WaterPro - Northern Runoffs into Profits

T1 Good Practice Tools and Guidance

Output 1.4.1

Collected methods for quality and field water flow determination in the NPA region

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1 Introduction

Traditionally, water sampling has been used to monitor natural waters, from which the desired variables are largely analyzed in the laboratory and the results are obtained within a few days of sampling. Modern sensor technology enables continuous measurement of multiple variables from watercourses and the transmission of this information directly to the person in need. Traditional water sampling shows the water quality only at that sampling time and possible quick quality fluctuations can distort the actual result. Sensor technology, however, allows for up-to-date monitoring and the method can take into account abrupt changes in water quality, resulting in increased representativity of the results. Existing water quality data can be used to create different profiles to estimate, for example, to assess the need of reduction of the loading into the waterways, as well as the drifting of different substances. Accurate and up-to-date monitoring of water quality also allows the development of the water quality models.

Automation and the development and introduction of new methods for improving water quality monitoring have long been sought (Huttula et al. 2009). Online water quality meters have been shown to reveal a much better picture of the fluctuation of water quality over different seasons than traditional water sampling (eg Tarvainen et al 2017). Generally speaking, the use of online water quality stations has many benefits in comparison to traditional water sampling techniques however expertise in use must be employed in order to derive reliable and high quality data.

However, online water quality meters cannot yet fully replace water samplers because the number of variables measured or measured by the data is limited. In addition, the use of meters is more expensive thuis limiting their use to regionally comprehensive information acquisition.

The acquisition, maintenance and quality control of on-line measuring stations can be carried out either by full-time, in-service, or by a partial purchasing service. The organization of measurement activities and the quality assurance of the materials involve demand bargaining skills and special expertise, whose availability must be ensured. When looking for more accurate metering points for measuring activities, it is advantageous if the site is already an intensive aquatic sampling destination, near the flow metering station, and it is easy to organize the station's year-round maintenance.

This report outlines various available water quality determination and flow measurement options in northern rural and arctic regions. The main aim of this review is to clear out the foundations for comprehensive, modular on-line measurement system to be deployed for monitoring of aquatic environment quality in rural areas such as: mine water systems or agricultural waters.

2 Measurement equipment for water monitoring

2.1 Principles of online measurements

Current optical measuring devices can measure turbidity, nitrate nitrogen, oxygen and organic concentrations in natural water. Phosphorus measurement is no longer optically possible even though development work has been going on for years. Measurement of turbidity with optical sensors is based on either the loss of light penetration or light scattering. Measurement of nitrate nitrogen concentration is based on spectrometry. The differences between the sensors are due the lamp types (eg. deuterium, xenon), cuvette length and process algorithms.

The most commonly used sensors in Finland have proven to be durable and reliable in terms of their design and technology (especially light sources). Below are some of the devices that are in use in Finland.

- OBS turbidity sensors measure backscattering of electromagnetic radiation. The source of radiation is either an infrared or laser diode. The OBS3 + sensor transmits infrared light to water and measures back light scattered from particles in water and converts these data to turbidity values using the Nephelometric turbidity unit (NTU). The most common lens cleaner mechanism for OBS3 + devices is brush scraper. Liquid rinsing has also been tested with ethanol-water mixture. The zero point for the OBS sensor can be calibrated against reference ("zero" NTU sample solution), but always local calibration should be done also.
- S::can multifunctional sensors (xenon light source, 256 photodiodes) measure light attenuation. They are multifunctional devices able to measure e.g. turbidity, nitrate nitrogen and organic matter. The "fingerprint" of the signal allows simultaneous measurements of several parameters and very precise compensation for light source changes. The device measures UV and visible light (in the wavelength range of 200-750 nm).
- YSI turbidity sensors are also optical scanners for backscattering. They are very stable and reliable. The measurement takes place at a wavelength range of 830-890 nm. The YSI turbidity sensor is a single sensor, which requires YSI multi-parameter probe to functioning. It has a wiper as standard. Other variables such as temperature and conductivity can be added to the probe.

2.1.1 Operational range of instrumentation

In order to purchase the correct and most suitable monitoring equipment, it is important to know the range and average concentration of the specific parameters of interest at selected monitoring site. No quality standards for individual analyses have been presented to nutrients. (Näykki et al., 2013).

To aid this decision, previously observed data and respective correlations between various water quality parameters should be taken into consideration. For example, data derived from routine water quality analysis of sites in localized area and subsequent correlations observed between turbidity and solids, turbidity and total phosphorus, and nitrate nitrogen and total nitrogen, may inform the feasibility and operational range under which high resolution instruments (e.g. turbidity sensors, nitrate sensors etc.) should be deployed. This will provide information on whether the use of turbidity is possible, for example in the assessment of total phosphorus at the planned monitoring location.

2.2 Flow rate (discharge)

Traditionally, prevailing method to capture flow rate in natural environments (river, stream, ditch etc.) is area-velocity method. On the basis of continuity equation, discharge (m^3/sec) can be calculated from the product of the cross-sectional area (m^2) of the river and the flow velocity (m/s). Due to usually complicated shape of natural channels, cross-section area is divided into sections, so that the total flow rate can be accurately derived depending on the actual velocity profile.

Flow measurements in open-channels and irregularly shaped cross-sections are challenging tasks and must be considered on a case-by-case basis. Deployment of flow measurement methods depends largely on characteristics of location, expected variations of flow and level of waterbody. Measurement station require regular inspection and maintenance.

Flow measurement in pipe flow (pressurised and free-surface) is relatively inexpensive and less complicated for natural channels (streams or ditches). The most frequently used equipment are electromagnetic, ultrasonic flow meters and acoustic doppler profilers.

There is a possibility to provide hybrid measurement solution, when part of cross-section in measurement section is replaced with prefabricated element. It is recommended to use culverts for measurement if possible.

For rough flow rate estimation calculation methods can be used:

- Chezy-Manning equation based on slope, hydraulic radius and properties of channel bed (roughness),
- Developing level to discharge rating curve based on one-time measurement.

Traditional but robust on-demand methods for flow measurement are:

- Bucket method (manual method) – timed volumetric or gravimetric,
- Float method (manual method),
- Tracer method (manual method) – dye or salt dilution.

Flow measurement methods that allow for continuous reading:

- Weirs (overflow,Thomson or V-notch overflow, compound weirs: rectangular-triangular) – continuous level measurement,
- Flumes (Trapezoidal, Venturi, Parshall, Palmer-Bowlus, RBC flume, HS/H/HL flumes, cutthroat flume) – continuous level measurement,
- Flow meters (mechanical - propeller-type current meters, doppler ultrasonic probes, ultrasonic and electromagnetic flow meters for pipe flow) – continuous flow measurement

Flow measurement in pipe flow (pressurised and free-surface) is relatively cheaper inexpensive and less complicated forto natural channels (streams or ditches). The most frequently used equipment are electromagnetic, ultrasonic flow meters as well asand acoustic doppler profilers.

2.2.1 General characteristics of Doppler technique

Water velocity can be measured manually using a propeller type flow meter or acoustic doppler current profiler (ADCP) – alternative term used is acoustic doppler velocity meter (ADVM). For mounted version of doppler devices, flow rate measurements can be automated and delivered online but it is assumed that the cross-sectional area is fixed. In natural environments (trench, ditch, river or stream) when measurement section has not been regulated, there is an increased uncertainty due to scouring or deposition of material, growth of plants etc. Boat-mounted ADCP can be used to scan measurement cross-section. Overall flow measurement uncertainty is affected by variability of flow rate. Especially for flow regime (close to seeping), when water level at the measurement section is low, this technique will tend to be inaccurate. Most of producers suggest that measurement cut-off level (minimum depth) is between 5 to 30 centimetres (in practical application minimum depth should be above 12 cm). Preferable solutions are devices capable to produce beams that measure both the horizontal and vertical distribution of velocities in cross-section with designated resolution (size of profiling cells) - to capture actual velocity profile along both axes. For channels with variable water depth it is crucial to provide accurate level measurement.

There are two types of Doppler instruments that can be used to measure water velocity:

- **Coherent** (or profiling/gated - broadband) Dopplers transmit encoded pulses with the carrier frequency at target locations (gates – between 16 - 128), and only measure signals reflected from these targets. This allows the velocity in a stream to be profiled (Acoustic Doppler Current Profiler). This method of flow velocity measurement is also known as cross correlation (Nivus).
- Incoherent (or continuous – narrowband) Dopplers devices, emit a continuous signal and measure any signals returning from scatterers anywhere and everywhere along the beam. These are resolved to a mean velocity is then calculated which related to the channel velocity at the chosen sites. These types of devices are considerably less expensive then Doppler profilers.
- **Transit time method** - The flow velocity measurement is based on the determination of the transit time (time of flight) of ultrasonic signals between two sensors. It is possible to increase number of measurement paths (usually 4) to overcome problems with natural channels (sediment transport, moving river bed).

Depending on particular details in cross-section Doppler ultrasonic probe is usually mounted on channel bottom (bed-mounted ADCP), near the riverbed bottom or below surface (side-looking ADCP or horizontal ADCP). Usual mounting is on dedicated piling (mount), bridge pillars or canal walls.

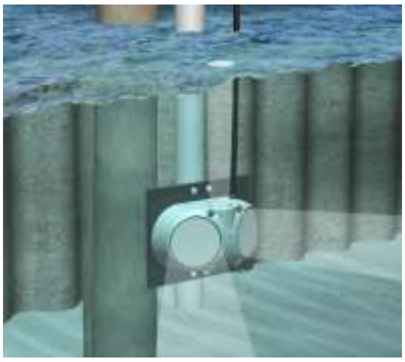

Figure 1. Example of side-looking ADCP device (www.sontek.com)

Ultrasonic probe measures the velocity and depth of the water flowing above it (for increased accuracy in most cases external vented level sensor is used) as well as temperature. The Doppler signal received, and the accuracy of the computed velocity, is related to the flow and cross-section characteristics of the site. In some applications (for irregular shaped channels) an area rating table will be required. Rating table describes a relationship between depth and cross-sectional area. ADCP method mounted at the bottom of a channel is suitable for small streams, culverts, channels, pipes and drains. Side-looking type are suitable for larger streams and rivers.

Example manufacturers and types: Sontek SL-series and IQ-series, HydroVision AquaProfiler M-Pro, Unidata StarFlow.

2.3 Level measurement

Water level can be measured using a variety of sensor-based methods with varying accuracy, power and signal output requirements as well as specific mounting requirements (wet, dry). Typical solutions include:

1. Pressure transducer (wetted and below low water level and can also be an integral element of water quality multi-probe or a flow sensor)
2. Bubbler (uses a small in-situ bubble tube mounted below low water level)
3. Radar sensor (mounted to a structure such as a bridge above high water level)
4. Ultrasonic sensor (mounted to a structure above high-water level)
5. Acoustic sensor (mounted in-situ below low water level and typically integral to an acoustic Doppler flow sensor)
6. Shaft encoder (wetted float and weight with the digital shaft encoder above high water level)

Level measurement has to be related to some fixed point i.e. stage height or staff gauge. Typical the zero of staff gauge represents level above datum or level to bottom point on a V-notch weir. If the level logger is correlated to the staff gauge it allows monitoring how level changes over time in relation to a fixed point at the river profile.

2.4 Challenges of measuring in rural and arctic areas

2.4.1 The main challenges to overcome in a planned system:

- **Data transfer in remote areas** – GSM/GPRS network coverage, alternative low-power transmission methods (e.g. 169 MHz RF, IoT, NB-IoT, signal transmission for online monitoring, maintenance, self-diagnostics.
- **Extreme weather conditions** – winter time (ice, snow cover), flooding.
- **Power supply** – (battery/accumulator, solar/wind power stations) Cold climate conditions – resistant to freezing, moisture. Power requirements for online monitoring.
- **Different protocols and interfaces used by manufacturers** – favouring ready-made kits, limit number of measurement equipment providers (simplify maintenance and limit OPEX).
- **Raw data processing** – modular system for data processing deployed at the server side.

2.4.2 Challenges in measuring Phosphorus

A significant weakness in insitu water quality monitoring is the lack of a reliable and sufficiently accurate phosphorus sensor. Different techniques are being developed but to date the phosphorus concentration has been estimated by the correlation of turbidity. In some places, this produces fairly reliable results, while in other places this is not the case. This is due to the fact that, for example, the phosphorus from grass cultivation areas is usually in a soluble form and therefore its concentration cannot be indirectly estimated from a turbidity measurment. In addition, the soil type affects the mobility of phosphorus. There are many factors which can affect the correlation between turbidity and total phosphorus so the significance of correlationmust always be verified locally on the basis of analysed water samples.

Instead of the using phosphorus sensor, nutrient analysers based on wet chemistry have been tested for nutrient analysis in field conditions. Several analytical systems have been tested, e.g., Italian Systems NPA devices that have been able to measure either nitrogen (total nitrogen, NO_2, NO_3) or phosphorus (total phosphate, PO_4). These systems typically use on board reagents for in situ wet chemistry analysis to determine nutrient concentration. For example, soluble reactive ortho-phosphate is typically measured colorimetrically in accordance to Murphy and Riley, (1962) blue method based on the yellow molydophosphoric acid complex formed between molybdate and orthophosphate ions that is then reduced insitu to a blue compound (phosphomolybendnum). According to user experience, the functionality of these devices has been inadequate and calibration has been difficult. In addition, they require a power supply in field conditions, which limits the extent of their practical application. The repeatability of the results is also variable. In general, the equipment has not been considered as the most suitable devices for use in the field. On-going development in this area however is progressing and new devices are being developed however the scope of this report does not cover this development.

Measuring nutrient concentrations in environmental water bodies is therefore a challenging activity. Instead of using on-site analyses or monitoring equipment, some automatic water samplers are proposed for collection of composite water samples. Water samples will be refrigerated in situ and later analysed in a laboratory where nutrient analysis will be accelerated and enhanced e.g. due to multi-channel flow analysers. It would be good to find out more about the shelf life of the samples in the samplers. The stability of the samples in the samplers is crucial for the analysis and as such automated samplers will often store refrigerated samples. Samples will also be frozen for analysis at a later date.

3 Characteristics required from the field meters

The use of a field meter or instrument must be evaluated from a variety of angles, in order to consider its suitability for the specific measurement needs. Summarised below are the features which need to be taken into account when evaluating the suitability of a device. The decision on the suitability of a meter or device should always be a result of an overall assessment and consideration of which features are more important and beneficial than others. For example, when measuring natural waters, the range and accuracy of the measurement is often the primary consideration. User experience is also very useful in assessing the suitability of a meter or device however with new equipment there may be little or no experience in Northern or Arctic conditions. A device used for instantaneous water quality measurement requires slightly different properties in comparison to a continuous-measuring device. Some devices are well suited to both instantaneous and continuous measurement of water quality parameters.

Reliability and adequate measurement accuracy

- The reliability and accuracy of the measurement are the most important criteria. Accuracy requirements must take into account the legal requirements and environmental management guidelines.

Ease of use

- The use of a field meter should be relatively simple and straight forward. Clear and simple instructions make it easy to learn how to operate the device and even in difficult situations, for a workable solution to be implemented. Well-organized training can help implement the use more sophisticated properties. Simple data transfer from the meter to the computer and the clarity of the software on the computer are also important. Device maintenance and calibration should also be straightforward.
- Ease of use is emphasized with instantaneous water quality measurement devices. In continuous water quality measurements, other meter features may become more important.

Applicability for the field deployment

- The use and access of the device must be safe under all circumstances. A meter and any manual display attached to it should be waterproofed and resistant to UV/Wind and freezing temperatures. The screen should also be clear in sunny and bright weather. Small and low weight devices are usually beneficial for ease of transportation, adjustment and manipulation. The meter power supply (usually a combination of battery pack and solar panel) should allow for a long operation time to limit maintenance. Devices include diagnostic parameters for self-monitoring to schedule battery pack replacement.
- For instantaneous measurement devices, high speed measurement performance is emphasized, i.e. the measuring sensors should react quickly to the parameter to be measured (short stabilization time). For instantaneous measurements, a manual display or other recording solution, enabling real-time monitoring of the measurement is essential for accurate measuring.
- For continuous measurement devices, features which reduce maintenance need, such as various automatic sensor cleaning mechanisms, improve the collection of appropriate quality and quantity of reliable data.

Cost-effectiveness

- Prices of water quality measurement devices vary from a few hundred to thousands of euros. The service life of the devices also vary. Optical sensors are generally durable and reliable. Cost-effectiveness is also influenced by the number of measurements required. If the measurement requirement is low, it may be more cost-effective to carry out water analyses in the laboratory and thus implement a lower cost collection device in the field. In the case of measurement devices placed in the field, account should be taken of the costs of establishing and maintaining a telecommunication system or main power supply.
- For instantaneous measurement, cost-effectiveness is influenced by the speed of measurements, particularly in situations where there is need for several measurements. Continuous measuring produces valuable information about varying conditions, but it can become very expensive. Th.

Replaces the previous measurement method

- The purpose of introducing a new method or device is usually to bring cost savingsor increase the quantity, quality or reliability of the data being collected. Currently, a lot of water samples and laboratory analysis tasks are still required to ensure the quality of the data collected by the indicators are reliable, accurate and comparable.
- For instantaneous water quality measurements, a good meter can reduce the number of water samples in some cases. Field devices can currently only measure a few parameters reliably, which substantially limits replacements for currently existing Lab analytical methods.

Suitability for different environments

- The cost-effectiveness and usefulness of the measuring instruments improves if the device has the flexibility to be used in different environments such as lakes, rivers and the sea. These different environments will have contaminants in widely varying concentrations and as such this flexibility is a challenge for the equipment designers, developers and manufacturers.
- As a result of this, a water quality measurement device is usually chosen according to what is being measured. This will improves the quality of the measurement data however conversely may restrict their transferability to other locations.

3.1 Overview of regularly measured parameters

General variables - temperature, temperature profiles, colour, odour, residue and total suspended solids, suspended matter, turbidity and transparency, conductivity, pH, acidity and alkalinity, redox potential (ORP/Eh), dissolved oxygen, chlorophyll

Hydrological variables – discharge (flow rate), velocity, water level, rainfall, suspended matter transport and dynamics

Nutrients - Nitrogen compounds (nitrate NO_3, nitrite NO_2, ammonium ion NH_4^+, molecular nitrogen N_2, ammonia), phosphorous compounds (dissolved orthophosphates and polyphosphates, and organically bound phosphates)

Organic matter - TOC, COD, BOD, Humic and fulvic acids

Major ions – Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, HCO_3^-

Inorganic compounds – sulphide (H_2S), fluoride (F^-), Boron, Cyanide

Metals and metalloids - Al, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Zn + Be, Tl, V, Sb, Mo, As

Organic contaminants – mineral oil and petroleum products, phenols, pesticides, surfactants

Microbiological indicators – bacterial pathogens, viruses

4 System architecture and main components of a measurement station

Implementation of a measurement station will depend on location and will be customised in order to accommodate specific requirements. A typical location is near the water body: lake, stream, ditch or channel). Locked housing will often be necessary to safely house sensors' wiring, data collection and power supply systems as well as auxiliary equipment (e.g. autosampler). The installed system should allow for any adjustments with regards to requirements of flow rate and level measurement. Depending on location, the flow rate will be measured with an overflow structure (e.g. weir, flume) or flow meter (e.g. ADCP, ultrasonic, electromagnetic).

Special consideration must be given to power supply, energy efficient communication protocols and maintenance to allow steady and reliable data collection. Data collected by sensors will be stored into a datalogger where data is transferred regularly either by manual access to a computer terminal or wirelessly by telemetry. For example, GSM network (e.g. GPRS, LPWAN NB-IoT) or local network (e.g. LoRa) can be used for wireless transmission. Subsequently the data can be processed, visualized or use for modelling purposes.

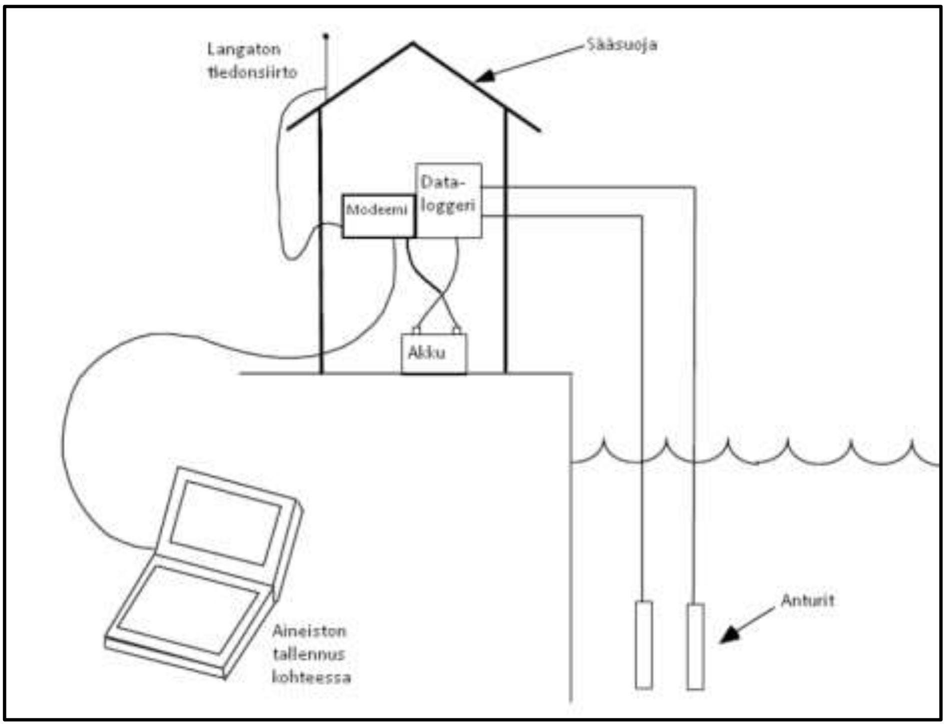

Figure 2. Principle of the measurement station

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