Summary of Finnish water discharge measurements

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1. Introduction

Finland can be with good reason regarded as a land of waters. Some numbers: we have 187 888 lakes, 314 000 km of shoreline, 178 947 islands, 22 085 springs and 647 rivers. Our renewable freshwater resources are 21 200 m^3 per year per capita. For example, in Germany the respective figure is 1 300 m^3. To keep record of this invaluable national resource, a network of hydrological measurement stations (Table 1) has been established and being maintained by the Finnish environmental authorities. In this report we concentrate on river flow (or discharge) measurements.

Table 1. Active Hydrological stations in Finland (as of 2019).

	Number of stations/sites
Surface waters	
lake water level	668
river flow	391
ice thickness	50
water temperature	34
runoff/small basins	35
Hydrometeorology	
snow water equivalent	143
evaporation (Class A)	5
precipitation*	200
Geohydrology	
groundwater level	75
ground frost depth	38

* Finnish Meteorological Institute

2. Flow measurement techniques

2.1 Traditional current meters

The amount of water flowing in a riverbed per unit of time (= flow rate, Q) can be estimated if the cross-sectional area of the riverbed (A) and the water velocity (v) are known. The flow rate is obtained by multiplying these two figures (Q = v*A). Initially, the water velocity was estimated by means of a float, etc. floating on the surface of the water, and the cross-sectional area by measuring the depth and width of the channel by means of, for example, a measuring stick, twwwape, rope, wire, etc. The results were mostly overestimated because the water velocity at the surface is usually clearly higher than the cross-sectional average. To solve this issue, engineer Woltmann introduced in 1790 in Hamburg, Germany a method of measuring water velocity in different depths and widths of a cross-section with a propeller-like device. The current rotates the propeller and the number of revolutions per unit of time are recorded with a counter device and, subsequently, converted to the water velocity (De Doncker et al. 2008). When the cross-sectional area of the channel is simultaneously measured, the flow rate can be calculated. The Woltmann type of current meter was first used in Finland on June 25, 1862, on the Rokkalanjoki river in the then Vyborg region, and it is still in use with slight modifications (Fig. 1).

Fig. 1. OTT® C31 current meter (www.ott.com/products/water-flow-3/ott-c31-958).

In Finnish environmental administration, the current meter recordings are entered in a computer application for flow calculation included in the HydValikko system. An example is shown in Fig. 2a. In this case, the measuring tape stretched across the ditch showed reading 1.4 m at the one bank of the ditch (water depth 0 m). The first vertical where flow velocities were measured was at the measuring tape reading 2.2 m, where water depth was 88 cm, and the measurements were made at depths 78, 60, 30 and 10 cm from the water surface. In this vertical, the numbers of spins of the current meter during the 50 sec. standard measurement period were 59, 95, 18 and 10, and the water velocities 0.172, 0.265, 0.067 and 0.047 m/s, respectively (see first five rows of the table in Fig. 2a). The other verticals were at the measuring tape readings 2.7, 3.2, 3.6, 4.0, 4.5 and 4.9 m (the last three verticals are not shown in Fig. 2a) with flow measurements made at 2–4 depths. The other bank of the ditch (water depth 0 m) was at the tape reading 5.3 m, i.e. the width of the water in the ditch during the measurement was 5.3 m – 1.4 m = 3.9 meters.

U:\koskiaho_Uuhikonoja1_14112019.txt

Tiedosto Muokkaa Kuva Asetukset Laskennan ohje

Measurement site: Uuhikonoja 1

Measurement time: 14.11.2019 14:20-15:00

Current meter type: OTT

Current meter ID: 101180-A : Runko = 121528

Water height after the measurement (cm): -3,5

Measurement time (s): 50

Name of the measurer: J.Koskiaho

	Vertical (m)	Water depth (cm)	Current meter depth (cm)	N of propeller spins	N of prop. spins per second	Water velocity (m/s)
1	1.4	0				
2	2.2	88	78	59	1.180	0.172
3	2.2	88	60	95	1.900	0.265
4	2.2	88	30	18	0.360	0.067
5	2.2	88	10	10	0.200	0.047
6	2.7	90	80	100	2.000	0.278
7	2.7	90	60	159	3.180	0.429
8	2.7	90	30	125	2.500	0.342
9	2.7	90	10	86	1.720	0.242
10	3.2	90	80	38	0.760	0.119
11	3.2	90	60	81	1.620	0.229
12	3.2	90	30	55	1.100	0.162
13	3.2	90	10	107	2.140	0.296
14	3.6	84	74	99	1.980	0.275
15	3.6	84	60	120	2.400	0.329
16	3.6	84	30	109	2.180	0.301

Fig. 2a. The form page of the HydValikko system entered with the results of the flow measurement made at the Uuhikonoja ditch in Tammela, Finland on 14th November 2019. The measurer enters values for all columns, except for the last one (water velocity), the values of which are calculated by the system.

A result graph of the application is presented in Fig. 2b with flow velocities shown for each measured spot in m/s. In this case, flow (Q) was 0.5796 m^3/s at the water level -3.5 cm from a local culvert's upper edge.

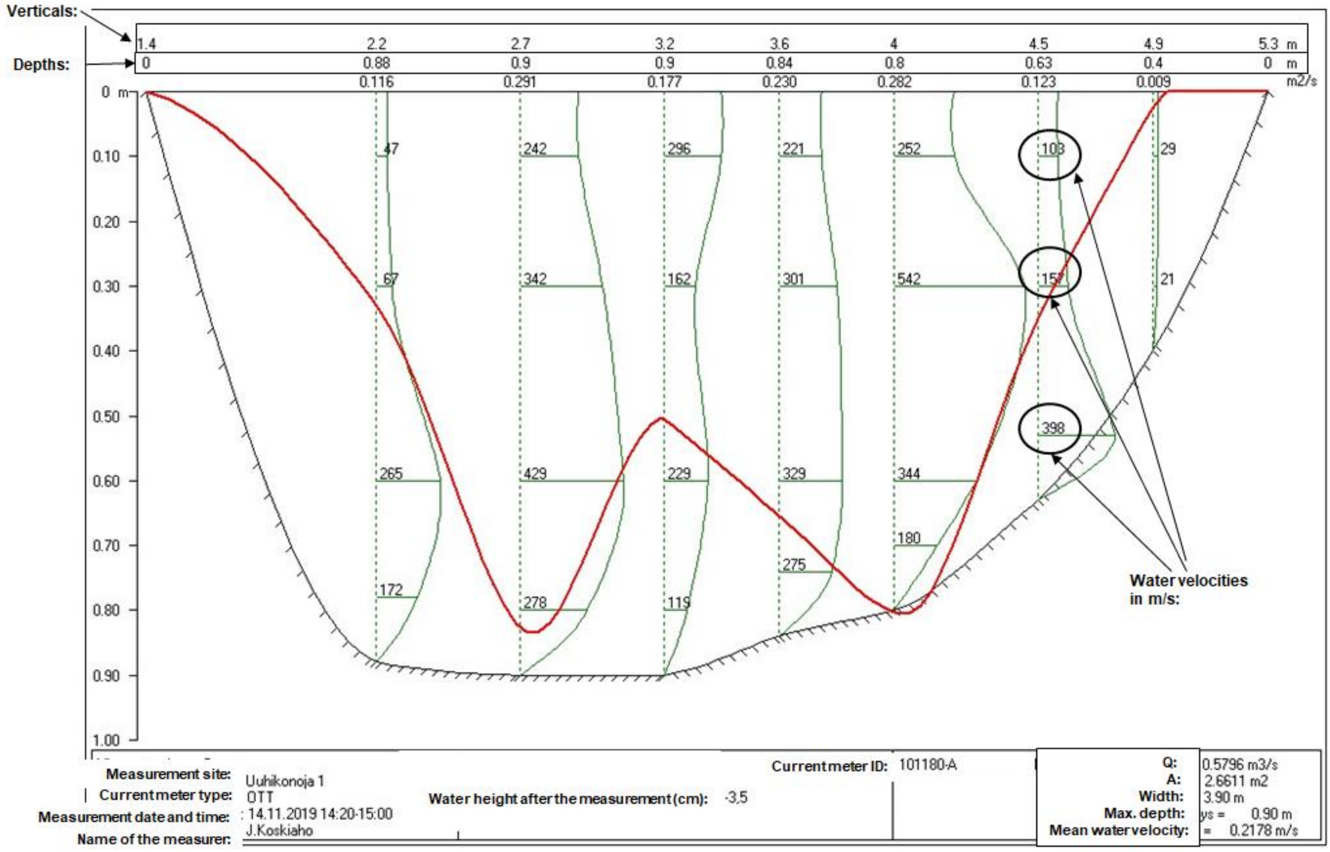

Fig. 2b. The result graph of the flow measurement made at the Uuhikonoja ditch in Tammela, Finland on 24th April 2019.

2.2 Acoustic flow metering

Nowadays, propeller-type flow measurements are already giving way to newer methods and the flow measurements are mainly performed using acoustic doppler current profiler (ADCP, Muste et al. 2004) equipment (Fig. 3a). The ADCP measures water current with sound, using the principle of Doppler effect. The ADCP works by transmitting "pings" of sound at a constant frequency into the water. As the sound waves travel, they ricochet off particles suspended in the moving water, and reflect back to the instrument. Due to the Doppler effect, sound waves bounced back from a particle moving away from the profiler have a slightly lowered frequency when they return. Particles moving toward the instrument send back higher frequency waves. The difference in frequency between the waves the profiler sends out and the waves it receives is called the Doppler shift. The instrument uses this shift to calculate how fast the particle and the water around it are moving.

Sound waves that hit particles far from the profiler take longer to come back than waves that strike close by. By measuring the time it takes for the waves to bounce back and the Doppler shift, the profiler can measure current speed at many different depths with each series of pings. To measure an entire channel cross-section, the measurer(s) first stretch a wire or rope across the channel and then slowly shift the continuously recording ADCP device from one bank to another (see Fig. 3a). The results include not only the flow rate (e.g. $m^3 s^{-1}$) during the measurement, but also a graph describing water velocities in different parts of the cross-section (Fig. 3b).

Fig. 3a. An ADCP measurement in a cross-section of the river Vantaanjoki.

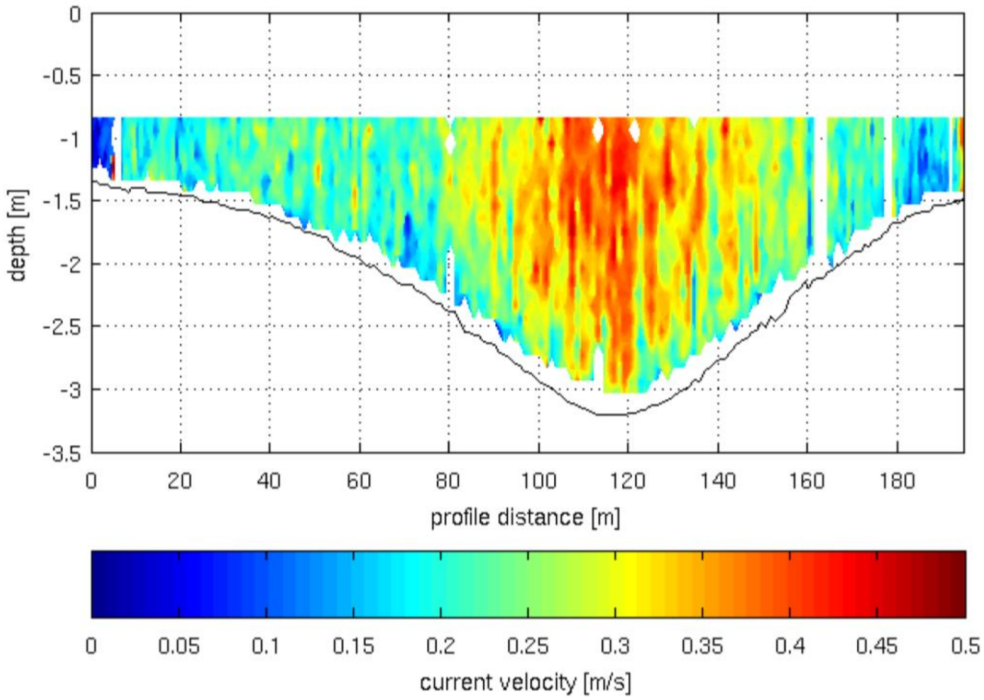

Fig. 3b. An example of the graphical description of an ADCP measurement.

2.3 Radar-based flow metering

The radar measurement method enables contactless flow velocity metering (Cheng et al. 2004). Hence, it is ideal e.g. for applications with strong sedimentation on the bottom of the channel. The radar metering, in contrast to other measurement systems, entails the benefit that it is largely independent from the properties of the measurement medium such as temperature, viscosity, density, or conductivity. Additionally, the microwave-based method stands out from the other flow measurement methods because of easy installation and low need of maintenance. Radar sensors are installed outside of or above the measurement medium. A signal with a certain frequency is transmitted out by the radar sensor. This signal is reflected when it impinges on the water surface. Once the signal is reflected from the water surface, a frequency shift is created. The radar sensor detects the reflected signal, which will be assessed through the Doppler principle (see section 2.2).

Wave formation on the water surface is the precondition for the radar technique. The sensor measures the waves' movement and therefore the surface velocity of the water. A single velocity is selectively measured on the water surface. With the help of hydraulic models, it is possible to calculate the average flow velocity from selective single velocity. An extra level sensor, which allows the determination of the wetted area, is used to measure the water level (Fig. 4a). Flow is then calculated as the product of the wetted area and the average velocity. The result graphs produced by radar measurement systems (Fig. 4b) are similar to those of ADCP (*cf.* Fig. 3b).

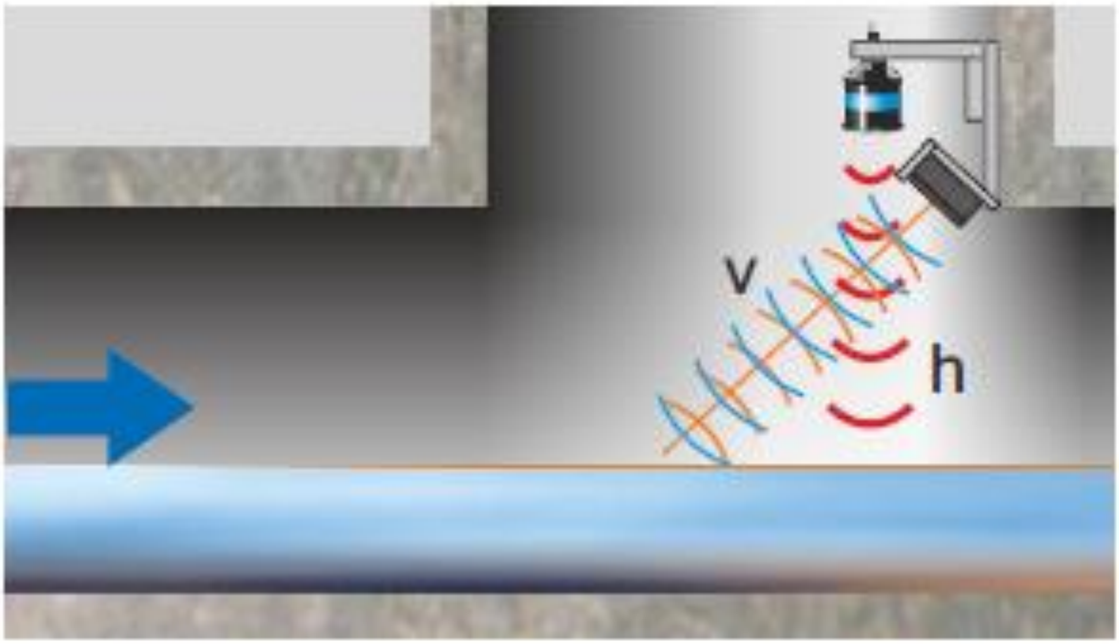

Fig. 4a. The principle of radar flow metering. Two devices measure water velocity (v) and height (h).

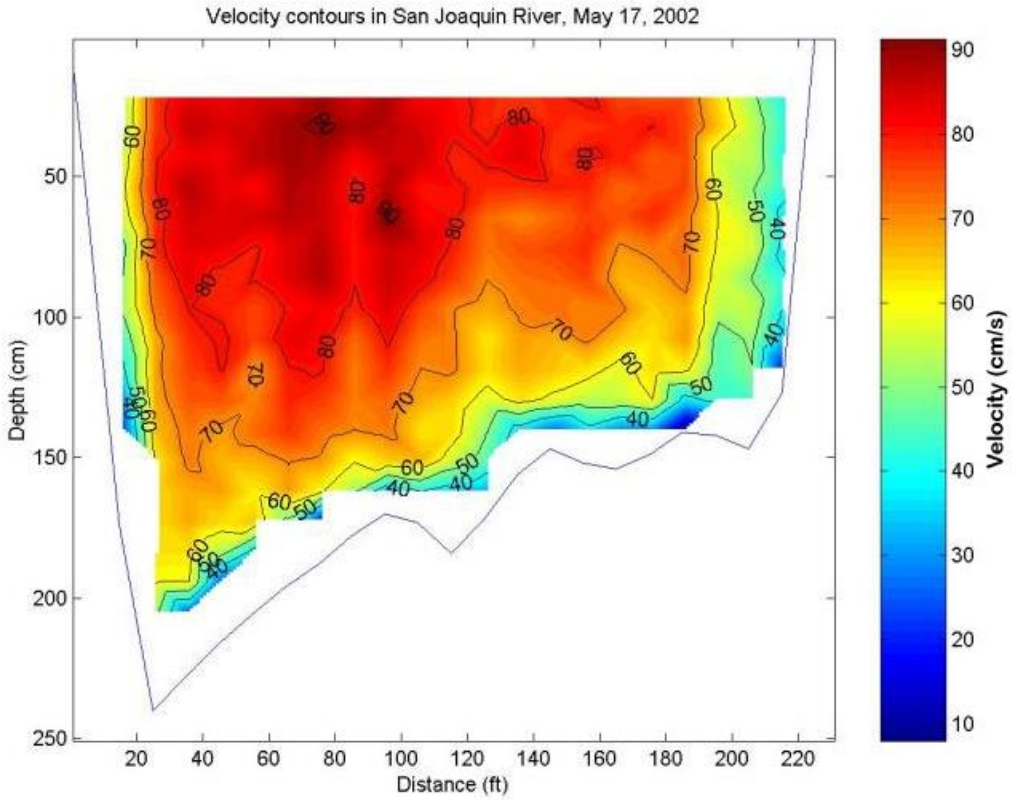

Fig. 4b. An example of the graphical description of a radar-based flow measurement (Cheng et al., 2004).

2.4 Uncertainties related to flow measurements

In hydrological measurements, there is always a degree of uncertainty involved (Di Baldassarre & Montanari 2009). These uncertainties may be due to several sources, including errors in water level and flow velocity measurements during individual measurements, assumptions regarding a particular form of the discharge curve, extrapolation of the discharge curve beyond the maximum measurement value, and cross-section change due to vegetation growth and/or bed movement.

McMillan et al. (2010) presented a method to quantify uncertainty in river discharge measurements. They introduced a concept of an ‘uncertain discharge curve’ which decomposes into a probability density function (PDF) of discharge for any given water level measurement. Use of the uncertain discharge curve provided model predictions with confidence bounds, which were more successful at enclosing the measured flow during discharge curve model validation. The uncertainties included specifically in ADCP measurements were dealt with by Lee et al. (2014), who demonstrated how a standardized uncertainty analysis framework can be successfully applied for hydrometric measurements with ADCP.

3. Flow measurements in Finland

The longest, still continuous water level time series in Finland is available from Lauritsala, Lake Saimaa, since 1847. The hydrological office in Finland was set up in 1908 and since then the measurement activity has extended to cover several new sites and variables. Today, the Finnish Environment Institute's hydrological database contains flow data based on almost real-time water level observations from the 391 stations (see Table 1), of which the Finnish Environment Institute (SYKE) and the regional centers for Economic Development, Transport and the Environment (ELY centers) maintain about 185 stations. The most important external information producer group is formed by hydropower companies. The observations are compiled as daily average flows into the hydrological database.

SYKE and the ELY centers observe the water levels mainly from natural channels. The time series of the flow are determined on the base of continuous water level observations with discharge curves (Fig. 5). A discharge curve equation can be estimated from flow measurements (see Section 2) coupled with information on simultaneous water levels. A total of 5–10 measurements are required from different water levels, in addition to which control measurements are made from time to time to check the curve equation. Discharge curves can change as a result of human activity or natural changes in the channel (hydraulic engineering, erosion, vegetation). In winter, at about 70 stations ice dams the water so that the correct flow readings cannot be obtained directly from the discharge curve. In such places, the so-called ice reduction based on winter flow measurements, watershed model (WSFS, https://www.syke.fi/en-US/Research__Development/Water/Models_and_tools/Watershed_simulation_and_forecasting_system) simulation results, and ice and weather observations is made. The stations of external flow data producers are mainly hydropower plants or control dams, the flows of which have been checked by means of calibration measurements made at the sites.

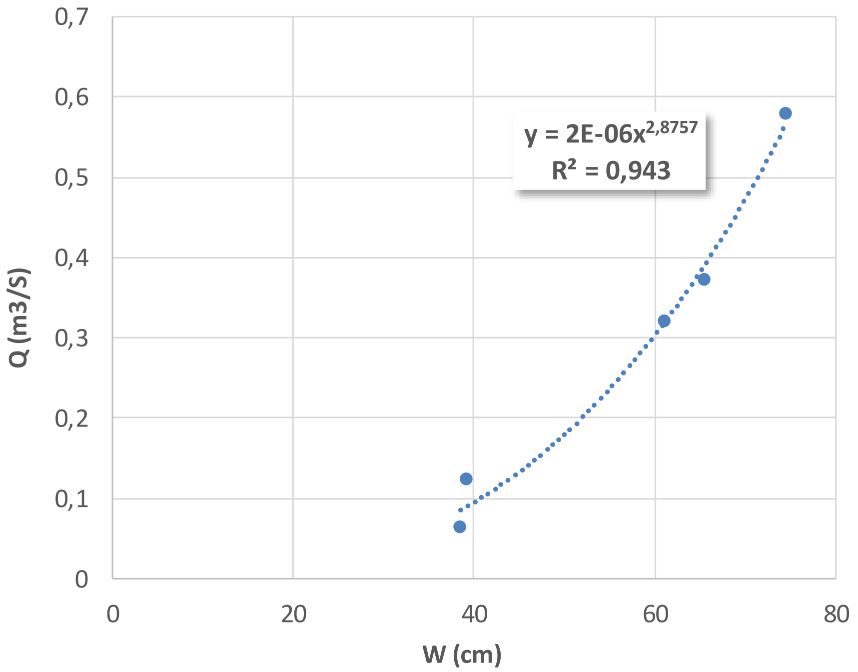

Fig. 5. An example of discharge curve. Water level (W, cm) in the x-axis and the flow rate (Q, $m^3 s^{-1}$) in the y-axis. In this case the discharge curve equation is: $Q = 2*10^{-6}*W^{2.8757}$.

The results of flow measurements are presented in www-pages of the Finnish environmental administration not only in Finnish (https://www.ymparisto.fi/vesitilanne, http://wwwi2.ymparisto.fi/i2/yleisoEnnusteetJaVaroitukset/#homeFi), but also in English (http://wwwi2.ymparisto.fi/i2/yleisoEnnusteetJaVaroitukset/#homeEn) and in Russian (http://wwwi2.ymparisto.fi/i2/yleisoEnnusteetJaVaroitukset/#homeRu).

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