Climate Change
Hydrological Change
Security of Supply

Oslo Water Supply 2012-2100

Report from studies for Norconsult and SINTEF

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Background

Water supply is vital for all

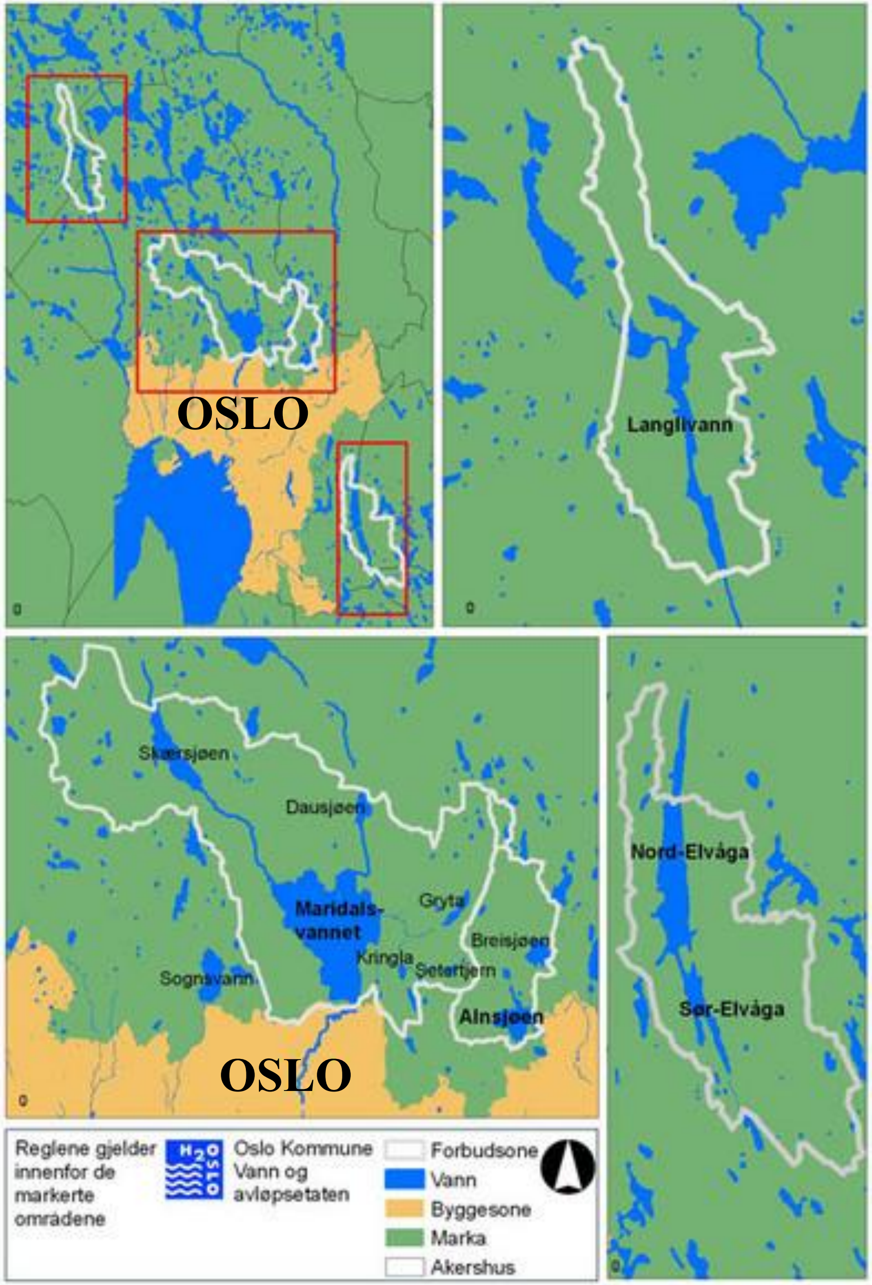
Increasing focus on security

Will climate change be a threat?

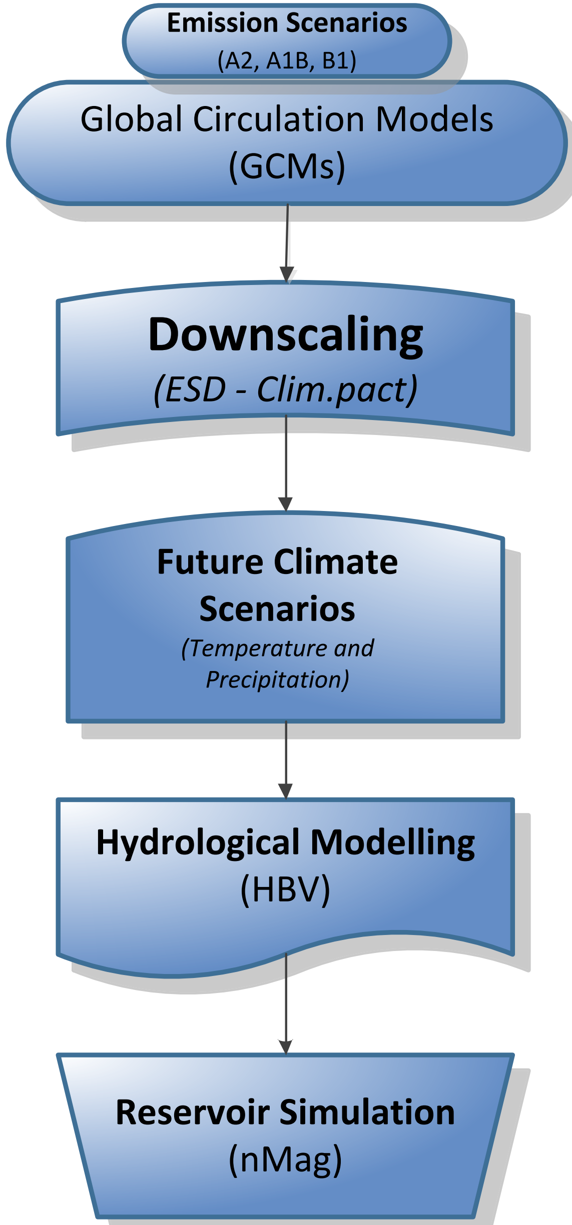
If so – what counter-measures?

What? When?

Plan for next 100 years



Main steps in the Climate Change study



Review - Previous Studies

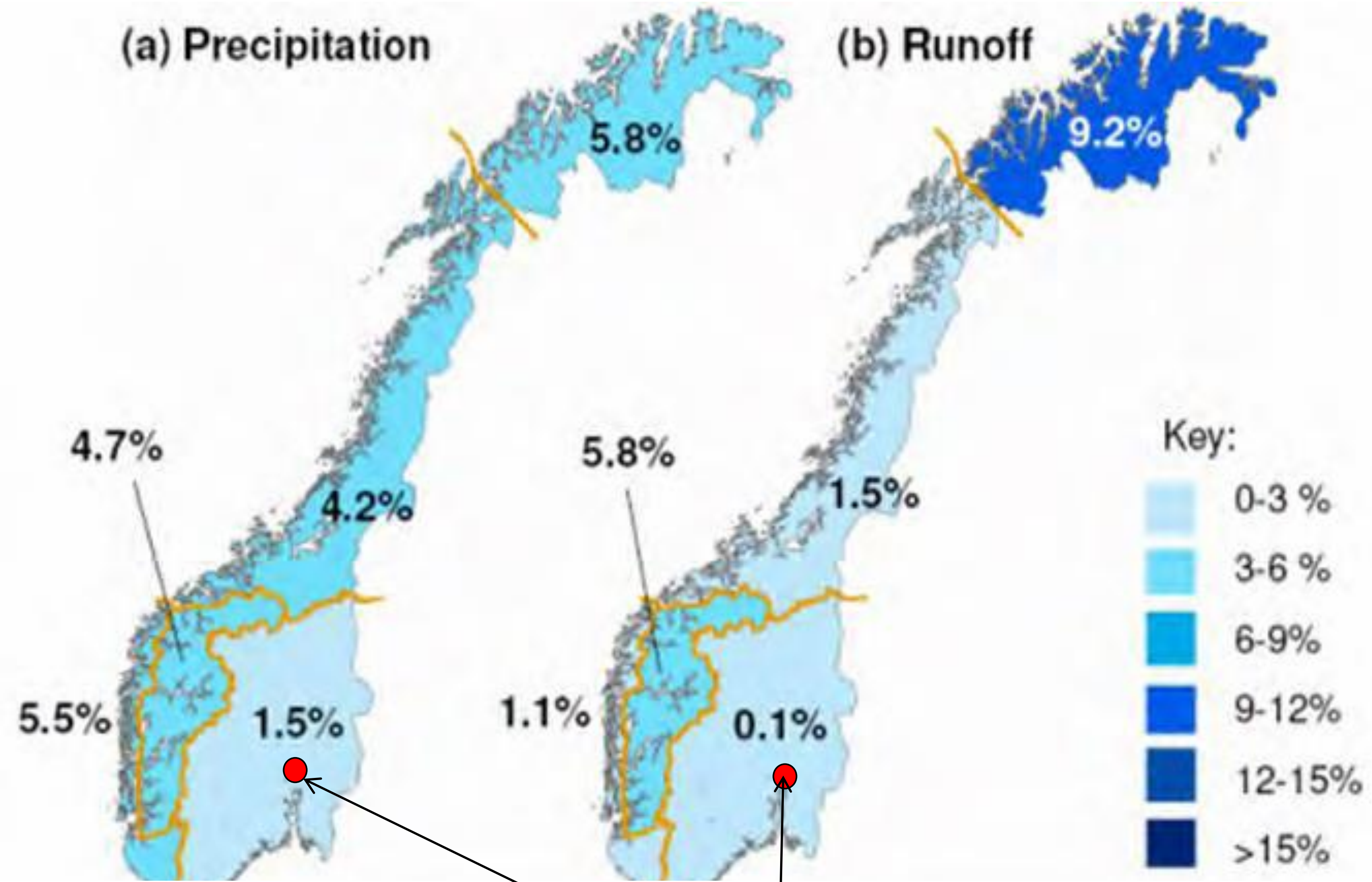


Figure 5. *Percentage increase in the regional a) precipitation and b) runoff in Norway in the period 1990–2003, relative to the 1961–1990 reference periods (from).*

Study area

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Review - Previous Studies

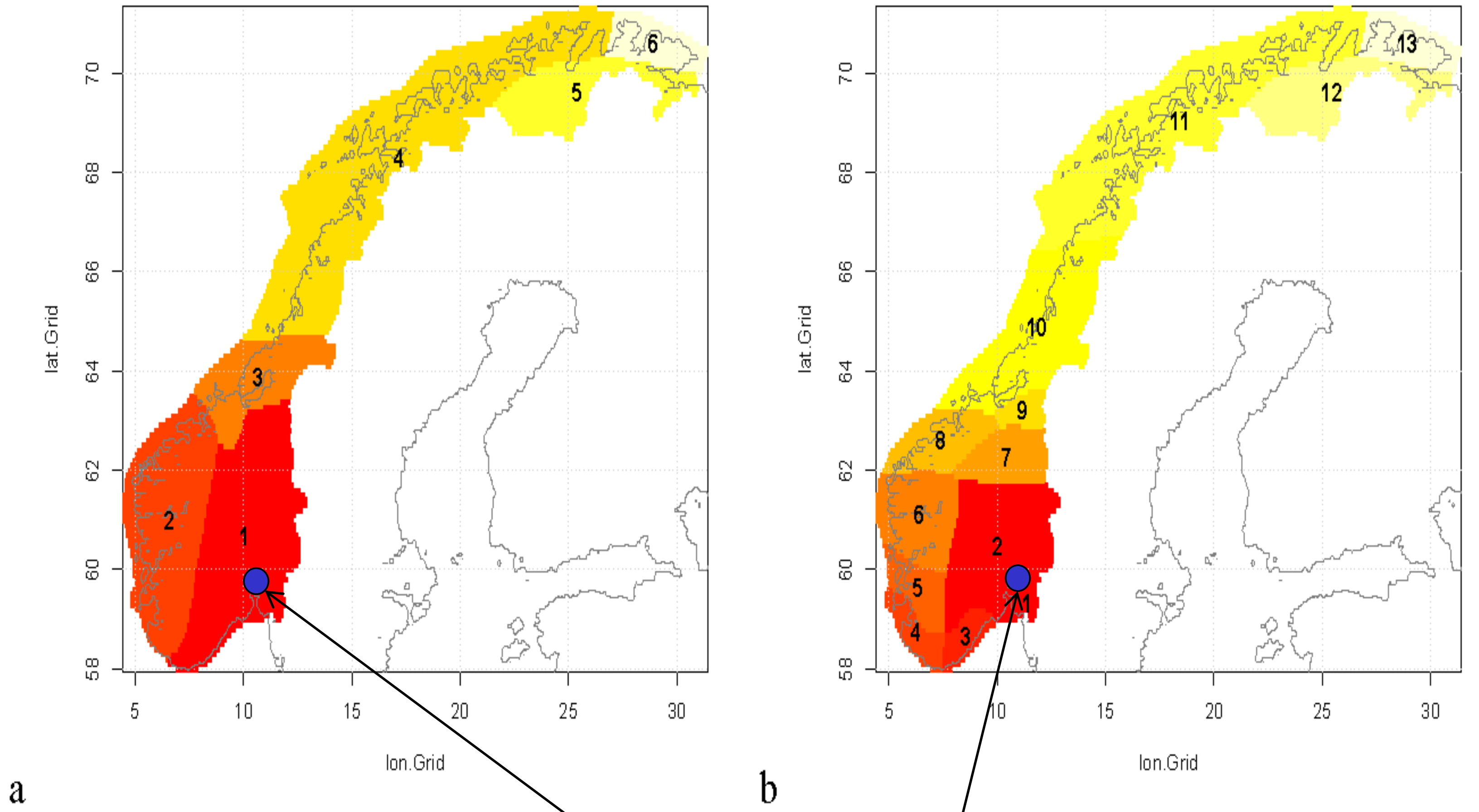

__Figure 6__ Maps showing the six temperature regions in (a) and 13 precipitation regions in (b) from Benestad. According to met.no, Norway is subdivided into 6 temperature regions and 13 precipitation regions

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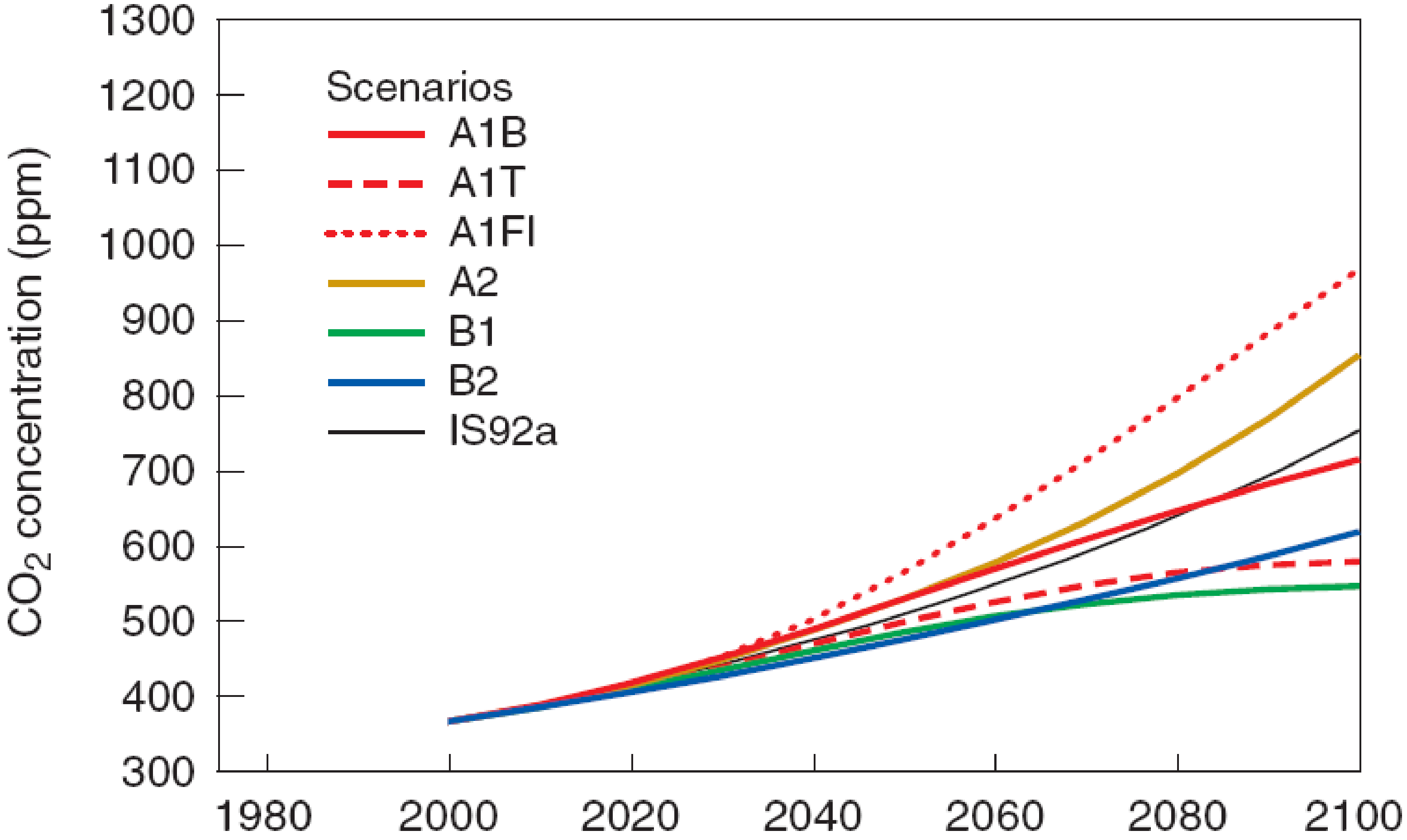
Emission Scenarios (IPCC)



Main Scenario used in this study: A1B, but also A2 and B1

Downscaling to Oslo-Nordmarka

Empirical (statistical downscaling)

- Using 3 Emission Scenarios
  - A2
  - B1
  - A1B (Most used in CC studies in Norway)
- Using 5 Global Climate Models (GCM)
- Using tools developed by Benestad, DNMI
- Using Oslo-Blindern and Gardermoen as targets

Downscaling to Oslo-Nordmarka

Oslo Gardermoen Median monthly temperature Delta changes from 5 GCMs

Scenario	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ANN
	1961 -1990	**-6.1**	**-6.5**	**-1.3**	**3.3**	**9.8**	**14.0**	**15.5**	**14.1**	**9.6**	**4.8**	**- 0.9**	**-5.1**	**4.3**
A1B	**2011 -2040**	3.4	3.3	3.4	3.4	3.5	3.0	3.7	3.3	2.9	3.0	3.2	2.9	3.2
	2041 - 2070	4.0	4.2	3.9	3.7	3.9	3.2	4.1	3.6	3.4	3.5	3.7	3.3	3.7
	2071 - 2100	4.9	5.1	4.4	3.8	4.4	3.1	4.1	3.4	3.5	3.9	3.9	3.4	4.0
A2	**2011 -2040**	2.5	2.9	2.3	2.7	2.8	2.8	3.0	3.2	2.8	2.8	2.3	2.4	2.7
	2041 - 2070	3.9	4.1	3.5	3.2	3.7	3.2	3.7	4.0	3.6	3.5	3.5	3.7	3.6
	2071 - 2100	5.6	5.3	4.9	4.3	4.8	3.9	4.3	4.3	4.5	4.7	5.1	4.9	4.7
B1	**2011 -2040**	2.6	3.8	3.2	3.5	3.3	3.6	3.5	3.3	3.4	3.6	3.3	2.5	3.3
	2041 - 2070	3.0	4.4	3.6	3.7	3.5	3.8	3.6	3.4	3.5	3.8	3.6	2.7	3.6
	2071 - 2100	3.0	4.8	3.8	3.8	3.7	3.8	3.7	3.4	3.6	4.0	3.8	2.9	3.7

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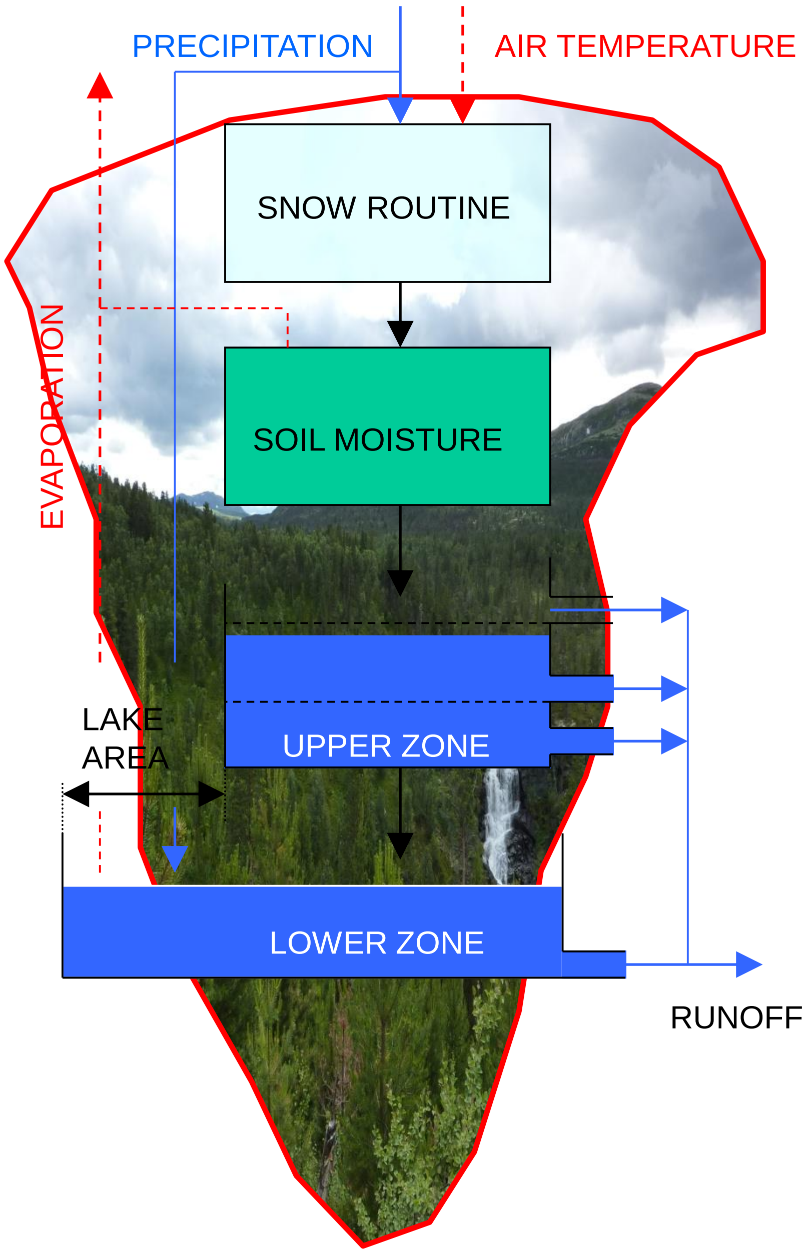
Downscaling to Oslo-Nordmarka

Oslo Gardermoen Median monthly precipitation Delta changes from 5 GCMs

Scenario	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ANN
	1961 -1990	**80**	**61**	**69**	**63**	**73**	**94**	**113**	**120**	**130**	**134**	**121**	**106**	**1164**
A1B	**2011 -2040**	109	114	116	115	112	110	108	107	106	107	109	109	**110**
	2041 - 2070	104	122	118	115	110	107	110	112	104	107	108	111	**111**
	2071 - 2100	109	127	111	115	106	103	109	112	107	107	105	117	**111**
A2	**2011 -2040**	109	114	115	113	107	110	102	110	104	106	104	105	**108**
	2041 - 2070	111	116	123	113	106	105	109	117	108	106	102	111	**111**
	2071 - 2100	108	135	134	113	102	99	119	128	114	106	100	127	**115**
B1	**2011 -2040**	101	106	104	103	103	106	99	96	99	102	105	95	**102**
	2041 - 2070	102	108	104	103	100	107	100	99	99	102	100	96	**102**
	2071 - 2100	101	109	105	103	100	108	102	101	99	102	100	97	**102**

The HBV-model – a Precipitation-Runoff model



HBV is an acronym formed from **H**ydrologiske **B**yrån avdeling för **V**attenbalans at SMHI, Sweden

The model structure was made by Sten Bergstrøm, previous research director at SMHI

The model is extensively used for making runoff/inflow forecasts to hydropower systems in Norway, Sweden and Finland, and many other countries in Europe (and outside)

HBV-model analysis

Calibration using 40 years (1970-2010)

Combined Manual and Automatic calibration

Using Gryta VM (gauging station) in Nordmarka

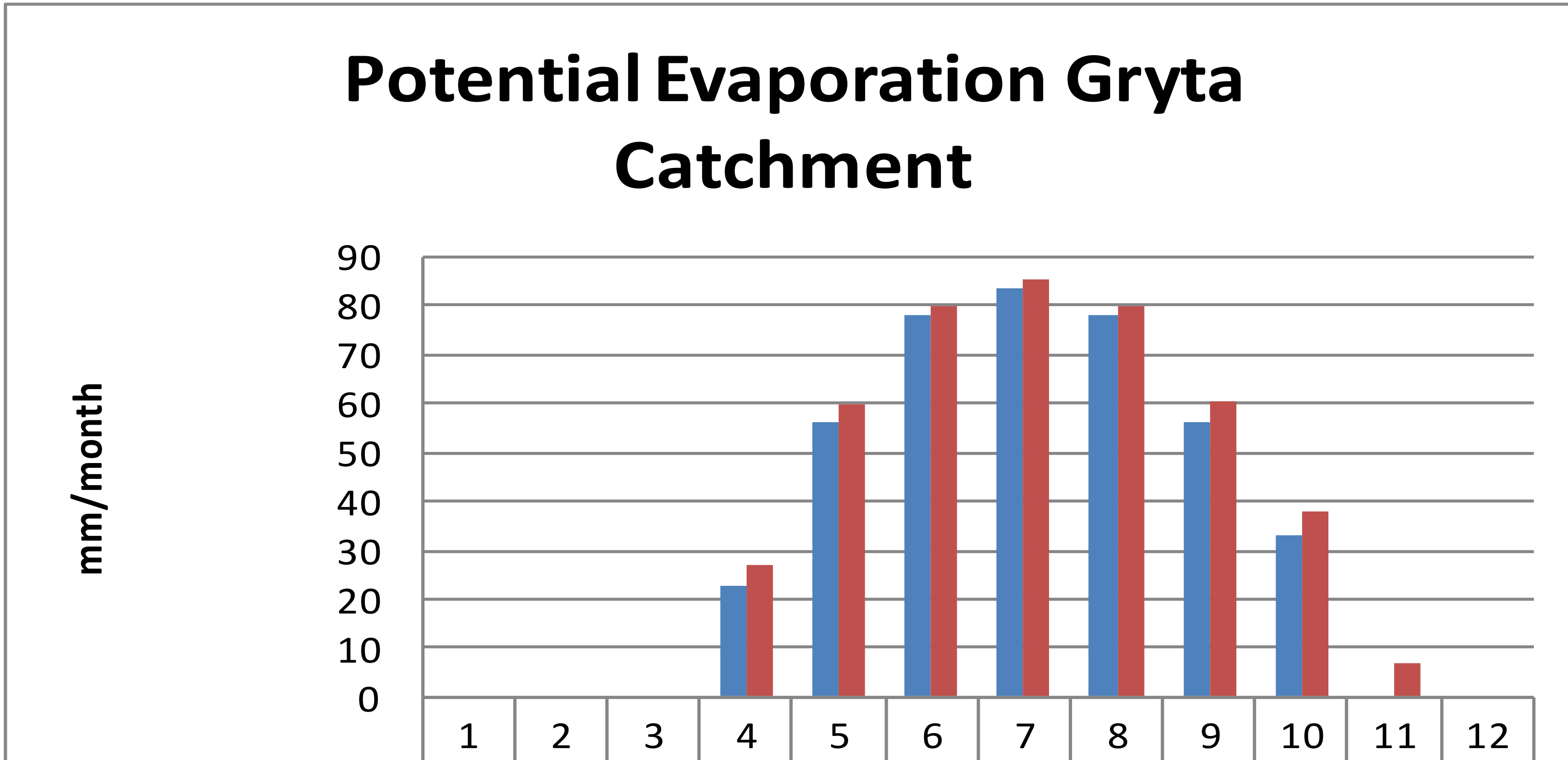
Some months in obs data series were corrected

Results fairly good (R^2 = 0.67)

Simulated flows compared for Today (Stadium 1990)

Future Climate Scenarios for: 2020, 2050, 2080

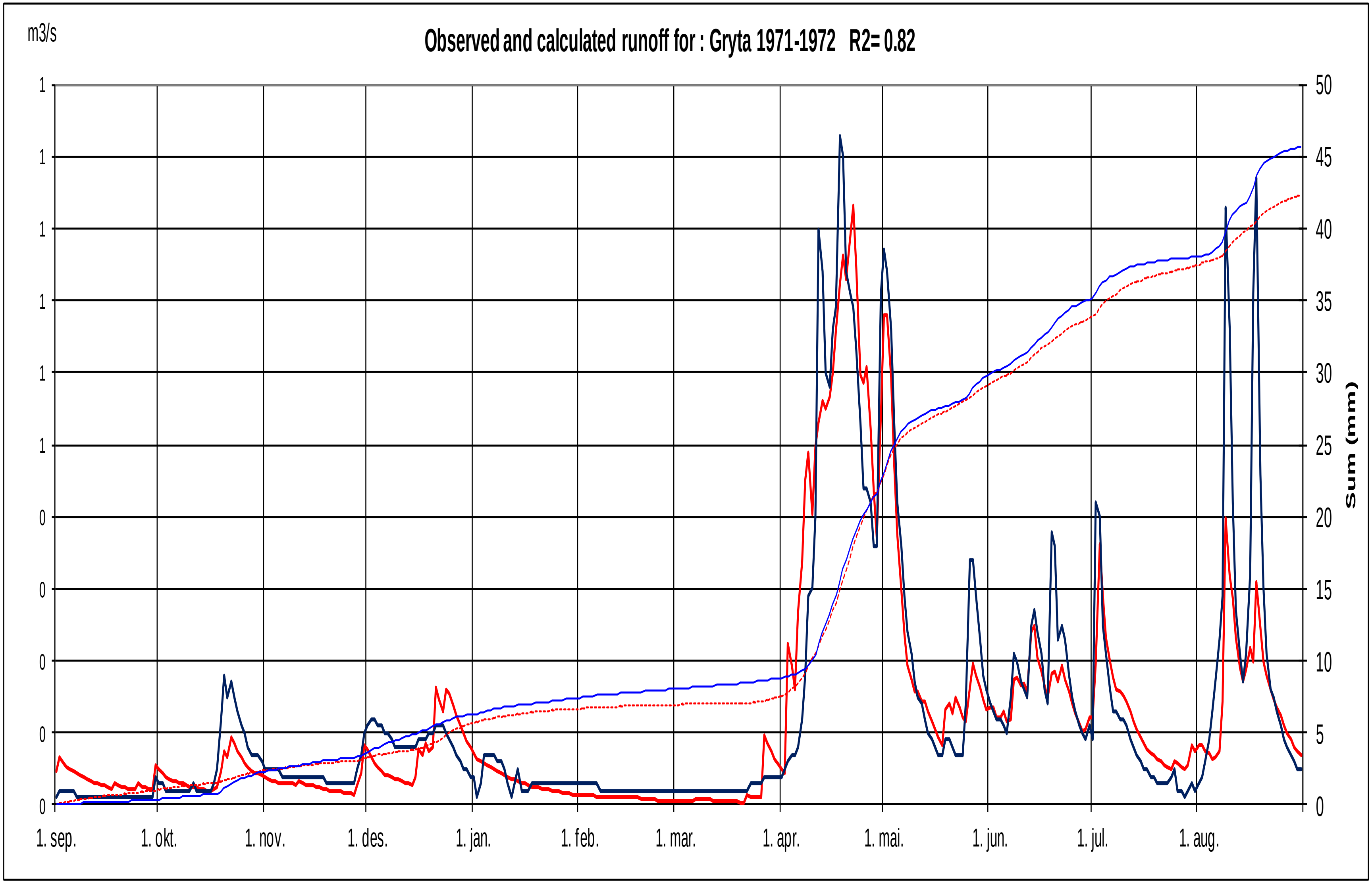
Potential evaporation for HBV-model



	1	2	3	4	5	6	7	8	9	10	11	12
Present Climate	0	0	0	23	56	78	83	78	56	33	0	0
2020	0	0	0	27	60	80	86	80	61	38	7	0

Computed Potential Evaporation (mm/month) in Gryta Catchment For 'Present Climate' (1990) and in 2020. Thorntwaite method

HBV-model calibration
Example some years



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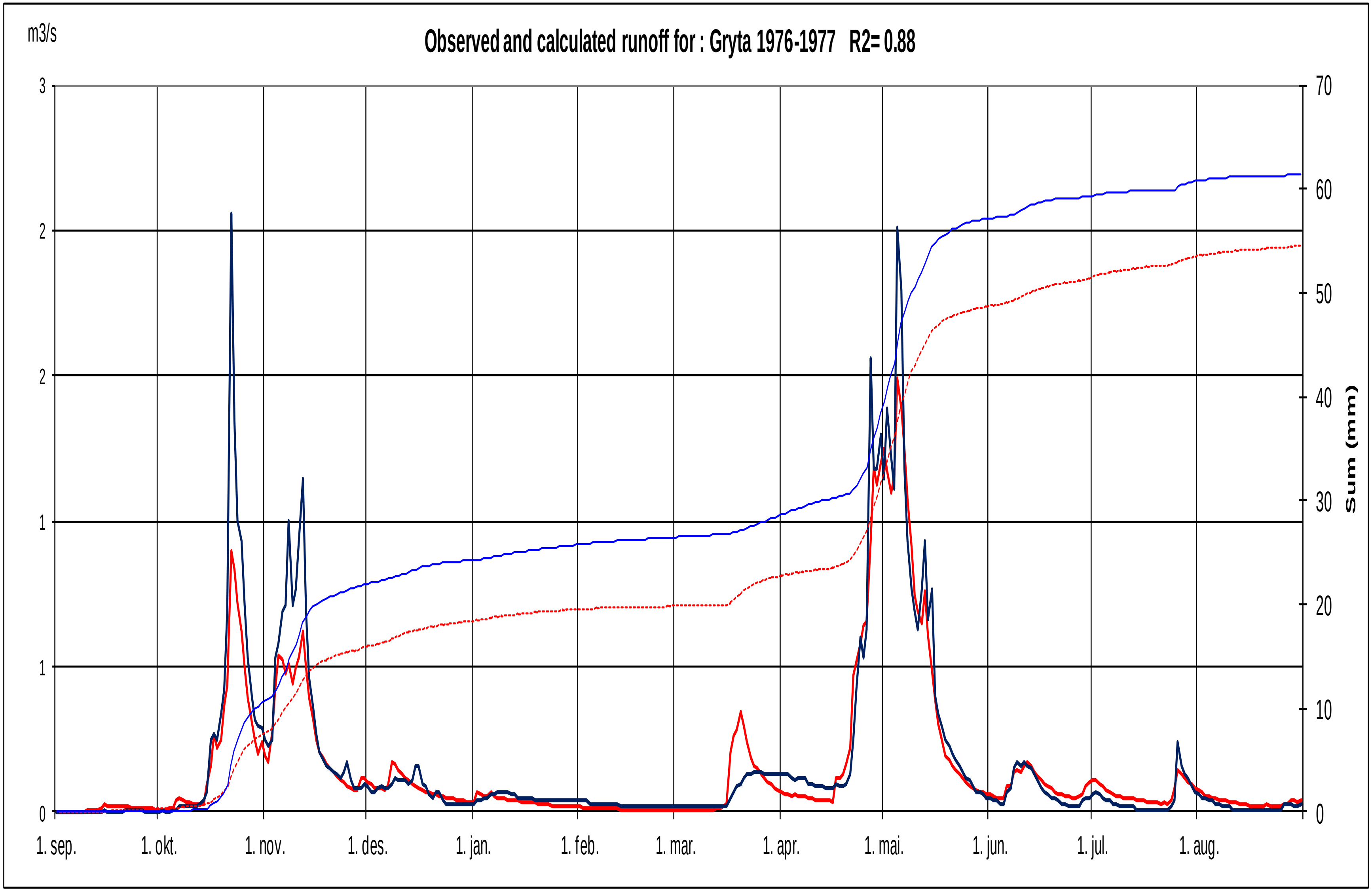
HBV-model calibration
Example some years



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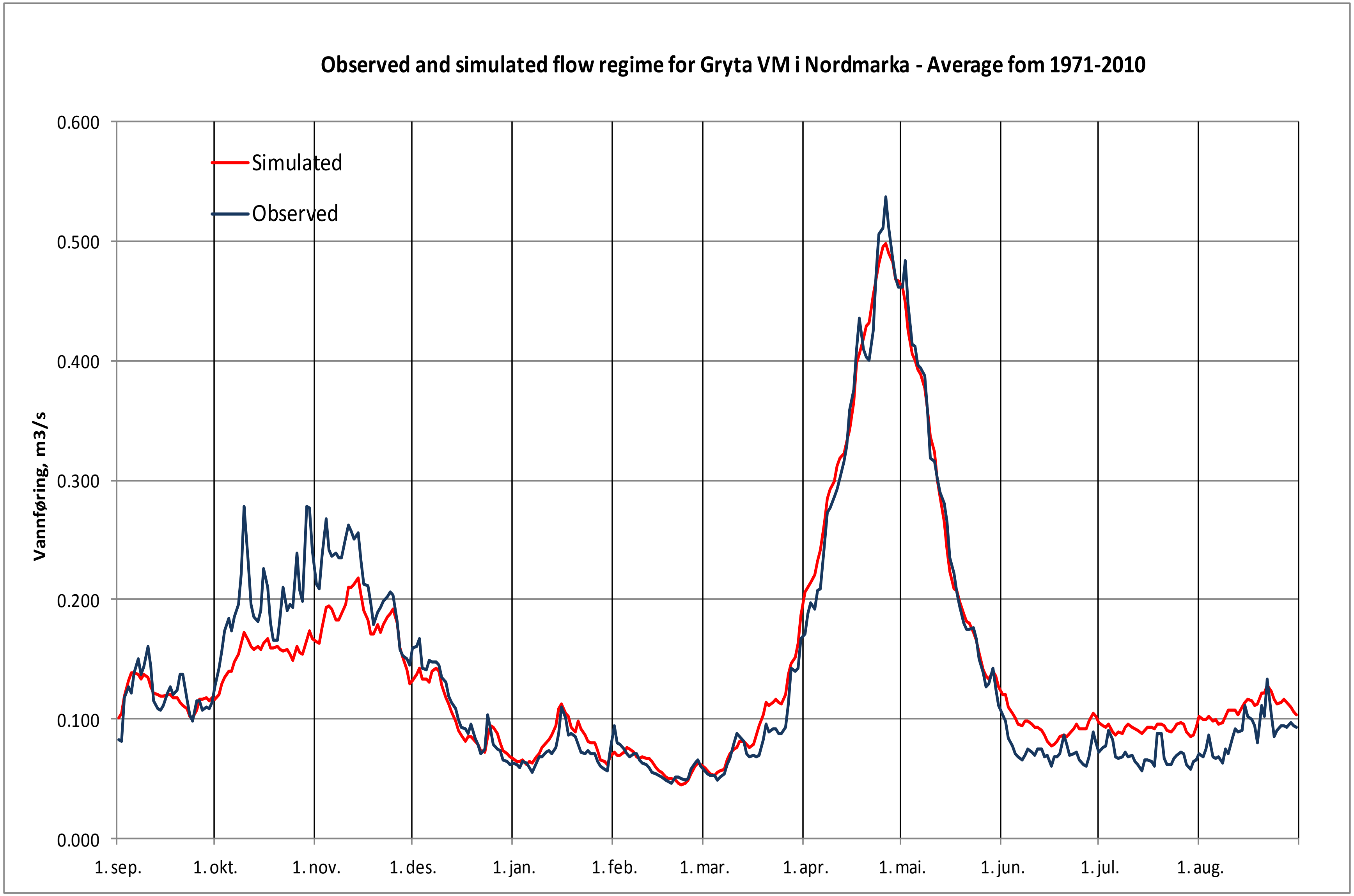
HBV-model calibration – average for all years



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HBV-model climate change simulations Using the Delta change method

- Use the calibrated model
- Simulate present climate 1970-2010
- Future climate = Present + Delta
- Run simulations for future climate
- Compare $\text{Sim}_{\text{Today}}$ with $\text{Sim}_{\text{Future}}$

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Climate Change impact on runoff

Delta changes used in HBV-model simulations

Air temperature (Temp), Precipitation (Precip), Potential Evaporation (Evap)

Stadium 2020 (2011-2040)

Climate Change parameters Month	Temp °C	Precip %	Evap mm
Jan	2.0	7.0	0.0
Feb	2.0	7.0	0.0
Mar	1.3	3.0	0.0
Apr	1.3	3.0	0.1
Mai	1.3	3.0	0.1
Jun	1.0	-2.0	0.1
Jul	1.0	-2.0	0.1
Aug	1.0	-2.0	0.1
Sep	1.5	5.0	0.1
Okt	1.5	5.0	0.2
Nov	1.5	5.0	0.2
Des	2.0	7.0	0.0
Average	1.5	3.3	30.0

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Climate Change impact on runoff

Delta changes used in HBV-model simulations

Air temperature (Temp), Precipitation (Precip), Potential Evaporation (Evap)

Stadium 2050 (2036-2065)

Climate Change parameters Month	Temp ^oC	Precip %	Evap mm
Jan	3.6	12.0	0.0
Feb	3.6	12.0	0.0
Mar	2.2	4.0	0.2
Apr	2.2	4.0	0.2
Mai	2.2	4.0	0.2
Jun	1.7	-2.0	0.1
Jul	1.7	-2.0	0.1
Aug	1.7	-2.0	0.1
Sep	2.5	8.0	0.2
Okt	2.5	8.0	0.3
Nov	2.5	8.0	0.4
Des	3.6	12.0	0.0
Average	2.5	5.5	54.8

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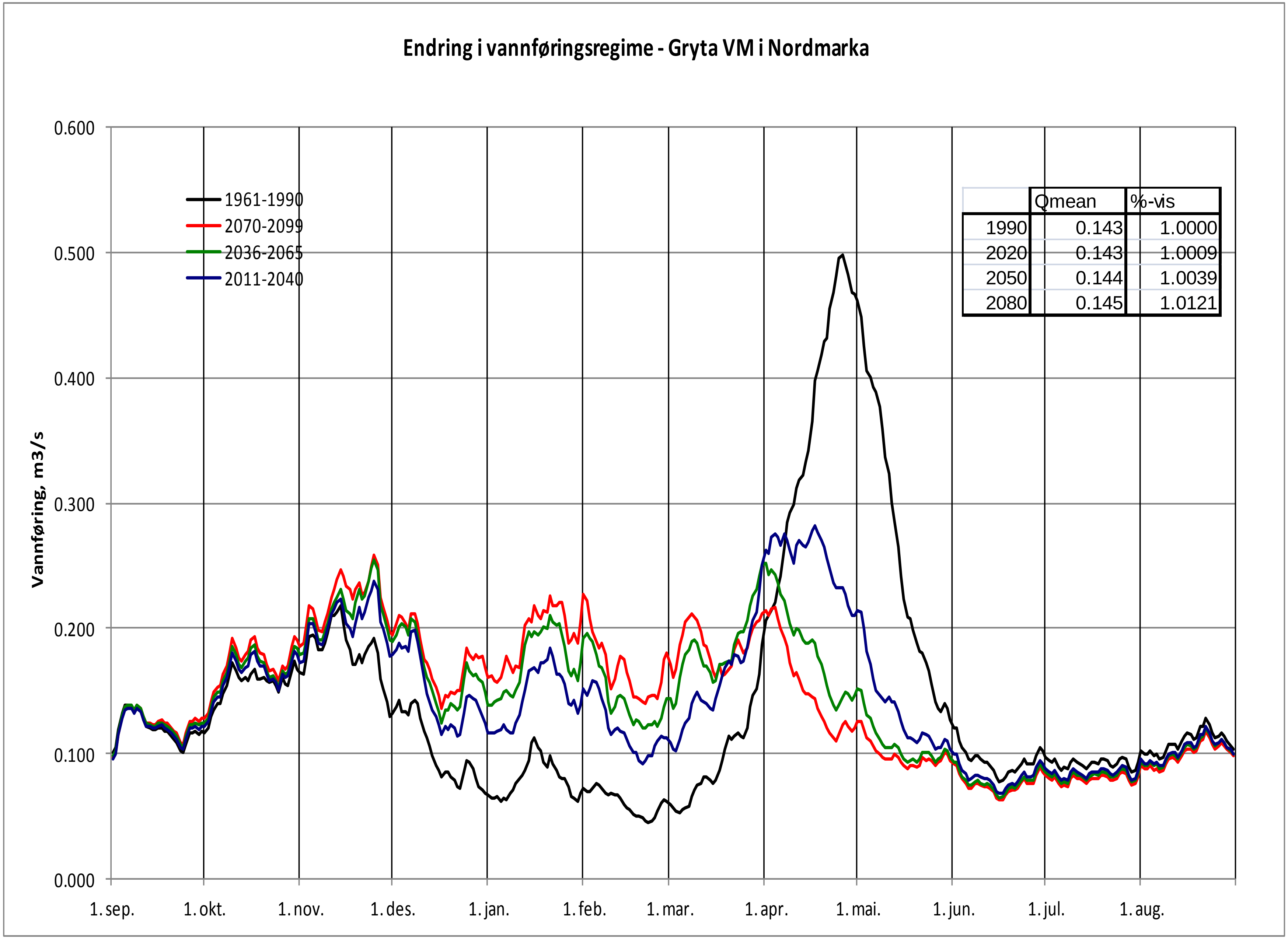
Climate Change impact on runoff

Delta changes used in HBV-model simulations
Air temperature (Temp), Precipitation (Precip), Potential Evaporation (Evap)

Stadium 2080 (2071-2099)

Climate Change parameters Month	Temp ^{o}C	Precip %	Evap mm
Jan	4.8	18.0	0.0
Feb	4.8	18.0	0.0
Mar	3.2	6.0	0.3
Apr	3.2	6.0	0.3
Mai	3.2	6.0	0.2
Jun	3.3	-1.0	0.3
Jul	3.3	-1.0	0.3
Aug	3.3	-1.0	0.3
Sep	3.4	11.0	0.3
Okt	3.4	11.0	0.3
Nov	3.4	11.0	0.5
Des	4.8	18.0	0.1
Average	3.7	8.5	85.8

Climate Change impact on runoff - Average



	Qmean	%-vis
1990	0.143	1.0000
2020	0.143	1.0009
2050	0.144	1.0039
2080	0.145	1.0121

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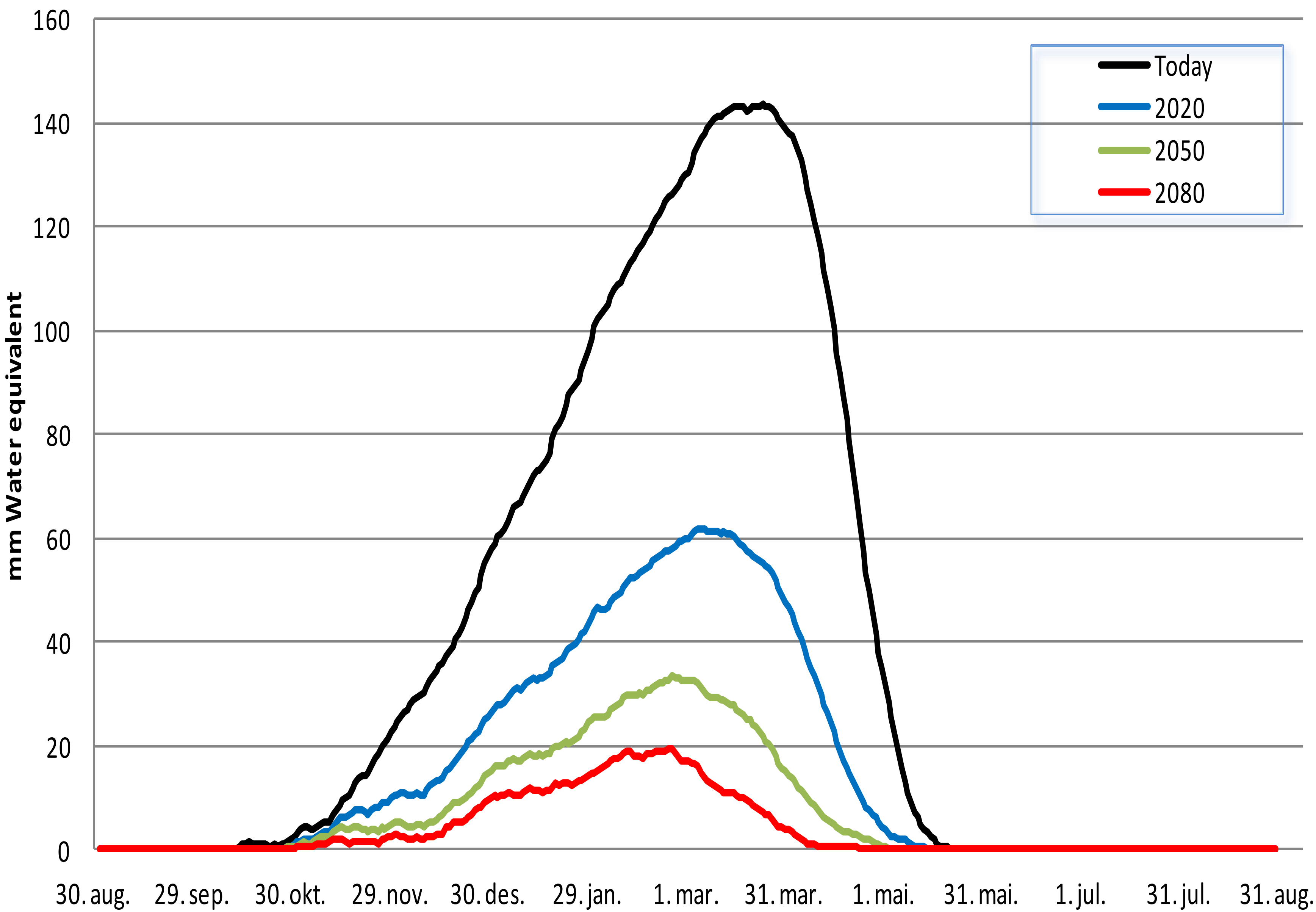
Climate Change impact on snow - Average



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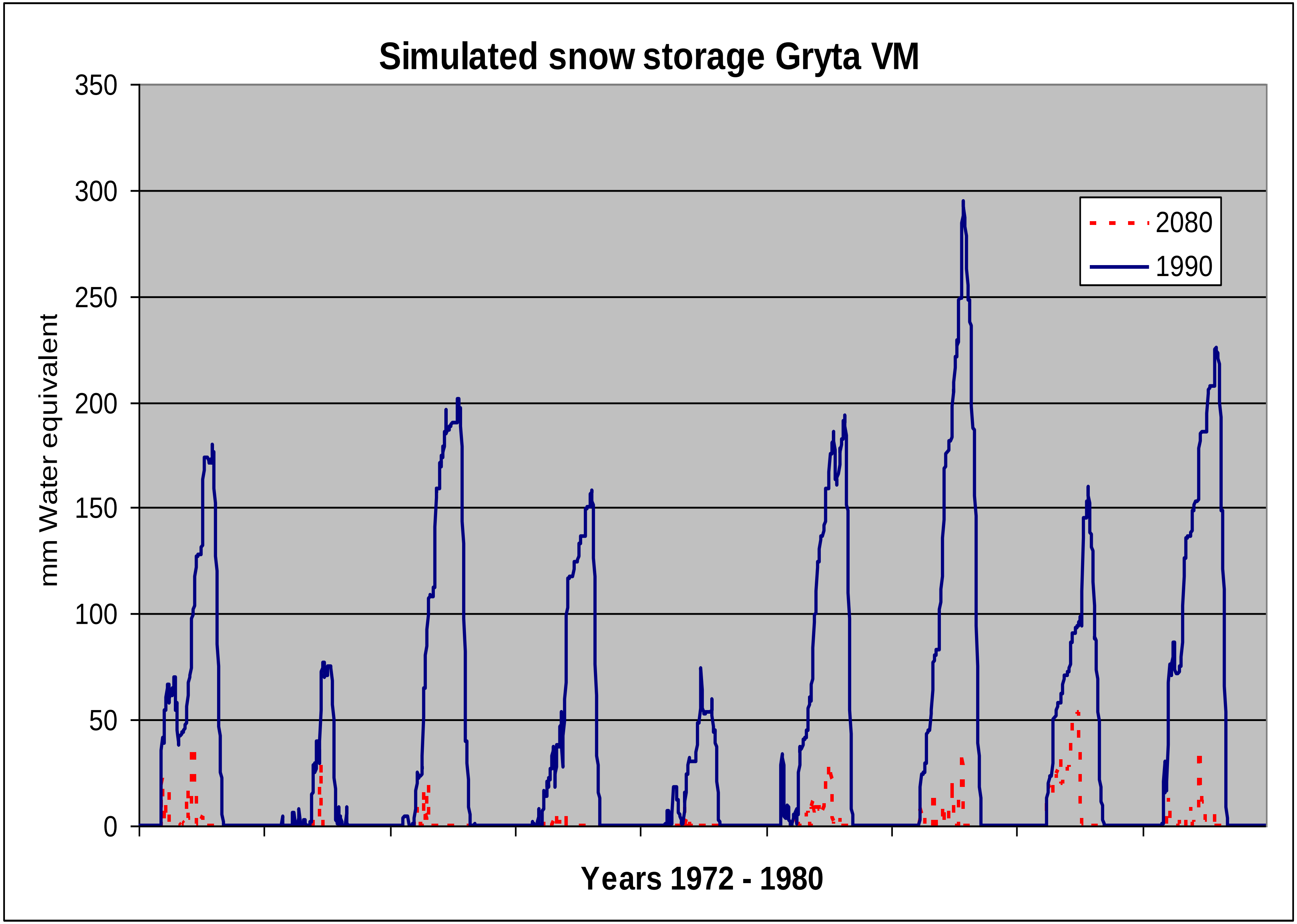
Climate Change impact on snow in some years



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Reservoir operation - nMAG simulations

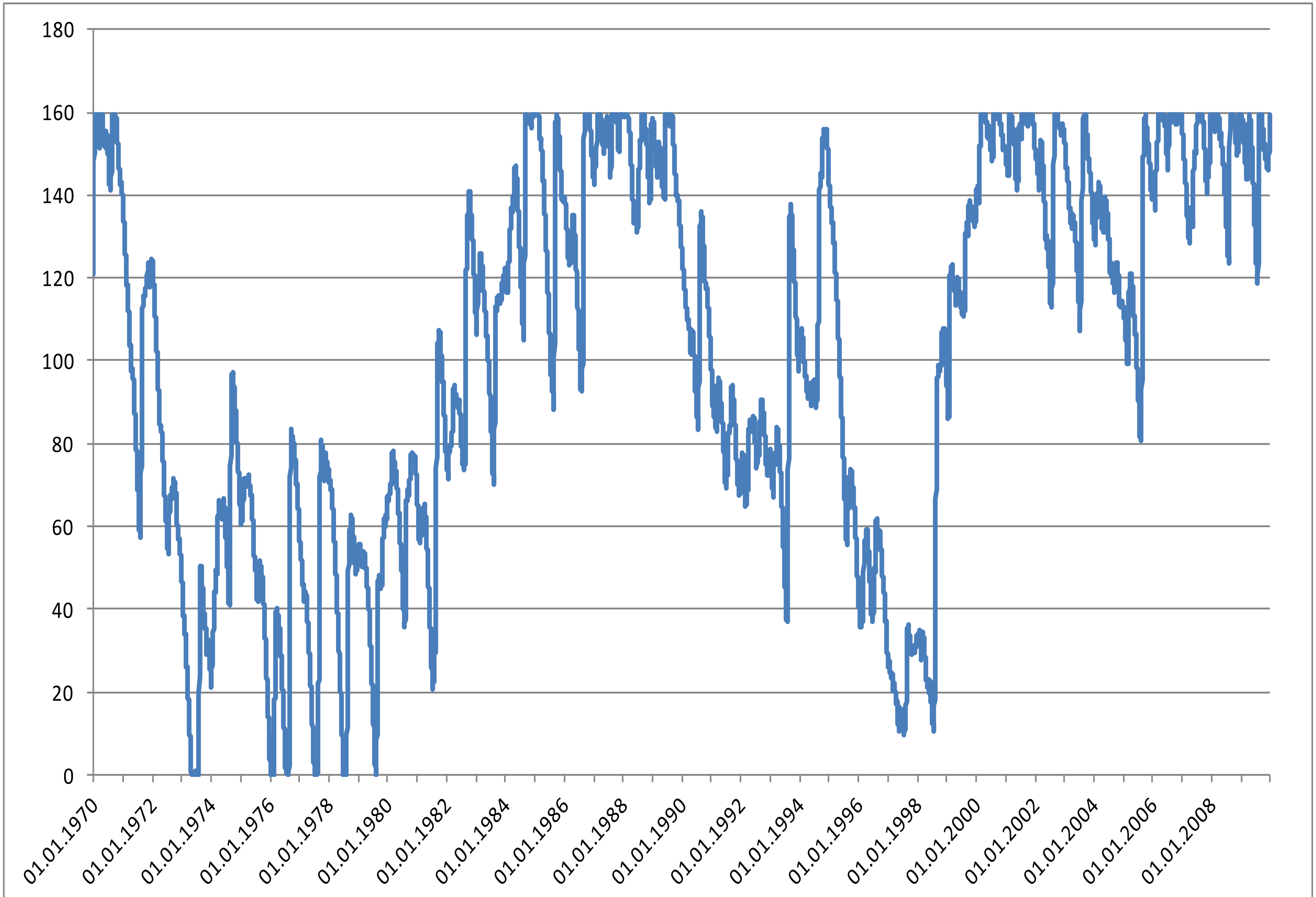
Output data from HBV-simulations are used as input to nMAG model

Simulations done for
- -Today (1970 – 2010)
- 2020
- 2050
- 2080

Main focus on reliability of supply

nMAG simulation results –

Example: Reservoir filling (sum) during 40 years



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Reservoir operation – nMAG simulations

Firm flow (100% security of supply)

1990: 4. 941 m^3/s (155.8 Mill. m^3/year)
2020: 4. 878 m^3/s (153.8 Mill. m^3/year)
2050: 4. 909 m^3/s (154.8 Mill. m^3/year)
2080: 4. 941 m^3/s (155.8 Mill. m^3/year)

Practically no change even if climate changes!

Reservoir operation - nMAG simulations

Some main results:

Average inflow does not change much
(Increased precipitation but also increased evaporation)

Reliability of supply does not change much

Future climate - change in critical low flow events from winter to summer