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Variation in discharge data and correction routines at the Norwegian Water Resources and Energy Directorate, Norway

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The Norwegian Water Resources and Energy Directorate (NVE) is responsible for managing the Norwegian water resources. A fundamental activity is the collection and quality control of hydrometric data from discharge stations.

Two main challenges in performing quality control is the correction of erroneous data due to ice formation and reconstruction of lost data. Both processes are scientific disciplines involving use of support data, statistical tools, discharge measurements as well as personal experience and opinion.

This study has aimed to analyze variations in corrected discharge data as well as in belonging routines for data correction among field hydrologists at NVE. Field hydrologists were given an identical set of three data correction tasks. Two tasks involved ice correction from both an on-off-ice discharge series and a stable-ice discharge series, while the third task was on data reconstruction. In the ice correction tasks, variation of individual performance were quantified by calculating the relative deviation and Root Mean Square Error from the mean result. In the data reconstruction task, individual performance were quantified by calculating Root Mean Square Error values and Nash-Sutcliffe model efficiency with reference to the real data, hidden for the participants. Differences in methodology, time of service working as a field hydrologist and preceding acquaintance with the two discharge stations used for the exercises were documented from questionnaires. Participants were also asked whether their work effort was affected by time pressure, impatience with slow software or other factors.

When comparing mean daily runoff (m^3/s) in the ice correction tasks, results from the on-off-ice discharge series varied 12%, while results from the stable-ice discharge series varied 156%. Participants using identical support data for the on-off-ice series ended up with unequal results. In data reconstruction, the best results produced by field hydrologists with the most experience had RMSE values of $\leq 14\ m^3/s$ and NSE values of 0.94. Poor performances had RMSE values of $\geq 50\ m^3/s$ and NSE values of 0.14. When reconstructing data, most participants build their own discharge series through linear regression analysis, while only few used data from a hydrological model. Answers from questionnaires revealed that time pressure had a higher effect on the work effort in this study than in a normal work situation, where professional contentment defines when work is considered completed.

1. Introduction

River discharge data is used for many purposes, including flood forecasting, runoff analysis, calculation of hydropower potentials, environmental concerns, and more. The output of analysis using hydrological data depends on the data input quality. Two large contributors determining data quality of discharge time series is the rating curve uncertainty and the uncertainty from data corrections. If instrumentational adjustments is disregarded from the category of data corrections, remaining alterations in discharge data can be divided into two main categories. One comes from the correction of backwater due to ice formation, while the other is due to reconstruction of missing data.

A wide variety of approaches for ice correction and reconstruction of missing discharge data are described in literature. For ice correction, many methods are qualitative, while a number of quantitative approaches have also been developed. Qualitative techniques are reviewed in Rosenberg and Pentland (1966); Rantz (1982); Melcher and Walker (1990); Pelletier (1990). These include 1) the effective gauge height-, backwater shift- and K-factor methods that rely on empirical relationships between ice-affected vs. measured stage or discharge values 2) the interpolated discharge-, adjusted discharge- and hydrographic/climatic comparison methods, which primarily depend on of discharge measurements and various support data 3) and recession estimates. The simplest quantitative methods for ice correction includes linear interpolation between discharge measurements, empirical relations between the open-water to ice-cover hydraulic mean depth (Melcher and Walker 1990) and relationships between stage, discharge and fall heights (Carey 1967). Other approaches involve linear regression (Fontaine 1983; Chokmani *et al.* 2008) in one case using specific conductance as input variable (Melcher and Walker 1990), and the establishment of winter rating curves (Melcher and Walker 1990; Pelletier 1990). Quantitative ice correction has also been tested by use of hydraulic approaches (Carey 1967; Hicks and Healy 2003), hydrological modelling (Hamilton *et al.* 2000) and several other modelling techniques (Holtschlag 1996; Holtschlag and Grewal 1998; Huttunen *et al.* 1997; Chokmani *et al.* 2008). For data reconstruction, the simplest, methods often used for short data gaps or periods with little discharge variation are manual infilling of values or interpolation between one or several data points (Rees 2008). Another group of approaches is flow comparison techniques, where discharge values for the target station are calculated using weighed/scaled values from donor station(s) (Hirsch 1979; Wallis *et al.* 1991) or by comparison of flow duration curves (Hughes and Smakhtin

1996; Harvey *et al.* 2012). Data can also be reconstructed by use of linear regression (Salas 1993; Harvey *et al.* 2012; Tencaliec *et al.* 2015; Kamwaga *et al.* 2018) or by hydrological modelling (Ilunga and Stephensen 2005; Zhang and Post 2018).

Having good tools at hand when performing ice correction and data reconstruction is essential. However, data output may also be highly affected by personal opinion and experience in choice of method as well as in interpretation of data during the correction process. Hence, consequences for further analysis may depend on which person performs the data correction.

In Norway, The Norwegian Water Resources and Energy Directorate (NVE) is responsible for collecting and correcting runoff data from discharge stations. Field hydrologists perform quality control on the incoming stage and discharge data. The task of correcting erroneous discharge data is highly subjective. As shown by Petterson (2004), individual results from 10 persons performing ice correction on three Norwegian discharge series at NVE varied 47% to 59% in daily runoff (m^3/s) November-April, compared to the mean result of all participants. Other literature on individual differences in data correction is sparse. In an evaluation of numerous approaches for ice correction by Melcher and Walker (1990), three field hydrologists performed ice correction on three time series in Iowa, USA, using six different subjective approaches. Depending on method and time series, results between participants compared to a reference baseline time series varied from 7% to 76%, and in 10 of 18 cases more than 30%. Also, in Hamilton *et al.* (2000) three field hydrologists did ice correction on a data series from Yukon, Canada by use of discharge measurements and climatic comparison. Calculations of a mean absolute relative error index compared to reference data composed of other discharge measurements revealed individual differences from 1% to 10%, highest during fall and lower in the mid-winter and spring period.

The current study has aimed to further analyze variations in corrected discharge data and belonging methodologies for data correction at NVE. Data for the analysis has been collected through two ice correction tasks and one data reconstruction exercise performed by all hydrologists. Variation of individual performance has been quantified by calculating differences in average daily runoff (m^3/s), and by use of Root Mean Square Error (RMSE) and Nash-Sutcliffe model efficiency (NSE) statistics. Methodological differences as well as individual time of service working as a field hydrologist and preceding acquaintance with the two discharge stations used for the exercises has been documented through questionnaires. Finally, field hydrologists has been asked whether the work effort in the exercises has been affected by time pressure, impatience with slow software or other factors.

2. Physical Setting

Norway covers an area of ~ 324,000 km^2 and reaches from latitude 58°N to 71°N. Because of the latitudinal distance and varied topography, the Norwegian climate displays large variations. Along the Atlantic coast, the North Atlantic Current influences the climate whereas the inland areas experiences a more continental climate. Based on the Köppen-Geiger classification scheme, the Norwegian climate can largely be classified in three types: warm temperate fully humid climate, snow fully humid climate and polar tundra climate (Kottek *et al.* 2006). The largest annual precipitation values are found near the coast of Western Norway with up to 3575 mm/year. In contrary, the driest areas receiving <500 mm/year are found in parts of Eastern Norway and

Finnmark (Førland 1993). Following the classification of hydrological regions by Gottschalk *et al.* (1979), runoff of Norwegian rivers can be divided into several flow regimes. Inner and Northern parts of Norway exhibits long lasting low flows in winter and highest peak floods in spring / early summer due to snowmelt. Fjord areas along the west coast and inner areas of Eastern Norway also have low flows in winter, however peak floods are both caused by snowmelt as well as rain events, typically during autumn. Areas closer to the sea can be divided into several transition regimes, while outermost coastal regions, except from areas north of Lofoten, are dominated by summer low flows and highest peak floods in autumn / early winter caused by rain (Gottschalk *et al.* 1979).

3. Data Correction Routines at NVE

At NVE, a group of 20-25 field hydrologists review and correct incoming stage and discharge data from ~570 discharge stations around the country. Data correction procedures are divided in two categories. 1) Non-subjective corrections with the purpose to provide correct (but not necessarily complete) stage data. Adjustments belonging in this category are typically related to instrumentational problems, such as gauge corrections, adjustment for sensor drifting or removal of false spikes in data. 2) Corrections with the purpose to provide complete discharge data. This latter group of corrections can be divided into two main categories. One includes the correction of backwater due to ice formation, while the other is due to reconstruction of missing data.

In contrast to many other agencies using commercially available software for data computation, at NVE all computer programs for visualization and analysis of discharge data are in-house products. A variety of tools and data are available, including geospatial catchment statistics, infilling-, interpolation- and scaling of target vs. donor discharge time series, support data on precipitation, air- and water temperature, as well as data from winter discharge measurements and manual gauge readings. Discharge series for data reconstruction can be generated through simple or multiple linear regression or, by use of hydrologically modelled data. The main hydrological model used at NVE for computing discharge is the semi-distributed conceptual HBV-model, described by Bergström (1992); Sælthun (1996); Lindström *et al.* (1997); Ruan and Langsholt (2017).

4. Materials and Methods

4.1. Discharge Series for Analysis

Field hydrologists were given an identical set of discharge series for each of the three data correction exercises, hereafter termed E1, E2 and E3. Data was taken from the two discharge stations Kinne and Svartfossberget. Data from Kinne was applied for the exercise E1 dealing with ice correction through the winter period 2010 – 2011 (Table 1). The station is located in Western Norway (Figure 1). Winter runoff is dominated by low flows, interrupted by short increases in discharge due to temporary warmer weather. The control at the station consists of a natural cross section of 30-35 meters width (Figure 1; Table 2). Backwater in winter at Kinne is typically caused by active frazil and anchor ice, following the river ice classification model of Turcotte and Morse (2013). Data for the ice correction exercise (E2) and for data reconstruction (E3) was taken from the discharge station Svartfossberget (Table 1). The station is located inland in Northern Norway (Figure 1) in an area with stabile cold winters. Thus, winter runoff is low from November to April followed by the highest annual peak floods occurring in spring / early summer, due to snowmelt (Table 2). The control at Svartfossberget consists of a natural reach with a width of 35-40 meters (Figure 1). Backwater in winter is believed to be due to both frazil ice, anchor ice and the observed surface ice cover. However, it is unknown whether the surface ice exhibits confining or only floating behavior, referring to the surface ice definitions of Turcotte and Morse (2013).

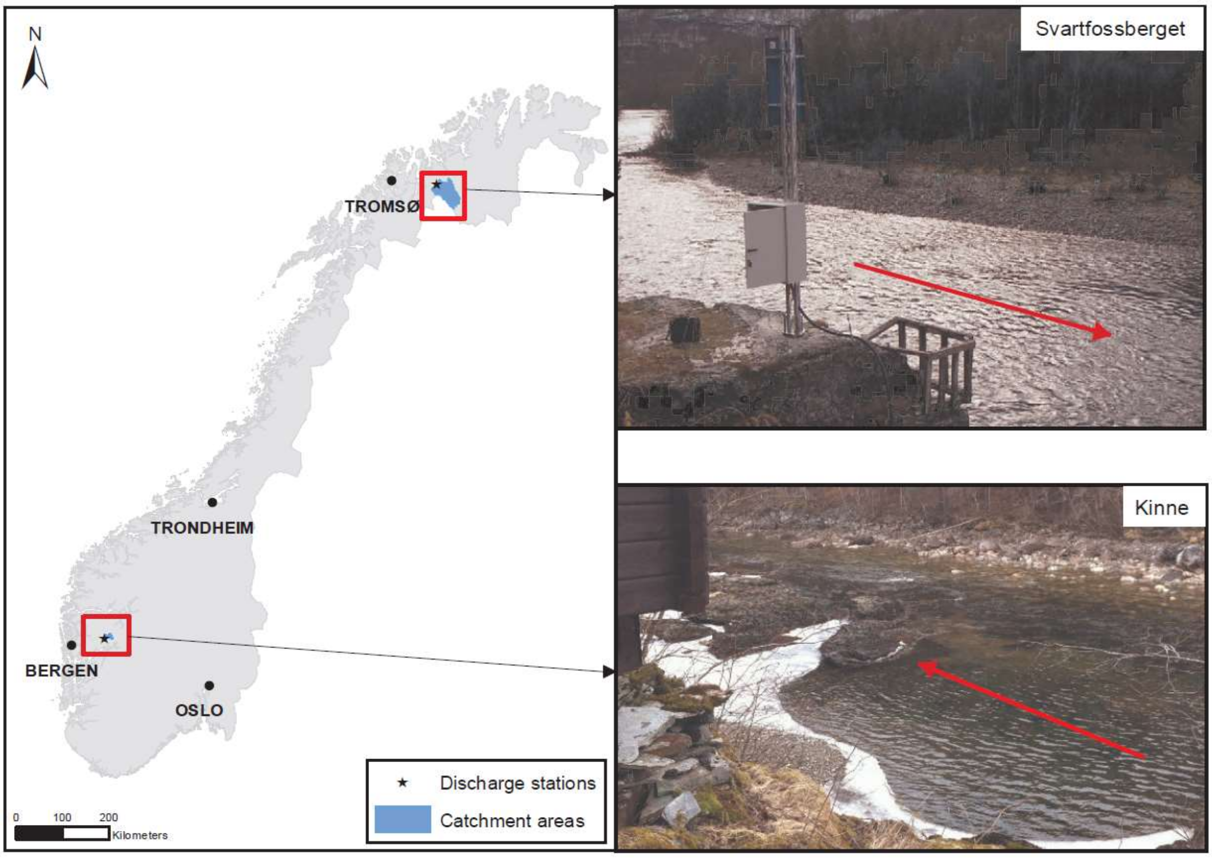

Figure 1. The discharge stations Svartfossberget and Kinne. Red arrows in pictures indicate flow directions.

Table 1. Discharge stations and time periods used in exercises E1, E2 and E3.

	Discharge station	Type of data correction	Time period
Exercise 1 (E1)	Kinne	Ice correction	Winter 2010 – 2011
Exercise 2 (E2)	Svartfossberget	Ice correction	Winter 2005 – 2006
Exercise 3 (E3)	Svartfossberget	Data reconstruction	May 15th – August 31st 2006

Table 2. Basic characteristics for the discharge stations Kinne and Svartfossberget.

	Kinne	Svartfossberget
Catchment area	511 km^2	1932 km^2
Height above sea level	80 m	88 m
Flow pattern, winter	Varying, mostly low flow	Low flow, Nov-May
Flow pattern, highest peak floods	Varying, spring-autumn	Spring / early summer
Control characteristics / width	Natural cross section / 30-35 m	Natural reach / 35-40 m

4.2. Support Data

Available support data from Kinne and Svartfossberget is shown in Table 3. For ice correction in E1, data on air temperature as well as a manual gauge reading was available from the station, while precipitation records had to be collected from either meteorological or other discharge stations. For ice correction in E2, data on air- and water temperature, a winter discharge measurement and HBV modelled discharge data was available from Svartfossberget, while precipitation records had to be collected from other stations. For data reconstruction in E3, a discharge measurement as well as manual gauge readings existed for the station, as well as HBV modelled discharge data. For all three exercises, observed stage and discharge time series was available from other donor stations.

Table 3. Available support data at Kinne and Svartfossberget.

	Air temp.	Water temp.	Precipitation	Discharge measurements	Manual gauge readings	HBV model Q
Kinne	Yes	No	No	No	No	No
Svartfossberget	Yes	Yes	No	Yes[*]	Yes[**]	Yes

[*] For use in E2 and E3. [**] For use in E3.

4.3. Statistical Analysis

An average daily discharge value (m^3/s) through the winter period November 1st – April 30th was calculated for each participant in the ice correction exercises E1 and E2, as well as an overall average daily discharge for all participants together. Variation in results was then quantified by 1) calculating individual percentage deviation from the overall average daily discharge and 2) calculating RMSE values for each ice corrected time series (Equation 1), using the overall average daily discharge as reference:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - \bar{X})^2} \qquad [1]$$

with X representing the estimated discharge and $\bar{X}$ representing the overall average discharge at day i of n days.

Variation in results from the reconstruction exercise E3 was quantified by calculating RMSE values (Equation 2) and NSE values (Equation 3) for each time series (Nash and Sutcliffe 1970), using the actual daily discharge as reference.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i)^2} \qquad [2]$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Y_i - X_i)^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2} \qquad [3]$$

with Y representing actual discharge at day i of n days and $\bar{Y}$ representing the average actual daily discharge.

4.4. Questionnaires

All participating field hydrologists were equipped with questionnaires in order to provide information on how the three exercises were carried out. Demanded information included use of support data and methodology as well as time of service working as a field hydrologist and preceding acquaintance with the two discharge stations used for the exercises. To evaluate the representativeness of the results, participants were asked to rank from 1 (least important) to 4 (most important) which of the factors A) professional contentment, B) time pressure, C) conscience, D) impatience with slow software or other factors determined their work effort in the exercises as well as in ordinary data correction work. An overall importance of each factor A-D was calculated as:

$$Importance\ of\ factor\ A = \frac{\sum_{i=1}^{n} RA_i}{n} \qquad [4]$$

with R as the rank number *1-4* of factors *A-D* for participants i to n.

5. Results

5.1. Ice Correction Exercises E1 and E2

Seventeen participants of which only one had previous experience with data correction on data from Kinne carried out exercise E1. Of the 16 persons completing exercise E2, three had previous experience with data correction on data from Svartfossberget.

Discharge series from E1 is shown in Figure 2. Typically for Kinne, winter runoff is dominated by low flows, interrupted by short increases in runoff due to temporary warmer weather. Consequently, some stage rises are due to ice formation, while others represent genuine increases in discharge. As seen in Figure 2, all participants interpreted the stage rises at November 27th, January 28th, February 14th and February 21st to be caused by ice, while there was disagreement in results at the events of January 18th, February 27th and March 22nd. One of the 17 participants performed ice correction by use of linear regression, while the rest did hydrographic/climatic comparison by use of stage/discharge, air temperature and precipitation data. Seven of the persons carrying out ice corrections through hydrographic/climatic comparison applied identical support data (stage/discharge data: Bulken, Myrkdalsvatn; air temperature: Kinne; precipitation: Vossevangen) for the analysis. Nevertheless, none of these, or any of the other time series gave identical results (Figure 2).

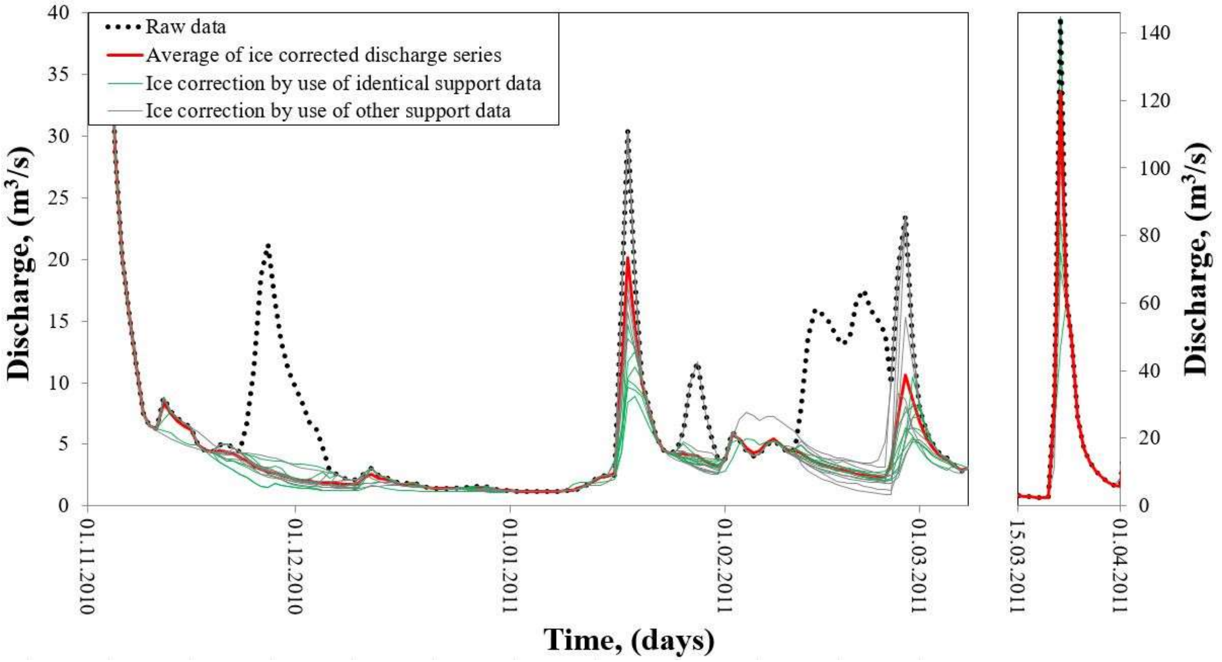

Figure 2. Discharge time series from E1 through the winter period 2010 – 2011. Green time series represent ice corrections by use of identical support data, including stage/discharge data: Bulken, Myrkdalsvatn. Air temperature: Kinne. Precipitation: Vossevangen. The figure has been divided in two due to scaling purposes.

Discharge series from E2 is shown in Figure 3. Characteristically for Svartfossberget, winter runoff is low from November to April. Of the 16 participants, 10 performed ice correction by hydrographic/climatic comparison by use of stage/discharge, air temperature and precipitation data (in this case the term hydrographic/climatic comparison also includes the interpolated- and adjusted discharge approaches cf. methods for qualitative ice correction described in the Introduction). Five persons employed linear regression, in some cases combined with manual adjustments from other support data, while one person completed the exercise using only HBV-model data. Only nine of the 16 participants adjusted their data to the discharge measurement on February 23rd (Figure 3), and only one person used water temperature as support data. Time series from linear regression analysis showed rather low discharge values compared to the result produced from the HBV-model and to three of the time series produced only through hydrographic/climatic comparison. None of the time series gave identical results (Figure 3).

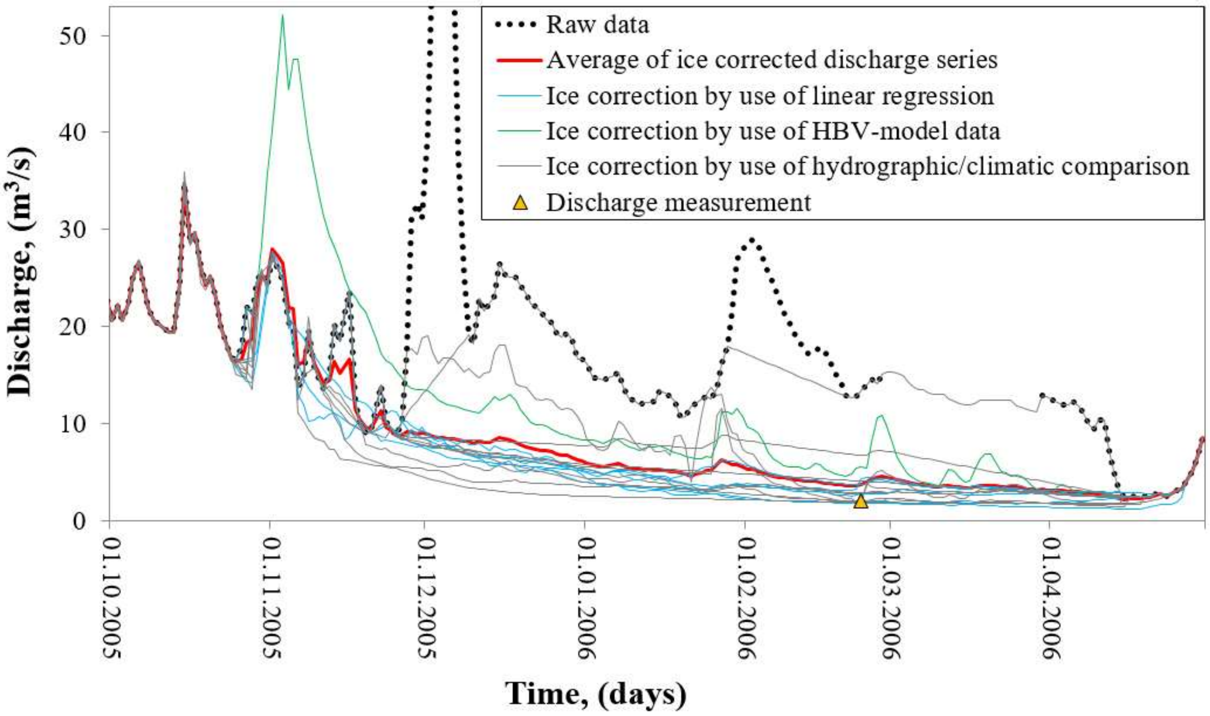

Figure 3. Discharge time series from E2 through the winter period 2005 – 2006.

When comparing variations in the results of both exercises, mean daily discharge from the on-off-ice discharge station in E1 varied 12%, while results from the stable-ice discharge station in E2 varied 156%, compared to the overall average daily Q (Table 4). Higher Coefficients of Variation in discharge as well as in RMSE values (Table 4), confirm the pattern of larger variation in E2.

Table 4. Numerical results of exercises E1 and E2.

	Average daily Q (m^3/s) November – April		% deviation from overall average daily Q		RMSE (m^3/s) with reference to overall average daily Q	
Participants	Kinne	Svartfossberget	Kinne	Svartfossberget	Kinne	Svartfossberget
1	15.9	5.1	6.4	-21.5	2.4	2.0
2	15.8	8.3	5.3	28.3	2.6	3.7
3	14.4	4.0	-3.8	-38.1	3.7	3.1
4	15.3	13.9	2.0	115.3	2.0	8.8
5	15.3	5.3	2.0	-17.6	2.2	1.8
6	14.8	10.2	-0.9	58.9	2.1	6.6
7	14.4	5.5	-3.2	-14.5	4.1	1.5
8	14.7	7.6	-1.8	18.2	1.8	2.0
9	14.1	5.9	-5.4	-9.2	5.8	1.3
10	15.5	4.6	3.6	-28.6	2.3	2.3
11	14.6	6.2	-2.2	-3.8	3.0	0.9
12	14.9	3.8	-0.3	-40.6	1.9	3.1
13	14.9	6.0	-0.7	-6.9	1.8	1.0
14	15.1	5.8	1.4	-9.9	2.0	1.2
15	14.8	5.8	-1.3	-9.7	1.3	1.4
16	14.8	5.1	-0.9	-20.3	2.0	1.8
17	14.9		-0.1		2.0	
Mean (m^3/s)	15.0	6.5			2.5	2.6
CV	0.03	0.40			0.43	0.82

5.2. Data Reconstruction Exercise E3

Of the 17 field hydrologists completing the data reconstruction exercise, three had previous experience with data correction from Svartfossberget. Twelve participants performed data reconstruction by use of linear regression, using data from either one or multiple donor discharge stations. Four persons employed HBV-model data, while one field hydrologist completed the task by manual infilling of data from a donor discharge station (Figure 4; Table 5). Nine of the participants using regression analysis also performed manual adjustments. Manual adjustments were either carried out to fit with the discharge measurement on June 21st, to fit with the manual gauge readings on July 27th and August 15th, or as other adjustments. Persons with long time of service produce the most accurate results in terms of RMSE and NSE values (Table 5), and participants with earlier data correction experience from Svartfossberget produced two of the three most accurate time series. Time series produced from HBV-model data were the least accurate and highly overestimated the discharge values for most of the time period (Figure 4; Table 5). However, four participants stated that their effort in the exercise might not be representative for ordinary data correction work. Therefore, results of E3 have to be interpreted with some degree of reservation.

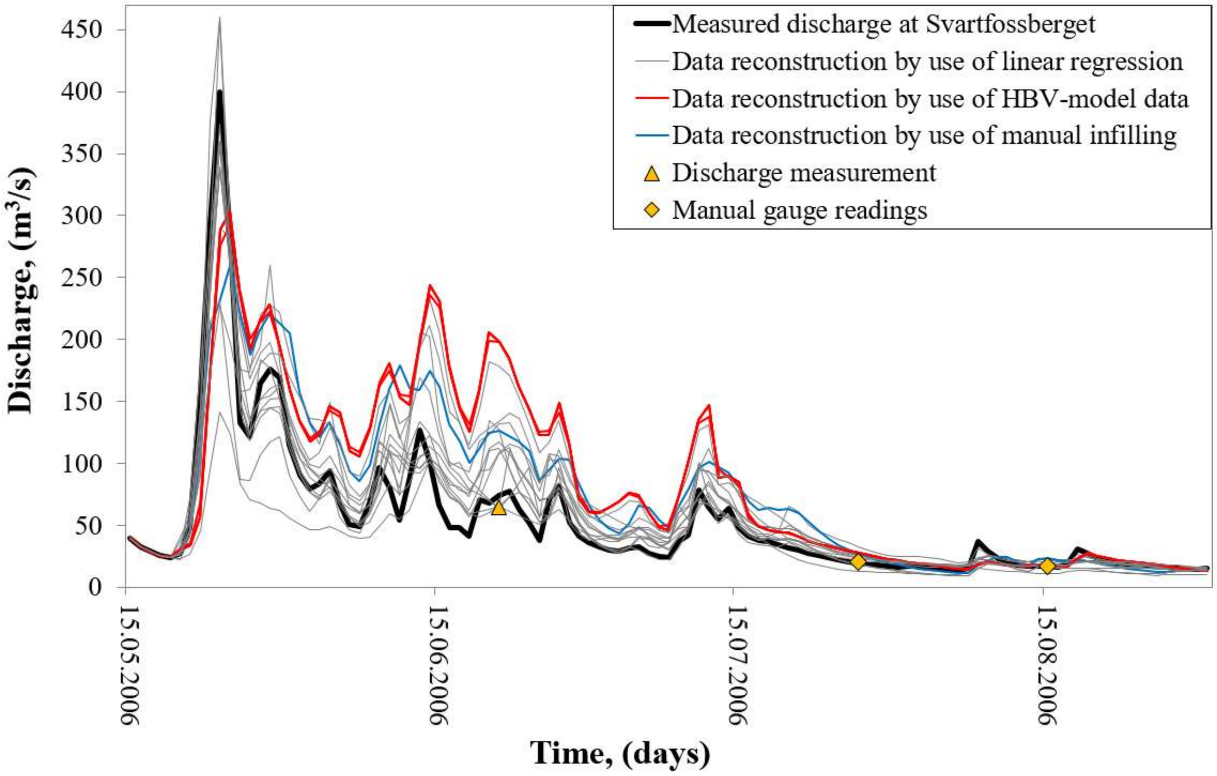

Figure 4. Discharge time series from E3 through the period May 15th – August 31st 2006.

Table 5. Accuracy, methodology and background of the data reconstruction time series in E3. Regression S: Use of only one donor station. Regression M: Use of multiple donor stations. Categories for manual adjustment: A) adjustment to discharge measurement, B) adjustment to manual gauge readings, C) other adjustments. Rows with ( ) indicate participants stating that their effort in the exercise might not be representative for ordinary data correction work.

Time of service (years)	Previous data correction on Svartfossberget	Method	Manual adjustment	RMSE (m^3/s)	NSE
26	Yes	Regression, S	A, C	13.65	0.94
35	No	Regression, S		14.07	0.94
19	Yes	Regression, M	C	14.47	0.93
4	No	Regression, M	A, C	17.93	0.89
5	No	Regression, S	C	18.20	0.89
6	No	Regression, M	C	19.96	0.87
4	No	Regression, S	C	25.62	0.78
4	No	Regression, S	A, B	29.27	0.72
(6)	(No)	(Regression, M)		(29.82)	(0.71)
5	No	Regression, M		31.48	0.68
5	No	Manual infilling	A, C	38.85	0.50
2	No	Regression, S	A	41.27	0.44
(3)	(Yes)	(Regression, M)		(42.71)	(0.40)
(15)	(No)	(HBV-model)		(50.91)	(0.15)
3	No	HBV-model		51.12	0.14
(4)	(No)	(HBV-model)		(51.16)	(0.14)
2	No	HBV-model		51.16	0.14

5.3. Further Results

Participants were asked through questionnaires to rank which of the factors A) professional contentment, B) time pressure, C) conscience, D) impatience with slow software or other factors determined their work effort in the exercises as well as in ordinary data correction work. Ranking results are shown in Figure 5. Time pressure played a substantial role for the work effort in all three exercises compared to normal circumstances. In ordinary data correction work, professional contentment and conscience are the main factors determining when a data correction task is considered done, while impatience with slow software and other factors has little influence.

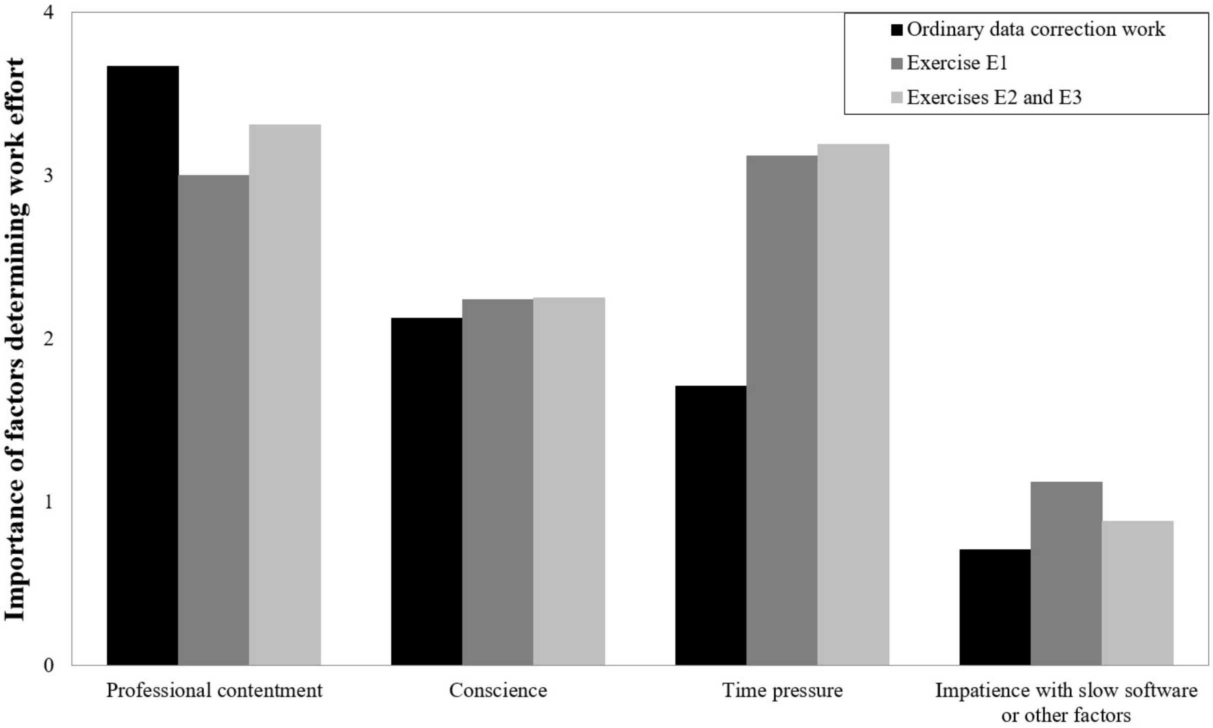

Figure 5. Importance of factors determining the work effort in the exercises as well as in ordinary data correction work.

6. Discussion

In the ice correction exercises E1 and E2, mean daily discharge from the on-off-ice discharge station varied 12% with a CV in average daily Q of 0.03, while results from the stable-ice discharge station in E2 varied 156% with a corresponding CV of 0.40 (Table 4). Results from Melcher and Walker (1990) and Petterson (2004) also produced larger variation in ice corrected data from stable-ice vs. on-off-ice discharge stations. In the former study, three field hydrologists performed ice correction on three time series in Iowa, USA, using six different subjective approaches. Two time series had intermittent ice periods during winter, while the last had one continuous frozen period from December 15th to March 2nd. Results from five of the six approaches showed higher variation between participants at the stable-ice time series compared to the series with intermittent ice periods (Melcher and Walker 1990). In Petterson (2004), 10 participants performed ice correction on three Norwegian discharge series through the winter period 1977 – 1978. Mean daily discharge from the on-off-ice discharge station Staupåga varied 47% from the overall average daily Q with a CV in average daily Q of 0.14, while results from the stable-ice discharge station Selfoss varied 59% with a corresponding CV of 0.17.

In Melcher and Walker (1990), depending on method and time series, results between participants compared to a reference baseline time series varied from 7% to 76%, and in 10 of 18 cases more than 30%. In another study from Hamilton *et al.* (2000) three field hydrologists performed ice correction on a time series from Yukon, Canada. Calculation of a mean absolute relative error index compared to reference data revealed individual differences from 1% to 10%, highest during fall and lower in the mid-winter and spring periods. The comparison of results from the present study together with Melcher and Walker (1990), Hamilton *et al.* (2000) and Petterson (2004) provides a unique insight into how much ice corrected data may vary as a function of individual interpretation and experience.

Exercise E3 revealed no pattern of regression analysis by use of one vs. multiple donor discharge stations outperforming each other (Table 5). The result differs from findings of Harvey *et al.* (2012) who tested numerous data reconstruction techniques on 26 discharge series in the UK. Measured in NSE values, results from regression analysis using multiple donor stations did as least as good or in several of the discharge series even better than analysis using one donor station only. Likewise, Kamwaga *et al.* (2018) achieved higher NSE values using multiple vs. one donor station for data reconstruction in Tanzania. However, due to the manual subjective adjustments carried out in the current study, comparisons to the above-mentioned studies has to be done with some reservation.

Data reconstruction from regression analysis, manual infilling and adjustments outperformed the use of HBV-model data in exercise E3 (Table 5). It should be stressed that HBV-model data has not been specifically calibrated for use in the current study but for general use in hydrological analysis and forecasting at NVE. A visual inspection of HBV-modelled vs. measured discharge at the test station Svartfossberget for the period 2004-2008 (test year for exercise E3 was 2006) reveal large variations in model performance, albeit a large overestimation of discharge during summer 2006. Thus, the results cannot contribute to a general discussion on whether or not data from hydrological models are suitable for data reconstruction purposes, however, the example of exercise E3 stresses the importance of carefully checking data properties (for example fit with measured data at beginning/end of gap, discharge measurements and manual gauge readings) when using for data reconstruction.

Participants with long time of service produced the most accurate results in the data reconstruction exercise, and persons with earlier data correction experience from Svartfossberget produced two of the three most accurate time series (Table 5). Another data reconstruction exercise carried out at NVE has confirmed the importance of experience when working with data correction, (Dahl unpublished). In the latter study, seven groups of field hydrologists reconstructed a discharge time series from January 1st to May 31st 2011 by use of regression analysis. Participants with experience from the particular discharge station and local hydrology produced the best results in terms of RMSE values compared to reference data. Subsequent to building their regression model, the group carried out manual adjustments on peak flood values by hydrological comparison, based on their unique local knowledge. However, as shown by Melcher and Walker (1990) and Hamilton *et al.* (2000), data corrected by experienced field hydrologists may still exhibit substantial individual variation. In the former study, all three participants were experienced in performing ice correction and two of three were familiar with the local hydrology and discharge stations used for the analysis. In Hamilton *et al.* (2000), the three field hydrologists performing ice correction had more than 50 years of cumulative experience. Yet, the role of experience when performing data correction underlines the importance of sharing knowledge between colleagues and the relevance in asking for a second opinion or perform a peer-review in difficult cases.

Time pressure played a considerable role for the work effort in all three exercises of this study compared to ordinary data correction work at NVE where professional contentment and conscience are the main factors determining when a data correction task is considered done (Figure 5). Four participants also stated that their effort in exercise E3 might not be representative for ordinary data correction work (Table 5). Moreover, the authors recognise that having a large number of field hydrologists to perform corrections on data from a discharge station and in a local hydrological setting where only a few of the persons have previous experience does not completely reflect ordinary circumstances for data correction. However, the capability of evaluating the representativeness of the results has added strength to the analysis and should be included in future related studies.

7. Conclusion

Through three data correction tasks, the current study has aimed to analyze variations in corrected discharge data as well as in belonging routines for data correction among field hydrologists at NVE.

Large individual variations are seen in results from two ice correction- and one data reconstruction task. When comparing mean daily runoff (m^3/s) in the ice correction tasks, results from the on-off-ice discharge series (E1) varied 12%, while results from the stable-ice discharge series (E2) varied 156%. In data reconstruction, results varied from RMSE values of ≤ 14 m^3/s and NSE values of 0.94 to RMSE values of ≥ 50 m^3/s and NSE values of 0.14, when compared to actual discharge data.

Data output was highly affected by personal opinion and experience. In the ice correction exercises none of the time series were identical, not even from participants using identical support data for the task. In data reconstruction, field hydrologists with long time of service produced the most accurate results in terms of RMSE and NSE values, and participants with earlier data correction experience from the relevant discharge station produced two of the three most accurate time series.

Answers from questionnaires revealed that time pressure had a higher effect on the work effort in this study than in a normal work situation, where professional contentment defines when work is considered completed.

The study has provided an essential insight into variations in corrected discharge data and routines for data correction at NVE and underlines the importance of training employees as well as sharing and storing data correction knowledge.

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9. References

Bergström, S. 1992. The HBV model – its structure and applications. Swedish Meteorological and Hydrological Institute, Reports Hydrology No. 4, Norrköping, Sweden. 35 pages.

Carey, K.L. 1967. Analytical approaches to computation of discharge of an ice-covered stream. United States Geological Survey, Professional Paper No. 575-C, Washington D.C., USA. 8 pages.

Chokmani, K., Ouarda, T.B.M.J., Hamilton. S., Ghedira, M.H., Gingras, H. 2008. Comparison of ice-affected streamflow estimates computed using artificial neural networks and multiple regression techniques. Journal of Hydrology, **349**, 383-396.

Fontaine, R.A. 1983. Uncertainties in records of annual mean discharge in Maine. United States Geological Survey, Water-Resources Investigations No. 83-4025, Augusta, Maine, USA. 108 pages.

Førland, E.J. 1993. Precipitation normals, normal period 1961-1990. Norwegian Meteorological Institute, Report No. 39/93 Klima, Oslo, Norway. 60 pages (in Norwegian).

Gottschalk, L., Jensen, J.L., Lundquist, D., Solantie, R., Tollan, A. 1979. Hydrologic regions in the Nordic Countries. Nordic Hydrology, **10**, 273-286.

Hamilton, A.S., Hutchinson, D.G., Moore, R.D. 2000. Estimating winter streamflow using conceptual streamflow model. Journal of Cold Regions Engineering, **14**, 158-175.

Harvey, C.L., Dixon, H., Hannaford, J. 2012. An appraisal of the performance of data-infilling methods for application to daily mean river flow records in the UK. Hydrology Research, **43**, 618-636.

Hicks, F., Healy, D. 2003. Determining winter discharge by hydraulic modeling. Canadian Journal of Civil Engineering, **30**, 101-112.

Hirsch, R.M. 1979. An evaluation of some record reconstruction techniques. Water Resources Research, **15**, 1781-1790.

Holtschlag, D.J. 1996. A dynamical systems approach for computing ice-affected streamflow. United States Geological Survey, Water-Supply Paper No. 2473, Washington D.C., USA. 14 pages.

Holtschlag, D.J., Grewal, M.S. 1998. Estimating ice-affected streamflow by extended kalman filtering. Journal of Hydrologic Engineering, **3**, 174-181.

Hughes, D.A., Smakhtin, V. 1996. Daily flow time series patching or extension: a spatial interpolation approach based on flow duration curves. Hydrological Sciences Journal, **41**, 851-871.

Huttunen, M., Vehviläinen, B. 1997. Neural networks in the ice-correction of discharge observations. Nordic Hydrology, **28**, 283-296.

Ilunga, M., Stephenson, D. 2005. Infilling streamflow data using feed-forward back-propagation (BP) artificial neural networks: Application of standard BP and pseudo Mac Laurin power BP techniques. Water SA, **31**, 171-176.

Lindström, G., Johansson, B., Persson, M., Gardelin, M., Bergström, S. 1997. Development and test of the distributed HBV-96 hydrological model. Journal of Hydrology, **201**, 272-288.

Kamwaga, S., Mulungu, D.M.M., Valimba, P. 2018. Assessment of empirical and regression models for infilling missing streamflow data in Little Ruaha catchment Tanzania. Physics and Chemistry of the Earth, **106**, 17-28.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. 2006. World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift, **15**, 259-263.

Melcher, N.B., Walker, J.F. 1990. Evaluation of selected methods for determining streamflow during periods of ice effect. United States Geological Survey, Open-File Report No. 90-554, Madison, Wisconsin, USA. 51 pages.

Nash, J.E., Sutcliffe, J.V. 1970. River flow forecasting through conceptual models, Part 1 – a discussion of principles. Journal of Hydrology, **10**, 282-290.

Pelletier, P.M. 1990. A review of techniques used by Canada and other Northern Countries for measurement and computation of streamflow under ice conditions. Nordic Hydrology, **21**, 317-340.

Petterson, L.-E. 2004. Ice adjustment. Norwegian Water Resources and Energy Directorate, Internal Report, Oslo, Norway. 5 pages (in Norwegian).

Rantz, S.E. and others. 1982. Measurement and computation of streamflow: Volume 2. Computation of discharge. United States Geological Survey, Water-Supply Paper No. 2175, Washington D.C., USA. 373 pages.

Rees, G. 2008. Hydrological data. In: Gustard, A., Demuth, S. (editors). Manual on Low-flow Estimation and Prediction. World Meteorological Organization, Operational Hydrology Report No. 50, Geneva, Switzerland. 14 pages.

Ruan, G., Langsholt, E. 2017. Recalibration of HBV-models for flood warning using in-data from seNorge, Version 2.0. Norwegian Water Resources and Energy Directorate, Report No. 71-2017, Oslo, Norway. 37 pages (in Norwegian).

Rosenberg, H.B., Pentland, R.L. 1966. Accuracy of winter streamflow records. Proceedings of the 23rd Annual Eastern Snow Conference, Hartford, Connecticut, USA, February 10-11, 1966, 51-72.

Salas, J.D. 1993. Analysis and modeling of hydrologic time series. In: Maidment, D.R. (editor). Handbook of hydrology. McGraw-Hill Inc., USA. 72 pages.

Sælthun, N.R. 1996. The “Nordic” HBV model. Norwegian Water Resources and Energy Directorate, Report No. 07-1996, Oslo, Norway. 27 pages.

Tencaliec, P., Favre, A-C., Prieur, C., Mathevet, T. 2015. Reconstruction of missing daily streamflow data using dynamic regression models. Water Resources Research, **51**, 9447-9463.

Turcotte, B., Morse, B. 2013. A global river ice classification model. Journal of Hydrology, **507**, 134-148.

Wallis, J.R., Lettenmaier, D.P., Wood, E.F. 1991. A daily hydroclimatological data set for the Continental United States. Water Resources Research, **27**, 1657-1663.

Zhang, Y., Post, D. 2018. How good are hydrological models for gap-filling streamflow data? Hydrology and Earth System Sciences, **22**, 4593-4604.