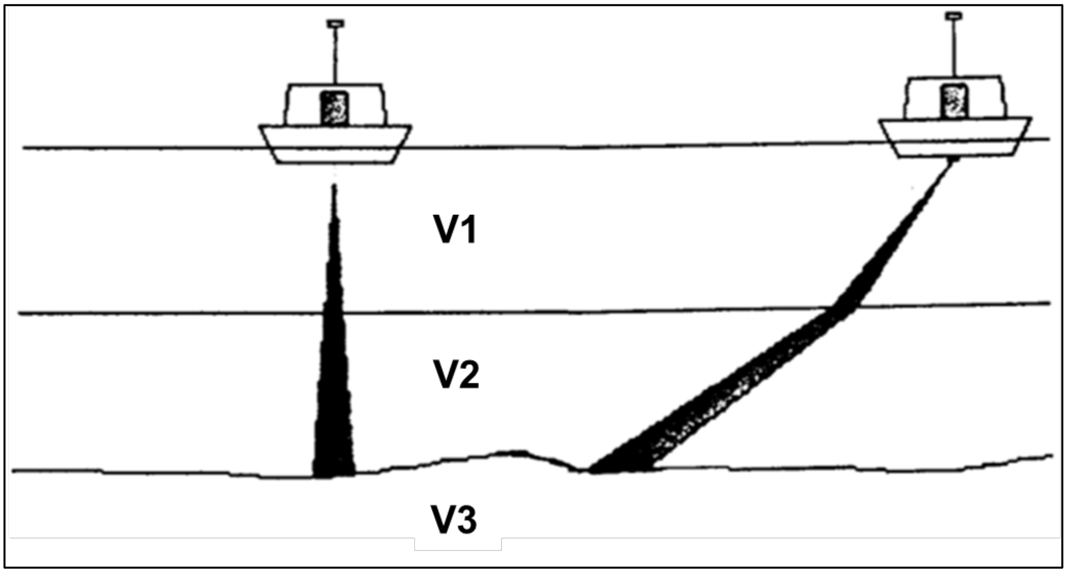


Figure 5.—Sonar beam deflection due to changes in sound velocity. Note sound velocity increase in zone V2 deflecting beam upward. Source: HYPACK - A Xylem Brand (HYPACK / Xylem, Inc.).

Raw multibeam datasets are very large, usually with many data spikes and anomalies, requiring significant filtering and editing before they can be used for final map development. Hydrographic survey software packages contain many routines for manipulating and editing large raw datasets. Filtering and editing can be conducted automatically in the software editing processes, but must be conducted with *much* caution to avoid accidentally eliminating useful data. During the editing process, each group of soundings (each ping) can be viewed separately and edited manually. Multiple pings can be stacked together to reduce the amount of time spent during manual editing. This viewing and manual editing procedure can be very time consuming, but it should be performed on most of the datasets as a means of conducting quality control checks of the automated filtering process. A general guide on multibeam editing published by HYPACK - A Xylem Brand (HYPACK / Xylem, Inc.) is included in the next section, “Processing Multibeam Data Using the HYPACK® MBMAX64 Multibeam Editor” in this users guide.

Even after the raw datasets are edited and filtered, additional data reduction may be necessary to produce the final deliverables. Generating final Geographic Information System (GIS) surfaces and subsequent maps from massive multibeam bathymetry datasets can be time-consuming and even impossible. Filtering processes have been developed, tested, and incorporated into hydrographic software routines that allow data to be reduced without sacrificing significant quality or resolution. These filtering routines must also be used with caution to avoid eliminating important details and actual bottom features from the dataset. Filtering routines can be adjusted to identify important details such as dam faces, possible sinkholes, trashracks, and other objects of interest.

Many other viable methods for underwater mapping of reservoir and river bottoms exist. Manufacturer references and hydrographic survey manuals published by the U.S. Army Corps of Engineers (USACE) et al. should be consulted for more detail (USACE, 2004).

Processing Multibeam Data Using the HYPACK® MBMAX64 Multibeam Editor

On behalf of Joe Burnett, HYPACK - A Xylem Brand (HYPACK / Xylem, Inc.)

[unedited]

Multibeam Editor Guide for MBMAX64

For almost 20 years, I have been collecting and processing Multibeam data, and have done my best to find the ‘best way’ to process all of the billions of data points that I have collected. By the “best way”, I mean the method that is the simplest, easiest, quickest way that will produce the most accurate, cleanest, and complete final dataset.

When I perform a Multibeam Training Course, and reach the ‘Editing’ portion of it, I always explain to the attendees, that Multibeam Editing, is, in reality, the operation of performing ‘data interpretation’. If I were to provide everyone in the Course with the same RAW Multibeam dataset, and ask each attendee to ‘edit’ the data, it would be an extremely rare coincidence that any two or more of the attendees would produce exactly the same final XYZ dataset. This is due to the fact that each attendee would look at the data points, from their previous experience and knowledge, and use their own ‘interpretation’ of which points are ‘bad’ and which points are ‘good’.

With the introduction of HYPACK’s MBMAX64 Multibeam Editor, just a little over 2 years ago, multibeam processing has made significant leaps and bounds towards making this a much easier and visually understandable process.

The main focus and purpose of this “Guide” is to provide you with a good fundamental approach to processing multibeam data. I have set it up in an Outline, step-by-side walk-thru of how to ‘possibly’ use HYPACK’s MBMAX64 Multibeam Editor. It will NOT go over EVERY aspect of the MBMAX64 Editor. From this Guide, I hope that you will be able to modify, adapt, and expand on its premise, and allow you to create a Guide of your own.

In the Outline, “The Prep Work” walks thru the loading of the data, the selection of corrections and devices, the verification of the offsets, the verification of the calibration values, and how some specific devices’ data will be applied to the soundings. Continuing into Stage 1, each device’s time sequential data is verified and modified for ALL of the currently loaded files.

In “The Heart of the Beast” Section, Filters will be selected and applied to individual files, groups of files, and/or ALL files. Here is where your experience and knowledge of Multibeam surveying and processing will come into play. After the Filters have been applied, the Manual Editing will clean up the remaining ‘spikes’ and ‘bad’ data points.

When you reach “The Finish Line”, you will be ready to Save all of your hard work into the predefined outputs from your Scope of Work.

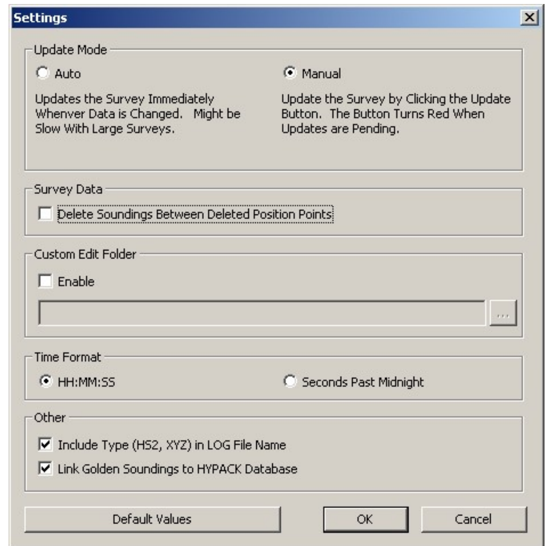
Again, this is just the Outline. I am working on a detailed version, with screen captures and in-depth explanations and reasoning of all the steps contained within the Outline. Until the detailed version is ready, you can get most of the details from the “MBMAX64” PowerPoint on our 2014 and 2015 Training DVDs.

Processing Outline

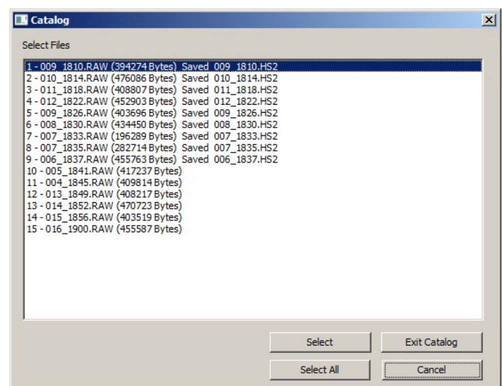
1 Open MBMAX64

2 Configure Settings

Edit > Settings



3 Load Survey Data



"The Prep Work"

4 Read Parameters Window

4.1 <u>Survey Tab</u>

4.1.1 Perform Memory Test

(Don't exceed 100% of your computer's RAM)

4.1.2 Select Survey Mode (Vertical Reference)

4.1.3 Set up/Select Matrix and Cloud Sections

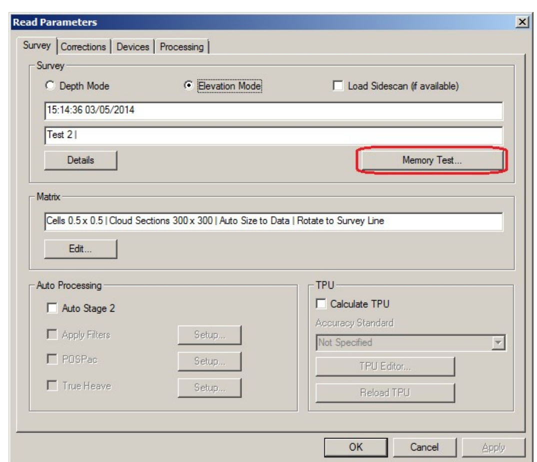
(Per your Scope of Work)

4.1.4 Auto-Processing

(Not applicable for this Outline)

4.1.5 TPU

(Not applicable for this Outline)

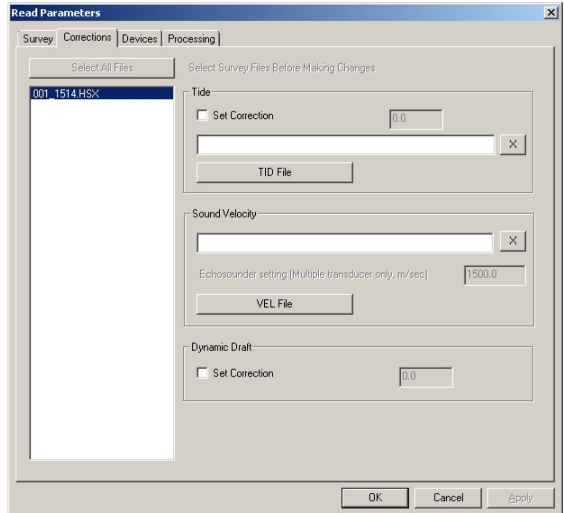


4.2 <u>Corrections Tab</u>

4.2.1 Set or Select Tide

4.2.2 Select Sound Velocity Profile(s)

4.2.3 Set Dynamic Draft

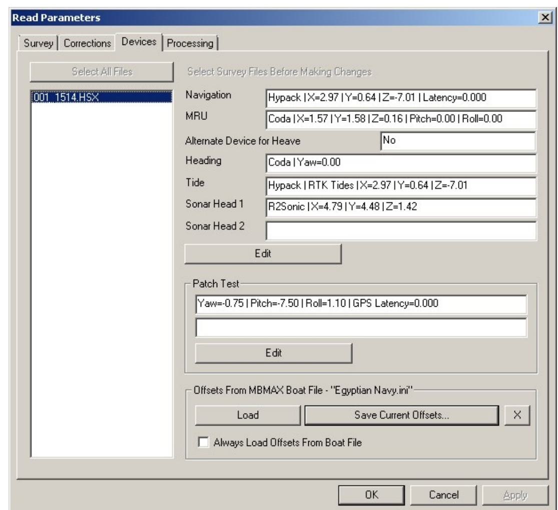


4.3 <u>Devices Tab</u>

4.3.1 Verify/Modify Device Offsets

4.3.2 Verify/Modify Patch Test Offsets

4.3.3 Save Offsets to a 'BoatOffsets.ini' file



4.4 <u>Processing Tab</u>

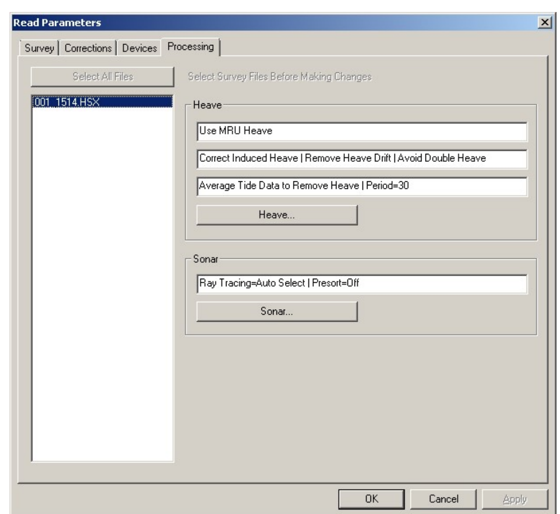
4.4.1 Select Heave Device

4.4.2 Select additional Heave Options

4.4.3 Select the Sonar ID for Geocoder

4.4.4 Select the Sound Velocity Method

4.4.5 Select a Presort Option



5 Proceed to Stage 1 of the MBMAX64 Editor

Stage 1

6 Open the 'Speed' Window
(Verify/ Modify the Speed of each file)

7 Open the 'Heave/Tide' Window
(Verify/ Modify the Heave and Tide of each file)

8 Open the 'HPR' Window
(Verify/ Modify the Heading, Pitch, and Roll of each file)

9 Open the 'SV' Window
(Verify/ Modify the Sonar Probe's Speed of Sound for each file)

10 Proceed to Stage 2

"The Heart of the Beast"

Stage 2

11 Run Filters (CTRL+F)

11.1 <u>Basic Tab</u>

11.1.1 Select a Filter (ONLY 1 !!)

11.1.2 'Update Filter Preview'

<u>Actions Tab</u>

11.1.3 Apply the Filter to 'All' or 'Selected' Files

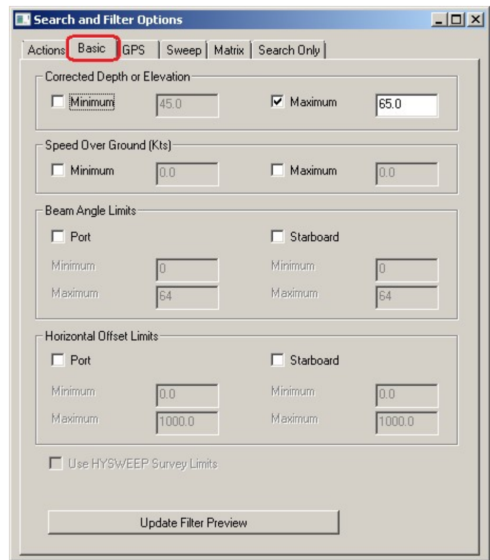
11.1.4 'Reset All' Filters

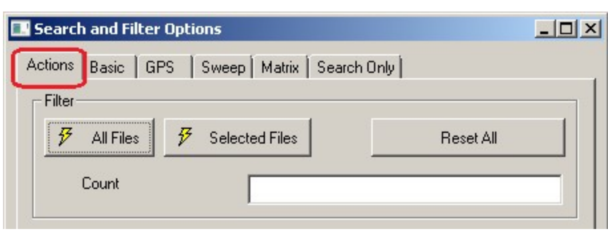
<u>MBMAX64 Main Window</u>

11.1.5 'Update' changes made by Filter

11.1.6 Select the next Filter from the Basic Tab

11.1.7 Repeat the above Steps until you have applied all the Filters you wish to apply from the Basic Tab (Again, 1 at a time. This allows you to visualize how each Filter affects the data.)





11.2 <u>GPS Tab</u> (CTRL+F)

11.2.1 Select a Filter (ONLY 1 !!)

11.2.2 'Update Filter Preview'

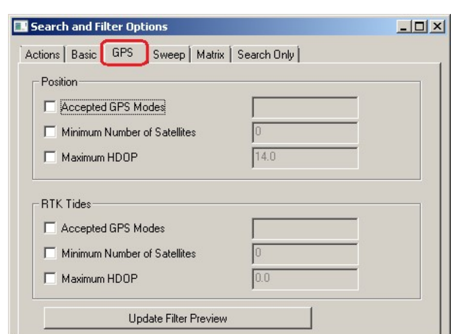
<u>Actions Tab</u>

11.2.3 Apply the Filter to 'All' or 'Selected' Files

11.2.4 'Reset All' Filters

<u>MBMAX64 Main Window</u>

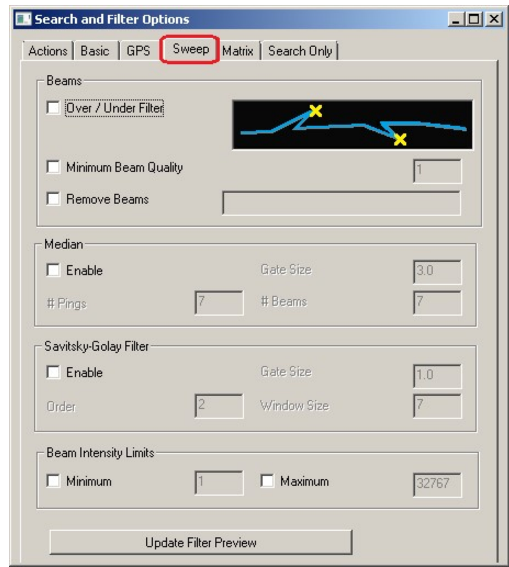
11.2.5 'Update' changes made by Filter



11.2.6 Select the next Filter from the GPS Tab

11.2.7 Repeat the above Steps until you have applied all the Filters you wish to apply
(Again, 1 at a time. This allows you to visualize how each Filter affects the data.)

Important NOTE: In the Sweep Tab, each of its Filters may need to be run thru several times. Each time the Main Window is updated, the Filter reruns with the current selection and may find additional 'bad' points after extraneous points have been removed. 5 or more times may be common. Pay close attention to the following order of Steps.



11.3 Sweep Tab

11.3.1 Select a Filter (ONLY 1 !!)

11.3.2 'Update Filter Preview'

Actions Tab

11.3.3 Apply the Filter to 'All' or 'Selected' Files

MBMAX64 Main Window

11.3.4 'Update' changes made by Filter

11.3.5 If additional Yellow X's appear on Main Window, repeat the Actions Tab.

11.3.6 When NO additional Yellow Xs appear on the Main Window, go to next Step.

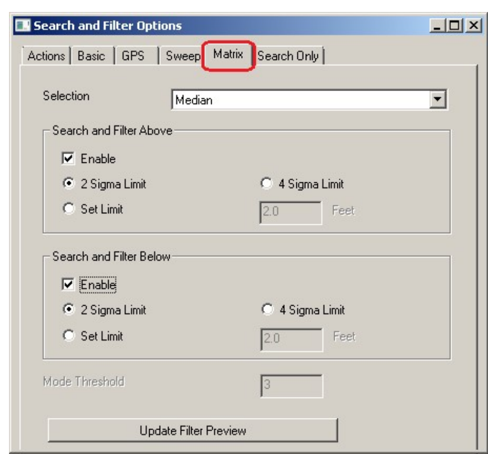
Actions Tab

11.3.7 'Reset All' Filters

11.3.8 Select the next Filter to be used from the Sweep Tab

11.3.9 Repeat the above Steps until you have applied all the Filters you wish to apply
(Again, 1 at a time. This allows you to visualize how each Filter affects the data.)

Important NOTE: The Matrix Tab and its Filters can ONLY be used if you have the proper Tide, Sound Velocity Cast, Device Offsets, and Patch Test information entered. This is due to the fact that the Matrix Filter is performing the filtering on overlapping files, and not individual files, like the Filters above.



11.4 Matrix Tab

11.4.1 Select Vertical Option

11.4.2 Enable Above, Below, or Both

11.4.3 Select Vertical Tolerance

(2 Sigma = 95% Confidence)

(4 Sigma = 99.994% Confidence)

(Set Limit)

Actions Tab

11.4.4 Apply the Filter to 'All' or 'Selected' Files

11.4.5 ‘Reset All’ Filters

<u>MBMAX64 Main Window</u>

11.4.6 ‘Update’ changes made by Filter

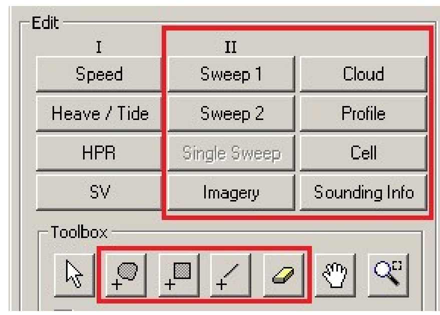
11.4.7 Select the next Vertical Tolerance to be used from the Matrix Tab

11.4.8 Repeat the above Steps until you have applied all the Vertical Tolerances that you wish to apply from the Matrix Tab

NOTE: Dependent upon how ‘clean’ your initial raw data is, using the Filters can potentially remove 80 – 90+ % of your unwanted, incorrect data, making your Manual Editing a much easier task.

12 Manual Editing

Using the Manual editing Tools (Lasso, Block, Line, Eraser, etc.):



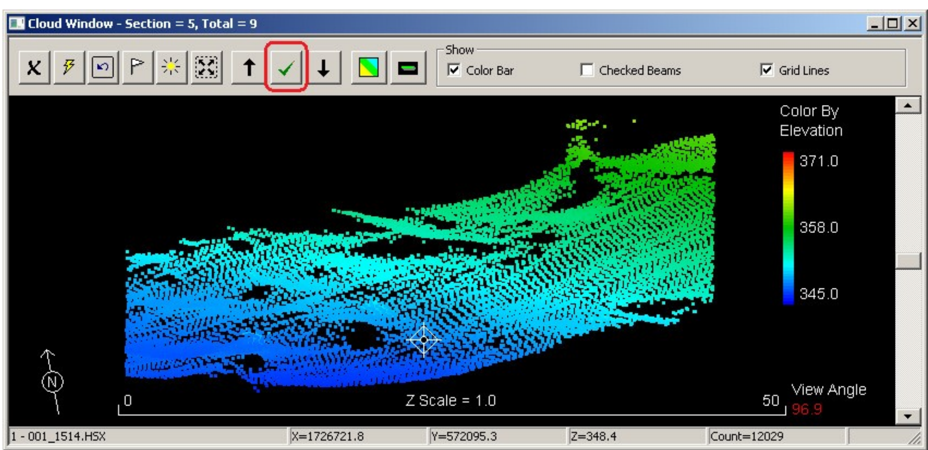
12.1 Sweep 1 and 2 Windows

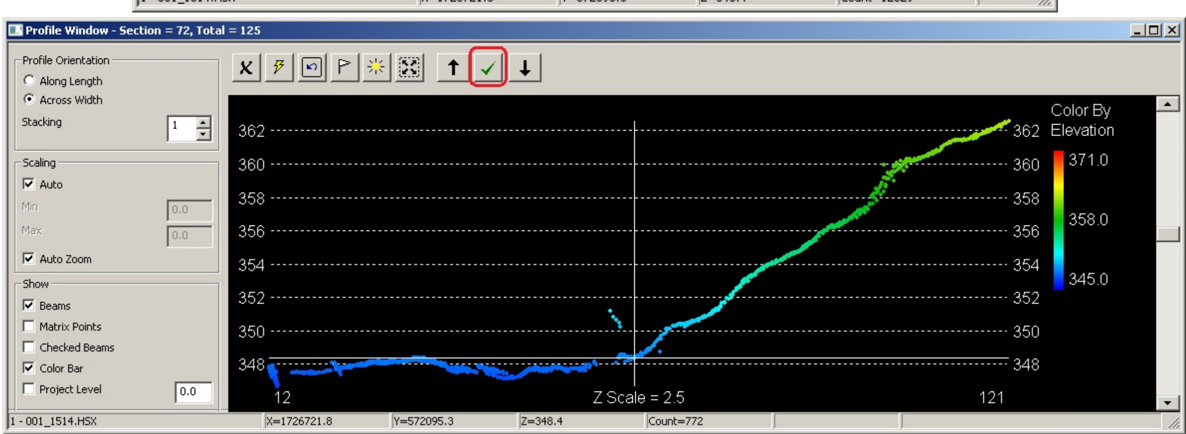
Edit remaining spikes from individual files

12.2 Cloud Sections - Edit and Mark as ‘Checked’

12.3 Profile Window - Edit and Mark as ‘Checked’

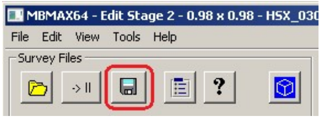
13 When ALL Cloud Sections and/or Profiles have been ‘Checked’ (verifying that ONLY ‘Good’ data points remain), you are ready to Save your data.

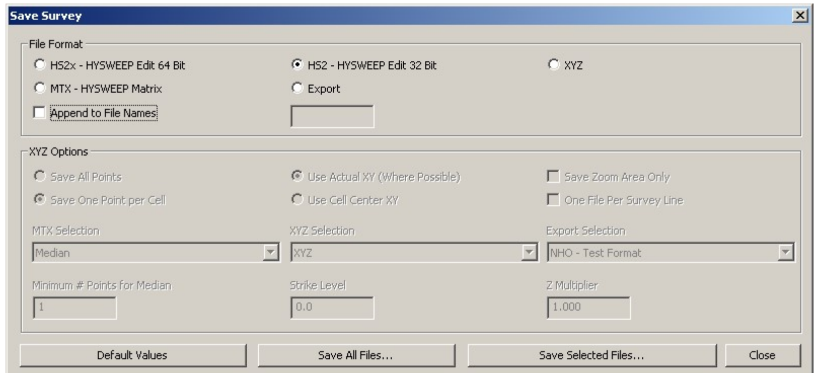




"The Finish Line"

14 Save Files



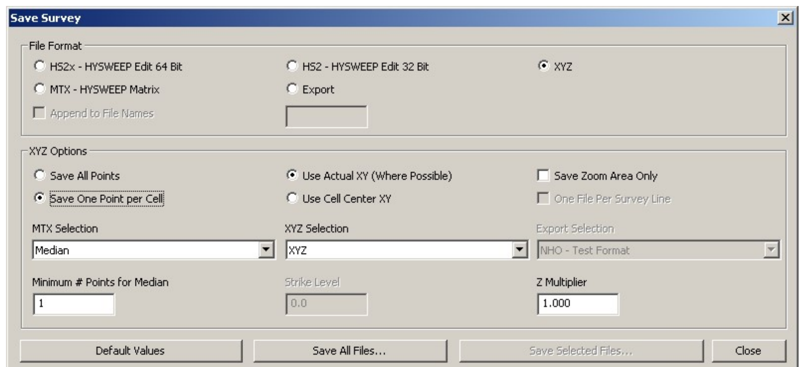


14.1 Save to HS2 format

14.2 Save to HS2x format

NOTE: Saving to these 'Edited' formats

Offsets, bad SV Profiles, incorrect Tides, incorrect Patch Test values, etc.)



14.3

14.3.1

(Ability to create detailed subsets from it)

14.3.2 Save 'One Point per Cell' datasets

14.3.2.1 Save with different Cell Sizes
(Modify the Cell Size in the Read Parameters Window)

14.3.2.2 Save with different Z-value Selection
(Change the 'MTX Selection')

Examples of Selections: 1x1 Median, 1x1 Average, 1x1 Minimum, 1x1 Maximum
3x3 Median, 3x3 Average, 3x3 Minimum, 3x3 Maximum
5x5 Median, 5x5 Average, 5x5 Minimum, 5x5 Maximum, etc.

14.3.2.3 Save data from 'Save All Files' or 'Save Selected Files'

14.3.2.4 Name the File by its contents

Example: Boat Name_Jobsite_Date_Cell Size_Z-value.XYZ
MV Simpson_St Louis Harbor_11112014_1x1_Median.XYZ

14.4 Save to other formats as needed

Hydro-Acoustics Processing Software

By Daniel Dombroski, Ph.D., P.E.

Introduction

Details regarding the development and guidelines for application of Reclamation's "Sedimentation and River Hydraulics–Hydro-Acoustics Processing Software" (henceforth referred to as SRH-HAPS) for processing bathymetry data are described. The computational backbone of the processing software is comprised of freely available geodetic source codes that have been modified and integrated under a single user interface. The software is designed to process data collected using a SonTek S5 or M9 Acoustic Doppler Current Profiler (ADCP) and either the HydroSurveyor or RiverSurveyor Live software package. The processing software provides a seamless and efficient means for producing point-based bottom bathymetry and related products from data collected using the ADCP with integrated Global Positioning System (GPS) information. The methods are generally extendable to variations in equipment, data collection procedures, and end-user needs.

Purpose

The purpose of SRH-HAPS is to improve the efficiency of developing finished bathymetric mappings by partially automating the task of post-processing and integration of GPS information.

Need

The depth soundings collected using the SonTek RiverSurveyor Live software are referenced only to the nadir beam of the ADCP even though there are a total of five beams available for any measurement. More complete bathymetry can be efficiently mapped by using depth soundings from all available beams. Because the RiverSurveyor Live software does not provide positioning information for the depth measurement associated with each beam, it is necessary to calculate beam locations based on the geometry, pitch, and roll of the instrument. Further, the RiverSurveyor Live software does not provide a full suite of velocity products, such as depth-averaged velocity.

The depth soundings collected using the SonTek HydroSurveyor or RiverSurveyor Live software are not generally referenced to the desired geographic reference frame or appropriate geoid model of the earth's surface. There is a general need to convert the data to an appropriate reference frame and apply a geoid model. There may be additional needs, such as filtering the data to enhance quality or projecting the data from a geographic coordinate system, in order to produce finished bathymetric data for a project.

User Interface

The SRH-HAPS user interface and driver is written in the Matlab language and compiled into a PC-executable using the Matlab Compiler. This allows SRH-HAPS to be used on computers without a full Matlab installation. It is necessary to run the Matlab Compiler Runtime (MCR) installer, which provides the underlying Matlab engine to run the executable.

SRH-HAPS processing is generally conducted in the office after the data acquisition trip has been completed. The opening screen of the SRH-HAPS interface (figure 1) queries the user to select the type of data processing operation they would like to perform. The format of stored data differs based on which software platform was used to collect the data. Data must be exported appropriately from HydroSurveyor or RiverSurveyor before the SRH-HAPS program can post-process the data.

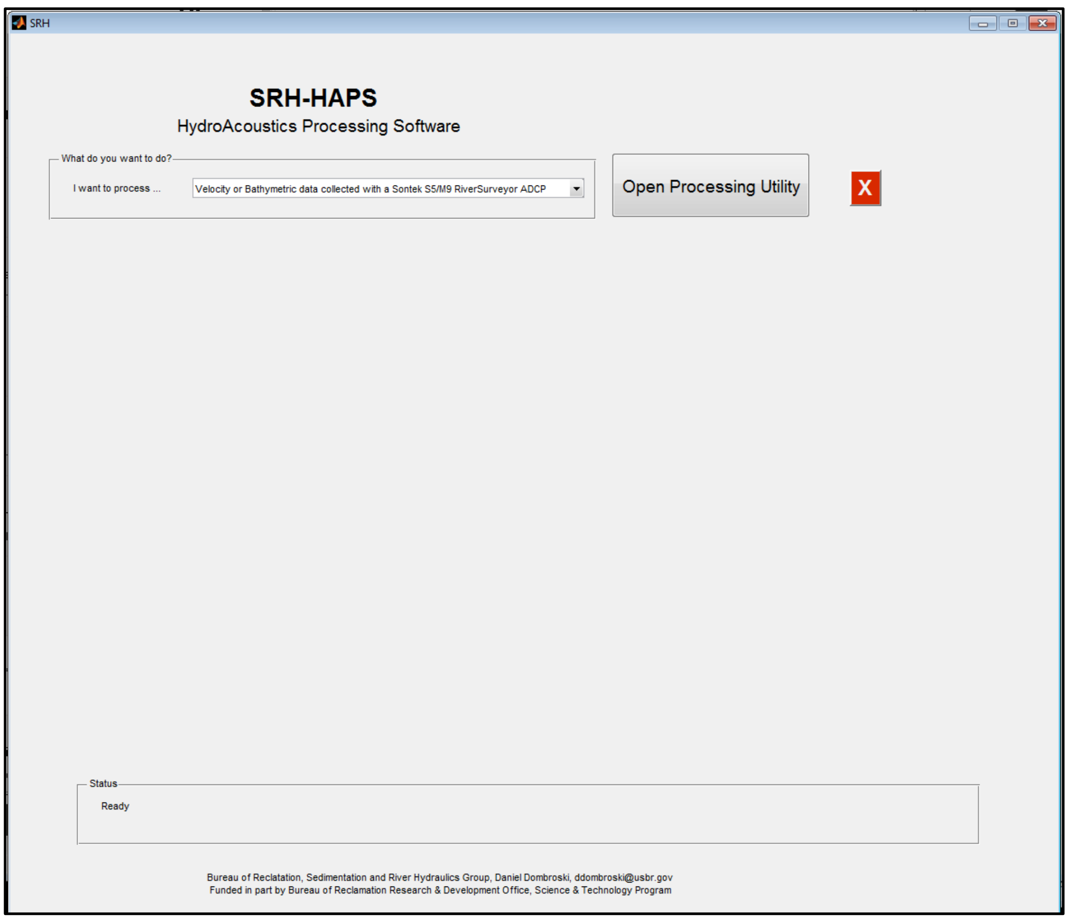


Figure 1.—SRH-HAPS opening screen. User is queried on what type of data processing operation they would like to perform.

Option 1 – Velocity or Bathymetric Data Collected With a SonTek S5/M9 RiverSurveyor ADCP

Selecting option 1 invokes a tool for post-processing velocity data and depth soundings collected using the SonTek S5 or M9 ADCP with GPS when operated in the RiverSurveyor mode.

RiverSurveyor Data Export

After field data acquisition using the SonTek ADCP and RiverSurveyor Live software is complete, the input dataset for SRH-HAPS can be generated. Click on the “Show/Hide Processing Tools” icon (looks like a hammer and wrench). Within the “Processing Toolbox,” select “Matlab Export All” (figure 2).

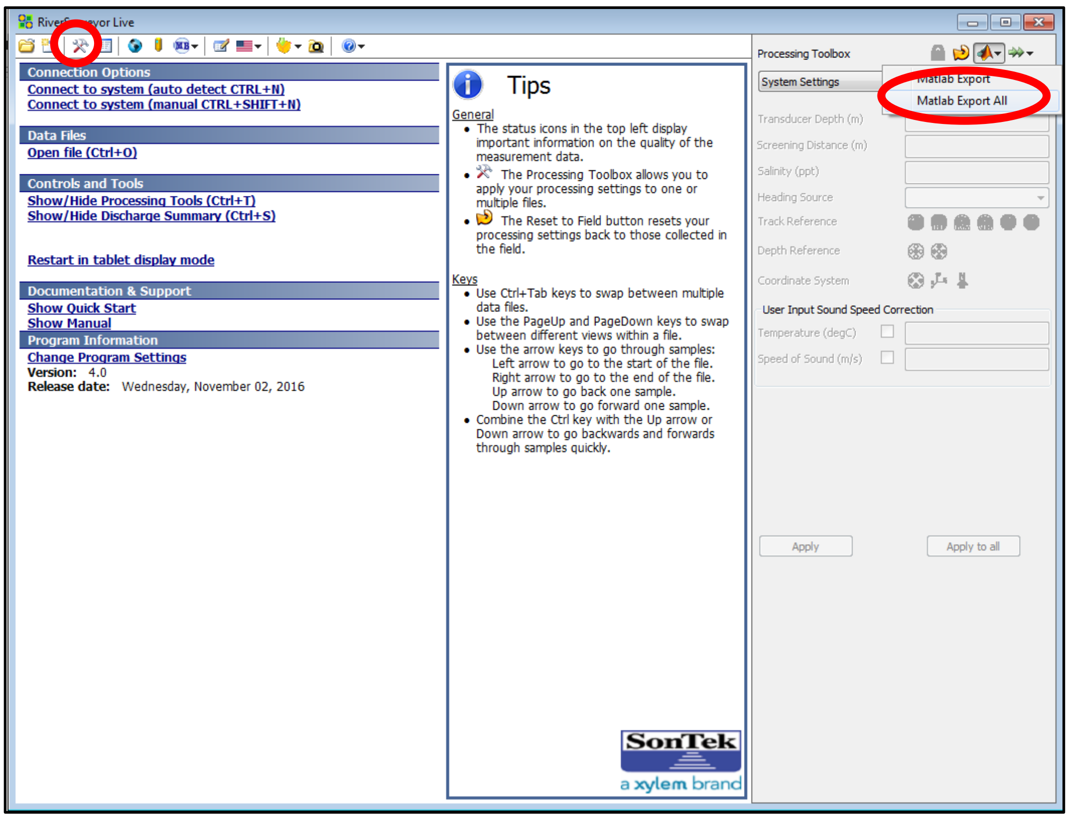


Figure 2.—Export data from RiverSurveyor Live software by showing the “Processing Toolbox” and selecting “Matlab Export All.”

SRH-HAPS Processing Interface

The graphical user interface (GUI) is shown in figure 3.

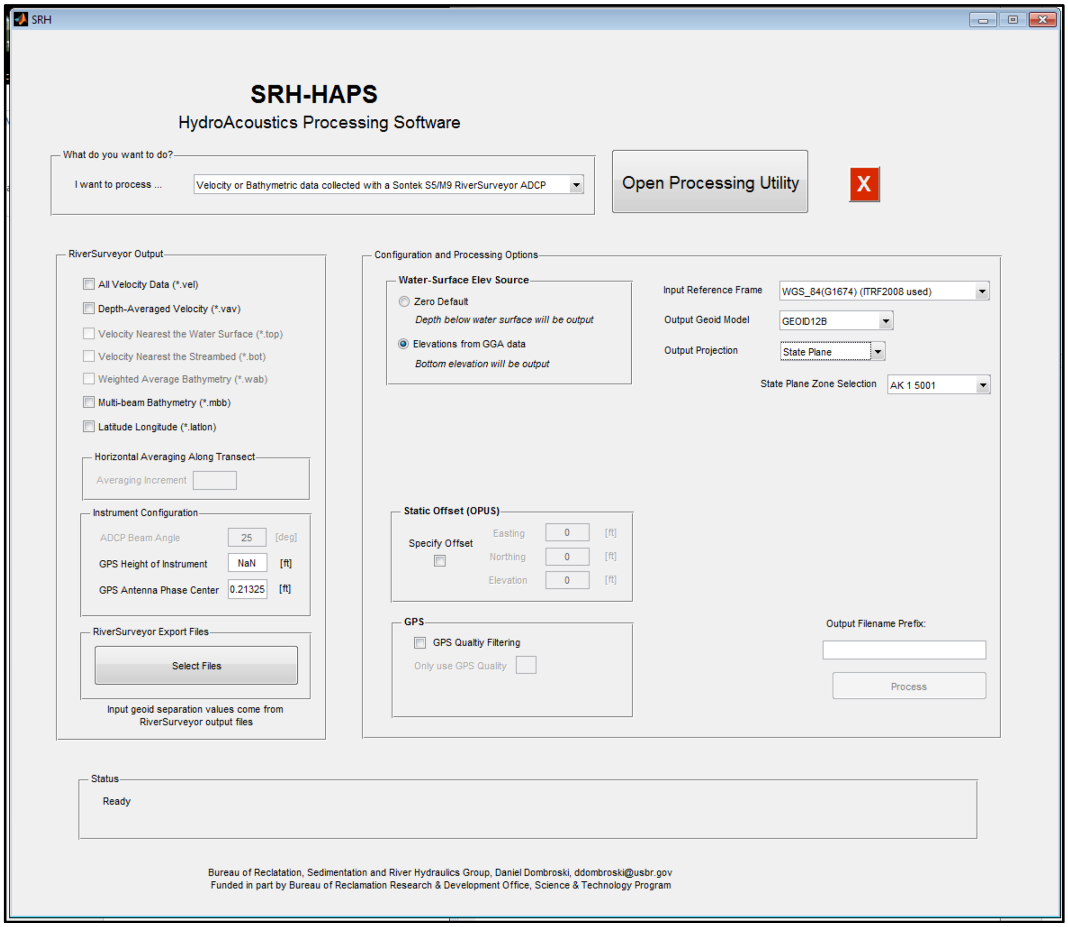


Figure 3.—SRH-HAPS graphical user interface for processing “velocity or bathymetric data collected with a SonTek S5/M9 RiverSurveyor ADCP.”

Code Development

AdMap, a previously used processing software, was originally developed by the U.S. Geological Survey (Dave Mueller) for use in processing data from the WinRiver software/Teledyne RD Instruments ADCP. Significant changes, however, were required regarding the data format and instrument geometry in order to process data from the SonTek RiverSurveyor Live software, thus some of the underlying code structure from AdMap was adapted for use in SRH-HAPS. Along a parallel path, features and capabilities have been added that were not included in the original AdMap.

Units

Input units from RiverSurveyor can be either English or Metric. SRH-HAPS checks the units tag within the input file, and runs units conversions appropriately. Horizontal positioning is always taken from the latitude and longitude information in the input file, and converted to Universal Transverse Mercator (UTM; meters [m]) coordinates or State Plane Coordinates (SPC; feet [ft]). If using initial position capability (instead of RiverSurveyor GPS output), the initial positions need to be specified in meters regardless of whether RiverSurveyor input units are English or Metric.

Water Surface Elevation Source

Zero Default.—References all elevations from zero water surface elevation so that the resulting bathymetry represents depth values instead of elevation.

Elevations from GGA data.—Uses the elevation from the GGA string. This option is also only available if the GPS data were correctly fed to RiverSurveyor during data collection (see the “SONTEK M9 Acoustic Doppler Current Profiler Setup” section in this users guide).

User Supplied Data

ADCP Beam Angle (deg).—Default is 25 degrees for SonTek S5/M9 systems.

GPS Height of Instrument (m or ft).—Refers to the height of the GPS receiver relative to the water surface in meters. All geographic coordinates (horizontal and vertical) are referenced from the GPS receiver. Entering a “Height of Instrument” value into SRH-HAPS will remove the instrument height from the elevation measured by the GPS, thus reflecting the water surface elevation.

GPS Antenna Phase Center (m or ft).—SRH-HAPS automatically removes an additional GPS phase center height (default 0.065 m is valid for Trimble R8 receiver) from the measured elevation, which accounts for the distance between the antenna reference point (ARP) and the antenna phase center (APC). Thus, the water surface elevation (WSE) is calculated as:

$$\text{ELEVATION}_{\text{WSE}} = \text{ELEVATION}_{\text{GGA}} - \text{HI} - \text{HEIGHT}_{\text{APC}}$$

where $\text{ELEVATION}_{\text{GGA}}$ is the elevation reported by the GPS receiver, HI is the user-specified Height of Instrument, $\text{HEIGHT}_{\text{APC}}$ is the distance between the APC and the ARP (0.065 m for Trimble R8 receiver), and $\text{ELEVATION}_{\text{WSE}}$ is the calculated water surface elevation (figure 4).

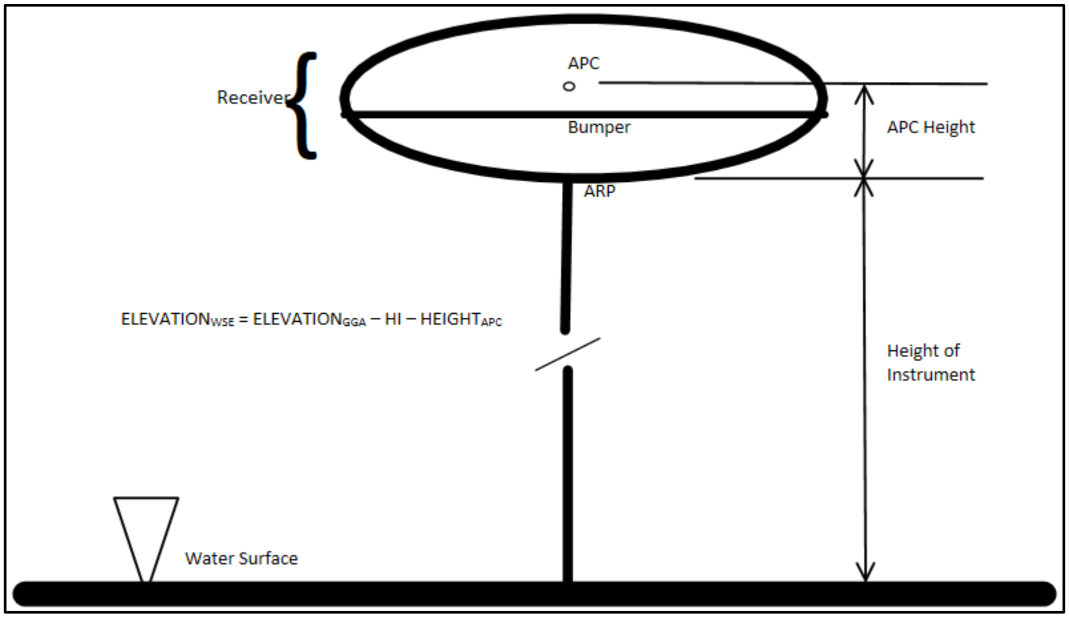


Figure 4.—Schematic of GPS receiver geometry.

RiverSurveyor Export Files.—The “Select Files” button opens a file browser for selection of the exported data files from RiverSurveyor (*.mat format) (see the “RiverSurveyor Data Export” subsection previous to this).

Reference Frame.—The “Input Reference Frame” and “Output Projection” specify the geographic reference frame of the input soundings and the desired output geographic projection of the finished bathymetric data. SRH-HAPS performs transformations between reference frames (details follow). Output projection can be specified in either UTM (meters) or State Plane (U.S. Survey Feet) coordinates. If “State Plane” is selected, the appropriate zone also needs to be specified via drop-down menu.

Output Geoid.—The “Output Geoid Model” is the desired geoid model to be applied to the finished bathymetry, based on the North American Datum of 1983 (NAD83) reference frame. The input geoid separation is pulled from the Matlab data export from RiverSurveyor and, hence, does not need to be explicitly specified.

Output Filename Prefix.—The user enters a name they would like the output file to be called. The different types of output will be identified with a three-character suffix (see labels under “Data Output”).

Data Output

Filtering.—The “GPS Quality Filtering” check box under “GPS” determines whether or not filtering is performed on the data. If checked, only soundings with GPS quality values specified (typically, 4) are used.

Note: The northing and easting are in meters for UTM coordinates and U.S. Survey Feet for SPC. The other data are in whatever units were used in the output from RiverSurveyor. For UTM output, the zone is picked based on the first latitude and longitude coordinate read from the files. For State Plane output, the zone is selected via a drop-down menu.

All Velocity Data (*.vel).—Outputs an American Standard Code for Information Interchange (ASCII) tabular file for all velocity data for every bin and every ensemble (figures 5 through 9).

Depth-Averaged Velocity (*.vav)

TransNo	EnsNo	Easting(m)	Northing(m)	u(cm/s)	v(cm/s)	hmag(cm/s)	hdir(deg)
0	549	740230.81	4617063.64	49.17	-45.65	67.09	132.87
0	550	740230.49	4617063.89	66.66	-54.19	85.91	129.11
0	551	740230.19	4617063.93	48.90	-63.64	80.26	142.46
0	552	740229.85	4617063.89	58.44	-54.74	80.07	133.12

Figure 5.—Outputs the average velocity for each ensemble using the average of all the bins in that ensemble, but ignoring the unmeasured areas.

Velocity Nearest the Water Surface (*.top)

TransNo	EnsNo	Easting(m)	Northing(m)	Elev(m)	Depth(m)	u(cm/s)	v(cm/s)	w(cm/s)	hmag(cm/s)	mag(cm/s)	hdir(deg)	vdir(deg)
0	549	740230.81	4617063.64	99.31	0.69	38.80	-74.30	-7.30	84.14	83.82	152.43	-0.09
0	550	740230.49	4617063.89	99.31	0.69	67.90	-96.70	-7.00	118.37	118.16	144.92	-0.06
0	551	740230.19	4617063.93	99.31	0.69	82.20	-51.50	-8.80	97.40	97.00	122.07	-0.09
0	552	740229.85	4617063.89	99.31	0.69	68.00	-87.60	-9.10	111.27	110.90	142.18	-0.08
0	553	740229.60	4617063.94	99.31	0.69	80.30	-42.40	-19.40	92.86	90.81	117.83	-0.21
0	554	740229.36	4617064.17	99.31	0.69	63.60	-77.20	-4.80	100.14	100.02	140.52	-0.05
0	555	740229.14	4617064.34	99.31	0.69	79.90	-51.10	-4.50	94.95	94.84	122.60	-0.05
0	556	740228.88	4617064.30	99.31	0.69	72.60	-50.50	3.20	88.49	88.44	124.82	0.04

Figure 6.—Outputs the velocity in the first valid bin from the water surface.

Velocity Nearest the Streambed (*.bot)

TransNo	EnsNo	Easting(m)	Northing(m)	Elev(m)	Depth(m)	u(cm/s)	v(cm/s)	w(cm/s)	hmag(cm/s)	mag(cm/s)	hdir(deg)	vdir(deg)
0	549	740230.81	4617063.64	97.71	2.29	2.00	-37.20	2.80	37.36	37.25	176.92	0.08
0	550	740230.49	4617063.89	97.71	2.29	23.60	-40.00	-2.90	46.53	46.44	149.46	-0.06
0	551	740230.19	4617063.93	97.81	2.19	1.80	-37.70	0.20	37.74	37.74	177.27	0.01
0	552	740229.85	4617063.89	98.01	1.99	73.80	-48.50	1.20	88.32	88.31	123.31	0.01
0	553	740229.60	4617063.94	98.11	1.89	37.30	-44.00	1.70	57.71	57.68	139.71	0.03
0	554	740229.36	4617064.17	98.11	1.89	29.60	-90.80	6.80	95.74	95.50	161.94	0.07
0	555	740229.14	4617064.34	98.21	1.79	2.30	-67.60	-4.70	67.80	67.64	178.05	-0.07
0	556	740228.88	4617064.30	98.31	1.69	45.30	-48.30	11.80	67.26	66.22	136.84	0.18
0	557	740228.68	4617064.33	98.31	1.69	73.10	-54.40	-2.90	91.17	91.12	126.66	-0.03
0	558	740228.64	4617064.67	98.41	1.59	41.80	-37.00	-2.40	55.87	55.82	131.51	-0.04
0	559	740228.84	4617065.27	98.31	1.69	72.50	-55.10	-5.00	91.20	91.06	127.23	-0.05
0	560	740229.25	4617066.06	97.61	2.39	54.70	-6.80	6.30	55.48	55.12	97.09	0.11

Figure 7.—Outputs the velocity and location of the last valid bin in each ensemble.

Weighted Average Bathymetry (*.wab)

TransNo	EnsNo	Easting(m)	Northing(m)	Elev(m)	Depth(m)
0	549	740230.81	4617063.64	-2.71	2.71
0	550	740230.49	4617063.89	-2.71	2.71
0	551	740230.19	4617063.93	-2.71	2.71
0	552	740229.85	4617063.89	-2.38	2.38
0	553	740229.60	4617063.94	-2.35	2.35
0	554	740229.36	4617064.17	-2.38	2.38

Figure 8.—Outputs a single depth for each ensemble based on the inverse weighted average of the four beams.

Multi-beam Bathymetry (*.mbb)

TransNo	EnsNo	Easting(m)	Northing(m)	Elev(m)
0	549	740230.38	4617062.86	97.89
0	549	740231.43	4617064.26	97.89
0	549	740230.20	4617064.08	97.85
0	549	740231.61	4617063.04	97.94
0	550	740230.13	4617063.06	97.90
0	550	740231.05	4617064.56	97.89
0	550	740229.84	4617064.27	97.85

Figure 9.—Outputs the position and elevation of the streambed for each of the four beams.

Static Horizontal Offset (OPUS Correction)

Offsets between the GPS receiver and the ADCP due to the mounting configuration within the boat, hydroboard, or other structure should be accounted for within the configuration settings in the RiverSurveyor Live software. This is because this correction must follow the instrument heading.

Offsets that are related to global positioning (namely, the OPUS correction of the base station location) should be applied using the static offset option in the SRH-HAPS GUI. This is because this type of offset is independent of the instrument heading.

Horizontal Averaging Along Transect

Averaging Increment.—Often the raw data vectors are so close together that they do not make a good presentation of the flow. The value entered here will create average vectors spaced at this increment along the curvilinear path of the transect.

Files Button

The “Files” button opens a dialog to select all files for processing, using Shift-Click or Ctrl-Click to select multiple files.

Process Button

The “Process” button begins processing the files. The status window will show which file is being processed.

Close Button

The “Close” button closes the program.

Filtering Options

GPS Quality Filtering.—Filters out data with poor GPS quality. Only keep data with specified quality (typically, quality 4).

Dealing With Bad Data

Bad depth readings collected by the ADCP are assigned a value of zero when output to file. Because the instrument takes measurements from multiple beams simultaneously, any combination of beams may be bad for any given sample. Accordingly, the file output depth readings (*.mat) may contain any combination of zeros at each sample. In the event that the instrument does not receive a valid depth reading from at least one or two out of the possible five beams, the RiverSurveyor Live software tags the sample as “invalid” in the “Depth Reference” column of the display. However, the file output will still contain the appropriate number of zeros for each beam in the sample.

Note: It is also possible for a “very large” number to be written to the file instead of a zero, although this behavior has not yet been observed.

In theory, a bad depth reading could be the result of 1) the water being too shallow (in which case the actual depth is close to zero anyways), 2) a double-return (in which the acoustic signal actually travels down and back twice, resulting in a reported depth that is twice the actual depth) or, 3) some other unknown system malfunction. Due to the uncertainty associated with the source of “bad” data, a zero filtering function was *not* implemented so that more awareness of the data is forced upon the user.

Frequency Output

RiverSurveyor outputs several different types of frequency information associated with the measurements.

- There is a bottom track frequency (BT Frequency) array that contains the frequency tag associated with each depth measurement. It indicates whether the 1- or 3-megahertz (MHz) beams were used for the multibeam depth measurements. This information is used by SRH-HAPS to calculate the beam positioning since the geometry calculations are slightly different depending on which beam set is used for a given sample.

- There is a water track, or profiling, frequency (WT Frequency) array that contains the frequency tag associated with each velocity measurement. It indicates whether the 1- or 3-MHz beams were used for the velocity measurements at each sample.

- There is a "Depth Reference" column that can be viewed in the RiverSurveyor output table. This information indicates whether the depth measurement displayed is the vertical beam (representing the nadir beam alone) or bottom track (an arithmetic average of the four outer beams).

Option 2 – Bathymetry Data Collected With a SonTek S5/M9 HydroSurveyor ADCP

Selecting option 2 invokes a tool for post-processing depth soundings collected using the SonTek S5 or M9 ADCP with GPS when operated in the HydroSurveyor mode.

GPS Configuration

GPS positioning is provided with the Trimble R8 system (the Trimble R10 could theoretically be used, but has not yet been tested). The GPS hardware can be operated in either a "generic GPS" or "auxiliary GPS" configuration, as defined by the HydroSurveyor software. There are implications to the data processing workflow within SRH-HAPS depending on which GPS configuration is implemented during the data collection process. According to SonTek / Xylem, Inc. (Dave Velasco, personal communication), "auxiliary GPS" is the preferred configuration, although there is uncertainty as to why that is the case.

When using the "generic GPS" configuration, a NMEA log file for each data collection session is produced by the SonTek HydroSurveyor software, which contains geodetic information that can be useful in post-processing data. In the "auxiliary GPS" configuration, a NMEA log file is not recorded, which puts some additional constraints on data processing using SRH-HAPS. However, SRH-HAPS is set up to perform the data processing in either mode of operation, with or without the NMEA log files.

HydroSurveyor Data Export

After field data acquisition using the SonTek ADCP and HydroSurveyor software is complete, the input dataset for SRH-HAPS can be generated using the “Export soundings” and “Export” utility within the HydroSurveyor software.

1. Soundings must be exported as elevations, not depths. Thus, verify that the “Fixed Altitude (ft)” check box is *not* selected within the “Project Settings” tab under the “Project Configuration” menu (figure 10).

2. Export the soundings within the soundings data layer by selecting “Export soundings” in the expandable drop-down menu (figure 11).

3. Export the session files in Matlab (.mat) format by selecting “Tasks” then “Export Session” (figure 12). In the “Export data” dialogue box, select “All” sessions from the “Session to export” drop-down menu (figure 13).

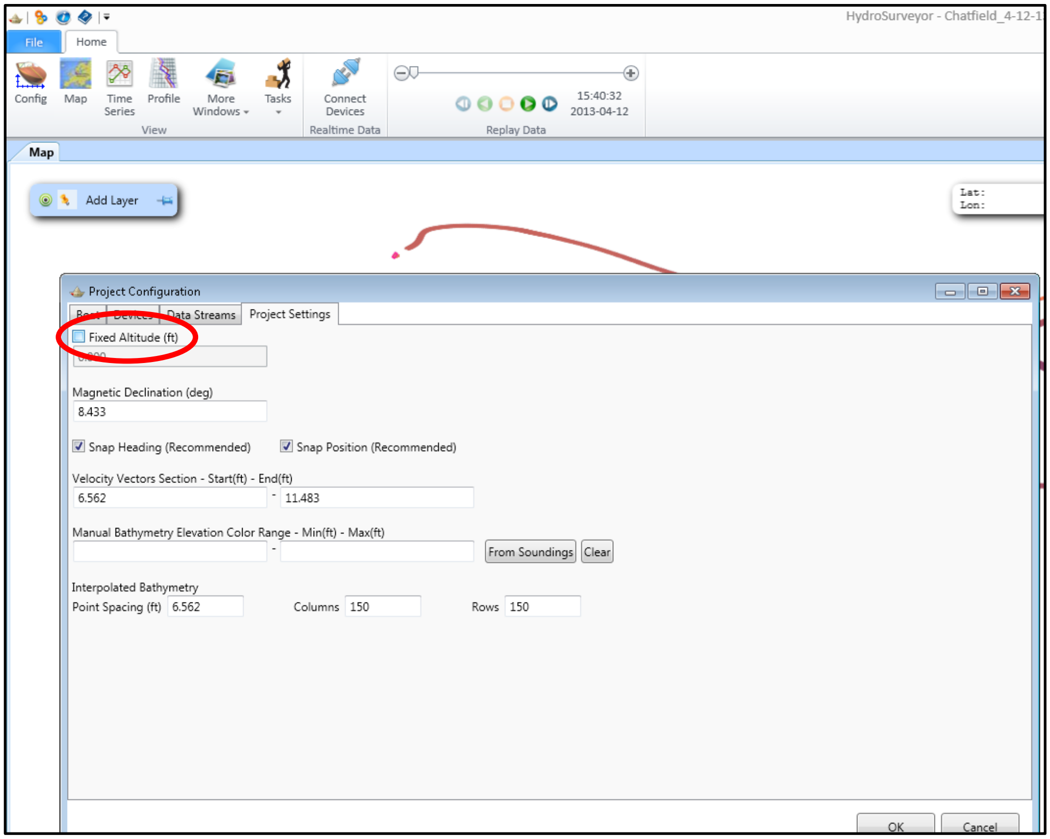


Figure 10.—In the SonTek HydroSurveyor software, verify that "Fixed Altitude" is *not* selected prior to the soundings export.

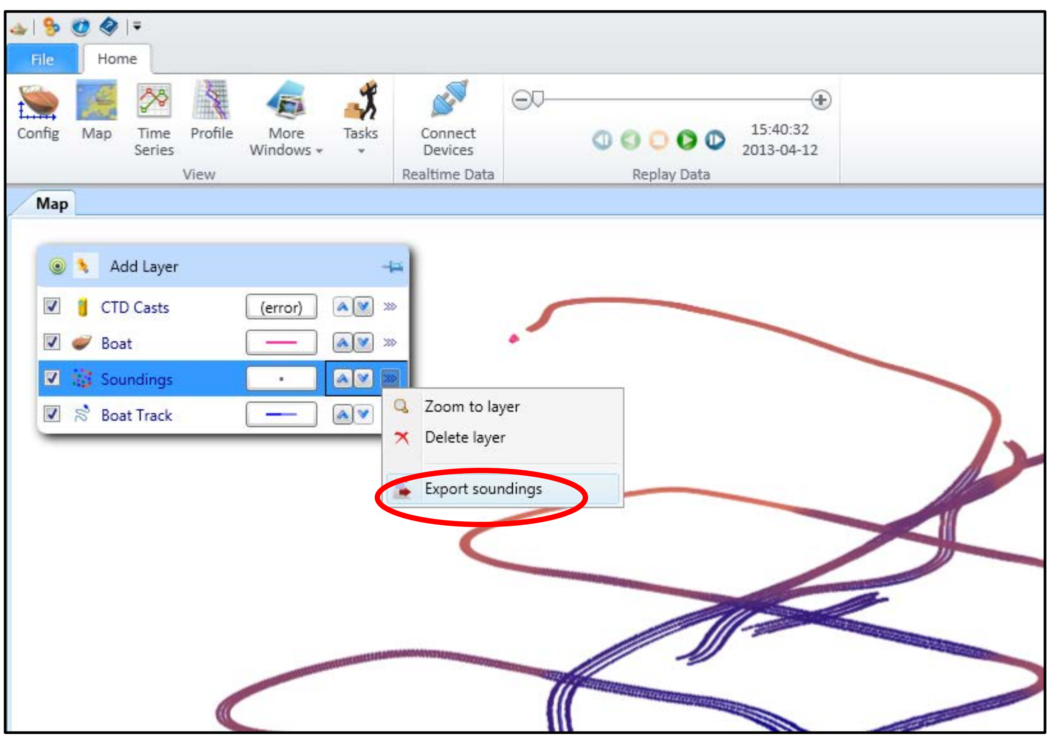


Figure 11.—"Export soundings" within the SonTek HydroSurveyor software.

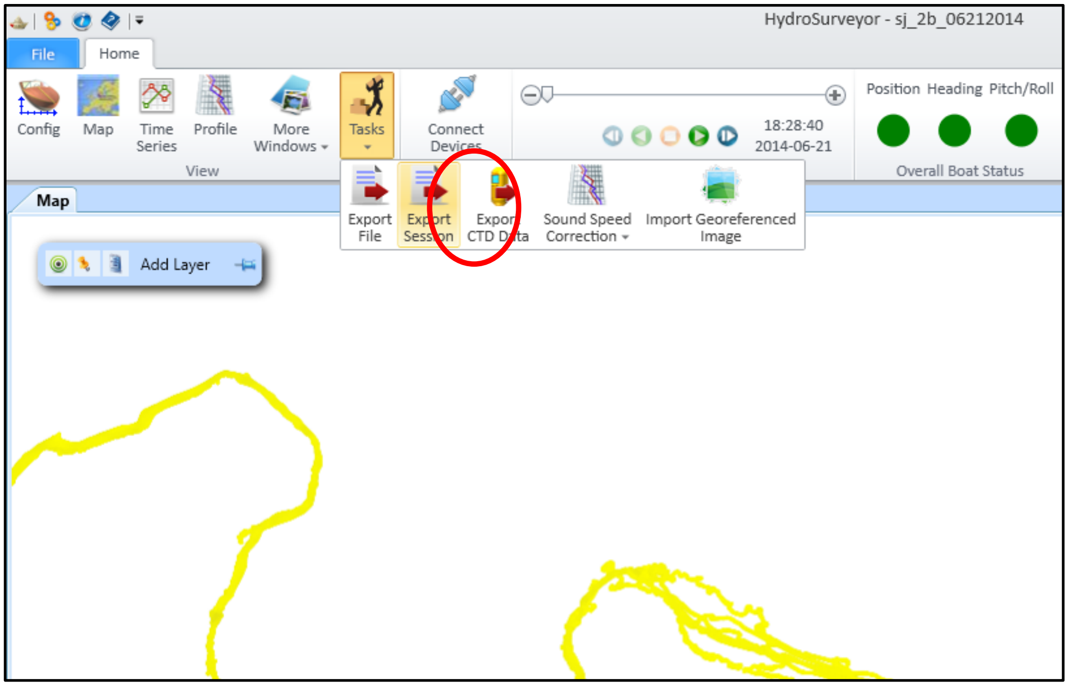


Figure 12.—In the HydroSurveyor software, export session files by selecting "Export Session" under the "Tasks" drop-down menu.

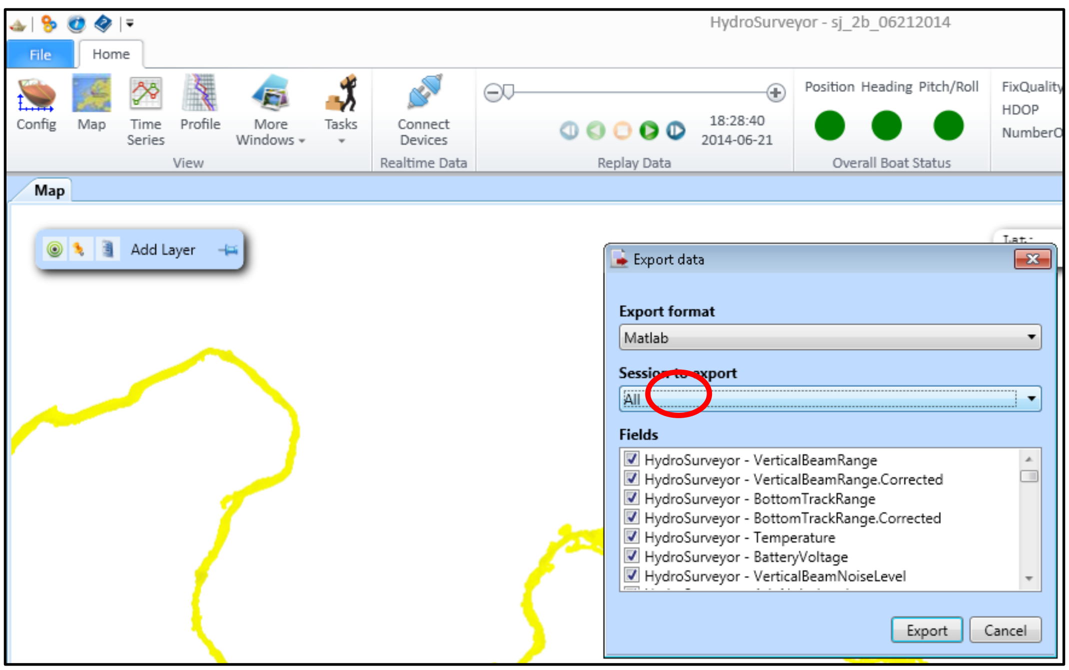


Figure 13.—In the HydroSurveyor software, select "All" sessions to export in the "Export data" dialogue box.

SRH-HAPS Processing Interface

The graphical user interface (GUI) is shown in figure 14.

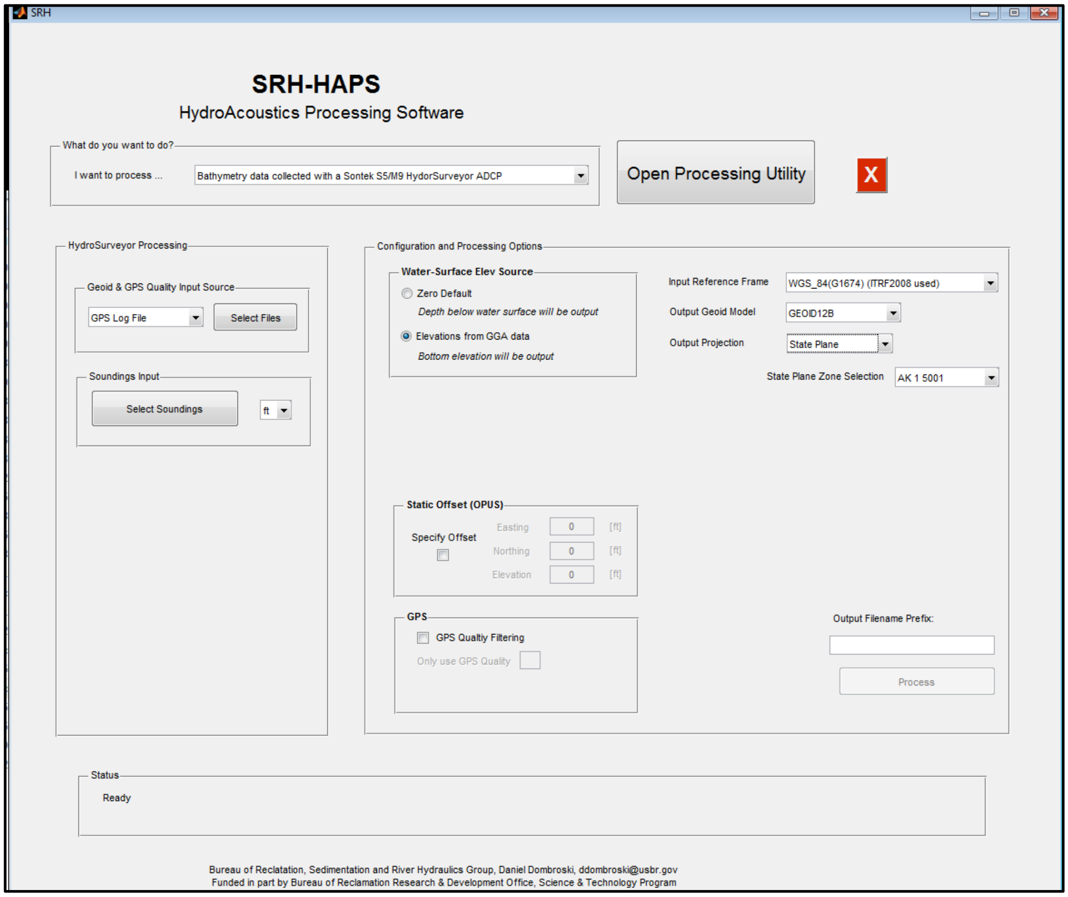


Figure 14.—The SRH-HAPS graphical user interface for processing "bathymetry data collected with a SonTek S5/M9 HydroSurveyor ADCP."

Geoid Input Source

The geoid separation distance must be removed from the orthometric heights (elevations) given in the soundings file so that the coordinate system may be updated and a new geoid separation applied. Removing the geoid separation from the orthometric height produces the ellipsoid height (height above the model ellipsoid). The "Geoid & GPS Quality Input Source" drop-down menu specifies how the geoid separation that is to be removed from the soundings elevation data is to be determined (details follow):

- If "GPS Log File" is selected, then the geoid separation values are pulled from the GGA string in the NMEA sequences contained within the GPS log files ("Generic GPS" configuration is required in order for GPS log files to be created during data acquisition). SRH-HAPS will ask for the parent folder where the GPS log files reside. The appropriate GGA string is paired to each soundings point based on a nearest neighbor search of a spatial triangulation of the data.

- If “Session File” is selected, then the geoid separation values are pulled from the Matlab session output files (SessOut#.mat) that can be exported from HydroSurveyor. SRH-HAPS will ask for the “.mat” session files. The appropriate geoid separation value is paired to each soundings point based on a time stamp interpolation.

- If “Calculated (EGM96)” is selected, the geoid separation is calculated based on the latitude/longitude pair at each soundings point using the NGA F477 tool (details follow).

Water Surface Elevation Source

Zero Default.—References all elevations from zero water surface elevation so that the resulting bathymetry represents depth values instead of elevation.

Elevations from GGA data.—Uses the elevation from the GGA string.

Select Soundings

The “Select Files” button opens a file browser for selection of the exported soundings file from HydroSurveyor (see the “HydroSurveyor Data Export” subsection previous to this). Soundings coordinates are expected to be in positive east convention when exported from HydroSurveyor software, which is currently the default convention used by HydroSurveyor. In positive east convention, California longitude is approximately -120 or +240. Longitude is then stored as both an east and west convention array within the code in order to ensure that the appropriate convention is used at each stage in the processing (see the following NGS tools). Be sure to also specify the correct units (m or ft) of the soundings from the drop-down menu.

Reference Frame

The “Input Reference Frame” and “Output Projection” specify the geographic reference frame of the input soundings and the desired output geographic projection of the finished bathymetric data. SRH-HAPS performs transformations between reference frames (details follow). Output projection can be specified in either UTM (meters) or State Plane (U.S. Survey Feet) coordinates. If “State Plane” is selected, the appropriate zone also needs to be specified via the drop-down menu.

Output Geoid

The "Output Geoid Model" is the desired geoid model to be applied to the finished bathymetry; it is left to the user to ensure that the output reference frame and output geoid model are compatible. The input geoid separation is pulled from either the GPS log files or the Matlab data export from HydroSurveyor and, hence, does not need to be specified.

Filtering

The "GPS Quality Filtering" check box under "GPS" determines whether or not filtering is performed on the data. If checked, only soundings with GPS quality values specified (typically, 4) are used.

SRH-HAPS Geodetic Code Basis

NGS INTG

The INTG (INTerpolate Geoid) tool was developed by the National Oceanic and Atmospheric Administration's (NOAA) National Geodetic Survey (NGS; Dan Roman) for interpolating geoid height given a user-specified position and geoid model. Interpolation is performed using either spline or bilinear interpolation. Gridded data model files (*.bin) are direct access, unformatted in binary format, and must be located within the search directory. The gridded data files are available for download from the NGS Web site, and are specific to each geoid model (e.g., Geoid09 vs. Geoid12A).

The INTG source code was written in C/C++ language. Integration into SRH-HAPS was performed by building a Matlab gateway routine and compiling the code into a Matlab executable (MEX) file. This allows the INTG program to be called as a function at the Matlab command line, or in script.

Note: SRH-HAPS uses INTG version 3.2, which is currently the latest release.

The INTG source code can be found at:
https://www.ngs.noaa.gov/GEOID/GEOID12A/GEOID12A_data.shtml.

The INTG readme file (specific to GEOID12A) can be found at:
https://www.ngs.noaa.gov/GEOID/GEOID12A/g2012Arme.txt.

NGS HTDP

The HTDP (Horizontal Time-Dependent Positioning) tool was developed by NOAA's NGS (Richard Snay and Christopher Pearson) for transforming positional coordinates across time and between spatial reference frames.

The HTDP source code was written in the FORTRAN (FORmula TRANslation) fixed-format style language. Integration into SRH-HAPS was performed by building a Matlab gateway routine and compiling the code into a Matlab executable (MEX) file. This allows the HTDP program to be called as a function at the Matlab command line, or in script.

Note: SRH-HAPS uses HTDP version 3.2.3, which is currently the latest release.

The HTDP source code, user's guide, and revision log can be found at: https://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml.

NGA F477

The F477 tool was developed by Ohio State University (Richard Rapp) in collaboration with the National Geospatial-Intelligence Agency (NGA)/National Aeronautics and Space Administration (NASA). The program calculates geoid undulation at a user specified location using the EGM96 geo-potential model. The undulation is relative to the WGS84(G873) ellipsoid.

The F477 source code was written in the FORTRAN (FORmula TRANslation) fixed-format style language. Integration into SRH-HAPS was performed by building a Matlab gateway routine and compiling the code into a Matlab executable (MEX) file. This allows the F477 program to be called as a function at the Matlab command line, or in script.

The F477 source code, user instructions, and EGM96 coefficients files can be found at: https://earth-info.nga.mil/GandG/wgs84/gravitymod/egm96/egm96.html.

SPCS83

The SPCS83 tool was developed by NOAA's NGS (Edward Carlson and Craig Larrimore) to convert NAD83 geodetic positions to NAD83 SPC and vice versa.

The SPCS83 source code was written in FORTRAN (FORmula TRANslation) fixed-format style language. Integration into SRH-HAPS was performed by building a Matlab gateway routine and compiling the code into a Matlab executable (MEX) file. This allow the SPCS83 program to be called as a function at the Matlab command line, or in a script.

The SPCS83 source code and user guide can be found at: https://www.ngs.noaa.gov/PC_PROD/SPCS83/.

Future Work

It is likely that future work will be required to maintain the SRH-HAPS capabilities while updates to ADCP and GPS hardware and software progress. Bathymetry mapping utilizes rapidly changing technology and it will be important for users to remain up to date in order to maintain efficient workflow, particularly as data requirements increase in routine project work.

SonTek M9 Acoustic Doppler Current Profiler Setup

By Sean Kimbrel, M.S., P.E., and Michael Sixta, M.S., P.E.

Introduction

The Sedimentation and River Hydraulics Group (SRH) in Reclamation's Technical Service Center uses a SonTek M9 Acoustic Doppler Current Profiler (ADCP) to collect channel bathymetry data as well as measure velocities and discharge. If using the SonTek M9 for collecting bathymetry data, see the "SonTek M9 Acoustic Doppler Current Profiler Setup and Post-Processing Using HYPACK®" section in this users guide. All discharge computations are done internally within the SonTek M9 unit (not the computer) so data will not be lost if communications drop out. The device uses nine hydro-acoustic beams (including a vertical [nadir] beam) of varying frequencies for its measurements. It has an internal compass that compensates for vessel motion due to surface conditions; thus, it is important to calibrate the compass before every job. It has a bottom tracking feature that acoustically tracks the vessel speed over ground, independent of Differential Global Positioning System (GPS). The specifications, including its limitations, are listed in table 1.

Table 1.—SonTek M9 Specifications

Specifications	Value
Profiling Range – Distance	0.06 to 40 m
Profiling Range – Velocity	+/-20 m/s
Depth – Range	0.20 to 80 m
Discharge Measurement Range – Bottom-Track	0.3 to 40 m
Discharge Measurement Range – Real-Time Kinematic GPS	0.3 to 80 m

Source: SonTek / Xylem, Inc. (https://www.sontek.com/riversurveyor-s5-m9).

The SonTek M9 can be deployed using either a boat/raft or a hydroboard.

Boat Setup

1. Mount the ADCP to boat.

2. Mount radio antennae and GPS receiver (R8) to boat on adjustable survey poles (see boat setup in figure 1).

3. Start up laptop and connect to inverter hooked up to 12-volt battery.

4. Connect GPS receiver directly to the laptop with short, black serial DB9 cable (serial port to serial port) to check the NMEA outputs.

    a. Open GPS Configurator on laptop and apply the following settings:

    - Trimble R8
    - COM 1
    - Disable RT17/RT27 outputs
    - Add two NMEA strings if the current outputs window is blank
        - GGA and VTG
        - Port 2
        - Ten (10) hertz (Hz)
    - Ignore port settings

    b. Check NMEA outputs using HyperTerminal software:

    - Connect using: COM 1
    - Bits per second: 38400
    - Data bits: 8
    - Parity: None
    - Stop bits: 1
    - Flow control: None
    - Should see NMEA strings flowing
    - Exit HyperTerminal software; no need to save the connection

5. Connect the ADCP data cable to the laptop by using the white serial-to-USB adapter cable.

6. Connect the GPS receiver to the ADCP through the grey cable.

7. Open the RiverSurveyor Live software on the laptop and set up the ADCP.

    a. Click “Connect to system:”

    - COM 1

    b. Work top-to-bottom on the Smart Page:

    - Compass calibrating
        - Recommend calibrating while mounted in boat; turn boat two times in 2 minutes while inducing pitch and roll in excess of what is anticipated in river
        - Reduce magnetic interference to the extent possible

- System settings
  - Transducer depth (water surface to bottom of the ADCP)
  - Screening distance: A minimum distance of 0.52 foot from the bottom of the transducer should be included in the total screening distance due to interference with the bottom of the ADCP
  - Salinity: 0
  - Magnetic declination: https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#declination
  - Track reference: GPS-GGA (boat) or Bottom-Track if no GPS
  - Depth reference: Vertical beam (boat)
  - Coordinate system: East, North, Up (ENU)
  - SmartPulseHD: Enabled

8. Start system.
   - Profile data collecting

   Note: Try not to let a single file exceed 1,000 samples.

Figure 1.—Completed boat setup.

Hydroboard Setup

Note: Front = facing upstream; Back = facing downstream.

1. Prepare for setup.

   a. Charge battery packs and laptop.

   b. Ensure following items are in the black ADCP case:

      - Short connection cable
      - Allen wrenches
      - Bluetooth antennae for both hydroboard and laptop

   c. Ensure following items are in blue backpack case:

      - Hydroboard
      - Blue fins
      - Screw drivers
      - Y-cable for tagline connection
      - Carabiners

2. Install two blue fins on bottom of hydroboard.

   a. Unscrew rectangular plate and insert into slot (figure 2).

   b. Install each fin, pointing back and curved side to outside of hydroboard (figure 3).

3. Install Power & Communications Module (PCM; white rectangular box) on top of hydroboard.

   a. Insert battery pack into PCM and verify terminal contacts are in correct position, then tighten and close lid (figure 4).

   b. Loosen black star keys, insert PCM, and tighten to attach to hydroboard (figure 5).

   c. Install Bluetooth antennae with red tip facing front (figure 5).

4. Mount the ADCP to hydroboard.

   a. Remove pole mount (used for boat installation) from top of the ADCP (figure 6).

   b. Loosen screw on top and push the ADCP through.

c. Have 1- to 2-inch draft between hydroboard and bottom of the ADCP (figure 7).

d. Align the ADCP with cable connection facing the PCM.

e. Connect short, black cable to the ADCP and PCM (figure 8).

5. Set up laptop and test connection.

   a. Screw in black Bluetooth antennae to box (**IT IS REVERSE THREADED!**).

   b. Plug in box to serial port on laptop.

   c. Plug in power cable from box to USB on laptop (figure 9).

   d. Turn on antennae using switch on box.

   e. Turn on PCM (large button on top) and check Bluetooth is working with laptop. Should see both lights illuminate green if connected to laptop (figure 10).

6. Set up data collection operation.

   a. Set up tagline across the channel using stakes or trees.

   b. Connect hydroboard to tagline using white Y cable and carabiners (figure 11).

   c. Attach ropes to hydroboard to ferry it back-and-forth across channel (figure 12).

7. Measure discharge.

   a. Estimate edge distance (ADCP to bank) on both sides ahead of measurement and try to keep constant.

   b. Collect at least 10 edge samples before starting measurement (pulling across river), and after reaching other side, before ending transect.

   c. Collect enough measurements to where there is less than a 10 percent variance among a minimum of four transects (two each direction) with a total minimum exposure time of at least 720 seconds (12 minutes).

Figure 2.—Insert rectangular plates from the fins into slots before putting blue fins in.

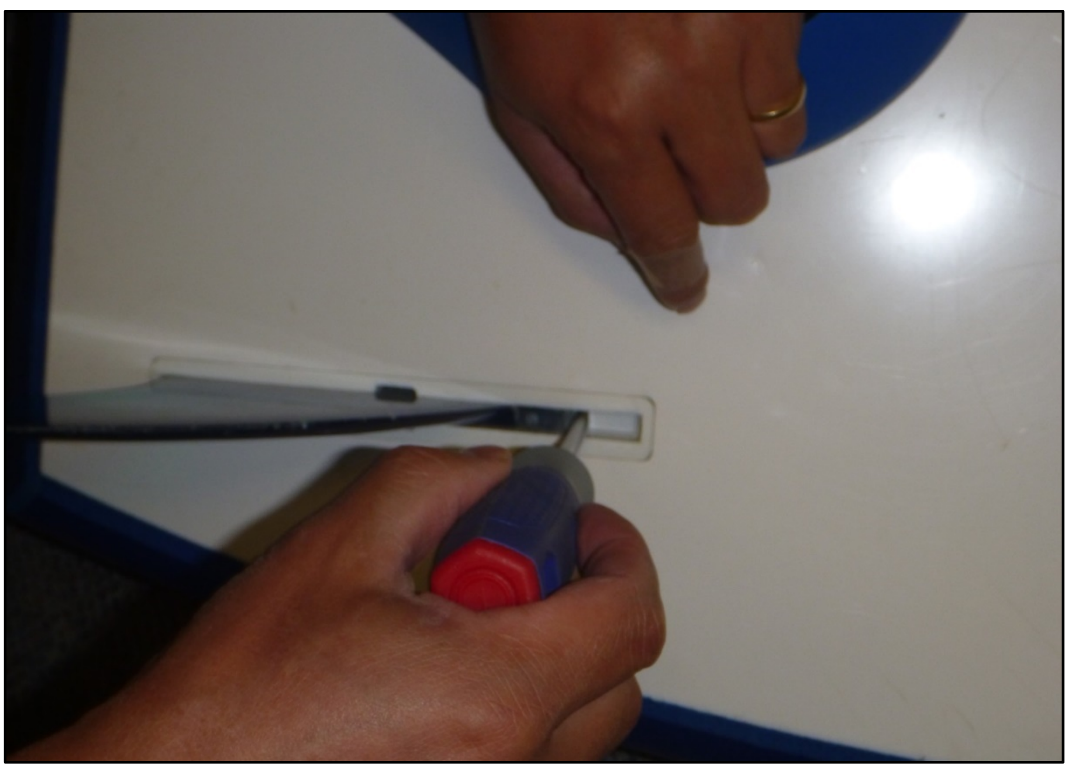


Figure 3.—Install blue fins on bottom of the ADCP by screwing fins into rectangular plates.

Figure 4.—Insert battery pack into power box (PCM). Verify terminals are correct.

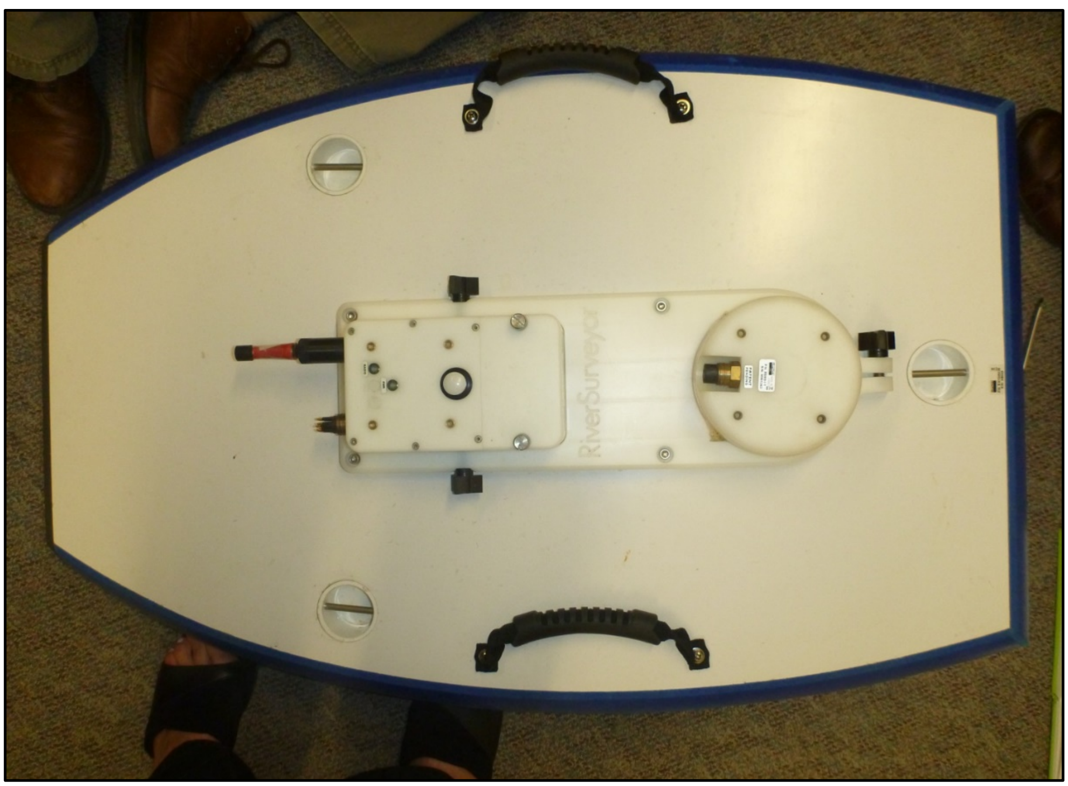


Figure 5.—Install Bluetooth antennae with red tip to power box (PCM).

Figure 6.—Remove top mount used for boat if setting up on hydroboard.

Figure 7.—Install ADCP with 1 to 2 inches of draft between hydroboard and bottom of the ADCP. Note: Do *not* install blue teardrop as it creates vortices.

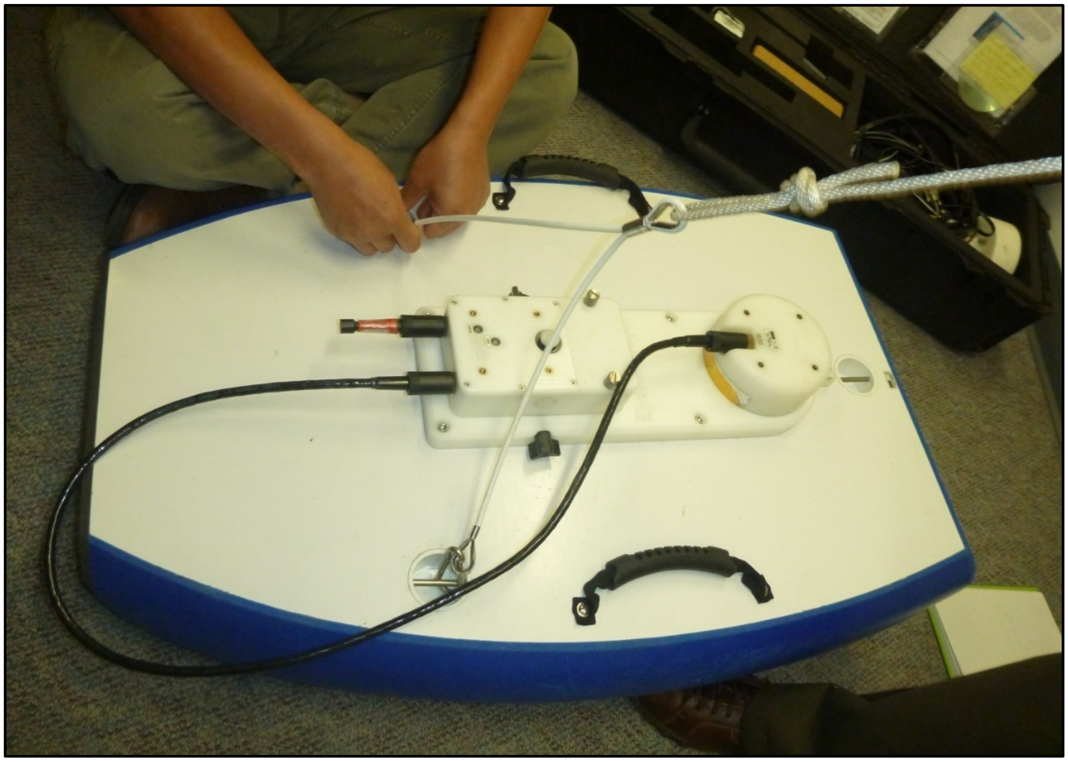


Figure 8.—Connect ADCP to PCM using short, black cable.

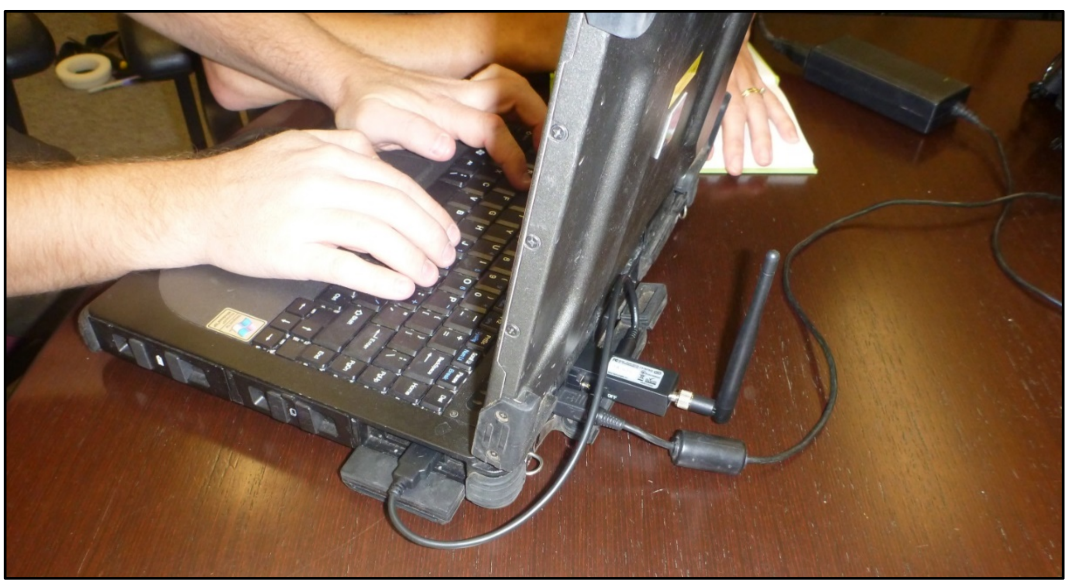


Figure 9.—Connect Bluetooth antennae to laptop and use USB cable to power on.

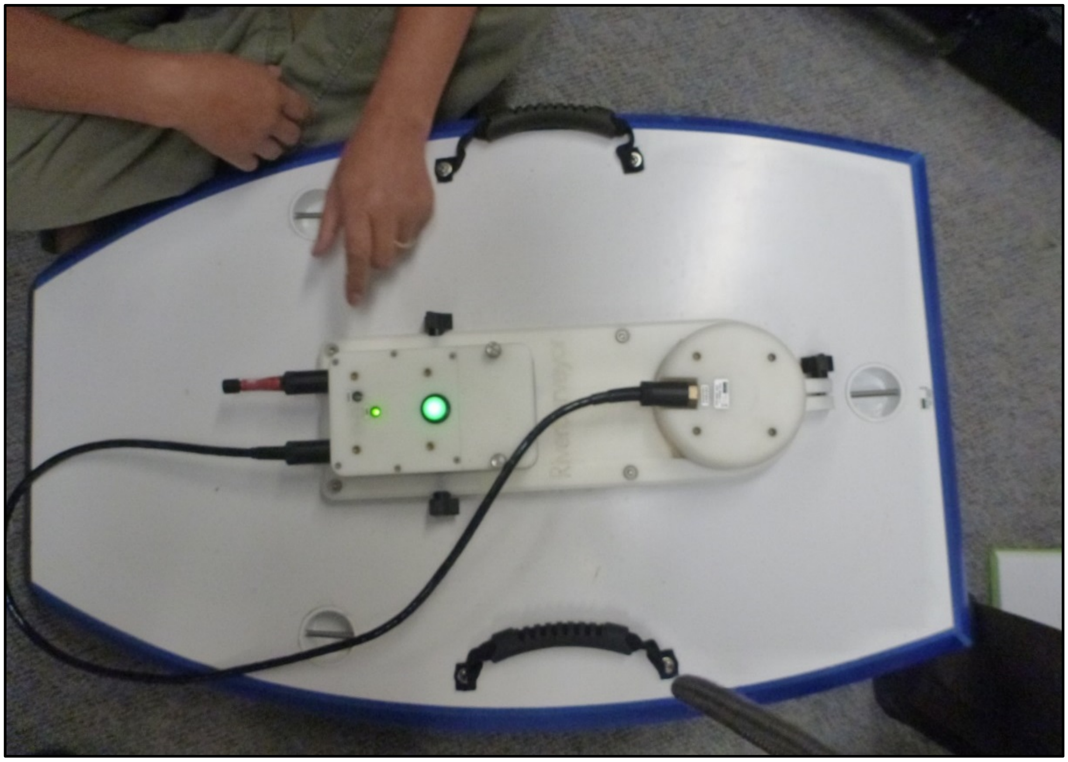


Figure 10.—Check Bluetooth is working with laptop. Should see both lights illuminate green if connected to laptop.

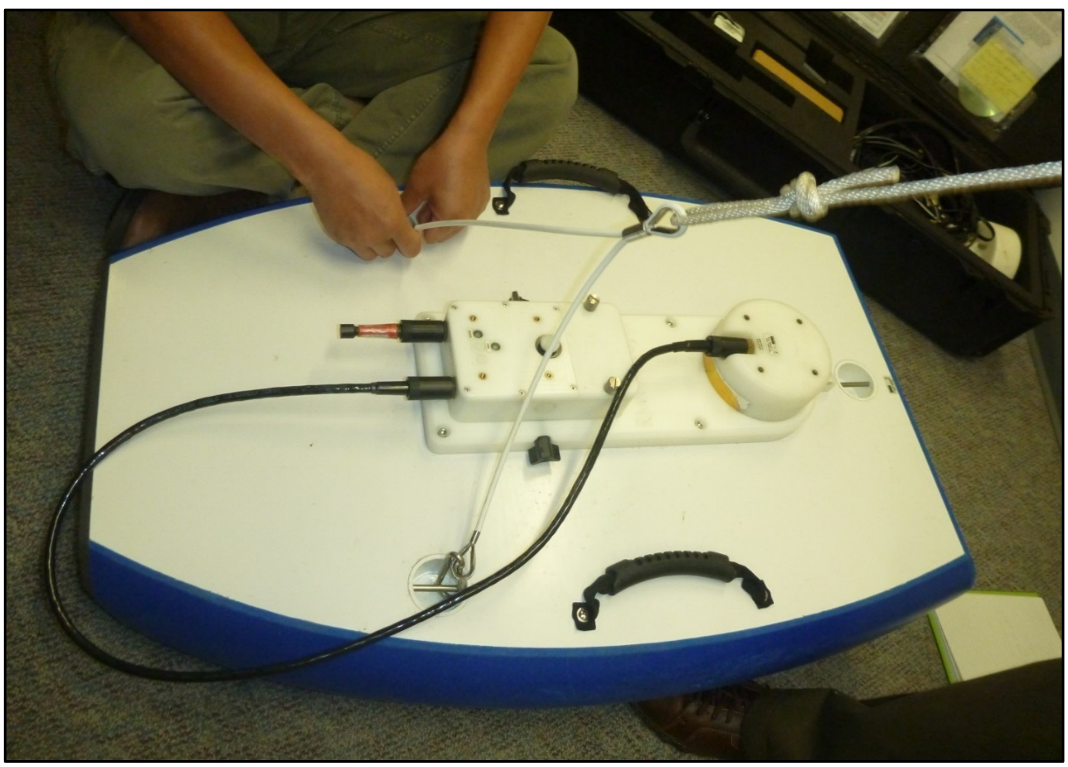


Figure 11.—Connect ADCP hydroboard to Y-cable and ropes for tagline to pull across river.

Figure 12.—Typical tagline setup with guide ropes for ferrying hydroboard back-and-forth across the channel.

SonTek M9 Acoustic Doppler Current Profiler Setup and Post-Processing Using HYPACK®

By Reece Carpenter and Kent Collins, P.E.

Introduction

The Sedimentation and River Hydraulics Group (SRH) in Reclamation's Technical Service Center uses a SonTek M9 Acoustic Doppler Current Profiler (ADCP) to collect channel bathymetry data as well as measure velocities and discharge. When collecting bathymetry data, the SonTek M9 is used with HYPACK®, a hydrographic surveying software for collecting and post-processing bathymetry data. This section describes the project and device setup within HYPACK, and the use of HYPACK for post-processing bathymetry data collected with the SonTek M9 ADCP. An additional "QuickStart Manual" published by HYPACK - A Xylem Brand (HYPACK / Xylem, Inc.) is also included as appendix C in this users guide.

Setup and Hardware Connection

In order to use the SonTek M9 with HYPACK for hydrographic surveying, the user must first set up a project within HYPACK and connect with the SonTek M9 to ensure proper functionality before continuing with data collection. A series of steps necessary for proper project and device setup and connection is outlined herein.

Project Setup

Each of the three subheadings under "*Project Setup*" indicates a different process required to establish a project in HYPACK. Each individual hydrographic survey site should have its own project.

Geodetic Parameters

The Geodetic Parameters window can be accessed via the drop-down menu in the HYPACK shell top menu bar (figure 1). Once the predefined grids and zone are established, ensure "Elevation Mode (Z-axis positive going up)" is checked. Under the RTK Tide Method radio buttons, verify "N from geoid model, K from user value" is also selected. This step will produce elevation values instead of raw or corrected depth values (figure 2). Once the geodetic parameters are set, click "OK" to exit the Geodetic Parameters window and re-enter the HYPACK shell.

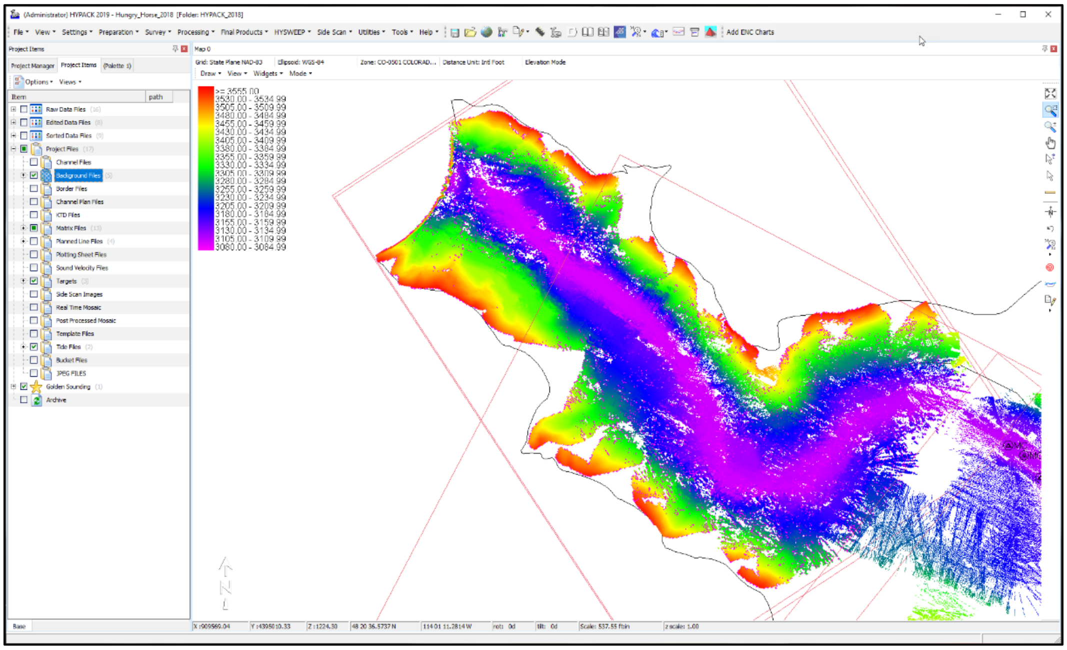


Figure 1.—Example of the HYPACK shell. This is the initial or home screen when using HYPACK.

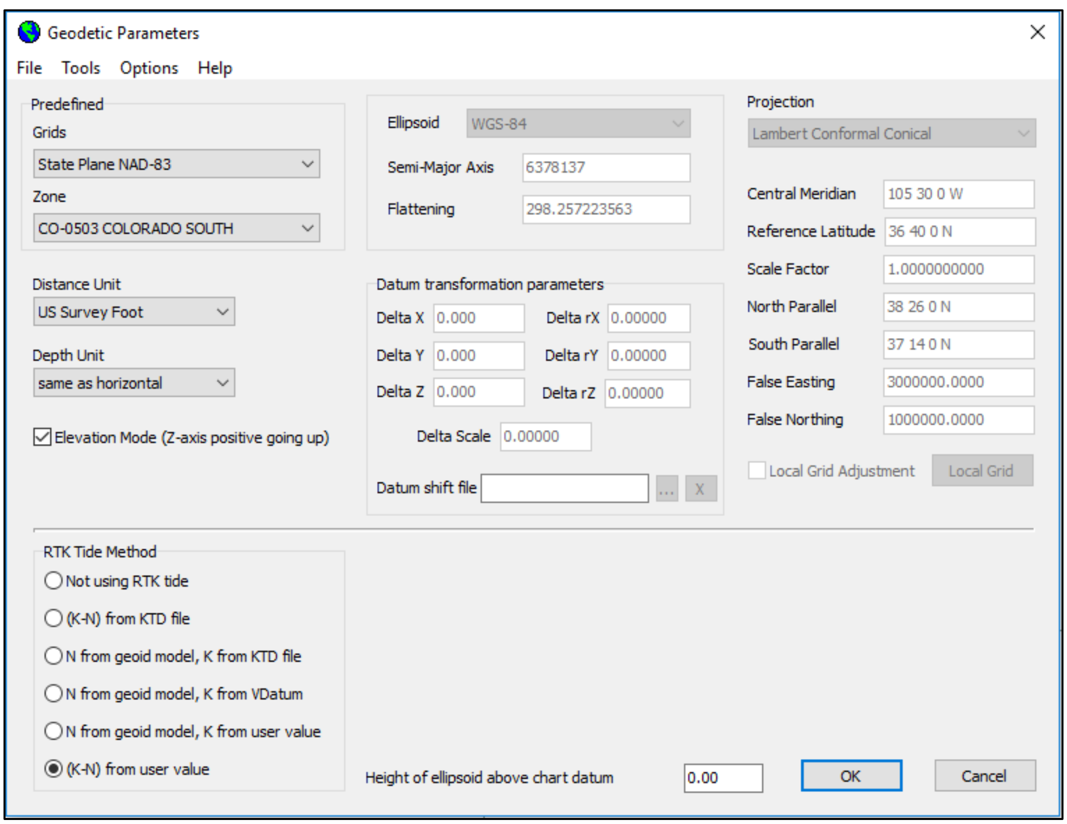


Figure 2.—Geodetic Parameters window.

Background Files

In the HYPACK shell under the Project Items tab in the left-hand screen (figure 1), open “Project Files,” right-click on “Background Files,” and then select “Add File.” This is typically a “.shp” file that shows the border of the project area or a georeferenced “.tif” file that shows aerial imagery, but can be a variety of georeferenced image types to provide background information during data collection and processing.

Planned Lines

Under the Preparation drop-down menu in the HYPACK shell top menu bar (figure 1), select “Line Editor” under “Editors” to create planned lines in the project area. Planned lines are used for orientation and navigation during data collection and represent the desired pattern for the survey vessel to traverse.

Matrix Setup

To view the survey coverage in real-time while collecting data, the user must create a matrix. Under the Preparation drop-down menu in the HYPACK shell top menu bar (figure 1), select “Matrix Editor” under “Editors” to create a rectangular box to use as a matrix. The matrix box does not need to conform to project borders, but should cover a larger area than anticipated. At this juncture, it is important to determine matrix cell size. For shallower areas, the cell size should be set to smaller dimensions. For deeper areas, the cell should be set to larger sizes. It may be useful to create multiple matrix areas for the survey depending on anticipated depth (figure 3).

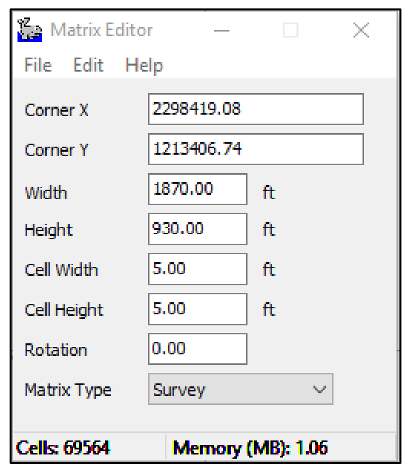


Figure 3.—Matrix Editor window.

Important Note: Memory usage increases as the matrix resolution increases (cell dimensions decrease) and as the matrix area increases. Individual matrices should not exceed 100 megabytes (MB) of memory. HYPACK has trouble updating quickly and redrawing the matrix when individual file sizes are greater than 100 MB. When saving the matrix file, naming each file according to location and cell size (e.g., “Boat Ramp 3x3.mtx” or “Outlet Works 5x5.mtx”) helps with organization during collection and processing.

Once matrix files are created, collected bathymetry data will display and update in real-time if it is selected in the HYPACK Survey window (figure 4). Under the Survey drop-down menu in the HYPACK shell top menu bar (figure 1), select “HYPACK Survey” to access this window. Once in the HYPACK Survey window, load the matrix files using the following two steps:

1. Click on “Matrix” from the HYPACK Survey menu bar (figure 4).
2. Select “Load all Matrices.”

If multiple matrices were created for the project, this will prevent the user from having to load each matrix individually as the survey vessel passes from one matrix to the next.

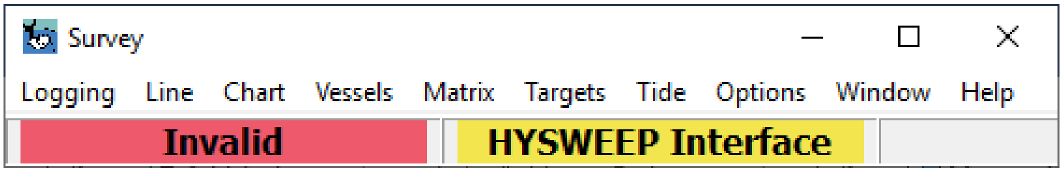


Figure 4.—HYPACK Survey window (and menu bar) accessed from the HYPACK shell.

Device(s) Setup

Within a project, survey devices are set up in the HYPACK Combined Hardware window (figure 5). Under the Preparation drop-down menu in the HYPACK shell top menu bar (figure 1), select “Hardware Setup” to access this window. Under the Hardware and Boat mobiles on the left side of the HYPACK Combined Hardware window, add two devices—one for the Global Positioning System (GPS) data (gps.dll) and one for the SonTek M9 (SonTek_M9.dll) (figure 5).

GPS Device Setup

1. In the HYPACK Combined Hardware window, verify both the GPS device and the **Survey Devices** tab are selected. In the Functions box in the lower left corner of the Survey Devices tab, ensure everything is checked EXCEPT “Depth” and “Heading,” then click on “Setup.” Under the Advanced tab in the GPS Setup popup window, ensure only the “GGA” and “VTG” used sentences are checked, then click “OK” (figure 5).

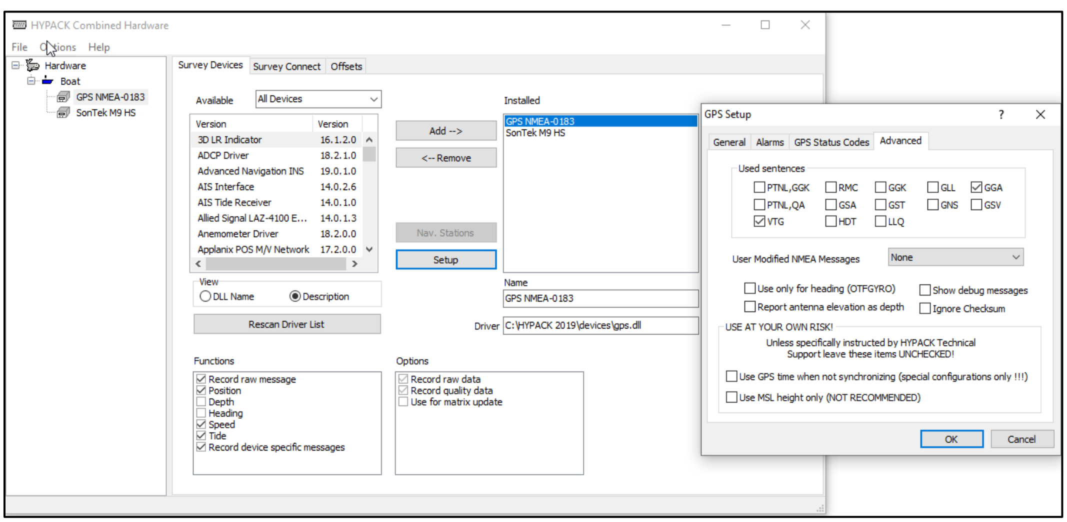


Figure 5.—HYPACK Combined Hardware window for setting up survey devices.

2. While still within the HYPACK Combined Hardware window, select the "**Survey Connect**" tab (to the immediate right of the Survey Devices tab). Click on the small box containing ellipsis, just right of the long Device Connection box. In the Device Connection popup window, the user can connect to the GPS device with the following settings (figure 6).

   - Set Connection Type to "Serial"

   - Set Serial Parameters to:

     - Port = COM1
     - Data bits = 8
     - Parity = None
     - Speed = 38400
     - Stop bits = 1
     - Flow control = None

   - Click "OK"

   Note: The COM port may vary depending on the user's laptop (figure 6).

   Back under the Survey Connect tab, click on "Test Device" to verify receipt of NEMA string data from the GPS receiver (figure 6).

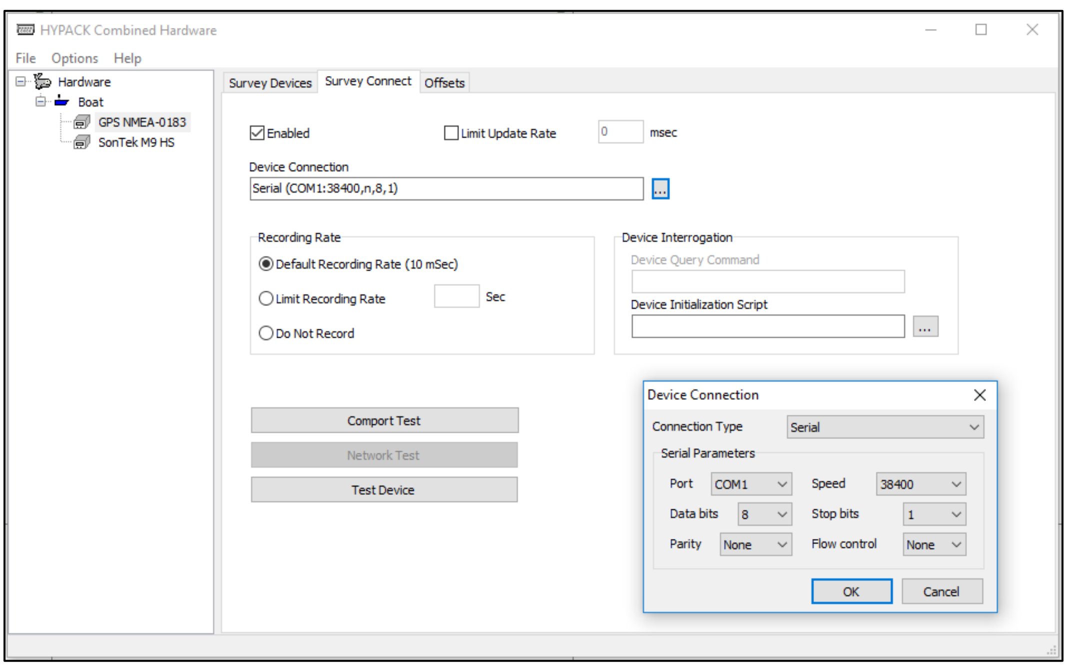


Figure 6.—Survey Connect tab for the selected GPS device within the HYPACK Combined Hardware window.

3. While still within the HYPACK Combined Hardware window, select the "**Offsets**" tab (to the immediate right of the Survey Connect tab) and input the GPS receiver offsets from Center of Mass or common reference point.

   Note: Vertical offset is positive downward and measured from the water line, as indicated within HYPACK.

SonTek M9 Device Setup

1. In the HYPACK combined Hardware window, verify both the SonTek M9 device and the **Survey Devices** tab are selected. In the Functions box in the lower left corner of the Survey Devices tab, ensure everything is checked EXCEPT "Position." In the Options box in the lower right corner of the Survey Devices tab, ensure "Use for matrix update" is checked. This will allow the user to create a coverage map in real-time. Then, click on "Setup." Under the Main tab in the Settings popup window, verify "Use as Multi-Transducer" is checked (figure 7).

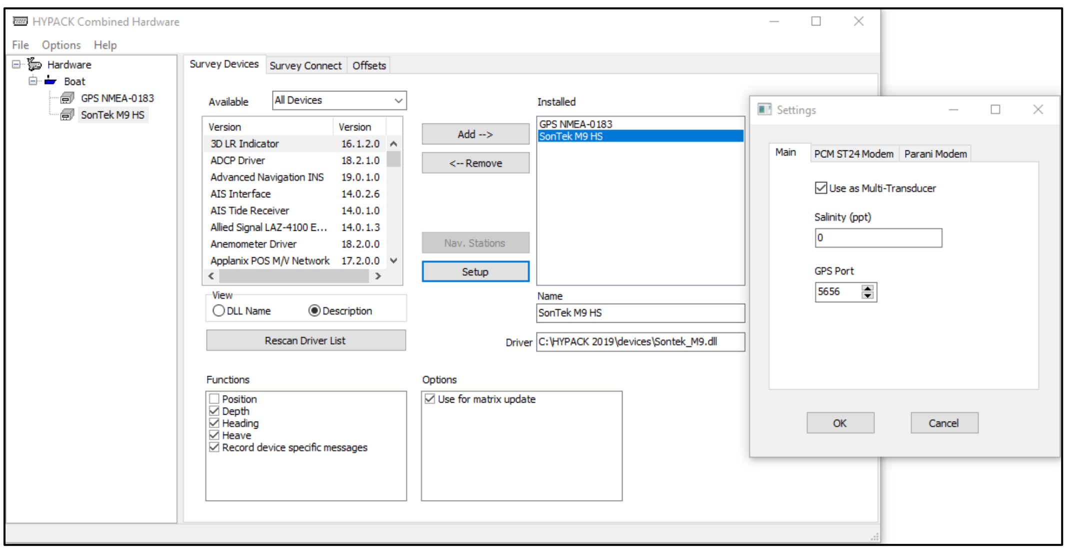


Figure 7.—Settings popup window under the Survey Devices tab within the HYPACK Combined Hardware window.

2. While still within the HYPACK Combined Hardware window, select the "**Survey Connect**" tab (to the immediate right of the Survey Devices tab). Ensure the "Enabled" box is checked and the "Limit Update Rate" box remains unchecked (default); the rate should be left at "0 msec." Click on the small box containing ellipsis, just right of the long Device Connection box. In the Device Connection popup window, the user can connect to the SonTek M9 device with the following settings (figure 8):

- Set Connection Type to “Serial”

- Set Serial Parameters to:

    - Port = COM14 (will vary by laptop used for data collection)
    - Data bits = 8
    - Parity = None
    - Speed = 57600
    - Stop bits = 1
    - Flow control = None

- Click “OK”

Note: Verify the “Default Recording Rate (10 mSec)” radio button under Recording Rate is selected (figure 8).

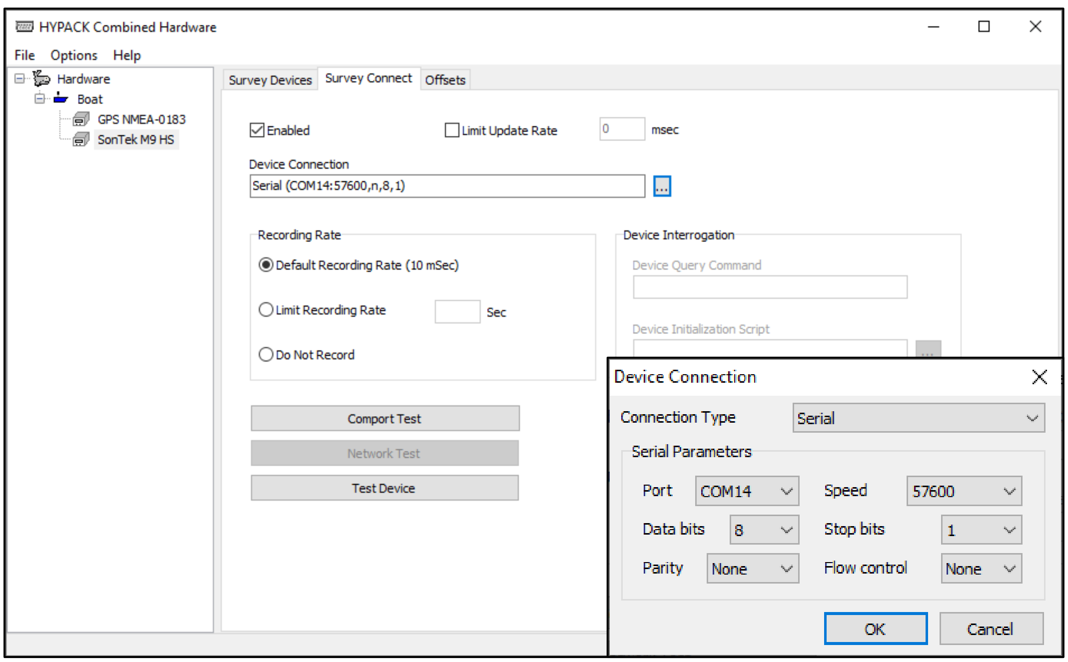


Figure 8.—Device Connection popup window under the Survey Connect tab within the HYPACK Combined Hardware window.

3. While still within the HYPACK Combined Hardware window, select the “**Offsets**” tab (to the immediate right of the Survey Connect tab) and input the SonTek M9 transducer offsets from Center of Mass or common reference point.

   Note: Vertical offset is positive downward and measured from the water line, as indicated within HYPACK.

Note: Under the "Rotation" column in the Offsets tab, enter the yaw to indicate the orientation of the SonTek M9 and its compass. The yaw is entered as the combination of the rotation of the SonTek M9 and the magnetic declination of the survey area:

- The rotation of the SonTek M9 refers to its orientation relative to pointing the data cable straight towards the center of the bow of the survey vessel (either +22.5^o or -22.5^o; clockwise rotation is positive).

- The magnetic declination is the influence of Earth's magnetic field on the internal magnetic compass of the SonTek M9. Magnetic declination (in degrees from True North) can be determined during project setup utilizing the National Oceanic and Atmospheric Administration's (NOAA) "Magnetic Field Calculators." These can be accessed offsite through NOAA's public Web site at www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#declination by entering the coordinates of the survey area, or they can be accessed onsite through NOAA's mobile Web site at www.ngdc.noaa.gov/geomag/calculators/mobileDeclination.shtml by using the location of any mobile device.

- The final yaw offset in degrees is calculated by adding the rotation of the SonTek M9 to the magnetic declination at the survey site. For example, a yaw of -22.5^o and a magnetic declination of +13.5^o would result in a final yaw offset of +9.0^o.

4. The final step of setting up a SonTek M9 device in the HYPACK Combined Hardware window is compass calibration. The magnetic compass inside the SonTek M9 must be calibrated to its surrounding magnetic field to read accurate headings. To calibrate the SonTek M9 internal compass:

    - Verify the SonTek M9 device is selected under the Hardware and Boat mobiles on the left side of the HYPACK Combined Hardware window and then select "Options" from the menu bar (figure 8 or 9). Select "SonTek Utilities," then click on "Compass Calibration" under standard functions (figure 9) to access the compass calibration routine.

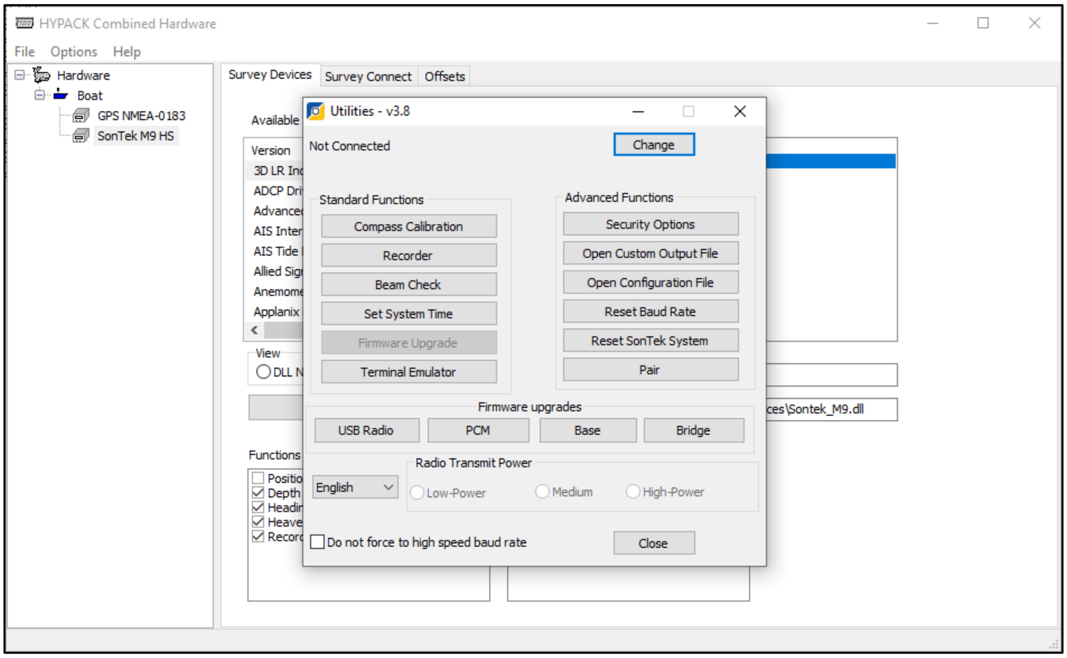


Figure 9.—SonTek Utilities home screen where Compass Calibration can be accessed.

- Perform compass calibration (two complete rotations of the SonTek M9 over 2 minutes). Repeat compass calibration until "Magnetic influence is acceptable" and "Passed Calibration" messages appear near the bottom of the compass calibration popup window (figure 10). If compass calibration fails multiple times, the survey vessel with mounted SonTek M9 may need to be moved to another nearby location within the survey area for proper calibration (away from ferrous metals, power lines, large metal structures, and other sources of magnetic influence). Examples of successful and unsuccessful compass calibrations are shown in figure 10 and 11, respectively.

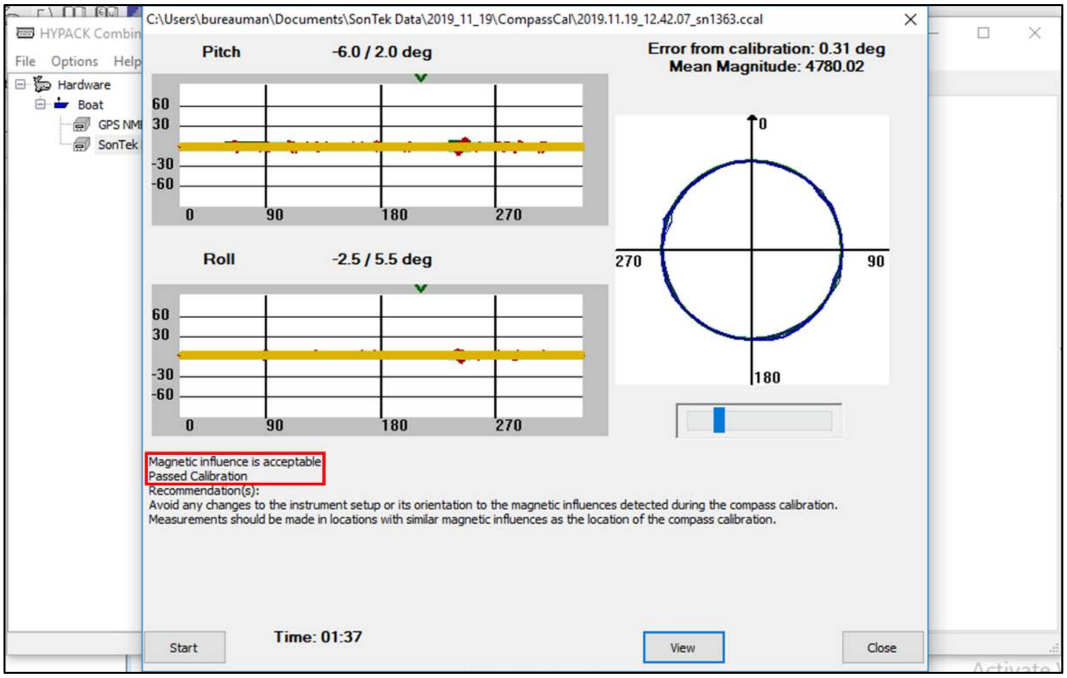


Figure 10.—Example of successful SonTek M9 magnetic compass calibration.

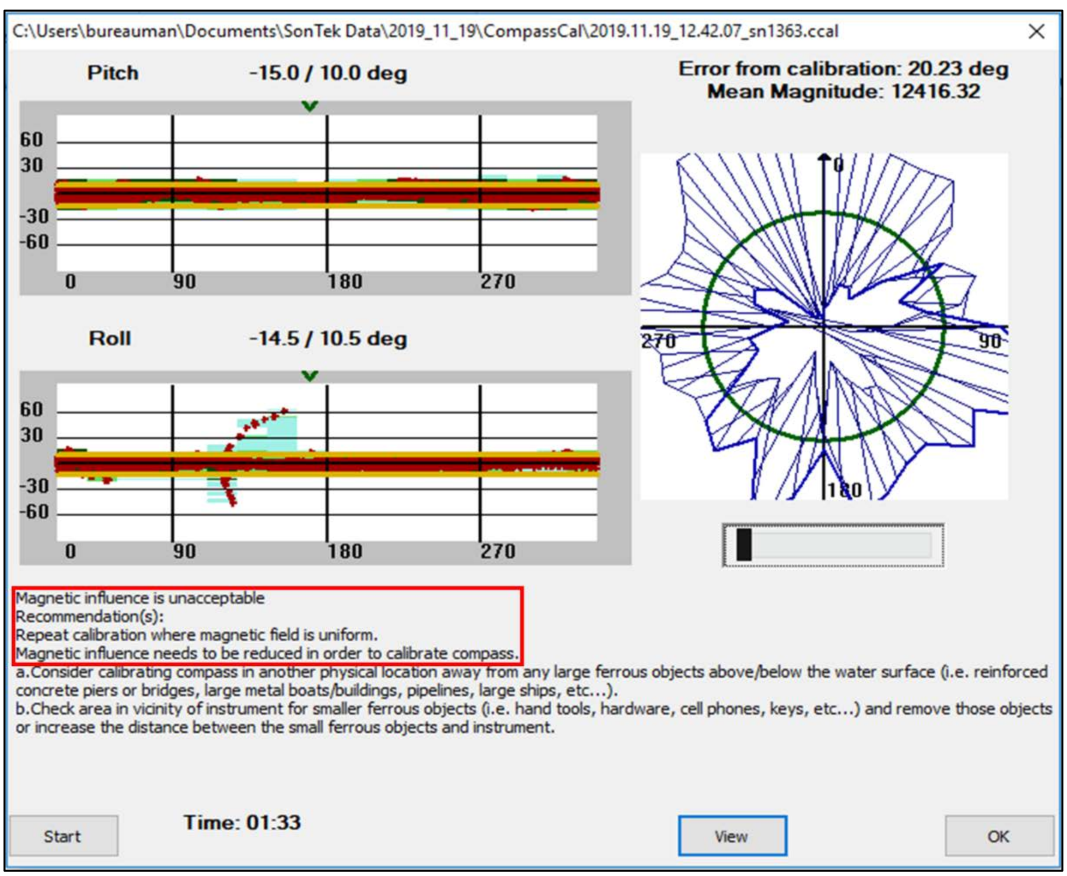
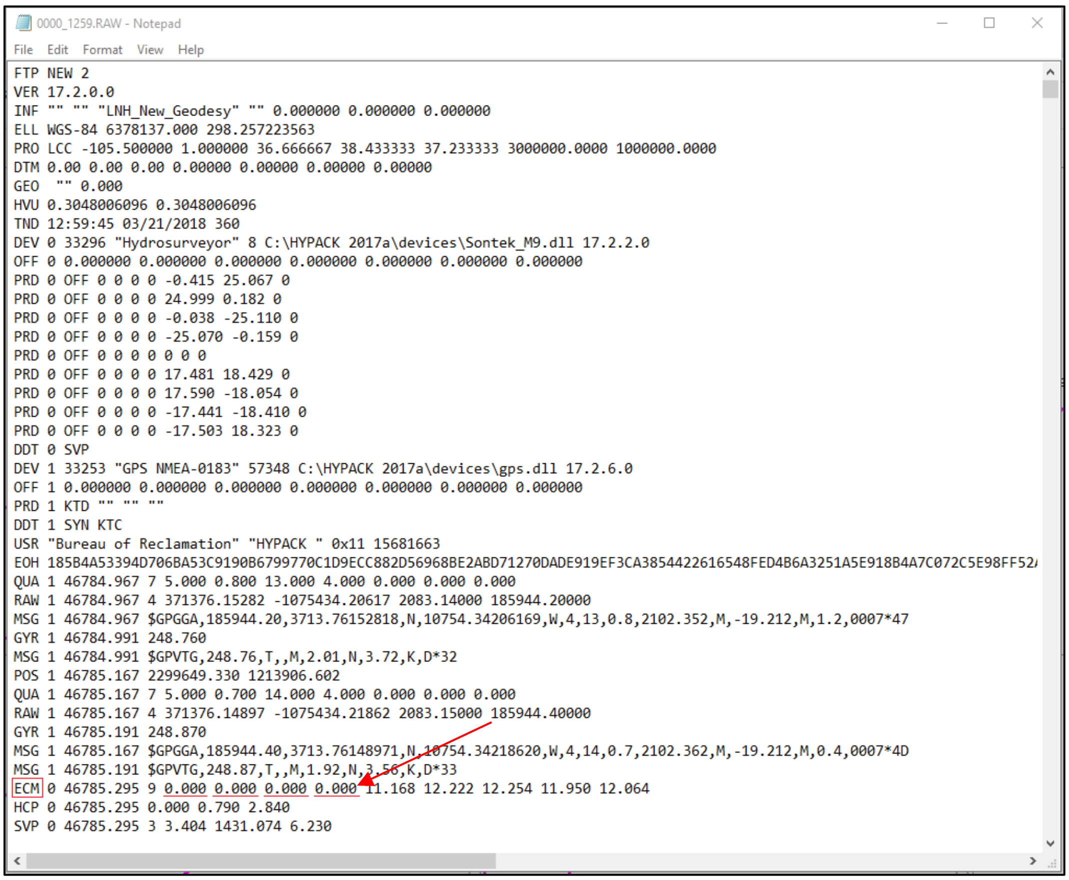


Figure 11.—Example of unsuccessful SonTek M9 magnetic compass calibration.

SonTek M9 Data Post-Processing

After data collection, when the raw data files are displayed in the HYPACK shell (raw collected data files are designated with ".RAW" extension), they will all display as ZERO measurements. This is because four of the nine beams that the SonTek M9 uses only measure the top 1 to 2 meters of depth and will return zero as the sounding measurement. The Hypack shell only displays the first measurement returned.

The user can view this by opening the ".RAW" file in Notepad and scrolling down to "ECM." The first four sounding measurements are underlined and are all zero. The next five sets of numbers are the actual soundings from the five beams in use (figure 12).




```
FTP NEW 2
VER 17.2.0.0
INF "" "" "LNH_New_Geodesy" "" 0.000000 0.000000 0.000000
ELL WGS-84 6378137.000 298.257223563
PRO LCC -105.500000 1.000000 36.666667 38.433333 37.233333 3000000.0000 1000000.0000
DTM 0.00 0.00 0.00 0.00000 0.00000 0.00000 0.00000
GEO  "" 0.000
HVU 0.3048006096 0.3048006096
TND 12:59:45 03/21/2018 360
DEV 0 33296 "Hydrosurveyor" 8 C:\HYPACK 2017a\devices\Sontek_M9.dll 17.2.2.0
OFF 0 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
PRD 0 OFF 0 0 0 0 -0.415 25.067 0
PRD 0 OFF 0 0 0 0 24.999 0.182 0
PRD 0 OFF 0 0 0 0 -0.038 -25.110 0
PRD 0 OFF 0 0 0 0 -25.070 -0.159 0
PRD 0 OFF 0 0 0 0 0 0 0
PRD 0 OFF 0 0 0 0 17.481 18.429 0
PRD 0 OFF 0 0 0 0 17.590 -18.054 0
PRD 0 OFF 0 0 0 0 -17.441 -18.410 0
PRD 0 OFF 0 0 0 0 -17.503 18.323 0
DDT 0 SVP
DEV 1 33253 "GPS NMEA-0183" 57348 C:\HYPACK 2017a\devices\gps.dll 17.2.6.0
OFF 1 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
PRD 1 KTD "" "" ""
DDT 1 SYN KTC
USR "Bureau of Reclamation" "HYPACK " 0x11 15681663
EOH 185B4A53394D706BA53C9190B6799770C1D9ECC882D56968BE2ABD71270DADE919EF3CA3854422616548FED4B6A3251A5E918B4A7C072C5E98FF52
QUA 1 46784.967 7 5.000 0.800 13.000 4.000 0.000 0.000 0.000
RAW 1 46784.967 4 371376.15282 -1075434.20617 2083.14000 185944.20000
MSG 1 46784.967 $GPGGA,185944.20,3713.76152818,N,10754.34206169,W,4,13,0.8,2102.352,M,-19.212,M,1.2,0007*47
GYR 1 46784.991 248.760
MSG 1 46784.991 $GPVTG,248.76,T,,M,2.01,N,3.72,K,D*32
POS 1 46785.167 2299649.330 1213906.602
QUA 1 46785.167 7 5.000 0.700 14.000 4.000 0.000 0.000 0.000
RAW 1 46785.167 4 371376.14897 -1075434.21862 2083.15000 185944.40000
GYR 1 46785.191 248.870
MSG 1 46785.167 $GPGGA,185944.40,3713.76148971,N,10754.34218620,W,4,14,0.7,2102.362,M,-19.212,M,0.4,0007*4D
MSG 1 46785.191 $GPVTG,248.87,T,,M,1.92,N,3.56,K,D*33
ECM 0 46785.295 9 0.000 0.000 0.000 0.000 11.168 12.222 12.254 11.950 12.064
HCP 0 46785.295 0.000 0.790 2.840
SVP 0 46785.295 3 3.404 1431.074 6.230
```

Figure 12.—Sounding measurements displayed in the ".RAW" file via Notepad. The first four soundings (of nine) are underlined and are all zero.

SBMAX64

All bathymetric data editing takes place in SBMAX64, the editing subroutine within the HYPACK software package. To display sounds as elevations in the HYPACK shell, the user needs to run the raw data files through SBMAX64. Under the Processing drop-down menu in the HYPACK shell top menu bar, select and open “Single Beam Editor (64 bit).”

With SBMAX64 now open, load the survey by clicking on the yellow folder icon under Survey Files. Select the raw data “.LOG” file and then click “Open” (figure 13).

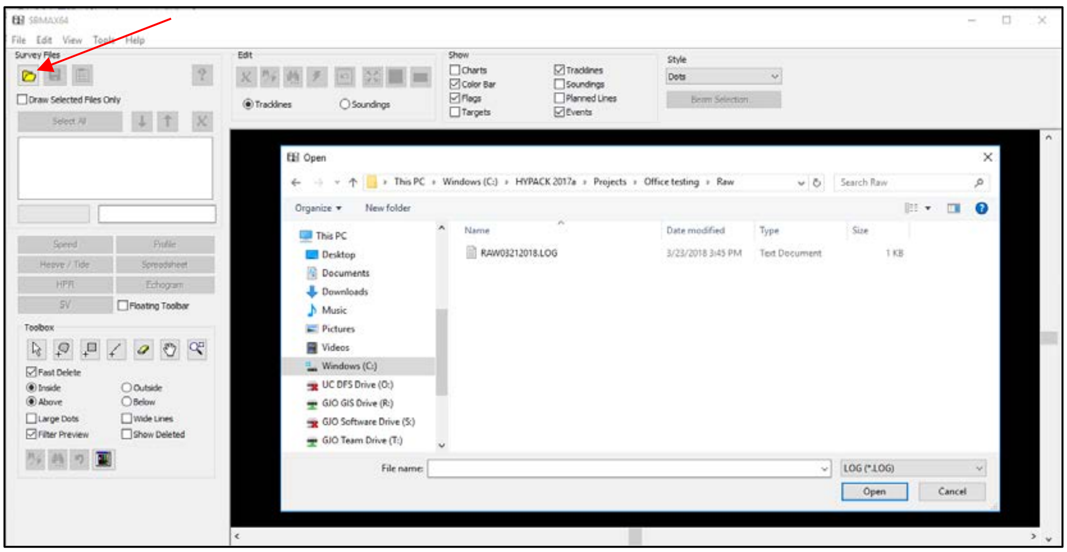


Figure 13.—SBMAX64 main menu window.

In the Catalog popup window, highlight the file(s) to process and click “Select.” The user can either “Select All” or click and highlight the specific file(s) to look at. To get back to the file directory, click “Exit Catalog” (figure 14).

Once the files are selected, the user will need to configure the parameters to be read.

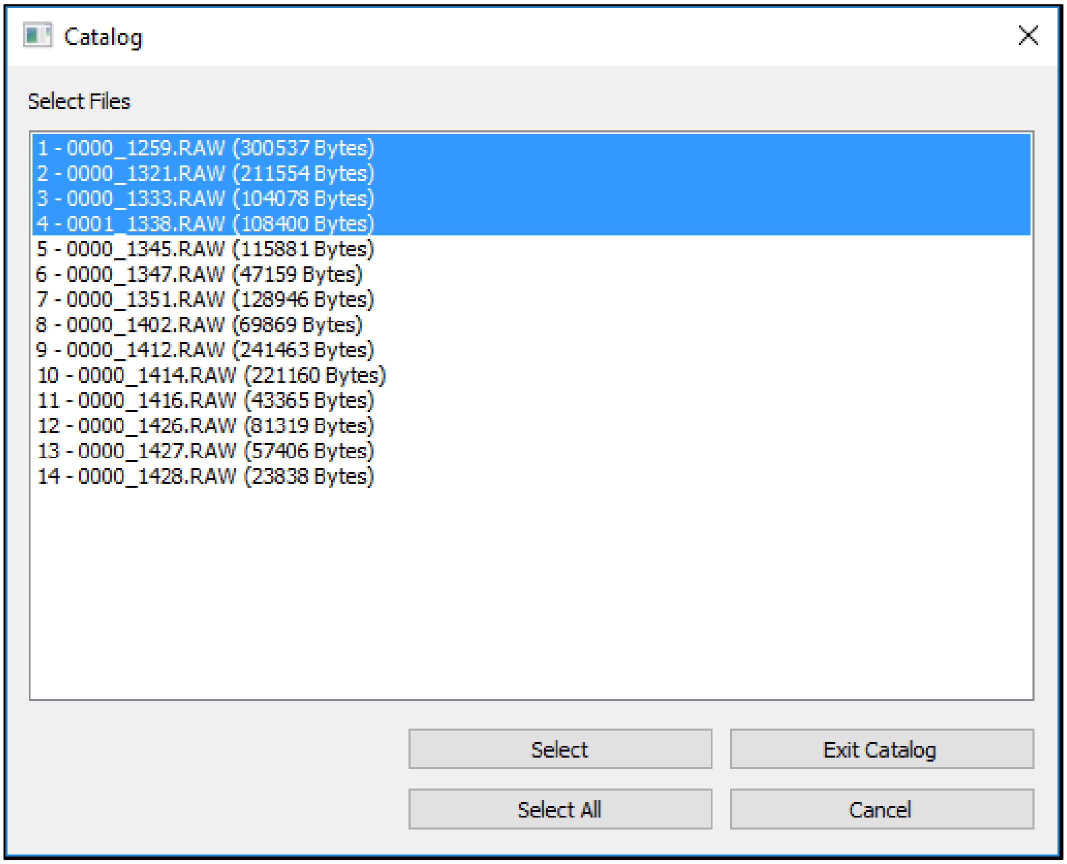


Figure 14.—Raw data files (for selection) in the Catalog popup window in SBMAX64.

Parameters Setup

In the SBMAX64 main menu window, click on the blue bullet list icon under Survey Files to access the Read Parameters window (figure 15).

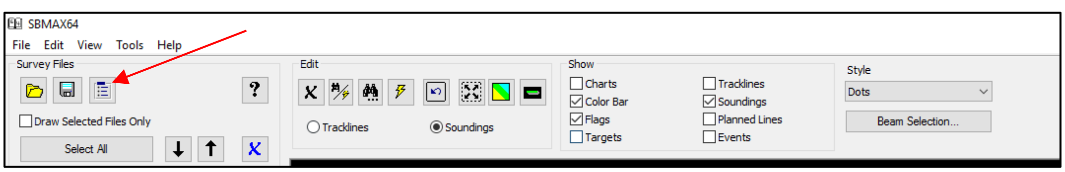


Figure 15.—Read Parameters icon (blue bullet list) in SBMAX64 main menu window.

1. Under the **Survey** tab in the Read Parameters window, verify the “Elevation Mode” radio button is selected. Under Depth Conversion, verify “Invert Tide Values” is checked (figure 16).

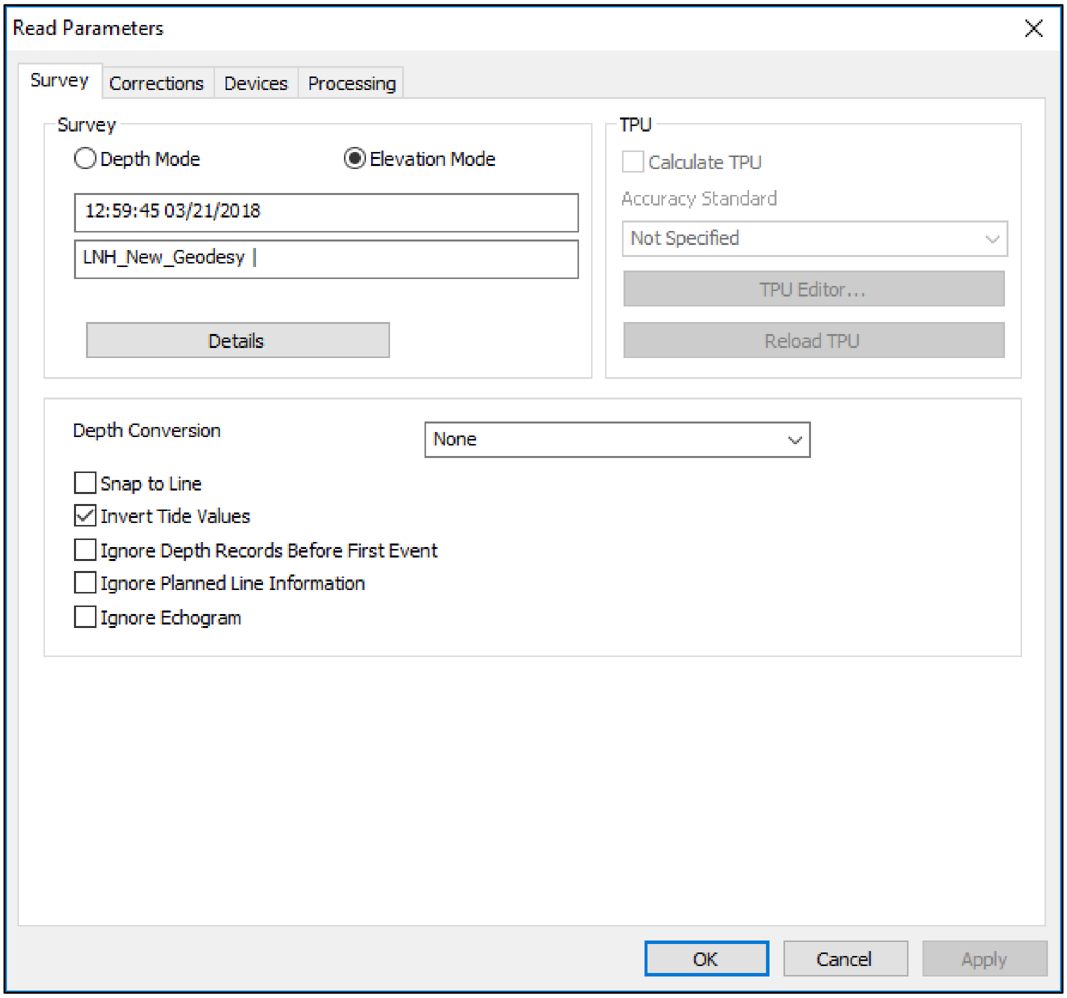


Figure 16.—Survey tab in the Read Parameters window in SBMAX64.

2. Under the **Corrections** tab in the Read Parameters window, the user can upload sound velocity files from the CastAway data collection by clicking on “VEL File” and selecting the sound velocity file(s) (figure 17).

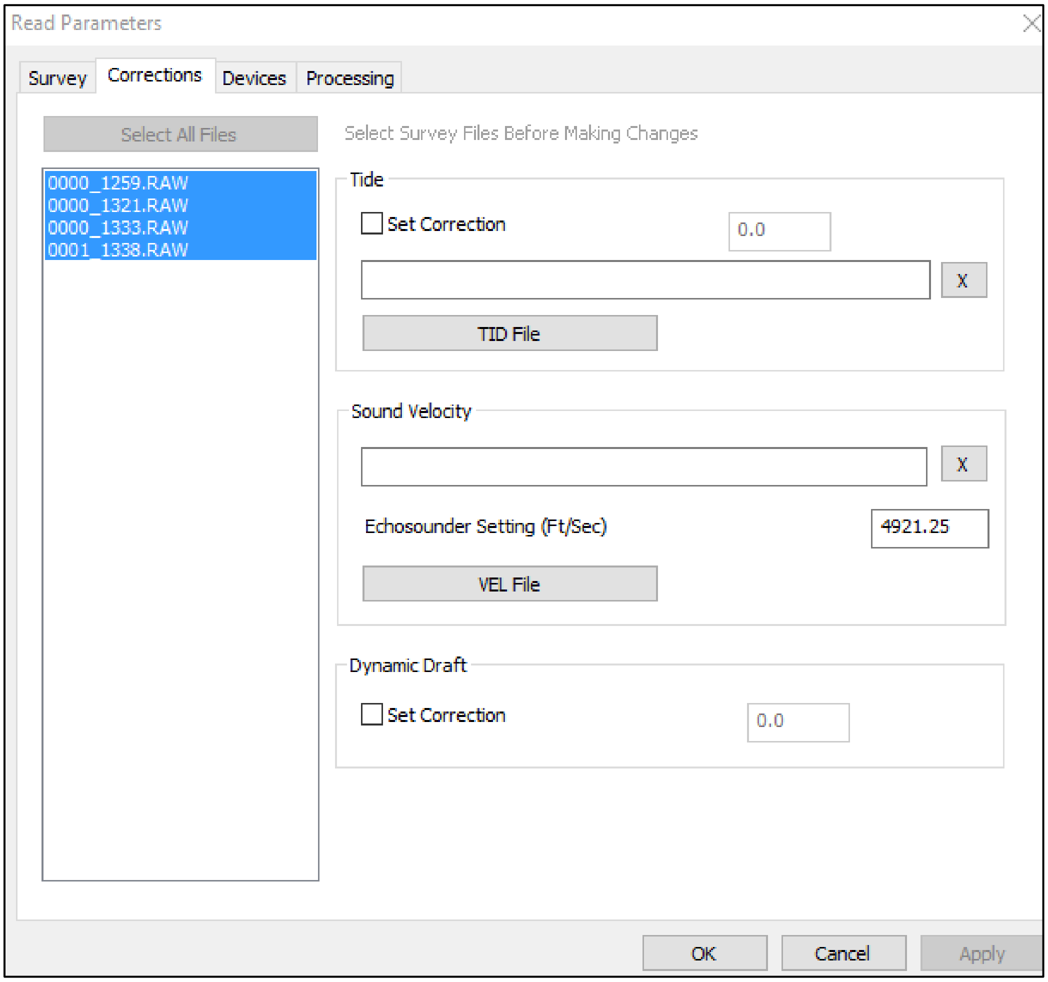


Figure 17.—Corrections tab in the Read Parameters window in SBMAX64.

3. Under the **Devices** tab in the Read Parameters window, click “Edit.” In the Device Offsets popup window, set Navigation to the GPS device and both MRU and Sonar to the echosounder. Under Heading, input in combination of the SonTek M9 rotation and magnetic declination for the Yaw offset as discussed in the “SonTek M9 Device Setup” subsection previous to this. Under Tide, verify “RTK Tides” is checked. Click “OK” (figure 18).

   Click “OK” again to return to the SBMAX64 main menu window.

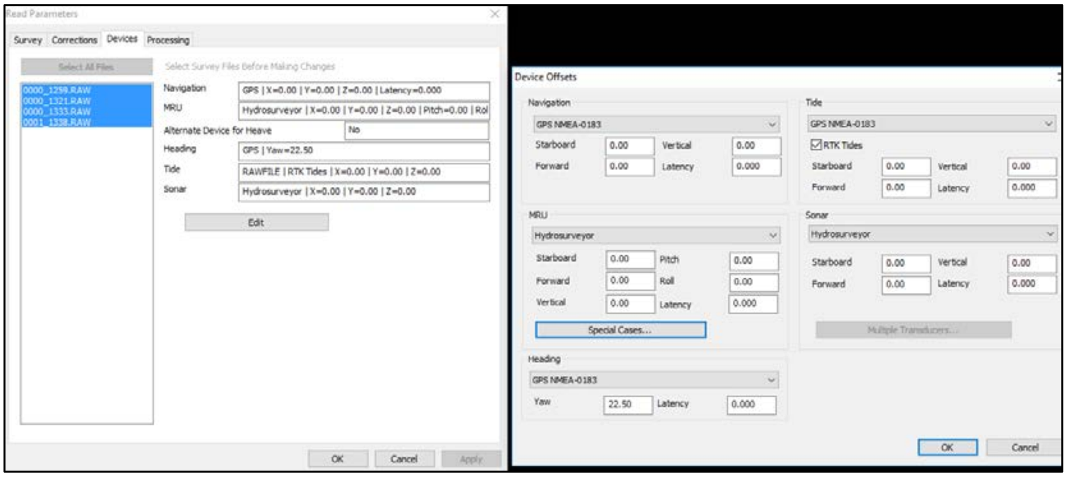


Figure 18.—Device Offsets popup window via the Devices tab in the Read Parameters window.

4. Then, under Tools in the SBMAX64 menu bar, open “HYPACK Raw File Adjustments.” Check the “Recalculate RTK Tides Using Project Geodesy” box under RTK Tide Device and Offsets. Set HYPACK Device to the GPS device. Click “Adjust” when it shows “Done,” then click “Close” (figure 19).

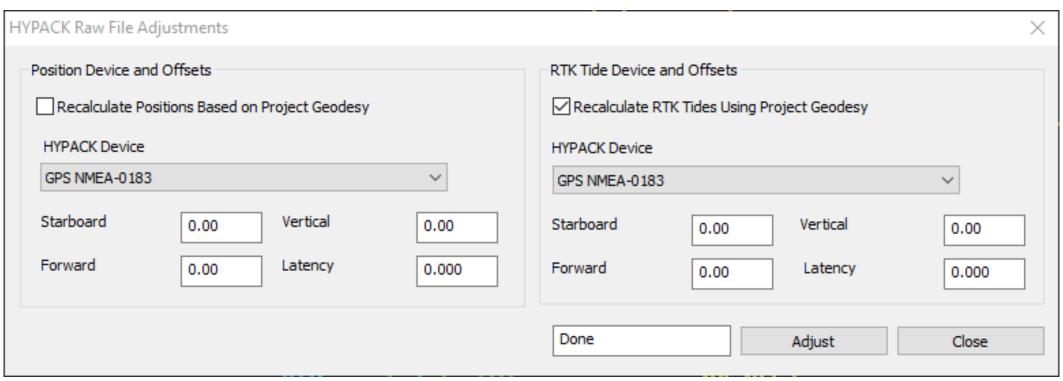


Figure 19.— HYPACK Raw File Adjustments window via Tools in the SBMAX64 menu bar.

At this juncture, go back into “Read Parameters” (figure 15). Under the Devices tab in the Read Parameters window, click “Edit” (figure 18). In the Device Offsets popup window, under Tide, the selection should now be “RAWFILE” and the “RTK Tides” box is still checked. Click “OK” (figure 20).

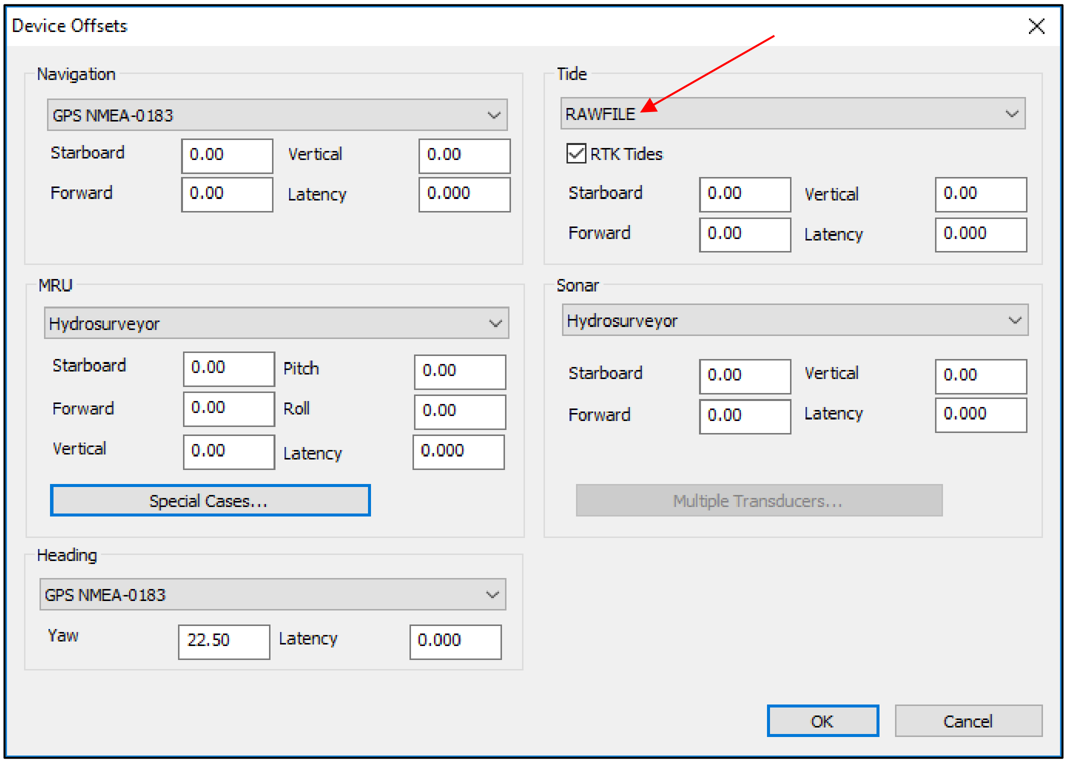


Figure 20.—RAWFILE selection under Tide in the Device Offsets popup window.

While still within the Read Parameters window, select the “Processing” tab. Under Single Beam, verify “Apply Pitch and Roll Corrections” and “Steer Sounding Beam” are both checked. The Transducer Beam Width in Degrees should be set to “1.5” (figure 21).

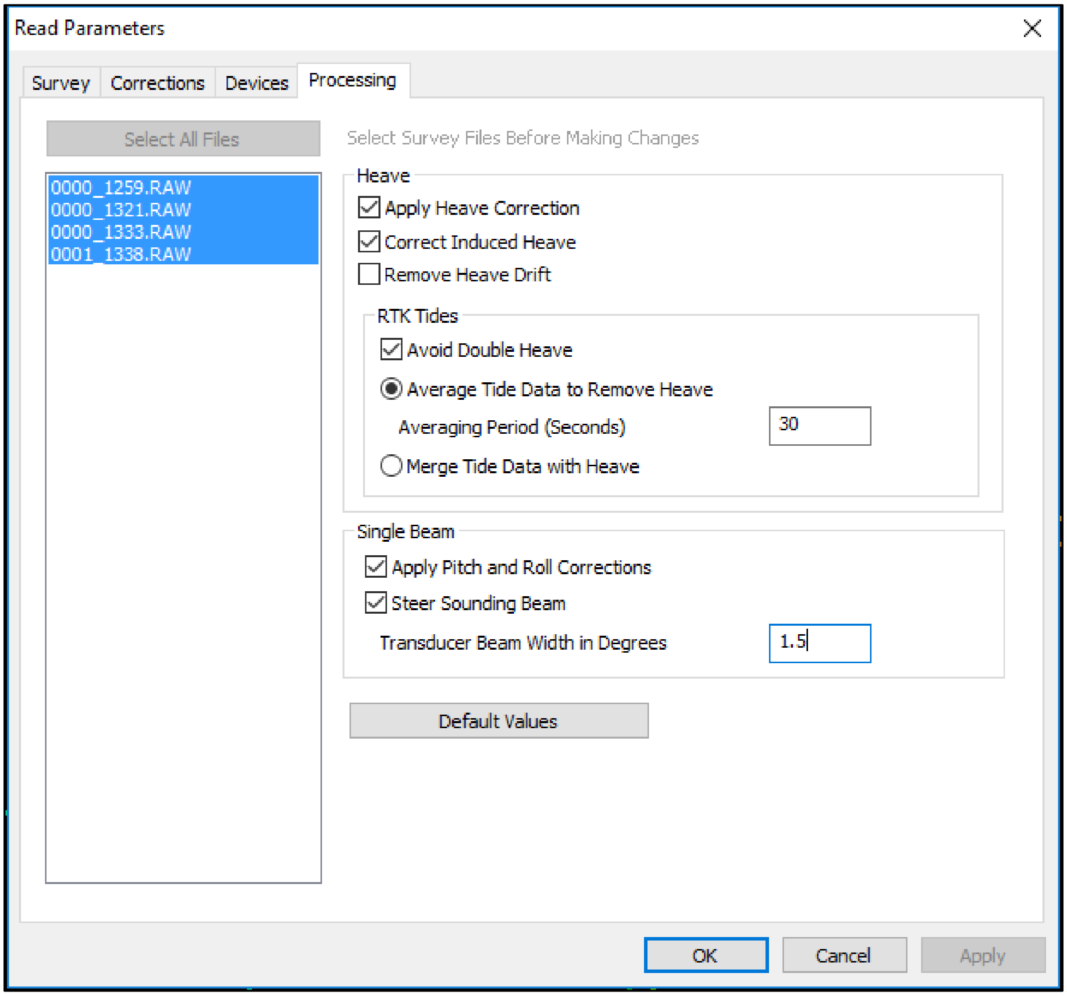


Figure 21.—Processing tab in the Read Parameters window in SBMAX64.

Reviewing and Troubleshooting in SBMAX64

It is possible that the user may encounter problems with SBMAX64 displaying properly. Although not confirmed, these issues might arise from not having all the files selected when changing parameters. Sometimes clicking back and forth from “Tracklines” to “Soundings” in the SBMAX64 main menu window will help (figure 22). In addition, verify the Depth Conversion “Invert Tide Values” box is checked under the Survey tab in the Read Parameters window (figure 16).

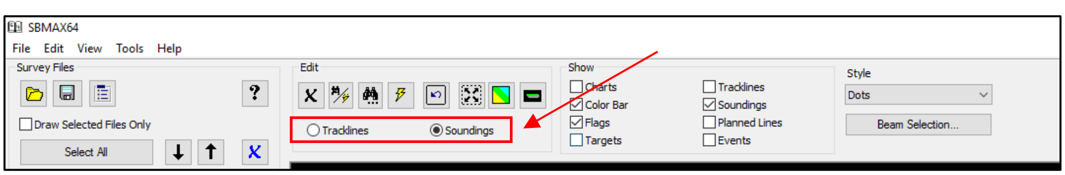


Figure 22.—Tracklines and Soundings in the SBMAX64 main menu window.

The user should then have everything set right and can view the soundings in elevation. The user can also view each beam and filter out data in map view or profile view (figure 23).

Note: Holding "Ctrl + Shift" and scrolling the mouse zoom wheel will increase/decrease the Z-value or vertical exaggeration. This is helpful in shallow, relatively flat areas.

Use the selection tools under Toolbox in the SBMAX64 main menu window to delete erroneous points. If something is deleted by accident, just click "Undo" to go back (figure 23).

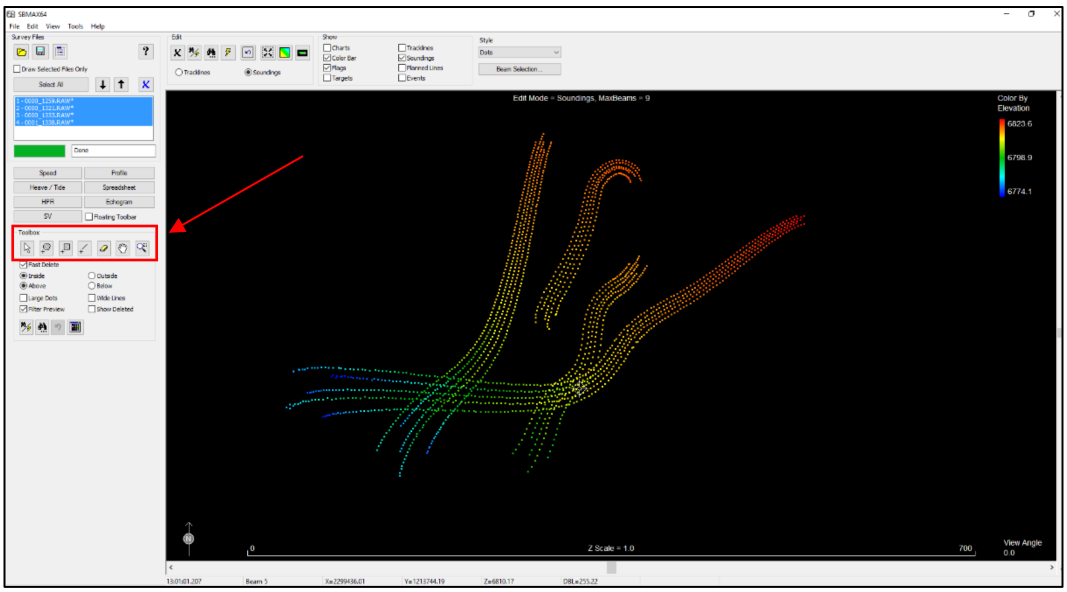
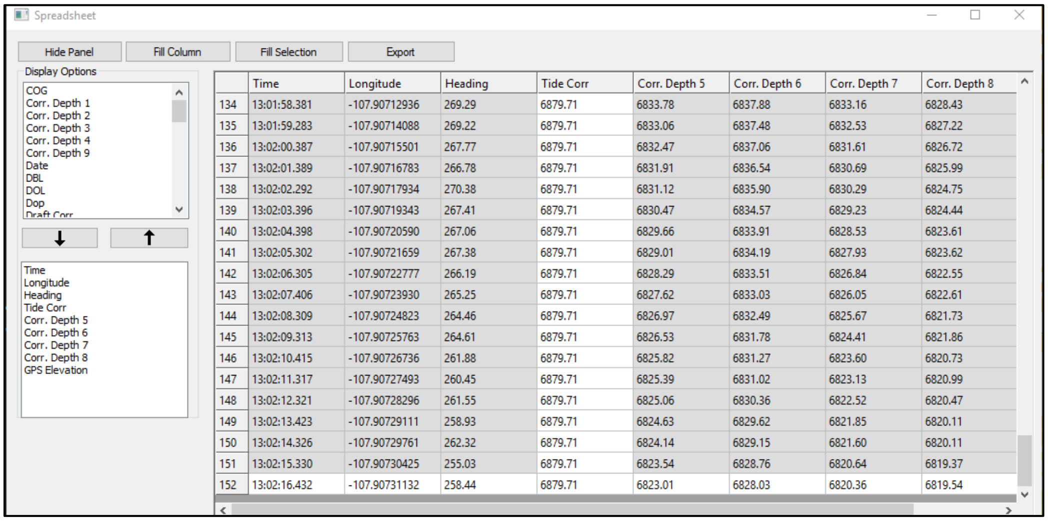


Figure 23.—Viewing soundings in elevation and the selection tools under Toolbox in the SBMAX64 main menu window.

Additionally, it is beneficial to look at the "Spreadsheet" (button in right column above Toolbox in the SBMAX64 main menu window; figure 23) to ensure the tide correction and corrected depths make sense (figure 24).

After reviewing and editing the data, the user can save all files in ".xyz" or ".HS2x" formats.



	Time	Longitude	Heading	Tide Corr	Corr. Depth 5	Corr. Depth 6	Corr. Depth 7	Corr. Depth 8
134	13:01:58.381	-107.90712936	269.29	6879.71	6833.78	6837.88	6833.16	6828.43
135	13:01:59.283	-107.90714088	269.22	6879.71	6833.06	6837.48	6832.53	6827.22
136	13:02:00.387	-107.90715501	267.77	6879.71	6832.47	6837.06	6831.61	6826.72
137	13:02:01.389	-107.90716783	266.78	6879.71	6831.91	6836.54	6830.69	6825.99
138	13:02:02.292	-107.90717934	270.38	6879.71	6831.12	6835.90	6830.29	6824.75
139	13:02:03.396	-107.90719343	267.41	6879.71	6830.47	6834.57	6829.23	6824.44
140	13:02:04.398	-107.90720590	267.06	6879.71	6829.66	6833.91	6828.53	6823.61
141	13:02:05.302	-107.90721659	267.38	6879.71	6829.01	6834.19	6827.93	6823.62
142	13:02:06.305	-107.90722777	266.19	6879.71	6828.29	6833.51	6826.84	6822.55
143	13:02:07.406	-107.90723930	265.25	6879.71	6827.62	6833.03	6826.05	6822.61
144	13:02:08.309	-107.90724823	264.46	6879.71	6826.97	6832.49	6825.67	6821.73
145	13:02:09.313	-107.90725763	264.61	6879.71	6826.53	6831.78	6824.41	6821.86
146	13:02:10.415	-107.90726736	261.88	6879.71	6825.82	6831.27	6823.60	6820.73
147	13:02:11.317	-107.90727493	260.45	6879.71	6825.39	6831.02	6823.13	6820.99
148	13:02:12.321	-107.90728296	261.55	6879.71	6825.06	6830.36	6822.52	6820.47
149	13:02:13.423	-107.90729111	258.93	6879.71	6824.63	6829.62	6821.85	6820.11
150	13:02:14.326	-107.90729761	262.32	6879.71	6824.14	6829.15	6821.60	6820.11
151	13:02:15.330	-107.90730425	255.03	6879.71	6823.54	6828.76	6820.64	6819.37
152	13:02:16.432	-107.90731132	258.44	6879.71	6823.01	6828.03	6820.36	6819.54

Figure 24.—The Spreadsheet window in SBMAX64.

Finalizing in the HYPACK Shell

Back in the HYPACK Shell, under the Project Items tab in the left-hand screen, click and open the Sorted Data Files to display them in elevations. The user may need to adjust the color bands for the elevations to display properly, which can be done by selecting "Sounding colors" under the Settings drop-down menu in the HYPACK Shell top menu bar (figure 25).

From here on out, the user can then develop the Triangular Irregular Network model, and whatever else is desired.

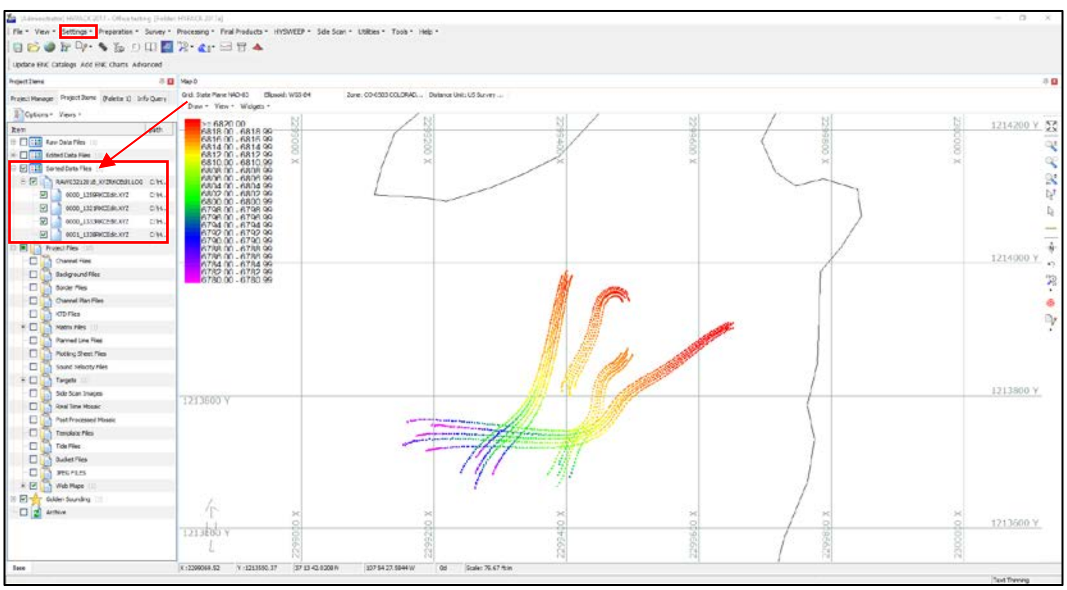


Figure 25.—Sorted Data Files (left-hand screen) and Settings drop-down (top menu bar) in the HYPACK Shell.

Discharge Measurements

By Caroline Ubing, M.S., P.E.

Introduction

This section provides a quick guide for collecting discharge measurements with an Acoustic Doppler Current Profiler (ADCP) or a velocity meter. While several different types of velocity meters exist, electromagnetic (HACH 950) or acoustic (SonTek FlowTracker) meters are available within the Water, Environmental, and Ecosystems Division in Reclamation's Technical Service Center.

This section also provides recommendations for each step of the process: planning, equipment and instrument setup, measurement procedures, and post-processing. Please contact Caroline Ubing (303-445-2555) with emergency questions while in the field.

Planning

Before Leaving the Office

- Become familiar with the project site via Google Earth to expedite site selection in the field (https://www.google.com/earth/).
- Note magnetic declination of the project site (https://www.ngdc.noaa.gov/geomag-web/#declination).
- Read and print pertinent sections of *Measuring Discharge with Acoustic Doppler Current Profilers from a Moving Boat* (Mueller, et al., 2013; https://pubs.usgs.gov/tm/3a22/pdf/tm3a22.pdf).
- Prepare and print maps of, and datasheets/field forms for, the project site (e.g., page 59 at: https://pubs.usgs.gov/tm/3a22/pdf/tm3a22_lowres.pdf).

Measurement Location

Site selection is the most *critical* step. Take the time to find a suitable flow-measurement site.

Ideal hydraulic conditions:

- Uniform and steady-state flow conditions
- Roughly parabolic, trapezoidal, or rectangular cross-sectional geometry
- Straight reach length ten times the stream width

- Minimum depth of 2 feet (ft)
- Minimum aquatic or bank vegetation

Sites to avoid:

- Rapidly expanding or contracting widths
- Unsteady hydraulic conditions (including waves)
- Local hydraulic influences (eddies, recirculation, standing waves, backwater, inline/lateral structures, etc.)
- Sections that steepen in slope (glides or riffles) and moving-bed conditions
- Asymmetric cross section channel geometries
- Shallow cross sections (depth less than 2 ft)
- Sites with heavy vegetation, large boulders, or debris
- Tight curvatures along the river planform

Equipment

Discharge measurement devices:

- SonTek S5 or M9 ADCPs
- Teledyne RD Instruments (TRDI) StreamPro ADCP
- Handheld velocity meters (HACH FH950 or SonTek FlowTracker)

Other useful tools:

- Thermometer

Boat Setup

Materials:

- Discharge measurement device
- Power box
- Power and communication cables
- Laptop/tablet.

Hydroboard Setup

For more details regarding hydroboard setup for the SonTek M9 ADCP, see the "SonTek M9 Acoustic Doppler Current Profiler Setup" section in this users guide.

SonTek S5 or M9	StreamPro
Materials: ADCP, power box, battery packs, brown antenna box, power cable, communication cable, tablet/laptop, two pulleys, rope and anchors for cable pull across channel. 1. Connect the Bluetooth antenna to laptop/tablet using the little screwdriver that should stay in the box. 2. Connect the plug to the power box. 3. Insert the battery packs into the power box. 4. Mount the ADCP to hydroboard. Remove the boat mount from the top. 5. Measure the draft from the water surface to the bottom face of the instrument. 6. Mount the control box to hydroboard with the plugs pointing away from the ADCP. 7. Connect the ADCP to the control box (this cable will be in the hydroboard bag). 8. Turn on the ADCP and verify that the lights turn on. 9. Attach the ADCP to the rope or tagline and put it in the water.	Materials: ADCP, new batteries, solar shield, tablet/laptop, two pulleys, rope, and anchors for cable pull across channel. 1. Connect USB to Bluetooth antenna adaptor (UD100 or other) to laptop/tablet and start it. 2. Install new AA batteries in the StreamPro ADCP at beginning of flow measurements. 3. Mount the ADCP to either the standard boat or the OceanScience boat for high flow. 4. Measure the draft from the water surface to the bottom face of the ADCP (usually 0.152 ft). 5. Set up anchors and rope-pulley tagline. 6. Turn on the ADCP and establish Bluetooth connection. 7. Attach the ADCP to the rope or tagline and place it in the water. 8. Determine edge areas with two good bins and apply tape to start/stop locations. 9. Perform a 5-minute moving-bed test midchannel in fastest moving water.

Collecting Discharge Data Using an ADCP in the Field

Pre-Measurement Procedures

1. Select an ideal location for a measurement and make a preliminary crossing before setting up the tagline. During this crossing, observe the general depth and velocity values across the channel. Modify the cross section, where practical, to improve measurement conditions. Clean any debris, rocks, or vegetation from the transect. In small streams, the user can build a small dike to cut off dead water and/or shallow flow areas. Fasten the tagline to one bank, taking note of the initial measurement location. String the tagline across the river, perpendicular to the flow direction, and secure the tagline to the opposite shore (Resources Information Standards Committee, 2009). If depths are less than 2 ft, measure discharge using a handheld velocity meter.

2. Put the boat in the water to allow the internal thermometer to adjust. Temperature is the most influential variable to calculate the speed of sound. A 5-degree Celsius error can result in a 3 percent (%) bias in the measured discharge (Turnipseed and Sauer, 2010).

3. Measure temperature and salinity with the CastAway.

4. Open the RiverSurveyor Live software on the laptop/tablet. Establish connection between the ADCP and laptop/tablet (figure 1).

Figure 6.—RiverSurveyor Live software toolbar. Click the highlighted button to establish a connection between the ADCP and laptop/tablet.

5. Enter site information.

6. Enter system settings.

   a. "Transducer Depth" is measured from the face of the M9 to the water surface.

   b. "Blanking Distance" is the depth below the face of the ADCP that the user wants to start collecting data from, which should be set to 0.52 ft (Mueller et al., 2007) unless mounted to a boat. Depth is then set to avoid the turbulence from the wake of the boat.

c. "Magnetic Declination" calibrates the compass to magnetic north, and can be adjusted in the office if unknown.

d. "Salinity" can impact the speed of sound, influencing the discharge measurement. Use the CastAway to measure salinity.

e. "Track Reference" should be set for bottom tracking reference velocity. As of September 2019, the Sedimentation and River Hydraulics Group (SRH) in Reclamation's Technical Service Center does not own a unit with Global Positioning System (GPS) capability.

f. "Depth Reference" should be set to vertical beam.

g. "Coordinate System" should be set to default (East, North, Up [ENU]).

7. Select the discharge method from the drop-down menu. The "Mid-Section" method is recommended.

8. A compass calibration test must be performed at the beginning of each day. One person starts the test on laptop/tablet. The second person slowly rotates the ADCP through two complete circles varying pitch and roll angles to exaggerate what would occur on the water surface. This test should be performed as close to the measurement location as possible. All mobile devices should be removed from the immediate area. For an example of this process, see the "RiverSurveyor Compass Calibration Video Part I - The Compass Dance" video at: https://www.youtube.com/watch?v=-gSOR2NsaOU.

   a. If the error is more than 1 degree, repeat the test.

   b. If after several attempts, the total compass error cannot be reduced to less than 1 degree, the compass error should be noted and special attention should be paid to potential heading errors (directional bias and irregular ship track).

   c. If the instrument does not report a numerical error, the manufacturer's manuals and supplemental U.S. Geological Survey (USGS) guidance should be consulted as to what criteria can be used to determine an acceptable compass calibration.

9. Perform a system test.

10. Verify that the internal clock is correct.

11. Perform a beam check and verify there are no irregular patterns.

12. Start a measurement (F5).

13. Perform a moving-bed test. This test should be performed before collecting data at every measurement site for each flow condition. Save the moving-bed test; it will used during post-processing. If a moving bed is detected, it is recommended to find a new location where a moving bed is not present. If that is not possible, a correction can be applied in the office. Different measurement techniques are recommended and explained in the following “Measurement Procedures” subsection.

    a. **Stationary Test Without GPS.**—The ADCP should be positioned at the location in the measurement section expected to have the highest potential for a moving bed. The ADCP should be held stationary in that same position while recording for no less than 5 minutes if tethered; 10 minutes on an unanchored boat. A moving-bed condition is present when the ADCP appears to have moved upstream (figure 2). The bed is considered to be in motion if the moving-bed velocity (or boat speed) is greater than 1 or 2% of the mean water velocity for tethered and manned boating conditions, respectively.

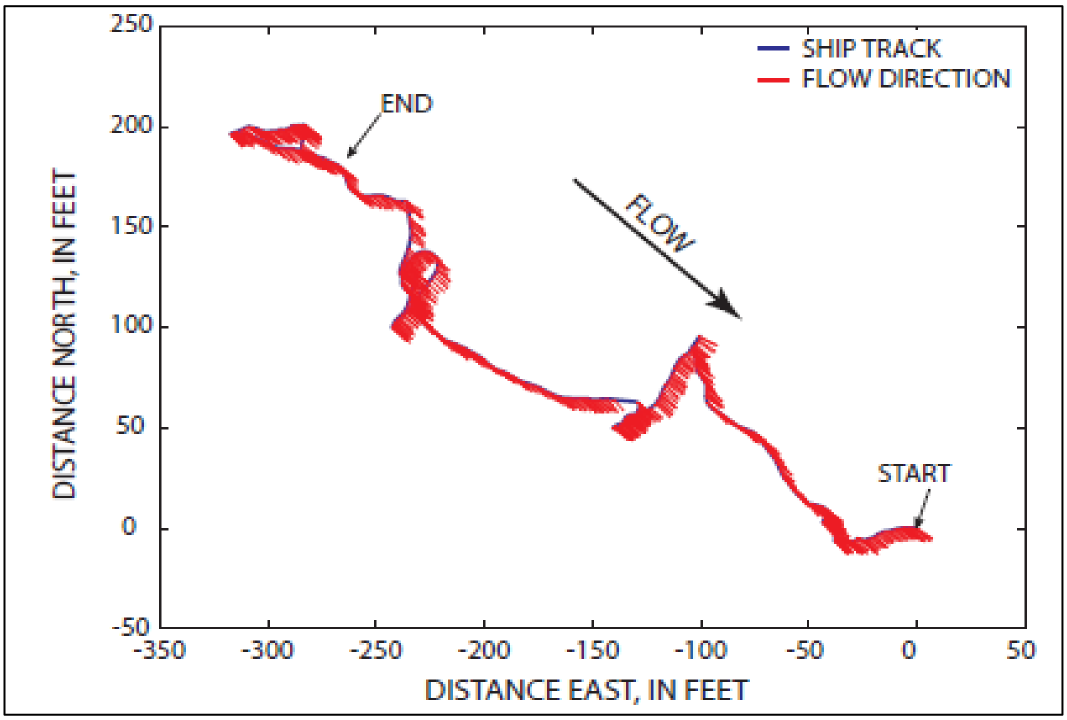


Figure 2.—Example of a moving bed measured with an ADCP on the Mississippi River, Chester, Illinois (Mueller et al., 2013).

b. **Loop Test.—**The ADCP is moved continuously across the channel width and returns to the starting position while recording. The test should be performed for a minimum of 3 minutes. A moving bed is present if the moving-bed velocity is greater than 0.04 foot per second (ft/s) and less than 1% of the mean water velocity, or is in a distorted ship track loop (figure 3). If the moving-bed velocity is greater than 0.04 ft/s and less than 0.8 ft/s, a stationary test will provide more conclusive results. The moving-bed velocity can be computed from the distance the ADCP moved upstream of the starting location, and the time required to keep the loop.

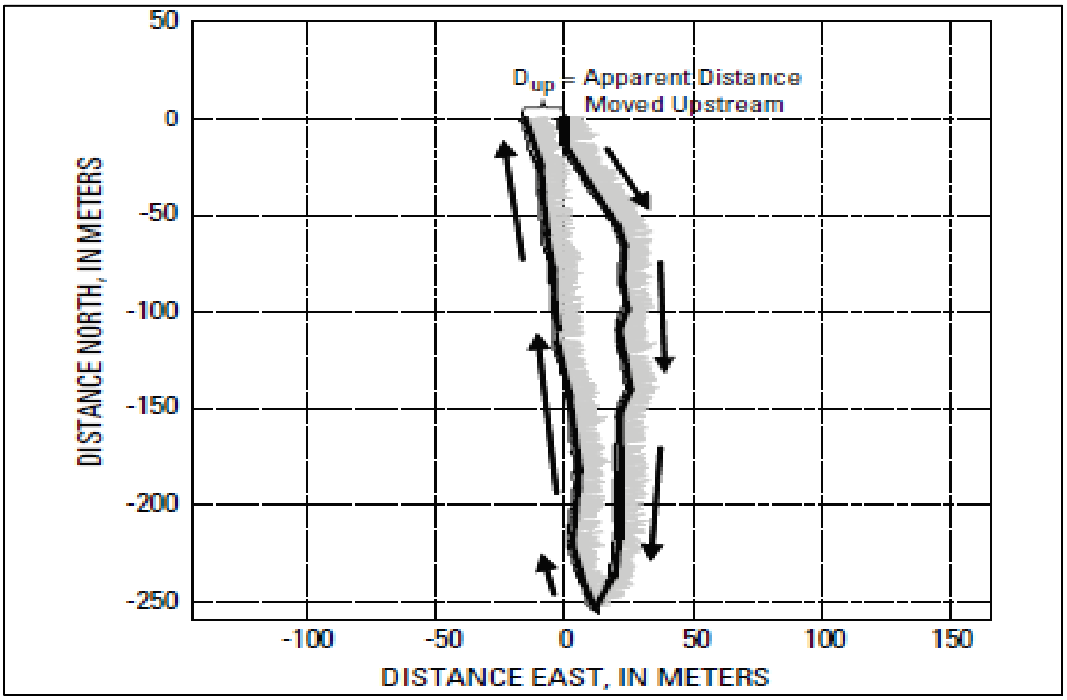


Figure 3.—Example of a moving bed measured with the loop method (Mueller et al., 2013).

Measurement Procedures

Be sure to fill out the ADCP measurement datasheet while taking the measurements.

1. Start Edge. Keep the ADCP as stationary as possible. Collect, at the least, 10 edge ensembles (or measurements). A *minimum* of 10 measurements (each lasting 1 second) at each edge are required, but 15 measurements are recommended. Depths must be greater than 2 ft to collect velocity readings. If the edge depth is too shallow, start the edge further into the center of the transect or consider measuring the edge discharge with the velocity meter.

2. Start Moving. Move the boat across the channel width. *Smooth* boat operation (maintaining a uniform speed and gradual transitions when necessary) is key to a successful measurement. The average boat speed should be equal to or less than the average water speed (Turnipseed and Sauer, 2010).

3. End Edge. Once the boat is at the end of the transect, click “End Edge.” Allow the instrument to collect a minimum of 10 ensembles at this edge, keeping the ADCP as stationary as possible.

4. End Transect.

5. Repeat.

When post-processing the data, select the transects wanted in the overall measurement. Measurements must consist of reciprocal transects (sequential right and left pairs) and have a recording time of 720 seconds or greater. The minimum number of transects is four per measurement. It is recommended to collect more than four as discharge values will change during post-processing. Transects should all be within 5% of each other to be a “good” measurement. Measurements outside of this range will be highlighted in red in the discharge measurement summary. The smaller the error now, the better it will be after post-processing.

Moving-Bed Conditions

The preferred method of making discharge measurements with an ADCP in moving-bed conditions is to use GPS as the navigation reference. Alternative correction methods include the loop method or multiple moving-bed test method depending on the bottom tracking quality. Data are collected using these methods (details follow) and the adjustments are made during post-processing.

Loop Method

The loop method of measuring discharge involves an ADCP making a two-way crossing of the stream with a moving bed and returning to the exact starting position, the same process used for the loop test (previously discussed). Careful field procedures are critical for the loop method to be successful. The technique is unusable in the following scenarios: failure to accurately return the instrument to the starting point, uncalibrated or improperly calibrated compass, changes in magnetic interference, or loss of bottom tracking during the loop. The data can then be post-processed in the office using the techniques described in Mueller and Wagner, 2006.

Multiple Stationary Moving-Bed Test Method

If the compass cannot be calibrated or bottom tracking cannot be obtained to apply the loop method, the multiple stationary moving-bed test method can be applied. Instructions for a single stationary moving-bed test without GPS are included in the “Loop Method” subsection previous to this. The steps for multiple tests are to:

1. Conduct at least three stationary moving-bed tests equally spaced across the width of the cross section. Each test should be 5 to 10 minutes in duration and the location should be noted. Additional moving-bed tests will result in more accurate discharge corrections.

2. Make ADCP discharge measurements following standard procedures.

The disadvantages of this method are: the procedure is time consuming, an accurate cross-sectional area perpendicular to the flow is required, and measured velocities will remain uncorrected once the discharge is adjusted.

Removing the ADCP From the Water

Before removing the ADCP from the water:

1. Finish field book notes.

2. Take photographs.

3. Note any significant hydraulic characteristics.

Evaluating the discharge summary:

1. Ensure there are an even number of selected reciprocal transects.

2. Ensure exposure time of selected transects are greater than 720 seconds.

3. Verify consistency in measurement characteristics (area, width, boat speed, stick ship plots, flow speed, etc.). Look for outliers and errors.

Preliminary data checking before leaving the site will ensure measurement is good. It is recommended that the user perform the preliminary checks in the QRev software program (QRev). QRev was developed by USGS to apply consistent algorithms and a logical workflow to post-process discharge data from both SonTek and TRDI instruments. The steps for this process are:

1. Export the data into “.mat” files for QRev.

2. Show “Processing Tools” (Ctrl T).

3. Click on the Matlab icon, then select “Matlab Export All” from the drop-down menu.

4. Open files in QRev (select data).

5. Load “System Test.”

6. Load “Compass Calibration” file.

7. Load “Moving-Bed Test.”

8. Save the measurement number/name in the “_QRev.mat” file name format.

9. Proceed if “Select Data,” “Temperature,” “BT Filters,” “Depth Filters,” “WT Filters,” and “Edges” are green.

10. Check “Temperature” range and verify it is reasonable. If outside of 1 degree Celsius and other filters are flagged, consider repeating the measurement. If the temperature measurement is obviously incorrect, measure the temperature with a thermometer or any measuring device that records water temperature. The temperature can be manually entered during post-processing.

11. Check “BT Filters,” “Depth Filters,” and “WT Filters.” The buttons will be yellow if more than 5% of the ensembles are invalid. The buttons will be red if more than 25% of the ensembles are invalid. Repeat the measurements if one or more of these filters failed.

12. Check “Edges.” If edges have zero discharge (flagged red) or are difficult to collect, repeat the measurement at a slightly different location.

If all of this is complete, the user is now ready to remove and break down the instrument.

After Each Field Day

1. Download the data from the ADCP. Download the data from the laptop/tablet; however, if there were communication problems during the measurement, there will be missing ensembles. If there are missing ensembles, the file will be labeled with “MissingSamples” at the end of the file name.

2. Back up the data.

3. Erase the ADCP memory for the next day.

4. Charge necessary equipment.

Collecting Discharge Data Using a Velocity Meter in the Field

Measurements should be made with a velocity meter when depths are too shallow to use the ADCP. This document focuses on acoustic and electromagnetic velocity meters; however, the general instructions can be applied to any type of velocity meter. When using a velocity meter, right and left banks are determined looking upstream, as the user should be facing that direction.

Pre-Measurement Procedures

1. Set up a tagline perpendicular to the direction of flow in a place with ideal conditions. Use a measuring tape with units in tenths of feet instead of a rope.

2. Attach the velocity meter to the wading rod ensuring that it is level and oriented upstream.

3. Take photographs of the measuring tape and survey the stakes on both banks.

4. Determine the measurement spacing. Generally, 25 to 30 velocity measurements are recommended. Even spacing is not required. Velocity measurements should be spaced so that no partial section has more than 10% of the total discharge, ideally 5% increments.

Measurement Procedures

1. Record location, date, who performed the measurement, measurement time, and other pertinent information in field book.

2. Begin transect measurement with velocity meter mounted on a wading rod.

3. Measure and enter depth.

4. At depths greater than 2.5 ft, velocity should be measured at 20 and 80% of the total depth (Rantz, 1982). Velocity can be measured at only 60% depth below the water’s surface when flow depths are less than or equal to 2.5 ft.

5. Complete the transect, check the quality of the flow measurement, and if needed and time permits, repeat the measurement potentially moving in the opposite direction (i.e., if the first measurement was conducted from left bank to right bank, repeat the measurement moving right bank to left bank).

> **Note:** If the quality of the flow measurement or the change in discharge between the two measurements is too high, the transect may need to be measured a third time.

Post-Processing QRev ADCP Data

QRev was developed by USGS to apply consistent algorithms and a logical workflow to post-process discharge data from both SonTek and TRDI instruments. The software and corresponding documentation can be found at: https://hydroacoustics.usgs.gov/movingboat/QRev.shtml.

Graphical User Interface

The graphical user interface (GUI) is designed to take users logically through the steps necessary to post-process discharge measurements, starting with the pre-measurement steps. The buttons on the left (figure 4) will turn green, yellow, or red based on the automated data quality assessment (ADQA). If a button is yellow, ADQA has identified a potential issue, which is unlikely to be critical. An associated message will be displayed in the “Messages” panel. If a button is red, ADQA has identified an issue that could have a significant effect on the measurement, or one that violates USGS policy. An associated message will be displayed in the “Messages” panel.

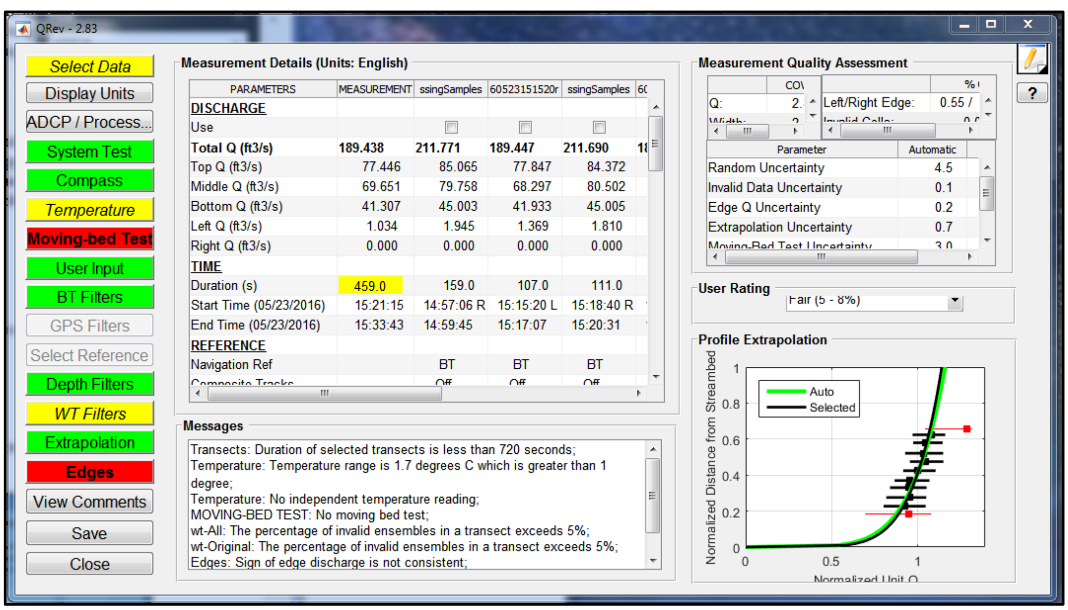


Figure 4.—QRev main window.

Steps

The following steps are adapted from the QRev user's manual (Mueller, 2016) and assume that preliminary data checking was performed in the field:

1. **Select Data.**—Select Data→ QRev file→ select the file saved in the field. At this point, the user's files for the system test, compass, and moving-bed test should all be loaded and all of these buttons are green.

2. **Temperature.—**Check that the temperature is consistent and is reasonable. Enter the temperature measured by the CastAway.

3. **Moving-Bed Test.—**This window allows the user to look at the quality and results of the test. If a moving bed was present, corrections can be made to the measured discharge. QRev does not allow the user combined use of loop and stationary tests.

4. **User Input.**—In this window enter the site name, station number, and add any notes about the site. Verify the draft, magnetic variation, and salinity are correct and consistent.

5. **Bottom Track (BT) Filters.**—BT filters present the bottom track data for each transect. The number of invalid ensembles is listed in the table. If a high percentage of ensembles is invalid, that transect should not be included as part of the final measurement. The user can evaluate the bottom track data for each transect and change the filter settings for all transects. Three filters can be adjusted: beam filter, error velocity, and vertical velocity. Use the automatic setting for all three and "Smooth" under "Other Filter" (details follow).

6. **Beam Filter.—**The beam filter adjusts the number of beams used in the final measurement. SonTek and TRDI ADCPs are based on four-beam configurations, even though only three beams are required to compute the three orthogonal velocity components. If one of the beams fails to provide sufficient acoustic return for the Doppler shift, boat velocity can be computed with the remaining three beams. However, three-beam solutions can be erroneous. In automatic mode, QRev compares the three- and four-beam velocities. If they are within ±50% for each component, the three-beam solutions are selected; if not, the three-beam solution is marked invalid.

7. **Error Velocity.**—The error velocity compares the velocity readings between the four beams. QRev automatically computes a threshold based on a statistical measure of variance and automatically identifies outliers and marks them as invalid.

8. **Vertical Velocity.—**The vertical velocities measured by an ADCP traversing a stream should only be caused by wave action; thus, averaging to zero. Like error velocity, the distribution of vertical boat velocities is expected to be random, and deviations are assumed to be erroneous. QRev automatically computes a threshold based on a statistical measure of variance and flags outliers as invalid.

9. **Other Filters.—**Other filters include a locally weighted scatterplot smoothing algorithm that identifies outliers based on the velocity time series. Best practices for measuring discharge is to operate the boat smoothly without any sudden accelerations or decelerations; therefore, smoothing the time series is appropriate.

10. **GPS Filters and Select Reference.—**These will remain inactive as, of September 2019, SRH does not own a GPS-enabled ADCP.

11. **Depth Filters.—**This window analyzes the depth from the water surface to the streambed. Depth can be determined by an inverse depth-weighted average of the four slant beams or from the vertical beam (if available). Composite depths will use a secondary depth source when the primary source is invalid. If neither source is valid, QRev will determine a value use linear interpolation. Recommended values for this section include: comp four-beam preferred, inverse depth weighted bottom track beam averaging, and the smooth filter. The number of invalid ensembles is listed in the table. If a high percentage of ensembles is invalid, that transect should not be included as part of the final measurement.

12. **Water Track (WT) Filters.—**WT filters determine the velocity of the water. The excluded distance should be set to “16” centimeters for SonTek ADCPs and “0” centimeter for TRDI ADCPs. The automatic setting should be applied to all four filters. The number of invalid ensembles is listed in the table. If a high percentage of ensembles is invalid, that transect should not be included as part of the final measurement.

13. **Extrapolation.—**During the post-processing, the user has the greatest control in the “Extrapolation” window. At this point, the user should have selected which transects will be included in the final measurement. The user is then responsible for evaluating the profile and selecting the appropriate method for top and bottom extrapolations. Different extrapolation methods can be applied to each transect. However, these results are simply visual. Only one method can be applied to every transect for the measurement.

14. **Algorithms.—**The automatic fit algorithms are limited for extrapolation and adjusting them is recommended. Appropriate top and bottom fit lines should be selected individually for each transect. Select the measurement and then turn on the display of transect medians and fit, as well as the measurement medians and fit. Transect fit lines can provide a visual aid to select the measurement fit line.

15. **Edges.—**The unmeasured discharge at the edges are estimated using a ratio interpolation method documented by Fulford and Sauer (1986). The user can select the type of edges (triangular, rectangular, custom, and user Q). Triangular or rectangular (depending on the site) is recommended. If left/right bank discharge measurements were made in the field with a handheld velocimeter, user “Q” is recommended.

16. **Save.—**Save the measurement and note the final discharge and coefficient of variation (COV). Post-processing the transect is now complete.

Post-Processing Velocity Meter Data

Post-processing velocity meter output is dependent on the velocity meter. SonTek FlowTracker and HACH 950 meters are available within the Water, Environmental, and Ecosystems Division in Reclamation’s Technical Service Center, as initially discussed. The user manual for the applied instrument should be consulted. Results should be manually recorded on the datasheets while in the field. Download and plot the data as soon as possible to identify potential errors.

References

Fulford, J.M. and V.B. Sauer. January 1986. "Comparison of Velocity Interpolation Methods for Computing Open-Channel Discharge." In Seymour Subitsky, ed., *Selected Papers in the Hydrologic Sciences*. U.S. Geological Survey Water-Supply Paper 2290, p. 139–144. Available at https://pubs.usgs.gov/wsp/wsp2290/.

Mueller, D.S. and C.R. Wagner. June 2006. *Application of the Loop Method for Correcting Acoustic Doppler Current Profiler Discharge Measurements Biased by Sediment Transport.* U.S. Department of the Interior, U.S. Geological Survey, Scientific Investigations Report 2006–5079, 18 p.

Mueller, D.S., J.D. Abad, C.M. García, J.W. Gartner, M.H. García, and K.A. Oberg. December 2007. "Errors in Acoustic Doppler Profiler Velocity Measurements Caused by Flow Disturbance." *Journal of Hydraulic Engineering*, Volume 133(12), 1411-1420.

Mueller, D.S., C.R. Wagner, M.S. Rehmel, K.A. Oberg, and F. Rainville. December 2013. "Measuring Discharge with Acoustic Doppler Current Profilers from a Moving Boat." Version 2.0. *Techniques and Methods*, book 3, chapter A22, 95 p. U.S. Department of the Interior, U.S. Geological Survey. Available at https://pubs.usgs.gov/tm/3a22/pdf/tm3a22.pdf.

Mueller, D.S. 2016. *QRev—Software for Computation and Quality Assurance of Acoustic Doppler Current Profiler Moving-Boat Streamflow Measurements—User's Manual for Version 2.8.* U.S. Department of the Interior, U.S. Geological Survey, Open-File Report 2016–1052, 50 p. Available at https://dx.doi.org/10.3133/ofr20161052.

Rantz, S.E. et al. 1982. *Measurement and Computation of Streamflow*. U.S. Geological Survey Water-Supply Paper 2175, Volumes 1 and 2, 631 p. Available at https://pubs.er.usgs.gov/publication/wsp2175.

Resources Information Standards Committee. March 2009. *Manual of British Columbia Hydrometric Standards*. Version 1.0. Prepared by Ministry of Environment, Science and Information Branch, the Province of British Columbia, 204 p.

Rydlund, P.H., Jr. and B.K. Densmore. 2012. "Methods of Practice and Guidelines for Using Survey-Grade Global Navigation Satellite Systems (GNSS) to Establish Vertical Datum in the United States Geological Survey." *Techniques and Methods*, book 11, chapter D1, 102 p. with appendixes. U.S. Department of the Interior, U.S. Geological Survey. Available at https://pubs.usgs.gov/tm/11d1/tm11-D1.pdf.

Seafloor Systems, Inc. June 2017. *HydroLite-TM^{TM}, A quick start guide/user manual.* Available at https://seafloorsystems.com/support/software-support.

Turnipseed, D.P. and V.B. Sauer. September 2010. "Discharge Measurements at Gaging Stations." *Techniques and Methods*, book 3, chapter A8, 87 p. U.S. Department of the Interior, U.S. Geological Survey. Available at https://pubs.usgs.gov/tm/tm3-a8/tm3a8.pdf.

U.S. Army Corps of Engineers. April 2004. *Engineering and Design, Hydrographic Surveying*. Engineer Manual 1110-2-1003. U.S. Department of Army, Washington, D.C.

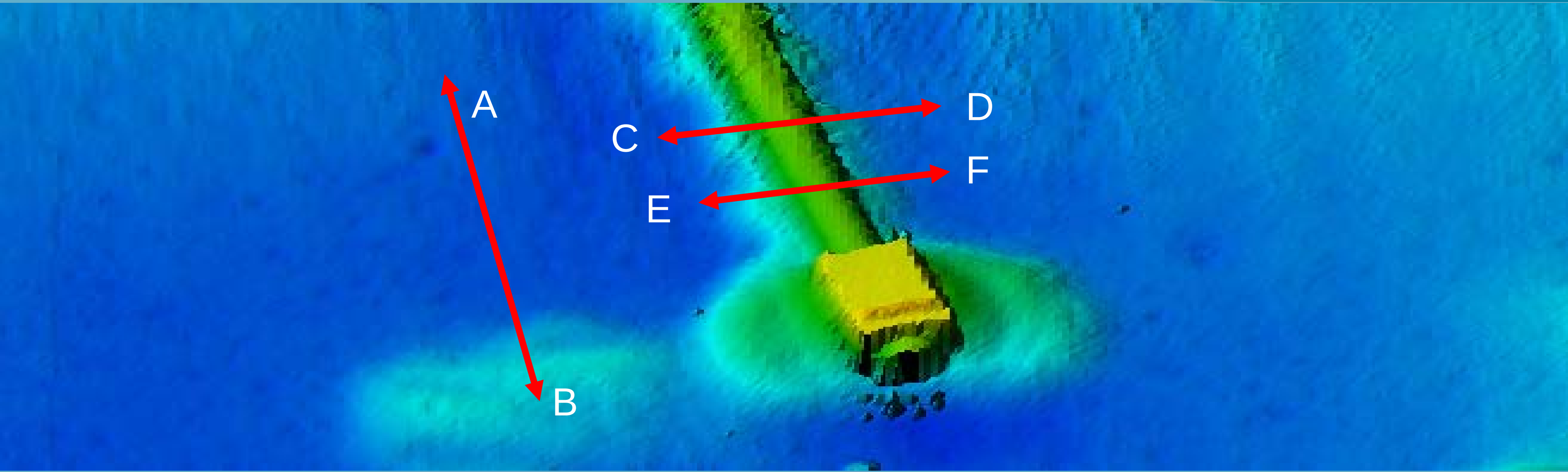
Appendix A—

MBES – Patch Test
HYPACK 2019 Training Event

January 2019

MBES – Patch Test

HYPACK 2019 TRAINING EVENT

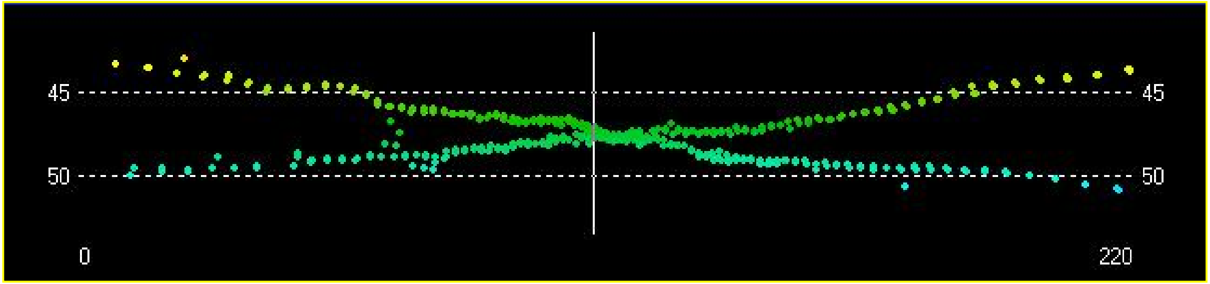


Multibeam Patch Testing

A Patch Test can Determine:

- The Roll, Pitch and Yaw mounting angle. The measurement angle is from the multibeam to MRU and to the heading of the boat. Can cause depth and position error in sounding data

- GPS Latency (time delay). Independent of sonar. Can cause position error of sounding data



An example of what a few degrees of a roll error can cause to the outer beams of the sonar

USACE Requirements for Patch Testing (EM1110-2-1003)

- Patch tests are performed after initial installation, and periodically thereafter if sensors are modified, to quantify any residual biases from the initial system alignment.

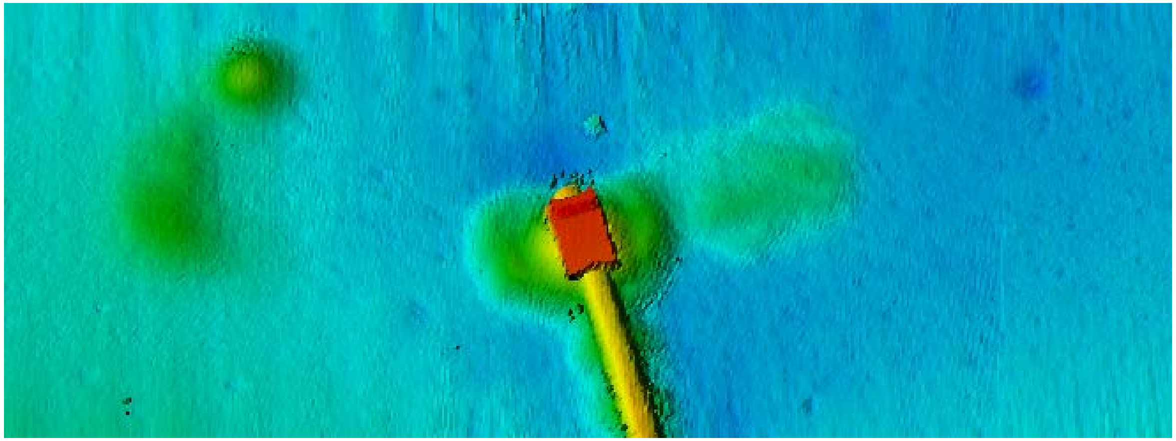
Patch Test Location

Roll Test:

- Look for an area that is reasonably flat.
- Along the center of a dredged channel should be OK.
- Anchorages are good.

Latency, Pitch and Yaw Tests:

- Look for an area with variable bottom terrain.
- The side slope of a dredged channel will work.
- Pipeline crossings are excellent!



The entire patch test can be done right here. There is a flat area and a feature.

Survey Lines – Single Head

Roll Test:

- Line A-B. Reciprocal lines, flat bottom, survey speed.

Pitch Test:

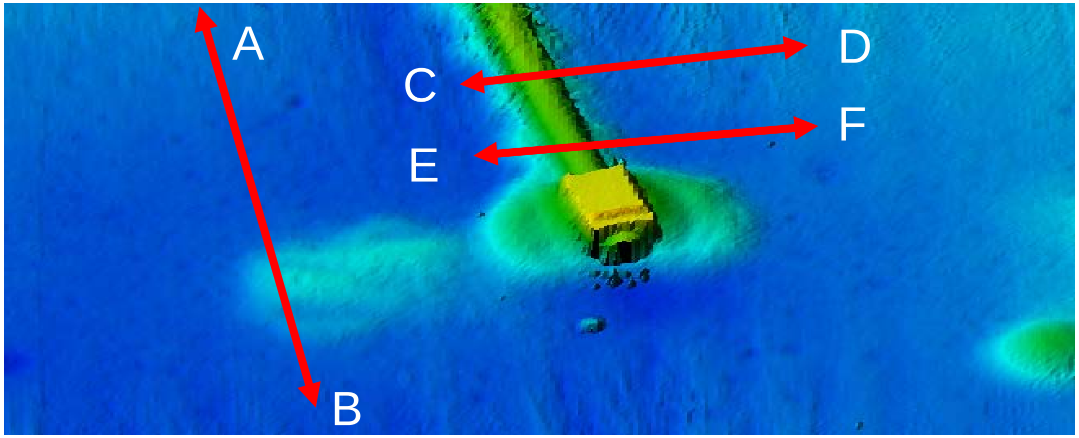
- Line C-D. Reciprocal lines, variable bottom, survey speed.

Yaw Test:

- Lines C-D and E-F. Offset lines, same direction, variable bottom, survey speed.
- If over a slope, use a separation distance of ½ the mid slope depth

Latency Test:

- Line C-D. Same direction, variable bottom, high speed then low speed.

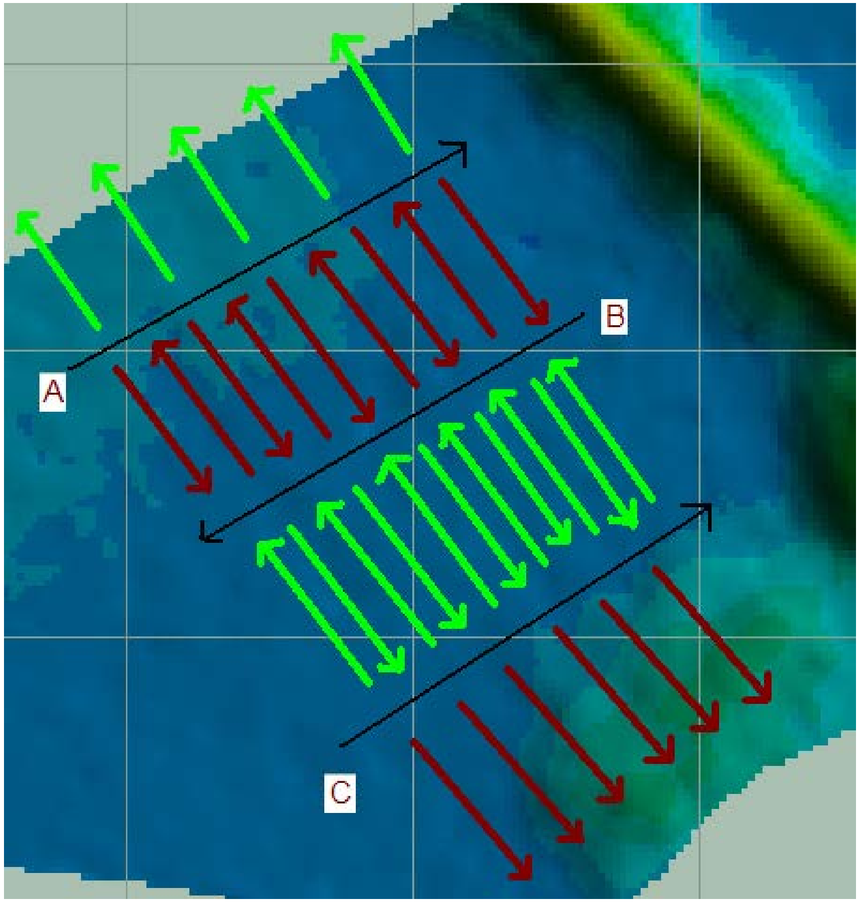


Survey Lines – Dual Head

Roll and Pitch Test

- Different line geometry to overlap port and starboard heads separately.
- Requires 3 survey lines instead of 2.
- Lines A and B overlap starboard head.
- Lines B and C overlap port head.

Some dual head systems are engineered mounting frames can be treated as single head.



Green = Port Head.

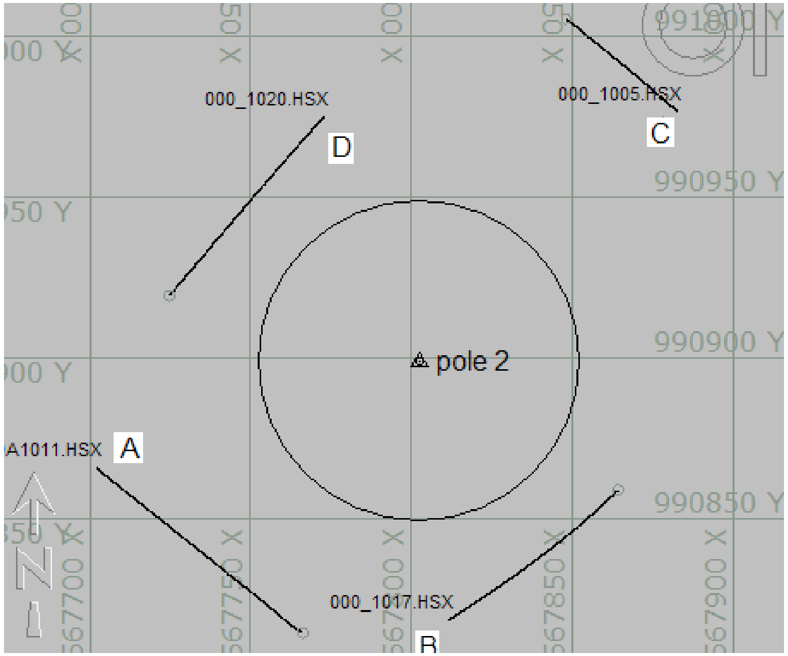
Red = Starboard Head.

Survey Lines – Laser Scanner

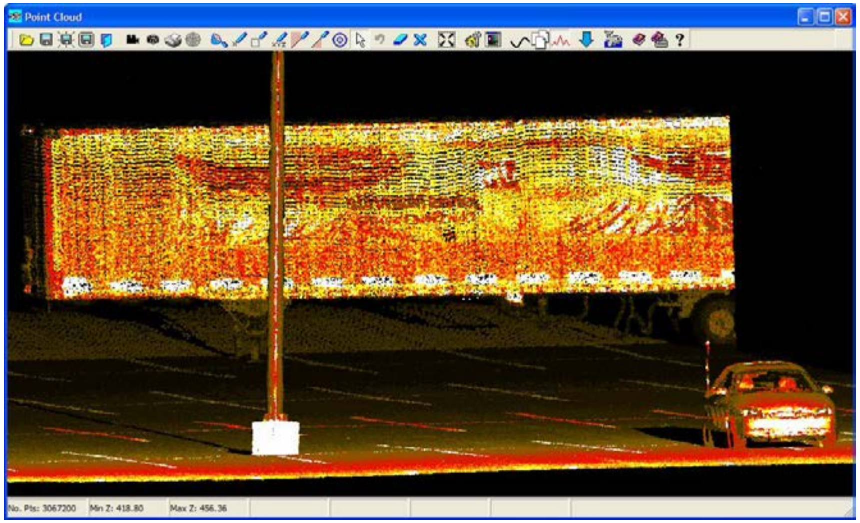
The best patch area is a parking lot with light posts!

- Line pairs A-C or B-D can be compared for all alignments: roll, pitch and yaw.

If you need to do it in water, find a day marker or piling out of the water



Parking lot survey lines



HYPACK® data from Optech ILRIS scanning laser.

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Some Things to Avoid

Avoid Patch Testing with Bad positioning

- Use RTK GPS whenever possible, to minimize any position errors.

Avoid Patch Testing in Very Shallow Water

- Patch testing becomes more reliable as the water gets deeper.
- Test in the deepest area available.

Do not view Patch Testing as EXACT!

- Try to run multiple tests and take an average (tools in MBMAX allow you to keep a history or results)

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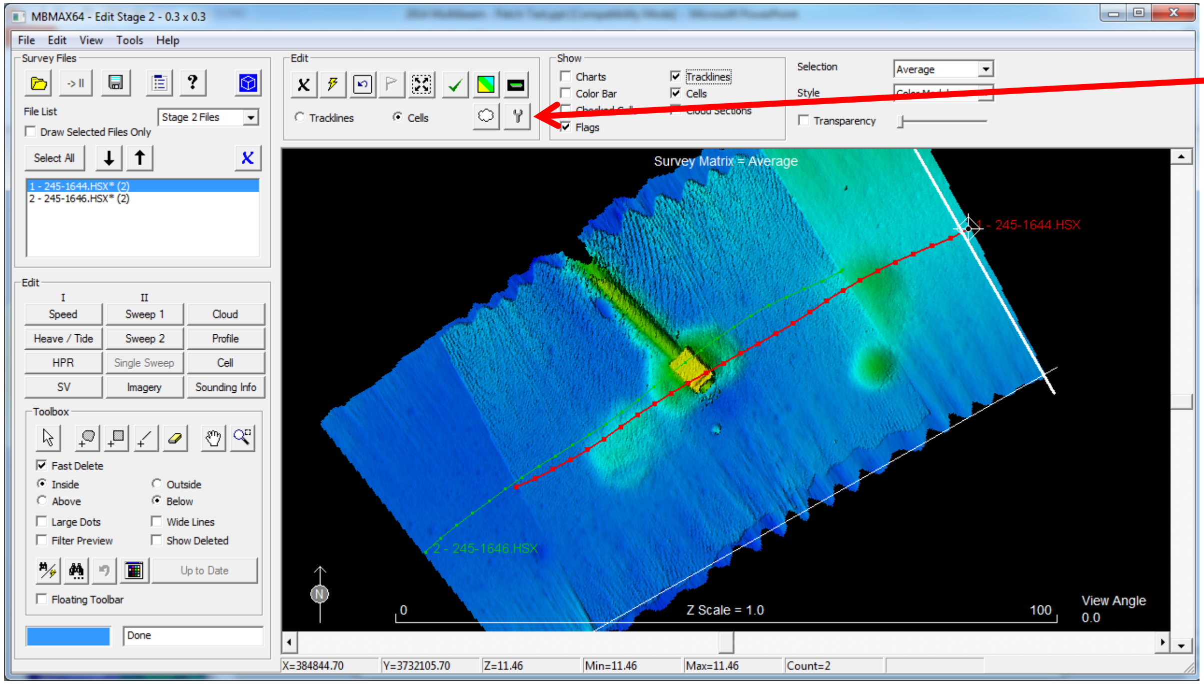
Patch Test Processing

In MBMAX64 You can load all survey lines at once, and then select the pairs needed for Stage 2 editing and testing

Once a pair is selected, edit the data for flyers and now ready for the Patch Test. Note the outer edge mis-alignment. This will be fixed with the computation of the Patch Test angles



- Use "Wrench" icon to manually cut the section.
- Roll section: Across track, flat area.
- Pitch section: Along track, over nadir.
- Yaw Section: Along track, half way between lines.
- Latency section: Along track, over nadir.

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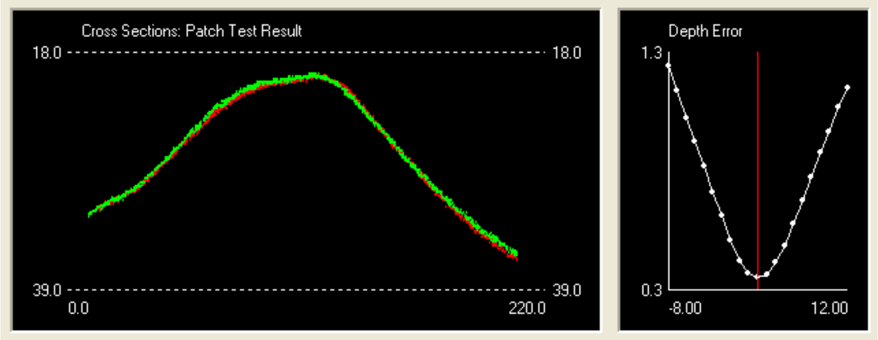
How It Works

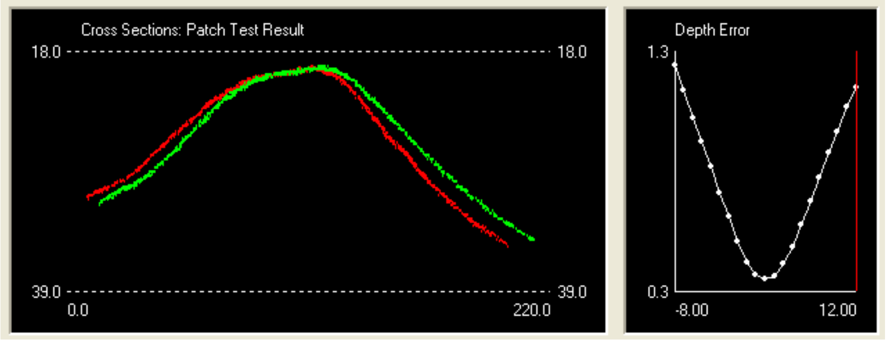
Numerical Method

- The cross sections are calculated at various angle offsets. For example; pitch offset from -10 to 10 degrees at one degree steps.
- An error value is calculated at each offset. Error = average depth difference between cross sections.
- Minimum error is usually the correct offset. But not always! Use the profile view to see cross sections and ensure the data looks good.



Good Fit

- Cross sections overlay well.
- Error is at the minimum point.



Poor Fit

- Cross sections overlay poorly.
- Large error.

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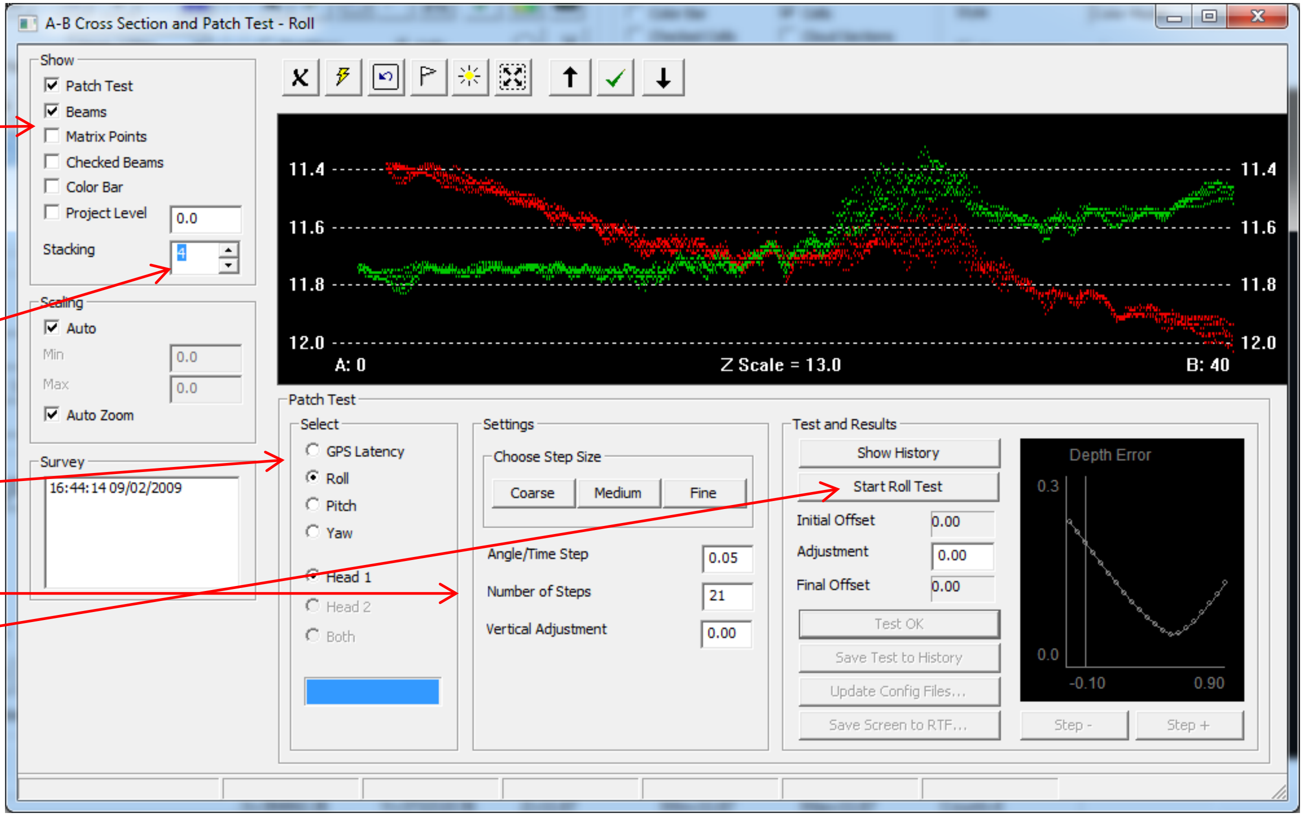
Patch Test Window

Using the profile tool in MBMAX, cut the desired section

- Select Patch test (window is also a profile view of the data)
- Stack swaths to get a denser set
- Select Test and sonar Head
- Select Step size
- START test



- The program will run through the iterations and come up with a minimum value. Use the step + and – to ensure the points in the profile are in agreement.
- Once done, Hit TEST OK

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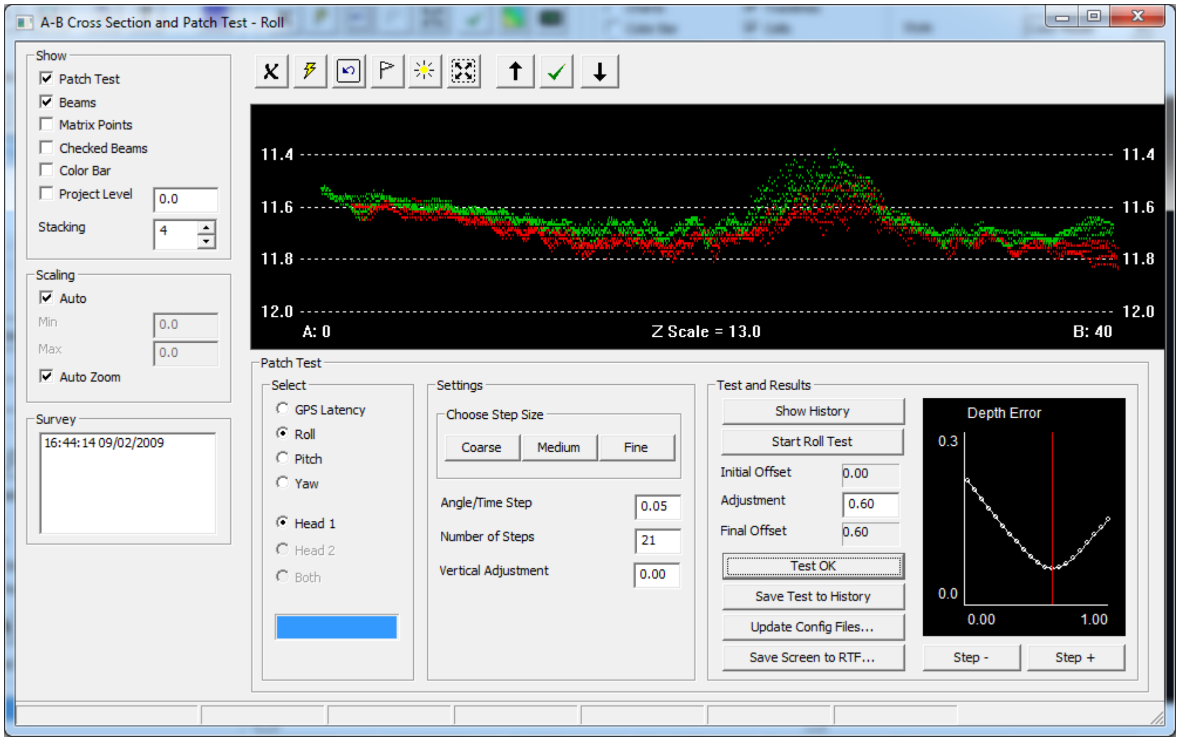
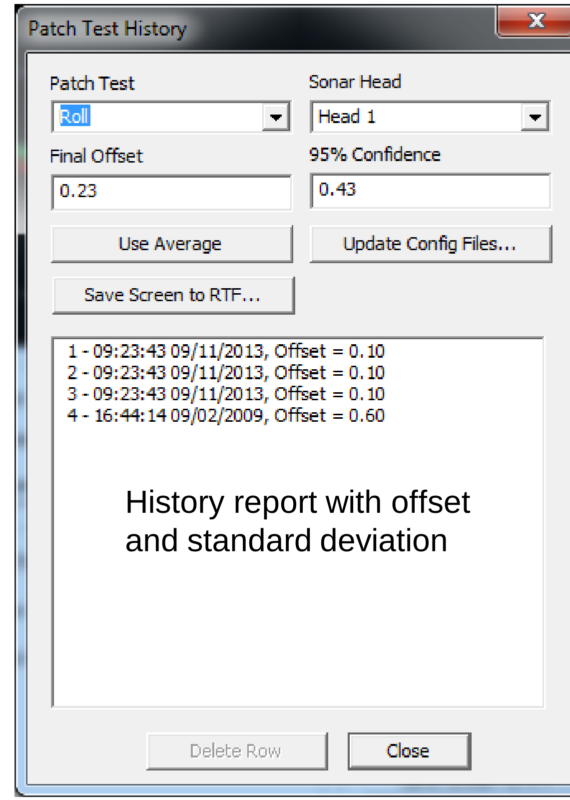
Patch Test Window

Once test is run, use a smaller step size to refine the results. Hit OK once you are satisfied with the results





Options:

- Save TEST to History. Shows previous results of tests
- Update Config file. Sets value in HYSWEEP hardware automatically
- Save screen to RFT. Useful for reports

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Testing Order and Repetition

Order of Processing makes a Difference

- Find the Latency offset first. (If Latency Test is necessary.)
- Apply latency, then do the Pitch test.
- Apply pitch, then do the Roll test.
- Apply roll, then finish with the Yaw test.

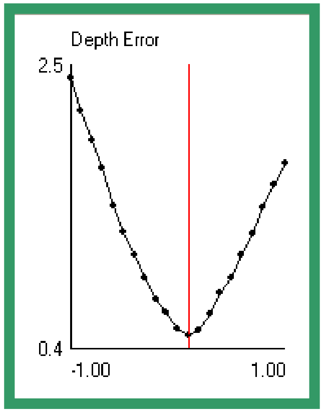
Do It Again to check results

- After finding initial results, repeat the testing.
- Use the same order – Pitch, then Roll, then Yaw.
- The second run gives tighter results.

If a test comes up with a value that is totally different, re-run the tests until there is agreement and consistency.

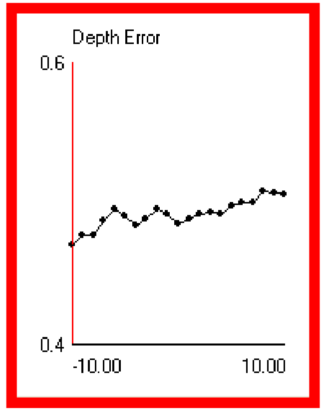
Results

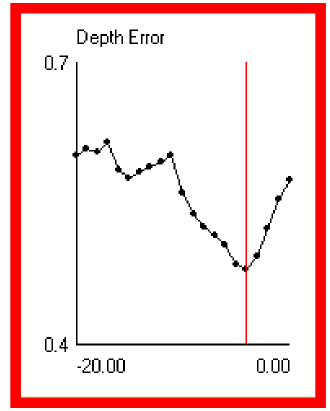
Some Error Curves

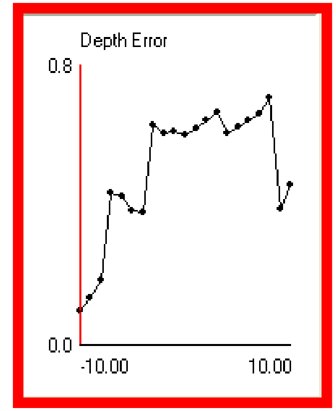


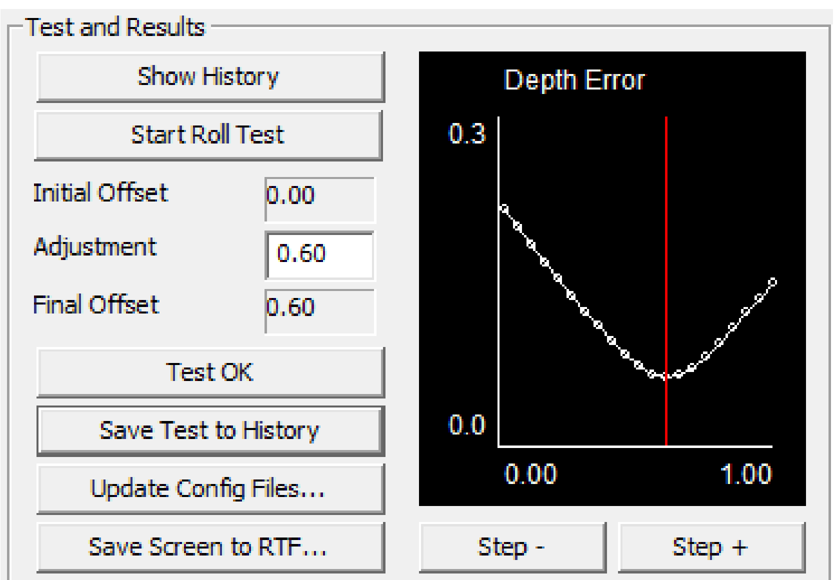
Good.

Not as Good. U-shaped error curve is preferred. But not always possible.









Test Results - what to do with them:

Initial Offset: Offset before patch test. (From HYSWEEP® Hardware.)

Adjustment: Patch test change to initial offset.

Final Offset: To be used in HYSWEEP® Hardware.

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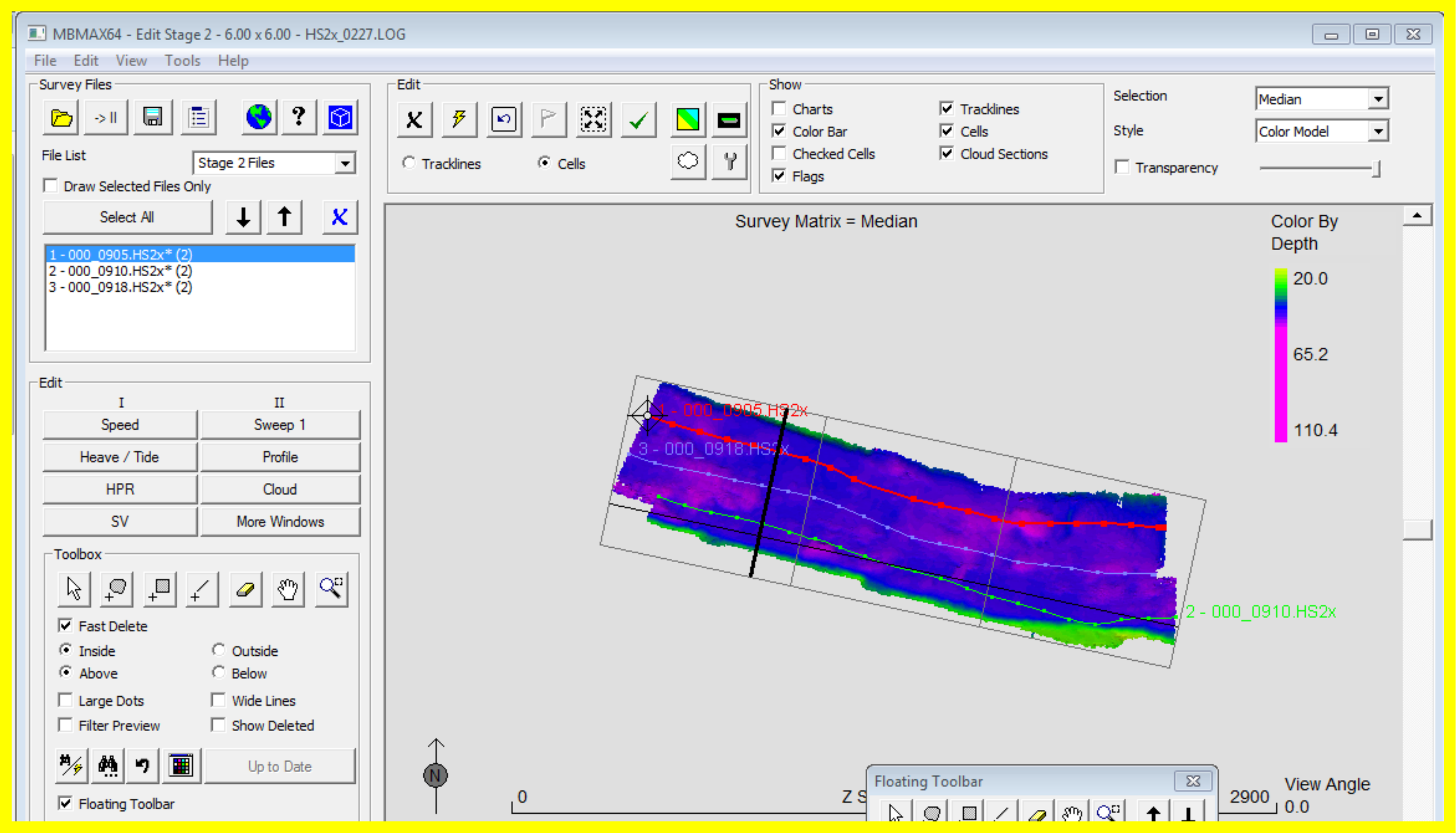
Patch Test Example: Roll



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January 2019

Thank You !

Contact Us:

Sales@HYPACK.com

Help@HYPACK.com

(860) 635 - 1500

Links to more information:

HYPACK on Youtube.com (Historical Sessions)

HYPACK on Youtube.com (Newer Sessions)

HYPACK SUPPORT Site

HYPACK Live Chat

HYPACK Ustream

HYPACK Website

Appendix B—

Processing Your Patch Test Data in the New MBMAX64

Processing your Patch Test Data in the New MBMAX64

By Joe Burnett

In my previous article, '***Multibeam System Setup and Calibration***', I explained the procedures and orientations of your survey lines, for collecting your patch test data. In this article, I'm going to provide you with the HYPACK® method of processing your patch test data and give a more in-depth look at processing your patch test data in the new MBMAX64 (64-bit HYSWEEP® EDITOR). You may have different steps that you follow, but these are the steps that we recommend that you follow.

Important: The values produced from a patch test are statistical values and should be treated as such. The quality of the data, the area in which it was collected, the overlap of the lines and how the boat was driven for each test can and will significantly affect these statistical values.

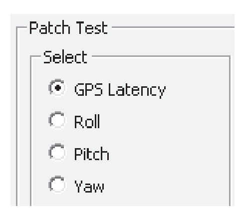
Process Your Data

1. **Load all of your patch test data files into the editor and remove the 'spikes' from each file**.

   Edit and remove what you consider to be false and erroneous data points ('spikes') from the data that you collected. If you do not remove these data points, they can and will influence the values that are produced from the patch test. Since your patch test files were collected over a short distance (usually 100 to 200 meters in length), removing the 'spikes' should be a relatively quick process.
2. **Save your edited files to the HS2 or HS2x format**.

   By editing all of the files at one time, you can now load them into MBMAX64 at one time and select them in groups for processing in the patch test. Repeating the loading process for each test within the patch test was a limitation in the 32-bit patch test.

Patch Test Processing Order



When removing the 'spikes' from your patch test data, there is *no set order* in which you load the files and perform this part of the process; however, the order in which you perform the four (4) tests in the patch test, *does* make a difference. The HYPACK® preferred processing order is this:

1. Latency
2. Roll
3. Pitch
4. Yaw

Latency is done first, because the 'timing' for all of your data must be correct before you can perform any of the 'angular' tests.

Roll is tested second, since it was collected over a flat bottom and any ‘positional’ errors will not significantly affect the test results.

Pitch is third, mainly because the yaw test has to be last.

Yaw is last, because it ‘needs’ the initial ‘rough’ test values from the previous three (3) tests, in order to help it calculate the best yaw test value.

In the MBMAX32 (32-bit HYSWEEP® EDITOR) and MBMAX64 programs, the values calculated from each previous test can be ‘applied’ to the next group of files, for the next test to be performed. For example:

> If your **latency** test produced a value of 0.15 seconds, that value (0.15 seconds) would be applied to the group of files that would be loaded into the roll test.
>
> If the **roll** test produced a value of -2.65 degrees, both the latency value (0.15 seconds) and the roll value (-2.65 degrees) would be applied to the group of files that would be loaded into the pitch test.
>
> If the **pitch** test produced a value of 3.35 degrees, the latency value (0.15 seconds), the roll value (-2.65 degrees), and the pitch value (3.35 degrees) would all be applied to the group of files that would be loaded into the yaw test.

By applying these values to each successive test, better results can be produced for each test. After each test has been performed once, they are again run through the patch test process. This is done to produce a more refined and accurate value for each test, as the first tests did not have the benefit of the values produced in the later tests.

A Third Pass through the tests can be performed, but it is unlikely that you will see any significant change in any of the values, if any change at all.

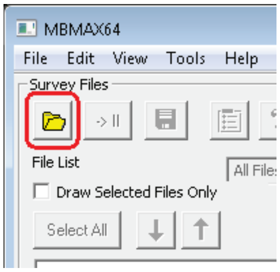
PERFORMING THE PATCH TEST IN MBMAX64

1. **Load all of the edited HS2 or HS2x patch test files into Stage 1** of MBMAX64.
2. **Check all settings and values in the Read Parameters window.** In the matrix settings, the Cell Size is typically set to 1’ x 1’ or 0.5m x 0.5m for patch test data.

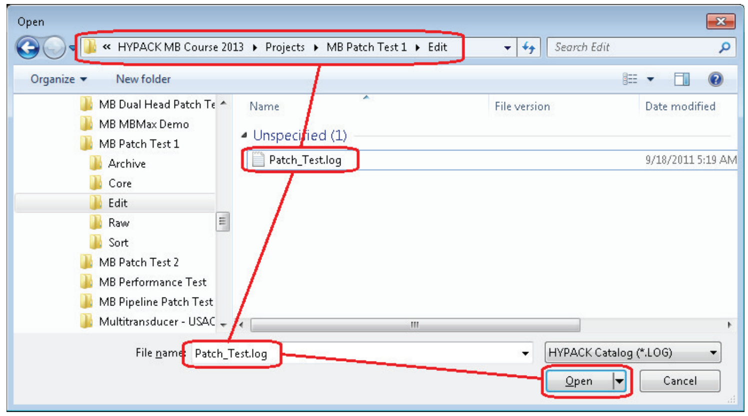
Note: If a value or setting needs to be changed, you can change it at any time or step in the processing, by simply re-accessing the Read Parameters window. Changing your read parameters without reloading your data is not possible in the 32-bit HYSWEEP® EDITOR.

TABLE 1. Loading the Files to MBMax64

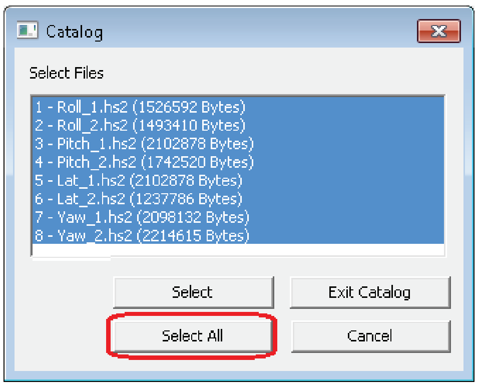
1



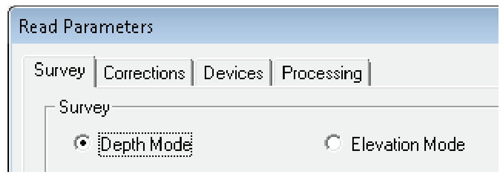
2



3



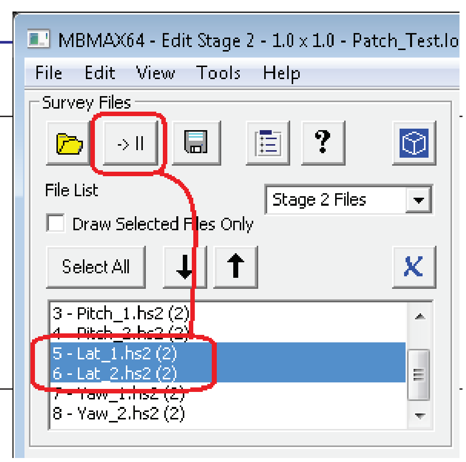
4



LATENCY TEST

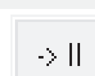
1. **Select the group of files to be processed to measure latency in the PATCH TEST routine**.

FIGURE 1. Loading the Files to Test Latency to Stage 2

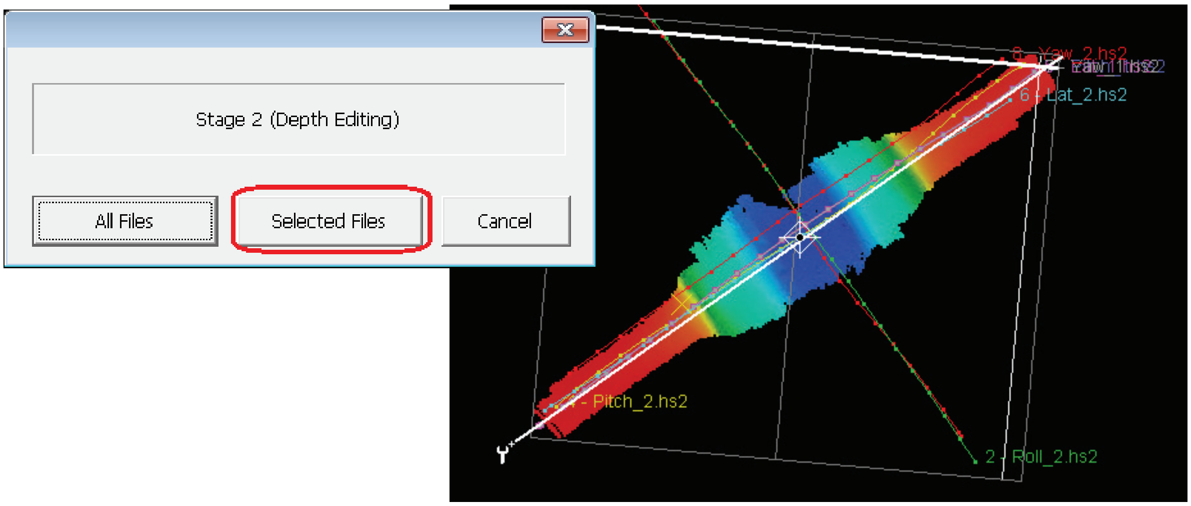


Note: The term ‘group’ is being used, because a minimum of two files is required for each test, but more than two files can be loaded at a time. Remember, PATCH TEST calculations are ‘statistical values’ and if you load more data for the PATCH TEST to use, you may get a more definable and supportable ‘statistical value’.

2. **Click on the Stage 2 button**.

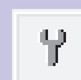


3. **Click the 'Selected Files' button.** The selected group of latency files will be displayed in the main window.

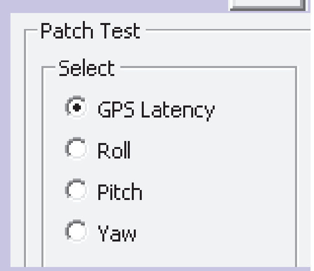


The PATCH TEST is embedded in MBMAX64 and can be accessed in two different ways:

- **Manual Cross Section Tool** which allows you to 'manually cut' the cross section needed for a particular test.



  Once the PATCH TEST window appears, you must select the correct test to be performed in the PATCH TEST interface.



OR

- Select TOOLS-PATCH TEST then the test that you want to perform. PATCH TEST will automatically cut the cross section for you will automatically cut the cross section for you and select the correct test to be performed in the PATCH TEST window.

FIGURE A. *Starting a Patch Test Through the Menu*

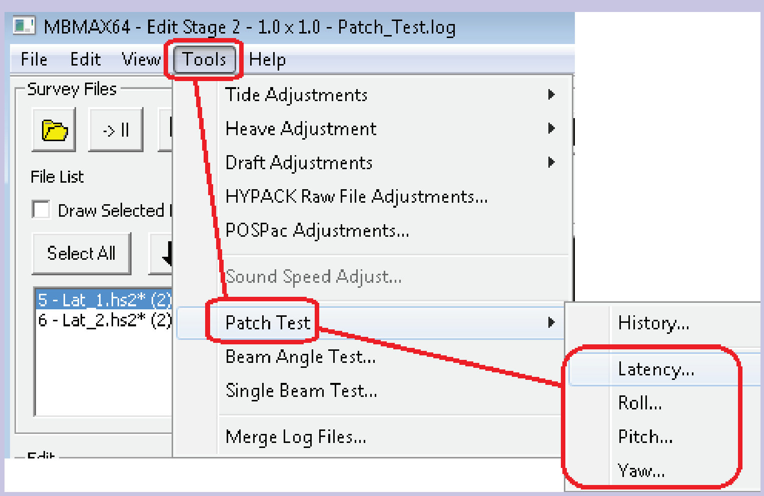
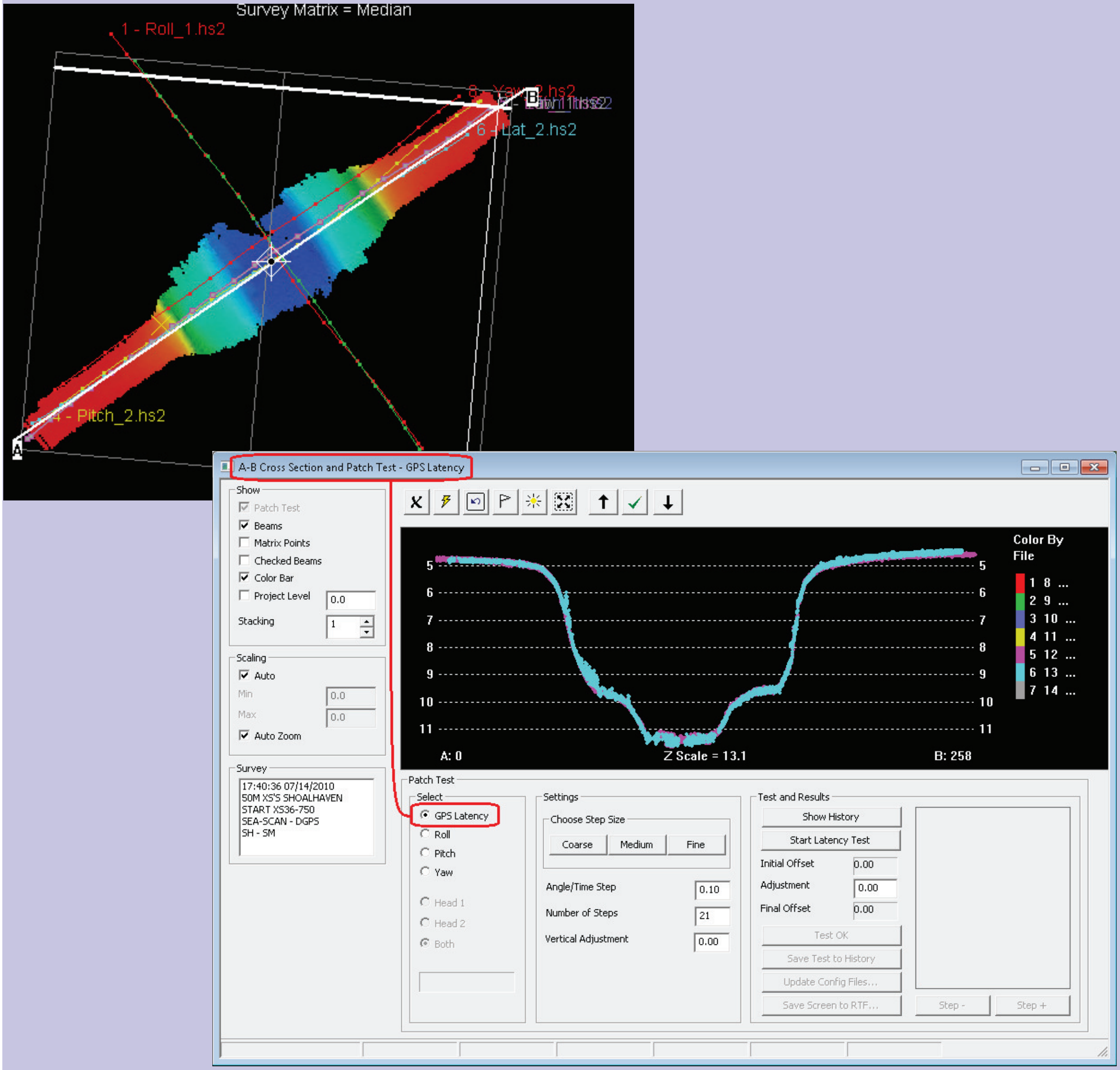


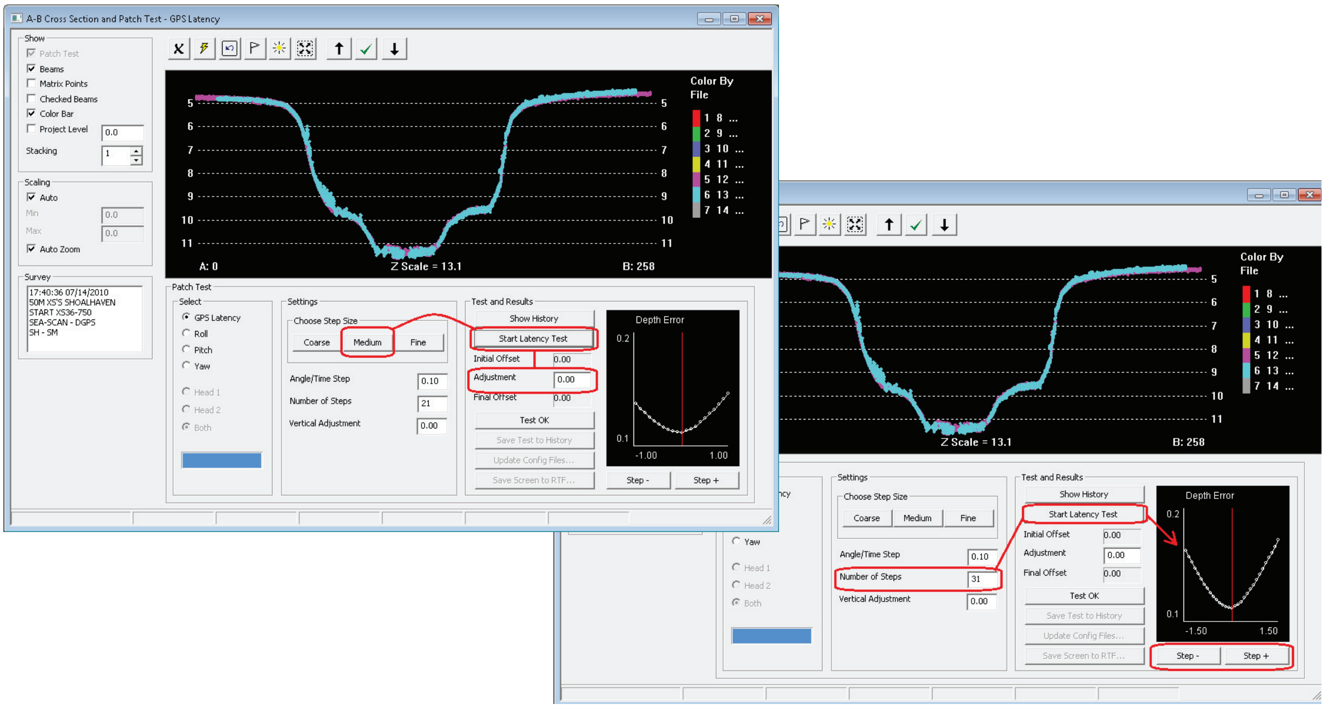
***FIGURE B.** Cross Section Automatically Cut by the PATCH TEST Routine*



Here is where your visual interpretation comes into play. Looking at the two overlapping cross sections, you can determine which Step Size to start with (Coarse, Medium, or Fine). If you see a significant separation, Coarse may be a good selection. If the overlap of the cross sections looks like Figure B (minimal to no separation), I would probably start with the Medium setting.

4. **Cut the cross section.**
5. **Select Step Size, Number of Steps, and click [Start Latency Test].**

FIGURE 2. Medium Step=0.10 sec. increments, Number of Steps = 21 (left), Medium Step = 0.10 sec. increments, Number of Steps increased to 31. (This gives a more pronounced 'V' shape.)



6. **Repeat 'Start Latency Test' until a 'V-Shape' is seen** in the Depth Error window. This is the first pass with the latency data, so there is no real need to do a fine step yet. Remember, these are statistical values and the red line will be at the lowest calculated statistical value found during the test. It is your job to verify its validity and modify it, if necessary. To adjust the position of the vertical red line, click on [Step -] and [Step +] to move it.
7. **Click [Test OK] and save the results as desired**. PATCH TEST automatically updates the offsets for the test that you just performed, in all of the files that are currently loaded and enables the next three buttons to enable you to store your results in other places as follows:
   - **To archive this test**, click [Save Test to History].
   - **To update the Hysweep.ini[1] and BoatConfig.ini[2] Files**, click [Update Config Files…].
   - **To save the results to a digital document**, click [Save Screen to RTF...], select the folder path and enter a file name.
8. **Close the PATCH TEST window**.

1. HYSWEEP® HARDWARE settings.
2. The Boat Configuration file stores all of the offsets in a central location so you can easily load the correct offsets (in the Read Parameters) when you load each data set for editing. In this case, the program updates the Boat Configuration file with the current offset calculation.

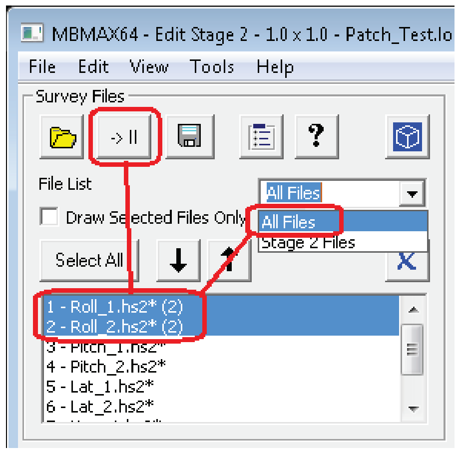
9. **If ‘Auto Update Mode’ is not set in the dialog under EDIT-SETTINGS,** click on the red ‘Update Devices’ button.

10. **Change the File List to ‘All Files’** and repeat the same steps for the next test.

ROLL TEST

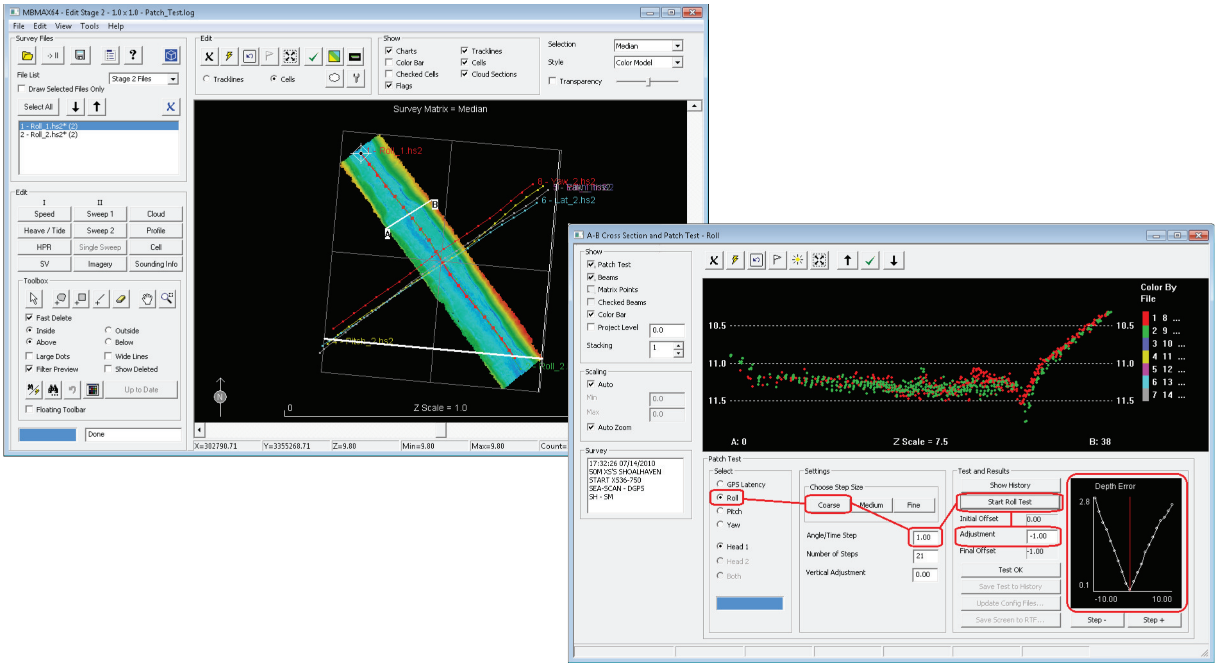
1. **Select the group of files to be processed to measure roll in the PATCH TEST routine.**

FIGURE 3. Loading the Files to Test Roll to Stage 2



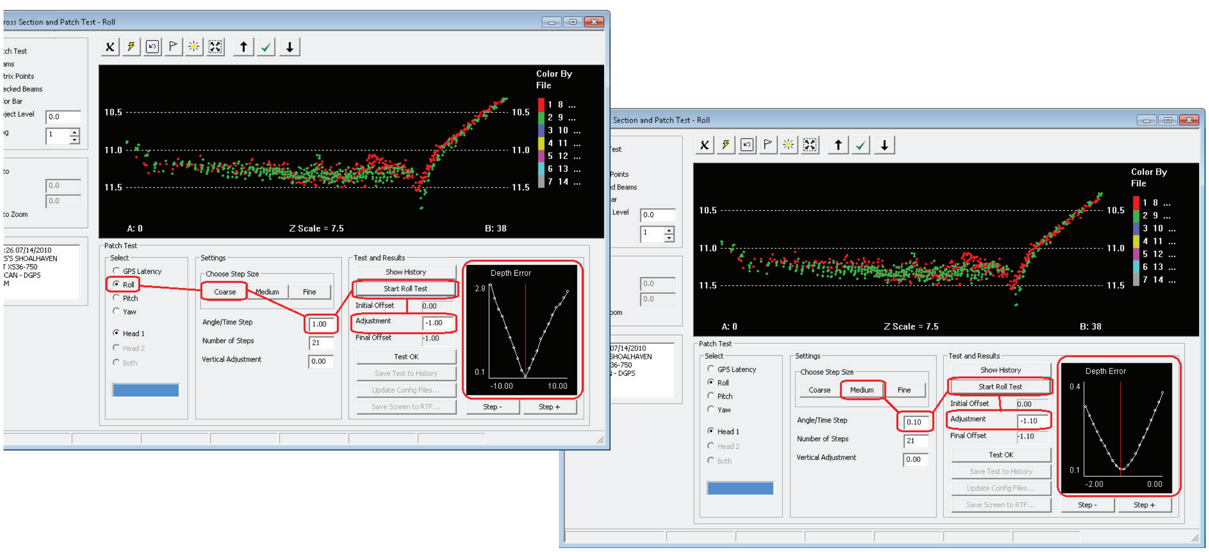
2. **Click on the Stage 2 button**.
3. **Click the ‘Selected Files’ button**.
4. **Cut the cross section.** Notice the amount of the separation.

FIGURE 4. Cutting the Cross Section and Checking the Separation



5. **Select the Coarse Step Size and click [Start Roll Test].**
6. **Change the Step Size to Medium and click [Start Roll Test].**

FIGURE 5. Coarse Test (left), Medium Test (right)



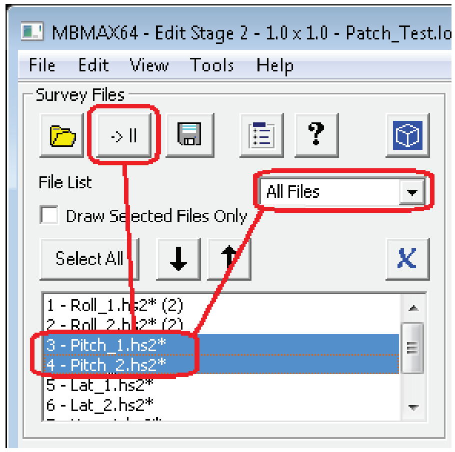
7. **Click [Test OK] and store your calculations** as desired.
8. **Close the PATCH TEST window**.
9. **If 'Auto Update Mode' is not set in the dialog under EDIT-SETTINGS,** click on the red 'Update Devices' button.

10. **Change the File List to 'All Files'** and repeat the same steps for the next test.

Pitch Test

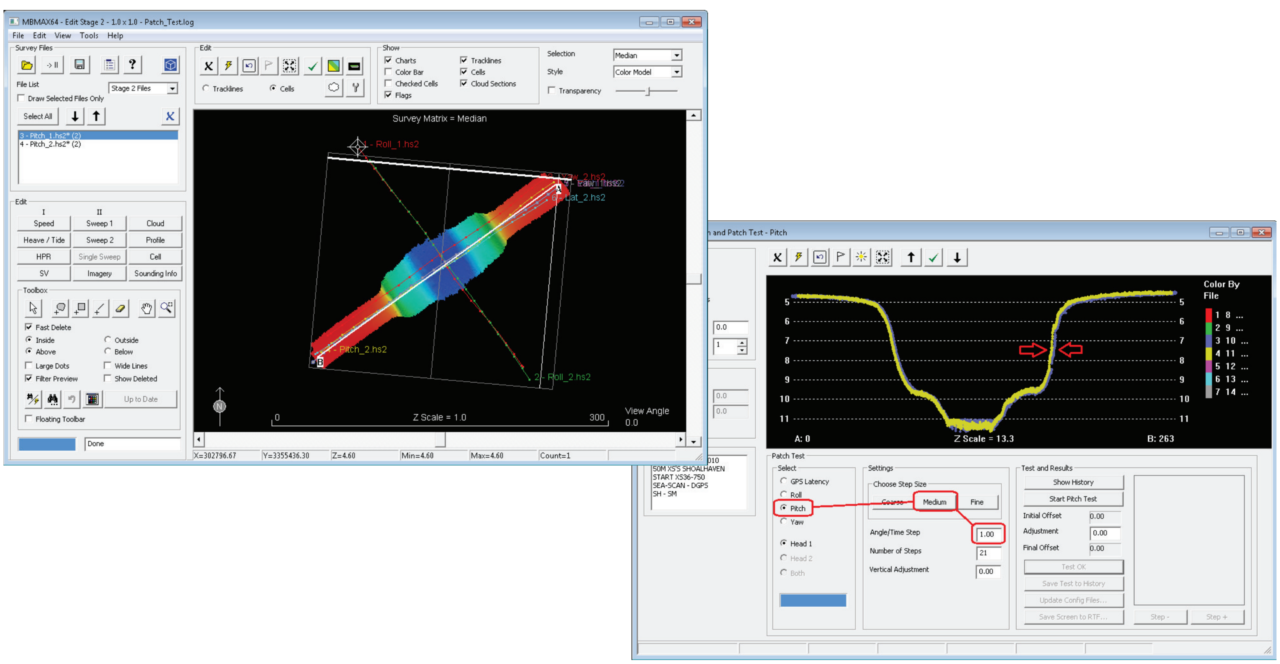
1. **Select the group of files to test for pitch in the PATCH TEST routine**.

FIGURE 6. Loading the Files for the Pitch Test.



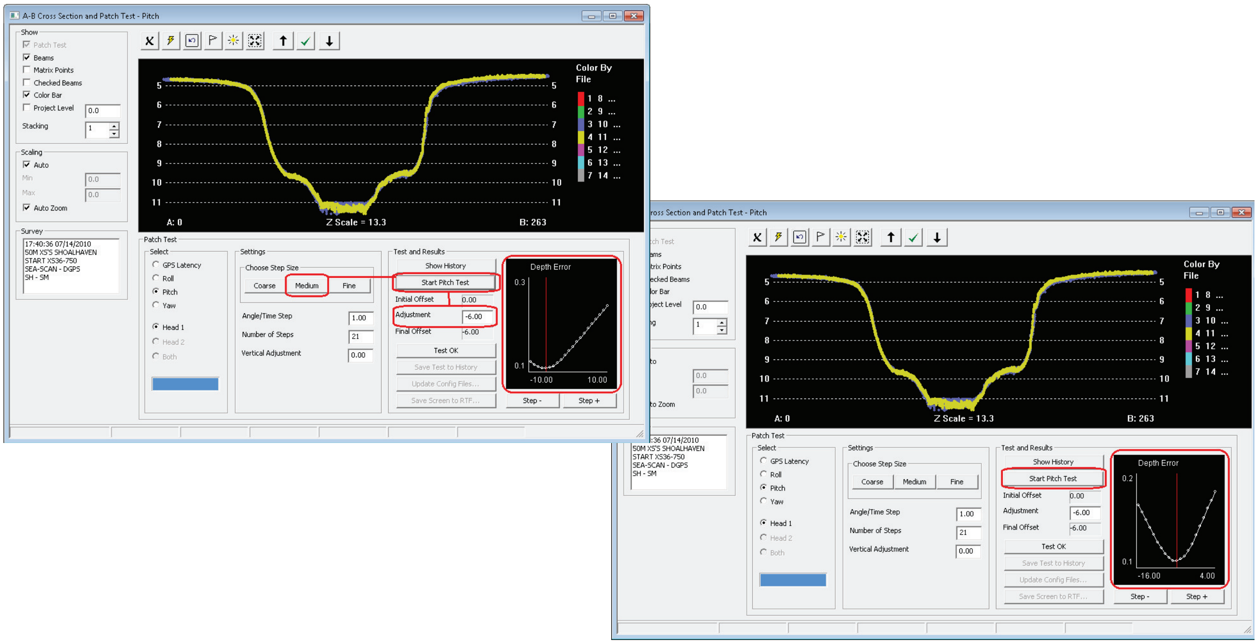
2. **Click on the Stage 2 button**.
3. **Click the 'Selected Files' button**.
4. **Cut the cross section.** Notice the amount of the separation.

FIGURE 7. Cutting the Cross Section and Checking the Separation



5. **Select the Medium Step Size and [Start Pitch Test].**
6. **Repeat [Start Pitch Test] until a V-Shape is seen in the Depth Error Window.**

FIGURE 8. Medium Step Size Results (left), Final Results (right)



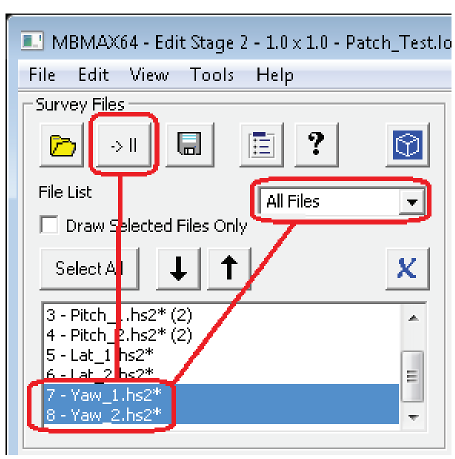
7. **Click [Test OK] and store your calculations** as desired.
8. **Close the PATCH TEST window**.
9. **If 'Auto Update Mode' is not set in the dialog under EDIT-SETTINGS,** click on the red 'Update Devices' button.

10. **Change the File List to 'All Files'** and repeat the same steps for the next test.

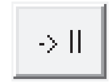
Yaw Test

1. **Select the group of files to test for yaw in the PATCH TEST routine**.

FIGURE 9. Loading the Yaw Test Files to Stage 2

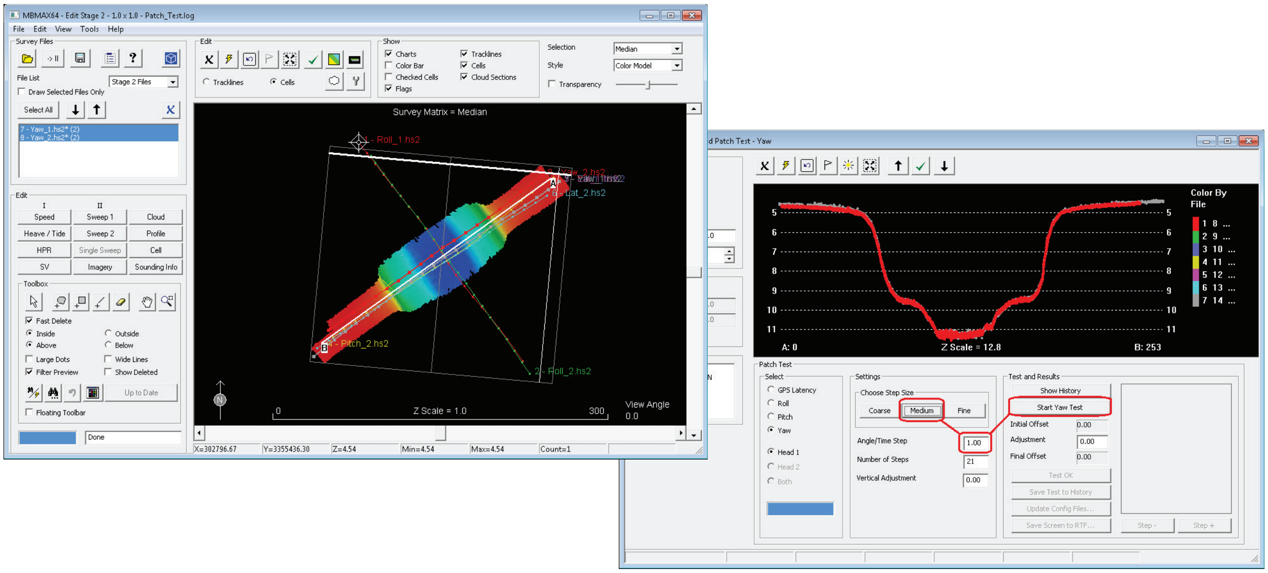


2. **Click on the Stage 2 button**.



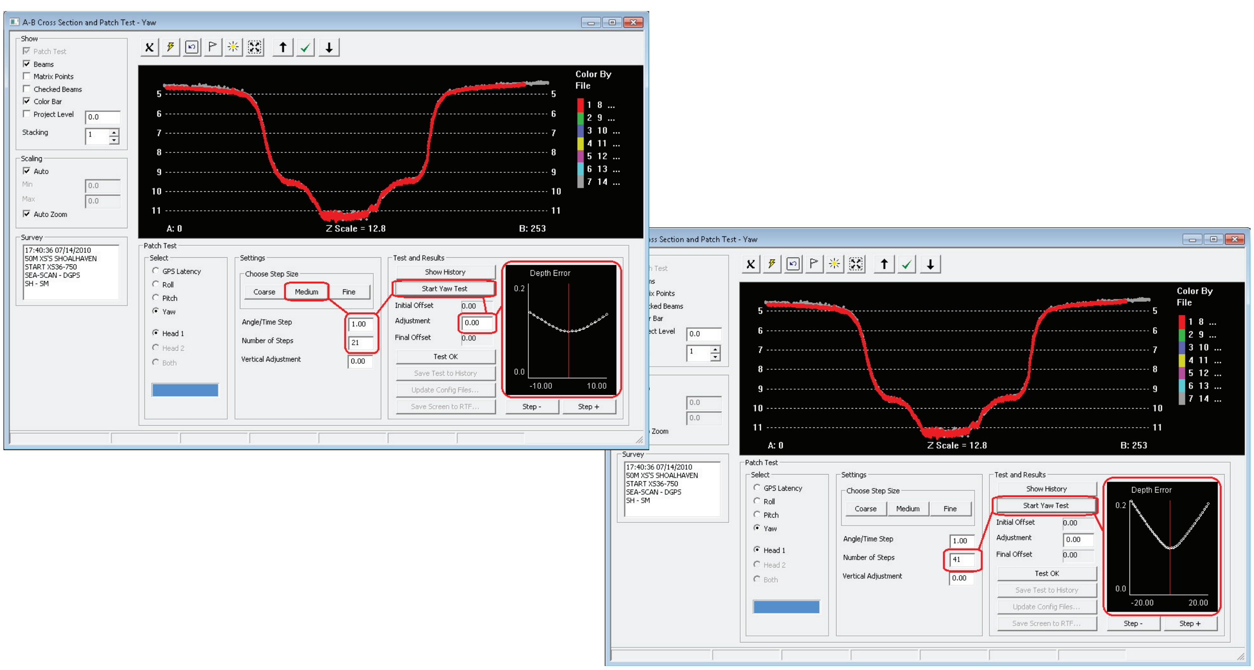
3. **Click the 'Selected Files' button**.
4. **Cut the cross section.** Notice there is almost no separation.

FIGURE 10. Cutting the Cross Section for the Yaw Test



5. **Select the Medium Step Size and click [Start Yaw Test].**
6. **Repeat [Start Yaw Test] until a V-Shape is seen in the Depth Error Window.**

FIGURE 11. Medium Step=1.00 Degree Increments, Number of Steps = 21 (left), Medium Step = 1.00 degree increments, Number of Steps increased to 41 (right) This gives a more pronounced 'V' shape).



7. **Click [Test OK] and store your calculations** as desired.
8. **Close the PATCH TEST window**.
9. **If 'Auto Update Mode' is not set in the dialog under EDIT-SETTINGS,** click on the red 'Update Devices' button.

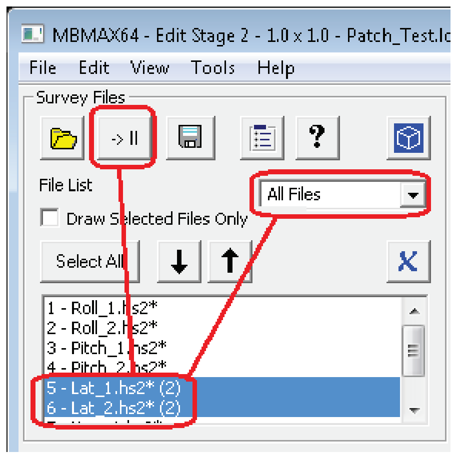
10. **Change the File List to 'All Files'** and repeat the same steps for the next test.

Latency Test (Second Pass)

Repeat the latency test, using *only* the Fine Step Size.

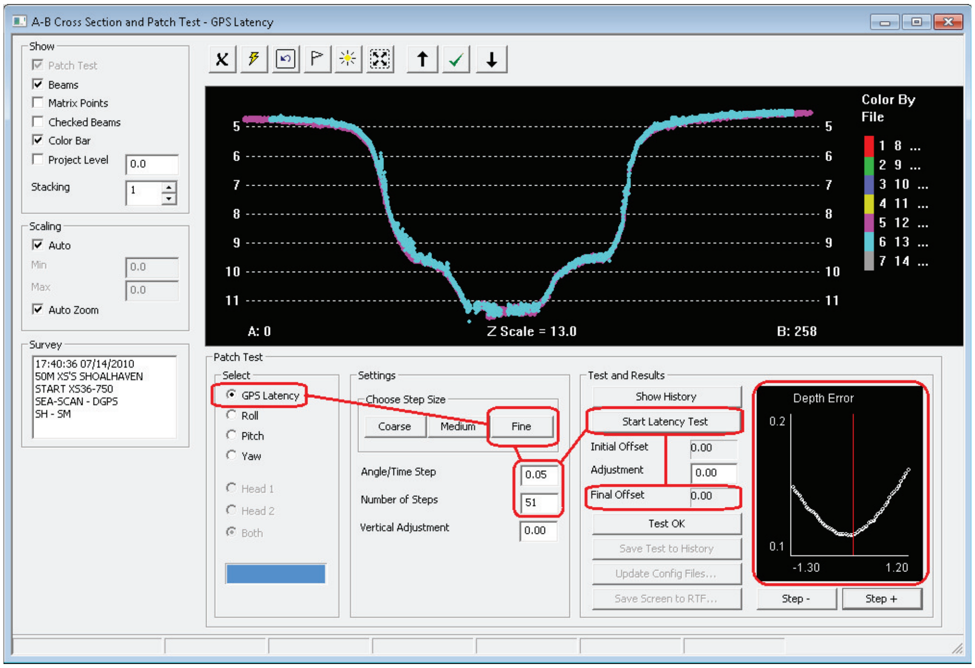
1. **Select the group of files to be processed to measure latency** in the PATCH TEST for the second time (second pass).

FIGURE 12. Taking your Latency Test Files to Stage 2



2. **Click on the Stage 2 button**.
3. **Click the 'Selected Files' button**.
4. **Cut the cross section.** Notice there is almost no separation.
5. **Select Step Size to Fine and enter Number of Steps.**

FIGURE 13. *Fine Step = 0.05 sec. Increments, Number of Steps Increased to 51. This gives a more pronounced 'V' shape.*



Important:

- Latency is *always* a positive value for the Final Offset. It can *never* be a negative value.
- Remember, these are statistical values.
- If the program produces a negative value (and it might), use [Step +] to bring the Final Offset value to 0.00.
- Almost every 'new' multibeam sonar produced today, time-synchronizes their data with the ZDA message and 1PPS Pulse from the GPS in order to provide zero latency (0.00).

---

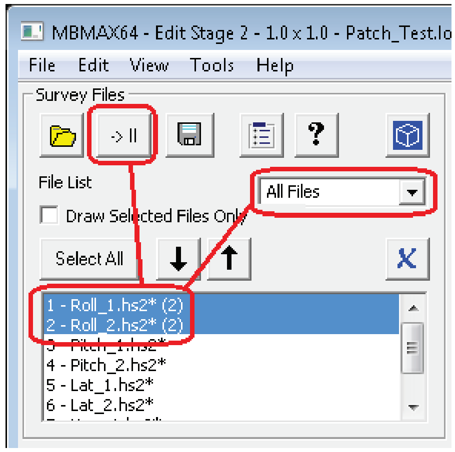
6. **Click [Start Latency Test].**
7. **Click [Test OK] and store your calculations** as desired.
8. **Close the PATCH TEST window**.
9. **If 'Auto Update Mode' is not set in the dialog under EDIT-SETTINGS,** click on the red 'Update Devices' button.

10. **Change the File List to 'All Files'** and repeat the same steps for the next test.

Roll Test (Second Pass)

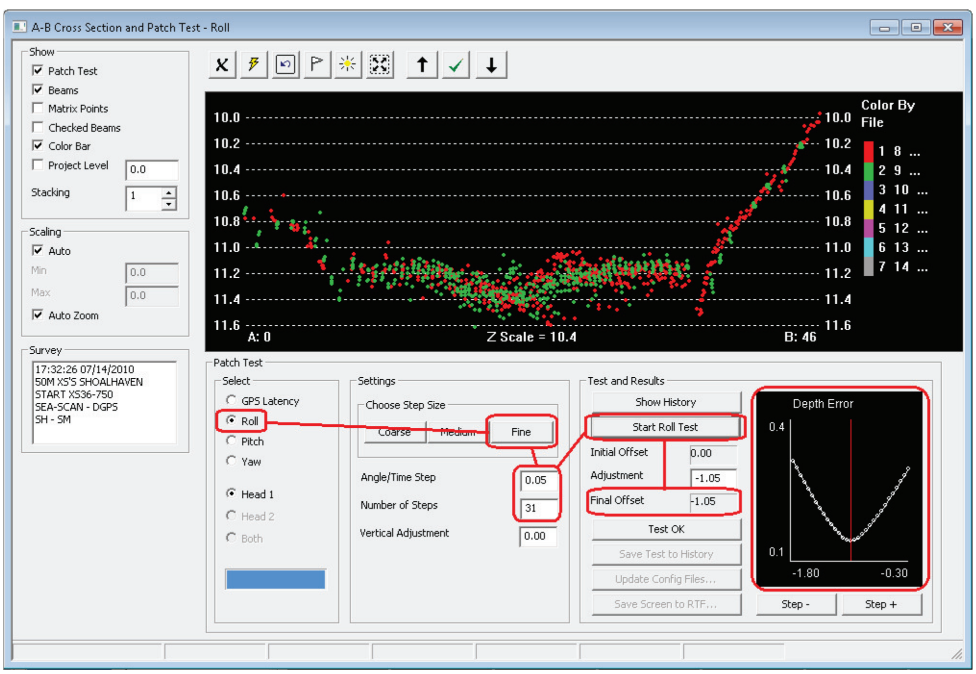
1. **Select the group of files to be processed to measure roll in the PATCH TEST for the Second Pass and repeat steps 2 through 10** for the roll test, using only the Fine Step Size.

FIGURE 14. *Taking the Files for the Roll Test to Stage 2*



2. **Click on the Stage 2 button**.
3. **Click the 'Selected Files' button**.
4. **Cut the cross section.** Notice there is almost no separation.
5. **Select Step Size to Fine and set the Number of Steps.**

FIGURE 15. *Fine Step = 0.05 degree increments, Number of Steps increased to 31. (This gives a more pronounced 'V' shape.)*



6. **Click [Start Roll Test].**
7. **Click [Test OK] and store your calculations** as desired.
8. **Close the PATCH TEST window**.

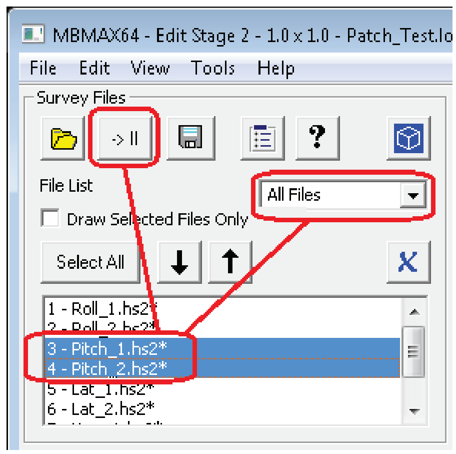
9. **If ‘Auto Update Mode’ is not set in the dialog under EDIT-SETTINGS,** click on the red ‘Update Devices’ button.

10. **Change the File List to ‘All Files’** and repeat the same steps for the next test.

PITCH TEST (SECOND PASS)

1. **Select the group of files to be processed to measure Pitch** in the PATCH TEST for the ‘Second Pass’, then repeat the pitch test, using *only* the Fine Step Size.

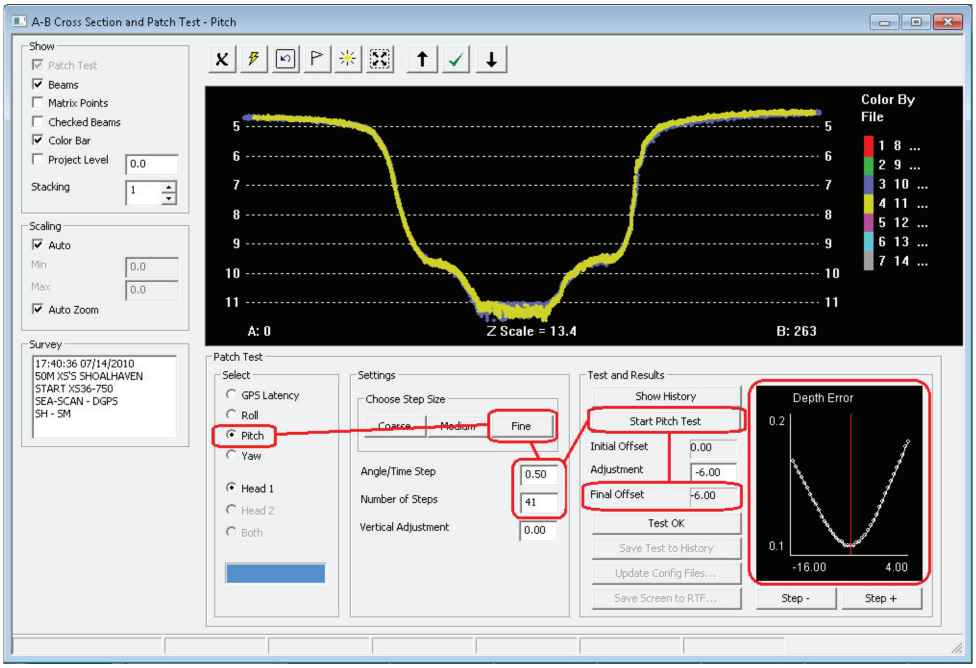
FIGURE 16. *Taking your Pitch Test Files to Stage 2*



2. **Click on the Stage 2 button**.
3. **Click the ‘Selected Files’ button**.
4. **Cut the cross section.** Notice there is almost no separation.
5. **Set the Step Size to Fine and set the Number of Steps.**

Note: With DGPS, 0.50 degrees is the best resolution. With RTK GPS, 0.10 degrees is the best resolution. This value can be manually entered in the Angle/Time Step field.

FIGURE 17. Fine Step = 0.50 degree increments, Number of Steps increased to 41. (This gives a more pronounced 'V' shape.)



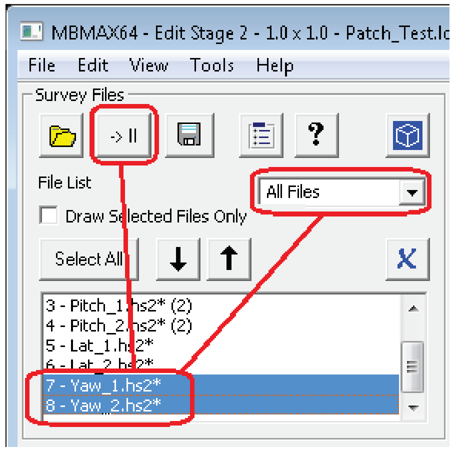
6. **Click [Start Pitch Test].**
7. **Click [Test OK] and store your calculations** as desired.
8. **Close the PATCH TEST window**.
9. **If 'Auto Update Mode' is not set in the dialog under EDIT-SETTINGS,** click on the red 'Update Devices' button.

10. **Change the File List to 'All Files'** and repeat the same steps for the next test.

Yaw Test (Second Pass)

1. **Select the group of files to be processed to measure Yaw** in the PATCH TEST for the 'Second Pass', then repeat the yaw test, using *only* the Fine Step Size.

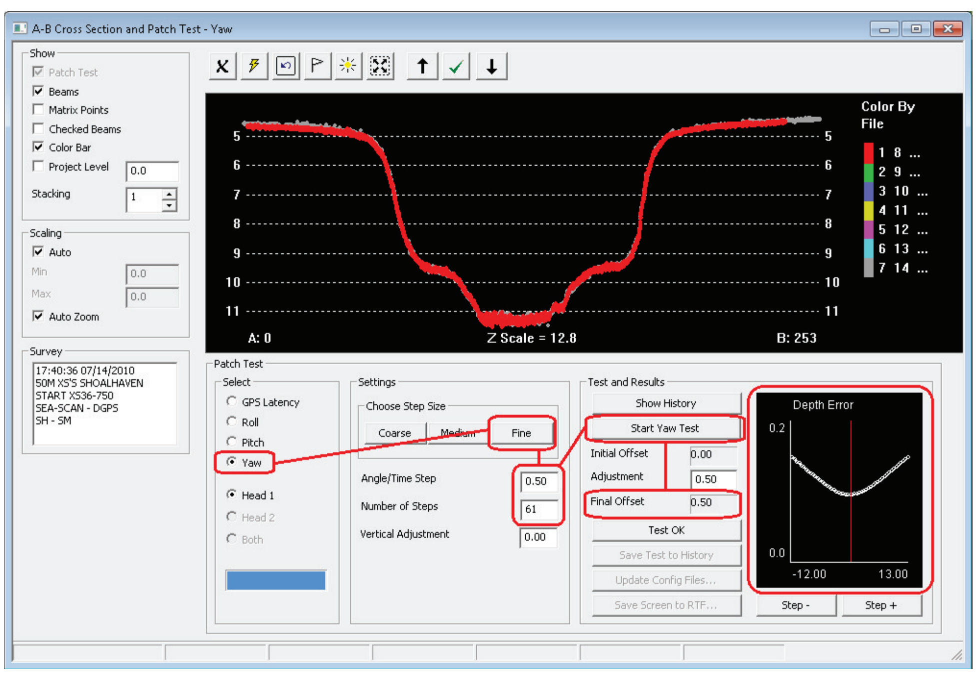
FIGURE 18. Taking the Yaw Test Files to Stage 2



2. **Click on the Stage 2 button**.
3. **Click the 'Selected Files' button**.
4. **Cut the cross section.** Notice there is almost no separation.
5. **Set the Step Size to Fine and set the Number of Steps.**

Note: With **DGPS**, 0.50 degrees is the best resolution.
With **RTK GPS**, 0.10 degrees is the best resolution.
This value can be manually entered in the Angle/Time Step field.

FIGURE 19. Fine Step = 0.50 degree increments, Number of Steps increased to 61. This gives a more pronounced V-shape.



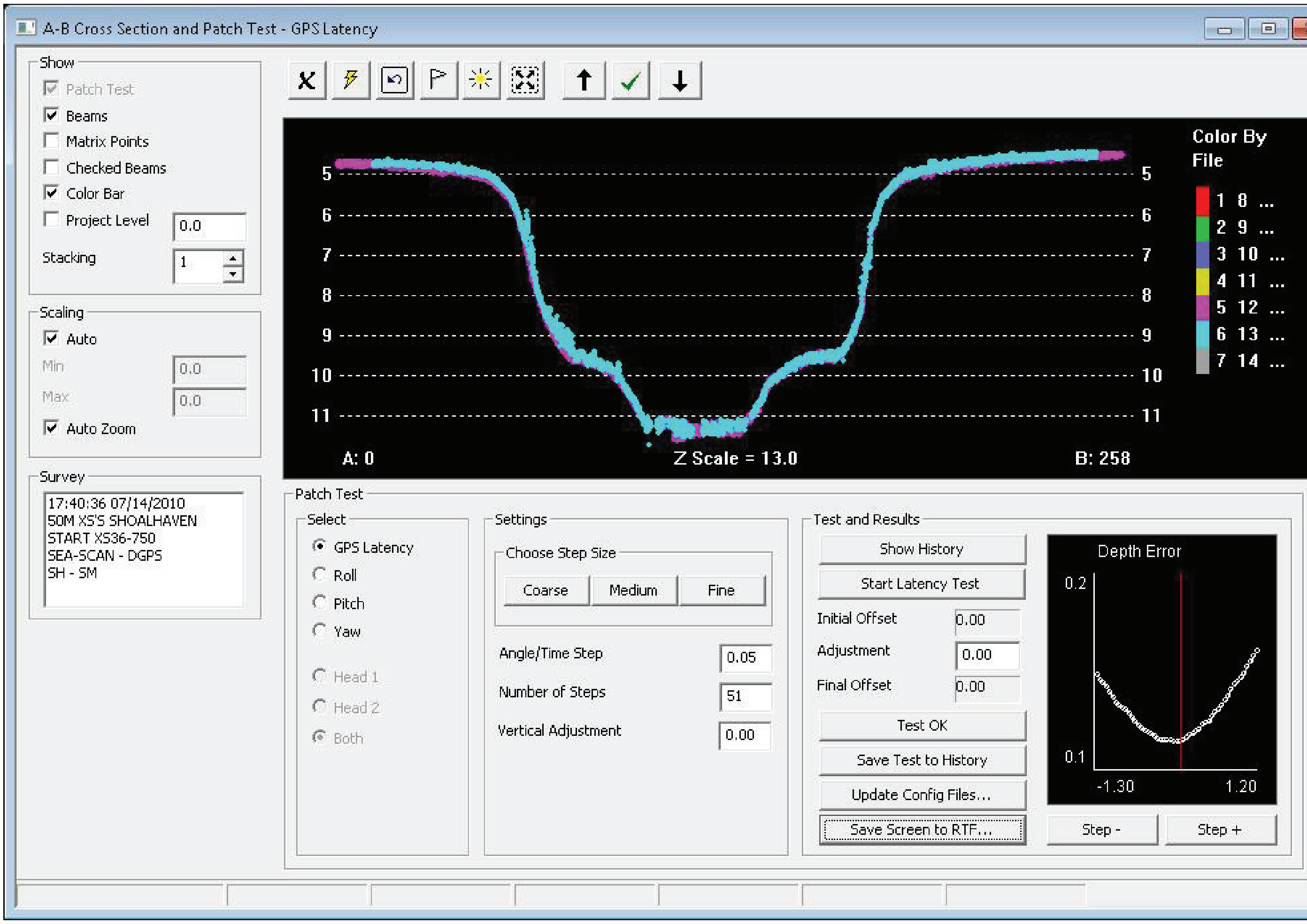
6. **Click [Start Yaw Test].**
7. **Click [Test OK] and store your calculations** as desired.
8. **Close the PATCH TEST window**.
9. **If 'Auto Update Mode' is not set in the dialog under EDIT-SETTINGS,** click on the red 'Update Devices' button.

CONGRATULATIONS! You have now completed a patch test in MBMAX64.

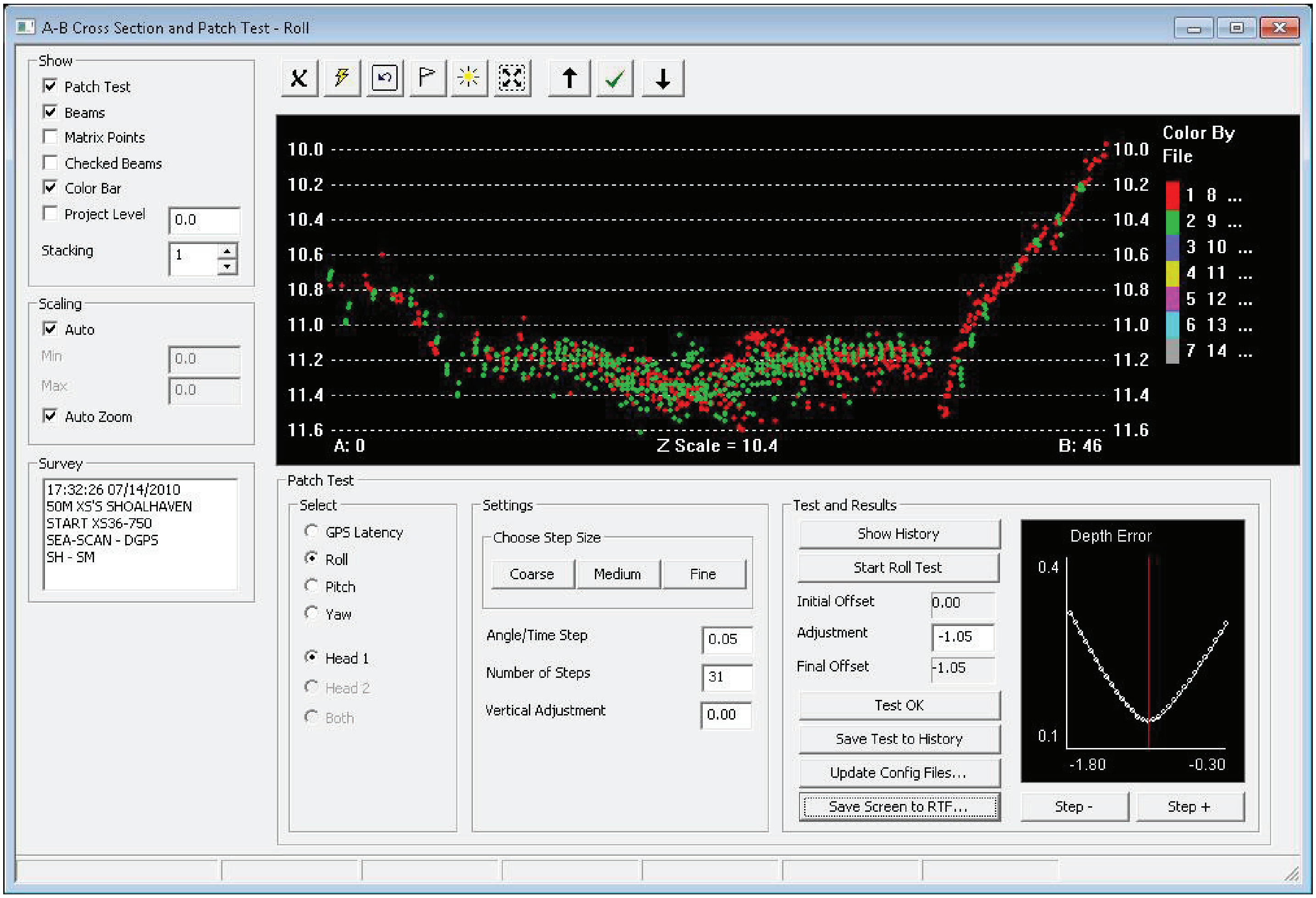
LAST NOTES

- If you updated your configuration files after the second pass for each test, the HYSWEEP® HARDWARE configuration (Hysweep.ini file) has been updated with the latest patch test result values and the offsets in the BoatConfig.ini file have been updated and can be read by MBMAX64 and applied to HSX, HS2, and HS2x files.
- If you did NOT update your configuration files after the second pass of each test, you must to open the HYSWEEP® HARDWARE program and manually enter the PATCH TEST values in their correct locations.
  a. The **latency** value goes in the latency offset for the 'Hypack Navigation' device.
  b. The **Roll**, **Pitch**, and **Yaw** values go in the offsets for your multibeam device.
  c. **Save the HYSWEEP® HARDWARE configuration file** (Hysweep.ini).
- Your next survey data collection will now have these offset values applied to the displays during data collection. The offsets are embedded in the header of each HSX file where they are read by the HYSWEEP® Editors when you process your data.
- If you saved your results to the RTF digital document, you will have an RTF document that looks like the next 4 pages. You can print this information for easy reference or copy and paste it into a report document for your survey project.

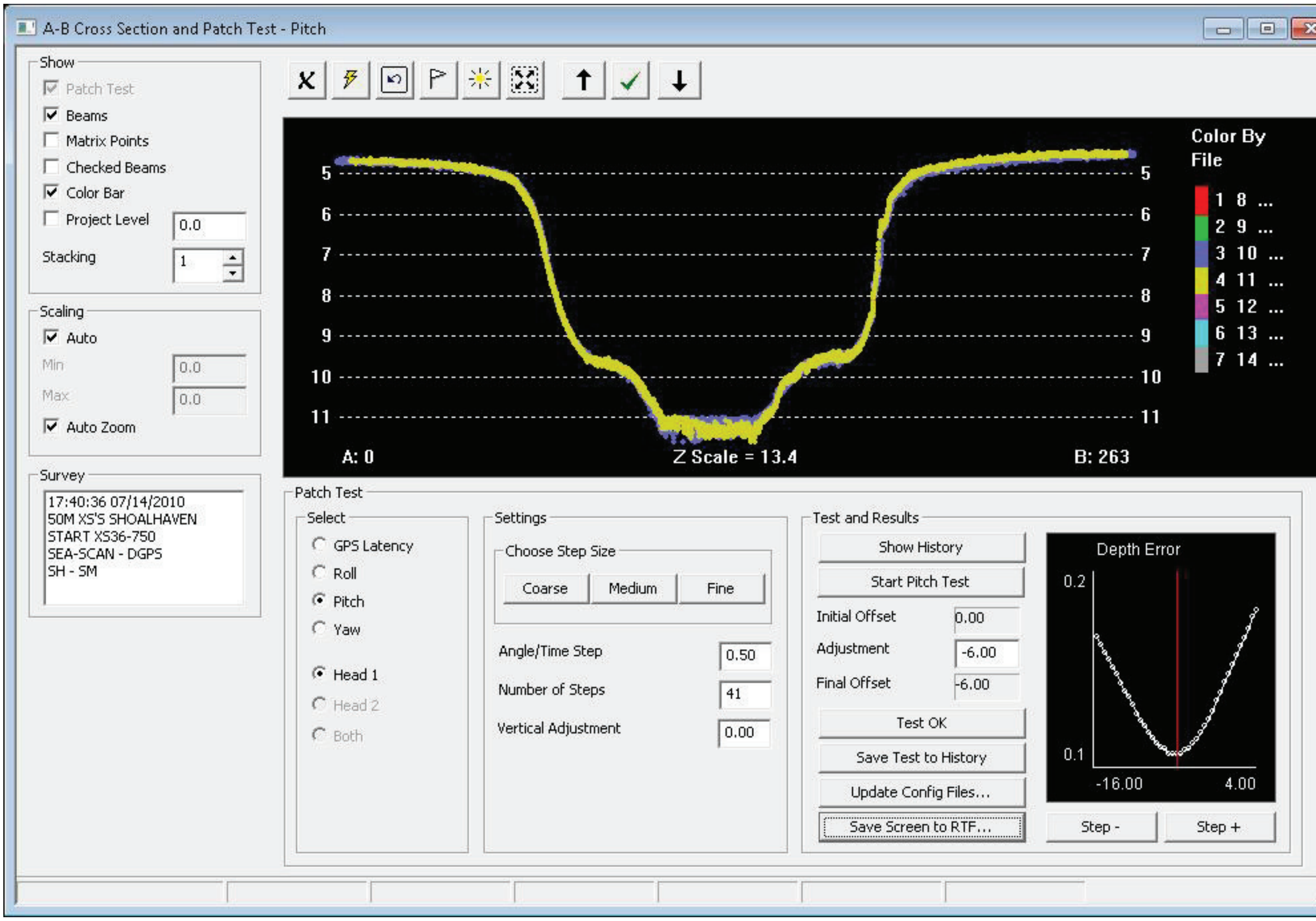
Patch Test = Latency. Sonar Head = Both.



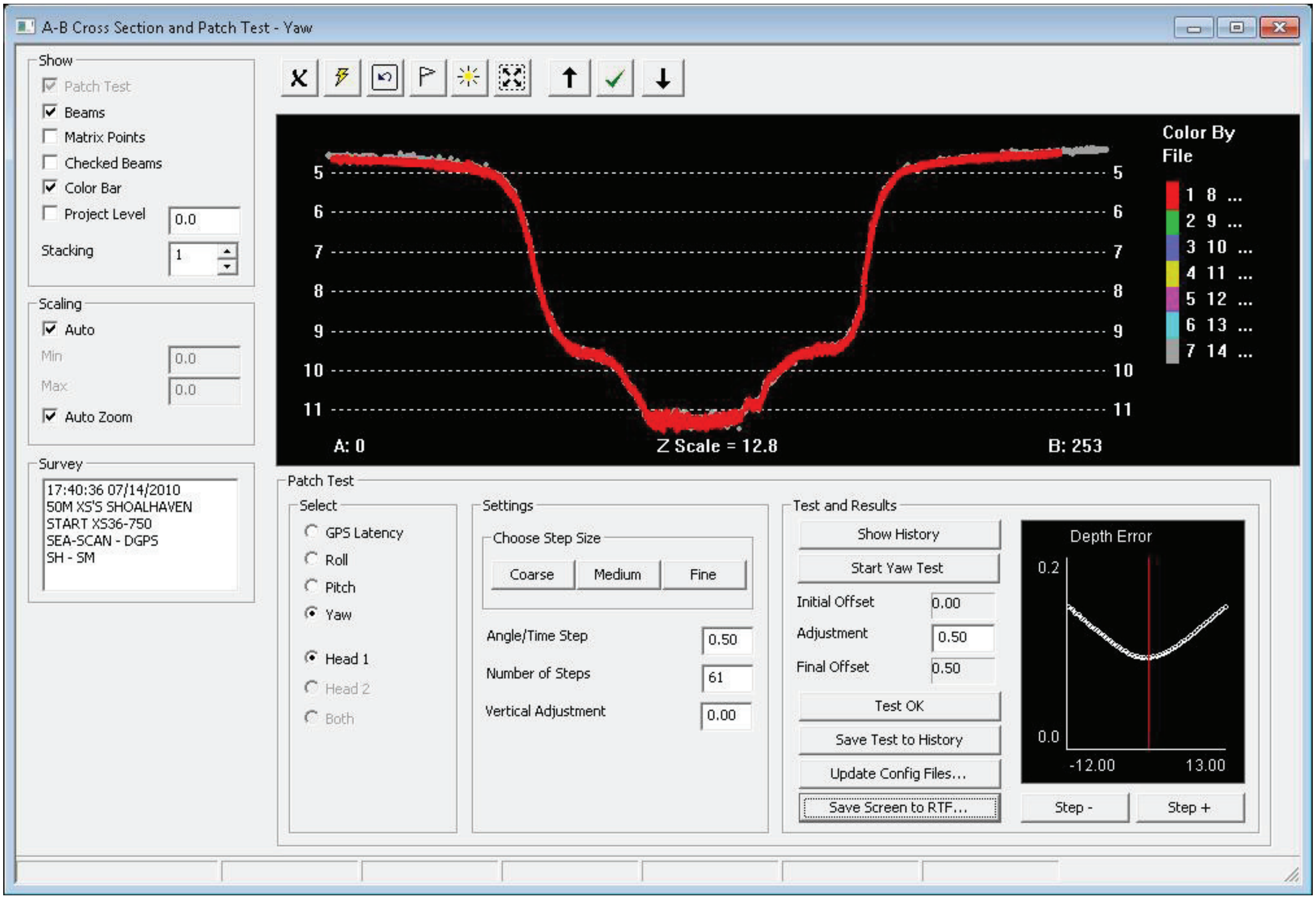
Patch Test = Roll. Sonar Head = Head 1.



Patch Test = Pitch. Sonar Head = Head 1.



Patch Test = Yaw. Sonar Head = Head 1.


A-B Cross Section and Patch Test - Yaw
Show
Patch Test
Beams
Matrix Points
Checked Beams
Color Bar
Project Level
0.0
Stacking
1
Scaling
Auto
Min
0.0
Max
0.0
Auto Zoom
Survey
17:40:36 07/14/2010
50M XS'S SHOALHAVEN
START XS36-750
SEA-SCAN - DGPS
SH - SM
Color By File
A: 0
Z Scale = 12.8
B: 253
Patch Test
Select
GPS Latency
Roll
Pitch
Yaw
Head 1
Head 2
Both
Settings
Choose Step Size
Coarse
Medium
Fine
Angle/Time Step
0.50
Number of Steps
61
Vertical Adjustment
0.00
Test and Results
Show History
Start Yaw Test
Initial Offset
0.00
Adjustment
0.50
Final Offset
0.50
Test OK
Save Test to History
Update Config Files...
Save Screen to RTF...
Depth Error
0.2
0.0
-12.00
13.00
Step -
Step +

Appendix C—

SonTek M9 HydroSurveyor in HYPACK® QuickStart Manual

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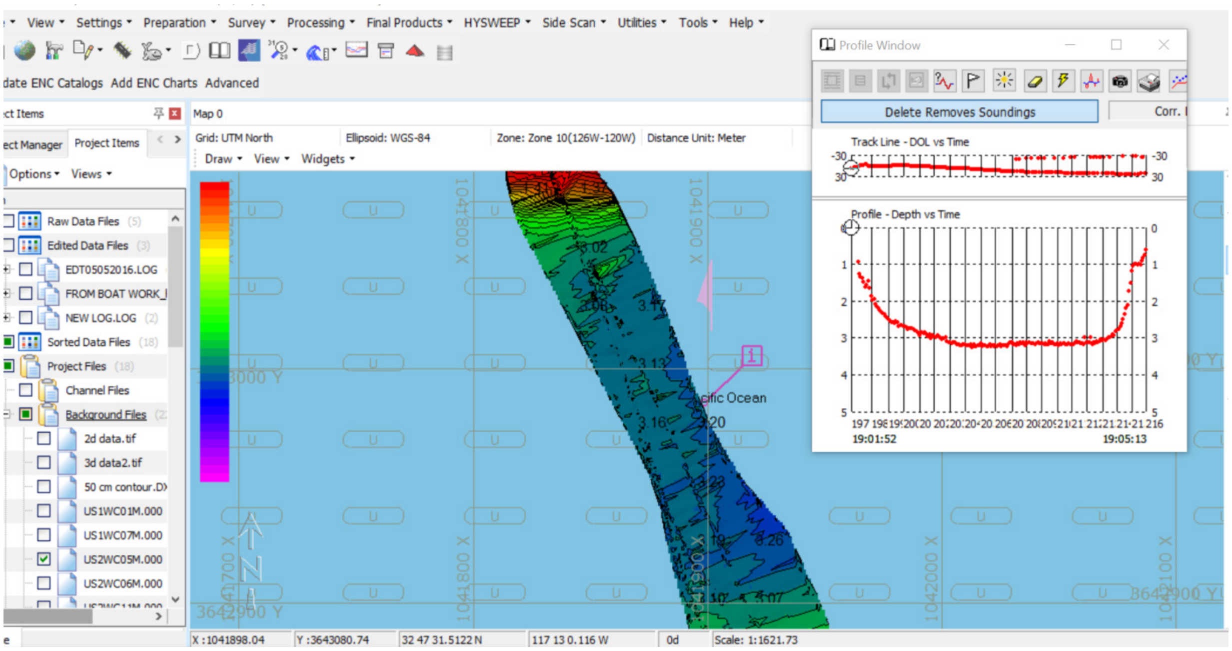
SonTek M9 HydroSurveyor in HYPACK®

QuickStart Manual



HYPACK

56 Bradley St.

Middletown, CT

06457

Web Address: www.hypack.com

Technical Support: help@hypack.com

Phone: (860) 635-1500

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Table of Contents

SYSTEM SETUP

There are two ways to connect to the HydroSurveyor:

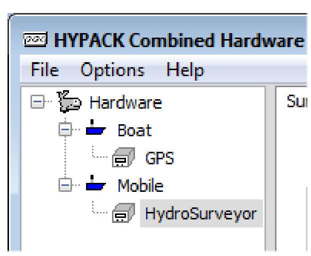
- **Standard Serial connection:** Enter only the port number. the driver automatically determines the best baud rate, parity and stop bit.
- **Radio modem and UDP network connection:** In this configuration, the GPS data comes through the base station. The SonTek HydroSurveyor driver then broadcasts the GPS data within Windows®, to the GPS driver.
  - The HydroSurveyor transmits the data to the SonTek HydroSurveyor driver via serial connection to a USB antenna on your survey computer.
  - SonTek HydroSurveyor driver parses the data and sends the GPS data to the GPS driver via the UDP port specified both in the SonTekM9.dll Driver Setup, and the GPS.dll connection settings.

HYPACK® HARDWARE CONFIGURATION

The simplest hardware configuration (Figure 1) includes only a GPS (GPS.dll) and the SonTek HydroSurveyor (SonTekM9.dll).

IMPORTANT: If you plan to use HydroSurveyor bottom tracking (DVL), the HydroSurveyor and the GPS should be assigned to *separate mobiles*.

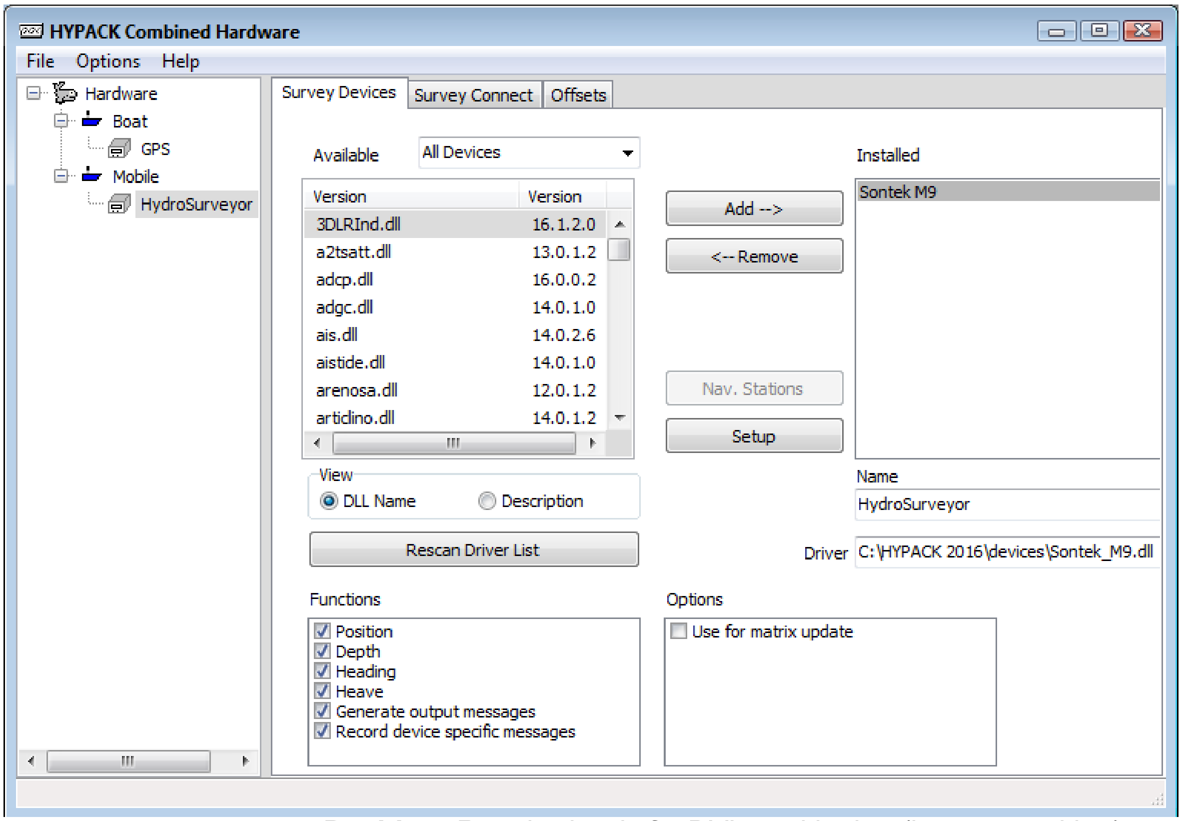
FIGURE 1. Assigning the SonTek HydroSurveyor to a Separate Mobile



SonTek HydroSurveyor

SonTek HydroSurveyor Device Setup

FIGURE 2. Configuring the SonTek HydroSurveyor in HYPACK® HARDWARE



Position: Required *only for* DVL positioning (bottom-tracking).

Depth: Logs sounding data.

Heading: Logs heading based on the change in position over time.

IMPORTANT: *Log heading from only one device*. If you are logging heading from your GPS, do not check this option for the M9 HS.

Heave: Logs pitch and roll data.

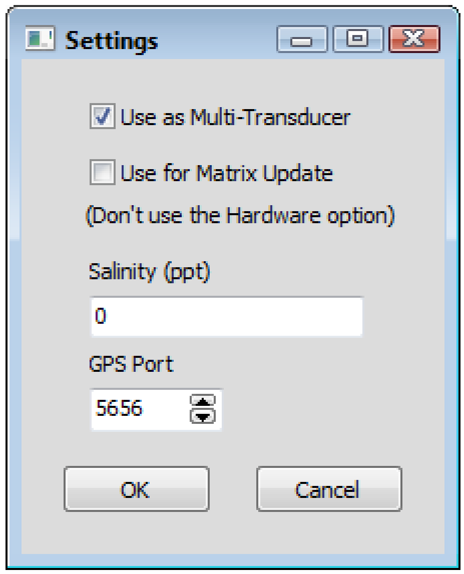
Generate Output Messages: Generates a SonTek YDFF file using the root name of the HYPACK® Raw file.

Record device specific messages: Required to calculate the sound velocity at the sensor depth based on salinity and temperature. This calculation is stored to an SVP record in the Raw data.

Use for matrix update: *Do not select this function!* To color the matrix with the HydroSurveyor, select the Use for Matrix Update option *in the Driver Setup dialog.*

SonTek HydroSurveyor Driver Setup

FIGURE 3. SonTek M9 HydroSurveyor Driver Setup



Use as Multi-transducer records all 5 beams as multi-transducer records (*.ECM) in the Raw files. Deselected, the driver reports only the nadir beam to an EC1 record.

Use for matrix update: Color-codes a matrix based on the data received from the five active beams.

Salinity (ppt) is used to calculate the speed of sound. The driver logs SVP records to the Raw file.

Tip: The driver defaults to 0, which is appropriate for fresh water surveys. An appropriate default for seawater surveys is 35 ppt.

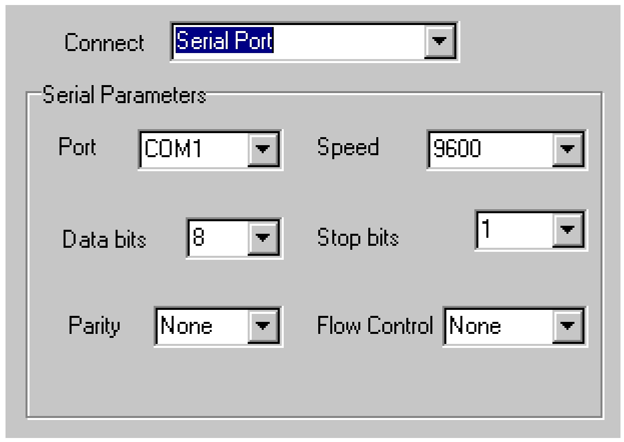
GPS Port: Required to connect the SonTek system with HYPACK®. This is the UDP Port from which your GPS driver reads the data. In this configuration, the GPS data comes through the base station. The SonTek M9 HS driver then broadcasts the GPS data *within Windows®*, to the GPS driver at this port.

NOTE: The GPS driver must be configured as a UDP Server on this port. (You can leave the Write Port blank.)

SONTEK HYDROSURVEYOR CONNECTIONS

- **Standard Serial connection:** Enter only the port number. the driver automatically determines the best baud rate, parity and stop bit.

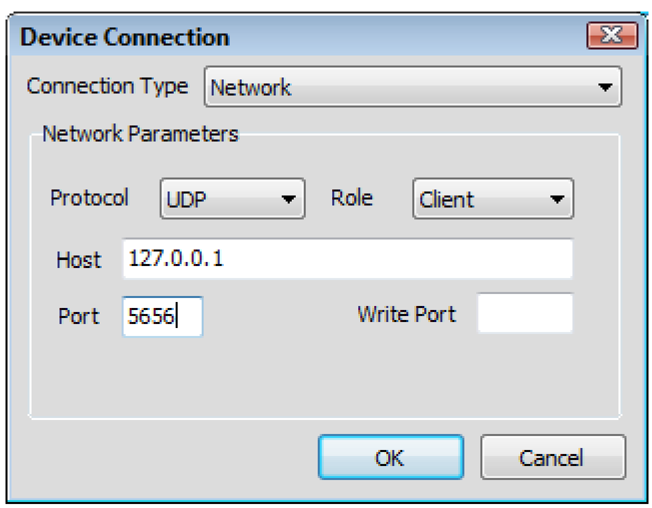
FIGURE 4. Configuring a Serial Connection in HARDWARE



Tip: Use the COM Port Test from the Survey Connect tab to determine the correct port number.

- **Network Connection:** Required to use the HydroSurveyor for bottom tracking (DVL). To connect the device to the HydroSurveyor with the radio modem, use the network mode with UDP port connection. The port address, by default, is 5656, but can be changed in the SonTek driver set-up.

FIGURE 5. Configuring a Network Connection in HARDWARE



GPS CONFIGURATION

Use the GPS.dll to read GPS data.

GPS DEVICE SETUP

Position (required)

Heading: If you have a dual antenna GPS, configure it to output a NMEA heading string (VTG) and check this option. Otherwise, leave this option unselected and configure the SonTek system to calculate heading in its Device Setup.

IMPORTANT: *Log heading from only one device*. If you are logging heading from your M9 HS, do not check this option for the GPS.

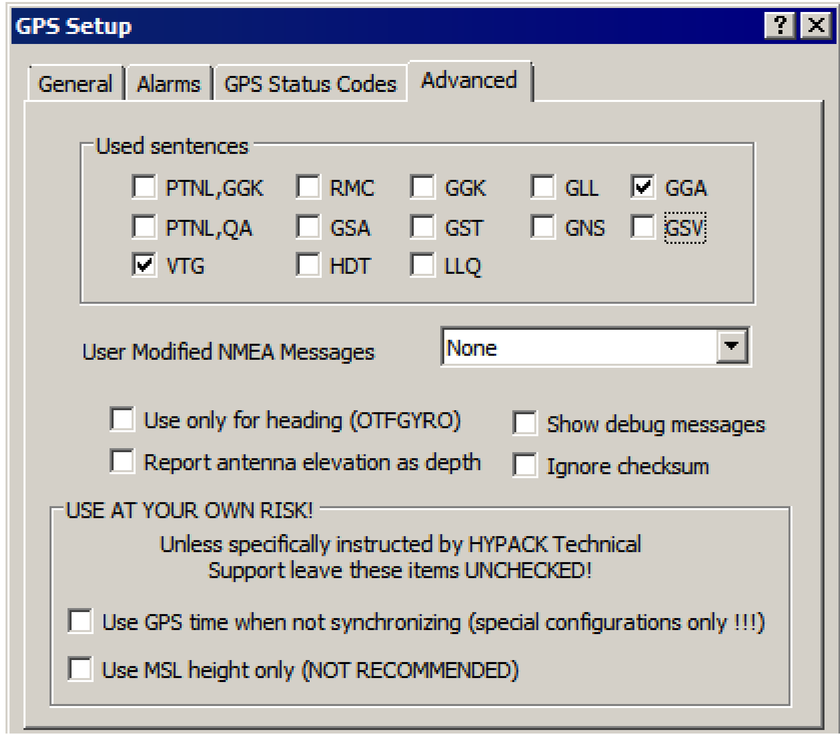
Tide: HYPACK® supports RTK tide corrections, with the correct project and driver configuration, and an RTK-capable GPS.

GPS DRIVER SETUP

To access the Driver Setup dialog, click [Setup] in the Device Setup dialog.

The most important part of the driver setup in the HydroSurveyor configuration is on the Advanced tab where you indicate the NMEA data strings the driver will read from the GPS. The typical output is GGA for position and VTG for heading.

FIGURE 6. GPS Driver Setup

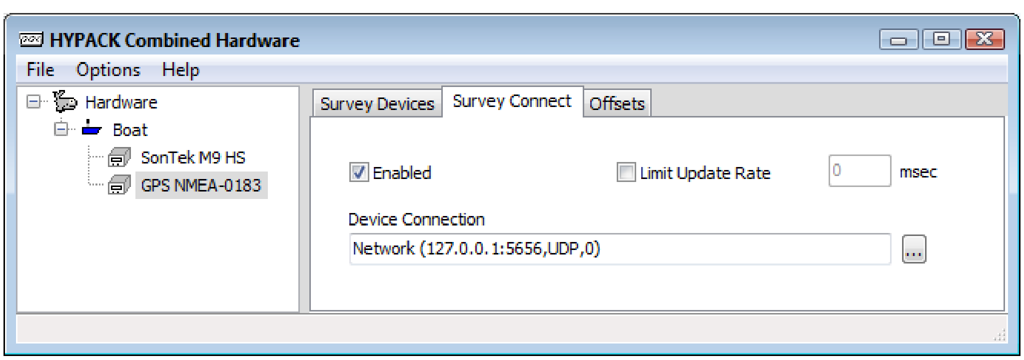


GPS CONNECTION

To connect a stand-alone GPS, the connection can be via a standard serial port or network port.

To connect the device to the SonTek HydroSurveyor with the radio modem, use the network mode with UDP port connection. The port address, by default, is 5656, but can be changed in the SonTek HydroSurveyor Driver Setup.

FIGURE 7. GPS Network Connection Settings



THE HYDROSURVEYOR IN HYPACK® SURVEY

The SonTek M9 HS driver has a tabbed device window in SURVEY, each tab with different displays and purposes: Depth, Beam Profile, and bottom tracking.

DEPTH TAB

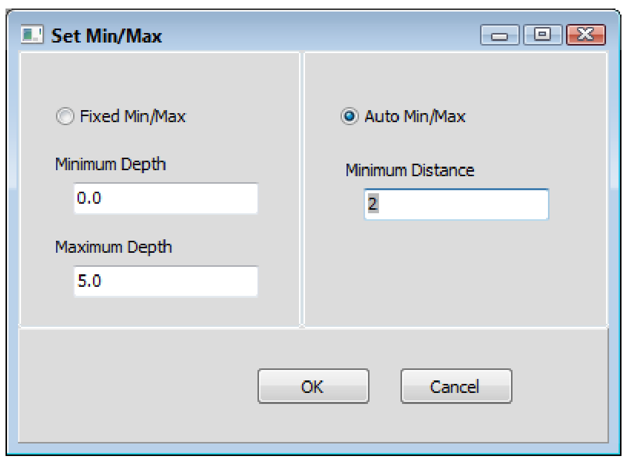
A chart with the last 100 depths. In addition, the window displays the uncorrected depths in the sensor head diagram.

The graph can scale automatically, but you can also manually set the depth range. You may also modify the trace color for each beam.

To set vertical scale for the depth graph, use the Chart Scaling options.

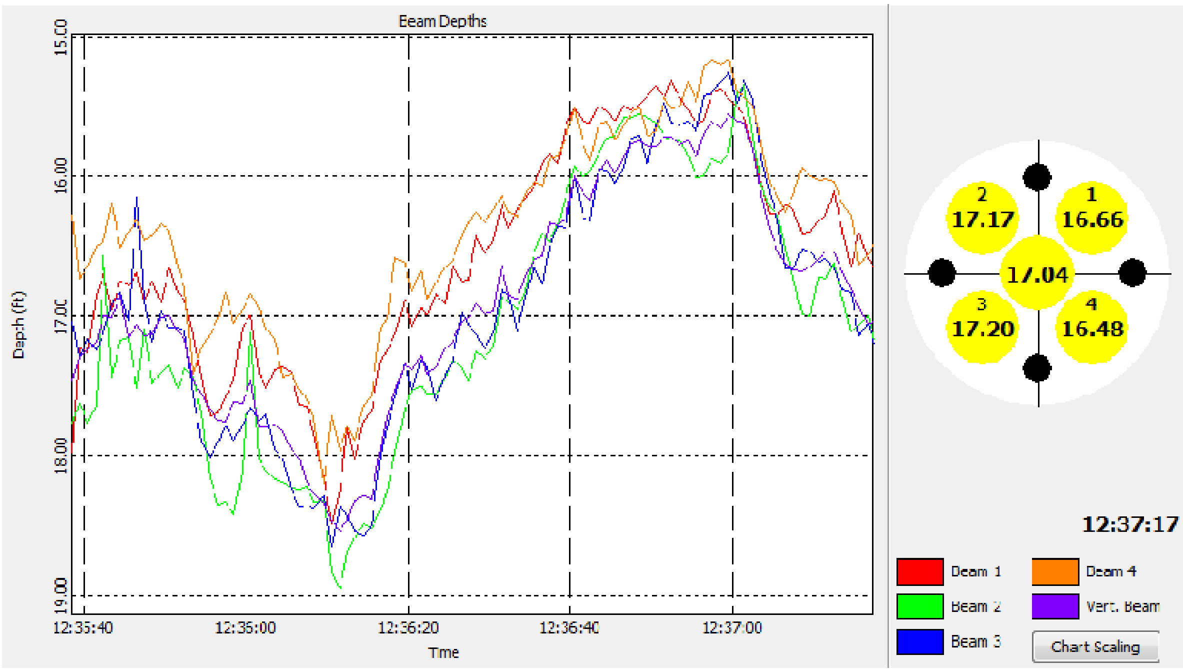
1. **Click [Chart Scaling]** to access the configuration dialog.

FIGURE 8. Chart Scaling Dialog



2. **Set your options and click [OK].**
   - **Autoscaling:** Select the Auto Minimum/Maximum option. The Minimum Distance option defines the smallest depth range you want to display.
   - **Manual Scaling:** Select the Fixed Minimum/Maximum option and enter the depth range you want to display.

FIGURE 9. SonTek M9 HS Device Window—Depths Tab



BEAM PROFILE TAB

The Beam Profile tab shows the current velocities (corrected for the bottom track velocity) and a beam amplitude profile along its path to the bottom.

On the right, the circular display shows the velocity of the current relative to the boat.

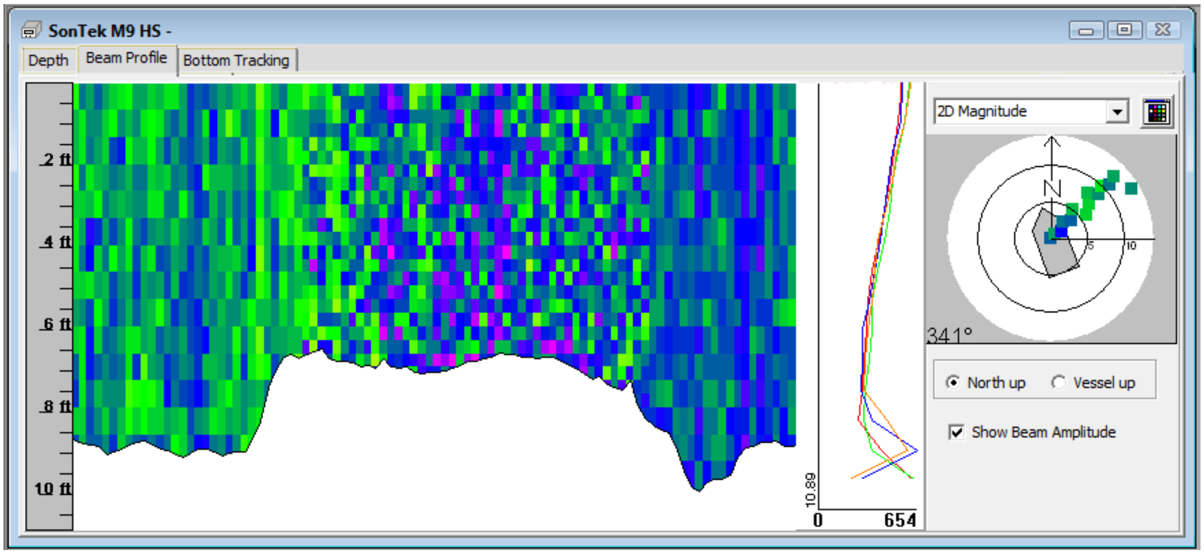
The optional amplitude profile display is useful to QC check your depths. The beams should descend smoothly together until they reach the bottom.

To show the amplitude profile, check the Show Beam Amplitude option.

To choose the value for the graph displays, select from the drop-down menu options.

To customize the color settings, the Colors icon accesses the standard Colors dialog. The colors configured from the Profile window affect only the Profile display.

FIGURE 10. SonTek M9 HS Device Window—Beam Profile Tab



USING BOTTOM TRACKING FOR POSITIONING

You can use SonTek M9 HS bottom tracking for positioning in areas where you are likely to lose GPS signal.

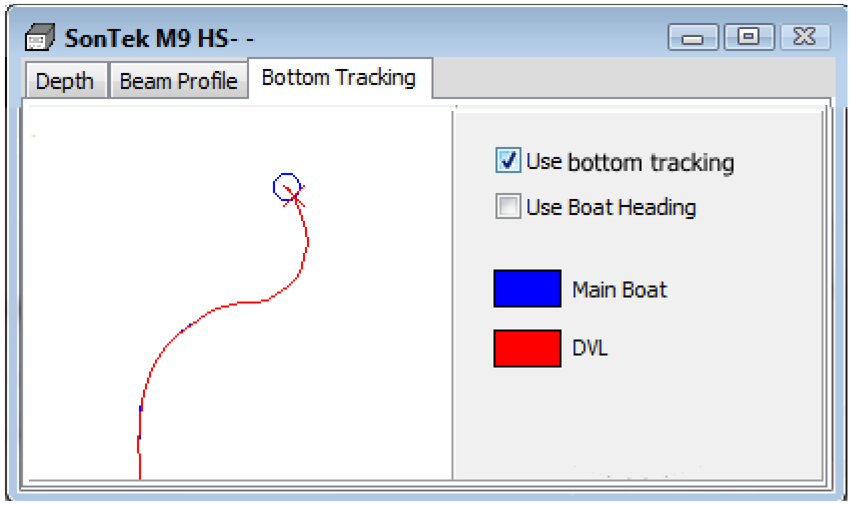
Tip: When using bottom tracking, it is useful to assign the HydroSurveyor and GPS to *separate mobiles*. This enables you to compare the positioning of each system and prevents the vessel display in the HYPACK® SURVEY Map window from jumping as you change systems.

During SURVEY, just before you lose GPS signal, check the **Use Bottom Tracking** check box in the Bottom Tracking tab of the Device window. When you regain GPS signal, clear the same check box.

IMPORTANT: *We recommend using the bottom tracking only when you need it*. Its position is relative to the last position allowing errors to propagate over extended periods of time.

The Device Window display in the Bottom Tracking tab shows the GPS position (blue) and the bottom tracking position (red).

FIGURE 11. SonTek M9 HS Device Window—Bottom Tracking Tab. GPS Position (blue) and the Bottom Tracking Position (red)



POST-SURVEY PROCESSING

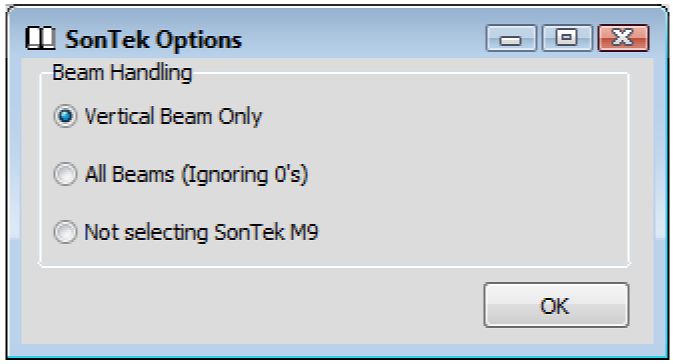
Use the SINGLE BEAM EDITOR to remove outliers, and apply additional corrections as necessary. After that, your postprocessing methods depend largely on your final product goals.

The following sections provide only brief descriptions. For the details of each procedure, please refer to the HYPACK® User Manual (available in the \Help folder of your HYPACK® install) or the HYPACK® Help system.

EDITING YOUR DATA IN THE SINGLE BEAM EDITOR

The SINGLE BEAM EDITOR recognizes you are loading SonTek HydroSurveyor data and asks for beam handling instructions:

FIGURE 12. SonTek Beam Handling Options



- **Vertical Beam Only:** Reads only the nadir depths into the editor.
- **All Beams:** This option ignores beams where depths are reported as zero, and presents each beam separately: the nadir named with the line name (eg. LineName.EDT), and each of the other 4 beams named LineName_*BeamNumber*.EDT" (eg. 001_0903_7.EDT).
- **Not Selecting SonTek M9:** Enables you to process sounding data logged simultaneously with another echosounder. Select the alternate echosounder in the Read Parameters.

If you have used both GPS and HydroSurveyor bottom tracking, you must edit the data set twice—once for each positioning device:

1. **Choose the Navigation device in the Selections tab of the Read Parameters dialog** during the file loading process.
2. **Remove outliers, and apply any additional corrections**.
3. **Save each data set separately**, setting different extensions in the File Save options, then compare the results.

The editor saves the resulting data, by default to the project \Edit folder, in edited ALL format files.

FINAL PRODUCTS

Once you have cleaned your data, the Final Products module you use next depends on your project output requirements.

TABLE 1. HYPACK® Modules for each Output Requirement

Output	Programs to Use
Current Profile	• ADCP PROFILE **NOTE:** ADCP PROFILE can also read SonTek YDFF files directly.
Depth Profiles	• TIN MODEL • CROSS SECTIONS AND VOLUMES
Volumes Calculations	• TIN MODEL • CROSS SECTIONS AND VOLUMES
Generate Contours	• TIN MODEL generates contours in DXF format. Display them as charts in HYPACK®, print them in HYPLOT, or open them in a 3rd party CAD program.

The following sections provide a very small preview of the nature of the output from each module. For full details on data processing, please refer to the HYPACK® User Manual or Help system. (Both may be found in the \Help folder in your HYPACK® install.)

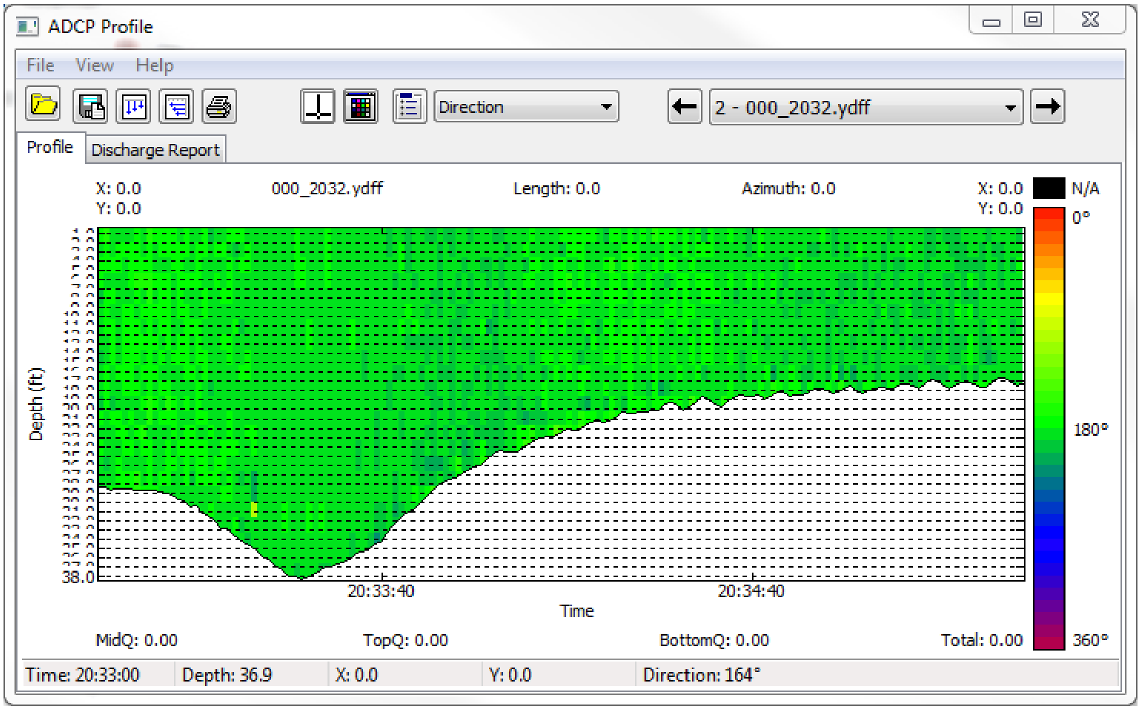
ADCP PROFILE

Use the ADCP PROFILE program to view the current profiles in the YDFF file

To view the current profiles, use the ADCP PROFILE program:

- **To use the HydroSurveyor bottom tracking for positioning,** load the YDFF files fromHYPACK® SURVEY.
- **To use positioning from the edited data**, load the edited LOG files. In this case, ADCP PROFILE merges the positioning from the All format files with the YDFF ADCP data. Recalculating positions in the SINGLE BEAM EDITOR can improve your positioning.

FIGURE 13. Current Profiles in the ADCP PROFILE Program

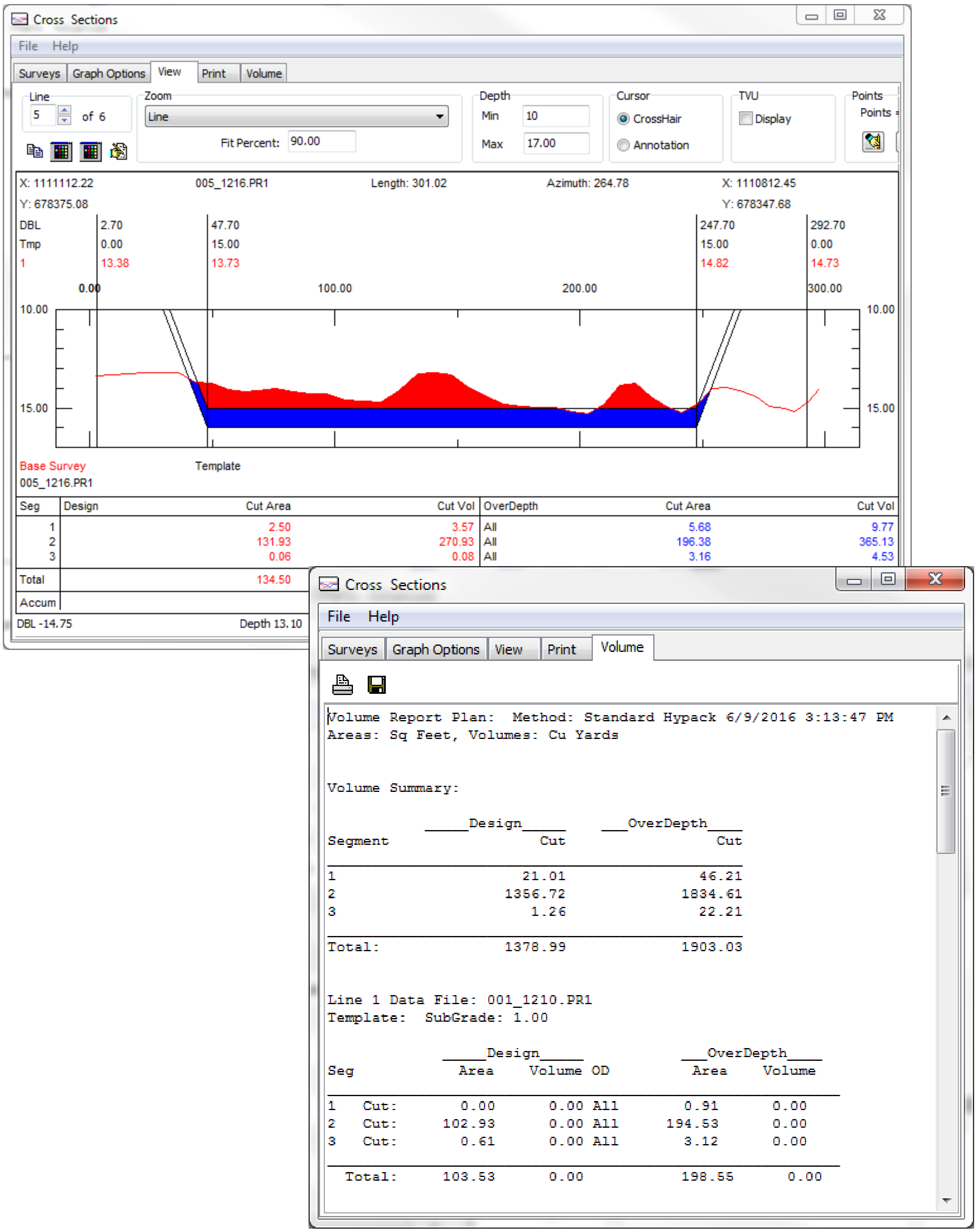


CROSS SECTIONS AND VOLUMES

The CROSS SECTIONS AND VOLUMES program uses edited or sorted ALL format data files to:

- Plot cross section graphs for each survey line.
- Calculate volume information with your choice of calculation methods.

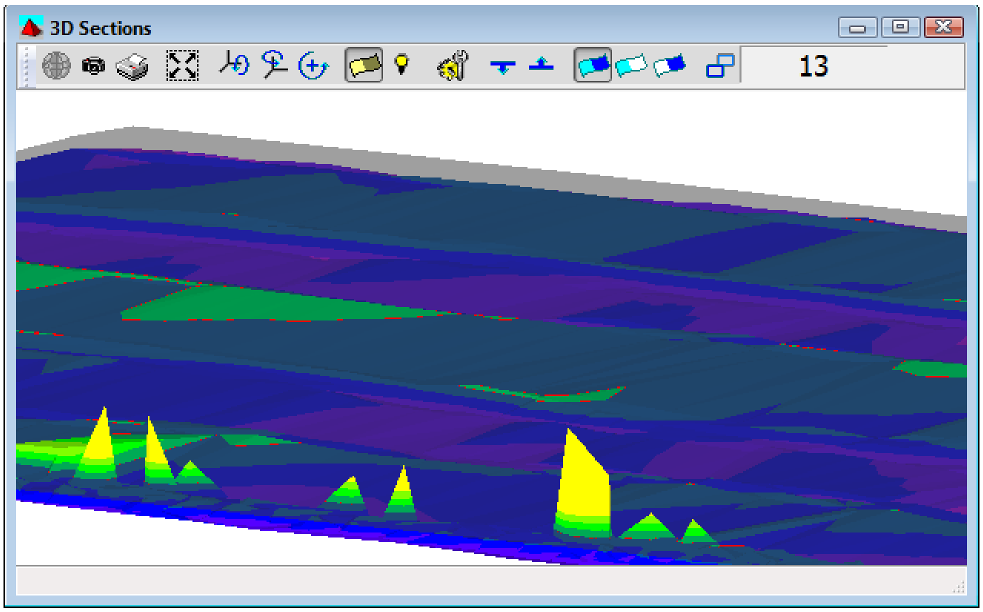
FIGURE 14. Sample Profiles and Volumes in CROSS SECTIONS AND VOLUMES



TIN MODEL

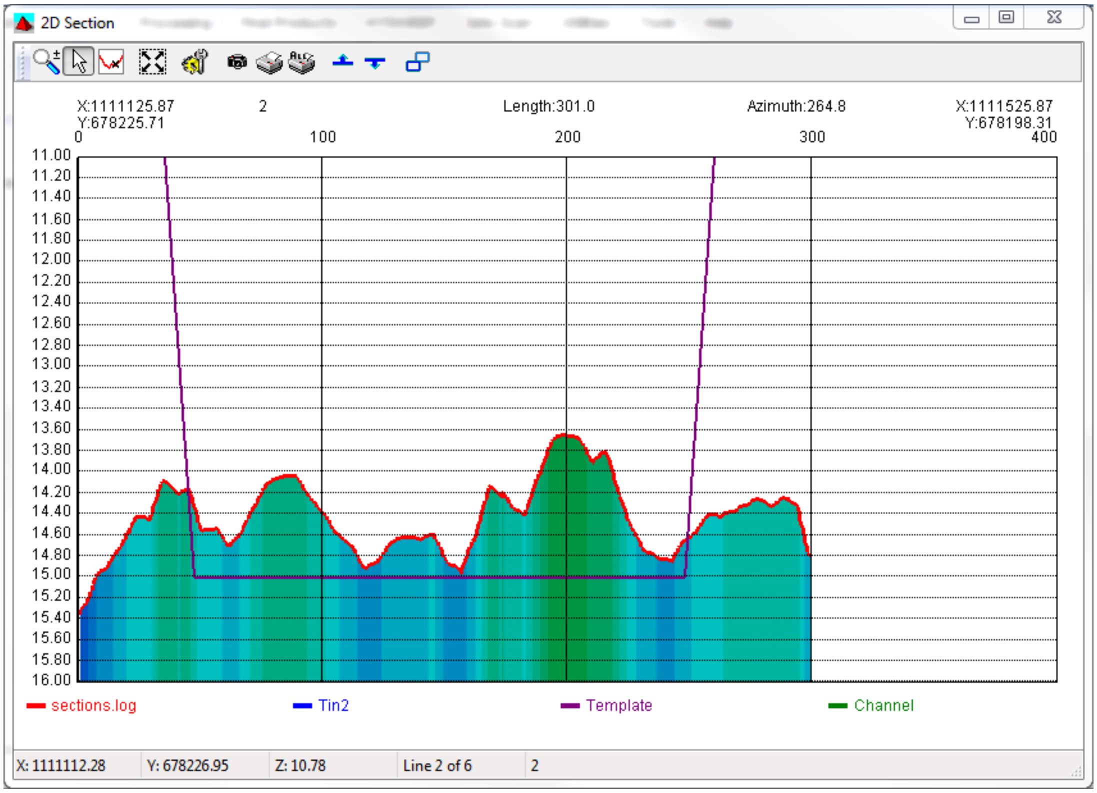
The TIN (Triangulated Irregular Network) MODEL program creates surface models from your edited or sorted ALL format files or the matrix files. The program creates the surface by connecting adjacent data points in optimized triangles.

FIGURE 15. Horizontal Profiles in TIN MODEL



Profiles

FIGURE 16. *Vertical Profiles in TIN MODEL*



Volumes

FIGURE 17. *TIN MODEL Information*

```
File Version 16.3.3.0
TIN File : C:\000 Test Projects\1Single Beam\Old Saybrook Test
M9\Edit\tin.log
Section File : C:\000 Test Projects\1Single Beam\Old Saybrook Test M9\say-
brook test lines 2.lnw
Channel File : C:\000 Test Projects\1Single Beam\Old Saybrook Test
M9\CTR_2016_06_chn.chn
Mode: Depth
Aligned to LNW: No
Remove Narrow Triangle: No

Max Leg: 75.00
X Maximum: 1111136.88
X Minimum: 1110802.79
Y Maximum: 678439.48
Y Minimum: 678143.94
Z Maximum: 16.90
Z Minimum: -2.71
Z Average: 14.19
Number of Points: 1695
Number of Triangles: 3378
```

FIGURE 18. *TIN-to-Level Volumes at 5-foot Intervals*

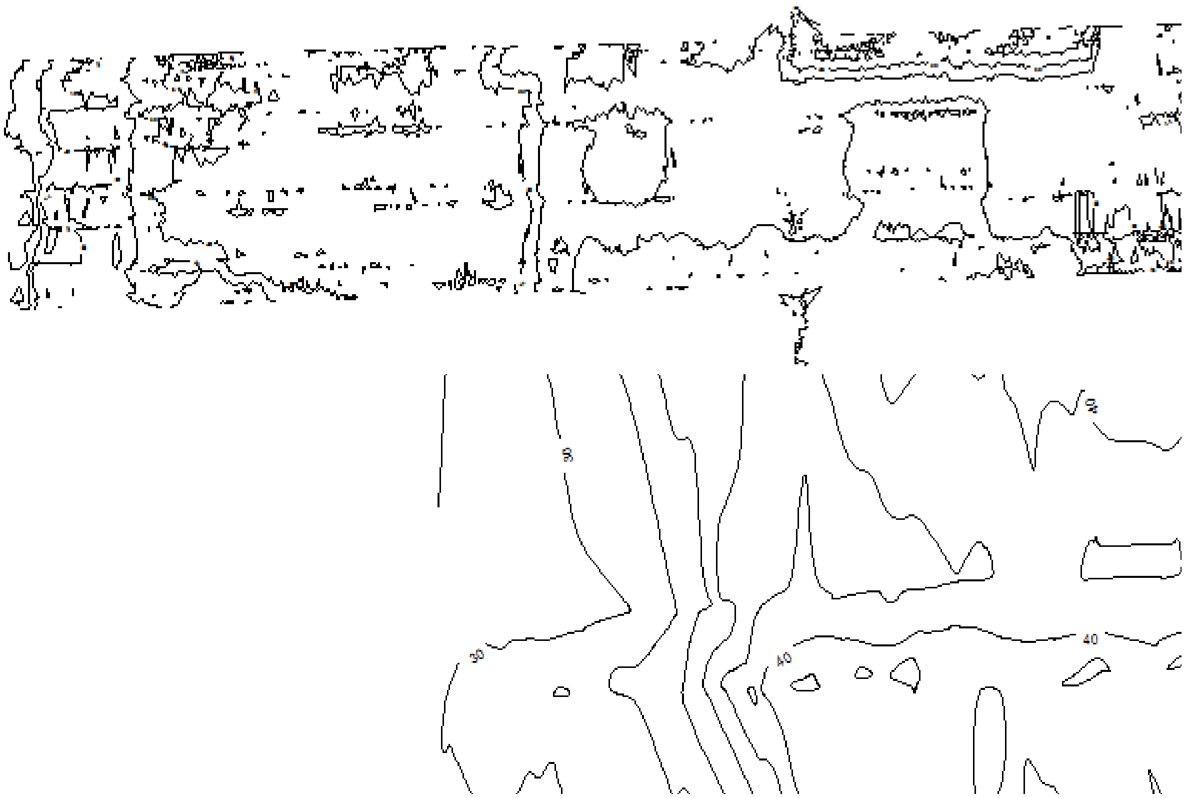
```
TIN vs Level Volume Totals
Volume unit: Cubic Yard
TIN File: C:\000 Test Projects\1Single Beam\Old Saybrook Test
M9\Edit\tin.log

Level     Volume Above    Area Above      Volume Below    Area Below
----------------------------------------------------------------------
    0.00            0.0            1.4         43467.4         82638.9
    2.00            0.3            4.4         37346.1         82635.9
    4.00            0.8            9.9         31225.1         82630.4
    6.00            1.9           22.9         25104.8         82617.4
    8.00            4.3           43.9         18985.7         82596.4
   10.00            8.7           76.0         12868.5         82564.3
   12.00           25.7          444.1          6764.0         82196.2
   14.00          824.3        38248.5          1441.1         44391.8
```

FIGURE 19. *TIN-to-Channel Volumes by Channel Faces*

```
TIN vs Channel Volume Totals - Itemized by Channel Faces
Volume unit: Cubic Yard
TIN File: C:\000 Test Projects\1Single Beam\Old Saybrook Test
M9\Edit\tin.log
CHN File: C:\000 Test Projects\1Single Beam\Old Saybrook Test
M9\CTR_2016_06_chn.chn
LNW File: C:\000 Test Projects\1Single Beam\Old Saybrook Test M9\saybrook
test lines 2.lnw
*****
        Design      Design      Area
        Cut         Fill        Above
Face    Volume      Volume      Design
--------------------------------------------
    9        1800.2       164.0     42835.5
    12         33.5      2895.3       997.3
    15         13.2      3102.7       544.3
--------------------------------------------
Total        1846.9      6161.9     44377.1
```

FIGURE 20. *TIN Contours—The Whole Chart (top), Zoomed Portion (below)*



WORK FLOW CHARTS

FIGURE 21. Volumes and Contours in TIN MODEL

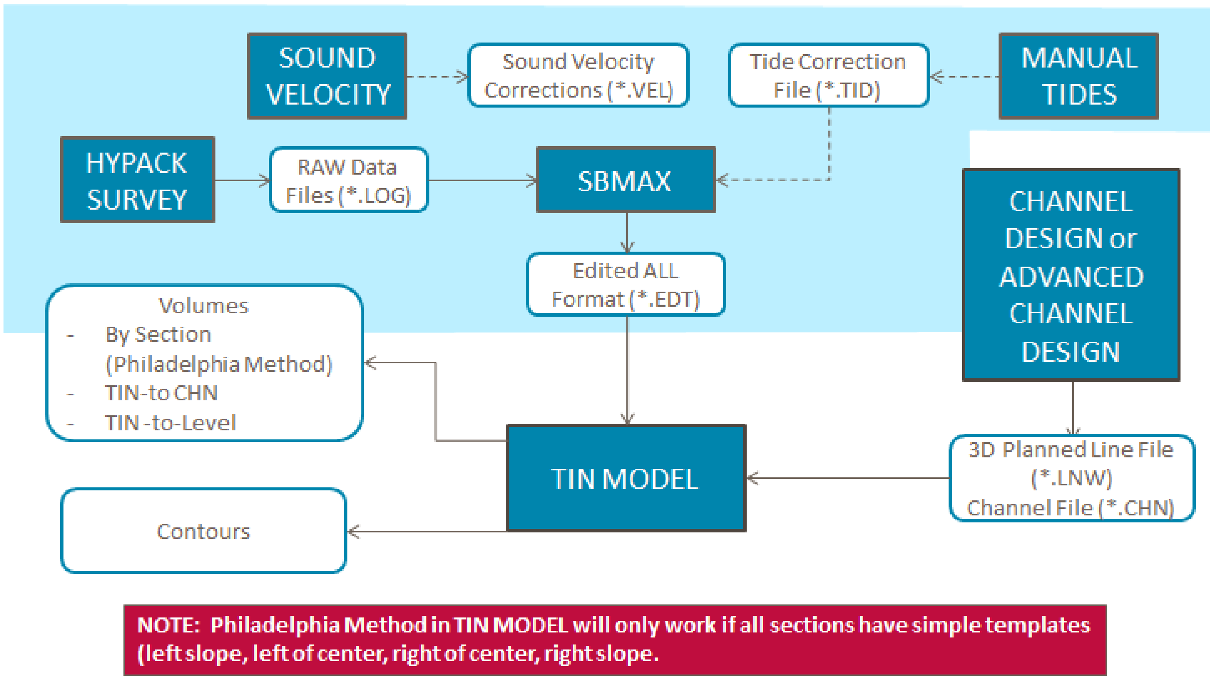


FIGURE 22. Profiles and Volumes in CROSS SECTIONS AND VOLUMES