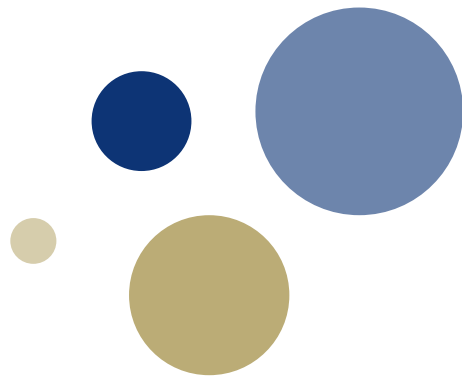




Norwegian University of
Science and Technology



Local flexibility in hydro-dominated power systems when considering environmental requirements on operation of hydropower plants

HPSC Oslo, September 2022

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Supervisors: Magnus Korpås (NTNU), Arild Helseth (SINTEF), Tor Haakon Bakken (NTNU)

Motivation



What is the impact of changed operational flexibility due to environmental constraints?

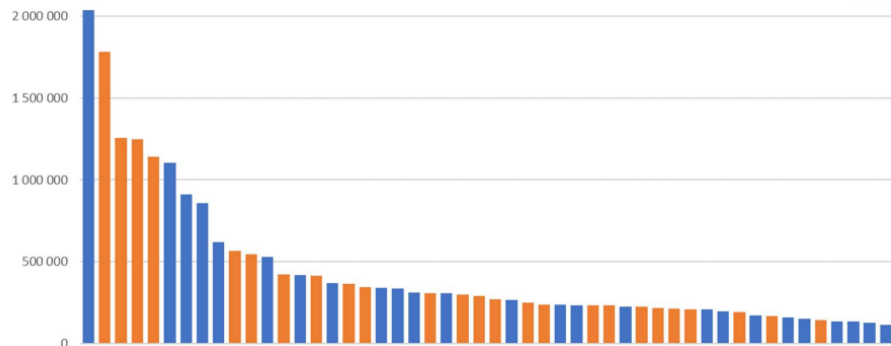


Certain hydropower plants are especially important for the system operation

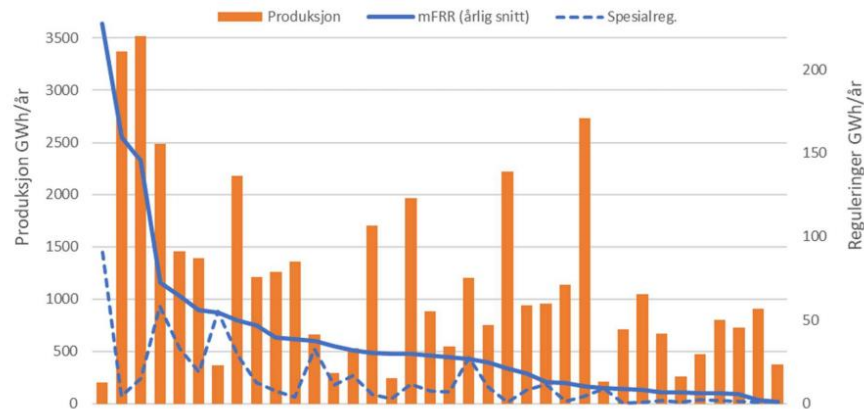


mFRR (tertiary reserves)

MWh

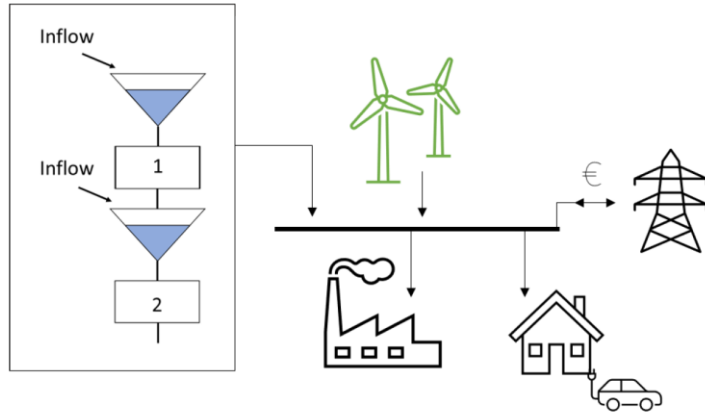


Production + mFRR



Reference: <https://www.statnett.no/contentassets/b82dcf206acc4762b2abcc3182e5bc52/verdien-av-regulerbar-vannkraft-statnett-mars-2021.pdf>

Research scope

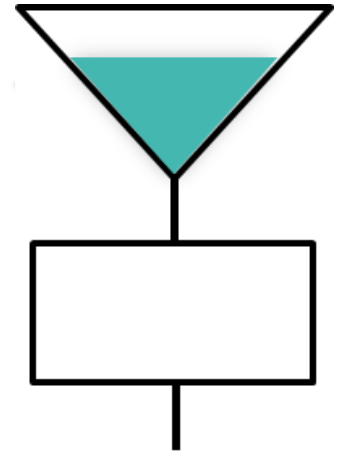
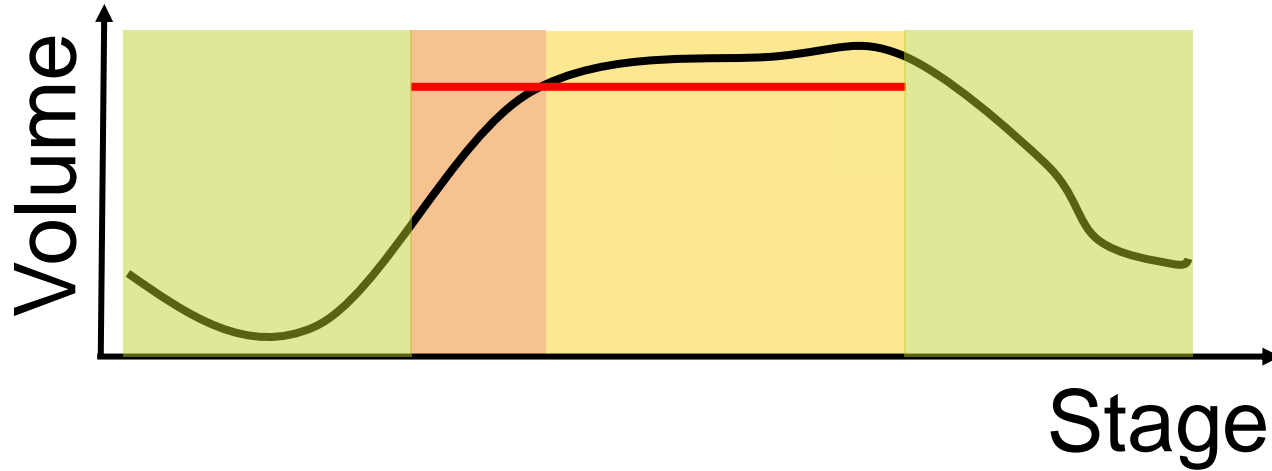


- Small renewable system with reservoir hydropower
- Partly self-dependent due to limited transmission capacity
- What is the “flexibility impact” on the system?

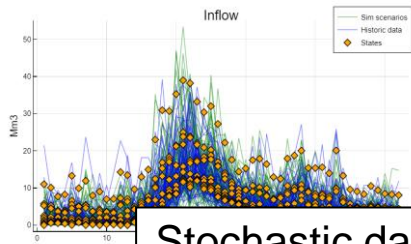
Environmental
requirements

Flexibility
HP-system

State-dependent discharge constraint



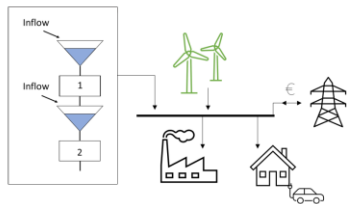
Optimization model



Stochastic data:
(inflow, wind, demand)

Markov model

Scenarios



System set-up

SDP model

- Yearly planning horizon
- Weekly stages
- 3h resolution

Water
values

Final
simulation

Forward optimization

Operational
results

Backwards recursion
iterates until convergence

	Base	NonSpin	Spin	Spin + NonSpin
Base	X	X	X	X
HighCap	X	X	X	X
LowCap	X	X	X	X
HighReg				
LowReg				

Case variations

Weekly optimization problem

- Objective: minimize system cost

- Constraints:

- Power balance
- Water balance in reservoirs
- Max/min capacities
- P_{\min} + concave PQ-curve
- Reserve capacity requirements
 - Non-spinning
 - Spinning
- Environmental requirements

Linear approximation

Non-convex future value
curve possible

Case study: 3 dimensions

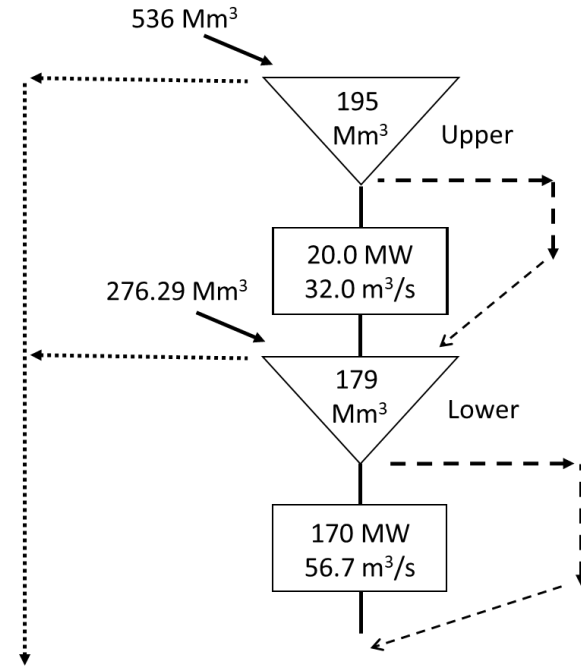
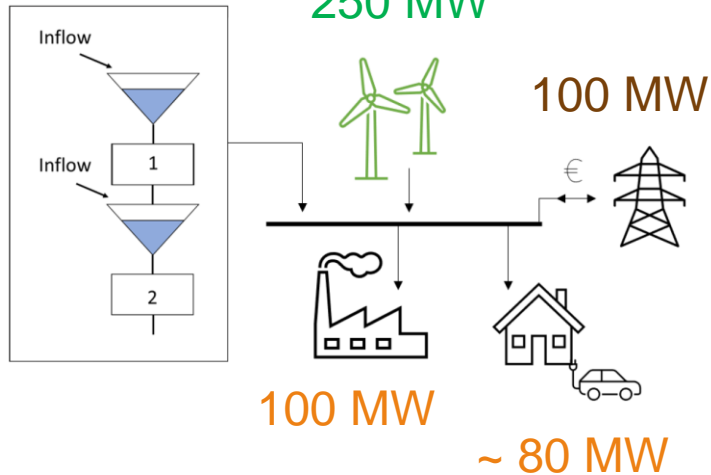
1. Changing the flexibility of the hydropower system
 - Degree of regulation
 - Utilization time
2. Adding reserve capacity requirements
 - Spinning reserves (up/down)
 - Non-spinning reserves (up)
3. Different environmental constraints
 - State-dependent reservoir constraints
 - Minimum discharge/bypass requirements
 - Maximum ramping restrictions

Work in progress!

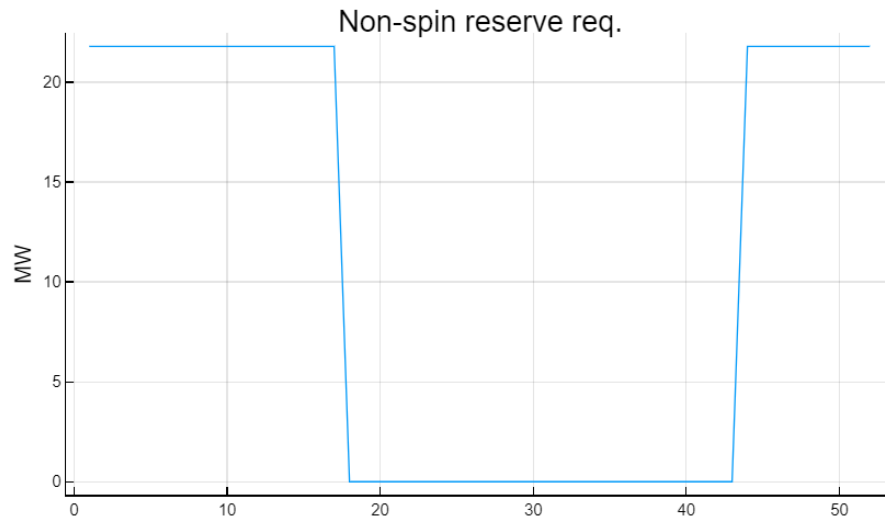
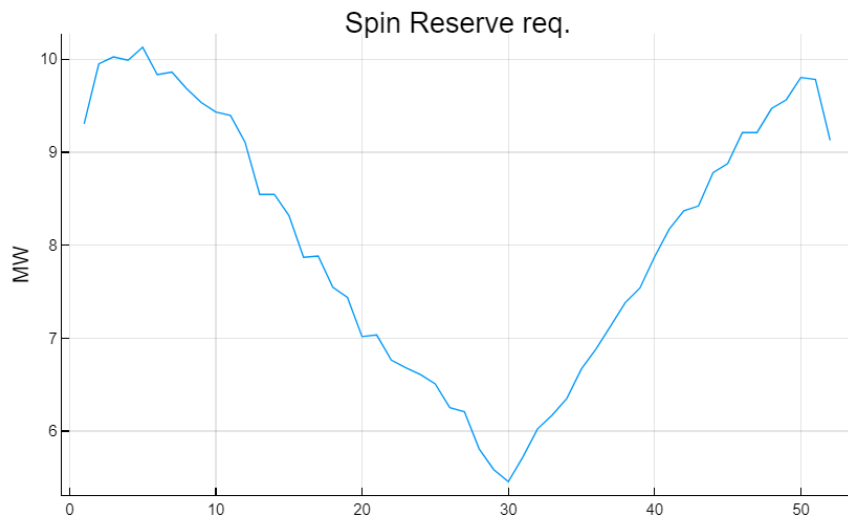
System design

Work in progress!

190 MW



Reserve Capacity Requirements



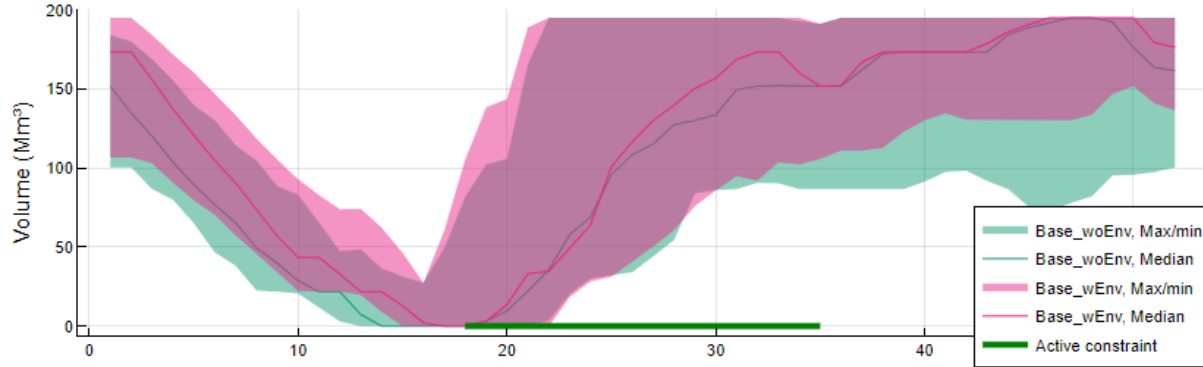
10% of avg. demand: 5.45-10.12 MW

10% of peak demand: 21.8 MW

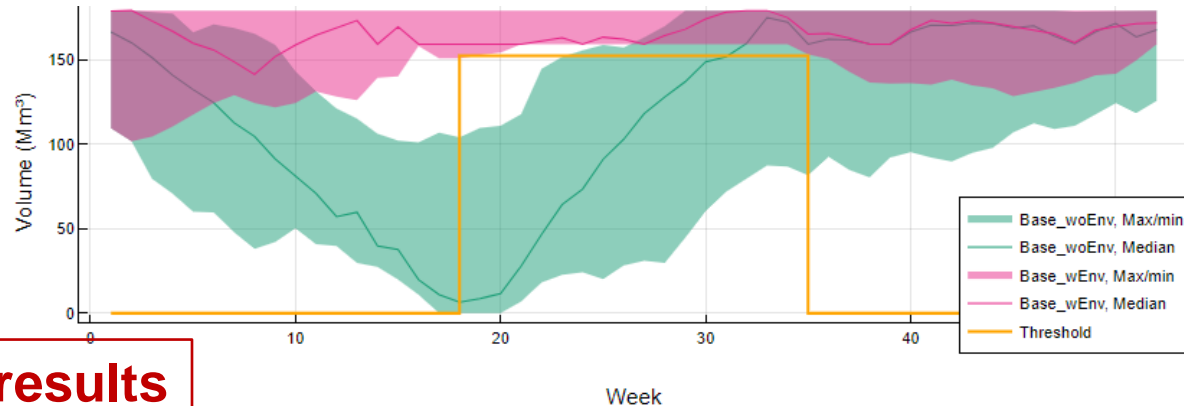
Work in progress!

Reservoir management: Base case, no reserves

Upper



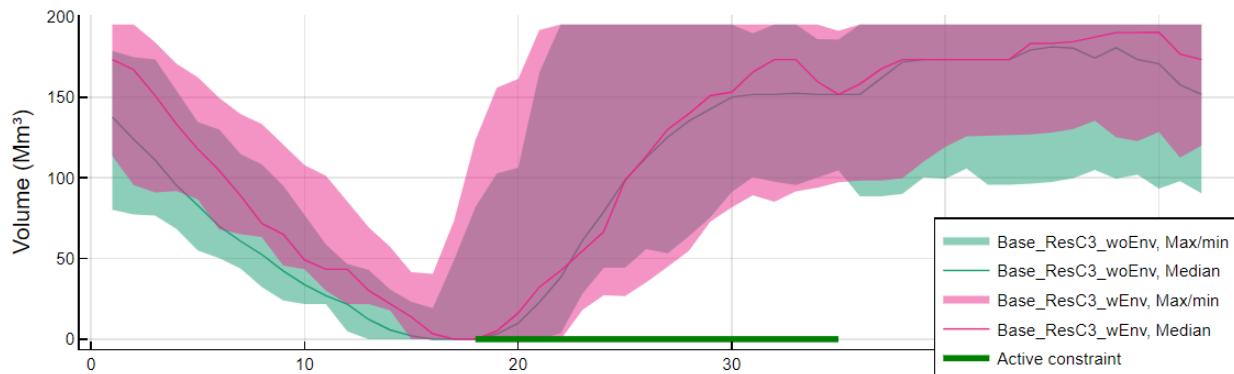
Lower



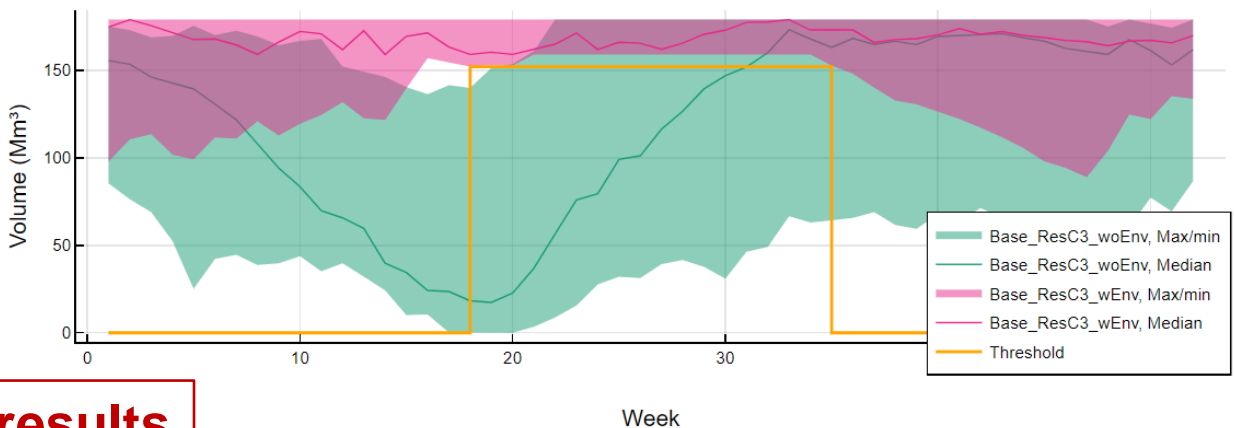
Preliminary results

Reservoir management: Base case, spin + non-spin reserves

Upper



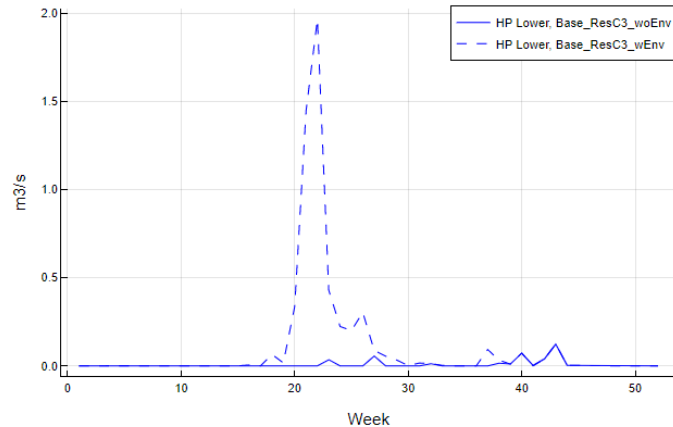
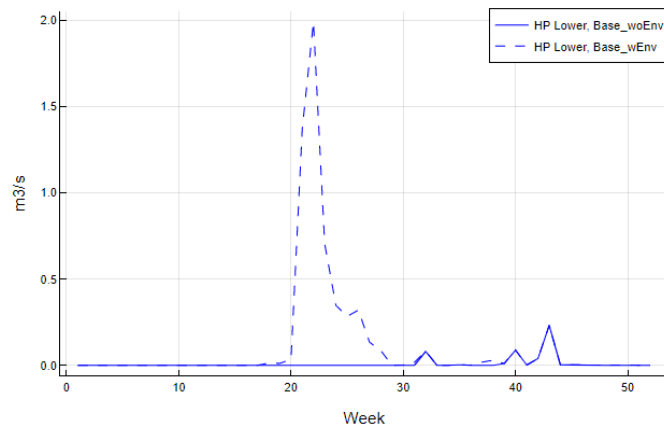
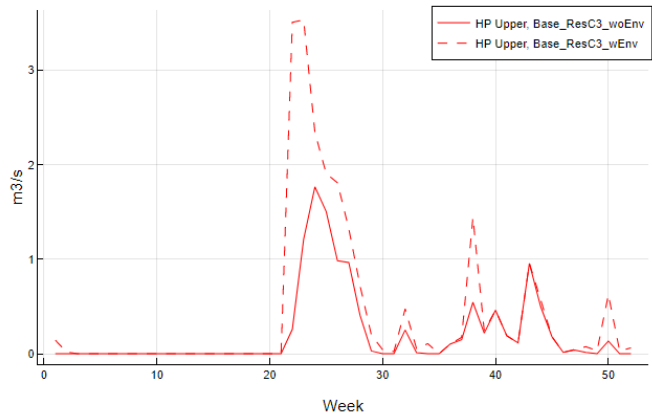
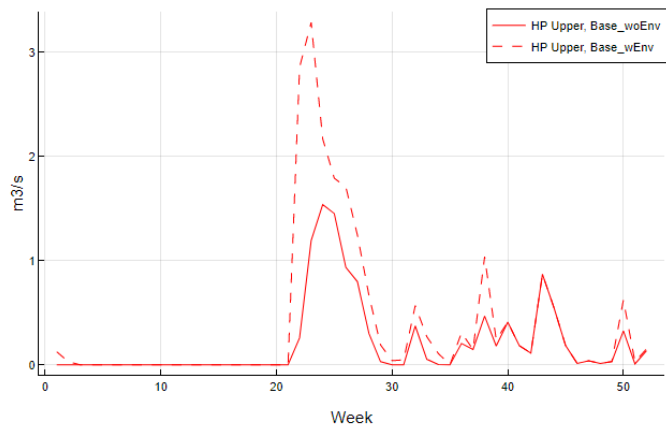
Lower



Preliminary results

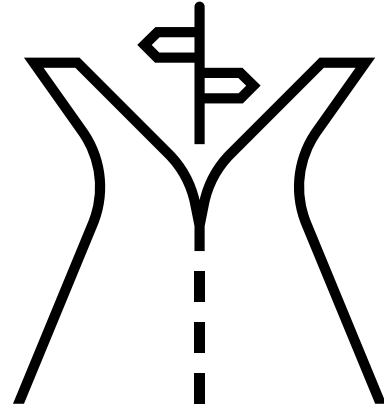
Average spillage

Preliminary results



Further work

- Improve base system in case study
 - Add more flexibility options
- Conduct broader case study
 - Hydropower system configurations
 - Reserve capacity requirements
 - Environmental constraints
- Measures to evaluate results
 - Change in flexibility
 - Impact on system of flexibility change





More interesting results to follow.... (hopefully!)

THANK YOU!