AOS PROTOCOL AND PROCEDURE: WADEABLE STREAM MORPHOLOGY

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See configuration management system for approval history.

The National Ecological Observatory Network is a project solely funded by the National Science Foundation and managed under cooperative agreement by Battelle. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A	02/29/2016	ECO-03668	Initial release, includes Rapid Habitat Assessment SOP
B	05/16/2017	ECO-04578	There is now only one type of survey implemented once every 5 years, or when a major channel altering event occurs. Added 13 cross-section (for a total of 15); Added a pebble count; Added a LWD tally; Set a maximum of 50 bankfull indicators collected; set a maximum of 50 floodprone width collected. With the exception of the 50 floodprone measurements collected at the transects, eliminated measuring any feature outside of the bankfull channel. Set minimum point amounts for features; wetted edge and thalweg. Changed the Total Station start of the project procedure; Changed the procedure for moving the Total Station; Updated Rapid Habitat to include gravelometer and detailed mapping survey. Changed the benchmark procedure to include –permanent benchmarks and Trimble points.
C	01/29/2018	ECO-05292	Updated and revised all sections to reflect current practices.
D	02/14/2020	ECO-06295	Section 1.1: Minor edits; Section 2.4: Updated, revised and added select definitions; Section 3.1, 4.1-5, 6.2: Updated with minor revisions; Section 7, SOPA: Removed instructions on how to load GPS data into the Trimble in order to find the BM's – this information may change over time and can be found in other documentation; Section 7, SOPB: Revised workflow with the assumption that all sites will contain five permanent benchmarks prior to the geomorphology survey and that survey will consist of two level traverse run closures between benchmarks; Added total station field calibration procedures; Added stipulation to re-shoot in initial benchmarks as a QA check; Removed mandate for Trimble Point collection

			unless requested by Science; Set requirement for a minimum of 3 control points to be used to setup each total station location; reduced total number of cross-sections to be mapped from 15 to 8; Set requirement that cross-sections be surveyed from left bank to right bank; Set requirement that additional shots be taken at each cross-section and that Transect ID's be incorporated into shot codes; Removed Downstream and Upstream Reach Boundaries section – this information is captured in Cross-Section Surveys section; Updated Table 4 to reflect new transect count and added Transect ID column; Updated Table 5; Added Figure 7; Updated Figure 8; Set requirement for pebble counts to be conducted at specific cross-sections; Minor revisions to QAQC Techniques section; SOPC: Minor revisions to Tips for Best Practices section; SOPD: Added upload instructions and rules for Rapid Habitat Assessment multi-day sampling. Updated format in accordance to new OS protocol template including new SOP flowcharts; Made minor revisions throughout document following Field Science review; Changed pebble count methods for Rapid Habitat Assessment.

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1 OVERVIEW

1.1 Background

Fluvial geomorphology is the study of the form and function of streams and the interaction between streams and the landscape around them. The morphology of a stream is dynamic over time - changes in water level and sediment supply shape the stream channel and dictate how the channel morphology responds to perturbation. Glacier-fed streams may shift from a braided, unstable network to a single, stable channel as the glacier retreats up valley and sediment supply diminishes (Marren and Toomath 2014). If precipitation declines over time in an arid- or semi-arid region, stream channels will begin to incise and form deep canyons, leaving former floodplains perched high above the contemporary active stream channel (Leopold 1994). Stream and rivers exhibit geomorphic response to smaller-scale events (i.e. annual peak flow events) in the form of bank erosion and aggradation, channel abandonment and recruitment, and changes sediment particle size distribution in the short-term. Characterizing these processes at different timescales is an important component of stream and river monitoring. Physical attributes that comprise a stream (including in-stream channel structures, sinuosity, density of wood, and channel morphology) are collectively referred to as the geomorphic template.

The geomorphic template exerts a strong influence on ecological processes within fluvial systems. Attributes related to geomorphic features significantly influence the quantity and quality of habitat for virtually all aquatic organisms at multiple spatial scales, from the frequency of small features such as pools to the sinuosity of the entire channel (Frissell et al. 1986). Sediment supply, transport, and stability, (largely a reflection of the geomorphic template) may also directly affect the composition of biotic communities residing in the stream across spatiotemporal scales (Lamouroux et al. 2004). Although in-stream biota play a limited role in structuring the physical nature of stream channels, riparian and upland vegetation may strongly influence stream channel shapes by controlling erosive forces (Keeton et al. 2007). Woody debris within the stream channel plays an important role for aquatic organisms, as large woody debris (LWD) creates refugia and provides unique structural habitats on which many aquatic species depend (Lemly and Hilderbrand 2000).

Fluvial geomorphology is an important component of the ecological system and a metric for assessing biological and physical processes in streams. NEON will measure the geomorphic attributes of all NEON wadeable stream sites on a minimum rotation of every five years. Geomorphology surveys will be conducted using standard surveying equipment. A number of metrics will be drawn from data products derived from the surveys to quantitatively depict in-stream and riparian habitat in NEON wadeable stream sites.

1.2 Scope

This document provides a change-controlled version of Observatory protocols and procedures. Documentation of content changes (i.e. changes in particular tasks or safety practices) will occur via this change-controlled document, not through field manuals or training materials.

1.2.1 NEON Science Requirements and Data Products

This protocol fulfills Observatory science requirements that reside in NEON's Dynamic Object-Oriented Requirements System (DOORS). Copies of approved science requirements have been exported from DOORS and are available in NEON's document repository, or upon request.

Execution of this protocol procures samples and/or generates raw data satisfying NEON Observatory scientific requirements. These data and samples are used to create NEON data products, and are documented in the NEON Scientific Data Products Catalog (**RD[03]**).

1.3 Acknowledgments

CHaMP (Columbia Habitat Monitoring Program). 2014. Scientific protocol for salmonid habitat surveys within the Columbia Habitat Monitoring Program. Prepared by the Columbia Habitat Monitoring Program.

CHaMP Transformation tool, http://ctt.joewheaton.org/

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

Applicable documents contain higher-level information that is implemented in the current document. Examples include designs, plans, or standards.

AD[01]	NEON.DOC.004300	EHS Safety Policy and Program Manual
AD[02]	NEON.DOC.004316	Operations Field Safety and Security Plan
AD[03]	NEON.DOC.000724	Domain Chemical Hygiene Plan and Biosafety Manual
AD[04]	NEON.DOC.001155	NEON Training Plan
AD[05]	NEON.DOC.050005	Field Operations Job Instruction Training Plan
AD[06]	NEON.DOC.004104	NEON Science Data Quality Plan
AD[07]	NEON.DOC.004257	NEON Standard Operating Procedure (SOP): Decontamination of Sensors, Field Equipment and Field Vehicles

2.2 Reference Documents

Reference documents contain information that supports or complements the current document. Examples include related protocols, datasheets, or general-information references.

RD[01]	NEON.DOC.000008	NEON Acronym List
RD[02]	NEON.DOC.000243	NEON Glossary of Terms
RD[03]	NEON.DOC.002652	NEON Level 1, Level 2 and Level 3 Data Products Catalog
RD[04]	NEON.DOC.001271	NEON Protocol and Procedure: Manual Data Transcription
RD[05]	NEON.DOC.003282	NEON Protocol and Procedure: Site Management and Disturbance Data Collection
RD[06]	NEON.DOC.001646	General AQU Field Metadata Sheet
RD[07]	NEON.DOC.001152	NEON Aquatic Sample Strategy Document
RD[08]	NEON.DOC.001717	TOS Protocol and Procedure: TruPulse Rangefinder Use and Calibration

2.3 Acronyms

Acronym	Definition
AP	Aquatic Plant
BFI	Bankfull Indicator
BM	Benchmark
COP	Control Point
DEM	Digital Elevation Model
GIS	Geographic Information System
GPS	Geographic Positioning System
HR	Height of Rod

LWD	Large Woody Debris
POC	Rugged hand held unit to record Total Station data.
StDev	Station Deviation
TP	Trimble Point
TS	Total Station
UTM	Universal Transverse Mercator Coordinate System
HD	Change in Horizontal Length
dH	Change in Height

2.4 Definitions

Active channel: The natural waterway that contains all streamflow at and below bankfull stage.

Assumed coordinate system: Localized coordinate system (i.e. not elevation, latitude, and longitude) of a survey established by attributing the first occupied point of a new site survey with the coordinates: 0 northing, 0 easting, 1000 elevation. All new surveys will be attributed an assumed coordinate system during the initial survey.

Backsight point: A sight or bearing on a previously established Control Point taken in the opposite (or backward) direction that the survey is headed. Backsight shots should be longer in distance than foresight shots, relative to the position of the original total station location.

Bankfull indicator: A physical marker created during the 1.5 to 2 year bankfull forming discharge used to identify the maximum channel height and width of that discharge. Indicators used may include slope breaks, changes in soil type, as well as terrestrial vegetation, lines, debris accumulation and sand lines.

Bankfull stage: the elevation of the water surface when the channel is completely filled and flows first begin to spill onto the floodplain.

Bank pin: Pins placed at bankfull locations on both sides of the stream.

Benchmark: A permanent geographic marker of a known location; elevation, latitude, and longitude [see also: **Datum**]. NEON benchmarks vary between bedrock and non-bedrock installations. Non-bedrock installations involve rods driven deep into the substrate with various levels of protection against disruption soil processes (heave/freeze/thaw/shrink/swell) depending on the site location. Non-bedrock installations contain a labeled, hinged access cap that protects the benchmark (rounded cap or bullet-shaped datum) that lies just below the ground surface. Bedrock installations are drilled straight into exposed bedrock outcrops and are generally the most stable datum points over time. These installations consist of a rounded cap that is labeled along the surface. Both benchmark types contain a divot point in the center in which to place the tip of the prism rod.

Closed level traverse: A series of total station setups that begin at one known datum and end on another. In the NEON geomorphology protocol two closed level traverses are carried out between the sensor set in which the staff gauge is co-located and the upstream and downstream reach boundaries. Each of these three locations contain nearby datums (see: **Benchmark**) through which a level traverse can be closed.

Control point: A permanent or temporary intervening survey point used to set up or orient the total station. Control points are typically located between total station locations and should be marked with magnetic spikes and clearly labeled with flagging. Control points are used as **Foresight points** and **Backsight points** while orienting new total station locations.

Cross-section profile: A transect running perpendicular to the channel where channel features are mapped.

Datum: A frame of reference for measuring locations on the surface of the Earth (i.e. lines of latitude and longitude) [see also: **Benchmark**].

Deposition zone: Area where sediments settle and accumulate on the streambed. This process typically occurs in areas where the current is slow moving.

Dry extent of reach: Hydrologically disconnected portions of the stream (i.e. surface water paths are discontinuous) within or across habitat units.

Established coordinate system: Spatially accurate coordinate system (UTM) established after the first survey of a site. All revisit site surveys must re-occupy the exact same established coordinate system as the first survey.

Floodplain: The relatively flat valley-floor surface that has been constructed during the present hydrologic regime.

Flood prone width: The valley floor outside of bankfull flood stage that is formed by floods two times the 1.5 to 2 year bankfull forming floods. Flood prone width elevation is defined as twice the bankfull depth.

Foresight point: A sight or bearing on a previously established Control Point taken in the direction that the survey is headed (i.e. "looking forward"). Foresight shots should be shorter in distance than backsight shots, relative to the position of the original total station location.

Geographic coordinate system: Data defined by a 3-dimensional surface and measured in meters or feet (i.e. latitude and longitude).

Geographic Information System: A system designed to connect data to geography. The system is designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data.

Gradient: A value used to define the slope of a stream. Expressed as the ratio of the amount a stream decreases in elevation over a selected horizontal unit length of stream. The resulting value is typically expressed as a number ranging from 0 – 1.0, or a percentage.

Habitat unit: A single habitat feature (e.g., a pool) within the stream reach.

Islands: Mounds of consolidated substrate that are surrounded by the stream. These features protrude above bankfull height.

Large woody debris (LWD): Woody debris characterized by ≥0.15m diameter and ≥1m length.

Left bank: By standard convention, left bank is the left side of the channel from the perspective of an individual facing downstream.

Left edge water: The location in the stream where the water makes contact with the streambed or bank surface on the left side of the channel, looking downstream.

LWD jam: Considered 3 or more pieces of LWD that touch each other with at least 3 of the pieces meeting both a diameter and length criteria of ≥0.15m and ≥1m, respectively.

Maximum pool depth: The deepest point of the pool habitat unit.

Meander: A bend in a sinuous stream or river. A meander is produced as sediment is eroded from the outer, or concave, bank and deposited downstream in the inner, or convex bank, which is typically defined as a point bar. The result is the formation of a sinuous channel course of channel migration across the down-valley axis of the floodplain.

Mid-channel bar: Mounds of consolidated substrate that are surrounded by the stream. These features protrude above the streambed but the maximum elevation is below bankfull.

POC: Rugged handheld tablet for controlling the robotic Hilti Total Station used to capture features during the survey.

POS: The Hilti POS 180 Robotic Head Total Station unit used during the geomorphology survey [see also: **Total station**].

Pool: A river and stream aquatic habitat unit created by scour or impoundment and the presence of a structural control. Pools are longer than they are wide, are 1.5 x deeper at their maximum depth than at their crest (upstream boundary), are characterized as areas of the sub-reach that exhibit relatively slow velocity, and are sources of fine sediment deposition.

Prism: A mirrored flat surface, typically installed on the end of the prism pole, that acts as a reflector to return the light pulse back to the Total Station in order to measure distance and elevation.

Prism pole: Graduated pole fixed with a prism on top used with the Total Station to measure the distance and elevation of survey points.

Projected coordinate system: Topographic data that is defined by a flat 2-dimensional surface measured in meters or feet.

Riffle: A shallow part of the stream where water flows swiftly over completely or partially submerged obstructions to produce surface agitation.

Right bank: By standard convention, the right bank is the right side of the channel from the perspective of an individual facing downstream.

Right edge water: The location in the stream where the water makes contact with the streambed or bank surface on the right side of the channel, looking downstream.

Run: A relatively shallow part of a stream with moderate velocity and little or no surface turbulence. Runs typically bridge pool and riffle habitat units.

Sinuosity: A measure of the deviation of a line from the shortest path. Calculated by dividing the total length by the shortest possible path.

Step pool: Areas within high-gradient streams where water cascades over a series of rock ledges or woody snags, dropping into small pools that form between the features.

Temporary points: A survey point that is not permanently benchmarked that can be removed once the survey and subsequent data processing has been completed. Magnetic nails are common and effective devices to serve as temporary points [see also: **Control point, Trimble point**].

Thalweg: The line that connects deepest part of the active channel.

Total station: A high-resolution instrument used in surveying to measure distances and angles from horizontal points of interest. Total stations utilize a laser pulse to determine distance and elevation and are equipped with a positioning system to determine the angle of rotation from a known datum to the point of interest.

Tributaries: Smaller order streams that feed into the mainstem of the monitoring reach. Tributaries may contain flowing water year round or be ephemeral.

Trimble point: A temporary point mapped with the total station and Trimble GPS with Tornado Antenna.

Waterfall: A feature that contains water falling at least 1.5m vertically, or very nearly so.

3 METHOD

The NEON Wadeable Stream Morphology protocol provides methods to conduct a high-resolution survey of the topographical aspects of a stream channel and the adjacent floodprone area. The survey captures the geometry of the stream channel within the NEON aquatic reach. Furthermore, it demarks the locations of biological habitats and stream channel features that are used for determining sample collection locations for other NEON aquatic protocols.

The survey covers the entire NEON aquatic reach, which, at most sites, is approximately 1000m in length. The location, or spatial position of points along the channel bed, water surface, floodplain, and the boundaries of in-channel habitats are recorded as Cartesian (X, Y, Z) coordinates using a total station (TS). Northing and Easting positions of each point are measured as X and Y coordinates and elevation is recorded as Z coordinates. All coordinates are recorded as the distance from the origin of the survey (e.g. 0, 0, 0 m) which is typically the first mapped benchmark point.

During the preliminary survey at a site, the first TS location is determined by using a common survey technique known as the “Missing Line” workflow. During this process two points are mapped and the total station location is established on the landscape based on the mapped points. During the missing line workflow one of the two points must be a benchmark point. Benchmarks, using data derived from Trimble Points, will geo-reference the survey into the latitude and longitude coordinate system. Upon completion of the geomorphology survey, raw data collected with the total station will be post-processed and transformed into a geographic coordinate system. Data products derived from the geomorphology survey include geo-referenced maps, shape and raster files that can be utilized by Arc GIS software, and a wide range of stream characterization metrics.

The geomorphology survey captures the fluvial geomorphic template of the reach by characterizing stream channel water surface elevation, the location of channel features and biological habitats, and, to a lesser extent, floodplain topography. Geomorphology mapping, used in concert with NEON’s Aerial Observation Platform (AOP), precipitation, groundwater, and turbidity data, provides researchers data to assess reach-level geomorphic processes in time and space. NEON’s geomorphology mapping is comprised of four components: cross-sectional profile mapping, longitudinal channel mapping, pebble counts, and LWD tallies.

Cross-sectional profile maps capture bankfull and floodplain width and height and stream channel depth and capacity. Longitudinal profile mapping characterizes streambed and water level elevation as well as the dimensions and locations of in-stream habitat, LWD, and mid-channel islands and bars. Pebble counts and LWD tallies quantify the dimension and distribution of substrate and large wood in the channel, two extremely important components of stream structure.

Field ecologists mapping the stream will use a HILTI POS 180 robotic head total station and prism pole with an attached 360^{o} mirrored prism. Survey points capture major slope breaks in the channel and floodplain, the edge of water along the streambed or channel banks, the dimension of mid-channel features, the position of the thalweg along the streambed, and the location and dimension of habitat features. A unique survey code is associated with each mapped point. All survey data is stored on the POC datalogger, a handheld device that is used to enter and log survey data. Survey codes organize the survey data and allow for the creation of various GIS-derived topographic layers of the surveyed area during post-processing.

The methods described herein provide a unified guide to surveying geomorphic features and biological habitats in wadeable stream channels at aquatic sites within the NEON Observatory. This protocol and associated data products are designed to interface with other habitat and geomorphology monitoring programs currently operating in the United States and Canada. Standard Operating Procedures (SOPs), in **Section 7** of this document, detail step-by-step directions, contingency plans, sampling tips, and best practices for implementing this sampling procedure. To properly collect and process samples, Field Ecologists must follow the protocol and associated SOPs, and utilizing the current NEON problem reporting system to document and find resolution to any field issues associated with executing this protocol.

The value of NEON data hinges on consistent implementation of this protocol across all NEON Domains, for the life of the project. It is therefore essential that field personnel carry out this protocol as outlined in this document. In the event that local conditions create uncertainty about carrying out these steps, it is critical that Field Ecologists document the problem and enter it in a trouble ticket. Quality assurance will be performed on data collected via these procedures according to the NEON Science Performance QA/QC Plan (**AD[05]**).

Standard Operating Procedures (SOPs), beginning in **Section 7** of this document, provide detailed step-by-step directions, contingency plans, sampling tips, and best practices for implementing this sampling procedure. To properly collect and process samples, field technicians must follow the protocol and associated SOPs. Use NEON's problem reporting system to resolve any field issues associated with implementing this protocol.

The value of NEON data hinges on consistent implementation of this protocol across all NEON domains, for the life of the project. It is therefore essential that field personnel carry out this protocol as outlined in this document. In the event that local conditions create uncertainty about carrying out these steps, it is critical that technicians document the problem and enter it in NEON's problem tracking system.

Quality assurance is performed on data collected via these procedures according to the NEON Science Data Quality Plan (**AD[06]**).

4 SAMPLING SCHEDULE

4.1 Sampling Frequency and Timing

The NEON geomorphology protocol shall be conducted once every five years or following an event that results in significant alteration of the stream channel. With regards to the standard five-year rotation, it is strongly recommended that the geomorphology protocol is conducted during the baseflow regime as this period facilitates access to geomorphological features and provides repeatability in scheduling future mapping efforts. If scheduling conflicts negate the ability to schedule a survey during baseflow conditions it is recommended that Domains attempt to schedule the protocol during periods where streamflow and water depth are reasonably moderate. This is to say that streamflow is not so high to inhibit Field Ecologists to safely access required features, but not so low that geomorphic features discernable during baseflow conditions are absent. Following the initial survey, subsequent survey dates should be scheduled at a time that matches the seasonal and hydrologic conditions similar to that of the initial geomorphology survey.

Channel altering events have many impacts on stream channels and can be the result of debris flows, hyper-concentrated flows, or severe flooding. Stochastic events such as these play a major role in coarse woody debris delivery to fish-bearing streams and provide a mix of sediment to the higher order streams. Channel altering events can reduce (or even temporarily eliminate) riparian vegetation along the stream channel and create changes in the stream bed such as aggradation and scour (Bell and Mikulovsky, 2012). The NEON geomorphology survey is well-suited to assess the magnitude of such events by quantifying changes in channel geometry, particle-size distribution, and habitat. Thus, if conditions are warranted, the protocol should be immediately re-instituted once a channel-altering event has been deemed to have occurred. In these instances, Science will work with Domain staff in order to determine if a potential major channel altering event has occurred at a site. A significant and prolonged shift in the stage-discharge rating curve is typically a strong indication of streambed alteration as well as more casual observations of bank failures and evidence of flooding (i.e. high water marks) following a large storm or tectonic event. Damage to AIS infrastructure and established sampling transects should also be taken into account. If a channel-altering event is suspected to have occurred, domain staff shall write a trouble ticket explaining the situation and, if possible, provide pictures or videos to document any supporting evidence. Science will then work with the Domain staff to determine if an additional geomorphology survey is warranted.

The Rapid Habitat Assessment SOP is conducted once during site characterization at each wadeable stream site during a period when the stream is safely wadeable. The Rapid Habitat Assessment should be scheduled at a time when the stream level is relatively close to baseflow, but not during an abnormally dry part of the year (e.g., similar conditions or time of year as a biological sampling bout) and, if working in a deciduous forest, when leaves are present on the trees (i.e., between Bio Bout 1 and Bio Bout 2 at the site). The Rapid Habitat Assessment SOP requires 4-8 hours of work for two highly skilled Field Ecologists.

Following characterization, the Rapid Habitat Assessment SOP will be performed once per year around the same time of year, optimally between Bio Bout 1 and Bio Bout 2. Some sites may deviate from this schedule with the approval of Science (e.g., D14 SYCA and site dominated by spring snowmelt). Changes noted from the annual Rapid Habitat Assessment (e.g., significant change in the frequency of habitat types) may trigger more frequent occurrences of the Stream Morphology protocol. If the Rapid Habitat Assessment cannot be completed in one day and the water level changes dramatically between sampling days, discard data and start the assessment over.

Scheduling Considerations

1. The ideal season for the wadeable stream morphology protocol to be conducted is during baseflow conditions (to assist in biological habitat typing) with minimal leaf cover (to increase line of sight).
2. After the wadeable stream morphology protocol is complete, the following points are critical with respect to timing:
    a. Review and upload all Fulcrum data.
    b. Provide the following items to the appropriate Science support contact:
        1. Raw survey data file
        2. Trimble GPS data (if applicable)
        3. Detailed report of survey (**Standard Operating Procedures**)
3. (Ideally) All required items will be uploaded and provided to Science within 1 week of survey completion.
4. (Required) All required items will be uploaded and provided to Science within 2 weeks of survey completion.
5. It is acceptable (and expected) to pause overnight between execution of these SOPs.

4.2 Criteria for Determining Onset and Cessation of Sampling

The protocol may be initiated at any time during daylight conditions and may be executed during mildly inclement weather, such as very light rain, however efforts should be made to keep the total station and POC datalogger dry at all times. Ideally the protocol will be conducted during periods of baseflow with minimal leaf cover. If these conditions are not met, the appropriate biophysical condition must be noted prior to the survey. The protocol shall be temporarily ceased if hazardous conditions (e.g., lightning or flooding conditions) threaten personnel safety. The protocol may be resumed on a different day without compromising data quality. Geomorphology survey dates should also coincide with minimal planned biological or chemical sampling in the stream reach so as not to compromise other data collection efforts. For instance, if personnel have been wading in the stream and disturbing sediments to conduct the geomorphology surveys, water quality samples cannot be collected for at least 12 hours.

4.3 Timing for Laboratory Processing and Analysis

At the end of each survey day raw data must exported from the POC datalogger, saved on a domain network drive, and emailed to the appropriate Science support contact. Following the completion of the survey, all raw data (including Trimble data, if collected) must be saved and sent to Science as well as additional notes and observations compiled during the bout. All data collected on the Fulcrum is synced daily and is automatically uploaded onto the network.

4.4 Sampling Timing Contingencies

Table 1. Contingency decisions for the Wadeable Stream Morphology protocol.

Delay/ Situation	Action	Outcome for Data Products
Nightfall	• Measure and record a minimum of 3 COP's upstream of current total station YS location. Turn off instrument. • Return to site and begin with a new TS setup using the COP's or BMs.	No change to the outcome of data products if COP's are shot correctly and the TS is level.
Heavy rainfall or rising water levels in the channel	• Never remain in the field during unsafe conditions. • If time allows, measure and record a minimum of 3 COP's upstream of current TS location. • Turn off instrument, cover with waterproof covering (e.g., heavy weight garbage bag), and move to higher ground. • Once waters have receded, set up TS and orient to COP's.	Altered wetted perimeters, thalweg elevations, and bankfull widths. Consult with Science if this occurs.
Dead batteries in total station	• Replace the dead battery with a fully charged one.	The survey should not be impacted by the TS battery running out of charge.
Accidental movement of tripod and total station	• Re-level TS and continue survey. • If this occurred while shooting in new COP's, re-shoot in COP's once the TS is level using new survey codes. • If this occurred while orienting to previously mapped COP's, re-shoot in COP's as targets once TS is level to set new station.	Increased station deviations and uncertainty in survey data. Contact Science if any data-based questions require discussion.
Wind	• Never remain in the field during unsafe conditions. • Keep prism pole at shortest height to avoid movement of the prism in wind. • Halt survey if wind gusts are impacting the plumb line of the prism pole.	Increased station deviations and uncertainty in survey data. Contact Science if any data-based questions require discussion.

4.5 Estimated Time

The time required to implement a protocol will vary depending on a number of factors, such as skill level, system diversity, and environmental conditions present during the survey. The timeframe provided below is an estimate based on completion of a task by a skilled two-person team (i.e., not the time it takes at the beginning of the field season). Use this estimate as framework for assessing progress.

To complete the protocol in the timeframe presented, field crews should attempt to map approximately 200 meters of the aquatic reach per day. It is expected that the total reach length surveyed will be somewhat less than 200m on the first day as the initial orientation of the TS (which may include benchmark installation, the missing line workflow and Trimble point installation) can be time consuming. Foul weather and site-specific conditions such as thick brush, steep banks, and meandering channels will also inhibit the survey speed.

If after the third day of mapping, Field Ecologists are unable to meet the 200m rate of mapping, submit a trouble ticket detailing survey rate and describe the issues contributing to the slower-than-expected pace. At that time Science will work with the Domain staff to identify problems and present potential solutions. If it is determined that the sites conditions are such that the reach cannot be completely surveyed within the allotted time, Science will direct domain staff to adjust survey requirements in such a way that Field Ecologists are able to reach the top reach boundary within the allotted time.

Table 2. Estimated staff and labor hours required for implementation of the Wadeable Stream Morphology protocol.

SOP	Estimated time	Suggested staff	Total person hours
SOP A: Equipment and Supply Overview	1 hour	1	1 hours
SOP B: Instrumentation Setup and Survey Workflow	3-10 days (depending on environmental conditions)	3	24-240 hours
SOP D: Rapid Habitat Assessment	8 hours	2	16 hours
SOP E: Data Entry and Verification	2 hours	1	2 hours

5 SAFETY

This document identifies procedure-specific safety hazards and associated safety requirements. It does not describe general safety practices or site-specific safety practices.

Personnel working at a NEON site must be compliant with safe field work practices as outlined in the Operations Field Safety and Security Plan (**AD[02]**) and EHS Safety Policy and Program Manual (**AD[01]**). Additional safety issues associated with this field procedure are outlined below. The Field Operations Manager and the Lead Field Technician have primary authority to stop work activities based on unsafe field conditions; however, all employees have the responsibility and right to stop their work in unsafe conditions.

Personnel should wear clothing appropriate for weather conditions at the site. Both team members are required to wear hip waders and wading boots with no-slip soles. Field Ecologists should consider wearing NEON approved personal flotation devices in high velocity streams or streams with pools and runs deeper than one meter. Activities in streams should only be performed when flow conditions are safe. Do not attempt to wade a stream where velocity times depth is ≥ 0.93 m^2/s (10 ft^2/s).

6 PERSONNEL

6.1 Training Requirements

All Field Ecologists must complete required safety training as defined in the NEON Training Plan (**AD[04]**). Additionally, technicians must complete protocol-specific training for safety and implementation of this protocol as required in Field Operations Job Instruction Training Plan (**AD[05]**). Field personnel shall be trained on how to:

- Calibrate, operate, troubleshoot, and retrieve data from robotic TS.
- Properly operate a prism pole with prism.
- Identify, delineate and, map in-channel and floodplain features.
- QA/QC survey procedures.
- Exhibit safe working practices related to in-stream field work.

All Field Ecologists must receive training in accordance with NEON EHSS Policy, Program and Management Plan (NEON. DOC.004300, **AD[01]**) and Field Operations Safety and Security Plan (NEON.DOC.004316, **AD[02]**). Field Ecologists working in or near wadeable waterways shall be trained in Cold Water Safety Awareness and shall be competent in the use of waders.

6.2 Specialized Skills

Field Ecologists must possess the following specialized skills

- Conduct a total station survey in an accurate and efficient manner
- Identify geomorphological features and biological habitat boundaries in an accurate and efficient manner

7 STANDARD OPERATING PROCEDURES

SOP Overview

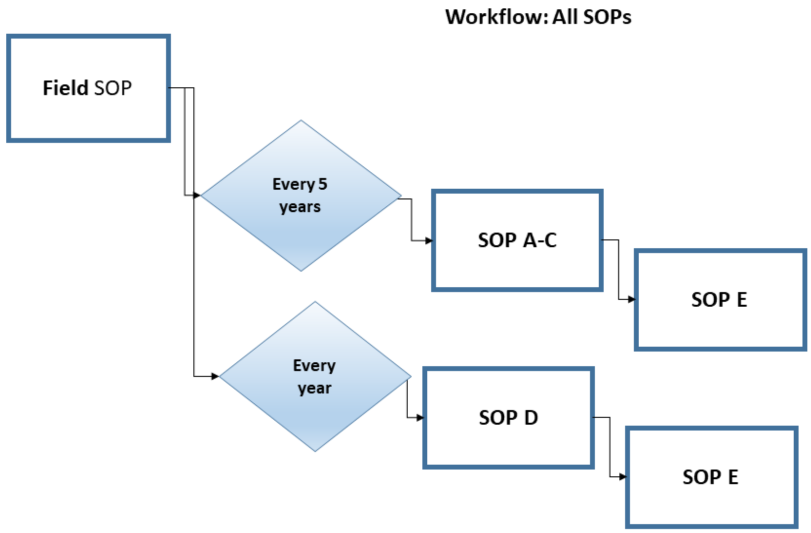


Figure 1. A high level workflow diagram that visually shows how the separate SOPs are sequentially connected.

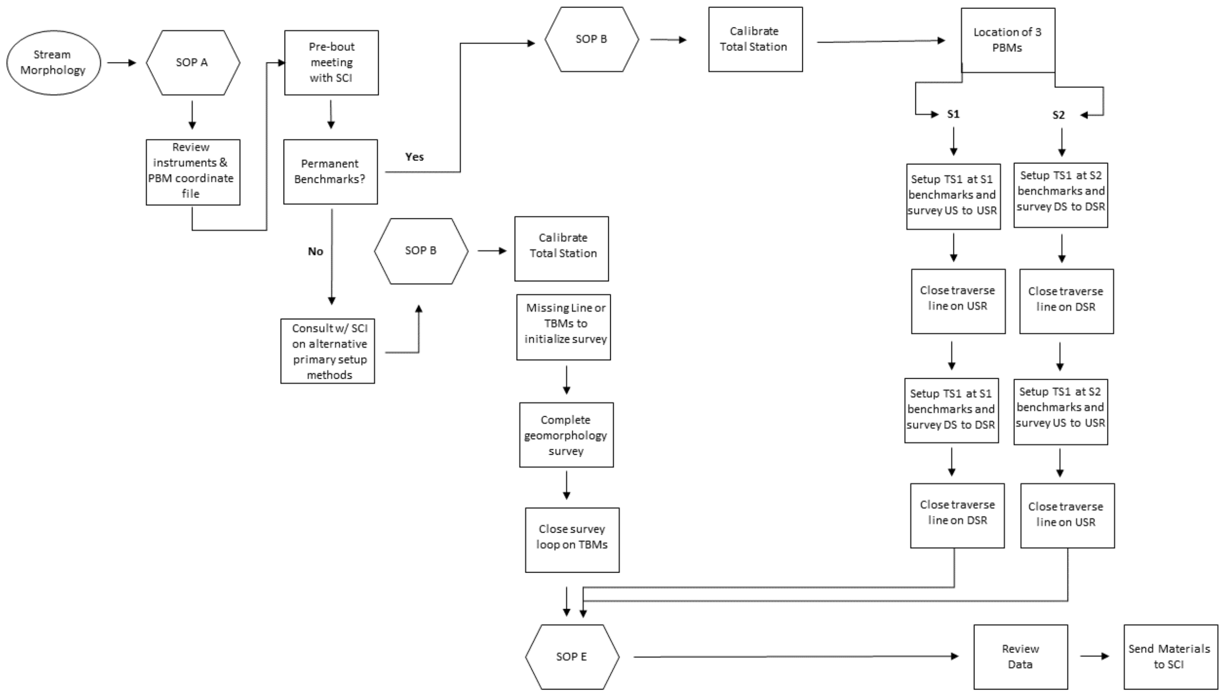


Figure 2. An expanded diagram of the workflow for the wadeable stream morphology protocol.

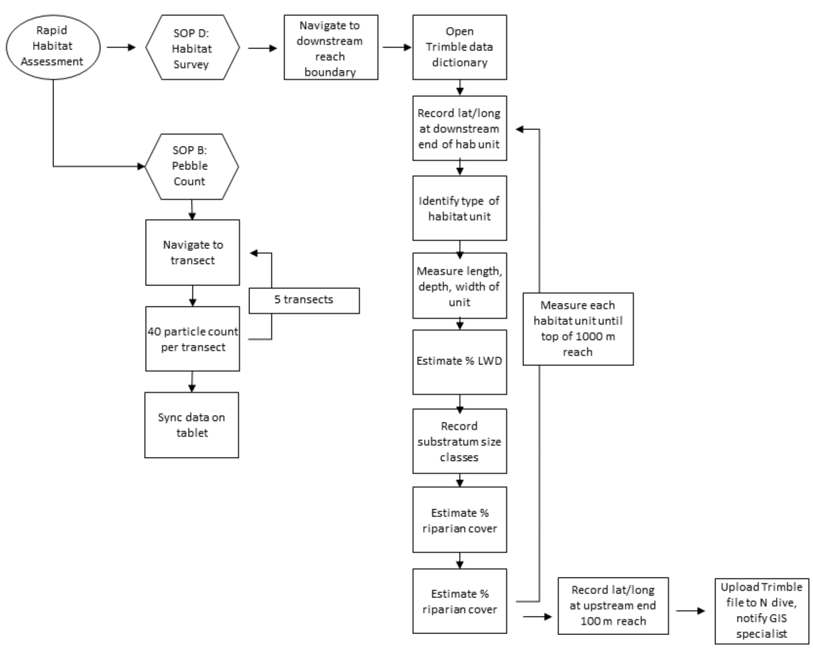


Figure 3. An expanded diagram of the workflow for the rapid habitat protocol.

SOP A Preparing for Sampling

A.1 Preparing for Data Capture

The Hilti POS-180 total station and the POC 100/200 operator keypads are the primary instrumentation used for mapping during the wadeable stream morphology protocol. Prior to the bout it is essential for Field Ecologists to become familiar with this equipment and how to operate it efficiently and accurately.

Mobile applications are the preferred mechanism for data entry. Mobile devices should be fully charged at the beginning of each field day, whenever possible. However, given the potential for mobile devices to fail under field conditions, it is imperative that field notebooks are always available to record data. Field notebooks should be carried along with the mobile devices to sampling locations at all times.

Check Equipment and Supplies Prior to the Start of the Survey

1. Check all surveying equipment to ensure it is ready for field use.
   a. Familiarize yourself with all TS instrumentation.
   b. Remove the TS from its case and check that all components are present and inspect for any signs of damage.
   c. Inspect the prism mirror for cracks or scratches.
      1. Clean the prism and TS head optics if needed with gentle wipes or a towel.
2. Check the prism and prism pole.
   a. Tighten all bolts on prism and prism pole.
   b. Check the prism pole knob lock to ensure it works properly (once locked the rod is securely held in place and does not slip).
   c. Check that the 10cm pole segment is installed between the top of the prism pole and the base of the 360° prism (**Figure 4**).
      1. This must remain installed throughout the stream morphology survey as it is critical to the height of rod calculations.
3. Ensure that primary and backup batteries for the TS and GPS are fully charged.
4. Ensure all equipment is decontaminated.
5. Prepare a field kit with all required equipment (**Table 7**).
6. Bring adequate supplies of water and food as surveys will require long days in the field.

Figure 4. 10 cm pole segment (blue arrow) that connects the 360 degree prism (shown on the top of the segment) to the prism pole (not shown). This segment must always be installed during the stream morphology survey.

A.2 Perform a Calibration of the Prism and Prism Rod

A calibration of the prism head (Hilti POA 20) and prism rod (Hilti POA 52) is required prior to the beginning of each stream morphology survey (**Figure 5**). It is critical that when the prism rod is level, the prism head is also level, and vice versa. This calibration is best done in the office prior to the stream morphology bout. The prism head and prism rod each contain a bubble level to evaluate the level of the rod during surveying. One level is located towards the top of the prism rod (prism rod level), the second is located on top of the 360° prism head (prism head level).

Once an initial calibration has been performed it is not necessary to perform another calibration of the prism head or prism rod during the stream morphology bout unless either instrument has been dropped, potentially damaged, or is noticeably out of level during use.

The following tools are required:

- Two-foot level
- Allen wrench (2.5mm)

To calibrate the prism head and prism rod:

1. Attach the 360° prism head to the prism rod and level the prism rod using the bipod.
2. Ensure that the prism rod level bubble is perfectly centered.

3. Place the two-foot level on one side of the prism rod to check the level on this plane.
   a. If the rod is out of level make slight adjustments at the base of the rod to bring it into level.
   b. Setting up the rod on a carpeted surface is helpful as it gives the tip of the rod something to stick to.
4. Rotate the two-foot level 90° and check the level on the other plane of the prism rod.
   a. If the rod is out of level make slight adjustments at the base of the rod to bring it into level.
5. Re-check the prism rod level bubble.
6. Release the prism rod clamp (used to adjust the height of rod) slightly and rotate the prism rod 360°.
7. Re-check the prism rod level bubble.
   a. If the prism rod is level on both planes using the two-foot level, and the prism rod level bubble remains perfectly centered following the rotation, proceed to **Step 11.**
   b. If the prism rod level bubble does not remain perfectly centered following the rotation, proceed to **Step 8.**
8. Tighten the prism rod clamp.
9. Using the Allen wrench, adjust the three screws under the prism rod level bubble until the bubble is in the exact center of the circle.
   a. Be sure not to bump the prism rod while doing this.
   b. It is critical that the prism rod remains perfectly level in both planes while adjusting the prism rod bubble level.
10. Once the prism rod level bubble has been adjusted, release the prism rod clamp (used to adjust the height of rod) slightly and rotate the prism rod 360°.
    a. If the prism rod level bubble remains perfectly centered following the rotation, proceed to **Step 11.**
    b. If the prism rod level bubble does not remain perfectly centered following the rotation, return to **Step 8** and re-adjust the prism rod level bubble with the Allen wrench**.**
11. Check the prism head level at the top of the 360° prism head.
    a. If the prism head is level (bubble is in the exact center of the circle), calibration of the prism and prism rod is complete.
    b. If the prism head is not level (bubble is not in the exact center of the circle), proceed to **Step 12**.

12. Using the Allen wrench, adjust the three screws surrounding prism head level bubble until the bubble is in the exact center of the circle.
    a. Be sure not to bump the prism rod while doing this.
    b. It is critical that the prism rod remains perfectly level in both planes while adjusting the prism rod bubble level.
13. Check the prism level at the top of the 360° prism head.
    a. If the prism head is level (bubble is in the exact center of the circle), proceed to **Step 14**.
    b. If the prism head is not level (bubble is not in the exact center of the circle), return to **Step 12** and re-adjust the prism head level with the Allen wrench.
14. Confirm that the prism rod has remained level on both planes with the 2-foot level.
    a. If level, calibration of the prism rod and prism head is complete.
    b. If out of level, return to **Step 5** and repeat calibration process.

Figure 5. Calibrating the prism rod and prism head.

A.3 Hilti POS-180 and POC 100/200 Total Station and Operator Keypad

The POS-180 consists of a theodolite with a built-in distance meter, enabling it to simultaneously measure angles and distances and determine the positions and elevations of points relative to the prism (**Figure 6**). The operator keypad, located on the front of the TS, and is used to turn the tool on and off, toggle the laser plummet, and scroll through/select items on the display. The keypad and display screen are also used for the fine-tune leveling of the TS. The POC-100 (**Figure 7**) and POC-200 (**Figure 8**) are the hand-held data collection units that are used to create, open, and setup survey job files, and to export, import, view, and map survey points. Either POC-100 or POC-200 models can be used to complete the survey.

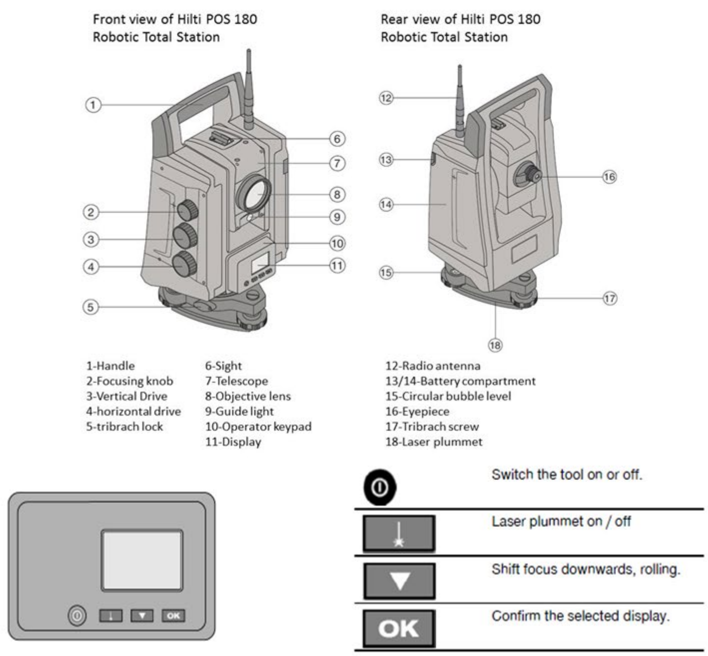
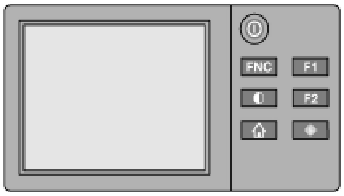


Figure 6. HILTI POS 180 Robotic Total Station schematics (above) and keypad diagram (below). Image credit: www.us.hilti.com.



	Switch the tool on or off.
	Switch the display backlight on or off.
FNC	Select the FNC menu for additional settings.
	Cancel or end all active functions and return to the start menu.
F1	User-configured function button
F2	User-configured function button
	Control and prism search function button

Figure 7. Hilti POC-100 schematics. Image credit: www.us.hilti.com.

Figure 8. Hilti POC-200 schematics.

A.4 Leveling the Total Station

Prior to wadeable stream morphology survey Field Ecologists should practice setting up and leveling the TS. This is a critical component to producing a high quality morphology survey.

1. Fully unfold the tripod so the legs are spaced at even intervals.
   a. If setting up the TS on penetrable surfaces (i.e. soft sand), make sure that the tripod legs are secure by stepping on the foot pedals until they are pushed into the ground surface and are stable and secure.
   b. If setting up the TS on impervious surfaces (i.e. flat a boulder or road), make sure the tripod is stable and secure.
   c. Wind or slippery surfaces can compromise the level of the TS.
   d. The unit is top heavy so take care that it does not fall over when setup on smooth or uneven surfaces.
2. Place the TS head onto the top base of the tripod and tighten the centering screw on the bottom of the unit.
   a. Ensure that it is properly secured to the tripod (**Figure 9**).
   b. Always keep one hand on the top of the TS head while it is being secured.
3. Level the TS by adjusting the tripod legs until the level bubble on the bottom of the TS head is fixed completely in the center area (**Figure 10**).
4. Ensure that a battery is in the TS (a pop-out slot on the side of the head) and turn the unit on.
5. View the TS keypad and screen to view the fine-tuning level of the TS (**Figure 11**).
6. Fine-tune the level of the TS using two of the three tribrach screw knobs until the display screen indicates the TS is level **(Figure 11**).
7. Press OK on the keypad display.
8. The TS is now level and ready for use.

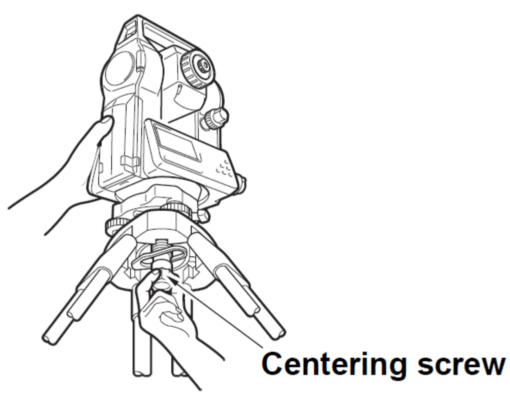


Figure 9. Attaching the total station head to the top of the tripod using the centering screw.

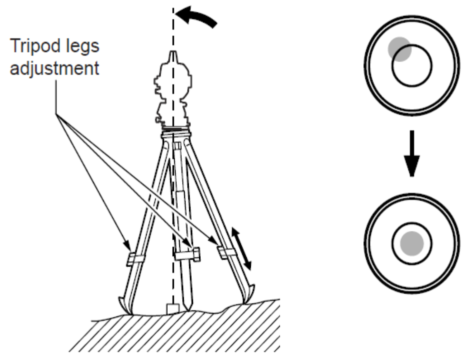


Figure 10. Leveling the tripod using the bubble level.

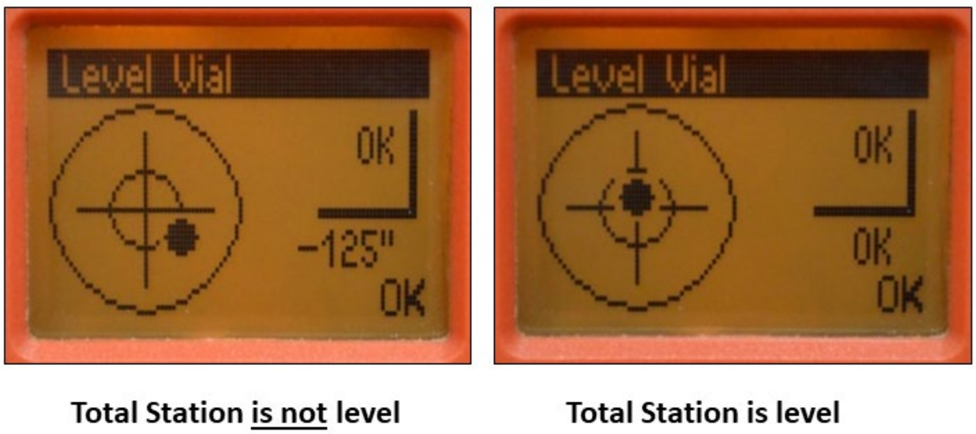


Figure 11. POS-180 total station fine-tuning leveling screen.

A.5 Preparing the Benchmark Coordinate File

A set of 5 permanent benchmarks should be installed throughout the monitoring reach prior to the geomorphology survey (details regarding site-specific benchmark configurations are provided in **Appendix B**, confirm with Science prior to the start of the survey). The coordinates of each benchmark will be provided by Science. Permanent benchmark locations within the aquatic monitoring reach are as follows:

- 3 permanent benchmarks within view of the staff gauge and pressure transducer.
- 1 permanent benchmark nearby the upstream reach boundary (near the TOP boundary marker).
- 1 permanent benchmark nearby the downstream reach boundary (near the BOT boundary marker).

If permanent benchmarks are not installed at the site a discussion will take place between Field Science and Science regarding the survey initialization. Additional steps such as a Missing Line workflow, installing/using temporary benchmarks, and/or collecting GPS Trimble points may need to be performed.

Science will provide a .CSV file that contains raw coordinates (Easting, Northing, and Height) associated with each of the permanent benchmarks. Review this file prior to beginning the geomorphology survey and complete the following steps.

- Create a folder on a USB flash drive called "Hilti Jobs".
- Save the .CSV file in this location and open it up in Microsoft Excel.
- Ensure that the column names in the .CSV file include 'Name', 'E', 'N', 'H', 'Attr1', 'Attr2', 'Attr3', 'Attr4', 'Attr5', 'HA', 'VA', 'HD', 'hr', 'ppm'.
  - Note the order of E, N, and H columns. Check that this heading order matches the settings in the POC.
    - In the POC main screen select Config > Settings > Coord Display/Input.
    - Make sure the order of E/N/H matches that of the file you plan on uploading (i.e. errors will occur if the .CSV column headers are in the order of N/E/H and the POC is in the order of E/N/H.
    - Contact Science if there are any questions regarding how the .CSV matches POC Coordinate Display settings
    - Note the names of the benchmarks in the "Name" column. They should correspond to the names of the permanent benchmarks installed at the site.
    - If all of the necessary data does not appear in the .CSV file or if there are any questions, submit a trouble ticket and contact Science.

SOP B Field Sampling

Reference **Figure 2** for a workflow diagram of field sampling within the stream morphology protocol. The (AOS) Stream Morphology [PROD] Fulcrum app is to be used to document data collected throughout the survey.

B.1 Create and Configure a Job File for the Stream Morphology Survey

1. Setup the handheld POC 100/200 device.
   a. Turn on POC and the TS.
   b. Check POC settings.
      1. POC-100/200:
         a) On the Home Screen select "Config" tab.
         b) Select "Settings".
         c) Set Coord/Disp/Inp to "ENH".
            (1) This must match the order of the benchmark coordinates contained in the .csv file that is loaded into the POC.
         d) Set "Decimal Format" to "1000.0".
         e) Set "Angle Units" to "DMS".
         f) Set "Angle Resolution" to 1".
         g) Set "Dist Units" to "Metric".
   c. Ensure Time and Date settings are correct.
      1. POC-100:
         a) On the Home Screen select "Config" tab.
         b) Select "Time/Date".
         c) Update Time/Date settings as necessary.
      2. POC-200:
         a) On the Home Screen, select the dash (-) in the very top right corner to bring up the main Windows desktop.
         b) Select the time and date listed in the lower right corner to make adjustments.
         c) Return to the Hilti Home Screen by selecting the Hilti icon in the bottom bar, or the Hilti POS shortcut on the desktop.
   d. Start New Job.
      1. POC-100/200:
         a) On the Home Screen select "Jobs" tab.
         b) Select "New" tab.
         c) Select ABC/--- button by "Job" to name new Job file.
         d) Name the job file appropriately (i.e. SITE.YYYYMMDD.g) and select "OK".
         e) Set the date to be the first day of the survey.

f) Select “OK” to save and load job.

e. Setup prism and ensure that it is linked to the POC/TS.

1. Stand at least 5m from the TS holding the prism pole upright with the prism in direct line of sight of the station.
2. Adjust your position until both colors (red/green) of the guide light are visible.
3. Hold prism pole in place and press the prism search button  on the outside of the POC.
4. Set “G’light” and “Prism” to “Auto”.
5. Select “Prism” tab.
6. Select appropriate prism type.
   a) During stream morphology surveys this will be 360° Stand Prism.
7. Select “OK”.
8. You will hear a “ding” noise when the robotic head of the TS and the prism are linked up.
9. Return to the POC Home Screen.

2. Upload the permanent benchmark coordinates into the POC.
   a. Import the .CSV file that contains the permanent benchmark coordinates into the POC.
      1. Insert the USB drive that contains the .CSV file into the POC.
      2. On the POC Home Screen, select the “File” tab.
      3. Select “Import”.
3. POC-100:
   a. Select “To Job” to designate the name of the job defined in Step 1c.
   b. Ensure file units are set to Meters.
   c. Ensure Data Format is *.csv.
   d. Select the box next to “From File”.
   e. Choose the .CSV file that you loaded onto the USB device.
   f. If you get an error here make sure that the .CSV file is saved under the “Hilti Jobs” folder on the USB flash drive.
   g. Click “OK”.
   h. On the ‘Import Design Points’ screen, click “OK”.
   i. The “Importing Points” screen will appear followed by “X points were imported”.
   j. Click “OK”.
   k. On the ‘Select Task’ screen, click “OK”.
   l. The points should now be loaded into your job file.
4. POC-200:
   a. Select the “Select File” box.
   b. Select the “USB” button on the top of the screen.

c. Choose the .CSV file that you loaded onto the USB device.
d. Click "OK".
e. Ensure file units are set to Meters.
f. Ensure that the correct Job File is selected.
g. Load the correct job file if needed by selecting the dialog box.
h. Click "OK".
i. The points should now be loaded into your job file.

B.2 Perform a Field Calibration of the Total Station

A field calibration of the total station is required prior to the beginning of each stream morphology survey. Field calibration should be completed one month prior to a survey event to allow adequate time if factory calibration or repair is needed. Shipping and rough handling are the most common causes for failing calibration; care should be made to reduce jostling of the POS (the robotic head) during transportation and the survey.

Once an initial total station calibration has been performed it is not necessary to perform another field calibration during the stream morphology bout unless the instrument has been dropped, potentially damaged, or is exhibiting signs of malfunction. Contact Science if any of these situations occur.

To perform a field calibration of the total station:

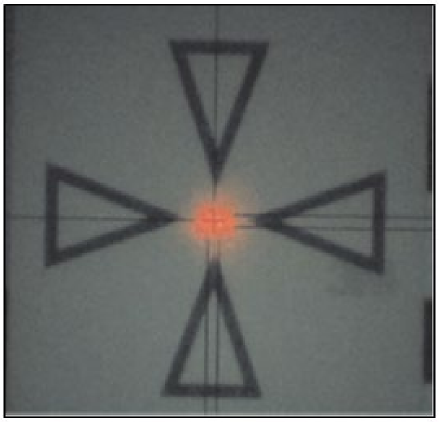
1. Set up and level the TS (see **SOP A: Leveling the Total Station**) in an area with a clear view to a target location 30 meters away.
   a. Avoid direct sunlight on the objective lens aperture.
   b. Spin the TS head in all directions to confirm that the TS is perfectly level.
   c. If finding an acceptable location where a 30 meter distance cannot be achieved near the site, perform the calibration along a road or parking lot.
2. Open the Calibration table in the Fulcrum app to record pre and post calibration values.
3. Check that the laser point aligns with the TS cross hairs.
   a. Use a measuring tape to set up the target plate (**Figure 12**) 30 meters from the TS.
   b. The plate can be taped to a prism-bipod setup so that the plate is flat and TS cross hairs can align with the triangles.
   c. Set the plate at roughly the same height as the TS.
   d. Note: If there is no test plate with your TS kit one can be made by drawing a 10mm diameter circle on a sheet of paper and marking a dot at the exact center (**Figure 12**).
   e. Manually sight in the plate so that the cross hairs in the scope sight are perfectly in line with the center of the target plate.
      1. Use the dials on the side of the robotic head to adjust the focus (top knob) and move the head up/down (center knob) and left/right (lower knob).

f. Switch on the laser pointer from the POC controller into RL (reflector-less laser) mode (WARNING: Never stare directly into the laser beam).

g. Push the lower right button on the POC controller to take you to the prism search screen .

h. In the upper right portion of the screen there will be an EDM option. Click and advance through the following options until you reach “DR: Laser On”

1. Prism Auto: Automatic prism tracking and continual distance measurement.
2. Prism Manual: Distance measurement at the touch of a button.
3. DR: Laser On: Reflector less distance measurement with laser pointer switched on (ensure that this option is selected).
4. Deviation from the center should be no more than 5mm at the 30m distance.
   a) This threshold can be visualized by the triangles on the target plate; i.e. it is considered a failed calibration if the laser enters the triangles a 30m distance.
   b) If the deviation is greater than 5mm, contact Science as Hilti repair service may be required.
   c) Note that it may be difficult to see the laser from the TS, walk up to the target plate to confirm laser location.
5. Enter whether the laser was within the target threshold in the app.



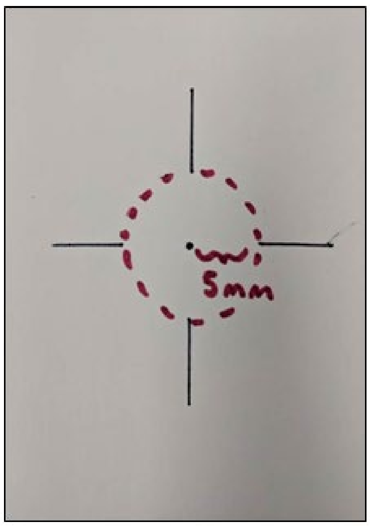


Figure 12. Above: Hilti target test plate with laser in the center. Below: Hand drawn target plate that includes a 10mm diameter circle with center point with 5mm delineation added.

4. During the remaining TS calibration steps:
    a. Setup and level the prism on bi-pod 50m away from the TS with a clear line of site.
    b. Best practice is to avoid direct sunlight on the prism or in the objective lens aperture.
    c. Placing your hand or a large folder over the prism, while being very careful not to touch or un-level the prism, is one way to shade the prism in extremely sunny conditions.
    d. Confirm that the bipod is level throughout the calibration process.
5. On the Main screen of POC select Config > Calibration.
    a. Record these values that are displayed on the first screen into the app:
        1. HA – Collimation
        2. VA – Collimation
        3. Comp – L

        4. Comp – T
        5. Prism Track
    b. Click “New”.
    c. Manually sight in the prism so that the cross-hairs in the scope sight are perfectly in line with the center of the white lines in the prism.
        1. Note that the TS robotic head will not be connected to the prism during this test so you have to sight everything in manually.
    d. Calibrate the tilt sensor compensators, COMP-L and COMP-T.
        1. With this first calibration, you are calibrating the two internal compensators which are aligned at an angle of 90° to each other.
    e. Manually sight in the prism as precisely as possible.
    f. Click the “Comp” tab.
    g. The TS will carry out measurements and rotate several times independently.
        1. Do not realign the TS to the prism.
        2. The TS will calculate the offset and correct the value.
    h. Record the new Comp values into the app.
    i. Calibrate the HA and VA Collimation error.
        1. Here you are ensuring that the measurements taken by two internal faces are exactly 360° apart.
    j. Return to configuration menu.
    k. Manually sight in the prism as precisely as possible.
    l. Click the “H-Coll” tab.
    m. Press Meas.
    n. Once the measurement in position 1 has been completed, the TS rotates automatically to position 2.
        1. Note that the TS head will never return to the center of the prism for position 2 with 100% precision automatically.
        2. You will always need to adjust the TS head following this rotation.
    o. Without moving the bipod, manually sight in the exact same spot on the prism again.
    p. Press Meas.
    q. The TS rotates back to position 1 and calculates and displays the new correction values.
    r. The TS will calculate the offset and correct the value.
        1. If this is not done very precisely, the calibration will fail and the software will use the old values.
    s. Record the new values into the app.
6. Calibrate the prism tracker.

a. The prism tracker error results when the prism tracker target axis deviates from the optical target.
   1. Note that this this calibration procedure requires the greatest degree of precision by the operator.
   2. Avoid reflective surfaces and stray light sources which can potentially bias the test.
b. Return to configuration menu.
c. Manually sight in the prism as precisely as possible.
d. Click the “P-Track” tab.
e. Press Meas.
f. Once the measurement in position 1 has been completed, the TS rotates automatically to position 2.
g. Without moving the bipod, manually sight in the exact same spot on the prism again.
h. Press Meas.
i. The TS rotates back to position 1 and calculates and displays the new correction values.
   1. The TS will calculate the offset and correct the value. C and I values are the offset values for the prism tracker calibration.
   2. Do not be surprised if the cross-hairs (after lock) are not 100% in the center of the prism.
   3. These offset values are stored in the file and will be applied to future measurements.
j. If successful, record new prism track calibration values in the app.
k. TS calibration is now complete.
   1. If you receive the message “The remaining C and I values of the tracker are too big – service may be required” this indicates that the prism track calibration has failed.
   2. Prism track calibration failure is a known issue, Hilti is currently reviewing the test parameters and is in the process of reducing the stringency for passing.
   3. Repeat Prism Track calibration steps up to two more times in order to attempt to successfully calibrate the prism.
   4. The most important component of this procedure is to ensure that you have precisely targeted to the center of the prism in position 1 and 2.
   5. The calibration will fail if this is not done very precisely and carefully.
   6. If, after two additional attempts, calibration fails, continue on to the next steps for survey initialization.
   7. The laser-total station cross-hairs alignment and HA/VA Collimation tests are most critical to ensure a successful calibration.
   8. If these tests have passed and the P-Track test has failed, document this occurrence in the app and continue on to the next steps of survey initialization.
   9. If laser-total station cross-hairs alignment and HA/VA Collimation tests fail after repeated attempts, contact Science immediately.

Factory calibration of the total station will typically occur on a less frequent basis than field calibration. The frequency of factory calibration depends on the NEON aquatic sites where the instrument is being used, the following guidelines are provided below.

When to factory calibrate the total station:

1. All NEON Aquatic sites:
   a. Factory calibration is required any time the total station fails the field calibration laser point alignment test.
   b. For total station kits that are still under the initial 2-year warranty include one free factory calibration per year, factory calibration should be performed the month before the warranty expires.
2. Stream sites:
   a. Factory calibration must be performed within 1 year leading up to the stream morphology survey.
   b. This results in a factory calibration every five years, at minimum.
3. Lake and River sites:
   a. Factory calibration must be performed every 5 years, at minimum, regardless of field calibration.

B.3 Setting up the first Total Station Location (TS1)

1. Setup the first total station location (TS1) at the sensor set that contains three permanent benchmarks.
   a. If the site does not contain any permanent benchmarks, reference the instructions provided by Science in the pre-bout meeting.
   b. Navigate to the location where the three permanent benchmarks are installed to begin the survey.
   c. Level the TS (see **SOP A: Leveling the Total Station**) on a flat surface with a clear view of each of the three permanent benchmarks and a section of the stream.
2. Shoot in each of the three benchmarks to orient the first TS location.
   a. For non-bedrock installations permanent benchmark ID's are engraved on access caps that protect each datum.
      1. Note the benchmark ID and lift the access cap up to reveal the benchmark that lies a few inches below the surface.
   b. For permanent benchmarks installed in bedrock, no access cap is present; a labeled cap is present that denotes the benchmark ID.
   c. Use the bi-pod to level the prism rod at exactly the center of the benchmark cap (see X-mark) or the divot in the center of the datum point.
   d. Ensure that prism and POC are linked up.

e. Sight the TS on the prism.
f. Select "Meas Rec".
g. Select "New Sta" tab.
h. In the "Select Station Type" screen, ensure the following settings are selected:
    1. Heights: on
    2. Point System: Coord/Graph
    3. Setup Location: Anywhere
i. Select "OK".
j. Click on the rectangle next to 'Stat Pt ID' and enter "TS1", the code to be used for the first TS location.
    1. Subsequent "Stat Pt ID" codes will be sequential ("TS2", "TS3", etc.).
k. Set "HI" to equal 0.00m.
l. Select the "Targets" tab.
m. Select the button to the right of "Pt ID", choose the benchmark point ID at which the prism is located (i.e. "BM1") and select "OK".
n. Select the numbers to the right of "HR" to enter the height of the prism rod.
    1. Enter this value to two decimal places (i.e. 1.60).
o. Ensure that the TS and the prism rod are perfectly level.
p. Select the "Meas" tab to shoot in the benchmark.
q. Do not move the TS.
r. Use the bi-pod to level the prism rod at exactly the center of the next benchmark cap (at the center X- mark) or the divot in the center of the datum point.
s. Select the button to the right of "Pt ID" and choose the benchmark point ID at which the prism is located (i.e. "BM2") and select "OK".
t. Enter "HR", the height of the prism rod.
    1. Enter this value to two decimal places (i.e. 1.60).
u. Ensure that the TS and the prism rod are perfectly level.
v. Select the "Meas" tab to shoot in the benchmark.
w. Do not move the TS.
x. Use the bi-pod to level the prism rod at exactly the center of the final benchmark cap (at the center X- mark) or the divot in the center of the datum point.
y. Select the button to the right of "Pt ID" and choose the benchmark point ID at which the prism is located (i.e. "BM3") and select "OK".
    1. The total station head may rotate and automatically move to the location of this point once entered. Check that the TS is sighted correctly on the prism.
z. Enter "HR", the height of the prism rod.
aa. Ensure that the TS and the prism rod are perfectly level.

bb. Select the "Meas" tab to shoot in the third benchmark.
cc. Do not move the TS.
dd. After each of the three permanent benchmark points have been measured, select "OK".
ee. Leave the bi-pod leveled on the center of the last benchmark.
ff. On the 'Set Station' screen, select "Calc".
gg. The error screen will display the station deviations calculated between the known BM coordinates and those you just measured from TS1.
hh. The following station deviation values will be listed:
    1. StDev(Pos): station deviation of the location of head unit of the TS.
    2. StDev(HA): station deviation of the horizontal angle.
    3. StDev(H): station deviation of the height.

3. Check that StDev(Pos) ≤ 0.005m.
    a. If StDev(Pos) is ≤ 0.005m:
        1. Record StDev(HA) and StDev(H) in the app and proceed to **Step B.3-3c**.
    b. If StDev(Pos) is > 0.005m:
        1. Click the "Back" two times to return to the Set Station screen.
        2. Repeat **Steps B.3-2h – 2hh** up to five times.
            a) Points to consider in attempting to reduce the station error:
                (1) Check the benchmarks to see if they appear stable in the ground.
                    (a) Any movement in the benchmarks since the initial survey would result in high station deviation.
                    (b) If the benchmarks are not stable in the ground immediately contact Science for consultation.
                (2) Check the level on the TS and the prism rod prior to each benchmark shot and ensure both are perfectly level.
                (3) If, after five attempts, StDev(Pos) > 0.005m.
                    (a) Stop work.
                    (b) Submit a trouble ticket and contact Science immediately (preferably from the field if possible).
                    (c) Either the benchmarks have moved since installation, the incorrect coordinates were loaded onto the POC, or other problems have occurred with regards to the TS setup procedures.
    c. Select "Set" to set station.
    d. Select "OK".
    e. The "Measure Points" screen will appear.
        1. Very Important:

a) If station is not set correctly, the survey will contain critical errors from this point forward without warning.

b) It is critical to ensure the station is set properly before continuing with the survey.

f. Verify you are at the correct station (TS1).

1. Hit the "Home" button on the outside of the POC.
2. Select the "Meas Rec" icon.
3. The "Meas Rec" screen appears that displays the job, current station, backsight point ID, and Height of Instrument.
4. Verify each of these values are correct.
   a) "Job" should be the current job file.
   b) "Current Station" should be the station you just set (i.e. "TS1").
   c) "Bks Pt ID" should be one of the backsight points or targets you used to set the station (i.e. "BM1").
   d) "Height of Instrument" should be 0.000m.
5. If all values are correct, hit "OK" and proceed to **Step B.3-4**.
6. If all values are not correct, return to **Step B.3-2g** and repeat the set station process.

4. From TS1, begin the geomorphology survey in the upstream or downstream direction, depending on the starting location.
   a. If the three permanent benchmarks used to establish TS1 are near S1:
      1. Survey in the upstream direction towards the upstream reach boundary (USR).
   b. If the three permanent benchmarks used to establish TS1 are near S2:
      1. Survey in the downstream direction towards the downstream reach boundary (DSR).
5. If possible, survey as much of the reach as you can from TS1 via the "Meas Rec" screen.
   a. Record the first thalweg point ID shot from this TS location in the app.
   b. Enter the correct code for each mapped point (**Table 2**, **Table 3**, **Table 5**) by clicking the button next to "Pt ID".
6. Once everything is mapped within the range of TS1, enter the last thalweg point ID shot in the app and prepare to move the TS following methods described **Section B.4**.
7. If nothing can be mapped within the range of TS1, prepare to move the TS following methods described **Section B.4**.

B.4 Setting up Subsequent Total Station Locations Using Control Points

1. Once all mapping is complete from TS1, prepare to move the TS to the next location using Control Points.
   a. It is critical that the TS is not physically moved from the current location until all of the below steps are complete.

b. First, find an optimal location for the next TS location (TS2) either in the upstream or downstream direction, depending on which direction the survey is headed.
   1. Ensure that an adequate portion of the reach can be surveyed from this location.

c. Install a minimum of 3 temporary Control Points (COP's) in a roughly equilateral triangle such that there are no overlapping sight lines.
   1. Drive magnetic nails (or other materials appropriate for site conditions) flush into the ground so that they are stable and can accurately and repeatedly mark location of each COP.
   2. Use flagging and a sharpie to label each COP.
   3. Each COP should be consecutively labeled beginning with COP1 as the first COP established during the survey.
   4. Utilizing (at least) 3 COP's to setup each TS location is critical in order to minimize the amount of vertical and horizontal error introduced into the survey during each TS move.
   5. Maximizing the angles between each COP is critical – this allows the new position of the TS to be more easily triangulated and reduces error.
      a) A 45 degree angle between the TS and the widest COP's is ideal.
   6. If forming an equilateral tringle is impossible due to site conditions, placing the COP's in horizontal lines (relative to both TS location) will suffice.
      a) This is not ideal and will lead to higher station deviations. Always attempt to maximize the space between the COP's.
      b) COP's cannot be arranged vertically relative to lines of sight from each TS location.
   7. More than 3 COP's can (and should) be used whenever possible to minimize error.
      a) The new TS location can be placed in the middle of them (**Figure 13**).
      b) This is a useful technique that maximizes the distance and angles between COP's in tight spaces.
         (1) Note in **Figure 13** the wide distance between COP1 and COP2 that creates a 45 degree angle between each COP and TS1 and TS2, how COP4 is beyond TS2, and the foresights are at shorter distance from TS1 than the backsights.
         (2) This offers a nearly 270 degree total angle in which to triangulate the new position. All of these components help ensure that setup errors are reduced.
         (3) The perfect TS setup is not always possible given environmental conditions, but foresights and backsight setups similar to this approach should be attempted.
   8. Ensure that a clear line of sight exists from each of the COP's to both TS1 (the current TS location) and TS2 (the next TS location).
      a) Shorter foresights and longer backsights are always required.
   9. Ensure that adequate spacing exists between each COP.
      a) Ideally each COP would be spaced >5m apart but this is not always possible in some locations.

b) Maintain a minimum of 2m spacing between COPS's in locations where lines of site are difficult to establish.

d. Ensure that the TS is perfectly level. If it has come out of level adjust accordingly prior to shooting in COP's.

e. From TS1, shoot in each of the COP's.

1. Use the bi-pod to level the prism rod on the center of COP1.
2. Select the button to the right of Pt ID to name this point "COP1" (or the COP ID that the prism rod is currently on).
3. Enter HR, the height of the prism rod.
4. Select "M&R" tab to shoot in COP1.
5. Repeat above steps for COP2, COP3, and all others used to setup the next TS move.
6. Make sure the TS is not disturbed between the COP shots and that it remains perfectly level.

   a) If the TS comes out of level between COP shots, re-level the TS and re-shoot any COP that was mapped when the TS was out of level.

      (1) These COP's will require new Pt ID's (codes).

      (2) Make sure this is well-documented in the app remarks and that the flagging on each COP is correct.

f. Ensure that all COP's have been shot in as foresights (minimum of three).

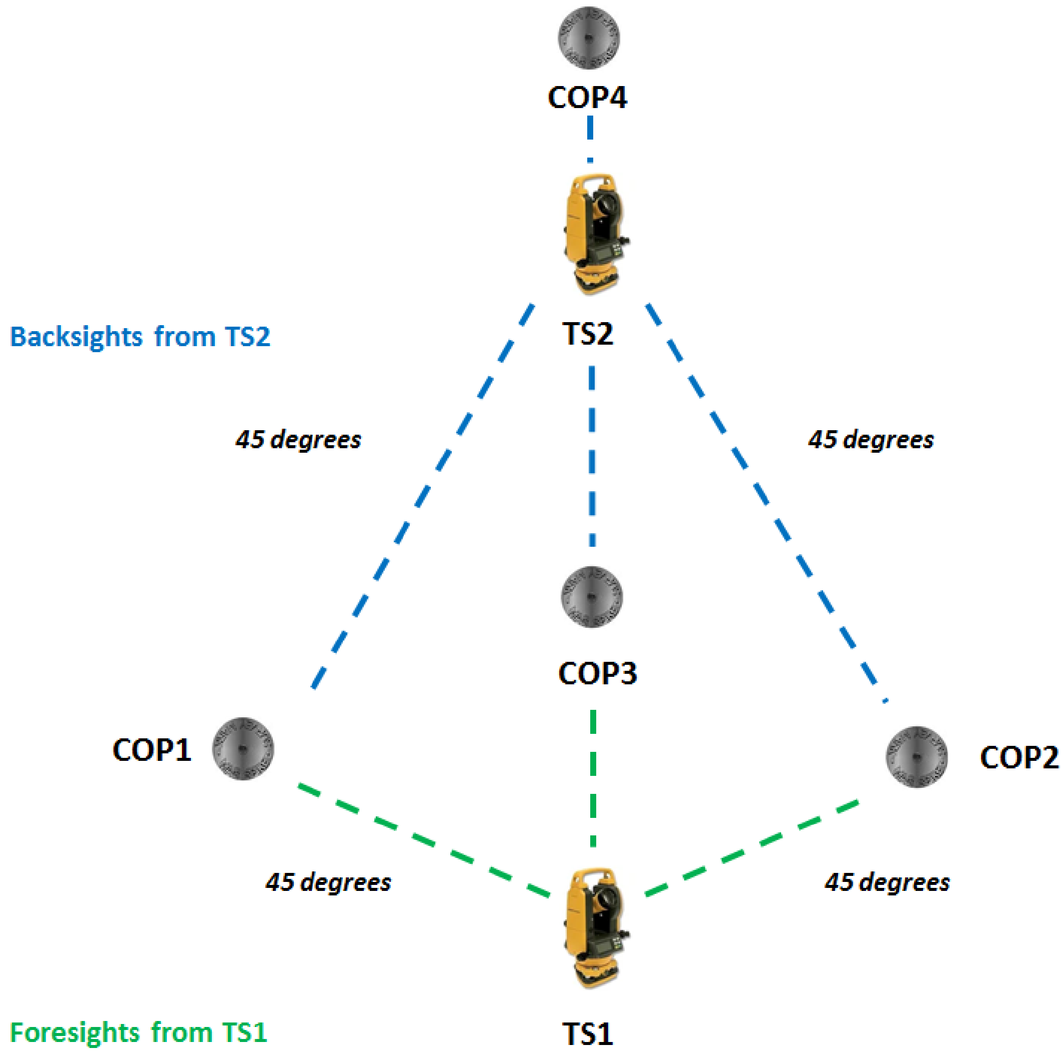


Figure 13. Idealized total station-control point setup using an optional fourth control point to set a second total station location (TS2).

2. Physically move the TS from TS1 to TS2.
   a. Level the TS at the new TS2 location.
   b. Using the POC, identify each of the COP foresights that were shot in from TS1 as new backsight targets:
      1. Navigate to the Home Screen.
      2. Select "Meas Rec" button.
      3. Select "NewSta" tab.
   c. In the "Select Station Type" screen, ensure the following settings are selected:
      1. Heights: on

2. Point System: Coord/Graph
3. Setup Location: Anywhere

d. Select “OK”.
1. Under “Set Station” screen, select the button to the right of “Stat Pt ID” to enter Stat Pt ID as “TS2” (for the second TS location).
2. Set HI = 0.000m.
3. Select “Targets” tab.
4. Under “Meas Target Pt 1” screen select the button to the right of Pt ID.
5. Scroll down to select “COP1”.
6. Select “OK”.
7. Use the bi- pod to level the prism rod on COP1.
8. Enter HR.
9. Check that TS is level.
   a) If it has come out of level, re-level TS prior to shooting in COP1.
10. Select “Meas Rec” to shoot in COP1.
11. Repeat above steps to shoot in COP2, COP3, and any other COP’s used to setup the new TS location.
    a) Make sure the TS is not disturbed between the COP shots and that it remains perfectly level.
12. If the TS comes out of level between COP backsight shots, re-level the TS and start over from **Step B.4-2**.

e. Once all three control points have been shot in Select “OK”.

f. Select “CALC”. The error screen will then show station deviation calculated between the COP shots taken from TS1 and TS2.

g. The following station deviation values will be listed:
1. StDev(Pos): station deviation of the location of head unit of the TS.
   a) Only provided when at least 3 COP’s were used.
2. StDev(HA): station deviation of the horizontal angle.
   a) Only provided when at least 3 COP’s were used.
3. StDev(H): station deviation of the height.

h. Evaluate the station deviation values associated with the new TS setup:
1. If StDev(Pos) ≤ 0.005m:
   a) Record all station deviation values in the app and proceed to **Step B.4-3**.
2. If StDev(Pos) is > 0.005m:
   a) Repeat **Step B.4-2** through **Step B.4-2h** one more time.
   b) Ensure that TS and prism rod on each COP are perfectly level and that a clear line of sight exists between the TS and the prism.

c) See **Appendix D.2** on ways to troubleshoot high station deviations while setting a new station.

d) If, after the second attempt, StDev(Pos) is > 0.005m enter a remark that the station setup was attempted multiple times and continue to the next step to set the station.

3. Select "Set" to set station.
   a. Select "OK".
   b. The "Measure Points" screen will appear.
      1. Very Important: If the "Set" button is not clicked, the survey will contain critical errors from this point forward without warning.
   c. Verify you are at the correct station.
      1. Hit the "Home" button on the outside of the POC.
      2. Select the "Meas Rec" icon.
      3. The "Meas Rec" screen appears that displays the job, current station, backsight point ID, and Height of Instrument.
      4. Verify each of these values are correct.
         a) "Job" should be the current job file.
         b) "Current Station" should be the station you just set (i.e. "TS2").
         c) "Bks Pt ID" should be one of the backsight points or targets you used to set the station (i.e. "BM1").
         d) "Height of Instrument" should be 0.000m.
      5. If all values are correct, hit "OK" and proceed to **Step B.4-4**.
      6. If all values are not correct, return to **Step B.4-2** and repeat the set station process.
   d. Survey as much of the reach as you can from this TS location.
   e. Once everything has been mapped within the range of the TS location, prepare to move the TS by repeating the methods described in **SOP-B.4-2** using consecutive label IDs for each TS location setup (i.e. TS3, TS4, TS5…).
4. Survey the entire extent of the monitoring reach in this manner **(Figure 14**) until you arrive at the upstream or downstream reach boundary.

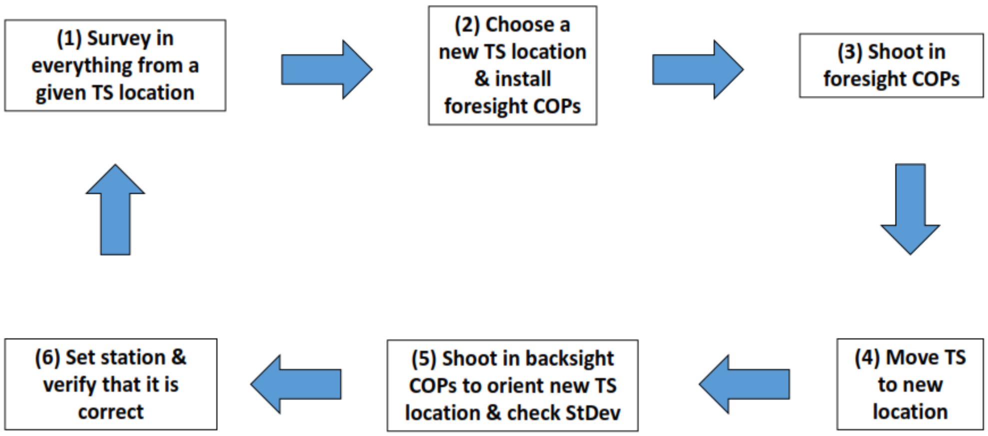


Figure 14. Total station setup workflow to be followed throughout the stream morphology survey.

B.5 Complete the Geomorphology Survey with Two Closed Level Traverse Runs

For sites with permanent benchmarks, each geomorphology survey will consist of two closed level traverse runs between the three permanent benchmarks installed at the sensor set that is co-located with the staff gauge and a single benchmark installed near the upstream and downstream reach boundaries. Closing level traverses must be conducted as a means to quantify and assess error associated with each geomorphology survey.

For sites without permanent benchmarks, or permanent benchmarks that are not located at sensor set locations, reference the instructions provided by Science during the pre-bout geomorphology meeting regarding starting and closing the survey.

<u>**If the survey began from sensor set 2 (TS1 setup using benchmarks co-located with sensor set 2):**</u>

1. Map points in the downstream direction until you reach the downstream reach boundary (DSR) following steps outlined in **SOP-B.4**.
2. Once mapping has been completed to the DSR, shoot in the center of the permanent benchmark near the DSR transect three times.
    a. Three shots will help evaluate potential outliers.
    b. This is a very important shot. Double check that the TS and prism rod are completely level.
    c. Label these points “BM#_CLOSE1-3”.
        1. The # being the permanent benchmark ID found on the access cap or monument cap, depending on the benchmark type.
    d. In the app, open the “Loop 1 Closure Shots” table and enter:

1. Names of the Initial Benchmarks.
    a) These are the names of the three benchmarks used to orient the first total station setup of this traverse run.
2. Northing/Easting/Height coordinates of the Initial Benchmarks.
    a) These are the coordinates of the three initial benchmarks that were loaded into the job file from the .CSV file sent by Science.
3. Closure Benchmark Shot Name.
    a) This is the name of the benchmark used to close this traverse run.
4. Northing/Easting/Height coordinates of the Closure Benchmark.
    a) These are the coordinates of the shot taken on the closure benchmark.
    b) These values are stored on the POC after the point(s) is mapped.
    c) To access them:
        (1) On the Home screen of the POC select the Info tab > the Points tab > All Pts tab > Click on the Pt ID box on the top right > Search for the name of the closing point and the E/N/H will be shown.
    d) Enter these values into the app.
    e) If coordinate differences between the three closing shots is greater than 0.005m, enter the values from the first shot and contact Science for discussion.
    f) It may be advantageous to take more shots on the closing BM in order to better identify outliers.

e. The app will calculate the horizontal and vertical misclosure error associated with the traverse.

3. Once the downstream benchmark has been mapped, the TS can be picked up and moved back to the S2 benchmarks.
    a. The next TS location can be set using these benchmark coordinates as targets, following the steps outlined in **SOP-B.4** and surveying in the upstream direction.
    b. Continue the TS numbering convention from the last TS setup (do not start over by naming the next TS setup “TS1”).
4. Once the station is set, begin surveying in the upstream direction heading toward the upstream reach boundary (USR).
5. Once mapping has been completed to the USR, shoot in the center of the permanent benchmark near the USR transect three times.
    a. Three shots will help evaluate potential outliers.
    b. This is a very important shot. Double check that the TS and prism rod are completely level.
    c. Label these points “BM#_CLOSE1-3”.
        1. The # being the permanent benchmark ID found on the access cap or monument cap, depending on the benchmark type.

d. In the app, select "Yes" to "Was a Second Loop Closed?" and enter the following information in the table:
   1. Names of the Initial Benchmarks.
      a) These are the names of the three benchmarks used to orient the first total station setup of this traverse run.
   2. Northing/Easting/Height coordinates of the Initial Benchmarks.
      a) These are the coordinates of the three initial benchmarks that were loaded into the job file from the .CSV file sent by Science.
   3. Closure Benchmark Shot Name.
      a) This is the name of the benchmark used to close this traverse run.
   4. Northing/Easting/Height coordinates of the Closure Benchmark.
      a) These are the coordinates of the shot taken on the closure benchmark.
      b) These values are stored on the POC after the point(s) is mapped.
      c) To access them:
         (1) On the Home screen of the POC select the Info tab > the Points tab > All Pts tab > Click on the Pt ID box on the top right > Search for the name of the closing point and the E/N/H will be shown.
      d) Enter these values into the app.
      e) If coordinate differences between the three closing shots is greater than 0.005m, enter the values from the first shot and contact Science for discussion.
      f) It may be advantageous to take more shots on the closing BM in order to better identify outliers.

e. The app will calculate the horizontal and vertical misclosure error associated with the traverse.

6. The geomorphology survey is now complete.

<u>**If the survey began from sensor set 1 (TS1 setup using benchmarks co-located with sensor set 1):**</u>

1. Map points in the upstream direction until you reach the upstream reach boundary (USR) following steps outlined in **SOP-B.4**.
2. Once mapping has been completed up to the USR, shoot in the center of the permanent benchmark near the USR transect three times.
   a. Three shots will help evaluate potential outliers.
   b. This is a very important shot. Double check that the TS and prism rod are completely level.
   c. Label these points "BM#_CLOSE1-3".
      1. The # being the permanent benchmark ID found on the access cap or monument cap, depending on the benchmark type.
   d. In the app, open the "Loop 1 Closure Shots" table and enter:

1. Names of the Initial Benchmarks.
   a) These are the names of the three benchmarks used to orient the first total station setup of this traverse run.
2. Northing/Easting/Height coordinates of the Initial Benchmarks.
   a) These are the coordinates of the three initial benchmarks that were loaded into the job file from the .CSV file sent by Science.
3. Closure Benchmark Shot Name.
   a) This is the name of the benchmark used to close this traverse run.
4. Northing/Easting/Height coordinates of the Closure Benchmark.
   a) These are the coordinates of the shot taken on the closure benchmark.
   b) These values are stored on the POC after the point(s) is mapped.
   c) To access them:
      (1) On the Home screen of the POC select the Info tab > the Points tab > All Pts tab > Click on the Pt ID box on the top right > Search for the name of the closing point and the E/N/H will be shown.
   d) Enter these values into the app.
   e) If coordinate differences between the three closing shots is greater than 0.005m, enter the values from the first shot and contact Science for discussion.
   f) It may be advantageous to take more shots on the closing BM in order to better identify outliers.

e. The app will calculate the horizontal and vertical misclosure error associated with the traverse.

3. Once the upstream benchmark has been mapped, the TS can be picked up and moved back to the S1 benchmarks.
   a. The next TS location can be set using these benchmark coordinates as targets, following the steps outlined in **SOP-B.4** and surveying in the upstream direction.
   b. Continue the TS numbering convention from the last TS setup (do not start over by naming the next TS setup “TS1”).
4. Once the station is set, begin surveying in the downstream direction heading toward the upstream reach boundary (DSR).
5. Once mapping has been completed up to the DSR, shoot in the center of the permanent benchmark near the DSR transect three times.
   a. Three shots will help evaluate potential outliers.
   b. This is a very important shot. Double check that the TS and prism rod are completely level.
   c. Label these points “BM#_CLOSE1-3”.
      1. The # being the permanent benchmark ID found on the access cap or monument cap, depending on the benchmark type.

d. In the app, select “Yes” to “Was a Second Loop Closed?” and enter the following information in the table:
   1. Names of the Initial Benchmarks.
      a) These are the names of the three benchmarks used to orient the first total station setup of this traverse run.
   2. Northing/Easting/Height coordinates of the Initial Benchmarks.
      a) These are the coordinates of the three initial benchmarks that were loaded into the job file from the .CSV file sent by Science.
   3. Closure Benchmark Shot Name.
      a) This is the name of the benchmark used to close this traverse run.
   4. Northing/Easting/Height coordinates of the Closure Benchmark.
      a) These are the coordinates of the shot taken on the closure benchmark.
      b) These values are stored on the POC after the point(s) is mapped.
      c) To access them:
         (1) On the Home screen of the POC select the Info tab > the Points tab > All Pts tab > Click on the Pt ID box on the top right > Search for the name of the closing point and the E/N/H will be shown.
      d) Enter these values into the app.
      e) If coordinate differences between the three closing shots is greater than 0.005m, enter the values from the first shot and contact Science for discussion.
      f) It may be advantageous to take more shots on the closing BM in order to better identify outliers.

e. The app will calculate the horizontal and vertical misclosure error associated with the traverse.

6. The geomorphology survey is now complete.

<u>Additional notes:</u>

1. Leave all COP’s labeled and in place until the survey is complete and the data is validated by Science. This way they can still be utilized if TS locations need to be re-established.
2. If the survey is not complete by the end of the day, the most recent set of COP’s will be used to continue the survey the following day.
3. At the end of each day, install and shoot in new foresight COP’s from the day’s final TS location.
4. At the beginning of the next day, set up the TS at the new location and shoot in these COP’s as backsights to orient the new TS location.

B.6 Reference Guide for Survey Mapping: Cross-Sections

A total of 8 cross-sections must be surveyed throughout the aquatic reach (**Table 2**). For the initial geomorphology survey the specific Aquatic Plant transects to be mapped will be chosen by Science and Field Science staff during the pre-bout meeting prior to the survey. The same Aquatic Plant transects are to be surveyed during all subsequent years. Contact Science for any questions regarding which cross-sections to survey.

Table 2. Cross-sections to be surveyed during the geomorphology survey.

Location	Transect ID	Count
Downstream extent of monitoring reach	DSR	1
Permanently marked aquatic plant transects	AP#*	3
Stream discharge transect	DSC	1
S2 sensor transect	S2	1
S1 sensor transect	S1	1
Upstream extent of monitoring reach	USR	1

*For aquatic plant transects, denote the appropriate Aquatic Plant Transect number in the Transect ID, i.e. Aquatic Plant Transect #4 = "AP4".

At all cross-sections:

1. Choose a TS location where a line of site exists to the greatest extent of the left and right floodplain.
2. Identify left bankfull (LBF) and right bankfull (RBF) indicators and mark these locations with stakes.
3. String meter tape taut from the LBF to the RBF stake.
4. If a pebble count sampling occurs at a given cross-section (see **SOP B.9**)
   a. For pebble counts, record the bankfull width based on the meter tape distance in the app.
   b. If a cross-section does not include a pebble count survey the bankfull width does not need to be recorded in the field, although bankfull locations must be identified and mapped during the cross-section survey.
5. Identify the thalweg.
   a. This is typically the deepest point of the cross-section where stream velocity is highest.
   b. It may be helpful to place a piece of flagging on the meter tape at this location.
6. Measure the stream depth at the thalweg from the center of the width of the meter tape down to the streambed surface with a stadia rod or other vertical measurement device.
   a. This value is considered the bankfull depth.
   b. Record this value in the app.
      1. This value is automatically multiplied by two in the app and expressed as the Floodprone Height.

7. Level the stadia rod at the thalweg.
8. Place a laser level (or sight an inclinometer) at the Floodprone Height value on the stadia rod.
9. Shoot the laser level (or sight an inclinometer) towards each bank.
10. Where the laser or inclinometer sightline intercepts the slope on either side of the channel is the edge of the Floodprone Height.
11. Mark the left bank (LFH) and right bank (RFH) floodprone height boundaries with stakes at these locations.
    a. Example: if the bankfull depth is 0.78 meters, the Floodprone Height value will be 1.56 meters.
    b. The laser level or inclinometer is to be placed at the 1.56m mark on the stadia rod and the locations on the banks are to be marked and mapped at these elevations.
    c. Obtaining Floodprone Height shots can be very challenging for sites with steep banks. These shots can be skipped in these instances.
12. Begin to survey the cross-section from the left bank to the right bank by mapping points with the TS.
    a. Begin the cross-section survey as far along the left bank floodplain as the line of sight from the TS allows.
        1. The goal is to map the greatest extent of the floodplain possible at a high resolution without taking an excessive amount of shots.
        2. 10 meters on each side of the channel is sufficient for sites with open lines of sights and flat floodplains.
    b. Code each shot mapped along the cross-section correctly by specifying the Transect ID (**Table 2**) and the feature (**Table 3**).
        1. Begin each code with the Transect ID then specify the feature you are mapping within the transect.
            a) Examples: the left bankfull shot at the S2 transect should be labeled “S2_LBF”; the right floodplain width boundary of the discharge cross-section should be labeled “DSC_RFH”; a shot within the AP7 transect that does not land on a specific feature should be labeled “AP7_XS”.
    c. Map points along the left bank floodplain, down the left bank and across the streambed towards the RFH.
    d. Survey the top of the permanent marker(s) that delineate each cross-section boundary and code these shots appropriately (**Table 3**).
        1. Map a point in the direct center of the “O” in “NEON”. If the “NEON” label does not exist, map a point in the direct center of the plot marker.
    e. Survey and label all of the marked features listed in **Table 3** as well as an additional 25-35 points along the cross-section with the TS (**Figure 15**).
        1. The exact number of cross-section survey points may vary relative to the width of the discharge cross-section and the line of site available along the floodplain.

2. Space the survey points in such a way that they are representative of the entire cross-section.
3. Map the thalweg and capture gradient changes within the channel and along the banks.
4. Capturing the topography of each floodplain is important and must be done if possible.
5. More mapped points are preferable to less as this will produce a high-resolution survey that can be utilized in a wide variety of analyses.

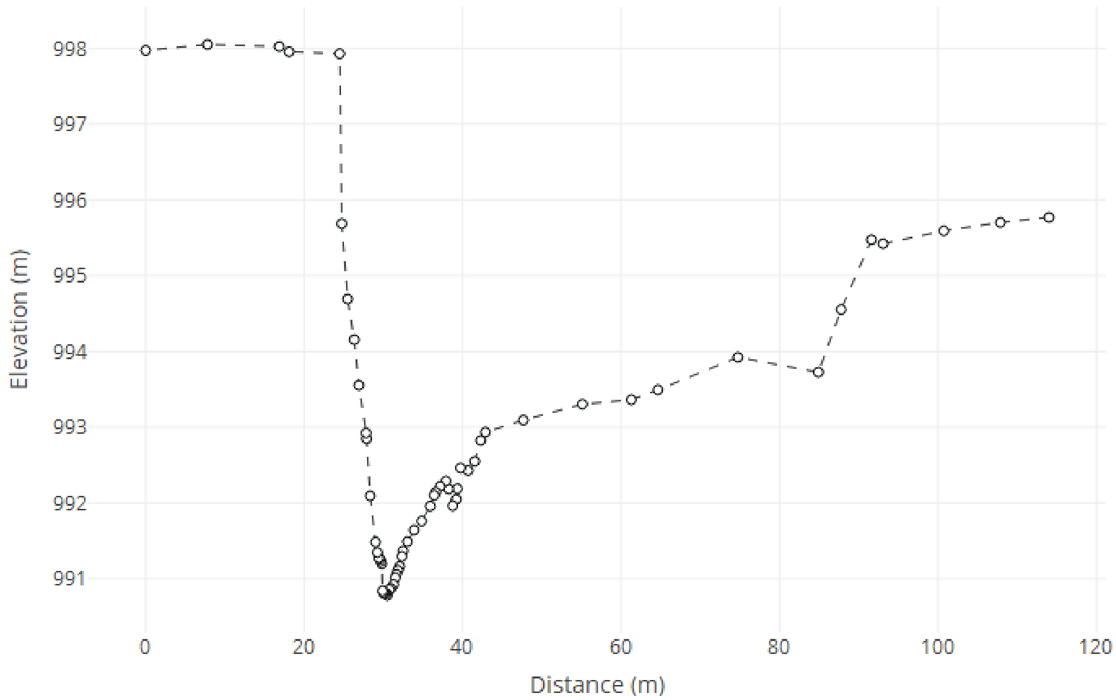


Figure 15. Example of high-resolution cross-section survey data where the floodplains, banks, and active channel are well-characterized by properly spaced points (each dot represents a mapped shot).

<u>Mapping the staff gauge:</u>

1. Survey the staff gauge at a specific meter mark and indicate the meter mark where the tip of the prism rod is located in the survey code (**Table 3**).
   a. For example, if the rod is placed at the 1.00 meter mark, label this point "SP_1.00M".
2. To obtain an accurate and level staff gauge shot, attach a clamp with a torpedo level to the staff gauge (**Figure 16**).
   a. Ensure that the level is placed exactly at meter mark you wish to shoot and is held firm by the clamp.
   b. Make sure the weight of the rod does not push the wood or level down while taking the shot.
   c. It may be helpful to have someone hold the clamp setup and tip of the rod in place while the shot is being taken.

3. If additional staff gauges are installed at the site (such as temporary gauges used during site characterization) survey these in as well.
    a. Identify these gauges accordingly (permanent, temporary, etc.) in the survey codes and remarks section of the app.
    b. Record the staff gauge asset tag ID number of each gauge surveyed in the app.

Figure 16. Mapping the staff gauge using a torpedo level and clamp. The red arrow indicates where the tip of the prism rod should be placed. The shot in this example would be coded "SP_1.20M" as the tip of the prism rod is at exactly the 1.20 meter mark on the staff gauge.

Table 3. Features to survey at each cross-section.

Cross-section Features to Survey	Code*
25-35 points along the cross-section, from the left to right floodplain	TransectID_XS
Left bank floodprone height (if line of sight exists)**	TransectID_LFH
Left bank permanent pin***	TransectID_LB_PIN
Left bank temporary pin****	TransectID_LB_PIN_TEMP
Left bankfull	TransectID_LBF
Left edge water (if present)	TransectID_LEW
Thalweg	TransectID_THL
Right edge water (if present)	TransectID_REW
Right bankfull	TransectID_RBF
Right bank permanent pin***	TransectID_RB_PIN
Right bank temporary pin****	TransectID_RB_PIN_TEMP
Right bank floodprone height (if line of sight exists)**	TransectID_RFH
Permanent staff gauge at specific meter mark	SP_#.##M
Temporary staff gauge at specific meter mark	SP_#.##M_TEMP
Base of S1 unistrut*****	S1_BASE
Base of S2 unistrut*****	S2_BASE

*See **Table 2** for a complete list of Transect ID's for each cross-section surveyed.

**Floodprone heights may not be possible to map at some sites as they may be too far from the stream and/or riparian vegetation may be present that prevents a line of site. If floodprone height shots require an additional TS setup or cannot be easily mapped from the current TS location these points can be skipped in the survey. Add a note in the app remarks section that the shot was skipped and why.

***Permanent markers may not be accessible or present at some sites.

****Temporary markers may not be present at some sites. If present (typically plastic stakes), map a point at the center of both the top of the left bank and right bank marker.

*****If present, map the southernmost corner of the base of the S1 and S2 unistruts while surveying the two sensor transects. If a shot on the southernmost corner cannot be achieved, take the shot as close as you can get to the strut with the prism rod remaining level and note this location in the remarks section of the app.

B.7 Reference Guide for Survey Mapping: Longitudinal Profile Survey

A longitudinal profile survey must cover the extent of the monitoring reach. The entirety of the monitoring reach must also be characterized using four standardized habitat unit categories (**Table 4**). The downstream extent, or tail, of each habitat unit must be mapped using the correct survey code (**Table 5**). It is assumed that the same habitat unit is present between each mapped tail point. Each delineated habitat unit must be >50% of the wetted width and be longer than it is wide. When in doubt it is best practice to lump units together rather than split them apart in order to expedite the survey.

Table 4. Habitat unit types and descriptions.

Habitat Unit Type	Habitat Unit Description
Run	A relatively shallow part of a stream with moderate velocity and little or no surface turbulence.
Riffle	A shallow part of the stream where water flows swiftly over completely or partially submerged obstructions to produce surface agitation.
Pool	A small part of the reach with little velocity, commonly with water deeper than surrounding areas.
Step-pool	Channel-spanning pools with boulder/cobble steps that cause subcritical flow (deep, slow flow) in the pool and supercritical flow (shallow, fast flow) over the steps. These features occur in gradients in the range of 5-20%.

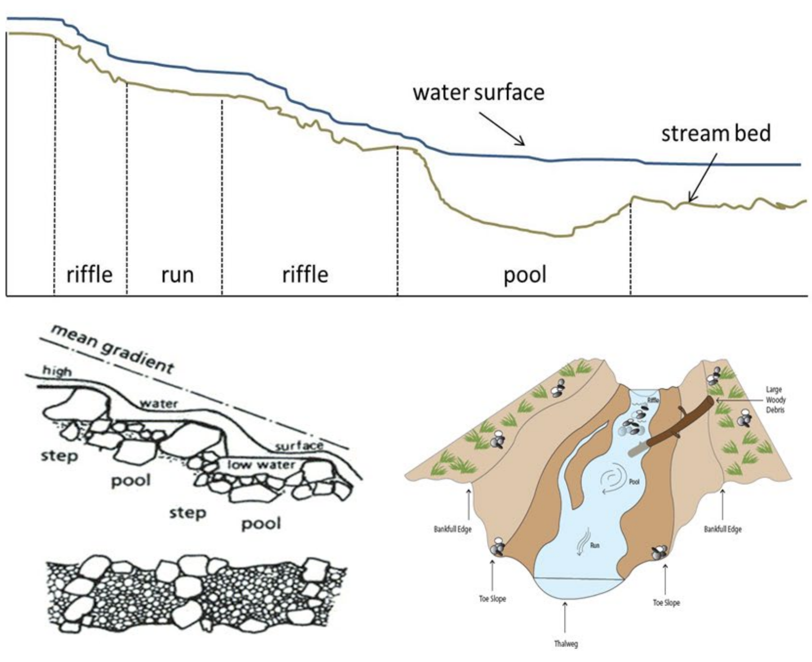


Figure 17. Above center: Long-profile illustration of riffle, runs, and pools. Bottom left: Illustration denoting step pools. Bottom right: Cross-section illustration denoting stream features.

Within each habitat unit specific geomorphic features are to be surveyed with the TS throughout the longitudinal profile (**Figure 17**). These features are described in detail below as well as in **Table 5**, which provides standardized survey codes associated with each feature that must be entered into the POC.

Right and Left Edge of Water (REW, LEW)

Map where water makes contact with the bank or streambed on both the right and left edges of the stream. Attempt to map at least one wetted edge point for the right and left side of each habitat unit but note that this may not be possible for pools that run long and are deep. Collect wetted edge shots that represent the average (rather than the maximum or minimum) wetted edge along the stream.

Thalweg (THL)

Map the line that connects the deepest part of the active channel. Collect a greater number of thalweg points along gradient changes and as the channel meanders and less thalweg points where the streambed is flat and homogenous. In some instances the thalweg may become divided around geomorphic features such as mid-channel bars, islands, or large boulders/bedrock. In these instances (if time allows), attempt to map multiple thalweg networks. Be sure to connect thalweg points that branch off into multiple networks where they meet in the main channel.

Maximum Pool Depth (MPD)

If possible, map the deepest part of the each pool unit. If a pool is too deep and it is unsafe to enter the deepest section, make a note in the remarks section of the app and skip mapping this point.

Mid-channel Bars (MCB)

Mid-channel bars are mounds of consolidated substrate that are surrounded by the stream. These features protrude above the streamflow but the maximum elevation is below bankfull. Map the upstream, downstream, left and right wetted edge of these features as well as the highest point of elevation (if possible) so that, in connecting the mapped points you would draw a polygon around the feature. Be sure to also survey in the thalweg network that surrounds these features – this helps to delineate them during post-processing.

Islands (ISL)

Islands are similar to mid-channel bars but contain a maximum elevation that rises above bankfull. Map the upstream, downstream, left and right wetted edge of these features as well as the highest point of elevation (if possible) in the same manner as mid-channel bars.

Tributaries (TRB)

Tributaries are smaller order streams that feed into the mainstem of the monitoring reach. Tributaries may contain flowing water or be dry. At each tributary, map a single point approximately one meter upstream from the confluence in the middle of the tributary.

Dry Extents of Reach (DDS/DUS)

If the stream becomes hydrologically disconnected (i.e. surface water paths are discontinuous) within a significant portion of the habitat unit, the downstream and upstream extent of these dry areas must be delineated. Consult with Science as to whether to delineate habitat units between the upstream and downstream dry extents – this determination will be made based on the dry extent. Map the thalweg (to the best of your ability given that the stream is dry) and any geomorphic features that are present. Right or left edge water shots cannot be mapped within dry reach extents.

Beaver Dams (BEA)

Map the upstream and downstream edge of every beaver dam that actively alters streamflow within the monitoring reach.

Water Falls (WFB, WFT)

Consider a feature a "waterfall" if water is dropping at least 1.5m vertically, or very nearly so. If possible use a stadia rod to measure the difference between the upper and lower bed elevations to make this qualification. Map two points at each waterfall, one at base and another at the top. The objective of these points is to identify the change in elevation of the stream caused by the waterfall.

Large Woody Debris Jams

Map all large woody debris jams using methods outlined in **SOPB.8**.

Table 5. Survey codes and descriptions for the geomorphology survey.

Features to map within each habitat unit	Feature Description	Code
Run unit tail	Downstream extent of habitat run unit	RUT
Riffle unit tail	Downstream extent of habitat riffle unit	RIT
Pool unit tail	Downstream extent of habitat pool unit	POT
Step-pool unit tail	Downstream extent of habitat step-pool unit	SPT
Dry extent downstream*	Downstream extent of hydrologically disconnected area	DDS
Dry extent upstream*	Upstream extent of hydrologically disconnected area	DUS
Right edge of water	Right edge of wetted perimeter	REW
Left edge of water	Left edge of wetted perimeter	LEW
Thalweg	Line that connects deepest points of channel	THL
Maximum pool depth (pool habitats only)	The deepest part of the pool	MPD
Downstream mid-channel bar*	Downstream wetted edge of bar (in middle)	MCB_DS
Right edge mid-channel bar*	Right wetted edge extent of bar (in middle)	MCB_RB
Left edge mid-channel bar*	Left wetted edge extent of bar (in middle)	MCB_LB
Upstream mid-channel bar*	Upstream wetted edge of bar (in middle)	MCB_US
Top of mid-channel bar* (if feasible)	Highest point of mid-channel bar	MCB_TOP
Downstream island edge*	Downstream wetted edge of island (in middle)	ISL_DS
Upstream island edge*	Upstream wetted edge of island (in middle)	ISL_US
Left edge island*	Left wetted edge of island (in middle)	ISL_LB
Right edge island*	Right wetted edge of island (in middle)	ISL_RB
Top of island* (if feasible)	Highest point of island	ISL_TOP
Upstream culvert boundary	Center upstream edge of culvert	CUL_US
Downstream culvert boundary*	Center downstream edge of culvert	CUL_DS
Tributaries*	1m upstream in tributary thalweg	TRB
Base of waterfall*	If qualifying, center of the base of the waterfall	WFB
Top of waterfall*	If qualifying, top of the waterfall	WFT
Upstream edge of beaver dam*	Upstream wetted edge of dam (in middle on substrate)	BEA_US
Downstream edge of beaver dam*	Downstream wetted edge of dam (in middle on substrate)	BEA_DS
Upstream terminus of LWD jam*	If qualifying, upstream edge of LWD jam	LWD_US
Downstream terminus of LWD jam*	If qualifying, downstream edge of LWD jam	LWD_DS
Left edge of LWD jam*	If qualifying, left edge of LWD jam	LWD_LB
Right edge of LWD jam*	If qualifying, right edge of LWD jam	LWD_RB
Height of LWD jam* (if feasible)	If qualifying, highest point of LWD jam	LWD_TOP
Top (upstream) of monitoring reach	On marker that delineates upstream boundary	USR
Bottom (downstream) of monitoring reach	On marker that delineates downstream boundary	DSR

B.8 Reference Guide for Survey Mapping: Large Woody Debris Tallies

Throughout the entirety of the monitoring reach, observe all large woody debris (LWD) that enters or lies within bankfull margins.

Record the number of pieces in the LWD tally field of the app that meet both of the following criteria:

- Diameter: ≥0.15 m
  AND
- Length: ≥1 m

In addition to the tally, all LWD jams must be surveyed. An LWD jam is considered 3 or more pieces of LWD that touch each other with at least 3 of the pieces meeting the above single piece criteria.

At each LWD jam map the following points:

1. The upstream (LWD_US) and downstream (LWD_DS) terminus edge.
2. The left edge (LWD_LB) and right edge (LWD_RB).
3. The highest elevation point (LWD_TOP, if this can be safely accessed).

Additional points on mapping LWD jams:

- If an LWD jam is large and/or scattered, map a reasonable amount of points surrounding it so that it is well-defined in space.
  - Consult Science with any questions regarding large or complex LWD jams.
- If a piece of the LWD jam is partially buried, map the location where the wood enters the substrate.
- If a piece of the LWD jam extends outside of the bankfull margin, map a point as far as you can outside the bankfull perimeter without having to move the TS.

B.9 Reference Guide for Survey Mapping: Pebble Count Surveys

Pebble count surveys are to be conducted at the following five cross-sections within the monitoring reach:

1. The upstream reach boundary cross-section;
2. The downstream reach boundary cross-section;
3. The discharge cross-section;
4. One sensor set cross-section depending on discharge cross-section co-location.
   a. If the discharge cross-section is co-located at S1 then a pebble count survey must be conducted in the S2 pool (preferably the tail of the pool if it is nearby).

   b. If the discharge cross-section is co-located at S2 then a pebble count survey must be conducted in the S1 pool (preferably the tail of the pool if it is nearby).
5. An Aquatic Plant transect characterized as a riffle habitat unit.
   a. The exact Aquatic Plant transect to be sampled will be determined with Science prior to the geomorphology bout.

Conditions of pebble count surveys:

- Each survey must contain 40-counts, or measuring points.
  - This will result in a 200-count survey across the monitoring reach.
- Substrate is to be measured on the b-axis using a gravelometer (**Figure 18**).

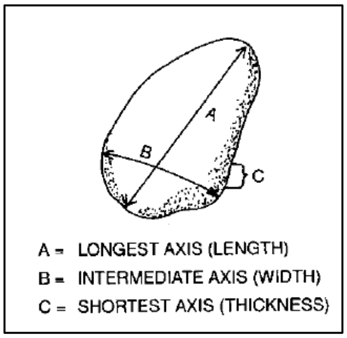


Figure 18. Illustration denoting the different substrate axes used during pebble count surveys.

Pebble count survey methods are as follows:

1. Record all pebble count data in the pebble count table of the stream morphology app.
2. Extend a meter tape across the cross-section survey transect from left to right bankfull.
3. Surveys are to be conducted from the left bank to the right bank.
   a. Avoid sampling in either bank (i.e. begin just inside bankfull indicator in the active channel zone).
4. Utilize the meter tape to determine the bankfull width, i.e. the distance between the bankfull indicators.
5. To determine sample spacing, divide the bankfull width by 40 and sample at this increment along the meter tape.
   a. It may be helpful to clip a Sharpie to the meter tape to slide along the transect and help track sampling intervals.
6. Sample the substrate directly below each sampling interval on the meter tape.
   a. Close your eyes and select the first particle you make contact with at each interval.

   b. This may be done using a rod or finger to reduce surveyor bias towards certain size substrate.
   c. Be consistent in the method used to select the sample particle.
7. Measure the b-axis (the intermediate axis) using a gravelometer.
   a. Select the closest size hole on the gravelometer that the particle will fit through.
   b. For example, a 60 mm particle would be classified in the 64 mm bin size class.
   c. If the substratum is too large to pick up, measure in situ.
   d. If the substratum is so large that it encompasses more than one sampling location:
      1. Do not measure it more than once.
      2. Head to the next sampling location (where it is not present) and reduce sample spacing so that 40 measurements can be obtained.

SOP C Post-Field Sampling Tasks

At the end of each day:

1. Download the survey data from the POC and view the .CSV file.
2. Insert a USB flash drive into the POC.
3. Select the "Home" button on the outside of the POC.
4. Select "File".
5. Select "Export" to upload the appropriate job file (CSV) onto the flash drive.
6. Use the MorphViewer Shiny App to view the survey data via a web browser.
    a. If something does not look right in these plots (i.e. the thalweg meanders right when you would expect it to stay straight), submit a trouble ticket immediately and discuss with Science before continuing the survey.
    b. Verify that all of the points you mapped that day are represented in the output .CSV.
    c. Verify that all mapped points were coded correctly.
    d. Note any points or features that were missed or mislabeled.
        1. If possible, survey in missed points the next day.
        2. Save these notes in the remarks section of the app within the appropriate TS location table.
7. Use the "Mapped Points That Contain Errors" table in the app to record entries as needed.
    a. Do not delete or edit any points within the .CSV file.
8. Send the .CSV file to Science at the end of each day.
9. If, by the second or third day of the survey, you are failing to complete approximately 200 meters of mapping, contact Science immediately for a discussion.

At the end of the survey:

1. Verify that all necessary points and features have been mapped using the lists provided throughout **SOP B**.
2. Ensure that each level traverse between the benchmarks has been closed.
3. Note any points or features that were missed or mislabeled. Ensure that these notes were entered appropriately into the app.
4. Review app data, sync once complete, and notify Science that it is ready for export.
5. Send Science the complete raw survey data .CSV file.
6. Send Science all Trimble data (if collected).
7. Submit a document to Science that includes the following items:
    a. List the Domain, Site, Survey Start Date and Survey End Date.
    b. List the names of the staff that conducted the survey.

c. Was the total station field calibrated prior to the survey?
    1. If yes: Did the Laser point alignment test pass?
    2. If yes: Did the Prism track (PTrack) test pass?
d. Were benchmarks installed prior to the survey?
    1. If yes: how many were installed, what type, and where were they installed?
e. Was the first total station location (TS1) setup using benchmarks?
    1. If yes: what type of benchmarks (permanent/temporary) were used?
f. Was the first total station location (TS1) setup using a Missing Line?
    1. If yes: what was the horizontal distance between the two points?
g. Was Trimble data collected during the survey?
    1. If yes: how many points were collected, where was the data collected, how long was each point logged?
h. Did you close a survey loop/transect?
    1. If yes: what point(s) served as each loop/transect closure, what was the difference in N/E/H between the initial shot and the loop/transect closure shots?
i. Is there Fulcrum data associated with the survey?
j. How did the survey go overall? What challenges did you encounter during the survey? How did you deal with them?
k. Were there any unique calls you had to make during the survey? Please describe as this will help aid the next survey crew and lead to better data comparability.

8. Upload any relevant survey pictures to the AOS Dropbox.

SOP D Data Entry and Verification

Mobile applications are the preferred mechanism for data entry. Data should be entered into the protocol-specific application as they are being collected, whenever possible, to minimize data transcription and improve data quality. Mobile devices should be synced at the end of each field day, where possible; alternatively, devices should be synced immediately upon return to the Domain Support Facility.

However, given the potential for mobile devices to fail under field conditions, it is imperative that field notes are always available to record data. A field notebook should be carried along with the mobile devices to sampling locations at all times. As a best practice, field data collected in field notebooks should be digitally transcribed within 7 days of collection or the end of a sampling bout (where applicable). However, given logistical constraints, the maximum timeline for entering data is within 14 days of collection or the end of a sampling bout (where applicable). See **RD[04]** for complete instructions regarding manual data transcription.

QAQC can be performed throughout all stages of the geomorphology survey to verify that mapped features are spatially aligned and that all necessary data is being collected. The following section provides QAQC strategies for field ecologists to implement to help ensure quality data is being collected during the geomorphology survey.

D.1 QAQC during the survey:

Quality Assurance and Quality Control (QAQC) must be performed throughout all stages of the geomorphology survey to verify that mapped features are spatially aligned, all necessary data is being collected, and survey error is minimalized. The following section provides QAQC strategies for field ecologists to implement to help ensure quality data is being collected during the geomorphology survey.

1. When establishing the preliminary TS location using the permanent three benchmarks, ensure that all station deviations are within tolerance.
2. When establishing new TS locations, ensure that all station deviations are within the tolerance.
3. Following each TS move:
   a. Ensure that the TS was set properly in the POC (the Station number (TS#) is correct).
   b. Map a few shots from the new TS location and utilize the map feature on the POC to verify that the new shots align with those from the previous TS location.
      1) To access the POC 100/200 map function:
         a) Click the home button on the outside of the POC.
         b) Select “Info”.
         c) Select “Points”.

d) This will bring up a map of the survey where the location of mapped shots can be evaluated relative to each other.

- Zoom in to where you are and check that the most recent mapped features are in correct alignment and that the stream morphology appears to be correct.

4. Check and re-check height of rod values as points are being mapped.

D.2 Tips for best practices during the survey:

If StDev(Pos) values are > 0.005m during total station setups, consider the following troubleshooting options:

1. Is the total station perfectly level?
   a. Are the legs of the total station stable on the ground surface?
   b. In soft substrate, push the total station legs into the ground so that the unit is less likely to come out of level while you are moving around it.
   c. If the total station was out of level when the control points were shot as foresights, high station deviation will result during setup using the control points as backsight targets.
2. Is the prism rod perfectly level using the bipod legs?
   a. In soft substrate, push the bipod legs into the ground so that the prism rod is less likely to come out of level while you are moving around it.
   b. If the prism rod was out of level when the control points were shot as foresights, high station deviation will result during setup using the control points as backsight targets.
3. Is there a clean line of sight between the total station head and the prism?
   a. The total station head may be able to lock onto the prism through a poor line of sight but this reduces location precision and increases station deviation.
   b. Attempt to create a clear line of sight between the total station head and the prism, particularly while shooting foresight and backsight points.
4. Can additional control points be used to set the station?
   a. In most situations, station deviation values decrease as the number of control points used to set the total station location increase.
   b. Surrounding all sides of the total station with control point backsight targets will almost always reduce station deviation.
5. Are the angles sufficient between the control points and the total station?

a. A critical component of the "setup anywhere" method (the total station is not setup over a point) is the spatial relationship between the total station and the control points.

b. If the angles between the total station and the control points are not sufficiently wide, station deviations will increase.

c. If possible, consider moving the total station or the control points in order to maximize the angles.

   1) If control points are re-located after they have been mapped as foresights and the total station has already been physically moved to the next location:

      a) The total station location will need to be re-established using previous control points (that haven't been re-located) as backsight targets.

      b) A new TS# must be entered into the app.

      c) From this new total station location the new control point locations can be mapped as foresights using new control point ID codes.

      d) Be sure to change the physical labels on the control points to match the new code names.

   2) The total station can then be physically moved to the next location and setup using these control points as backsight targets.

6. Is obtaining a StDev(Pos) value ≤ 0.005m possible given the environmental conditions around the total station?

   a. Uncertainty will always be higher at sites where the environment is not naturally conducive to surveying.

   b. Creating sufficient angles between the total station and control points is difficult at sites with thick vegetation. Higher station deviations are expected as the angle between control points and the total station narrows.

   c. At sites with unstable surfaces (i.e. wetland, taiga, tundra, etc.) keeping the total station and prism rod level can be very difficult. Higher station deviations are expected when the total station and prism rod are not perfectly level.

      1) Environmental conditions that affect data quality must be documented in the app within the individual station notes and the summary document created at the end of the survey.

   d. Have station deviations been consistently high throughout the survey?

      1) If so, environmental conditions may make low station deviations unachievable at the site.

2) If possible, review data collected during previous surveys. Do those values match with what is being measured during the current surveys?
3) Contact Science to discuss challenging field conditions and/or high station deviations.

Other tips regarding best practices:

1. It is critical that there is clear communication between the person holding the prism rod and the POC operator.
   a. Always enter the height of rod (HR) in meters with two decimal places (i.e. 1.60).
   b. When the HR changes it is imperative that the person operating the POC is made aware of the new height.
   c. In the instance of a HR error, record in the "Mapped Points that Contain Errors" table of the app:
      1) The HR value entered in the POC (the incorrect value).
      2) The correct HR value (what it should be changed to during post-processing).
2. Avoid using the 1.50m mark on the prism rod.
   a. Depending on the setup, it can be difficult to place the rod height at precisely 1.50m due to the assembly of the prism head.
   b. Instead, use the 1.60m height as the lowest HR. This is the lowest rod height that offers the greatest precision.
3. The prism pole must be level while points are being mapped.
   a. If the substrate is soft avoid pushing the point at the bottom of the pole into the ground, instead gently set it on top of the substrate.
   b. Always use the bi-pod for mapping foresight and backsight control points.
4. Always check the level bubble on the prism pole to ensure the rod is level before shooting the point with the total station.
   a. When leveling the prism rod by hand sometimes it is useful to balance the rod between the tips of your fingers.
   b. Exhale just before the shot is taken from the TS – this helps still yourself and keeps the rod level.
   c. This approach may not always be possible in every rod placement situation.
5. When setting up the TS, choose a location where the ground surface is fairly solid.
   a. Push the legs into the ground so that the TS will not move when you walk around the tripod perimeter.

   b. If the TS location is unstable the instrument can become un-level simply by people walking nearby.

   c. In that instance it will be difficult to maintain desired station deviations while shooting in control points as backsight targets.

   d. If solid ground is not available at a desired total station setup location, wooden hubs may be useful to set into the ground where TS legs are to be set. The TS legs can rest on these hubs to provide better stability for the TS setup.

6. Once the total station has been leveled, spin both the robotic head and the lens around 360°.

   a. Check the total station level after these rotations have been performed and make adjustments as needed.

   b. When the total station remains level after each of these spins the instrument can be considered truly level.

7. Always hold the total station head by the handle at the top when transporting the instrument or affixing it to the tripod.

   a. Follow the "one hand rule" – always have one hand on the robotic head handle whenever it is either not secured to the tripod or in the carrying case.

8. Never set the POC datalogger down on an unstable surface where it may slip and fall to the ground.

   a. The POC screen is fragile and if it is damaged the survey cannot continue until it is repaired by the manufacturer.

9. Prior to the survey, print out a map of the stream site (Google Earth, AIS As-Built maps, etc.).

   a. Maps can help in initializing the survey and can be used as a QAQC supplement during the survey.

   b. Periodically compare the stream morphology patterns observed on this map to what is being produced on the POC map.

   c. Thalweg shots mapped during the geomorphology should be consistent with the direction of the stream that is depicted on the map.

10. A workflow involving 4 people is the most efficient way to complete the geomorphology protocol.

    a. The total station should always be taking shots (i.e. avoid significant lag time in mapping other than when the total station is being moved or set up in a new location).

    b. Divide work between the four crew members as follows:

       1) 1 person: hold the POC and enter data into the app.

a) This person should be standing next to the total station in order to sight the prism in manually when the connection gets lost.

(1) To sight the total station in manually use the knobs on the side of the robotic head to focus and move the head vertically and horizontally.

(2) Sometimes the total station sight can be very out of focus. In this instance the knob must have to be rotated many times until the sight line comes into focus.

2) 1 person: hold the prism rod and map points up and down the stream.

a) Map points in an efficient manner:

(1) Begin by focusing one feature (i.e. LEW shots) and map this feature as far as can be viewed from the total station.

(2) Mark where the feature was last mapped with flagging so that it's easy to see where mapping should resume from the next total station location.

(3) Next, map another feature (i.e. THL) in the opposite direction, heading back to the total station. Mark the location where you started mapping this feature so that it's easy to see where mapping should resume from the next total station location.

(4) Finally, map the third feature (i.e. REW) heading away from the total station and mark where the last point was mapped with flagging.

(5) Along the way take tail shots at habitat boundaries and map any geomorphic features (MCB, LWD, etc.).

(6) Use radios to clearly communicate to the person at the total station.

(a) Always verify rod height, which feature you are mapping, whether the rod is level, etc.

3) 2 people: perform other tasks that allow the survey to continue in a smooth, efficient manner with minimal work stoppages.

a) Scout and mark the next total station location.

b) Install foresight control points.

c) Set up the meter tape along cross-section transects.

d) Conduct pebble counts and record data into the app.

e) Be available to move brush and clear lines of site for those mapping points with the total station.

11. Don't spend too much time mapping an overabundance of edge of water shots.

a. If the edge of water is reasonably straight, 3-4 edge water shots (per side) will suffice for a single TS setup.

b. Imagine edge of water points as a line connecting the shots you take.

1) Prioritize mapping changes in thalweg elevation and direction.

2) A roughly 2:1 ratio of thalweg to edge water shots should not be uncommon at the end of the survey.

12. Don't spend too much time trying to get shots that are far away from the total station (clearing lines of site, etc.).

a. It is likely that you will be able to easily obtain these shots from the next total station location.

13. Re-shooting "bad" shots:

a. It is a common occurrence to need to re-shoot points for a variety of reasons (the prism rod may have been un-level or slipped out of placement, the height of rod may have been entered wrong in the POC, etc.)

b. In these instances it is always advised to re-shoot the point in question.

c. Use the "Mapped points that contain errors" table in the app to track points that are in error, need to be re-labeled, etc.

d. During post-processing Science will use these notes to delete and/or re-label points within the survey job file.

14. Avoid prolonged exposure of the POC and the total station robotic head to direct and intense sunlight.

a. In extreme cases, the LED screen of the POC can be damaged and the total station can have difficult taking shots.

b. Use an umbrella to shield both the POC and the total station head during particularly hot and sunny days.

15. Keep the POC and total station dry at all times.

a. Take care when transporting instrumentation in the stream and avoid the equipment getting directly rained on.

SOP E Rapid Habitat Assessment

The Rapid Habitat Assessment SOP is performed once during AOS site characterization to define which habitats and samplers to target for stream biological sampling efforts. During Operations, this SOP will be performed annually to document channel changes and trigger more frequent occurrences of the stream morphology SOPs. Data must be entered using the Trimble data dictionary. If the Rapid Habitat Assessment cannot be completed within one day, and the water level changes dramatically before finishing data collection, discard data and start over.

The Rapid Habitat Assessment includes the Habitat Survey (below), as well as a Pebble Count Survey (**SOP B.9**). Collect pebble count data using the same cross section locations as in stream morphology, and enter data in the mobile application.

E.1 Habitat Survey: Annual

1. Navigate to the downstream boundary of the 1000 m sampling reach using reach boundary coordinates found in the Domain-specific Sampling Design (BOT plot marker).
   a. This point may be different from the bottom of the permitted reach.
2. Record the waypoint using the Trimble (latitude, longitude) and coordinate uncertainty (GPS accuracy) at the downstream boundary using the Trimble data dictionary.
   a. Allow the Trimble to log >30 points per location.
3. Determine and record the habitat type of the habitat unit directly upstream of the boundary (**Figure 19**).
   a. Tips for determining discrete habitat units:
      i. If the habitat is shorter than it is wide, do not consider it to be its own habitat unit. Consider it a part of the next habitat unit, or as part of a complex of the same unit.
      ii. If there is a small, embedded habitat within the main habitat unit (e.g., a small pool to the side of a riffle), consider it a unique habitat unit only if it accounts for >50% of the stream width.
   b. Habitat types
      i. Riffle
      ii. Run
      iii. Pool
      iv. Step pool
      v. Waterfall
      vi. Other (add comment)
4. Measure and record the length (to nearest 0.1 meter) of the habitat unit along the thalweg, and enter in the Trimble data dictionary.
   a. If a significant obstruction (e.g., deep pool, debris dam) exists so that you cannot follow the thalweg, estimate the length along the shore instead.
   b. If the stream branches, follow and measure the branch that appears to have the most flow. Note the existence of the branch in the remarks of the Trimble data dictionary.
   c. Waterfalls: length will be very small
5. Measure and record the maximum wetted width of the habitat unit and enter in the Trimble data dictionary. You may use either the laser rangefinder (**RD[08]**) or a meter tape.

6. Measure and record the depth of the habitat unit to nearest 0.01 meter and enter in the Trimble data dictionary.
   a. Pools: measure depth at the deepest point
      i. If too deep to wade, measure the deepest location that you can safely reach
   b. Riffles, runs: measure depth in the thalweg
   c. Waterfalls: measure the depth as the height or drop of the waterfall.
7. Estimate and record the percentage of submerged large woody debris (LWD%) for that habitat type to the nearest 5%. Think of this as debris that might be used as habitat for algae, macroinvertebrates, or fish. Enter in the Trimble data dictionary.
   a. This is a relatively subjective rating, so the same Field Ecologist should make the final decision for each habitat unit during the survey.
   b. Field Ecologists should break the habitat into visual sections to estimate percent cover more easily (**Figure 19**).
   c. Calibrate percent cover against other Field Ecologists, even though one Field Ecologist will make the final decisions.

Figure 19. Red box illustrates an example of habitat division between a riffle (above) and a run (below).

8. Estimate and record the size classes of the dominant substrata within the habitat unit. Substrata type classifications are used to determine sampling locations and sampler types for macroinvertebrate and periphyton sampling. Enter in the Trimble data dictionary.
   a. You may record one or multiple size classes per habitat unit.
   b. Substratum size classes
      i. Bedrock
      ii. Boulder: >256 mm
      iii. Cobble: 64.0 – 256 mm
      iv. Pebble 2.0 – 64.0 mm
      v. Sand: 0.062 – 2.0 mm
      vi. Silt: 0.004 – 0.062 mm
      vii. Clay: 0.001 - 0.004 mm

9. Estimate and record the percent riparian cover over the channel at the habitat unit. This is a coarse visual estimate (no densiometer) of how much of the water's surface is shaded throughout the day, which has been shown to directly affects algal growth on the stream bed (Lowe et al. 2006).
    a. This number may change dramatically depending on the time of year of the survey, but current conditions should be recorded. If the canopy is primarily deciduous and the survey is taking place when leaves are off the trees (due to scheduling during characterization), make a note on the field datasheet.
    b. Use the same estimating techniques and calibration between Field Ecologists as presented for LWD% above. This is a relatively subjective rating, so the same Field Ecologist should make the final decision for each habitat unit.
10. When all measurements have been recorded for the present habitat unit, move upstream to the next habitat unit and repeat the steps above.
11. Habitat units may be linked together if they occur multiple times in a row.
    a. For example, in streams where there are multiple short step pools, you may measure a series of step pools together rather than splitting them up to save time. Call this example a "step pool complex" provided there are no other habitat types in the middle.
12. Long habitat units may be split apart to make measurements easier.
    a. For example, a 100-m long riffle may be split into two units, each called "riffle" if it makes measurements easier.
13. Continue until the entire sampling reach (approximately 1000 m) has been surveyed. Record a waypoint and coordinate uncertainty at the upstream end of the survey (TOP plot marker).
14. To QC data prior to upload, submit a request to the GIS Support group to export the Trimble data to a csv file.
15. After data collection, upload the GPS data file to HQ for post-processing.
    a. Ensure that the date of data collection is included in the file name.
    b. Save file to N:\Science\GISData\FOPS\DomainXX\SiteXX
    c. Submit a request ticket to the GIS specialist (Melissa Slater) with the file name from the domain-specific folder

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APPENDIX A EQUIPMENT

The following equipment is needed to implement the procedures in this document. Equipment lists are organized by task. They do not include standard field and laboratory supplies such as charging stations, first aid kits, drying ovens, ultra-low refrigerators, etc.

Table 6. Equipment list – Wadeable Stream Morphology protocol.

Item No.	Exact Brand	Description	Purpose	Quantity
MX109898	Y	HILTI POS 180 Robotic Total Station and POC data collector	Measure and collect survey data	1
MX107405	Y	Sokkia knob lock prism pole	Graduated pole that is attached to prism assembly and used for marking points and recording height of prism during surveys	1
MX107406	Y	HILTI POA 360° mirrored prism	Mirrored target for total station measurement shots	1
MX107407	Y	Sokkia heavy duty fiberglass tripod	Supports and orients total station	1
MX102549	Y	Trimble© GEO XH 6000 GPS receiver or equivalent model.	Locate and mark benchmarks and Trimble Points	1
MX109898	Y	POA 84 Battery for the POS 180	Power for POS	2
MX109898	Y	POA 86 battery charger for the POC 180	Charge batteries for POC	2
MX109898	Y	POC Controller with Stylus	Operate total station from prism pole	1
MX109898	Y	POA battery for the POC 100	Power for POC	2
MX109898	Y	POA 81 AC adapter for POC 100	Charge battery for POC	1

Item No.	Exact Brand	Description	Purpose	Quantity
MX109898	Y	POA 100 Accessories case (tools)	Change battery on POC	1
MX109898	Y	POA 76 Frame clamp	Attach POC to prism pole	1
MX107144	N	Waterproof camera	Photo document the reach and associated features	1
	N*	Magnetic nails*	Used to mark locations of control points*	25
MX104363	N	Pin flags	Used to mark locations of survey boundaries, bankfull delineation, etc.	25
MX100320	N	Compass	Verify orientation of the survey	1
MX104369	N	50m measuring tape	Measuring and laying out of transects	1
MX100324	N	Radios (preferably waterproof)	For communication between team members	1 per person
	N	Rain Cover (e.g., heavy duty plastic bag)	Protect total station from rain	1
	N	Telescoping stadia rod	Measuring depth	1
MX100322	N	Laser rangefinder, laser level, or clinometer	Delineating floodprone areas	1
MX110827	Y	Gravelometer	Measuring particle sizes	1
MX106043 MX106199 MX104361	N	Stakes (wooden hubs), Clamps, & Chaining Pins	Secure meter tape during transect surveys, help secure TS during setups on un-solid ground.	2 sets

Item No.	Exact Brand	Description	Purpose	Quantity
MX111388	Y	Tablet with AOS Stream Morphology app	Recording data	1
MX103220	N	Hammer or mini-sledge	Monument installation	1
	N	Map of site (Google Earth, AIS As-Built)	Monument installation, periodic QAQC	1
	N	Torpedo level with clamp	To assist in staff gauge survey shot	1
	N	Cleaning wipes or towel	Clean/wipe the total station optics and rod prism.	1
MX102002	N	Permanent marker	Recording data	3
MX103940	N	Flagging tape, orange	Mark features and survey boundaries	1 roll per person

R/S=Required/Suggested, * = other varieties of the item may be more appropriate depending on environmental conditions, consult with Science to discuss other options, if necessary.

Table 7. Equipment list – Rapid Habitat Assessment protocol.

Item No.	Exact Brand	Description	Purpose	Quantity
MX102941 MX102942	N	Clipboard	Recording data	1
MX100491 MX100494 MX107505	N	Waders (hip or chest) or knee boots	Wading	1 pair/ person
MX102549	Y	Trimble© GEO XH 6000 GPS receiver or equivalent model with Rapid Habitat Data Dictionary loaded	Record data	1
MX100722	N	30 Meter tape	Measuring features	2
MX105823	N	Meter stick or foldable meter stick	Measuring depth or pebble size	1
MX100322	N	Laser rangefinder	Measuring streams width	1
MX110827	Y	Gravelometer	Measuring pebble size	1
MX103942	N	Field data sheets (all-weather copier paper, write in pencil)	Recording data	1 set

APPENDIX B SITE-SPECIFIC INFORMATION

The following table provides the type and location of benchmarks installed at NEON wadeable stream sites. This information is subject to change as permanent benchmark installation is ongoing. Consult with Science on benchmark locations prior to implementing a stream morphology survey.

Table 8. Benchmark type and locations at NEON wadeable stream sites.

Domain	Site	Benchmark Type	Number of Benchmarks	Benchmark Locations (Count)
1	HOPB	Permanent	5	S2(3), USR(1), DSR(1)
2	LEWI	Temporary	3	S2(3)
2	POSE	Permanent	5	S1(3), USR(1), DSR(1)
4	GUIL	Temporary	5	US Bridge(3), S2(2)
4	CUPE	Temporary	7	S1(3), S2(1), DSR(3)
6	KING	Temporary	6	DSR(3), S1(3)
6	MCDI	Permanent	3	S1(3)
7	WALK	Permanent	5	S2(3), USR(1), DSR(1)
7	LECO	Permanent	5	S2(3), USR(1), DSR(1)
8	MAYF	Permanent	5	S2(3), USR(1), DSR(1)
10	ARIK	Permanent	4	USR(1), S2(3)
11	PRIN	Permanent	5	S1(3), USR(1), DSR(1)
11	BLUE	Permanent	6	USR(3), DSR(3)
12	BLDE	Temporary	3	S1(3)
13	COMO	Temporary	3	DSR(3)
13	WLOU	Permanent	5	S2(3), USR(1), DSR(1)
14	SYCA	Permanent	5	S2(3), USR(1), DSR(1)
15	REDB	Temporary	3	DSR(3)
16	MART	Permanent	5	S2(3), USR(1), DSR(1)

Domain	Site	Benchmark Type	Number of Benchmarks	Benchmark Locations (Count)
16	MCRA	Temporary	3	DSR(3)
17	BIGC	Permanent	5	S2(3), USR(1), DSR(1)
17	TECR	Permanent	5	S2(3), USR(1), DSR(1)
18	OKSR	-	0	-
18	CARI	-	0	-