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Future changes in extreme precipitation estimated in Norwegian catchments

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Extreme precipitation leads to flooding at Bollingmo bridge, Holtålen, August 2011

Photo: Joakim Slettebak Wangen

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Abstract

A study of extreme precipitation based on adjusted daily RCM precipitation from 8 model runs and two time slices (2021-2050 and 2071-2100) is presented. The study is performed for 141 Norwegian catchments. The analyses are based on a Norwegian version of the so called NERC-method, which is an advanced scaling of the 5 year return period estimates based on 1 day precipitation (M5). M5 is estimated from the Gumbel distribution. The focus of the present report is therefore future change in M5 values. The results show that there is large spread in the results, both spatially and between different RCM-simulations. The projections indicate that the M5-value will increase for all catchments throughout the 21st century.

The results are uncertain, with many sources of uncertainties. The analyses therefore only provide a rough guide for future flood conditions.

Keywords

Extreme precipitation, PMP, return period, climate change

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1. Introduction

1.1 Background

Precipitation estimates for 1000 years return period and PMP (Probable Maximum Precipitation) are needed for flood estimations for river regulations and dam safety in Norway. There are approximately 3000 dams in Norway designed after guidelines given by Lundquist et al. (1986). The estimates of extreme rainfall are typically based on available long (> 30 years) precipitation series.

An increase in extreme rainfall may be of crucial importance for population and infrastructure along the rivers because of increased risk for dam breakdown. It is expensive to strengthen the solidity of the dams, and updated precipitation and flood estimates are therefore of large importance for the hydro power community as well as dam safety authorities. Knowledge of present and future return period values and extreme precipitation estimates due to climate change is therefore of large socio-economic importance.

Return values with high return intervals (e.g. 100, 500, 1000 years) are by definition rare. It is challenging to estimate e.g. the 1000 year return value, and particularly PMP-values, from time series of 30-100 years over the last decades. The use of extreme value theory to solve these problems has emerged. The methodology seeks to give an estimate of the tail of the precipitation distribution, and extrapolate to obtain estimates of the extreme values. However, the framework for return period values and extreme value estimates in Norway is still based on statistically derived guidelines outlined more than 20 years ago (Førland, 1992). PMP for river basins may also be estimated by using techniques like “storm models” or “storm transposition and maximization” (WMO, 2009, Førland & Kristofferssen, 1989).

Different methods used within the Nordic countries for estimating return values and extreme precipitation are summarized by Alexandersson et al. (2001). In Norway a survey of extreme value estimation was performed in the 1980s (Førland and Kristoffersen, 1989) and a manual for estimating PMP was produced (Førland, 1992). It was concluded that “the British M5-method” (NERC, 1975) was suitable also for Norwegian conditions (Førland and Kristoffersen, 1989; Tveito and Førland, 1996; Alfnes and Førland, 2006; Alfnes 2007). For Norway the 5-year return value (M5) is based on the Gumbel distribution fitted to maximum 1 day (d) precipitation. This was in accordance with WMO recommendations at the time (WMO, 1986). Higher return levels and extreme values are then obtained by a sophisticated weighting of the M5 estimate (See Section 3). A detailed description of the method (hereafter called the NERC-method) used in Norway for estimating return period values and PMP-values are presented by Førland (1992).

Since the recommendations for Norway were given, longer time series and improved statistical methods for extreme value analyses have become available. WMO has also published a new Manual for estimation of probable maximum precipitation (WMO, 2009). The methodological framework for estimating return value and extreme precipitation in Norway is therefore ready for an evaluation. This will be included in a PhD-thesis (2011-2014) in collaboration between NVE, Jernbaneverket, Vegvesenet, the University of Oslo and met.no.

1.2 Reported trends in extreme precipitation

In the 20th century an increase in precipitation was experienced all over Norway (Hanssen-Bauer and Førland, 1998, Hanssen-Bauer, 2005, Hanssen-Bauer et. al., 2009). During the period 1900-2008 the increase in annual precipitation was 1.7% per decade for the country as a whole, varying from 0.9 to 2.1%/decade in different regions (Hanssen-Bauer et al., 2009). Groisman et al. (2005) found a significant increase in annual precipitation of 16% over a period of 60 years (1951-2002) (2.7 % increase/decade) for Fennoscandia.

It is difficult to determine long-term trends in extreme events due to their rarity. It is simply too few cases to evaluate (Frei and Schär, 2001; Førland et al., 1998). It is in the nature of rare events that they appear locally and may not even be captured in the observation network. Analyzing extreme value precipitation based on time series of observations from stations is questionable also due to the sensitivity to inhomogeneities and outliers (Førland et al., 1998). And, estimates of return period and extreme values are influenced by the length of the time series (Trenberth et al., 2007; Førland et al., 1998). The observed time series should therefore be as long as possible. However, due to relocations and instrumental changes, very few homogenous long-term precipitation series are available.

Analyses of intense precipitation indicate a positive trend over parts of Europe (Frei and Schär, 2001; Schmidtli and Frei 2005; Achberger and Chen; 2006; Groisman et al., 2005). However, Achberger and Chen (2006) found no spatial coherent trend in the annual 99th percentile of daily precipitation amounts over the period 1961 – 2004 in Norway and Sweden. Førland et al. (1998) found no uniform tendencies in 1 d maximum precipitation for the entire Nordic area during the period 1880 - 1996. They found that there was a maximum in the 1930s and a tendency of increasing values during the 1980s and 1990s. Alfnes and Førland (2006) studied trends in extreme precipitation and return values at available precipitation series in Norway for the 20th century (1900 – 2004). They found that the frequency of extreme precipitation values (return value $\geq$5 years) was highest in the 1920s - 1930s and in 1980s – 1990s. They also found that during the 20th century the occurrence of the most extreme events seems to have decreased in south eastern regions, while minor changes were found for other regions. The number of slightly smaller precipitation events has increased in the same period. They also found positive long term trends in annual maximum 1 d precipitation. The increase is, however, significant only at very few locations in south western parts of Norway. Agersten (2002) studied annual maximum 1 d precipitation at selected Norwegian stations, and found no significant trend.

Mean seasonal precipitation amounts are projected to keep on increasing in the 21st century in our regions in winter and autumn seasons, while a decrease is expected during summer (Christensen et al., 2007, Hanssen-Bauer et al., 2009). Frei et al. (2006) found that the change in extreme winter precipitation for the European continent, i.e. M5- and M50-values based on 5 d precipitation, is expected to increase, however not in the same magnitude as seasonal increase. In summer 1 d M5 and M50 are expected to increase, but there is a large spread amongst the projections. The tendency of increased extreme precipitation in the future is supported in other studies (e.g. Benestad, 2007; Beniston et al., 2007). Based on an ensemble of downscaled scenarios, Hanssen-Bauer et al. (2009) concluded that in Norway there will in the 21st century be an increase in number of days with high precipitation amounts, and for the country as a whole a 16% increase in rainfall amount for days with heavy rainfall.

1.3 The outline of the present report

Dynamical downscaling of precipitation projections with regional climate models (RCMs) of Atmospheric Ocean General Circulation Model (AOGCM) results are analyzed with respect to return period estimates and extreme values. The aim of the analyses is to estimate future changes in 1 day rainfall in time series of daily precipitation at selected catchments in Norway. Estimates for other durations (6 and 12 h, and 2, 3, 5 and 10 days) are also carried out, but are not included in the present report. The analyses are carried out based on observed time series as well as data from RCM runs for two scenario periods (2021 - 2050 and 2071 - 2100) and two control periods (1961 – 1990 and 1981 – 2010).

As stated above, the precipitation amounts for long return periods (> 5 years) is a function of the M5 value, see details in Section 3. This leaves two questions; 1) How well is M5 estimated in Regional Climate Model control runs representative for the present climate ("control period")? M5 for the control period should be comparable with M5 based on observations for the same historic period. 2) What is the change in M5 estimated for present climate (control period) compared to future climate (scenario period)?

The time series of daily precipitation used in the analyses, for present as well as future climate, are presented in Section 2. The "NERC method" used is documented in Section 3. The results are presented in Section 4, discussion and concluding remarks are given in Section 5.

The analyses examines the use of interpolated precipitation representing area values for the selected catchments (see Section 2), rather than the traditional use of site-specific time series. Area estimates based on site-specific time series of daily precipitation adjusted by Area-Reduction-Factors (ARFs), are compared to grid-based series representing an area (Section 2.1) (cfr. Alfnes, 2007). Alfnes found that the estimates were close to those of the traditional method except at the western coast of southern Norway where the grid based values are considerably higher. For precipitation events lasting more than 1d the grid based method yield higher extreme values than the station based method. The estimates of seasonal and annual extremes showed rather large and partly non-systematic differences between the two methods.

The analyses presented here have been carried out within the Nordic and Baltic project Climate and Energy Systems, CES, funded by the Nordic Energy Research, the Nordic energy sector and the participating institutions, by the SAWA project funded by EU and the MIST project funded by Statkraft and met.no.

2. Daily precipitation

2.1 Observations for the time period 1957 - 2008

A total of 141 Norwegian catchments with hydropower systems and dams were selected for the present studies. The selection was carried out by NVE (the Norwegian Water Resources and Energy Directorate). The catchments differ in size and some are parts of larger catchments. Some of the catchments are situated along the Swedish border, covering both Norwegian and Swedish land areas. In this analysis only the Norwegian land area is included due to lack of data for the Swedish land area. The location of the catchments is shown in Figure 2.1. Information of the catchments is listed in Appendix A.

Daily precipitation with spatial resolution of 1x1 km^2 covering the Norwegian mainland is produced daily at the Norwegian Meteorological Institute (Mohr, 2009; Tveito et al., 2005; Jansson et al., 2007). The values are obtained by interpolation of observations of daily precipitation at 06 UTC. The spatial precipitation data are available from 1957 until present.

The daily gridded precipitation data is adjusted for under catch caused by wind-effects around the gauge (Førland et al,. 1996). The correction factors depend on wind exposure, and the precipitation stations on the Norwegian mainland are categorised in five exposure classes. For liquid precipitation the correction factor in the five classes varies from 1.02 to 1.14, and for snowfall from 1.04 to 2.50. For liquid precipitation the correction factors are independent of rainfall intensity; leading to too high corrections of heavy rainfall. The spatial interpolation also includes precipitation enhancement with increasing elevation. As indicated by e.g Alfnes (2007), the resulting gridded maps; adjusted for under catch and elevation; apparently give an overestimate of precipitation in high mountain regions.

Time series of daily precipitation for the catchments are extracted from the daily precipitation grids referred to above. Area estimates are obtained by averaging the precipitation values for all grid points within the respective catchments.

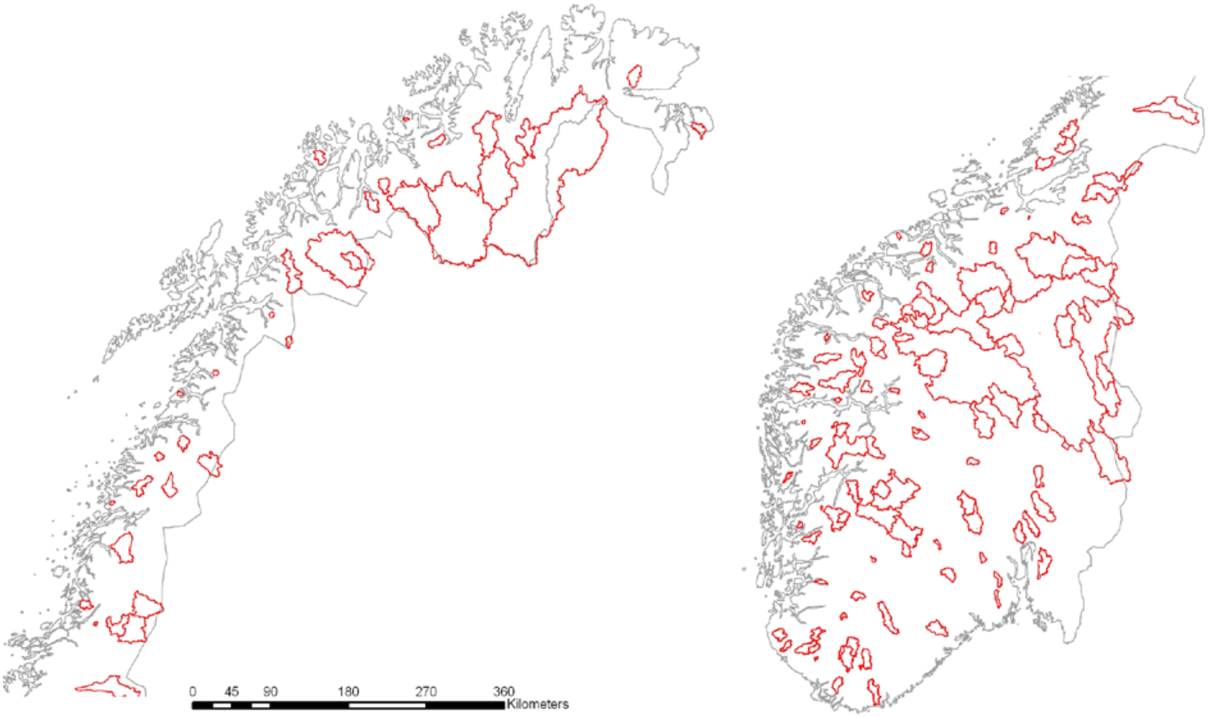

Figure 2.1 Selected catchments for extreme value analyses in Norway (see Appendix A for details)

2.2 Modeled values interpolated from RCMs

Atmospheric Ocean Circulation Models (AOGCMs) run with different emission scenarios, are dynamically or empirically-statistically downscaled (IPCC, 2007). Climate projections dynamically downscaled with three different RCMs are used in the study. These RCMs are the Norwegian HIRHAM model (Engen-Skaugen et al., 2007), the Danish HIRHAM model (Jungclaus et al., 2006; Roeckner et al., 2006) and the Swedish RCA3 model (Déqué et al., 1994; Bleck et al., 1992). Three of the model runs were performed within the ENSEMBLES project (http://ensemblesrt3.dmi.dk). The projections are adjusted for local applications, see Section 2.3. Details of the selected climate projections used are presented in Table 2.1.

Table 2.1. Information about the climate projections used in the analyses

AOGCM	**EMISSION SCENARIO**	**RCM**	**RESOLUTION**	**TIME PERIOD**	**Acronym**
HadAM3H	A2	HIRHAM	~55x55 km^2	1961-1990, 2071-2100	HADA2
HadAM3H	B2	HIRHAM	~55x55 km^2	1961-1990, 2071-2100	HADB2
ECHAM4	B2	HIRHAM	~55x55 km^2	1961-1990, 2071-2100	MPIB2
ECHAM4	B2	HIRHAM	~25x25 km^2	1961-1990, 2071-2100	MPIB225
ECHAM3/OPYC3	IS92a	HIRHAM	~25x25 km^2	1981-2010, 2021-2050	MPIS2
HadCM3Q0	A1B	HIRHAM	~25x25 km^2	1951-2050	HADA1B
ECHAM5	A1B	HIRHAM (DMI)	~25x25 km^2	1951-2099	DMIA1B
BCM	A1B	RCAO (SMHI)	~25x25 km^2	1961-2099	SMHIA1B

2.3 Adjusted temperature and precipitation projections from selected RCM runs

Precipitation projections downscaled with RCMs are representative for grids (25x25 km^2 or 55x55 km^2) and may therefore not be applicable locally. RCMs reproduce historical seasonality and variability rather poorly at local scale. Daily precipitation interpolated from RCMs (Table 2.1) is therefore adjusted empirically Engen-Skaugen (2007). In this adjustment method, the daily values in the control and scenario periods are normalized and standardized, then scaled up with mean monthly values and standard deviation estimated from observations. The corrections are performed for each calendar month separately. The adjustment method maintains the mean monthly climate signal obtained from the RCM runs. Each 1 km grid point is treated as time series by extracting interpolated RCM values. The correction is performed grid point by grid point. For more information see Engen-Skaugen (2007).

2.4 Uncertainty

As mentioned in the introduction, it is not trivial to estimate rainfall values for long return periods based on rather short time series. Trends in the rainfall series make the extreme value estimations even more complicated. It is possible to account for non-stationary conditions (climate change) in extreme value analysis, but the best way to do this is debated (WMO, 2009)

RCM-projections of local climate changes are affected by many uncertainties and shortcomings:

- Internal natural variability (particularly large in the Nordic region)
    - influences the representation of present climate and past climate variability
    - depends of the initial state
- Uncertainty in climate forcings
    - Natural forcings: solar radiation, volcanic eruptions
    - Human emissions of gases and aerosols
- Imperfect climate models
    - Validity of the approach, including the need for ensembles to estimate uncertainties
    - Imperfect knowledge about processes and their description/parameterisation

  - Errors in numerical solutions
  - Low spatial resolution in global models
- Weaknesses in techniques for dynamical downscaling:
  - inadequate spatial resolution for most impact studies (topography is too smoothened)
  - Systematic bias: Cannot be directly compared to observations
  - Choice of model domain

The uncertainties in the projections are in general smaller for long-term precipitation (annual, seasonal) than for daily and sub-daily values.

3. Estimation of return period and extreme precipitation estimation

Recommendations given by Førland (1992) are used to obtain return period values and extreme precipitation for selected catchments. The method is shown to give reasonable estimates for Norway (Førland and Kristofferssen, 1989; Førland, 1992; Alexandersson et al., 2001).

Annual five year return period values of daily precipitation (M5) are estimated based on annual maximum one day precipitation with the Gumbel-equation (Gumbel, 2004);

$$X(T) = X_{mean} - \left(\frac{\sqrt{6}}{\pi}\right) \times \left\{0.577 + \ln\left(-\ln\left(\frac{T-1}{T}\right)\right)\right\} \times X_{stdev}$$

where X_{mean} and X_{stdev} is mean value and standard deviation of annual maximum values respectively, T is the return value. Values for longer durations (number of days = n, e.g. n=2 , n=3, n=5, n=7 or n=10 d, are estimated useing annual maximum n-day precipitation.

Return period values for T > 5 years are estimated with the NERC method, which is a function of the M5 value (NERC, 1975:

$$X(T) = M5 \times \exp\{C \times (\ln(T - 0.5) - 1.5)\}$$

C is approximated by

$$\mathrm{C} = \begin{cases} 0.165 + 0.0236 \times \ln(\mathrm{M5}) & 2 < M5 \leq 10 \quad (mm) \\ 0.219 & 10 < M5 \leq 15 \quad (mm) \\ 0.300 - 0.0294 \times \ln(\mathrm{M5}) & 15 < M5 \leq 25 \quad (mm) \\ \underline{0.3584 - 0.0473 \times \ln(\mathrm{M5})} & \underline{25 < M5 \leq 350} \quad (mm) \\ 0.167 - 0.0145 \times \ln(\mathrm{M5}) & 350 < M5 \leq 1000 \quad (mm) \end{cases}$$

Probable Maximum Precipitation (PMP) is defined as the MT value where $\mathrm{T} \to \infty$ (WMO, 2009). For simplicity, in Norway PMP is approximated as X(T) for specific T-values where T is a function of M5 (Førland, 1992):

$$T = \begin{cases} 36000 & \text{(years)} \quad M5 \le 45 \quad (\text{mm}) \\ 47829 - 262.9 \times M5 & \text{(years)} \quad 45 < M5 \le 125 \quad (\text{mm}) \\ 225503 - 62.4 \times M5 & \text{(years)} \quad 125 < M5 \le 200 \quad (\text{mm}) \\ 10000 & \text{(years)} \quad M5 > 200 \quad (\text{mm}) \end{cases}$$

The NERC method for estimating MT is empirical. The coefficient C is estimated from a large number of precipitation measurements in the UK (NERC, 1975).

The NERC method should not be used for M5>350 mm. The equations for estimation of the C-coefficient in the NERC method have a marked discontinuity at M5 = 350 mm. M5 values up to 350 are decreasing logarithmically and X(T,M5,C) increases logarithmically. The sudden increase in C when M5=350 leads to a larger increase in X(T,M5mC) than for M5 < 350. Further investigation of this inconsistency is recommended if the equations are to be used for M5>350. It should, however, be mentioned that the highest 1 d M5-values for Norway in present climate are well below 250 mm (cf. Figure 4.1).

4. Results

The use of extreme value theory, in this case the Gumbel distribution, for return period calculations, requires the time series to be stationary. It also requires long time series. Ideally, the estimates should not differ in magnitude as a consequence of using different time periods. This criteria is seldom satisfied. It is, however, of interest to have an idea of how the estimates change between different time periods. Observations for the time period 1957 – 2008 is available. The precipitation projections used have two different control periods, 1961 – 1990 as well as 1981 – 2010. Estimates of M5 for the three different time periods, based on observations, are presented in Section 4.1.

Estimates of precipitation amounts with 5, 10, 50, 100 and 1000 years return periods as well as probable maximum precipitation (PMP) are presented for 141 selected catchments. The calculations are based on the datasets presented in Section 2. The estimates are developed for 5 durations (6 h, 12 h, 1 d, 2 d, 3 d, 5 d and 10 d). Results from 1-day duration are presented in Appendix B (tabular) and Appendix C (figures).

M5 estimates based on modeled data representing a historic period should agree with estimates based on observations. Such estimates are presented in Section 4.2. Finally; estimates of the future change in M5 is presented for the 141 selected catchments in Section 4.3.

4.1 M5 estimates based on observations

Estimates for three time periods are carried out, 1957 -2008, 1961 – 1990 and 1981 – 2008.

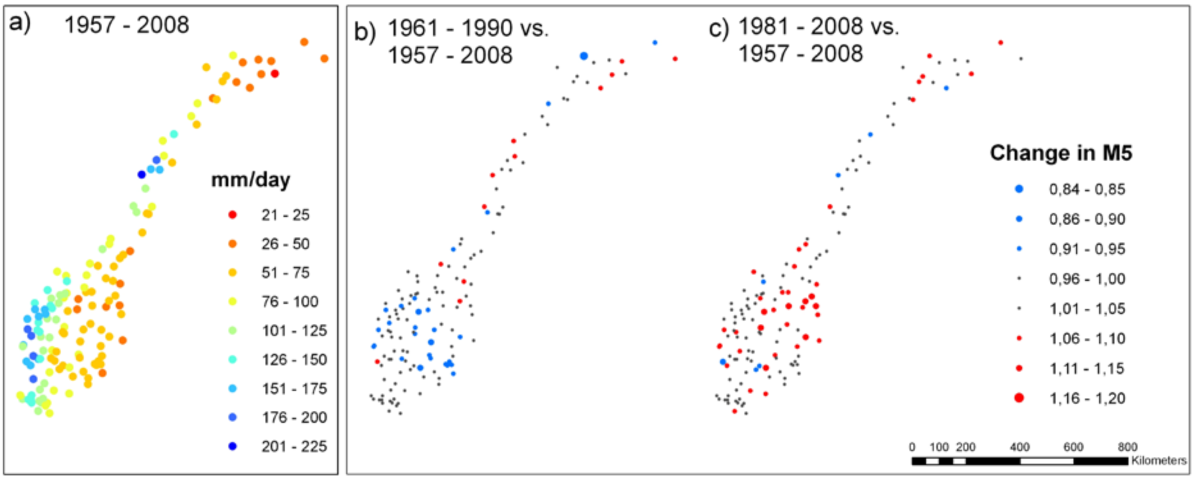

Figure 4.1 Annual 1-day precipitation for the selected catchments (cf. Figure 2.1) a) M5 values for the period 1957 – 2008, b) ratio between M5-values for the periods 1961 – 1990 and 1957 – 2008, c) ratio between M5-values for the periods 1981 – 2008 and 1957 – 2008

4.2 M5 estimates for present climate - modeled and observed data

M5-values are estimated based on modeled daily precipitation for present climate (“Control”) calculated in seven RCM-runs (cf. Table 2.1). The ratio between these estimates and the estimates of M5 based on observations for the same periods, are presented in Figure 4.2. The modeled results are based on adjusted RCM output. Figure 4.3 shows an example (for HADA1B) of how the adjustment procedure improves the M5 estimates.

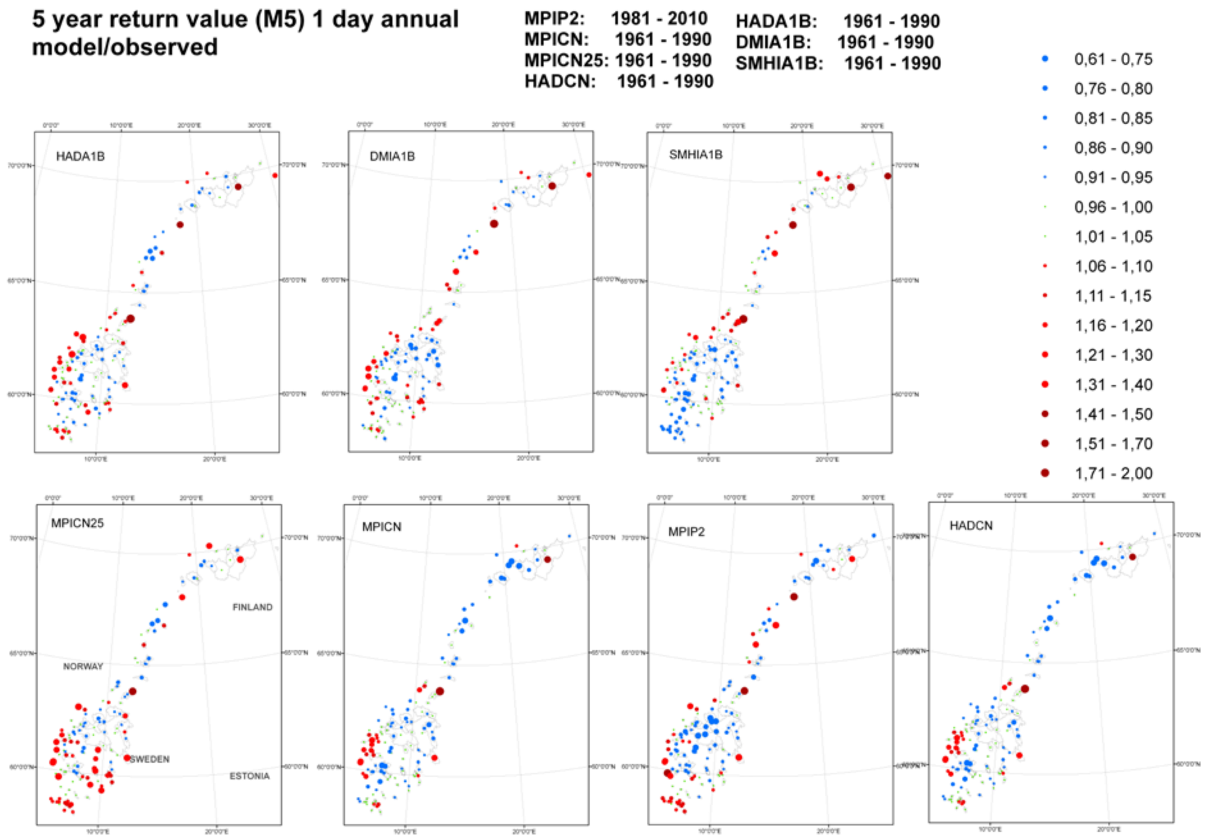

Figure 4.2 Ratios between 1-day M5-values from control runs and observations. The seven RCMs used are listed in Table 2.1

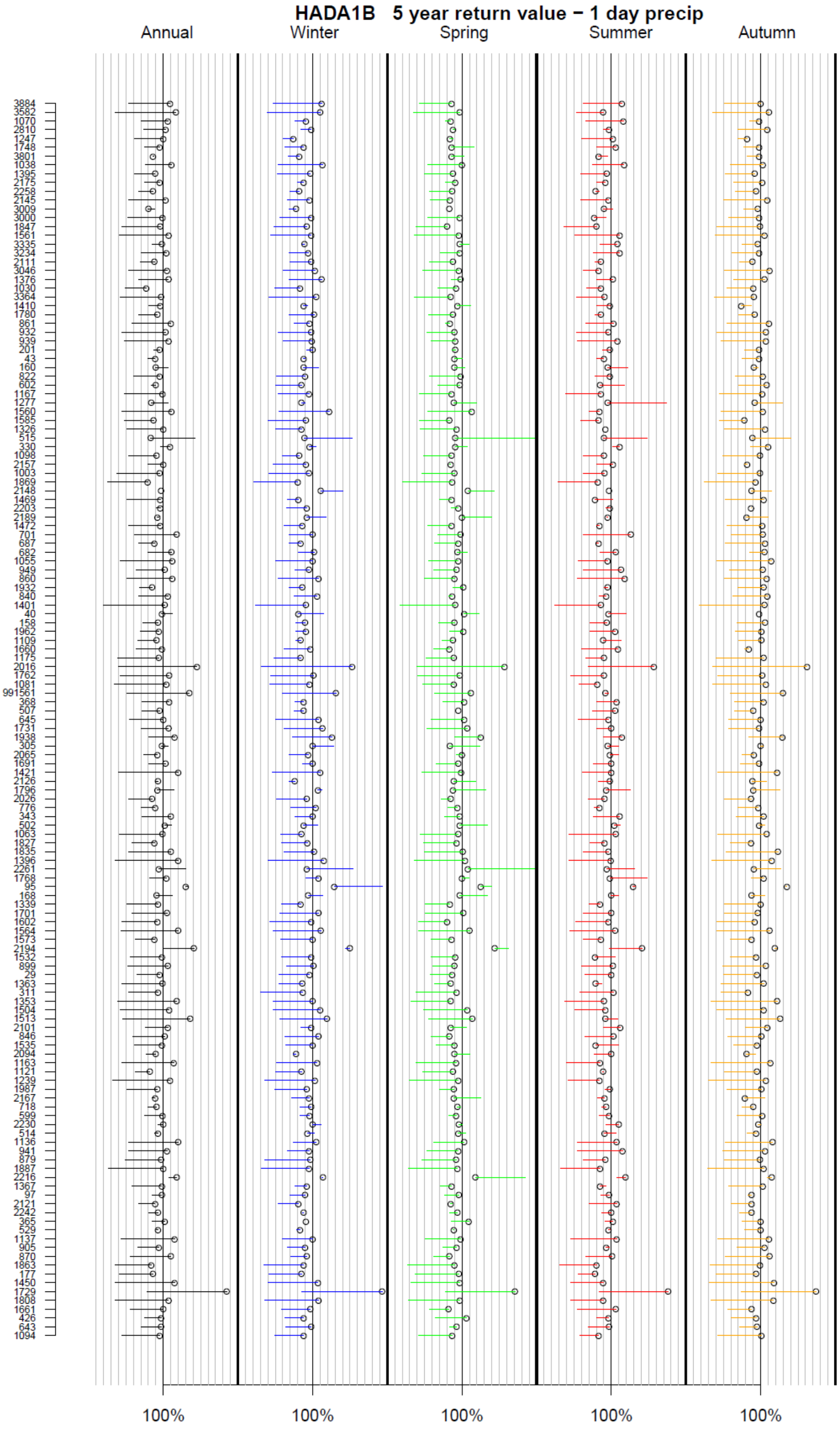

Figure 4.3 The black circles show the difference between 1 d M5-values based on control runs and observations. Values are shown for each catchment (cf. list in Appendix A), and the five columns indicate annual and seasonal values. For perfect match between M5-values from control runs and observations, the circles lie on the 100% line. Each vertical line indicates 10 %, ranging from 0 to 200%. Each vertical line denotes 10 %. The black, blue, green, red and orange lines indicate start and end point of the adjustments for annual, winter, spring, summer and autumn, respectively. The HadCM3Q0 calculation using the A1B emission scenario, is

the example chosen (cf. Figure 4.2 upper left). The adjusted estimates are in better agreement. Two catchments however, are in worse agreement. These catchments (2016 Coarveij and 1729 Veravatn) of medium size (63,6 and 175,4 km^2 respectively), have about half the catchments located in Sweden

4.3 M5 estimates representative for the future.

Estimates of projected changes in annual M5-values (1 d) for ten RCM runs are presented for the 141 selected catchments in Figure 4.4 and Appendix B. The estimates are presented in more detail in Figure 4.5 for 12 selected catchments, see Appendix C for all 141 catchments (annual as well as seasonal estimates).

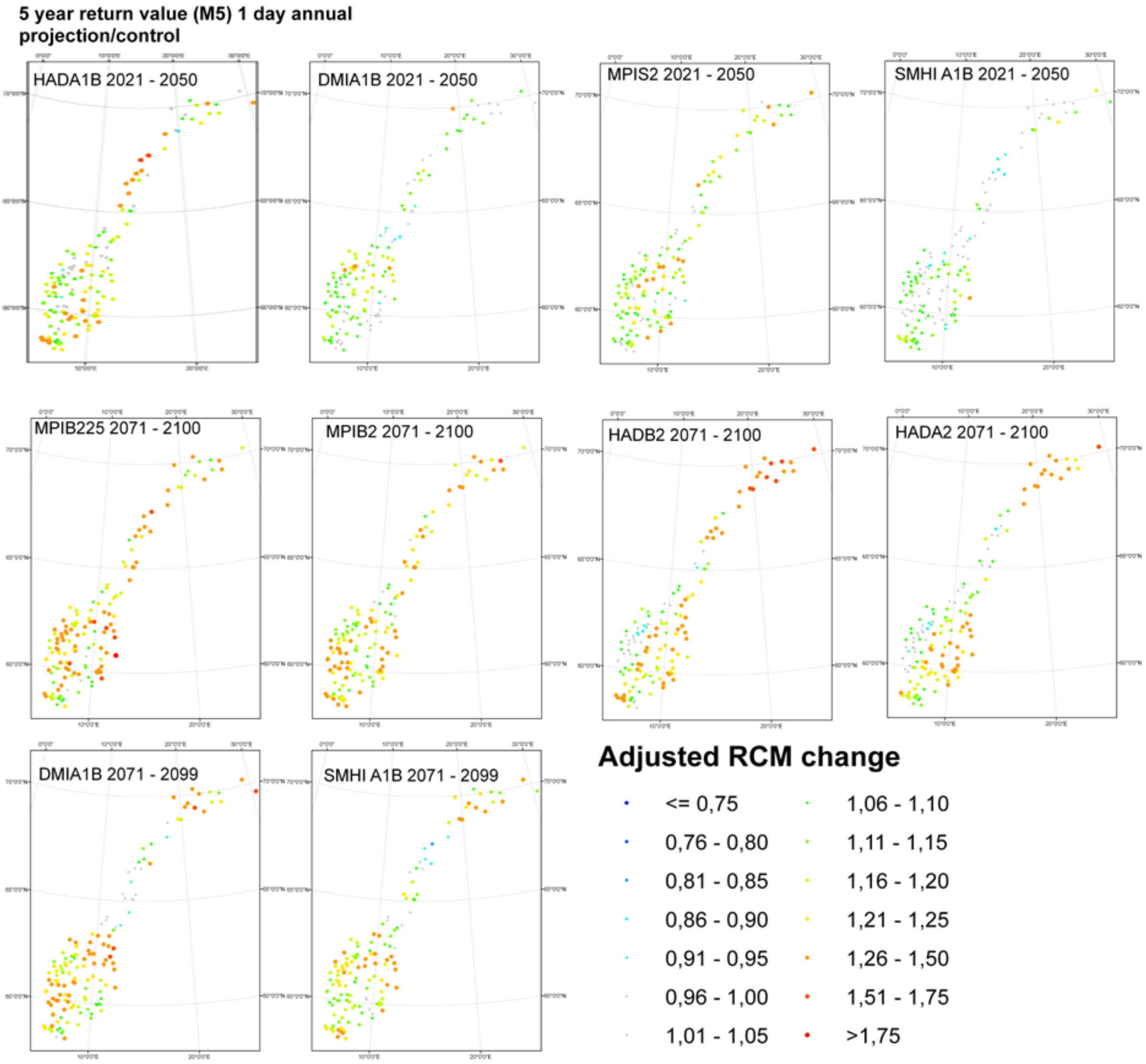

Figure 4.4 Ratio between annual 1 d M5-values from projection and control periods. Details on the RCMs and the control and scenario periods are presented in Table 2.1

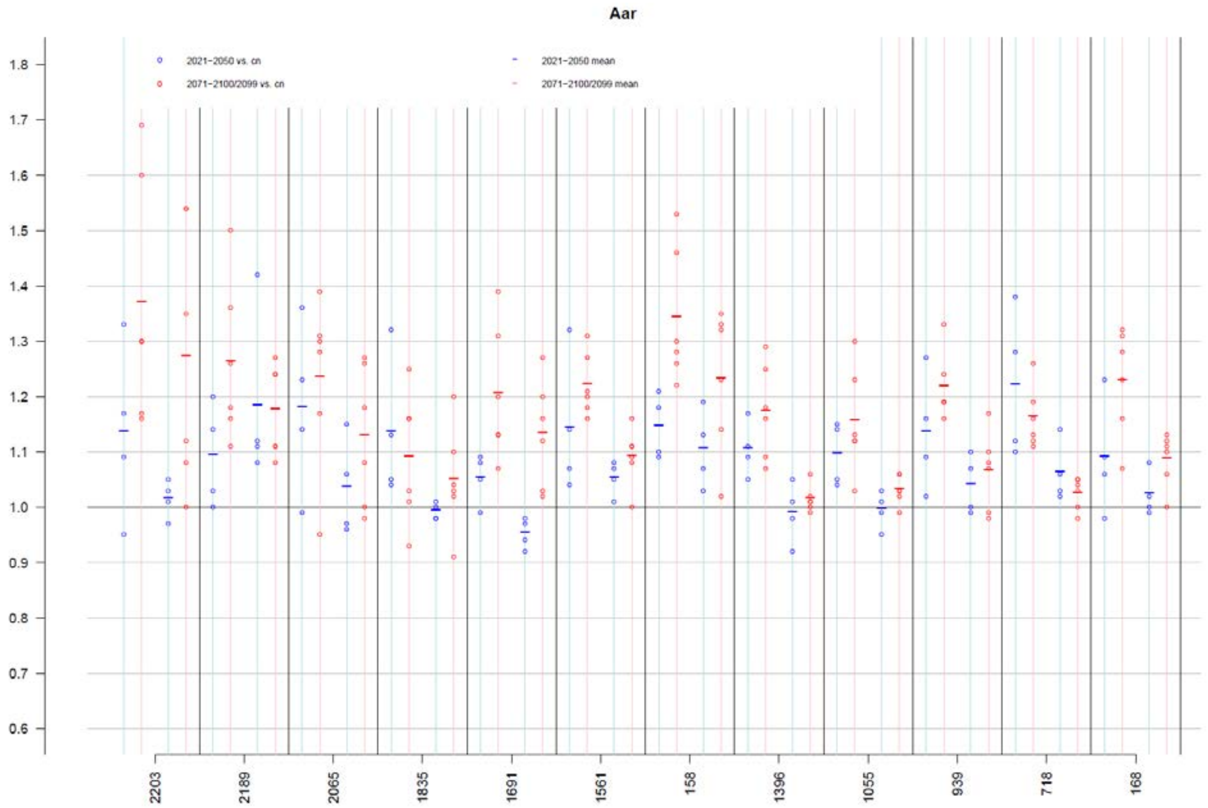

Figure 4.5 Ratio between projected and control 1 d M5-values for 12 selected catchments (cf. list in Appendix A). Changes from the normal period (1961-1990) to (2021-2050) are shown in blue, and changes from (1961-1990) to (2071-2100) are shown in red. The different model results are presented as circles, the mean values are presented as dash (-). For each catchment, divided by a black vertical line, there are two sets of results. The results to the left are based on adjusted RCM output while the results to the right are based on unadjusted RCM output

5. Discussion and conclusions

As discussed in the introduction there has been an increase in total precipitation amounts in Norway during the last century, however, most trends for heavy daily rainfall are not found to be statistically significant. The study reported here for 141 catchments, presents results for M5 estimates for 1 d precipitation. Absolute values for two “present climate” periods (1961 – 1990 and 1981 - 2008) and projected changes to two future periods (2021-2050 and 2071-2100) are presented.

Figure 4.1 to the left presents M5 estimates for each catchment for the time period 1957 - 2008. The estimates range from ~20 mm/d in eastern and north eastern parts of the country up to 225 mm/d in western parts and in Nordland. The M5 estimates for the first historic time period (1961 – 1990, middle) were mainly lower (blue dots) compared to estimates for the whole time period. This indicates that the normal period had rather few high rainfall events. The second historic time period studied (1981-2008, right) shows an increase in intense precipitation episodes (red dots). This was also found by Førland et al. (1998). The results also indicate that the time series analysed are not stationary. The results are not directly comparable to earlier estimates, though, as daily precipitation in the gridded maps used here is corrected for elevation enhancement and under catch in gauges (Section 2.1) which has shown to over estimate the heavy rainfall events, particularly in high mountain areas. The traditional way of doing the analyses is to use precipitation observations, and then reduce the values to be valid for the catchments. This is typically done by the use of ARF (Areal Reductions Factors). To obtain results comparable to earlier work, the analyses should be done on grid values of uncorrected precipitation.

Figure 4.2 presents M5 estimates for the control periods in the seven RCM runs (Section 2.2). These are compared to the respective historic M5 estimates presented in Figure 4.1. Only MPIS2 is using the control period 1981 – 2010. The Figure shows that there are large differences between the estimates based on observations and control runs in RCM-simulations, the differences range from -40% to +100%. The largest errors occur in the catchments in the border areas between Norway and Sweden due to the lack of observations from Sweden (Section 2.1). It is possible to detect a spatial pattern in the differences, at least in the south. The grid-based areal M5 estimates are too large in the south-west and too low in the south-east. One example is given to show how the adjustment procedure improves the M5 estimates; the results presented in the upper left panel of Figure 4.2 are shown in Figure 4.3. Seasonal values are also presented. The lines show that the adjustment procedure improves the M5-estimates. This is the case also for the other six models (not shown).

The projected changes from present to future climate are presented in Figure 4.4. The Figure shows an increase in the M5 1 d precipitation. The change is larger and the spatial pattern more variable in 2071-2100 compared to 2021-2050. There are, however, large differences in the spatial pattern from one projection to another. The results shown in Figure 4.4 are presented in more detail for 12 selected catchments in Figure 4.5.

The results show that there is large spread in the results, both spatially and between different RCM-simulations. The projections indicate, however, that the 1 d M5-values will increase and thus that also estimates for longer return periods will increase up to the end of the 21st century.

The results discussed in Section 2.4 are uncertain. There are several significant sources of uncertainties when estimating changes in return period values from present to future climate. We have still decided to produce and present the results, but it is stressed that the estimates in the present report should be considered only as a rough guide for future flood conditions.

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Appendix A

Catchments identification (ID), name, area (km^2) as well as information whether it contains a part of the Swedish land area (Swedish, parenthesis means only a inconsiderable part of the catchment) for the 141 selected catchments. Hyd mod denotes weather NVE use the hydrological model HBV or the routing model PQRUT in their design flood estimate.

ID	Name	Area	Swedish	Hyd mod
1094	Sandvenvatn	468,35		HBV
643	Grosettjern	6,48		HBV
426	Etna	570,12		HBV
1661	Eggafoss	653,1		HBV
1808	Mevatnet	109,23		HBV
1729	Veravatn	175,38	1	HBV
1450	Skjerdalselv	23,71		HBV
177	Tora	262,69		HBV
1863	Berget	210,97		HBV
870	Mygland	46,93		HBV
905	Jogla	31,14		HBV
1137	Dyrdalsvatn	3,24		HBV
529	Storeskar	120,27		HBV
365	Bjornegaardssvingen	190,38		HBV
2242	Engeren	394,83	(1)	HBV
2121	Manndalen_Bru	199,95		HBV
97	Losna	11208,33		HBV
1367	Nessedalselv	30,08		HBV
2216	Karpelva	138,33	1	HBV
1887	Vassvatn	16,56		HBV
879	Gjuvvatn	97,02		HBV
941	Ogna_Hetland	70,32		HBV
1136	Roykenes	49,89		HBV
514	Sundbyfoss	74,28		HBV
2230	Nybergsund	4420,24	1	HBV
599	Skorge	59,72		HBV
718	Gjerstad	236,37		HBV
2167	Lombola	877,93		HBV
1987	Morsvik_Bru	31,25		HBV
1239	Brekke_bru	267,18		HBV
1121	Bjoreio	262,61		HBV
1163	Bulken_Vangsvatnet	1093,92		HBV
2094	Malangsfoss	3114,17	(1)	HBV
1535	Horgheim	1098,79		HBV
846	Sogne	205,59		HBV
2101	Skogsfjordvatn	135,47		HBV
1513	Oye_ndf	138,75		HBV
1504	Fetvatn_Fitjavatnet	89,12		HBV
1353	Sogndalsvatn	110,21		HBV
311	Rosten	1828,24		HBV
1363	Boyumselv	40,42		HBV
29	Narsjo	118,94		HBV
899	Ardal	77,59		HBV
1532	Ulva_Storholen	436,65		HBV

2194	Polmak_nye	14156,58	1	HBV
1573	Driva_Risefoss	743,55		HBV
1564	Farstadelva_Farstad	23,91		HBV
1602	Rinna	91,09		HBV
1701	Hoggaas_Bru	495,12		HBV
1339	Nigardsbrevatn	65,29		HBV
168	Kraakfoss	432,86		HBV
95	Knappom	1648,12	1	HBV
1768	Oyungen	239,43		HBV
2261	Lena	180,56		HBV
1396	Nautsundvatn	218,96		HBV
1835	Fustvatn	525,86		HBV
1827	Nervoll	653,16	(1)	HBV
1063	Djupevad	31,93		HBV
502	Holervatn	79,38		HBV
343	Gryta	7,05		HBV
776	Austenaa	276,46		HBV
2026	Ovstevatn_Litlevatnet	28,44		HBV
1796	Trangen	853,64		HBV
2126	Svartfossberget	1928,9	(1)	HBV
1421	Hovefoss	234,5		HBV
1691	Kjelstad	142,22		HBV
2065	Ovrevatn	525,69	(1)	HBV
305	Elverum	15443,61	(1)	HBV
1938	Junkerdalselv	419,09	1	HBV
1731	Dillfoss	479,64	1	HBV
645	Tannsvatn_Lognvikvatnet	117,58		HBV
507	Eggedal	309,42		HBV
368	Seternbekken	6,33		HBV
991561	Osenelv_Oren	137,77		HBV
1081	Fonnerdalsvatn	7,01		HBV
1762	Krinsvatn_Kringsvatnet	206,61		HBV
2016	Coarveij	63,55	1	HBV
1175	Svartavatn	72,11		HBV
1660	Gaulfoss	3085,3		HBV
1109	Holen	232,39		HBV
1962	Strandaa	23,88		HBV
158	Unseta	620,81		HBV
40	Aulestad	866,3		HBV
1401	Viksvatn_Hestadfjorden	506,82		HBV
840	Myglevatn_ndf	182,28		HBV
1932	Skarsvatn	145,51		HBV
860	Moska_Skolandsvatnet	121,3		HBV
949	Haugland	140,35		HBV
1055	Stordalsvatn	129,4		HBV
682	Gjuvaa	33,08		HBV
687	Kvenna	821,82		HBV
701	Horte	155,64		HBV
1472	Lovatn	235,17		HBV
2189	Vakkava_Iesjokka	2077,52		HBV
2203	Bergeby	248		HBV
1469	Gloppenelva_Teita_Bru	219,3		HBV

2148	Masi	5625,58	(1)	HBV
1869	Bredek	228,9		HBV
1003	Djupadalsvatn	45,42		HBV
2157	Halsnes	144,76		HBV
1098	Reinsnosvatn	120,36		HBV
330	Hogfoss	298,94		HBV
515	Fiskum	51,85		HBV
1326	Krokenelv	46,16		HBV
1585	Driva_Elverhoy_Bru	2442,41		HBV
1560	Vistdal	66,39		HBV
1277	Sula	30,44		HBV
1167	Myrkdalsvatn	158,87		HBV
602	Orsjoren	1177,26		HBV
822	Lislefjodd	19,01		HBV
160	Akslen	795,13		HBV
43	Atnasjo	462,88		HBV
201	Fura	45,21		HBV
939	Helleland	184,65		HBV
932	Bjordal	123,82		HBV
861	Tingvatn_Lygne	272,16		HBV
1780	Bjornstad	1036,29		HBV
1410	Gaggavatn	515,6		PQRUT
3364	Vaavatn	37,54		PQRUT
1030	Arstaddammen	65,04		PQRUT
1376	Follavatn	251,7		PQRUT
3046	Ovre_Ringvatn	12,74		PQRUT
2111	Namsvatn	699,95		PQRUT
3234	Maridalsvatn	208,81		PQRUT
3335	Sonoren	702,1		PQRUT
1561	Hauklandstemmevatn	9,82		PQRUT
1847	Kvilesteinsvatn	23,67		PQRUT
3000	Zakariasvatn	181,46		PQRUT
3009	Oljusjoen	40,46		PQRUT
2145	Skjerkevatn	191,5		PQRUT
2258	Raudalsvatn	146,4		PQRUT
2175	Nord-Mesna	218,86		PQRUT
1395	Fundin	252,9		PQRUT
1038	Aursunden	849		PQRUT
3801	Mosvatn	1509,94		PQRUT
1748	Kildalen_inntaksdam	157,71		PQRUT
1247	Devdisvatn	252,87		PQRUT
2810	Tungefoss	11,29		PQRUT
1070	Bergsfjordvatn	15,88		PQRUT
3582	Hommelvatn	12,12		PQRUT
3884	Djupsjoen	3,18		PQRUT

Appendix B Tabular M5 estimates based on annual 1 d precipitation, projection period vs control period. MPIS2 represent the period 2021-2050 vs. 1981-2010, HADA1B2150, DMIA1B2150, SMHIA1B2150 represent the period 2021-2050 vs. 1961-1990, and MPIB2, MPIB225, HADA2, HADB2, DMIA1B7199 and SMIA1B7199 represent the period 2071-2100(2099) vs 1961-1990

STNR	MPIS2	MPIB2	MPIB225	HADA2	HADB2	HADA1B 2150	DMIA1B 2150	DMIA1B 7199	SMHIA1B 2150	SMHIA1B 7199
1094	1,1	1,2	1,1	1,1	1,1	1,1	1,1	1,3	1,0	1,1
643	1,0	1,2	1,3	1,3	1,2	1,4	1,1	1,2	1,1	1,2
426	1,1	1,2	1,1	1,2	1,2	1,3	1,2	1,2	1,0	1,2
1661	1,3	1,1	1,4	1,2	1,2	1,0	1,2	1,4	1,0	1,1
1808	1,0	1,3	1,2	1,1	1,0	1,3	1,1	1,0	1,1	1,2
1729	1,2	1,3	1,2	1,1	1,2	1,2	0,9	0,9	1,0	1,0
1450	1,1	1,1	1,3	1,1	1,1	1,1	1,1	1,1	1,1	1,3
177	1,1	1,1	1,2	0,9	0,9	1,0	1,2	1,1	1,0	1,1
1863	1,1	1,2	1,3	1,0	1,3	1,4	1,0	1,0	1,0	1,1
870	1,1	1,2	1,2	1,2	1,2	1,1	1,0	1,1	1,1	1,3
905	1,1	1,1	1,3	1,2	1,2	1,1	1,1	1,2	1,1	1,1
1137	1,1	1,3	1,2	1,0	1,0	1,1	1,1	1,2	1,1	1,1
529	1,1	1,1	1,3	1,3	1,3	1,1	1,1	1,3	1,0	1,0
365	1,2	1,2	1,4	1,3	1,3	1,2	1,0	1,1	1,0	1,1
2242	1,1	1,4	1,6	1,4	1,3	1,2	1,2	1,4	1,1	1,5
2121	1,2	1,2	1,1	1,4	1,4	1,1	1,1	1,3	1,0	1,2
97	1,3	1,2	1,3	1,2	1,3	1,2	1,2	1,2	1,1	1,3
1367	1,2	1,2	1,3	1,0	1,0	1,3	1,1	1,2	1,1	1,2
2216						1,3	1,0	1,6	1,1	1,1
1887	1,3	1,0	1,1	1,2	1,2	1,4	1,0	1,0	1,0	1,0
879	1,1	1,2	1,4	1,2	1,1	1,0	1,0	1,1	1,1	1,2
941	1,1	1,3	1,3	1,2	1,3	1,3	1,1	1,2	1,2	1,2
1136	1,1	1,3	1,2	1,0	1,0	1,1	1,1	1,2	1,1	1,1
514	1,1	1,1	1,1	1,2	1,3	1,2	1,0	1,1	0,9	1,0
2230	1,2	1,3	1,5	1,4	1,3	1,2	1,2	1,5	1,2	1,4
599	1,3	1,1	1,1	1,3	1,3	1,2	1,0	1,1	0,9	1,1
718	1,3	1,3	1,1	1,1	1,2	1,4	1,1	1,2	1,1	1,1
2167	1,1	1,2	1,1	1,2	1,5	1,4	1,0	1,2	1,0	1,1
1987	1,2	1,2	1,6	1,1	1,1	1,6	1,0	1,1	0,9	0,8
1239	1,0	1,3	1,2	1,1	1,1	0,9	1,1	1,3	1,0	1,2
1121	1,2	1,3	1,3	1,2	1,3	1,0	1,0	1,2	1,0	1,1
1163	1,1	1,3	1,2	1,0	1,0	1,1	1,1	1,3	1,0	1,2
2094	1,2	1,4	1,2	1,5	1,6	1,0	1,1	1,2	1,1	1,3

1535	1,0	1,2	1,2	1,0	1,0	1,0	1,3	1,2	0,9	1,1
846	1,0	1,4	1,2	1,1	1,0	1,3	1,1	1,3	1,1	1,2
2101	1,2	1,2	1,3	1,5	1,3	1,0	1,3	1,3	1,0	1,2
1513	1,2	1,1	1,3	1,0	1,0	0,9	1,3	1,1	1,0	1,2
1504	1,1	1,1	1,3	1,1	1,1	1,2	1,2	1,2	1,1	1,3
1353	1,0	1,2	1,4	1,1	1,0	1,1	1,0	1,1	1,1	1,3
311	1,2	1,3	1,3	1,2	1,3	1,3	1,1	1,3	1,1	1,3
1363	1,1	1,2	1,3	1,0	1,0	1,1	1,0	1,2	1,1	1,2
29	1,1	1,1	1,3	1,3	1,3	1,0	1,3	1,5	1,1	1,3
899	1,0	1,2	1,2	1,2	1,3	1,3	1,1	1,2	1,2	1,2
1532	1,0	1,1	1,2	1,0	1,0	1,0	1,3	1,2	0,9	1,1
2194	1,1	1,4	1,5	1,2	1,4	1,2	1,0	1,2	1,1	1,3
1573	1,4	1,3	1,4	1,2	1,2	1,2	1,0	1,3	1,1	1,2
1564	1,0	1,2	1,3	1,1	1,2	1,1	1,2	1,4	1,1	1,2
1602	1,1	1,2	1,2	1,1	1,1	1,2	1,1	1,3	0,9	1,1
1701	1,0	1,2	1,2	1,1	1,3	1,1	1,0	1,1	1,0	1,1
1339	1,1	1,2	1,4	1,0	0,9	1,1	1,1	1,3	1,1	1,2
168	1,1	1,3	1,3	1,3	1,2	1,2	1,0	1,1	1,1	1,2
95	0,9	1,2	1,8	1,3	1,2	1,2	1,1	1,4	1,3	1,3
1768	1,0	1,1	1,2	1,1	1,1	1,0	0,9	1,0	1,0	1,0
2261	1,0	1,4	1,2	1,3	1,2	1,2	0,9	1,1	1,2	1,2
1396	1,1	1,3	1,2	1,1	1,1	1,2	1,1	1,3	1,1	1,2
1835	1,1	1,2	1,2	1,0	1,0	1,3	1,1	0,9	1,0	1,2
1827	1,1	1,2	1,3	1,1	1,1	1,0	0,9	1,0	1,0	1,1
1063	1,1	1,3	1,3	1,0	1,1	1,2	1,2	1,4	1,0	1,1
502	1,0	1,1	1,0	1,3	1,2	1,3	1,2	1,2	1,0	1,1
343	1,1	1,2	1,5	1,2	1,2	1,2	1,0	1,1	1,1	1,2
776	1,1	1,1	1,0	1,1	1,1	1,3	1,1	1,2	1,1	1,1
2026	1,3	1,3	1,4	1,3	1,2	1,4	1,1	1,0	1,0	1,0
1796	1,2	1,2	1,5	1,2	1,2	1,2	1,0	0,9	1,0	1,0
2126	1,2	1,2	1,2	1,5	1,7	1,1	1,2	1,6	1,1	1,3
1421	1,1	1,1	1,2	1,1	1,0	1,2	1,1	1,2	1,1	1,2
1691	1,1	1,1	1,2	1,1	1,3	1,0	1,1	1,4	1,0	1,1
2065	1,2	1,3	1,3	1,4	1,3	1,4	1,1	1,0	1,0	1,2
305	1,2	1,2	1,4	1,2	1,2	1,1	1,1	1,4	1,1	1,2
1938	1,1	1,2	1,4	1,2	1,5	1,0	1,1	1,3	0,9	0,9
1731	1,1	1,2	1,2	1,1	1,2	1,2	0,9	1,0	0,9	1,1
645	1,0	1,1	1,2	1,2	1,2	1,4	1,1	1,2	1,0	1,2

507	1,1	1,1	1,1	1,3	1,2	1,2	1,2	1,2	1,0	1,0
368	1,2	1,2	1,4	1,3	1,3	1,2	1,0	1,1	1,1	1,2
991561	1,1	1,2	1,2	1,1	1,1	1,1	1,2	1,3	1,0	1,2
1081	1,1	1,3	1,2	1,0	1,1	1,1	1,1	1,3	1,0	1,1
1762	1,1	1,0	1,1	1,0	1,1	1,1	0,9	1,0	1,0	1,1
2016	1,1	1,2	1,3	1,3	1,3	1,2	1,1	0,9	1,0	0,9
1175	1,2	1,2	1,2	0,9	1,0	1,1	1,1	1,3	1,1	1,2
1660	1,2	1,1	1,3	1,1	1,1	1,0	1,2	1,5	1,0	1,1
1109	1,2	1,3	1,3	1,1	1,1	1,0	1,1	1,3	1,0	1,1
1962	1,1	1,1	1,3	1,1	1,2	1,6	1,0	1,1	0,9	0,9
158	1,2	1,2	1,5	1,3	1,3	1,2	1,1	1,5	1,1	1,3
40	1,2	1,2	1,2	1,3	1,2	1,2	1,2	1,2	1,0	1,2
1401	1,1	1,2	1,3	1,0	1,0	1,2	1,1	1,2	1,1	1,2
840	1,2	1,2	1,1	1,1	1,0	1,2	1,0	1,1	1,1	1,2
1932	1,2	1,2	1,3	1,0	1,4	1,4	1,2	1,1	0,9	0,9
860	1,0	1,4	1,1	1,1	1,2	1,2	1,0	1,0	1,1	1,3
949	1,1	1,3	1,4	1,3	1,3	1,5	1,2	1,2	1,2	1,2
1055	1,1	1,2	1,1	1,0	1,1	1,2	1,1	1,3	1,0	1,1
682	1,1	1,2	1,5	1,2	1,1	1,2	1,1	1,2	1,0	1,1
687	1,1	1,3	1,5	1,3	1,3	1,2	1,0	1,2	1,1	1,1
701	1,1	1,2	1,0	1,2	1,1	1,1	1,1	1,1	1,0	1,1
1472	1,2	1,1	1,4	1,0	0,9	1,0	1,1	1,2	1,0	1,2
2189	1,1	1,4	1,1	1,3	1,5	1,2	1,0	1,2	1,0	1,2
2203	1,3	1,2	1,2	1,6	1,7	1,0	1,1	1,3	1,2	1,3
1469	1,1	1,1	1,3	1,0	1,0	1,1	1,1	1,2	1,1	1,2
2148	1,3	1,2	1,4	1,4	1,7	1,3	1,1	1,3	1,3	1,4
1869	1,1	1,4	1,2	1,0	1,3	1,2	1,2	1,0	1,0	1,0
1003	1,1	1,2	1,1	1,2	1,2	1,2	1,2	1,3	1,1	1,2
2157	1,3	1,3	1,1	1,3	1,6	1,2	1,0	1,4	1,0	1,2
1098	1,1	1,3	1,2	1,2	1,2	1,1	1,1	1,4	1,0	1,1
330	1,4	1,2	1,6	1,2	1,3	1,3	1,0	1,2	1,1	1,3
515	1,1	1,1	1,1	1,2	1,2	1,3	1,0	1,1	1,0	1,0
1326	1,3	1,3	1,2	1,0	1,0	1,1	1,1	1,2	1,0	1,2
1585	1,2	1,3	1,2	1,1	1,0	1,0	1,2	1,3	0,9	1,1
1560	1,2	1,2	1,2	1,1	1,1	1,0	1,2	1,2	1,0	1,1
1277	1,2	1,2	1,4	1,2	1,3	1,0	1,2	1,3	1,0	1,1
1167	1,2	1,3	1,3	1,0	1,0	1,1	1,1	1,2	1,1	1,2
602	1,2	1,2	1,6	1,3	1,3	1,0	1,1	1,3	1,1	1,2

822	1,2	1,3	1,4	1,2	1,2	1,1	1,0	1,3	1,1	1,2
160	1,3	1,2	1,3	1,3	1,4	1,1	1,1	1,2	1,1	1,3
43	1,2	1,2	1,1	1,1	1,1	1,2	1,2	1,3	1,1	1,3
201	1,0	1,5	1,4	1,2	1,2	1,2	1,0	1,3	1,2	1,3
939	1,0	1,2	1,2	1,2	1,3	1,3	1,1	1,2	1,2	1,2
932	1,1	1,1	1,2	1,2	1,3	1,2	1,1	1,3	1,2	1,1
861	1,1	1,2	1,1	1,1	1,1	1,1	1,0	1,0	1,1	1,3
1780	1,1	1,3	1,3	1,0	1,1	1,1	1,0	1,0	1,0	1,1
1410	1,1	1,5	1,4	1,2	1,5	1,1	1,0	1,1	1,0	1,1
3364	1,0	1,0	1,1	1,0	1,0	1,2	1,1	1,2		1,3
1030	1,2	1,3	1,3	0,9	1,3	1,3	1,1	1,1	0,9	1,0
1376	1,0	1,1	1,2	1,0	1,1	1,1	1,0	1,0	1,0	1,0
3046	1,0	1,2	1,2	1,0	0,9	1,2	1,1	1,0	1,1	1,2
2111	1,2	1,3	1,3	1,0	1,1	1,1	1,0	1,0	1,0	1,1
3234	1,1	1,3	1,3	1,3	1,2	1,2	1,0	1,0	1,0	1,2
3335	1,2	1,1	1,1	1,3	1,2	1,3	1,1	1,2	1,0	1,0
1561	1,0	1,3	1,2	1,2	1,3	1,3	1,1	1,2	1,1	1,2
1847	1,2	1,3	1,3	1,0	1,0	1,2	1,1	1,2	1,1	1,2
3000	1,1	1,1	1,2	0,9	0,9	1,0	1,2	1,1	1,0	1,2
3009	1,1	1,1	1,2	1,3	1,3	1,1	1,2	1,3	1,0	1,1
2145	1,1	1,2	1,1	1,1	1,1	1,1	1,0	1,1	1,1	1,2
2258	1,1	1,1	1,3	0,9	0,9	1,0	1,1	1,2	1,0	1,2
2175	1,1	1,4	1,3	1,4	1,3	1,1	1,1	1,2	1,1	1,2
1395	1,3	1,2	1,7	1,2	1,2	1,2	1,1	1,4	1,2	1,3
1038	1,3	1,0	1,2	1,3	1,3	1,1	1,2	1,5	1,0	1,0
3801	1,1	1,2	1,4	1,2	1,2	1,3	1,0	1,3	1,1	1,2
1748	1,2	1,2	1,1	1,5	1,4	1,0	1,1	1,5	1,0	1,3
1247	1,1	1,4	1,2	1,4	1,6	0,9	1,1	1,2	1,2	1,4
2810	1,2	1,2	1,1	1,1	1,0	1,2	1,0	1,1	1,1	1,3
1070	1,0	1,3	1,3	1,5	1,5	1,1	1,1	1,3	1,0	1,1
3582	1,1	1,3	1,2	1,0	1,1	1,2	1,1	1,3	1,0	1,1
3884	1,1	1,1	1,2	1,0	1,0	1,1	1,1	1,4	1,0	1,3

Appendix C

M5 estimates based on annual and all seasons 1 d precipitation, projection period vs control period. MPIS2 represent the period 2021-2050 vs. 1981-2010, HADA1B2150, DMIA1B2150, SMHIA1B2150 represent the period 2021-2050 vs. 1961-1990, and MPIB2, MPIB225, HADA2, HADB2, DMIA1B7199 and SMIA1B7199 represent the period 2071-2100(2099) vs 1961-1990.