CEDREN Seminar on
Large Scale Balancing from Norwegian Hydropower

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Centre for Environmental Design of Renewable Energy

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Simulating Pumped Storage Operation in Reservoirs Used for Balancing of Wind Power

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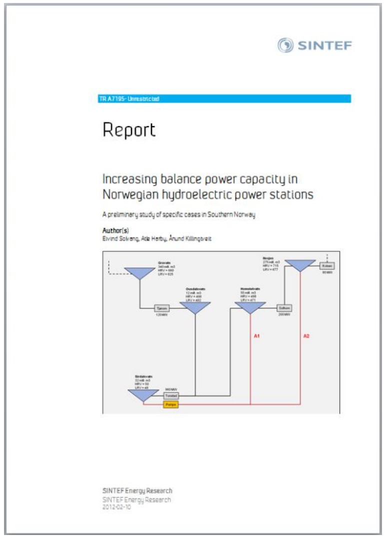
Pumped storage model

- Reservoir pairs in Southern Norway
- Balancing power capacity in addition to installed capacity
- Operation of existing power station remains unchanged
- Balancing power operation within current reservoir regulations
- Input data
  - Simulated wind power time series from North Sea
  - Observed reservoir water level and volume
    - → Current operational regime
    - → Natural inflow
- Time step: 1 day

Background

Increasing balance power capacity in Norwegian hydroelectric power stations – A preliminary study of specific cases in Southern Norway

Solvang, E. et al. (2011)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Report

Increasing balance power capacity in Norwegian hydroelectric power stations

A preliminary study of specific cases in Southern Norway

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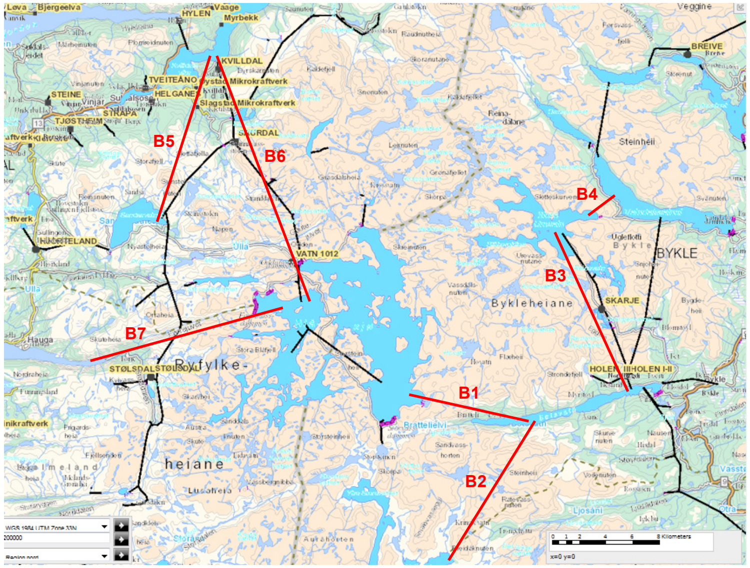
- **20.000 MW possible by 2030**
- Hydro storage + pumped storage
- Existing dams and reservoirs
- Outlet into reservoir or fjord/sea

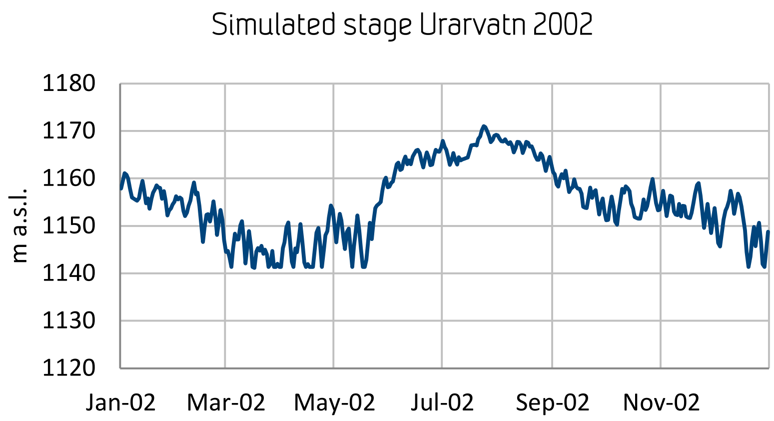


Model purpose

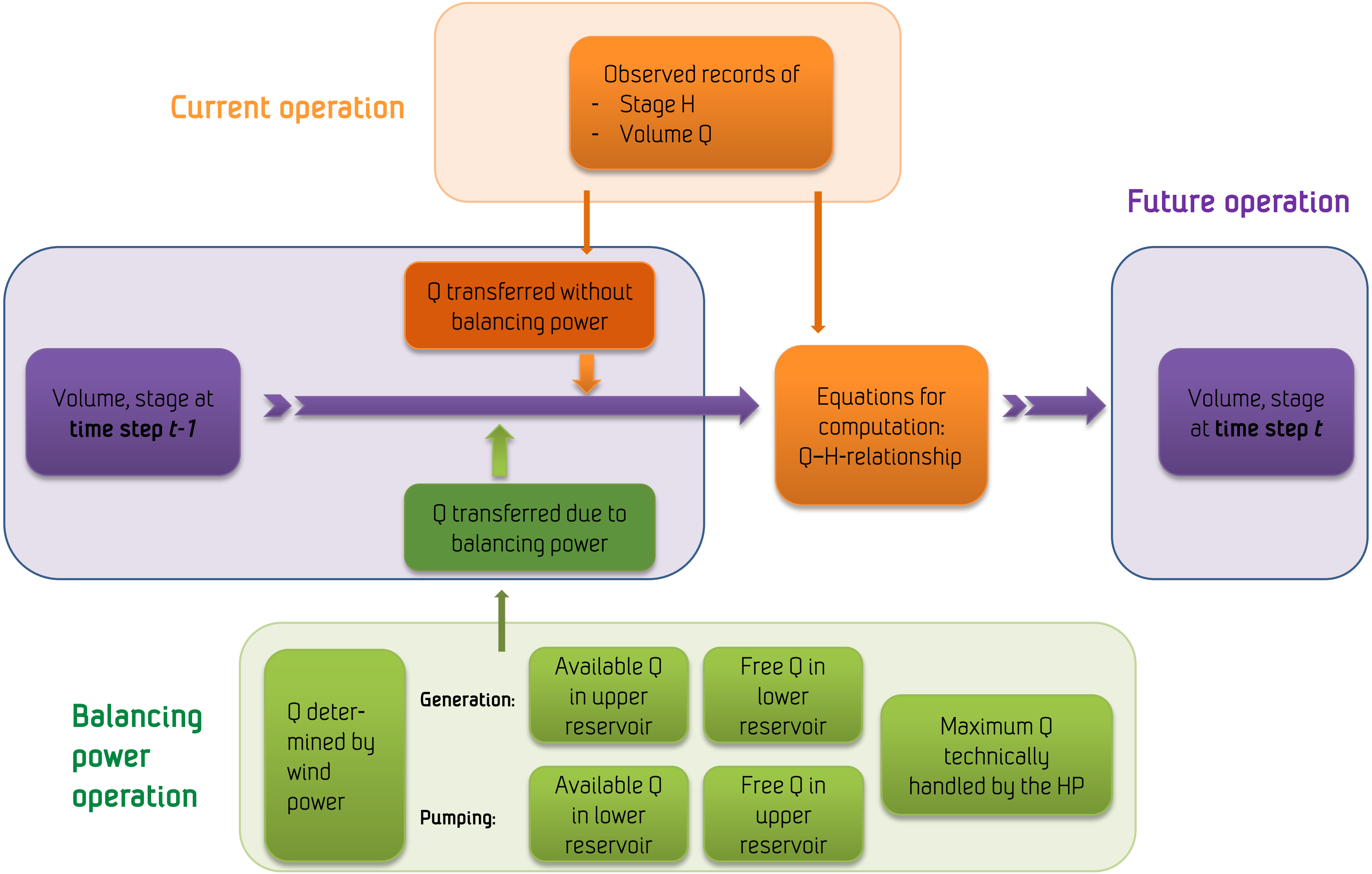
1. Simulate magnitude of water level fluctuations

2. What determines the amount of balancing power?
    1. Turbine capacity
    2. Reservoir capacity

3. Basis for assessment of environmental impacts

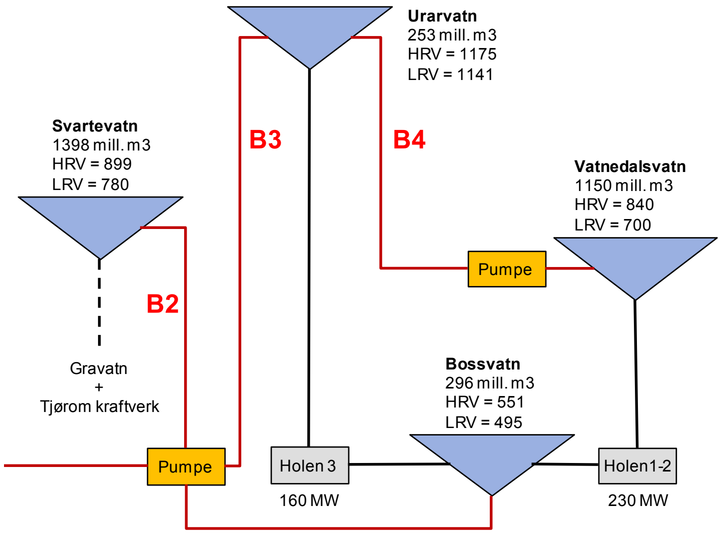


Model scheme

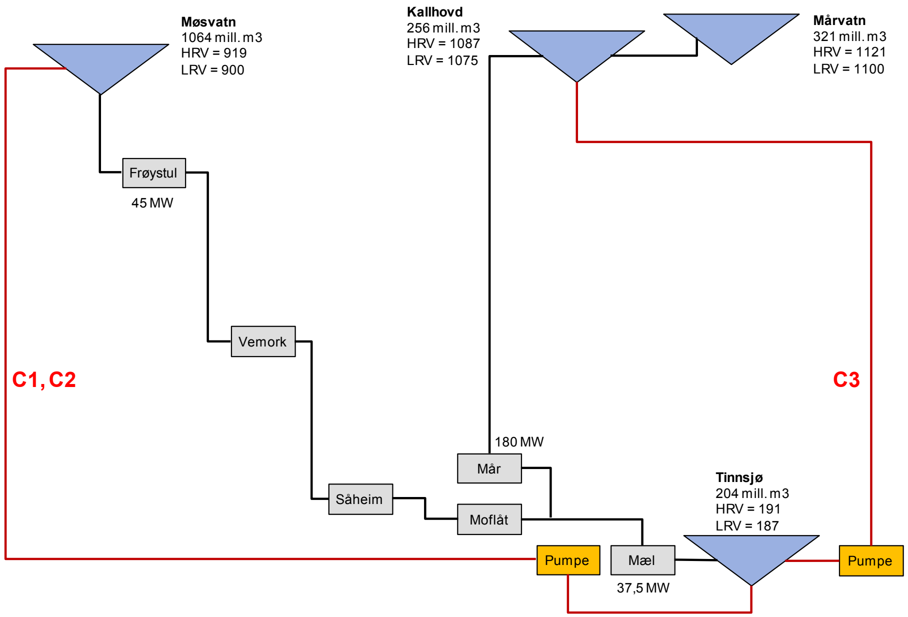


Example cases

Holen (Urarvatn–Bossvatn)



Rjukan (Møsvatn–Tinnsjø)



	Holen	Rjukan
Volume upper reservoir	253 mill. m^3	1064 mill. m^3
Volume lower reservoir	296 mill. m^3	204 mill. m^3

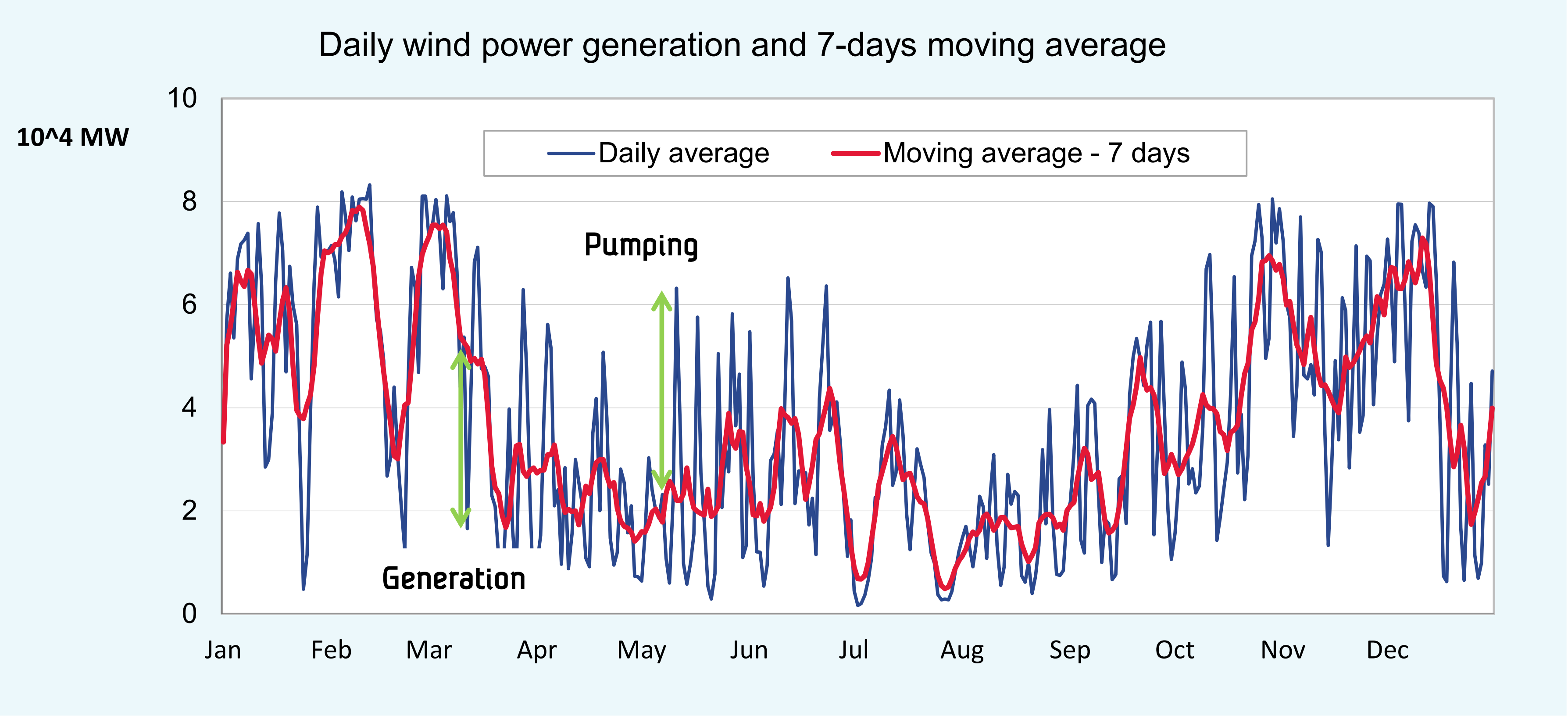
Assumptions

- Power stations
  - Reversible turbines
  - Energy equivalent [m^3/kWh] adapted to nominal head
  - Efficiency 0.9
-

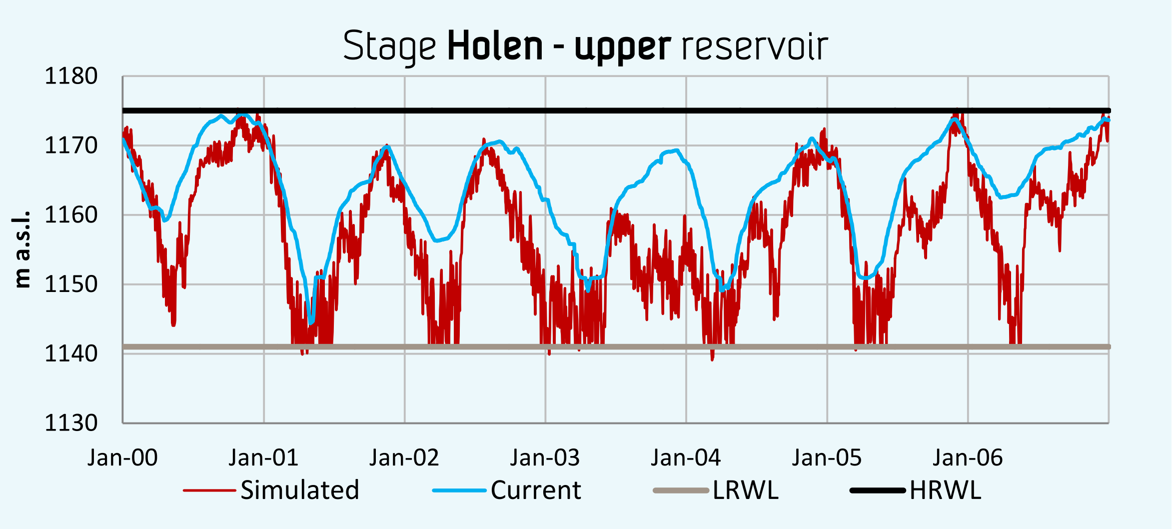
	Holen	Rjukan
Installed capacity	1400 MW	2800 MW
Percentage of total balancing load	7 %	14 %

- Wind power to balance
  - Above or below 7-days moving average

Balancing power needs

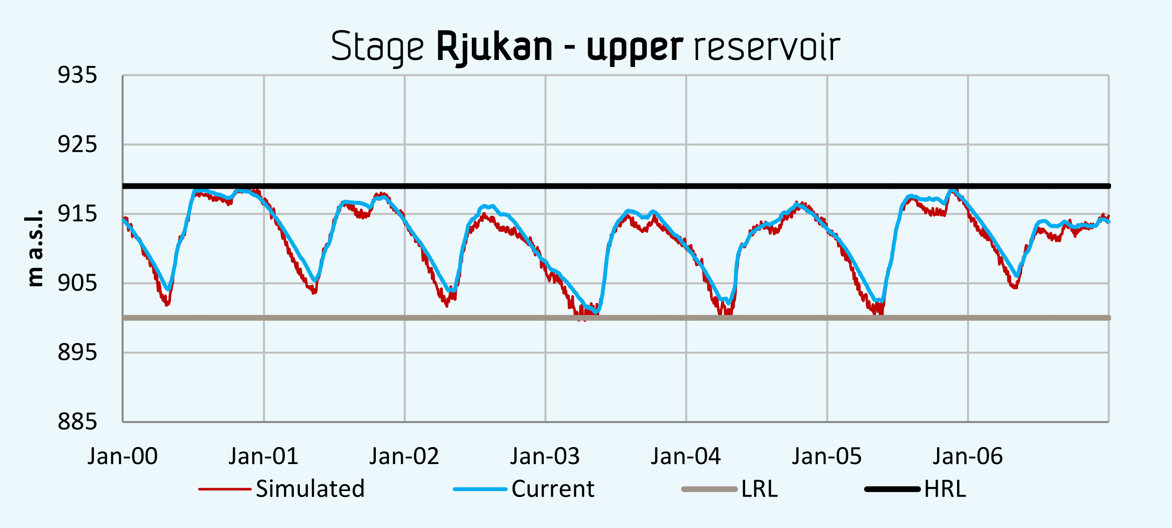


Water level fluctuations



	Current		Simulated	
m/day	Rate of stage INCREASE	Rate of stage DECREASE	Rate of stage INCREASE	Rate of stage DECREASE
Median	0.05	0.12	**1.10**	**1.23**
P90	0.21	0.26	**3.40**	**3.56**

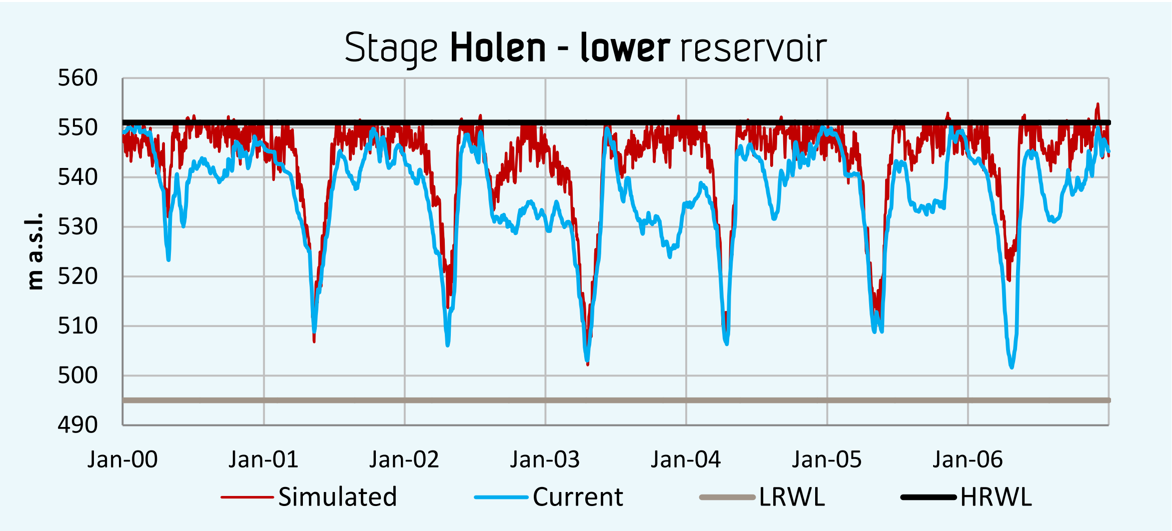
- Strong increase in rates of change in water level
- Shorter periods with high WL
  Longer periods with low WL



	Current		Simulated	
m/day	Rate of stage INCREASE	Rate of stage DECREASE	Rate of stage INCREASE	Rate of stage DECREASE
Median	0.07	0.07	0.22	0.21
P90	0.26	0.10	0.50	0.63

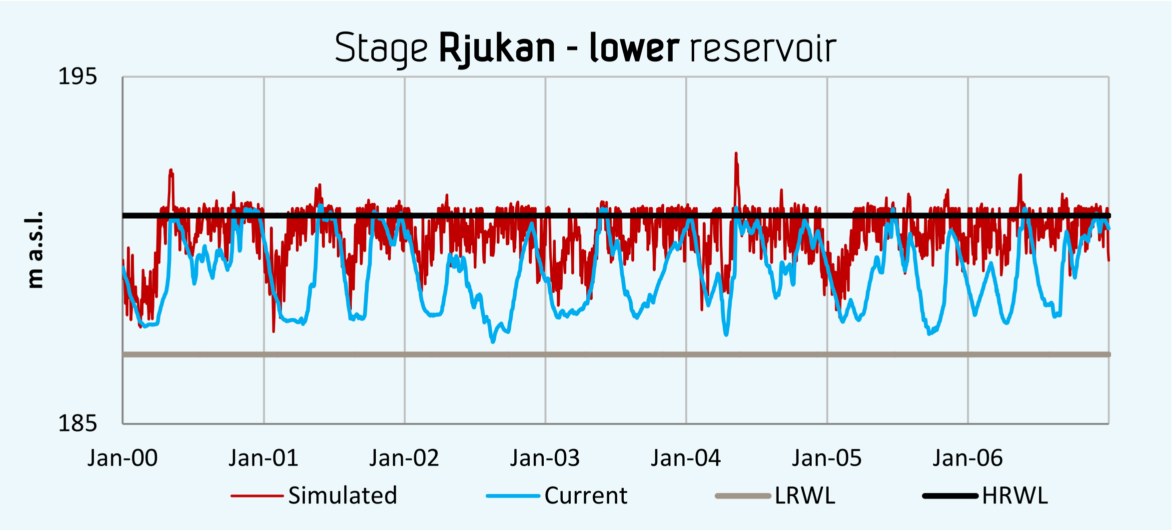
- Moderate increase in rates of change in WL
- Same seasonal cycle

Water level fluctuations



	Current		Simulated	
m/day	Rate of stage INCREASE	Rate of stage DECREASE	Rate of stage INCREASE	Rate of stage DECREASE
Median	0.28	0.28	**1.10**	**1.22**
P90	1.11	0.78	**3.04**	**2.70**

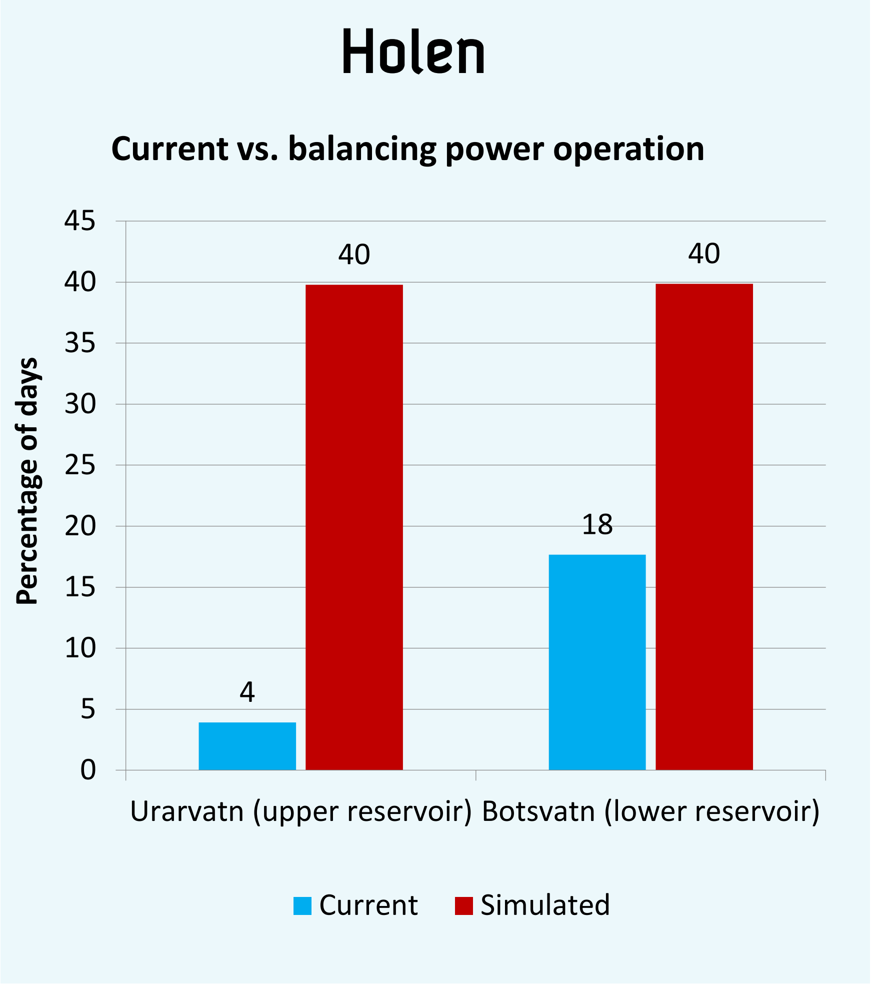
- Strong increase in rates of change in water level
- Longer periods with higher WL

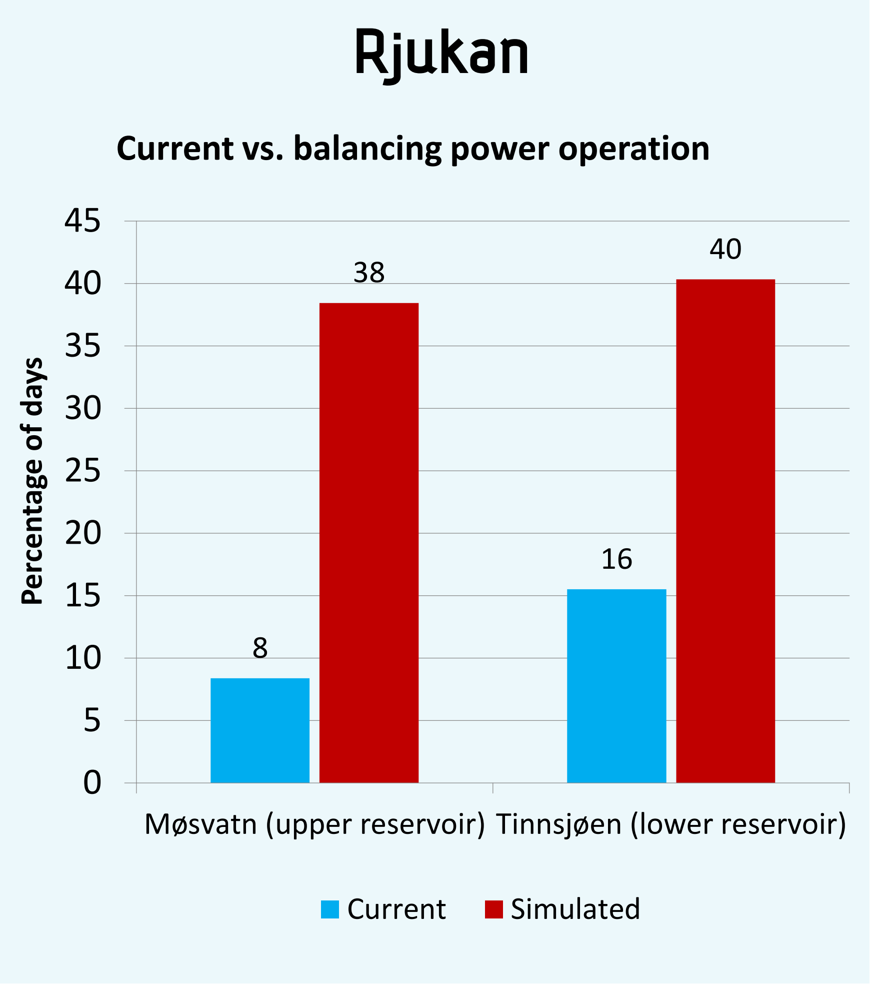


	Current		Simulated	
m/day	Rate of stage INCREASE	Rate of stage DECREASE	Rate of stage INCREASE	Rate of stage DECREASE
Median	0.03	0.04	**0.22**	**0.27**
P90	0.10	0.09	**0.69**	**0.60**

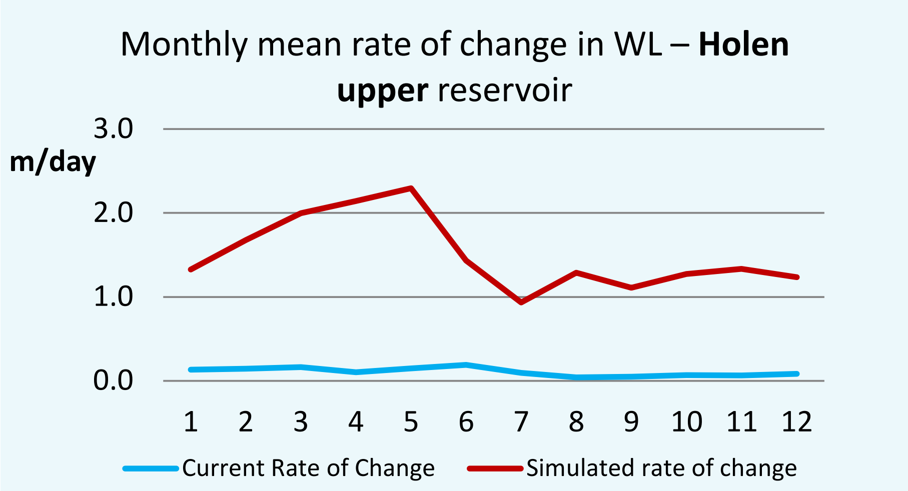
- Strong increase in rates of change in WL
- Different seasonal cycle

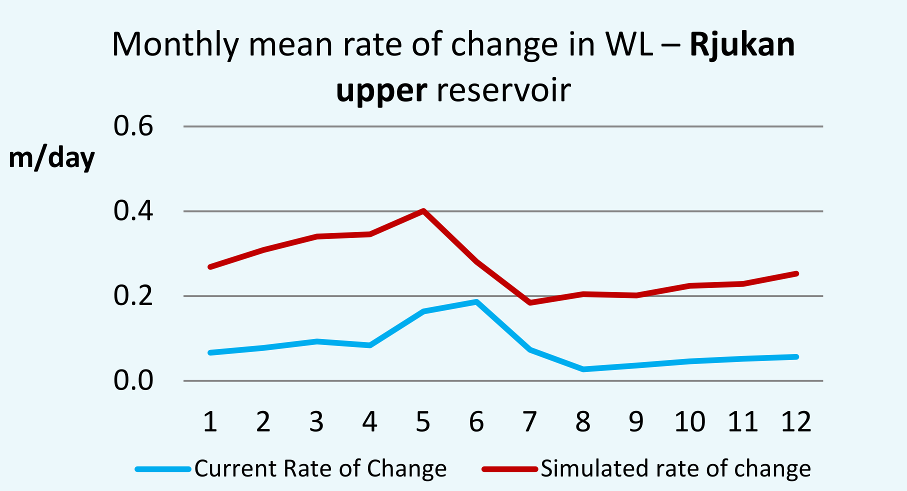
Number of changes in stage

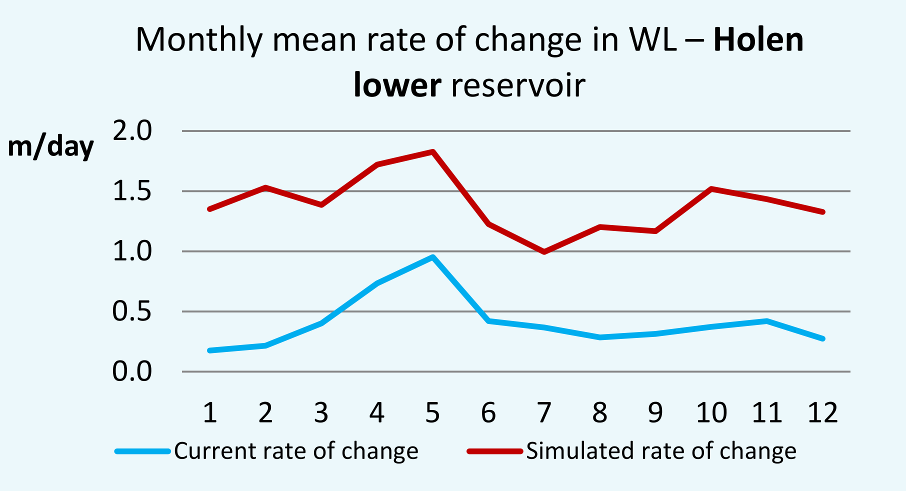


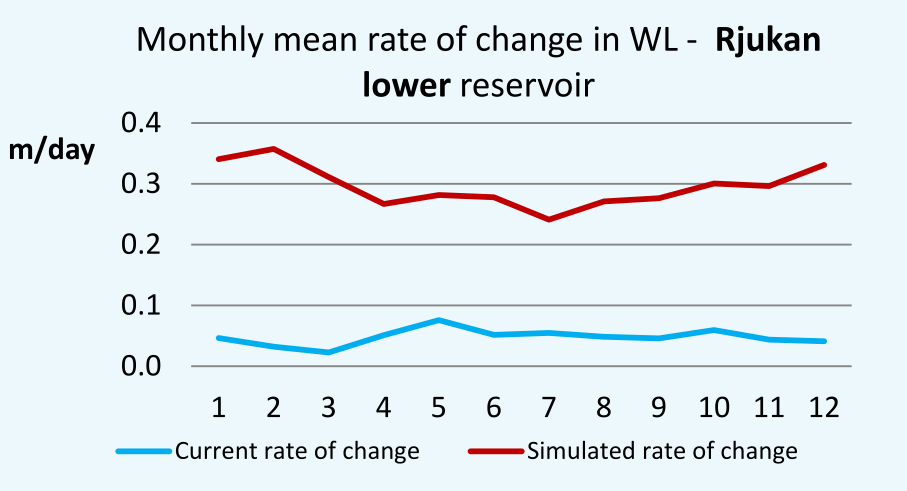


Necessity for seasonal regulations?

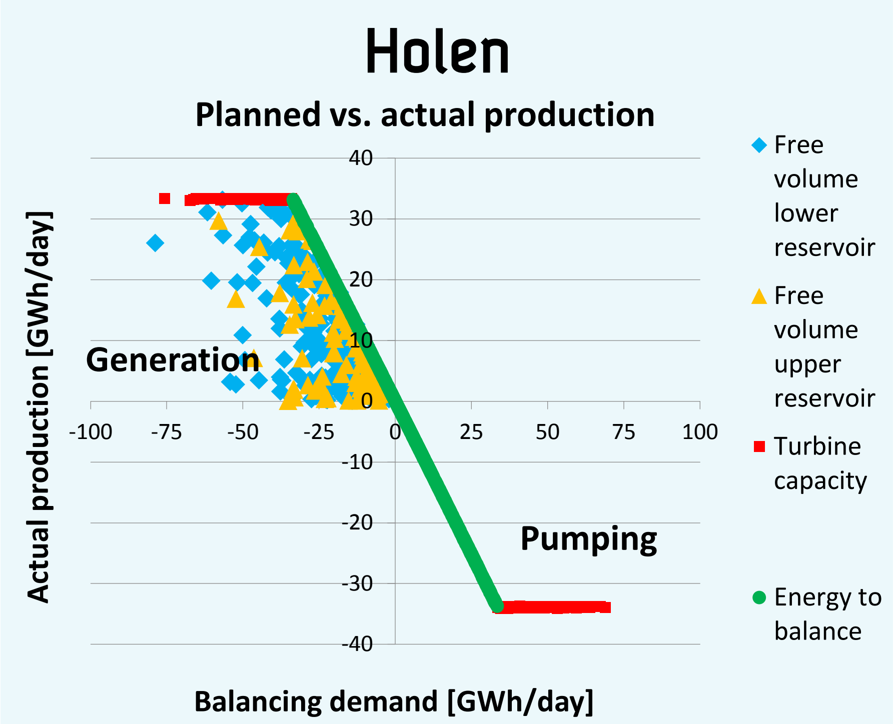


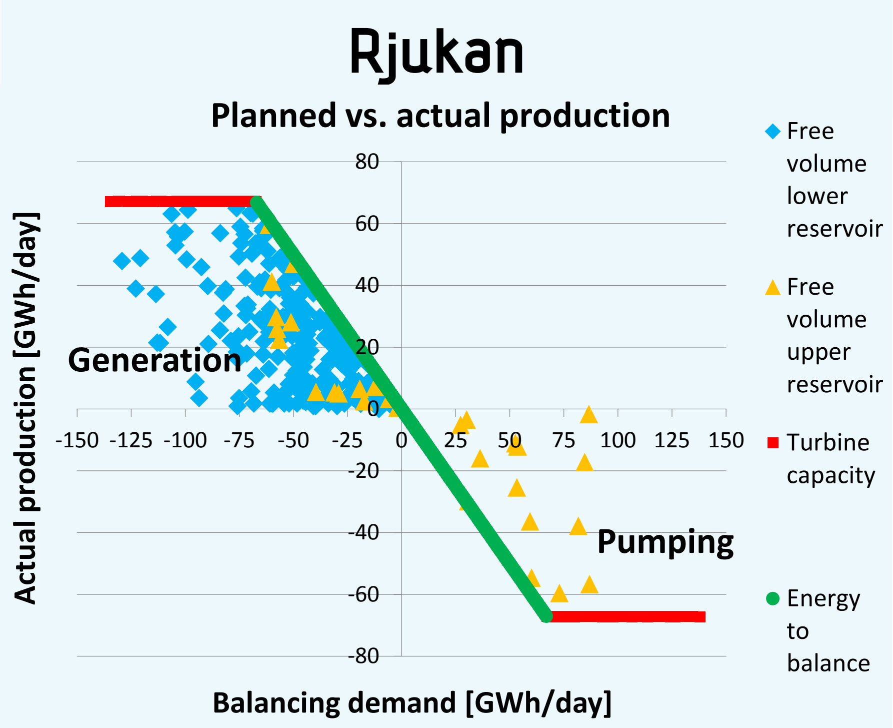






Limiting factors for providing balancing power demand



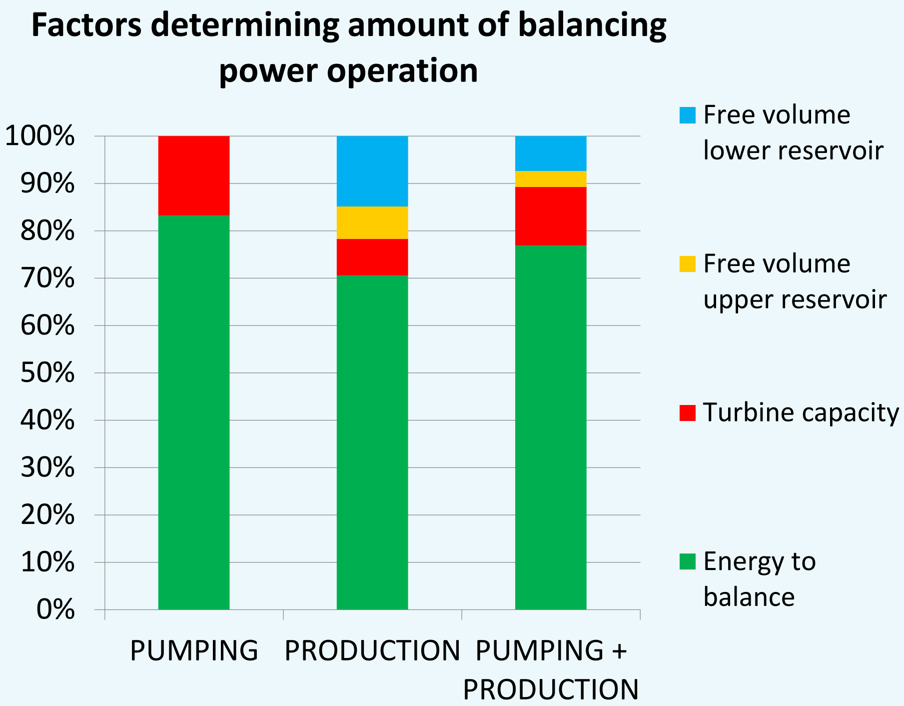


Holen		Limiting factors		
	Balancing demand can be met	Turbine capacity	UPPER reservoir	LOWER reservoir
% of days	77 %	12 %	4 %	7 %

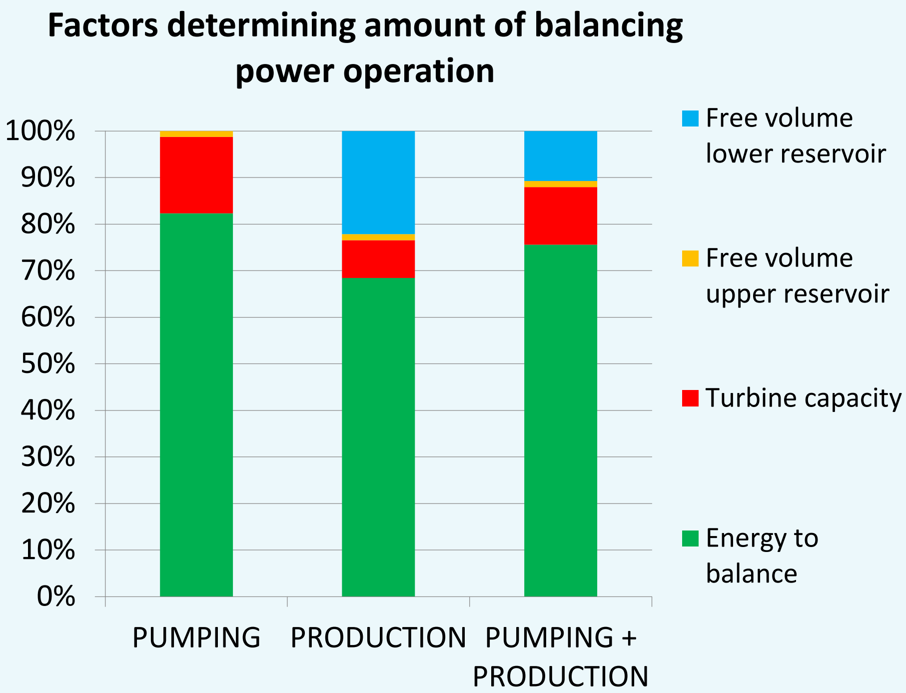
Rjukan		Limiting factors		
	Balancing demand can be met	Turbine capacity	UPPER reservoir	LOWER reservoir
% of days	76 %	12 %	1 %	11 %

Limiting factors for providing balancing power demand

Holen



Rjukan



Required balancing power can be provided on

77 % of all days

76 % of all days

Conclusions

- Simulated courses of reservoir filling similar to current patterns
- Speed of water level changes increases
- Higher number of changes from increasing to decreasing water level and vice versa
- Seasonality of water level rates may change
- Limiting for provision of balancing power for these cases
  - Turbine capacity during pumping
  - Lower reservoir or turbine capacity during generation

Thank you for your attention!

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