RAPPORT

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Uncertainty of salt discharge measurement: Analysis of NVE's database

Usikkerhet i vannføringsmålinger målt med saltfortynningsmetoden: Analyse av målingene i filarkivet

Alexandre Christophe Hauet

NVE Rapport 28/2020

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Usikkerhet i vannføringsmålinger målt med saltfortynningsmetoden: Analyse av målingene i filarkivet

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Sammendrag:

Denne rapporten beskriver usikkerheten til vannføringsmålinger gjort med saltfortynningsmetoden for omtrent 1300 målinger i NVEs filarkiv. Dette blir gjort ved å bruke metoden beskrevet i «Uncertainty of salt discharge measurement - The SUNY Framework» (Rapport 29/2020, ISBN: 978-82-410-2050-6). Halvparten av målingene har en usikkerhet på mindre en 6% og halvparten har usikkerhet mellom 4% og 11%. For målingene med høyest usikkerhet (mer enn 20%) er hovedkildene til usikkerhet sideveis blanding og at saltbølgen enten går mye høyere eller mye lavere enn spennet til kalibreringen av sensorene.

This report describes the uncertainty of water flow measurements made with the salt dilution method for approximately 1300 measurements in NVE's file archive. This is done using the method described in "Uncertainty of salt discharge measurement - The SUNY Framework" (Rapport 29/2020, ISBN: 978-82-410-2050-6). Half of the measurements have an uncertainty of less than 6% and half have an uncertainty between 4% and 11%. For the measurements with the highest uncertainty (more than 20%), the main sources of uncertainty are bad lateral mixing and measurements where the peak of the salt wave either goes much higher or much lower than the range of the calibration of the sensors.

Emneord:

Vannføring, vannføringsmåling, salt, fortynning, saltfortynning, saltmåling, nøyaktighet, usikkerhet, usikkerhetsberegning, måleusikkerhet, feilkilder, GUM, HUG, kvalitet

Discharge, discharge measurement, salt, dilution, salt dilution, salt measurement, accuracy, uncertainty, uncertainty calculation, measurement uncertainty, sources of error, GUM, HUG, quality

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Denne rapporten er en av flere rapporter om usikkerhet i vannføringsmålinger skrevet av Alexandre Christophe Hauet, PhD, for hydrometriseksjonen på NVE. Hydrometri - Teknikk og feltdrift HHT, Hydrologisk avdeling, NVE.

Hauet jobbet i ett år for HHT, NVE, fra august 2019 til august 2020, finansiert av FoU-midler i prosjektet 80501 «Nye metoder for måling av vannføring og sedimenttransport». Usikkerhetsberegning var en viktig del av dette prosjektet.

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Report

Uncertainty of salt discharge measurement: Analysis of NVE's database

Alexandre HAUET

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1 Database and cleaning

The salt gaugings used in this study were extracted from the NVE's discharge measurements folder[1]. The xml files exported by Sommer's TQ-Commander software were used. Only the gaugings realized with two probes were selected, which consists in about 1300 measurements. A quick overview of the gauging was realized, in order to remove erroneous measurements (abnormal signals, as illustrated in figure 1). There are probably still some abnormal signals in the database (the 1300 measurements have not been checked individually), and there are probably few duplicate measurements, but we assume that their number is negligible and that it does not affect the overall statistics on the database.

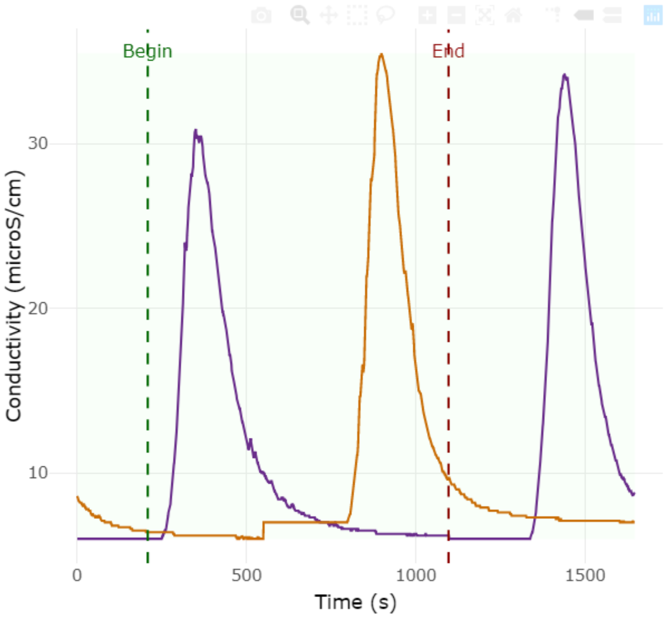


Figure 1: Example of measurement with abnormal signal, removed from the database

The final cleaned database consists in 1285 gaugings, ranging from $1L/s$ to $211m^3/s$, with a mean and median discharges of 7,65m^3/s and $1,28m^3/s$ respectively, as illustrated in figure 2.

50% of the gaugings have discharges ranging 0,260m^3/s to 5,15m^3/s, and 90% ranging 0,0248m^3/s to 36,9m^3/s, as shown in table 1.

As illustrated in figure 3, the duration of the tracer's waves of the studied measurements ranges from 255 to 13150s, with a median duration of 1340s (about 20min).

[1] //nve.no/fil/h/HH/Vannføringsmålinger

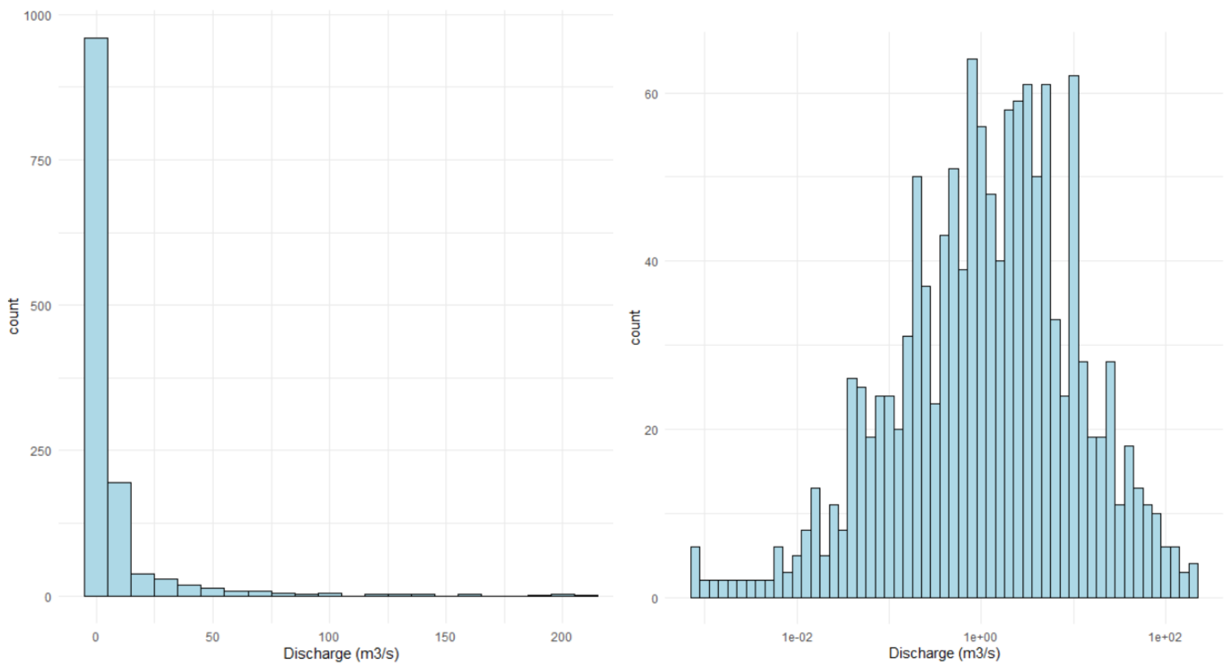


Figure 2: Bar-plots of the distribution of the discharges for the gaugings used in that study in normal scale (left) and log-scale (right)

Statistic	Mean	5%	25%	50%	75%	95%
Discharge (m^3/s)	7,65	0,0248	0,260	1,28	5,15	36,9

Table 1: Statistics of the discharges for the gaugings used in that study

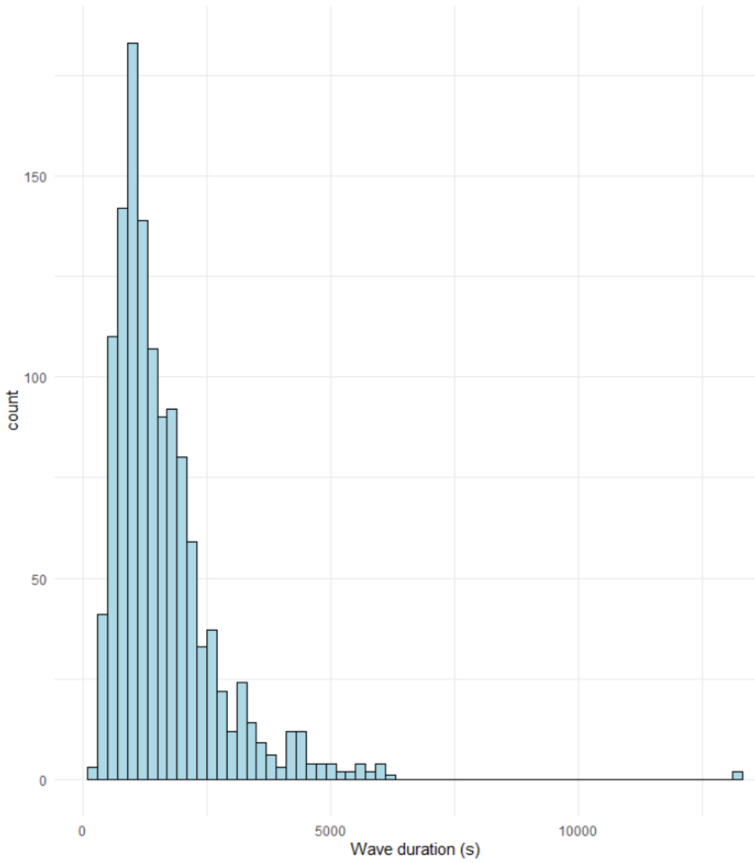


Figure 3: Bar-plots of the distribution of the wave duration for the gaugings used in that study

2 Uncertainty analysis

The uncertainty analysis called SUNY and described in the SUNY Technical Paper was applied to the database. The following uncertainty sources are considered:

- Mixing: uncertainty due to a bad mixing of the tracer, computed for each measurement using the difference of discharge measured by the two probes.
- Probe resolution and noise: uncertainty due to the resolution of the sensors (taken at 0,1 $\mu S/cm$ for the TQ-tracer) and to the noise of the signal, computed as the dispersion of the signal before and after the tracer wave, computed for each measurement.
- Location of end: uncertainty due to the accuracy of the location of the end of the wave, taken by default at 10%.
- Calibration law: uncertainty due to the accuracy of the equipment used for the calibration, including flask (tolerance of 0,1%) and pipette (tolerance of 1%), and the operator and environment effects (standard-deviation of 2%) computed for each measurement and to the uncertainty of the calibration solution (standard-deviation of 2%). The uncertainty of the linear regression is also taken into account.
- Range of calibration: uncertainty if the measurement conductivity range is not in agreement with the calibration conductivity range, for example if the wave peak is greater than the highest point of the calibration, if the measurement base is lower than the lowest point of the calibration, computed for each measurement..
- Sampling: uncertainty due to the limited number of points describing the tracer wave, computed for each measurement. If the wave is very short and only described with few points, the uncertainty will be high.

The following error sources are part of the uncertainty framework, but not taken into account for the automatic analysis of NVE's database:

- Temperature: uncertainty due to the accuracy of the temperature probe, taken at 0,5° by default.
- Mass of salt: uncertainty in the mass of salt injected, set to 0,5% by default.
- Base conductivity: uncertainty due to a possible variation of the base conductivity during the tracer wave, set to 0% by default.
- Residual errors: uncertainty due to the bias of the method itself, set to 0% by default.
- Flow steadiness: uncertainty due to the unsteadiness of the flow, meaning that the discharge changed during the wave of tracer, set to 0 m^3/s by default.

- Tracer loss: uncertainty due to a possible loss of salt during the injection, or in the river (sedimentation), set to 0 g by default.
- Time: uncertainty due to the accuracy of the measurement of the time between the recording of conductivity, set to 0 s by default.

2.1 Total expanded uncertainty

The total expanded uncertainty, at the 95% confidence level, ranges from 2,8 to 44,2%, with a mean and median values of 8,4% and 5,8% respectively. As illustrated in figure 4, the most represented uncertainty values are 3 to 6%. The statistics of the expended uncertainty are

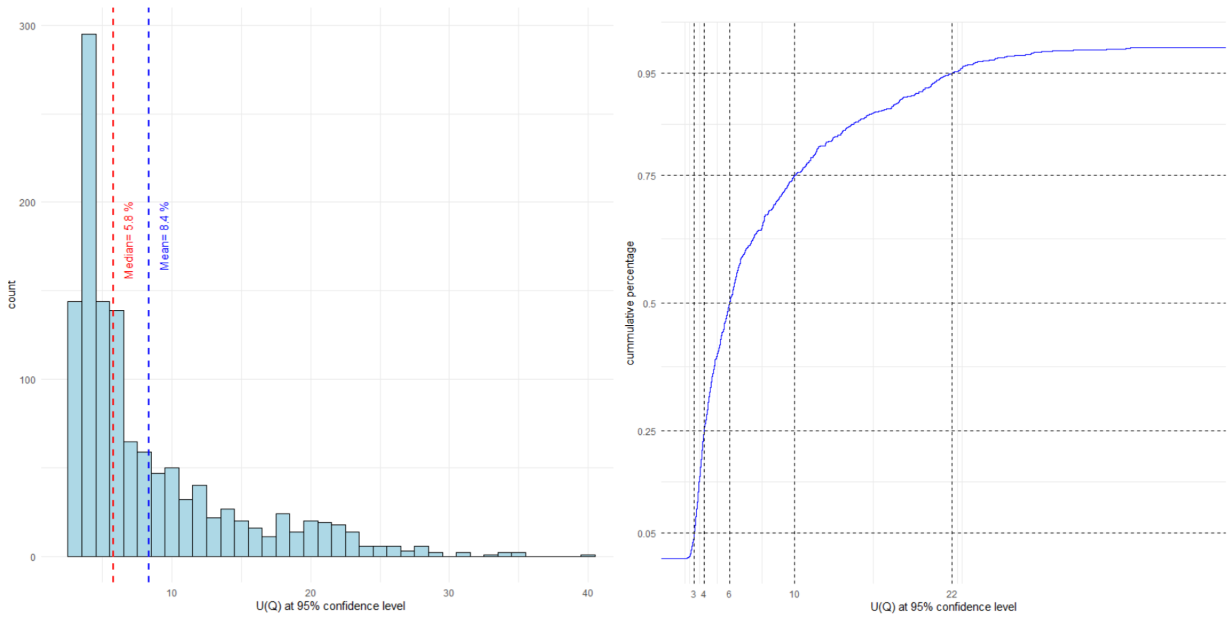


Figure 4: Distribution (left) and cumulative distribution (right) of the total expanded uncertainty

given in table 3

Statistic	Mean	5%	25%	50%	75%	95%
Expanded uncertainty (%)	8,4	3,3	4,0	5,8	10,6	21,9

Table 2: Statistics of the expended uncertainty for the gaugings used in that study

Figure 5 shows that there is no link between (i) the total uncertainty and the discharge and (ii) the total uncertainty and the base conductivity of the measurement.

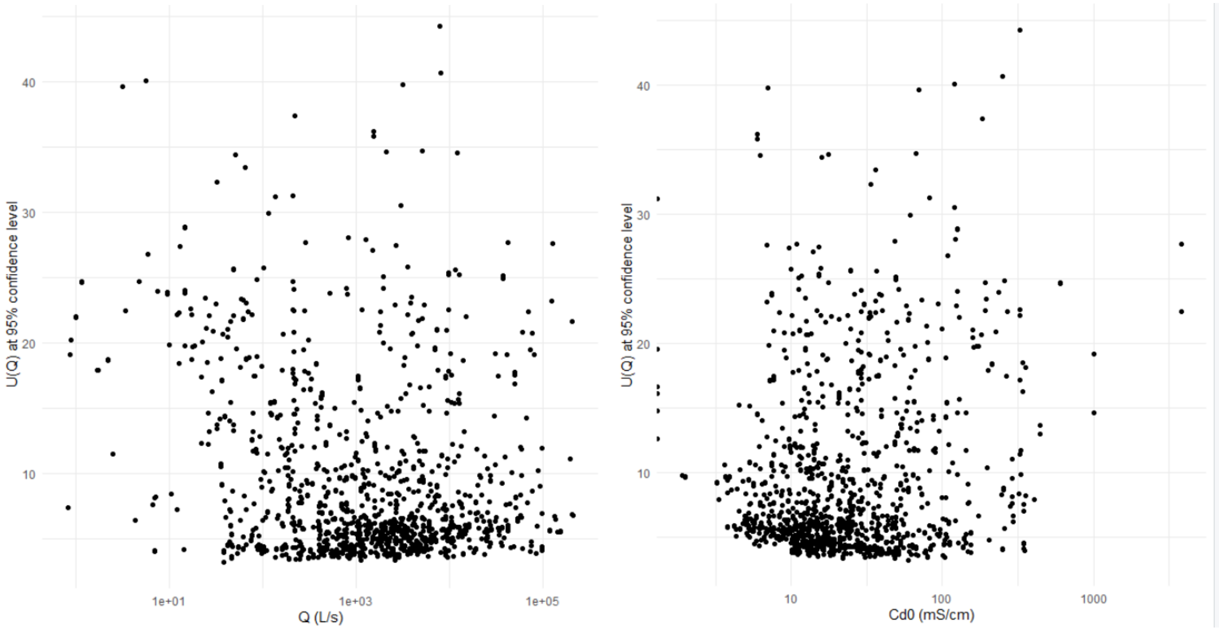


Figure 5: Relationship between the total uncertainty and the discharge (left) and the base conductivity (right)

2.2 Uncertainty budget

Figure 6 shows the global budget of uncertainty for all the gauging studied. On median values, the uncertainty due to the calibration coefficient (CF) is the most important source of uncertainty (2,8%), but with few dispersion (95% of the value are less than 3,1%). Uncertainty due to mixing has a median value of only 2%, but it can reach very high values (95% of the value are less than 13,9%), as for uncertainty due to the range of the calibration with a median of 1,3% and 95% of the values being less than 17,9%. Those two uncertainty sources are mainly responsible for measurements with high uncertainty.

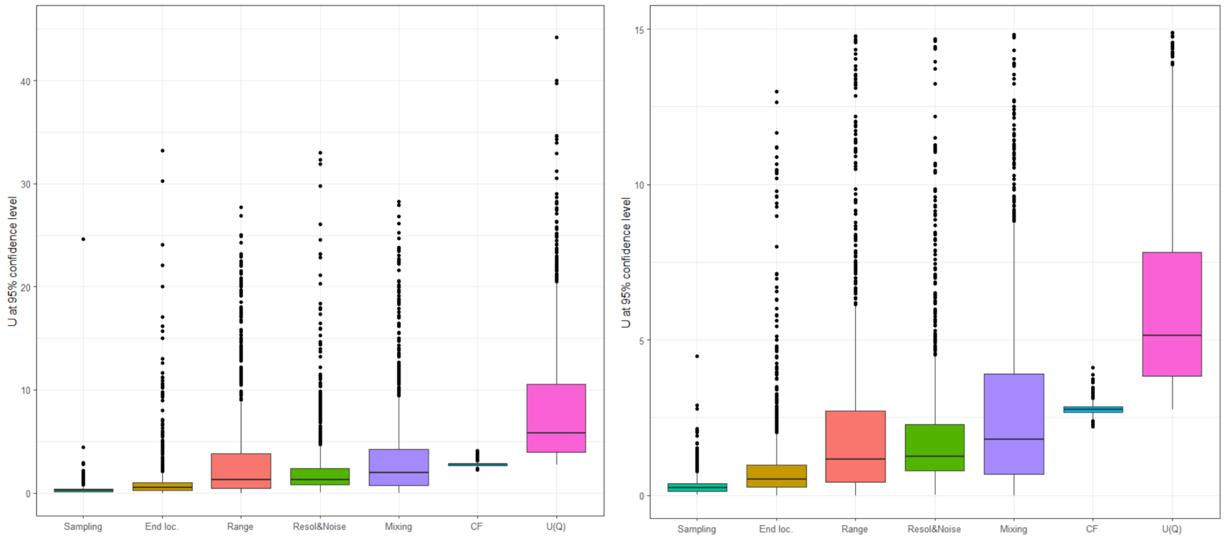


Figure 6: Global budget of uncertainty for the gaugings used in that study, sorted by median (right: zoomed view)

Uncertainty due to resolution and noise has a low median (1,3%), but it can reach quite high values, as the 95% quantiles is 7,3%. Uncertainty due to the location of the end limit of the tracer wave has a low median (0,5%) and low 95% quantile (3,4%). This source of uncertainty is often low in the total budget, except for very few specific gaugings. Uncertainty due to the limited number of time step (sampling) is always very low, with a median of 0,2% and 95% of the value lower than 0,9%, considering the high sampling frequency of the sensors (often 1 Hz). Table 3 presents the median and 95% quantile for all the computed uncertainty sources.

In order to show the uncertainty sources that are responsible for gauging with high total uncertainty, the global budget of uncertainty is presented in figure 7 for the measurements having a total uncertainty higher than 20%, coresponding to a total of 99 gaugings. It is clear from figure 7 that uncertainty due to Mixing and Range of calibration are dominant for measurements with high total expanded uncertainty.

Uncertainty Source	Median (%)	95% quantile (%)
Sampling	0,2	0,9
End location	0,5	3,4
Resolution and Noise	1,3	7,3
Range of calibration	1,3	17,9
Mixing	2,0	13,9
CF	2,8	3,1

Table 3: Global budget of uncertainty - median and 95% quantile of the uncertainty sources

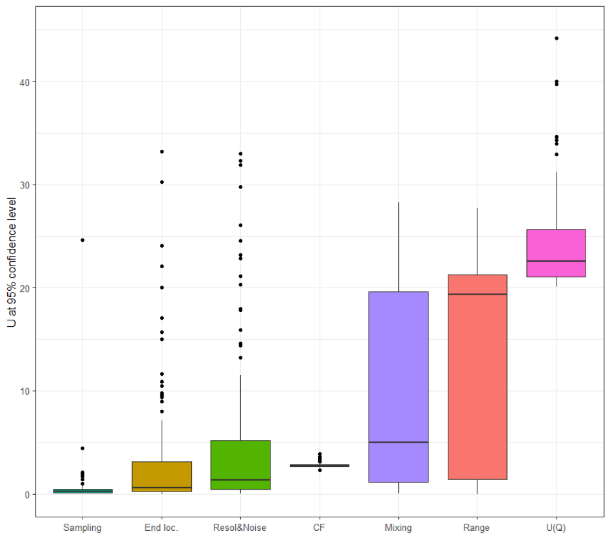


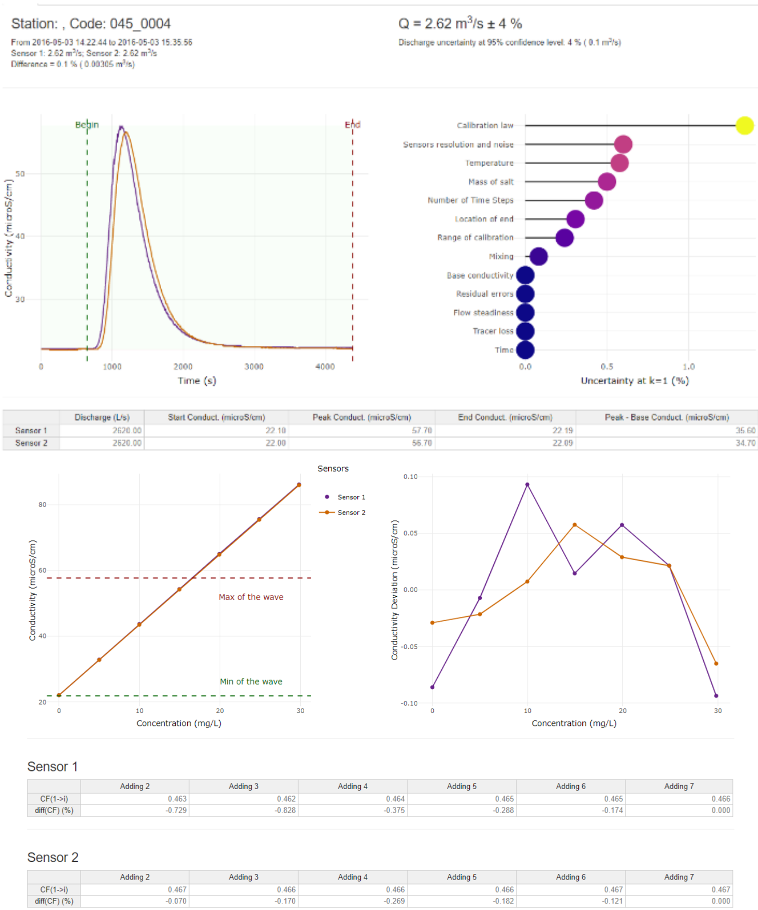
Figure 7: Global budget of uncertainty for the gaugings used in that study with total uncertainty higher than 20%, sorted by median

3 Example of measurements

In the following sections, some example of gaugings are presented to illustrate the uncertainty sources.

3.1 Low uncertainty measurement

The measurement shown in figure 8 shows a very well defined wave shape, with a constant base conductivity, a value of conductivity for the peak well above the base (+35 $\mu S/cm$). The wave is in the range of the calibration. The two probes give identical values of discharges. As a result, all the uncertainty sources are very low, and the total uncertainty expended at the 95% confidence level is 4%.



	Discharge (L/s)	Start Conduct. (microS/cm)	Peak Conduct. (microS/cm)	End Conduct. (microS/cm)	Peak - Base Conduct. (microS/cm)
Sensor 1	2620.00	22.10	57.70	22.19	35.60
Sensor 2	2620.00	22.00	56.70	22.09	34.70

Sensor 1

	Adding 2	Adding 3	Adding 4	Adding 5	Adding 6	Adding 7
CF(1->i)	0.463	0.462	0.464	0.465	0.465	0.466
diff(CF) (%)	-0.729	-0.828	-0.375	-0.288	-0.174	0.000

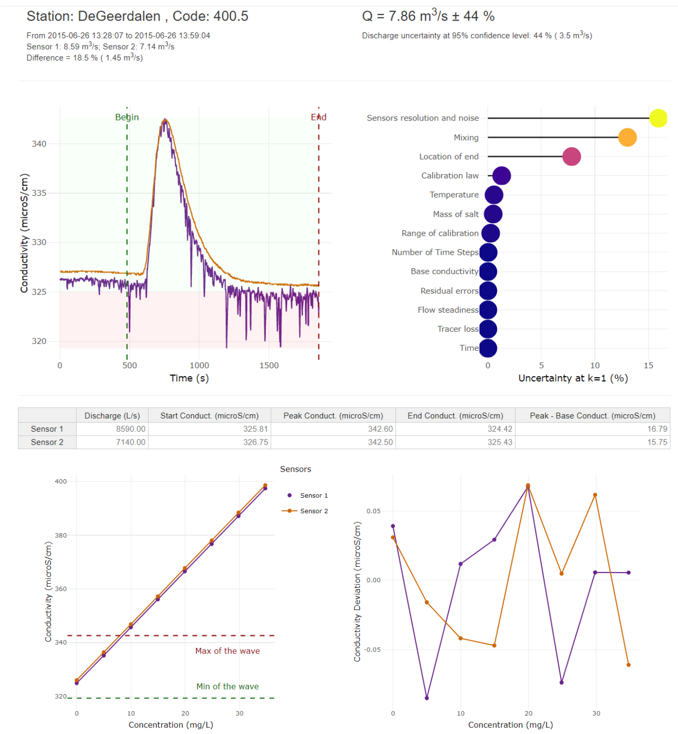
Sensor 2

	Adding 2	Adding 3	Adding 4	Adding 5	Adding 6	Adding 7
CF(1->i)	0.467	0.466	0.466	0.466	0.467	0.467
diff(CF) (%)	-0.070	-0.170	-0.269	-0.182	-0.121	0.000

Figure 8: Example of a low uncertainty measurement

3.2 High uncertainty measurement

Figure 9 shows a very noisy measurement, especially for one of the two sensors, with some spikes at $\pm$ 5 $\mu S/cm$ and a difference between the peak and the base conductivity of 25 $\mu S/cm$. The base conductivity evolved during the measurement (it seems to be lower at the end of the tracer wave), so that the location of the end is very sensitive. The two sensors also give different discharges (difference of 18%). As a results, the uncertainty due to the noise, to the mixing and to the location of the end are important, and the total expanded uncertainty reaches 44%.



	Discharge (L/s)	Start Conduct. (microS/cm)	Peak Conduct. (microS/cm)	End Conduct. (microS/cm)	Peak - Base Conduct. (microS/cm)
Sensor 1	8590.00	325.81	342.60	324.42	16.79
Sensor 2	7140.00	326.75	342.50	325.43	15.75

Sensor 1

	Adding 2	Adding 3	Adding 4	Adding 5	Adding 6	Adding 7	Adding 8
CF(1->i)	0.485	0.480	0.479	0.478	0.479	0.479	0.479
diff(CF) (%)	1.205	0.128	-0.066	-0.165	0.024	0.007	0.000

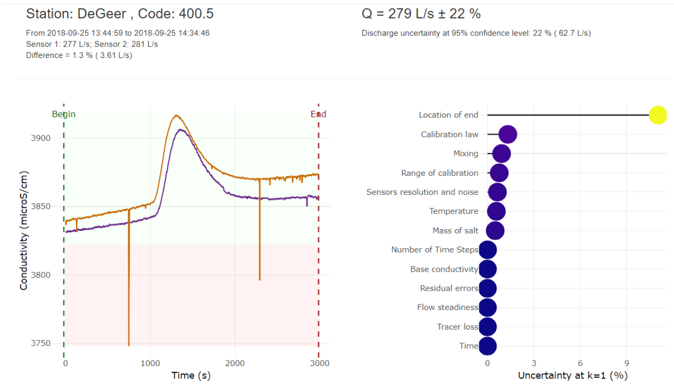
Sensor 2

	Adding 2	Adding 3	Adding 4	Adding 5	Adding 6	Adding 7	Adding 8
CF(1->i)	0.480	0.480	0.479	0.478	0.478	0.478	0.478
diff(CF) (%)	0.450	0.350	0.250	-0.043	-0.032	-0.083	0.000

Figure 9: Example of a high uncertainty measurement

3.3 High uncertainty due to the location of the end

Figure 10 shows a measurement with an increasing base conductivity. It is thus complex to identify when the signal is back to the base value, and the uncertainty due to the location of the end is high.

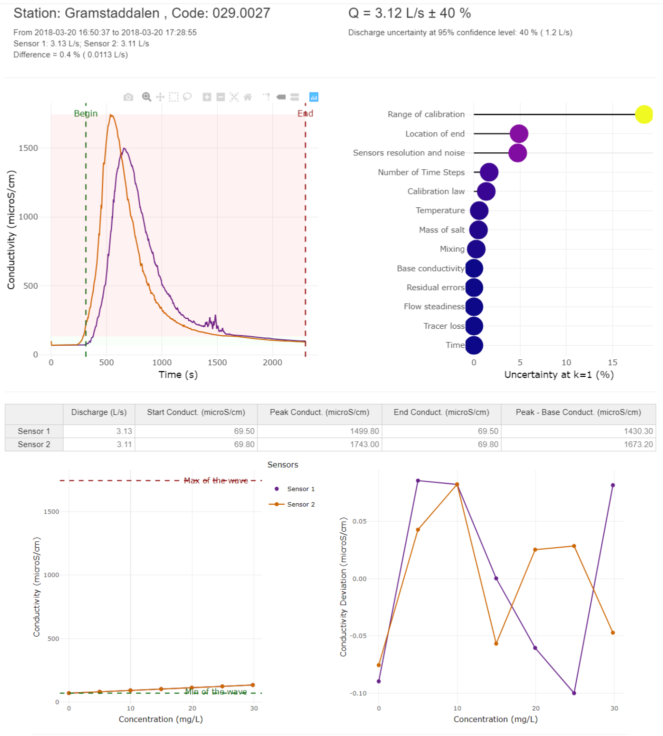


	Discharge (L/s)	Start Conduct. (microS/cm)	Peak Conduct. (microS/cm)	End Conduct. (microS/cm)	Peak - Base Conduct. (microS/cm)
Sensor 1	277.00	3831.20	3906.50	3856.78	75.30
Sensor 2	281.00	3839.50	3916.70	3871.45	77.20

Figure 10: Example of measurement with high uncertainty due to the location of the end

3.4 High uncertainty due to range of calibration

Figure 11 shows a measurement with a very high value of conductivity for the peak (1700 $\mu S/cm$) compared to the base (50 $\mu S/cm$). The calibration, realized prior to the measurement, ranges from 50 to 100 $\mu S/cm$, so a very important part of the wave is out of the range of the calibration (highlighted in red background in figure 11). As a result the uncertainty due to the range of calibration is high (18%).



	Discharge (L/s)	Start Conduct. (microS/cm)	Peak Conduct. (microS/cm)	End Conduct. (microS/cm)	Peak - Base Conduct. (microS/cm)
Sensor 1	3.13	69.50	1499.80	69.50	1430.30
Sensor 2	3.11	69.80	1743.00	69.80	1673.20

Sensor 1

	Adding 2	Adding 3	Adding 4	Adding 5	Adding 6	Adding 7
CF(1->i)	0.458	0.462	0.465	0.466	0.466	0.466
diff(CF) (%)	-1.606	-0.797	-0.250	0.024	0.153	0.000

Sensor 2

	Adding 2	Adding 3	Adding 4	Adding 5	Adding 6	Adding 7
CF(1->i)	0.463	0.464	0.467	0.467	0.467	0.468
diff(CF) (%)	-1.095	-0.734	-0.093	-0.097	-0.088	0.000

Figure 11: Example of measurement with high uncertainty due to the range of the calibration

3.5 High uncertainty due to noise and resolution of the probes

Figure 12 shows the impact of the probes resolution (0,1 $\mu S/cm$) and of the noise of the signal, especially when the difference between the base and the peak value is small. The measurement at the top of figure 12 shows a difference between the base and the peak conductivity of only 7 $\mu S/cm$ for one of the probe, and 9 $\mu S/cm$ for the second probe. The resolution of the sensor creates steps in the signal, and the associated uncertainty is important (about 16%). The measurement at the bottom of figure 12 shows important noise (with spikes of about $\pm$ 1 $\mu S/cm$) and a difference between the peak and the base conductivity of only 6 to 7 $\mu S/cm$, resulting in an uncertainty due to the noise of 17%.

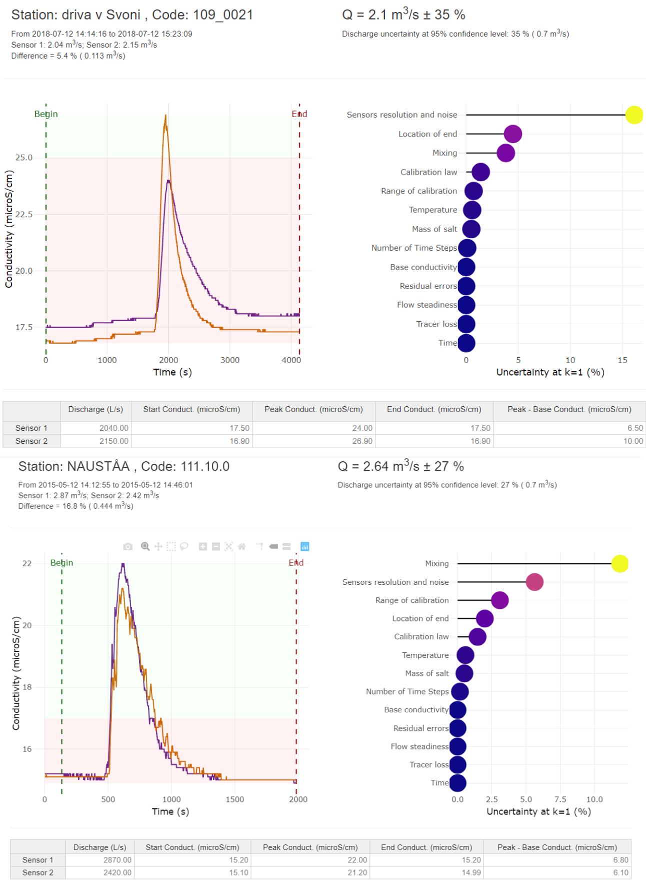
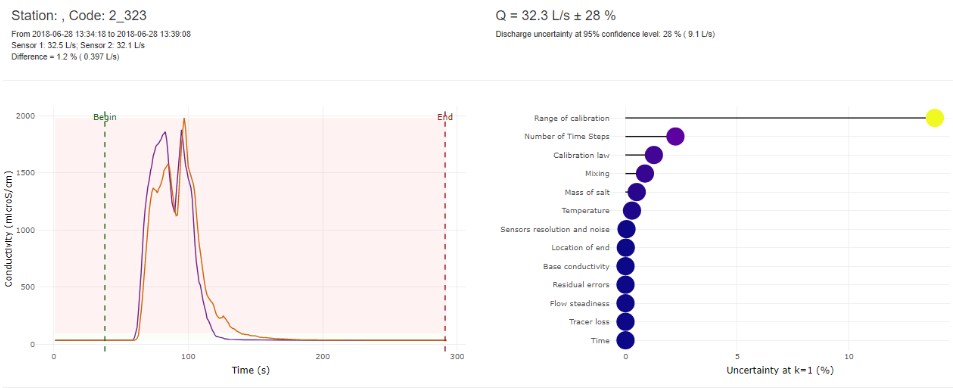


Figure 12: Example of measurement with high uncertainty due to the resolution (top) and the noise (bottom) of the probes

3.6 High uncertainty due to the limited number of time steps

The uncertainty due to the limited number of time steps can be high if the duration of the wave is very short or/and if the tracer wave has a very complex shape and not enough samples to describe it, as illustrated in figure 13. Considering the high sampling frequency, this uncertainty source is always low in NVE's database.

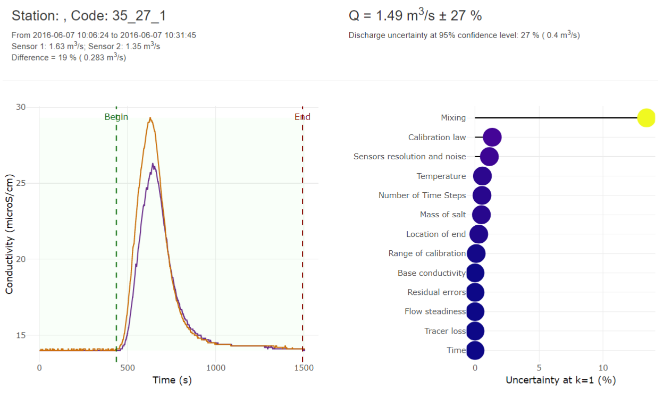


	Discharge (L/s)	Start Conduct. (microS/cm)	Peak Conduct. (microS/cm)	End Conduct. (microS/cm)	Peak - Base Conduct. (microS/cm)
Sensor 1	32.50	33.80	1875.90	33.80	1842.10
Sensor 2	32.10	33.90	1979.30	33.90	1945.40

Figure 13: Example of measurement with high uncertainty due to the limited number of time steps

3.7 High uncertainty due to bad mixing

The uncertainty due to bad mixing is high if the difference between the discharges computed by the two probes is important, as illustrated in figure 14.



	Discharge (L/s)	Start Conduct. (microS/cm)	Peak Conduct. (microS/cm)	End Conduct. (microS/cm)	Peak - Base Conduct. (microS/cm)
Sensor 1	1630.00	14.00	26.30	14.00	12.30
Sensor 2	1350.00	14.02	29.30	14.02	15.29

Figure 14: Example of measurement with high uncertainty due to bad mixing

4 Conclusions

In this report, we analyse the uncertainty of all the salt dilution gaugings stored in NVE's database using the SUNY framework. It consists in about 1300 measurements, ranging 1 L/s to 211 m^3/s.

The total expanded uncertainty, at the 95% confidence level, ranges from 2,8 to 44,2%, with a mean and median values of 8,4% and 5,8% respectively. The most represented uncertainty values are 3 to 6%.

Uncertainty due to mixing has a median value of only 2%, but it can reach very high values(95% of the value are less than 13,9%), as for uncertainty due to the range of the calibration with a median of 1,3% and 95% of the values being less than 17,9%. Those two uncertainty sources are mainly responsible for measurements with high uncertainty.

Uncertainty due to resolution and noise has a low median (1,3%), but it can reach quite high values, as the 95% quantiles is 7,3%. Uncertainty due to the location of the end limit of the tracer wave has a low median (0,5%) and low 95% quantile (3,4%). This source of uncertainty is often low in the total budget, except for very few specific gaugings. Uncertainty due to the limited number of time step (sampling) is always very low, with a median of 0,2% and 95% of the value lower than 0,9%, considering the high sampling frequency of the sensors (often 1 Hz).

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