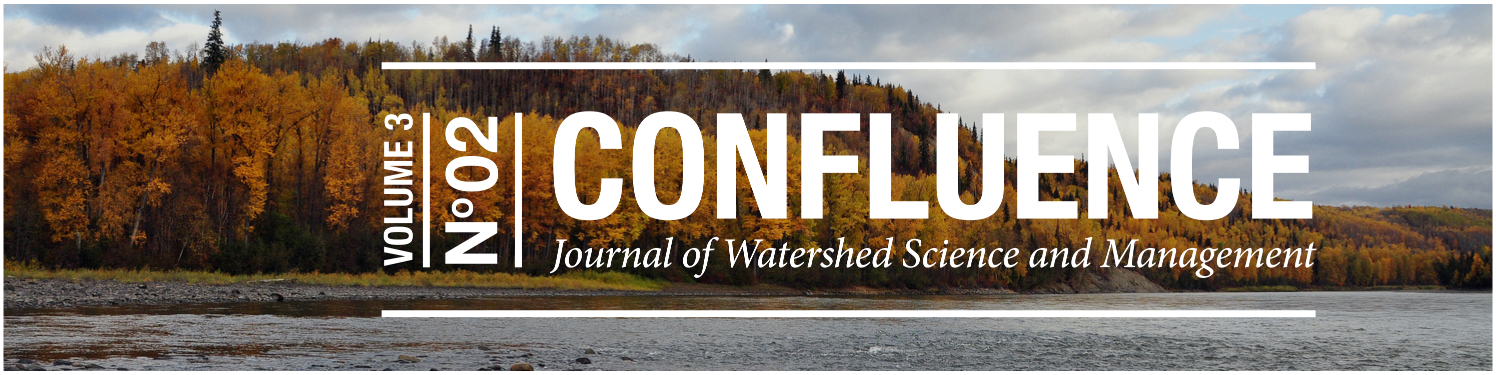

Key Hydrometric Planning Questions for Small Stream Monitoring

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Abstract

This article provides key questions to consider when planning and operating a small stream hydrometric station. Office planning components include defining hydrometric monitoring objectives; the availability of hydrometric expertise; resource availability; safety plans and standard operating procedures; equipment availability (hydrometric station installation and streamflow measurement); sampling frequency and data availability; permissions and permitting requirements; data processing, access, and archiving; and metadata requirements. Key parts of field-based hydrometric planning include site safety; site accessibility; flow variability; channel control features; flow containment, diversions and additions; low flow considerations; high flow considerations; flow measurement challenges in small streams; benchmarks and survey criteria; and public safety and vandalism. The overall goal of the article is to help non-professionals collect better hydrometric data and to highlight the varied planning aspects of typical hydrometric installations and operations.

KEYWORDS *hydrometric station; planning; measurement; monitoring*

Introduction

Hydrometric monitoring is a complex and sometimes risky undertaking. For most Canadian provinces, the Water Survey of Canada (WSC) program employs professionals with the technical and safety expertise to collect and disseminate hydrometric data. Hydrometric technicians with WSC apprentice for upward of four and a half years to reach the level of a fully trained hydrometric technician (Campbell et al. 1999). This level of mentorship is required not only for good quality data but also for worker safety.

The WSC, however, is not the only agency that collects streamflow data in Canada. Water consultants, industry, academia, government agencies, First Nations, and stream stewards all play an important role in the collection of hydrometric data. Yet, each organization collects data for different purposes, and consequently, levels of training (i.e., safety and expertise) differ. Enter the *infrequent hydrographer*, one who is not dedicated to a career of hydrometric monitoring but is involved in the collection of quality hydrometric data on an infrequent basis.

Infrequent hydrographers may visit a field site once or twice a year, may take infrequent spot measurements on a stream during drought conditions, or may monitor compliance over a defined season (e.g., summer). Frequently, their greatest challenge is a need to measure the smallest of streams at the lowest of flows, which can be difficult to accurately measure. These situations, especially for those new to hydrometric monitoring, can be compounded by a poor recollection of proper standard operating procedures, poorly maintained equipment, and an absence of adequate planning.

Planning for small streams hydrometric monitoring is a critical component of any adaptive management framework and can determine the success or failure of many monitoring activities. Planning defines the monitoring scope and objectives, which in turn dictates the amount of expertise, training, and resources required. Planning can highlight program deficiencies and ensure that critical aspects of the hydrometric installation and operations are addressed. The ultimate objective of the plan is to be prepared.

This article is written for the infrequent hydrographer and focusses on planning for hydrometric installations on small streams. The article does not provide a how-to guide for hydrometric station installation nor a procedures manual for hydrometric measurements best practices. For this information, the reader is referred to other publications, including but not limited to: Resources Information Standards Committee (RISC) 2018, United States Department of the Interior, Bureau of Reclamation (USBR) 2001, World Meteorological Organization (WMO) 2001, and Turnipseed and Sauer 2010, as well as seeking out local hydrometric mentorship opportunities.

The article is intended to provoke thought and, in some cases, highlight the unknowns of typical hydrometric monitoring planning. The objectives of this article are to outline: i) key planning questions to consider in the office and ii) key questions to consider in the field. These sections are presented together to reinforce the importance of sequential office and field planning. The overall goal is to help non-professionals collect better hydrometric data and to highlight the varied planning aspects of typical hydrometric installations and operations. The planning focus of the article can be used within any continuous improvement or adaptive management framework (e.g., see Owens 2009). Of importance, the evaluation of the successes and failures, at least annually, in the context of hydrometric monitoring objectives and station design allow for the adjustment of approaches to monitoring and are a key part of continued improvement.

Section 1: Key Planning Questions to Address in the Office

Some organizations buy hydrometric equipment in anticipation of launching a hydrometric monitoring program. The selection and purchase of equipment, however, is often most effectively performed near the end of the hydrometric planning process when the scope (monitoring objective) of the project is clearly defined. Highlighted here is the need to undertake office planning to define all hydrometric monitoring objectives that, in turn, inform the level of expertise, equipment, and resources required. Key parts of office hydrometric planning include defining:

1. monitoring objectives;
2. the availability of hydrometric expertise;
3. resource availability;
4. safety plans and standard operating procedures;
5. equipment availability (hydrometric station installation and stream discharge measurement);
6. sampling frequency and data availability;
7. permissions and permitting requirements;
8. data processing, access, and archiving; and,
9. metadata requirements.

Monitoring objectives

What are the monitoring objectives?

Which types of data are required to support the monitoring objectives?

Is the station seasonal or annual in operation?

How much data are needed to achieve the station purpose?

Defining the hydrometric monitoring objectives while considering the desired data quality levels (i.e., see RISC 2018 for examples from British Columbia) is one of the most important of all planning tasks. Defining objectives helps to address the scope and purpose of required hydrometric monitoring for everything from network design (spatial sampling), monitoring duration (discrete versus continuous, seasonal versus annual), and ultimately resource requirements (budget, staffing, etc.). Common station purposes may include

1. seasonal monitoring (e.g., drought or flood);
2. annual monitoring (trending or baseline);
3. water budgets and research;
4. habitat studies;
5. instream flow requirements;
6. water allocation;
7. verification of regulation; and,
8. water quality.

If data are used to support a decision or could possibly have legal implications (e.g., safety, environmental, or public concerns), planning for increased levels of expertise and effort may be required. Ultimately, the station purpose determines the types of data required, the accuracy of hydrometric equipment, and the duration of the site installation. For example, a station monitoring low flows (Figure 1) may only need to be installed for a few months and not be designed to withstand annual high-flow events. Yet, this station might require a higher level of field work to ensure an accurate rating curve, an accurate data logger, and possibly some means of communicating remotely if management decisions are to be timely across several stations. All these specific station requirements can be tied back to the initial definition of monitoring objectives.

Figure 1. Example of a temporary, low-flow hydrometric station. A non-vented pressure transducer is housed in a PVC stilling well with an external staff gauge that is tethered to the streambank. The equipment is anchored and levelled during install using T-bar and a modified cement paver. This type of station is not meant for long-term or high-flow applications and typically will only be used for a few months in the summer (Image: Dave Spittlehouse).

The length of station installation (e.g., seasonal, annual) is a second consideration that sometimes is contrary to the initial definition of station purpose. For example, the same monitoring site characterizing the low-flow regime (Figure 1) may need to characterize flow in the context of total annual discharge; for example, expressing low flows as a percentage of the station's mean annual discharge (MAD). In this situation, the collection of annual data may be required, even though the station purpose is focussed solely on the low-flow season.

The amount (e.g., number of years, months, or seasons) of data sought may also affect the type of installation and equipment required. Will data loggers and sensors have enough battery life for the planned duration of the installation (e.g., five, 10, or more years)? Will supplemental equipment need to be planned for and purchased?

The availability of hydrometric expertise

Are staff appropriately trained?

Is mentorship available?

Will the outside sourcing of expertise be required?

Once the station purpose has been defined, an assessment of the availability of staff and their levels of hydrometric experience and training can be conducted. Scheduling can often be problematic or complicated to coordinate during busy field seasons. Are staff available when needed? Do they have the appropriate amounts of experience and training to achieve the monitoring objectives as well as meet safety plan requirements? Plans to train staff prior to moving forward with subsequent tasks may be required. Where possible, mentorship from more senior hydrometric staff can help guide and speed the acquisition of knowledge. Every effort to seek out the assistance of a more experienced hydrographer is always beneficial for those new to small stream monitoring. Sometimes this may require multiple experts assisting with different phases of a monitoring project (e.g., contracting out high-flow measurements, developing rating curves, data archiving, and quality control). Re-examining the requirement for more qualified expert assistance is required after the field inspection of any potential hydrometric sites, particularly if any aspect of the station purpose and the measurement conditions are beyond the capabilities of staff. In these situations, plans may re-examine the station purpose to avoid these situations, seek alternate measurement sites, and/or seek out contracted services from professionals with training and equipment for the more advanced and hazardous hydrometric applications.

Resource availability

Is the time and effort required to achieve the station purpose reasonable?

Has a budget been developed for all tasks?

Is training required?

Who else is monitoring in the area?

For the infrequent hydrographer, the amount of resources and work required to prepare, install, and operate a hydrometric station can often be underestimated and overwhelming. Developing a budget allows for the identification of resource availability and constraints on the amounts of required personnel, staff time, and money necessary to achieve the station purpose. A list of common tasks requiring resources includes

1. station planning;
2. site assessments/reconnaissance;
3. safety equipment and training;
4. equipment and supplies procurement;
5. hydrometric training;
6. equipment testing;
7. station installation;
8. surveying;
9. data collection (discharge measurements, surveys, etc.) and scheduling;
10. station maintenance;
11. data processing and quality control;

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12. rating curve development;
13. data publication; and,
14. data archiving and metadata documentation.

The budget is a useful way to gauge the level of effort required by explicitly identifying areas where more resources or multiple staff may be required. The budget also assists identifying resource levels required to schedule site visits and brings in elements of hazard and risk to the station management as well as required training in all aspects of a hydrometric monitoring program.

Due to the varied tasks (see above), the review of resource availability can also highlight areas where further training or outside support will be required. For example, software to assist in the processing and archiving of data may be outdated, or even absent, and staff may lack the skills in more advanced tasks such as rating curve development. Do staff have safety training as per the safety plan (see below), and are they trained in all the required aspects of hydrometric measurements? One of the most common reactions to a well-planned budget is the recognition, which sometimes elicits amazement, of how much it costs to cover all the tasks for small stream monitoring. Some shock may be due to a lack of awareness of the numerous steps beyond the installation of equipment and periodic manual data collection. The list above is largely answered with secondary questions through the remainder of this article.

The preparation of a budget can help highlight a need to reduce the scope of initial hydrometric plans and may lead to seeking partnerships with outside groups to share costs. For small streams measurement, there are many excellent examples of partnerships between various organizations to provide hydrometric data for a common purpose. The identification of external groups monitoring in the area is, therefore, an important part of budget development.

Safety plan and standard operating procedures

Is the safety plan up-to-date and are all standard operating procedures current?

Are all the required personal protection equipment (PPE) available and functional?

Are staff trained for all hydrometric tasks?

Working outside and in/or around water is a risky task. A common issue for some is a lack of practice in safety training, the absence of training, or a lack of awareness of required standard operating procedures. High flows, swift water, wading and entanglement hazards, slipping/tripping hazards, animals, and ice safety can all be extremely dangerous hazards. Many organizations will have safe working procedures, standard operating procedures (SOPs), and other safety rules when working in and around water. For example, SOPs will often prescribe not only sanctioned approaches to hydrometric data collection but also requirements to ensure environmental safety (e.g., rules around cleaning all equipment before and after use to reduce the potential spread of invasive species). It is important to become aware of local requirements in review of the safety plan and safe work procedures.

A formalized safety plan is essential for any work in and around water. Typically, a safety plan identifies the risks associated with each planned task in terms of the hazards and consequences. A safety plan also prescribes administrative and engineering controls to mitigate issues. Administrative controls may include check-in procedures, protocols for missed check-in, safe work procedures (e.g., working in pairs, working from bridges or around swift water), and response procedures to provide clear documented actions for reducing the likelihood or impact of an incident. Engineering controls include safety equipment, PPE, and training (resulting in the authorization to perform specific tasks). All PPE require regular inspection and must be verified as being in good working condition and within service date. While not part of a formal safety plan, the exercise of updating the safety plan can often identify deficiencies and/or safety issues, allowing planners to plot a course to correct these inadequacies prior to the onset of monitoring activities.

A safety plan, however, does not guarantee field-worker safety. Everyone who works around water needs to constantly review and think about safety. A kickoff or "tailgate" meeting is commonly used to review the safety plan and identify new hazards onsite before work commences each day. Standard in most plans are requirements for workers to review their current physical and mental preparedness for the tasks to be performed, and whether it is consistent with procedures in the safety plan.

Equipment availability: Hydrometric station installation

What hydrometric station equipment is available?

Is the equipment suited for the station purpose and desired data grade?

What tools are required for station installation?

An inventory of available hydrometric station equipment helps to identify available resources and deficiencies for planning equipment purchases. This task can be daunting if one is unfamiliar with the specific equipment and the consumables usually required. In general, there are three components: i) benchmarks to establish and maintain a datum to reference water levels, ii) a stage-recording device (e.g., pressure transducer) to continuously monitor water levels, and iii) sometimes a manual gauge (e.g., staff or weight gauge) to reference recorded water levels to the datum. A basic inventory of station-related equipment to establish those components might include anchors, rebar, or metal rods and concrete for establishing benchmarks; data loggers; water level loggers; enclosures; armouring shields; staff gauges; and, other miscellaneous consumables (hardware) such as metal rods, wood, zip ties, electricians' tape, plastic pipe, locks, stainless cable, rope, and locking caps. It is also important to take stock of the specialized tools required for installation (e.g., cordless drill, generator, auger, concrete mixer, shovel) and assess whether specialized training is required for use of any equipment. The accuracy and precision of the sensors can then be evaluated against the station purpose considering the desired data quality (see RISC 2018 for examples). Good procedures will include the testing of all equipment prior to deployment to ensure function is within the manufacturer's specifications. In some instances, available equipment may not support achieving desired data grades due to precision and accuracy limitations or malfunction outside of the technical specifications.

Equipment availability: Stream discharge measurements

Which velocity or discharge measurement instruments are available?

Will this equipment be suitable to achieve the station purpose and desired data grade?

The next planning task is to identify what instruments are available to manually measure velocity or discharge at the station to conduct paired discharge and water-level measurements. Often a mix of instruments or methodologies (e.g., bucket and stopwatch, velocity meter, flumes, tracers, etc.) are required to cover the full range of flow conditions for a site. In many cases, specialized equipment and training will likely be required at the highest flows. This step of planning may highlight a need to amend the budget for equipment purchases, equipment rentals, and/or contracted services. It is also important to verify that all instruments whether owned or rented have been recently calibrated and serviced, as this can potentially be a large source of measurement error. The most typical velocity or discharge measurement instruments for small streams are mechanical, electromagnetic, or acoustic Doppler current meters. Specialized equipment for measuring high flows might include tracer (e.g., salt dilution) instrumentation, or acoustic Doppler current profilers (ADCP). Standard field equipment for small-stream measurement typically includes a top-set wading rod, velocity meter, tag line, field notebook, and survey equipment for checking benchmarks and reference gauges to the datum.

Sampling frequency and data availability

What data sampling frequency is needed to achieve the station purpose?

Are real-time data required, or will intermittent data access be acceptable?

Will available resources support timely data access and final published data?

The appropriate data sampling frequency for automated and manual measurements depends on the station purpose. For automated water-level measurements, a 15-minute recording interval provides an accurate representation of actual stage behaviour for most streams without resulting in large raw data files (RISC 2018). Manual measurements of stage and discharge are generally determined by the variability or rate of change in the channel control features (Hamilton et al. 2019), as reflected by shifts in the rating curve and desired data quality.

Station maintenance visits are usually combined with the collection of manual water-level and discharge measurements. However, more frequent station visits may be required depending on the consequence of data loss due to equipment failure or theft.

If real-time data is needed, then specialized communication equipment and installation requirements will be incorporated into the budget. A review of the schedule for publishing final quality-assured, quality-controlled data can ensure adequate time and money are allocated. The budget and station purpose may need to be revisited if available resources do not support the desired data communication frequency.

Permissions and permitting

Who owns the land around the proposed station and will access permissions be required?

Are notifications to all landowners near the proposed works planned?

Are permits or permissions required for working in the stream?

Are sensitive species present?

Will the proposed station cause any fish-passage issues, whether real or perceived?

Are mapped utilities present in the area?

Are there third party and/or engineered structures (e.g., bridges, culverts, etc.) that could be affected by the installation?

The investigation of land ownership and securing site access permissions is an imperative planning task. Do you have support from land owners adjacent to the installation? Have they been notified and involved with the proposed installation? The development of a good rapport with community members closest to the proposed installation not only helps to ensure buy-in for the project but also is an important step in ensuring data collection always occurs at the optimum level. Those who live closest to the proposed stations will often have the best knowledge of flow conditions and those community members are usually the first to report incidences of damage to an installation. It is important not to neglect the importance of this step.

To make changes in and about a stream in most jurisdictions requires formally applying for permissions and/or advice from local regulating agencies. In many cases, the magnitude of the hydrometric station and the potential level of disruption to the stream environment will dictate whether permits and/or permissions will be required. In some streams, the presence of sensitive species may require further advice about the proposed works from First Nations, municipal, provincial, tribal, and/or federal governments or community groups. This is a worthwhile task as it identifies other groups who have a common interest in hydrometric monitoring. Species that are not designated as sensitive will still require consideration, depending on the planned installation and habitat requirements. For example, the installation of a flume that prohibits fish passage would not be advisable during sensitive migration time periods. Advice from local fisheries and habitat experts/agencies is highly recommended, and often required.

Sometimes installations will require the anchoring and penetration of the streambed. It is always advisable to contact a local utility mapping service to investigate the possible presence of utilities (e.g., gas, electric, water, etc.) underneath a proposed installation. Where installations utilize bridges or other stream-crossing structures, never modify or affect the ability of the structure to pass water as designed. This almost always means a prohibition on anchoring directly to third-party infrastructure in the absence of direct permission from the structure owners. Water-passage structures are designed to function not only through the structure but upstream and downstream. It is important to determine structure ownership in advance and develop plans for further communication prior to any station installations.

Data processing, access, and archiving

How much time and money are needed for data processing and archiving?

Are data stored in a common coordinated time (e.g., standard time or Coordinated Universal Time [UTC])?

What methods of corrections will be used to adjust sensor data time-series?

Is there a clear audit trail from raw to published data?

How frequently do data users require access to approved data?

Budgeting adequate time, staff, and resources (i.e., hardware, software, access to expert help) to appropriately process, analyze, and store field measurements is another key planning component. Data processing steps verify the quality of collected field data (e.g., are times in UTC or standard or daylight savings time?) and cross-reference field observations to later develop rating curves. Data is often processed, graded, and stored in a database. This database may reside on a server or be remotely accessed via cloud technologies. Budgeting resources for data storage, and time for the development of rating curves using the paired field measurements are also required. Planning ensures that feedback occurs between those personnel processing the data and those collecting field data (where different). A disconnect between these two tasks (groups) can lead to the collection of bad data or data that carries a high degree of uncertainty. An external peer review of the data may also be required if internal expertise is unavailable. Planning can also budget for the extent of resources required for typical data corrections (e.g., water level logger offset). Similarly, plans can detail systems requirements for how field notes, data corrections, site photographs, and other metadata will be stored and available in the system. A plan to create a clear audit trail from data collection to published data cannot be overlooked as a crucial part of any hydrometric monitoring program.

Importantly, planning can also address access requirements by data users. How frequently do they require data access (i.e., immediately or every one to two years)? These answers will have a bearing on the equipment and resources required. Data access and storage may require a need to secure third-party permissions and /or may have legal or privacy implications, communication provisions, and/or lead to requirements to purchase specialized software, server space, and other secure interface programs.

Metadata requirements

What is the history of station instrumentation? Are there calibration records?

Have the locations of water level measurements and discharge measurements changed through the station's history?

What instruments/methods were used to collect discharge and water-level data for the rating curve?

What is the history of benchmarks representing the gauge datum?

How are metadata records linked to collected data?

The development of a plan to produce clear and easily accessible records of station metadata are the final component of office-based planning. Planning identifies methods to provide a clear record of the station's history that allows for an evaluation of the station and data collected. For example, shifts in the instrumentation used to record water level or discharge data will change through time. Can identified shifts in the data record be tied to changing equipment or the use of hydrometric equipment with different levels of precision and accuracy? Sometimes, uncertainty in a station record may be introduced through the movement of the station or through collecting rated points at different locations (e.g., through the high- and low-flow seasons) or at different stages. Can the benchmark (gauge datum) history be easily reviewed from the onset of the station's establishment? Are site photos and other metadata linked to the rated points? The establishment of good metadata practices at the onset of station establishment is an important part of the data quality assurance and quality control steps of hydrometric monitoring.

Office planning summary

The office-based questions in Section 1 are designed to highlight components of a typical hydrometric station planning process. Under-budgeting of cost, time, and expertise are generally the principal issues leading to station failure. Armed with monitoring objectives and resource availability, infrequent hydrographers can now turn their attention to field reconnaissance, where several different sites are explored to find a site that best minimizes potential limiting factors. Section 2 of this article outlines several field-based considerations.

Section 2: Key Planning Questions to Address in the Field

Small stream measurement can prove to be a challenging hydrometric activity due to extreme range in flows to be measured, the inherent limitations of rated sections, and frequently, ill-suited equipment. For new prospective sites, two distinct field trips are ideally conducted to examine candidate channels during both high and low flow conditions. In practice, however, this may not be achievable, and therefore, limitations of different stages are important to consider in the primary site assessment. The following field questions can be considered when determining the suitability of any proposed hydrometric station location. Key parts of field-based hydrometric planning include

1. site safety;
2. site accessibility;
3. flow variability;
4. channel control features;
5. flow containment, diversions, and additions;
6. low-flow considerations;
7. high-flow considerations;
8. flow measurement challenges in small streams;
9. benchmarks and survey criteria;
10. public safety and vandalism; and,
11. additional considerations.

Site safety

What are the site-specific safety factors and hazards?

Field planning begins with an onsite review of the safety plan and the identification of any new site-specific or time-specific safety factors prior to entering an area. On-site hazards are not limited to swift-water and downstream entrapment hazards; others may include overhead (wind or snow induced), tripping, falling, slipping, wading, wildlife, etc. Importantly, all additional safety concerns encountered in the field will be added and addressed via the safety plan prior to the commencement of any activities. If there is no available manner to address the hazard, then work cannot commence.

Site accessibility

Can all instruments be safely accessed at all flow levels?

Is access available on both sides of the stream?

Will high flows or seasonal conditions (e.g., ice, snow, deep water) complicate access and/or the ability to download data?

Is the site accessible during all seasons or will alternate modes of transport be required?

Field planning then examines the accessibility of the site, with consideration to high flows and the likelihood of access during the complete range of flows. For example, deployment of non-vented pressure transducers in the low-flow season might mean the logger becomes un-retrievable once water levels rise. Similarly, if observations of staff gauges are required, will staff need to enter the water at higher flows? Can this be completed safely under the highest of flow conditions, or will multiple staff gauges be required? In some cases, alternate equipment may be required (e.g., direct-read enabled data loggers, see Figure 2) or alternate methods of measuring manual water levels (e.g., surveyed or from a bridge deck) to keep staff safe during moderate and high flows. Finally, some sites may not be accessible by vehicle due to seasonal limitations (e.g., snow, ice, water) and/or distance. Alternate modes of transport may need to be considered.

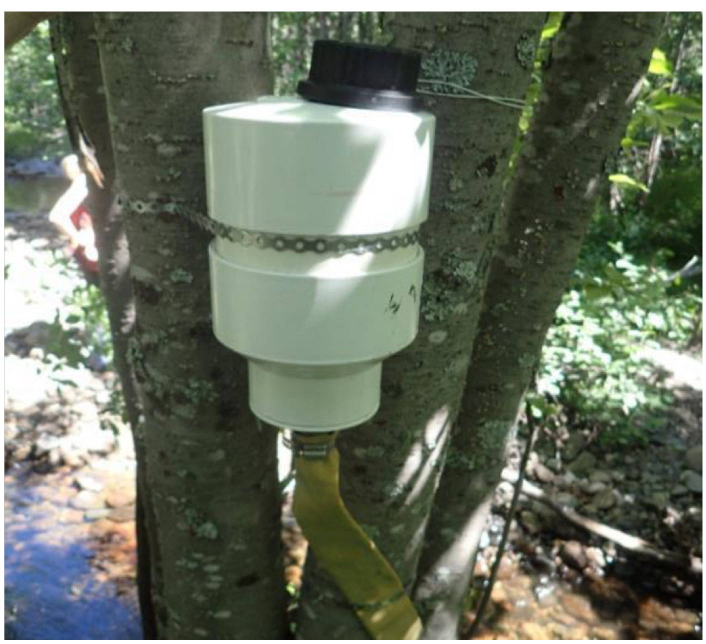

Figure 2: Example of direct read setup with cable protected by fire hose buried in a stream channel during low flows. Set-up provides terrestrial access to retrieve logger data at all flow levels (Image: Chelton van Geloven).

Flow variability

What is the range of stage from low to high flows?

How variable is the daily/hourly flow?

The seasonal and daily flow variability can be determined as part of the field reconnaissance planning review. Seasonal flow ranges can be estimated through several techniques not limited to the examination of channel vegetation, trash lines, and overall channel shape and condition. Daily variability can often be examined using the short-term deployment of a water level logger. This can be important to consider as in some systems, water withdrawals may render a site unmeasurable if the withdrawal rates cause stream levels to fluctuate more rapidly than can be measured using conventional methods (e.g., in the mid-section). In these situations, alternatives to using conventional mid-section approaches may be required. Sampling frequency can be planned accordingly to study the effects of rapid water extractions.

Channel control features

Does the site have an ideal measurement reach?

Are channel control change factors present (e.g., ice, grass, beavers, erosion, deposition, channel maintenance activities)?

How might ice affect your instruments and manual measurements?

What is the likelihood of the introduction/development of debris?

Will the installation of fish-counting fences or other seasonal structures complicate water-level and discharge measurements?

Is the control reach shape suited to producing a rating curve that is not overly complex?

Will the selected control reach need to be fenced off to protect from human or livestock modification?

The selection of a small stream monitoring site that has appropriate channel control features is the next step in a typical station's establishment. Example criteria of ideal channel features are found in RISC 2018. Features to avoid that may affect the channel control(s), thereby leading to rating curve complexities and adjustments, may include: areas with beavers, ice (Figure 3), grass (Figure 4), fallen leaves and branches, channel erosion, sediment deposition, and planned channel maintenance activities. For example, what is the proportion of deciduous tree cover upstream of the proposed site? Seasonal leaf drop from deciduous riparian species in many areas can modify the control by temporarily impounding water (Figure 5). The field plan will identify potential complications and sometimes approaches to address all identified change factors. In many instances, plans may call for the deployment of at least one trail camera to document the timing and amount of channel control changes.

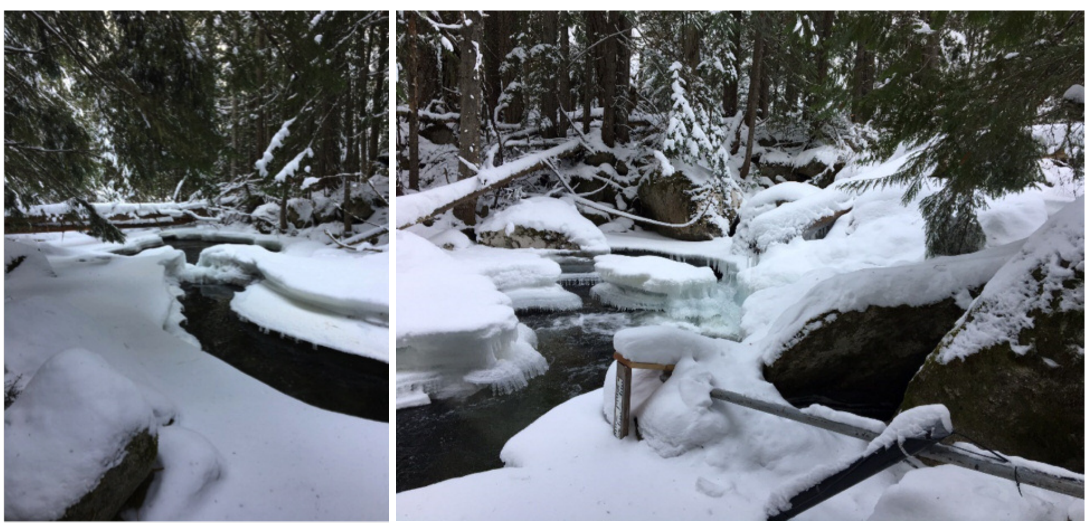

Figure 3: Example of a temporary ice-caused stream channel change, where ice has dammed up water in the stream channel causing a change in the channel control (left) impounding water, thereby altering the stage-discharge relationship (right) (Images: Sarah Crookshanks).

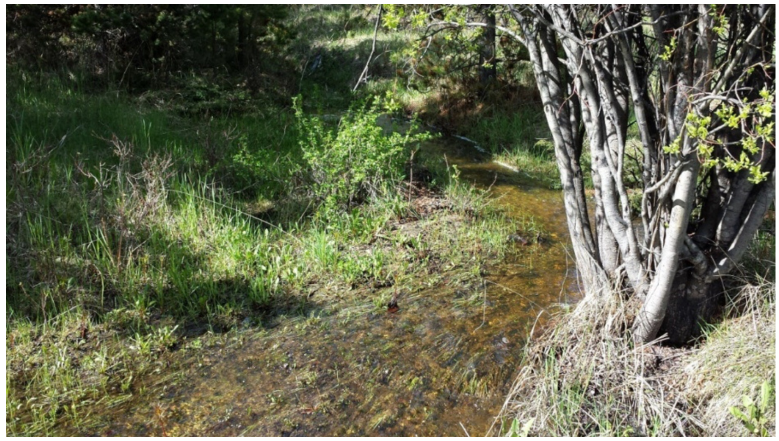

Figure 4: Grass growth in channel can complicate the creation of stage-discharge relationships (Image: Robin Pike).

Figure 5: Examination of riparian canopy demonstrates a high level of deciduous cover, and likely seasonal damming effect via fallen leaves thereby affecting stage-discharge relationship during low flows (Image: Robin Pike).

Ice is another seasonal phenomenon that can affect equipment use, access, and water level-discharge relationships. Most water level loggers are sensitive to freezing. If ice conditions are present, sensors need to be located where they will not freeze or be protected from freezing; freeze tolerant sensors can also be purchased or fabricated. Some seasonal events may be difficult to avoid or predict such as the episodic input of wood (see Figure 6), but field planning can look to implement measures to reduce the potential for equipment loss due to episodic events.

Figure 6: Episodic delivery of wood to a stream disrupts the stage-discharge relation-ship and can damage/untether measurement equipment (Image: Robin Pike).

Other potential changes in the control can be inferred through discussions with residents, focussing on their knowledge of typical erosion/deposition patterns and/or by walking the proposed measurement reach. Plan to connect with local stewardship groups and/or fisheries biologists to learn if temporary fish-counting structures are planned for seasonal installation. Fish counting structures can temporarily alter stage-discharge relationships via impounding streamflow. Furthermore, it is not uncommon to encounter human modifications to channel controls to enhance the swimming attributes of a stream (Figure 7) or monitor in areas that require fencing to protect hydraulic control features from livestock accessing the waterbody. These sites are generally best avoided as primary locations for establishing hydrometric stations due to the amount of work and costs required to protect, maintain, and/ or adjust hydrometric data to seasonal and event-based channel control alterations.

Figure 7: Example of recreationally modified channel control to enhance swimming and river tubing (Image: Robin Pike).

For most small streams, there are usually multiple channel controls that will influence the development of the rating curve (see Hamilton et al. 2019). Some of these controls can be observed at the time of the initial site visit, but many cannot. Field planning considers the channel control(s) and channel shape in relation to the flow level of interest with an objective of creating the simplest rating curve model possible. For the infrequent hydrographer, this is possibly one of the most challenging and advanced of tasks (see continued discussion below).

Flow containment, diversions, and additions

Is flow contained at all stages, or will channel banks be overtopped?

Will the measurement reach be a single channel at all flow levels?

Is there evidence of tidal influence, backwater under higher flows, tributary inputs, or diversions?

Is the streambed likely losing or gaining during the monitoring period of interest?

How many rating curve break points are estimated across the range of expected stages?

The selection of an appropriate stage-discharge measurement reach is required to create an accurate and reliable rating curve. Examination of the proposed rated section and projection of how different channel control elements might react at different flow levels provides the conceptual model that will be used later in the initial derivation of the rating curve. Examples of how the channel control can affect the development of the rating curve is contained in Hamilton et al. (2019). Is flow contained in the reach at all levels, or will channel banks be overtopped? If things look complex in the field, it most certainly will translate into complexity in the office when creating the rated model. The objective of field planning is to locate measurement reaches that can be represented by the least complex model possible (i.e., least number of distinct rating curve segments). Field planning examines the proposed reach, not only for potential gains and losses in the section, but also examines flow level-dependent complications such as tidal influence, backwater due to flooding, ephemeral inputs, overbanking levels, et cetera.

Often an objective of the field hydrographer is to create the most simplistic rating curve possible. Identification and avoidance of complicating factors listed above and selecting a reach that provides containment at all levels can assist in creating a curve with a minimum number of breakpoints. Further examples of information on reach selection criteria can be found in the RISC manual (2018).

Low-flow considerations

Will the stream dry up?

Will data loggers be submerged at all stages?

Will the flow velocities be too slow/shallow to measure?

Does the hydrometric equipment have the required precision and accuracy for low-flows measurement?

Will emergent channel bed substrate complicate or negate low-flow measurements?

Low flows in small streams can present a unique measurement challenge in that many streams can dry up to zero flow in the summer, particularly without a groundwater or lake storage baseflow component. Discussions with residents can help verify whether flow in the channel is likely perennial or intermittent. If water is present year-round, will the proposed instrument location provide depths deep enough to ensure the water level loggers are submerged for the duration of the monitoring period, while also being accessible during higher flows? Knowledge of the minimum velocity and minimum depth specifications for hydrometric measurement equipment can help in the selection of the most optimal field site, at the lowest of flows. In some instances, water will not be flowing fast enough to accurately measure manually. Site selection can try to minimize the occurrence of low water-velocity measurement conditions through the selection of reaches that are unlikely to stagnate. Finally, at the lowest of flows, sometimes emergent channel bed substrate can make flow measurements difficult if not impossible (Figure 8) to complete. The examination of bed materials for paired measurement issues at the lowest of flows can be tricky, but it is an important component of field inspection.

Figure 8: Example of emergent substrate that can complicate low-flows measurement (Image: Robin Pike).

High-flow considerations

How will high flows be measured safely?

Is the location downstream of, or monitoring within, an active alluvial fan, landslide, or avalanche area?

Can the stream be waded at all flows/velocities?

Does your hydrometric equipment have the required precision and accuracy for high flow measurement?

How will instream equipment be securely installed and protected from debris and erosion?

Will experts be required?

High flows in small streams present another complication that can be difficult to assess until after the hydrometric station has been installed, and high flows directly observed. High flows can be unsafe to wade and work beside or overtop. High flows can also change the hydraulic properties of the rated section, sometimes making flow that was best suited for the mid-section method too turbulent and better suited to alternate hydrometric techniques (e.g., tracer-based methods). It is important to identify reaches more likely to have unstable beds or high energy –scour/deposition regimes (e.g., alluvial fans, landslide, and avalanche areas) and make specific plans or avoid them altogether. For many organizations that lack specialized equipment (e.g., ADCP) and training, high-flow measurements in dangerous locations are best contracted out to experts. Field planning can confirm the likelihood of requiring supplemental safety or technical assistance in such cases.

Equipment installed year-round in a stream may require special consideration to withstand high flows. The calibre of the bed materials can provide an indication of stream power. To avoid equipment loss or damage, instruments may need to be located outside of the main flow paths (e.g., natural pools or constructed stilling wells) and/or installed using specialized anchors or shields. It is common that many small streams in the high-flow seasons cannot be measured by the infrequent hydrographer. Field inspection of the potential sites can include pictures that can be used to solicit specialized assistance from experts for portions of the rating curve beyond the competencies and training of staff.

Flow measurement challenges in small streams

What mid-section-related measurement limitations exist at the site?

What tracer-based-related measurement limitations exist at the site?

While small streams monitoring may sound routine, there are several common issues the infrequent hydrographer plans for—and sometimes around—when selecting optimal measurement locations. Field planning aims to select sites to minimize the influence of many of the following when using mid-section measurement approaches:

1. angular flow velocities due to irregularly sized channel materials, both vertical and horizontal, and/or the alignment of the measurement section (e.g., bridge/culvert);
2. boundary conditions on the streambed and edges that can interfere with instrumentation measurements (e.g., vegetation, rocks);
3. velocities below instrument sensitivity and calibrated ranges;
4. bad streambed conditions that affect instrumentation effectiveness (e.g., soft, sinking, excess roughness in front of measurement location);
5. insufficient spacing for panel widths (e.g., it is difficult to have greater than 20 panels in channels less than two metres in width);
6. incorrect measurement practices (e.g., measurement stance and/or upstream activities during measurements); and,
7. the concentration of flow in a small confined portion of the channel.

Of these potential issues, the concentration of flow in a narrow swathe of the channel can increase measurement uncertainty if any single mid-section panel measurement is in error. Specifically, the greater the percentage of overall streamflow that exists in a single panel, the greater the potential effect on the uncertainty of total calculated discharge. Therefore, adding more panels in the higher flow areas will help to reduce the overall measurement uncertainty. For many small streams, however, once flows begin to increase, channel limitations such as turbulence may tend to magnify, particularly at higher flows. For some small streams, this means that at certain stages, mid-section suitability criteria may become less than ideal and alternate techniques may be required.

For streams where tracer-based approaches are used, such as salt dilution, the infrequent hydrographer may encounter the following flow-dependent issues:

1. inadequate mixing properties in the channel (Figure 9);
2. vegetation and ice effects;
3. tracer loss (losing reach) before complete mixing is achieved;
4. tracer dilution via tributary or subsurface inflow in the mixing zone; and,
5. pooling, slow-flow velocities, and channel storage that slow tracer transit times.

With these potential limitations in mind, the infrequent hydrographer can best select sites that minimize the occurrence of these issues. For many streams, no perfect monitoring site exists at all flow levels, and hydrographers will typically balance known issues against the ideal in light of the monitoring objectives.

Figure 9: Example of inadequate mixing properties. These two rivers (one darker coloured, one glacial blue) maintain respective left bank-right bank compositions for some length after joining, as illustrated, due to a lack of mixing (Image: Robin Pike).

Benchmarks and survey considerations

Can stable benchmarks be located with clear sight lines?

Can the cross section, channel slope, and water surface be safely surveyed at all stages?

The establishment of benchmarks and levelling surveys are another important consideration of hydrometric station establishment. Prior to the installation of the hydrometric station, field planning can investigate and identify the potential locations of benchmarks with clear sight lines to propose survey-instrument locations with as few turning-points as possible. If stable benchmarks (i.e., benchmarks that do not shift over time) are not feasible and/or if there are only one or two benchmarks, data quality grades can be affected (see RISC 2018). In some cases, performing levelling surveys can become quite complex (e.g., narrow canyons, thick vegetation, elevation changes, etc.), and planning can help to minimize the overall complexity through the selection of appropriate benchmarks. Benchmark locations need to fulfill the station's purpose and make surveying as accurate and straightforward as possible.

Wherever possible, surveying the channel shape and any subsequent changes in the control can aid in rating curve development. An important component to survey is the elevation of the lowest portions of the control, where zero-flow is likely to occur, as this elevation in relation to the datum becomes a key parameter in the rating curve equation (Weiler et al., 2010). This measurement, however, is not always possible to determine from field surveys (Hamilton et al. 2019), particularly for complex controls. Field planning with respect to survey considerations can examine whether the channel cross section can be safety surveyed at various water levels. Planning considerations for safety concerns around the high-flows measurement of benchmarks and water levels need to be considered when locating the number and quantity of benchmarks.

Public safety and vandalism

How safe is the measurement site for the public?

Are there any concerns or public perceptions that need to be addressed prior to installation?

How visible is the station to tampering, vandalism, or alteration?

Are warning signs needed for public safety?

It is important to consider public safety in all aspect of a hydrometric monitoring program. Field investigations of safety concerning the interested or curious public may include planning for signage (both information and hazard warning), fencing, locks, locking caps, security cameras, and planning to install everything with an eye toward public safety. Will the installation be a potential tripping or entanglement hazard? How safe and secure is the site? Can the installation be designed to hide the instruments from the public eye or minimize exposure? What is the likelihood of tampering or vandalism? Signs of channel modification (Figure 7), well-built trails, garbage, and/or graffiti may give indication of traffic level and potential security concerns. Concealing pressure transducers in the streambed and purposefully omitting a visible staff gauge from an installation are two methods to reduce attracting attention to a site. Children can be especially curious and preventative measures can be planned. For example, using rebar to permanently secure tag lines in areas where there is a good amount of public traffic may prove to be hazardous if a member of the public trip and falls. Public safety for all hydrometric installations needs to be part of the plan.

Additional considerations

How far will equipment be transported?

Is specialized equipment required for installation?

Has remote communication reception been tested?

Are invasive species present or will a potential presence require modified SOPs?

Are there multiple photo point locations for installing a time-lapse camera?

Finally, field planning for the infrequent hydrographer can involve examining access to a potential site. If heavy equipment and supplies such as rock anchoring or heavy cables are required, then plans for the transport of this equipment to the site will be required. The protection of installed equipment from high flows may also require specialized installation equipment such as battery- or gas-powered drills. The training, safety and ability of staff to install this equipment is incorporated into the planning process.

Remote communication reception is another factor to consider. Cellphone signals can be tested for signal strength using a variety of cellphone apps and/or studying different cellphone provider coverage maps. Potential satellite communication issues can be flagged in advance; for example, thick canopy above the proposed station or topographic barriers may limit the "viewing" window from station to satellites. While the current monitoring objective may not be real-time communication, knowledge and planning may save future time and money if the station objectives expand.

In some areas, an evaluation for the potential presence of invasive species (e.g., zebra and quagga mussels, Eurasian watermilfoil, etc.) and how that may affect the SOPs for the safety of the station, people, and hydrometric field equipment. For example, if boats are used to access an area, it will be necessary to budget extra time to ensure clean equipment prior to departing the site as well as inspections before redeployment to avoid possibly contaminating another site.

Finally, many hydrographers consider using one or more time-lapse cameras (Figure 10) to document water levels and the timing of any episodic changes in channel controls (e.g., sediment deposition or erosion). Automated time-lapse cameras can also help to document the presence of seasonal conditions such as vegetation, leaves, ice, and debris. More information on photo point monitoring from the following publications: Hall 2001a, 2001b and Shaff 2007.

Figure 10: Trail cameras set to time-lapse or field-scan mode can provide an autonomous method to monitor sites and channel conditions for episodic and seasonal changes (Images: Robin Pike, left, Dave Spittlehouse, right).

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Conclusions

Hydrometric monitoring can be a complex science. There is no replacement for years of experience and hydrometric training, particularly in terms of safety and knowledge. For the infrequent hydrographer, however, developing hydrometric experience can sometimes be challenging, particularly when hydrometric duties make up only a small portion of their time. This article provides an extensive set of key questions to highlight common areas the infrequent hydrographer can focus on when approaching hydrometric monitoring. Questions for consideration are intended to provoke thought, highlight the potential amount of work required for monitoring, and identify potential deficiencies and/or issues at the outset, thereby saving time, money, and possibly frustration. The goal of this article is to help non-professionals collect better hydrometric data by ensuring typical aspects of the hydrometric installation and operations are considered.

It is important, however, to place the planning elements presented in this article into a suitable continuous improvement or adaptive management framework when approaching hydrometric monitoring. Circular adaptive management frameworks typically begin with declaring a monitoring objective (problem definition), progressively leading through components of design, implementation, monitoring, evaluation, and adjustment. The questions presented in this article assist the infrequent hydrographer with the first three of the six adaptive management components. However, the authors stress the importance of the continual examination of the successes and failures of monitoring activities, processes, and procedures. The evaluation and adjustment of approaches and planning elements presented above are key to a well-planned hydrometric monitoring approach for the infrequent hydrographer.

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References

Campbell, P.I., R.D. McBride, & C. Thomson. 1999. *The Water Survey of Canada – Hydrometric Technician Career Development Program*. The Water Survey of Canada. http://publications.gc.ca/collections/collection_2014/ec/En56-244-1999-eng.pdf [Accessed July 28, 2019].

Hall, Frederick C. 2001a. *Ground-based photographic monitoring. General technical report PNW-GTR-503*. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. https://www.fs.fed.us/pnw/pubs/gtr503/ [Accessed July 28, 2019].

Hall, Frederick C. 2001b. *Photo point monitoring handbook. General technical report PNW-GTR-526*. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. https://www.fs.fed.us/pnw/pubs/gtr526/ [Accessed July 28, 2019].

Hamilton, S., M. Watson, & R.G. Pike. 2019. Role of the hydrographer in rating curve development. *Confluence Journal of Watershed Science and Management*, *3*(1):1-15. doi: 10.22230/jwsm.2019v3n1a1

Owens, P.N. 2009. Adaptive management frameworks for natural resource management at the landscape scale: Implications and applications for sediment resources. *Journal of Soils Sediments*, *9*:578–593. doi: 10.1007/s11368-009-0137-2

Resources Information Standards Committee (RISC). 2018. *Manual of British Columbia hydrometric standards, Version 2.0, December 2018*. Victoria, BC: Knowledge Management Branch, B.C. Ministry of Environment and Climate Change Strategy. https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/man_bc_hydrometric_stand_v2.pdf [Accessed July 28, 2019].

Shaff, C., J. Reiher, & J. Campbell. 2007. *OWEB guide to photo point monitoring*. Salem, OR: Oregon Watershed Enhancement Board. https://digital.osl.state.or.us/islandora/object/osl:16450/datastream/OBJ/view [Accesed April 1, 2019].

Turnipseed, D.P., & V.B., Sauer. 2010. Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods book 3, chap. A8, 87 p. https://pubs.usgs.gov/tm/tm3-a8/ [Accessed July 28, 2019].

United States Department of the Interior, Bureau of Reclamation (USBR). 2001. *Water measurement manual* (3rd edition). Washington, DC: United States Department of the Interior, Bureau of

Reclamation Water Resources Research Laboratory, U.S. Government Printing Office. https://www.usbr.gov/tsc/techreferences/mands/wmm/ [Accessed July 28, 2019].

Weiler, M., D.L. Spittlehouse, R.G. Pike, R.D. Winkler, D.E. Carlyle-Moses, G. Jost, D. Hutchinson, S. Hamilton, P. Marquis, E. Quilty, R.D. (Dan) Moore, J. Richardson, P. Jordan, D. Hogan, P. Teti, & N. Coops. 2010. Chapter 17: Watershed measurement methods and data limitations. In Pike, R.G., T.E. Redding, R.D. Moore, R.D. Winker, & K.D. Bladon (editors). 2010. *Compendium of forest hydrology and geomorphology in British Columbia.* B.C. Min. For. Range, For. Sci. Prog., Victoria, B.C. and FORREX Forum for Research and Extension in Natural Resources, Kamloops, B.C. Land Manag. Handb. 66. www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh66.htm [Accessed July 28, 2019].

World Meteorological Organization (WMO). 2010. *Manual on stream gauging: Volume I – fieldwork. WMO-No. 1044*. Geneva, CH: World Meteorological Organization. http://www.wmo.int/pages/prog/hwrp/publications/stream_gauging/1044_Vol_I_en.pdf [Accessed July 28, 2019].