MEDIUM-TERM HYDROPOWER SCHEDULING BY STOCHASTIC DUAL DYNAMIC INTEGER PROGRAMMING: A CASE STUDY

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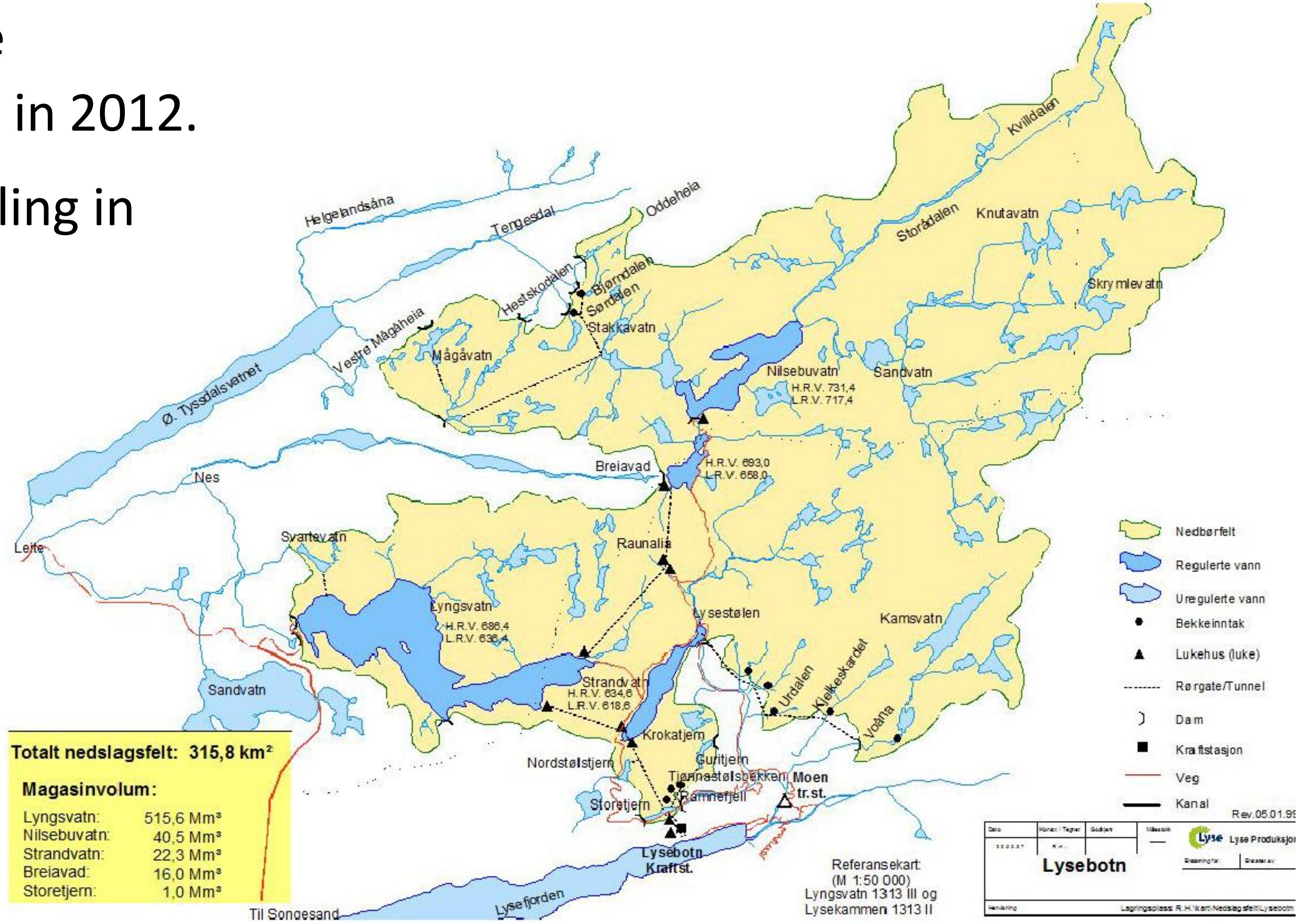
NTNU

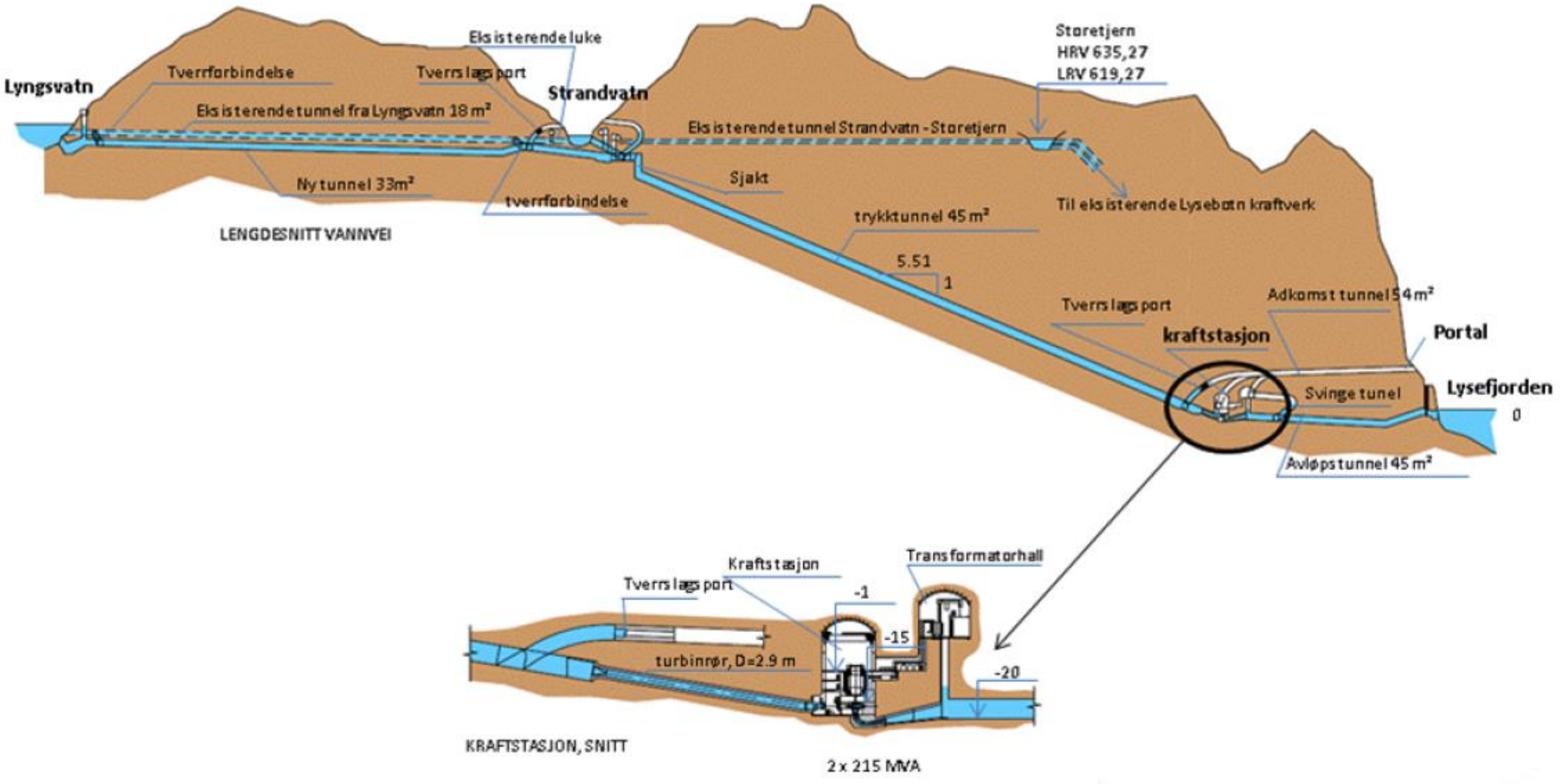
Background

- Research project initiated from the Hydropower Scheduling Workshop in 2012.
- Medium-term hydropower scheduling in multiple markets
  - Affects on Water Values



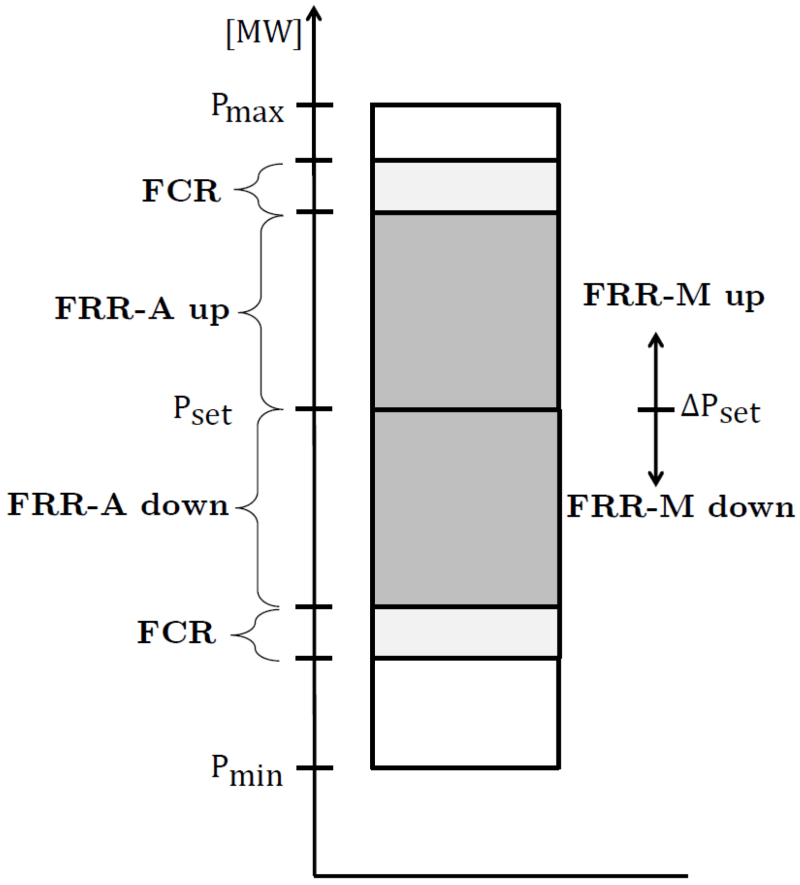
The Medium-Term Hydropower Scheduling (MTHS) Problem

- Challenges
  - Uncertainty of inflow and future energy/capacity prices
  - Level of details?
    - Individual generators
    - Unit commitment
    - Water head
    - Other system constraints



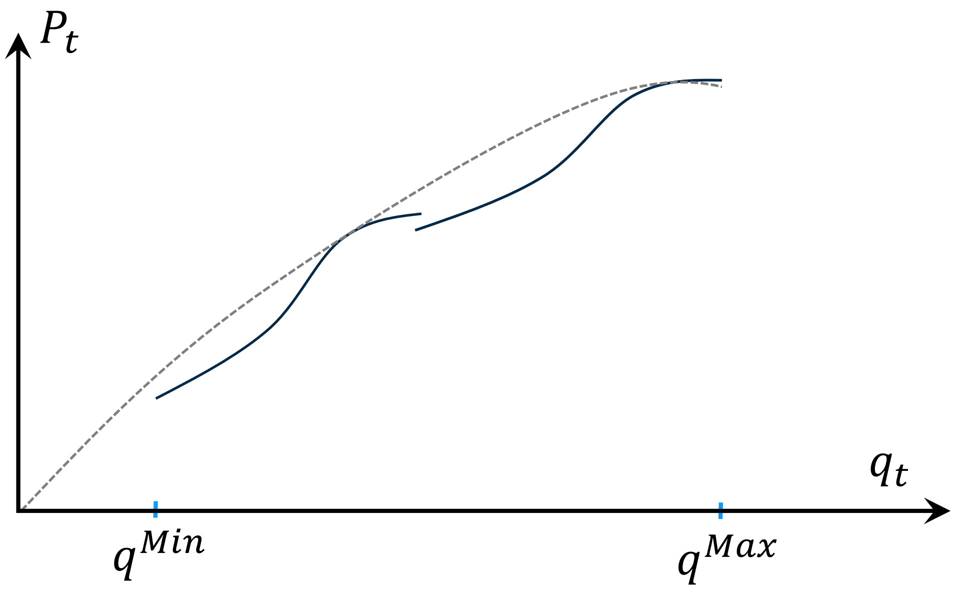
- Objective: Maximize income from energy and **capacity reserves**
  - Main scope of my PhD thesis

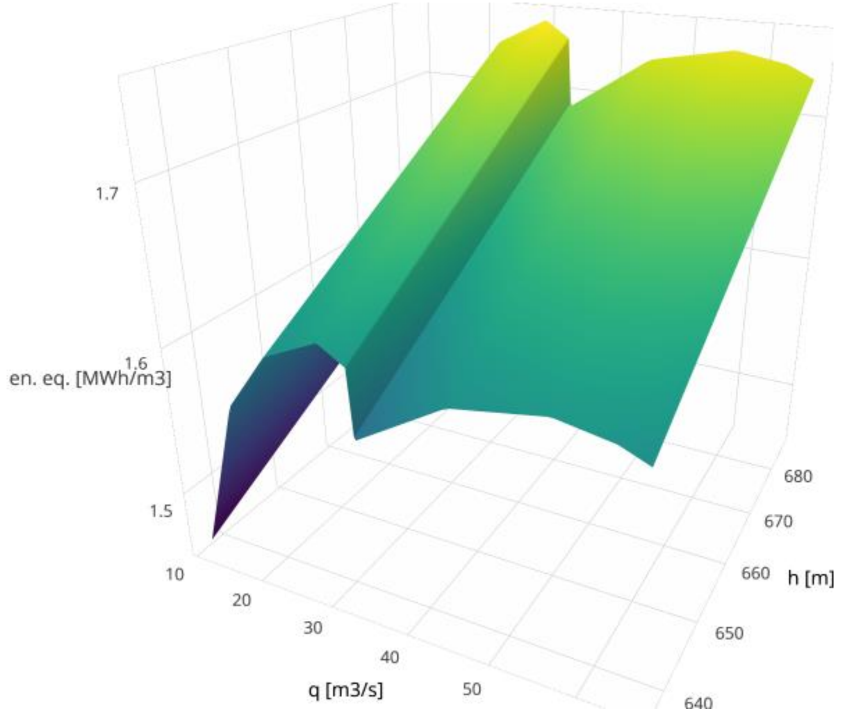
- Capacity reserves/Spinning reserves
  - Primary
  - Secondary



Nonconvex Generation Function

- Generation function for each hydropower station
- Head dependencies?



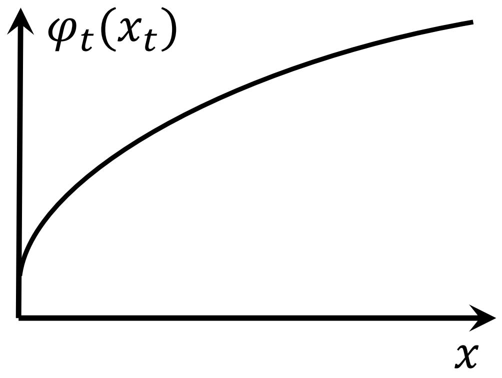


Stochastic Dual Dynamic integer Programming (SDDiP)

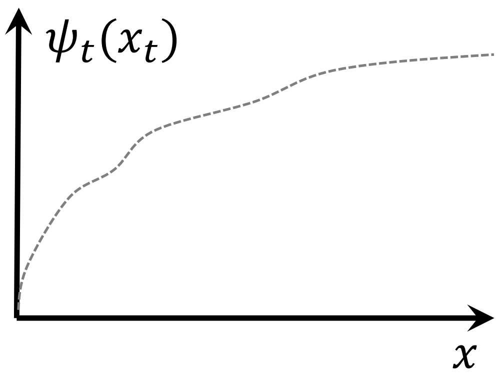
J. Zou, X. A. Sun and S. Ahmed, «Stochastic dual dynamic integer programming», Mathematical Programming 2018.

One-Stage Dispatch Problem (Weekly Decision Problem)

«Generic» Stochastic Dual Dynamic Programming (SDDP)



Stochastic Dual Dynamic Integer Programming (SDDiP)



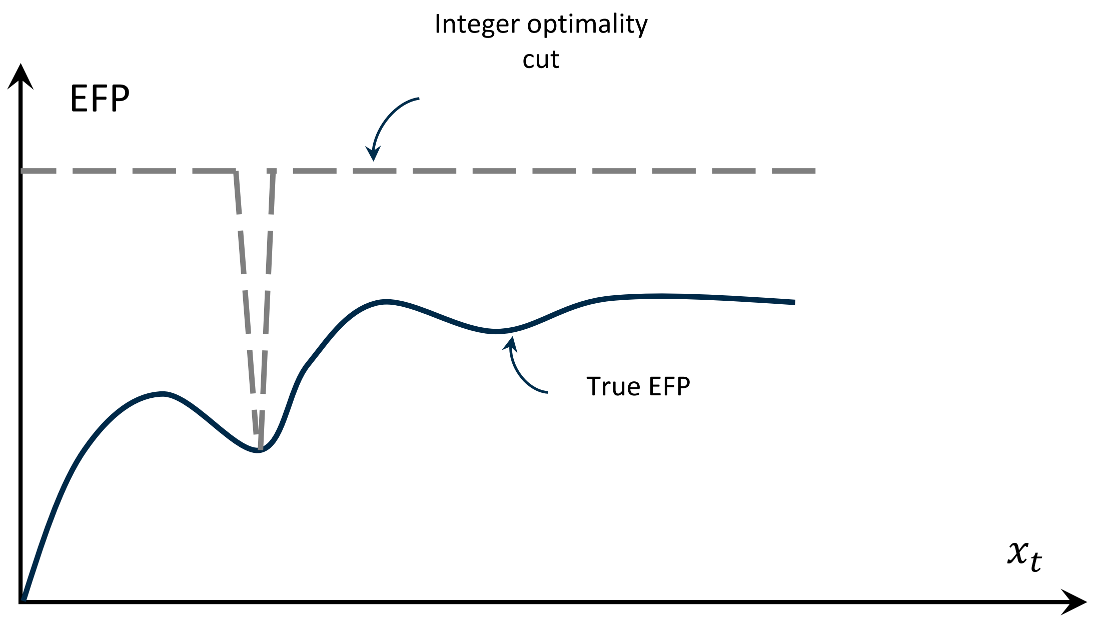
Cut Families

1	Benders Cuts
2	Integer Optimality Cuts
3	Lagrangian Cuts
3	Strengthened Benders Cuts

- Traditional
- Used in generic SDDP

1	Benders Cuts
2	Integer Optimality Cuts
3	Lagrangian Cuts
3	Strengthened Benders Cuts

- Evaluates that exact solution
- Large coefficients
  - Increased CPU time
- Not applicable in practice

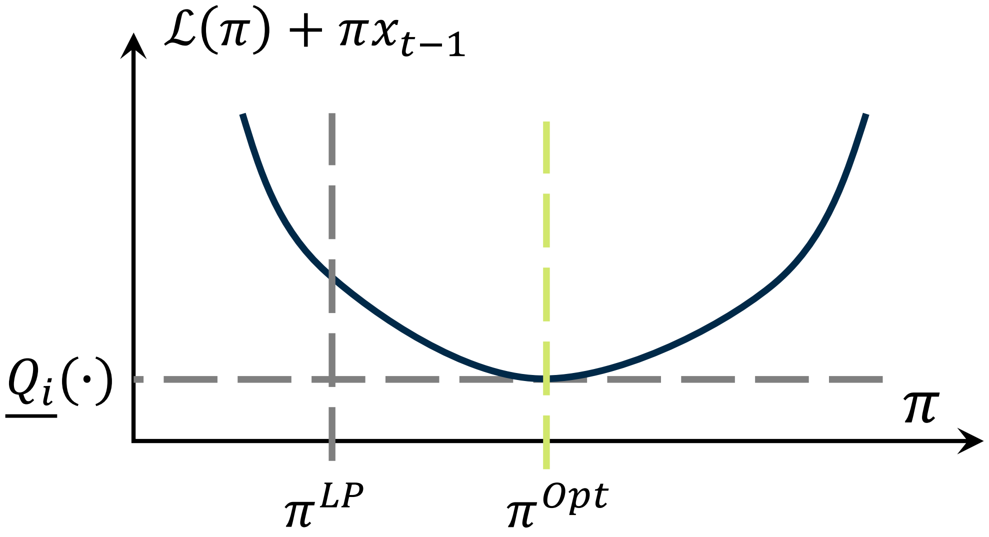


Cut Families

1	Benders Cuts
2	Integer Optimality Cuts
3	Lagrangian Cuts
3	Strengthened Benders Cuts

- Lagrangian relaxation is normally used for simplifying difficult constraints
- Here the problem is to find the Lagrangian multipliers that are used to generate tight cuts
- Relaxing time-linking constraint
- Computational demanding
  - Approx 30 MIP problems for subproblem

1	Benders Cuts
2	Integer Optimality Cuts
3	Lagrangian Cuts
3	Strengthened Benders Cuts



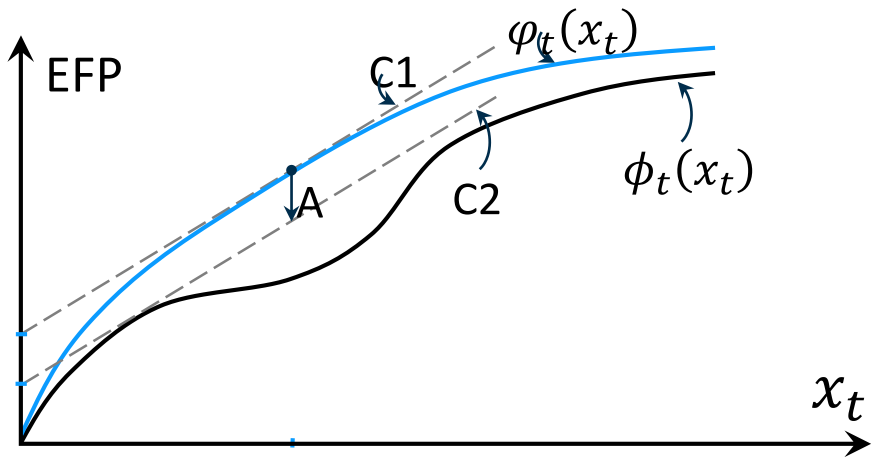
1 Benders Cuts

2 Integer Optimality Cuts

3 Lagrangian Cuts

3 Strengthened Benders Cuts

- Parallel to Benders Cuts
- Requires to solve one additional MIP problem



1 Benders Cuts

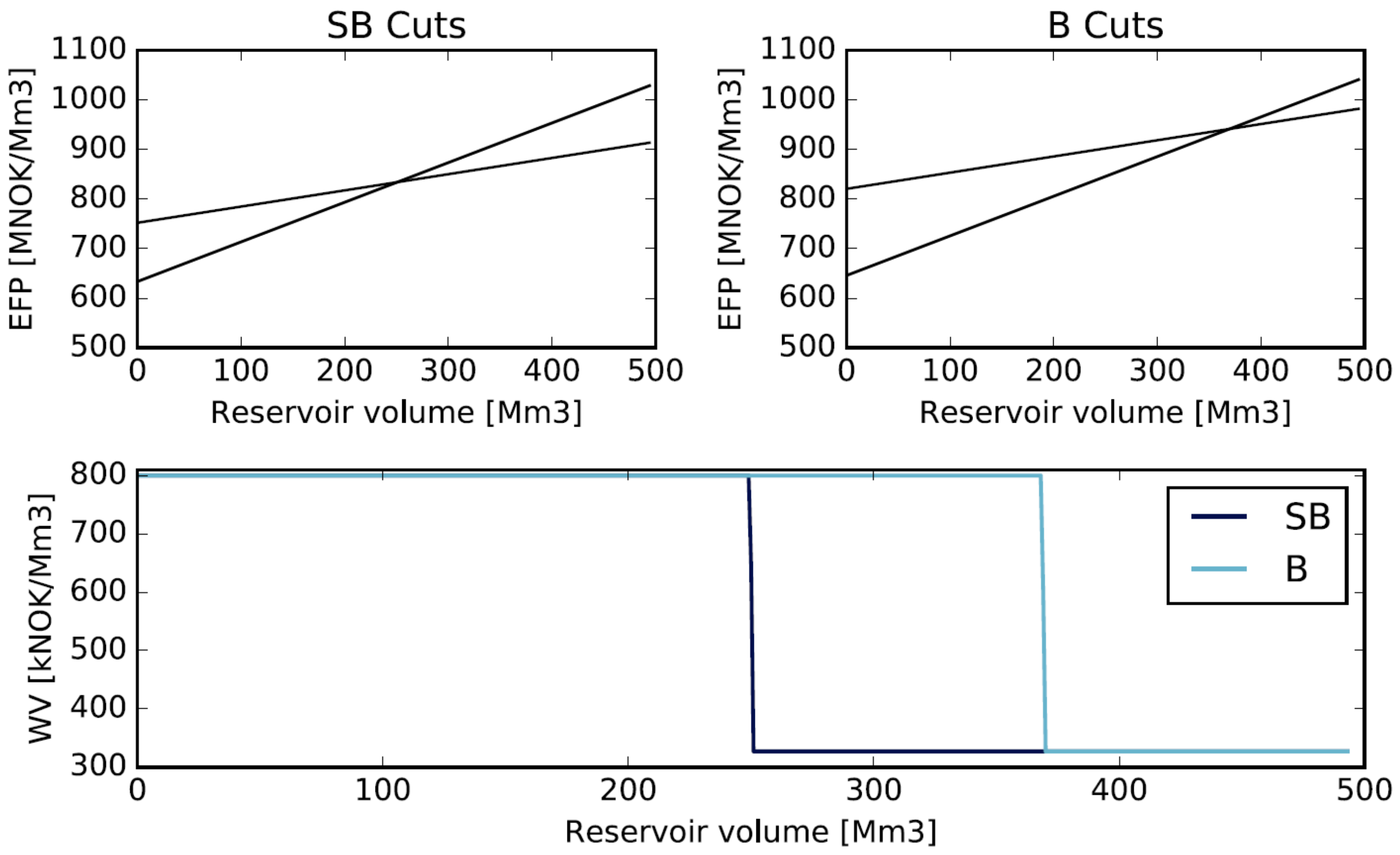
2 Integer Optimality Cuts

3 Lagrangian Cuts

3 Strengthened Benders Cuts

- Can be computed without having binary state variables
- Does not guarantee convergence but might provide a satisfying solution.

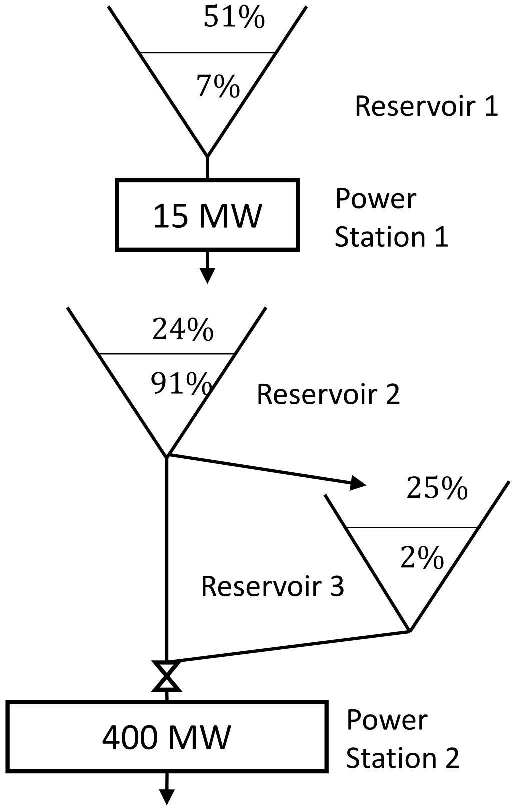
Implications of SB on the Water Values



Case Study

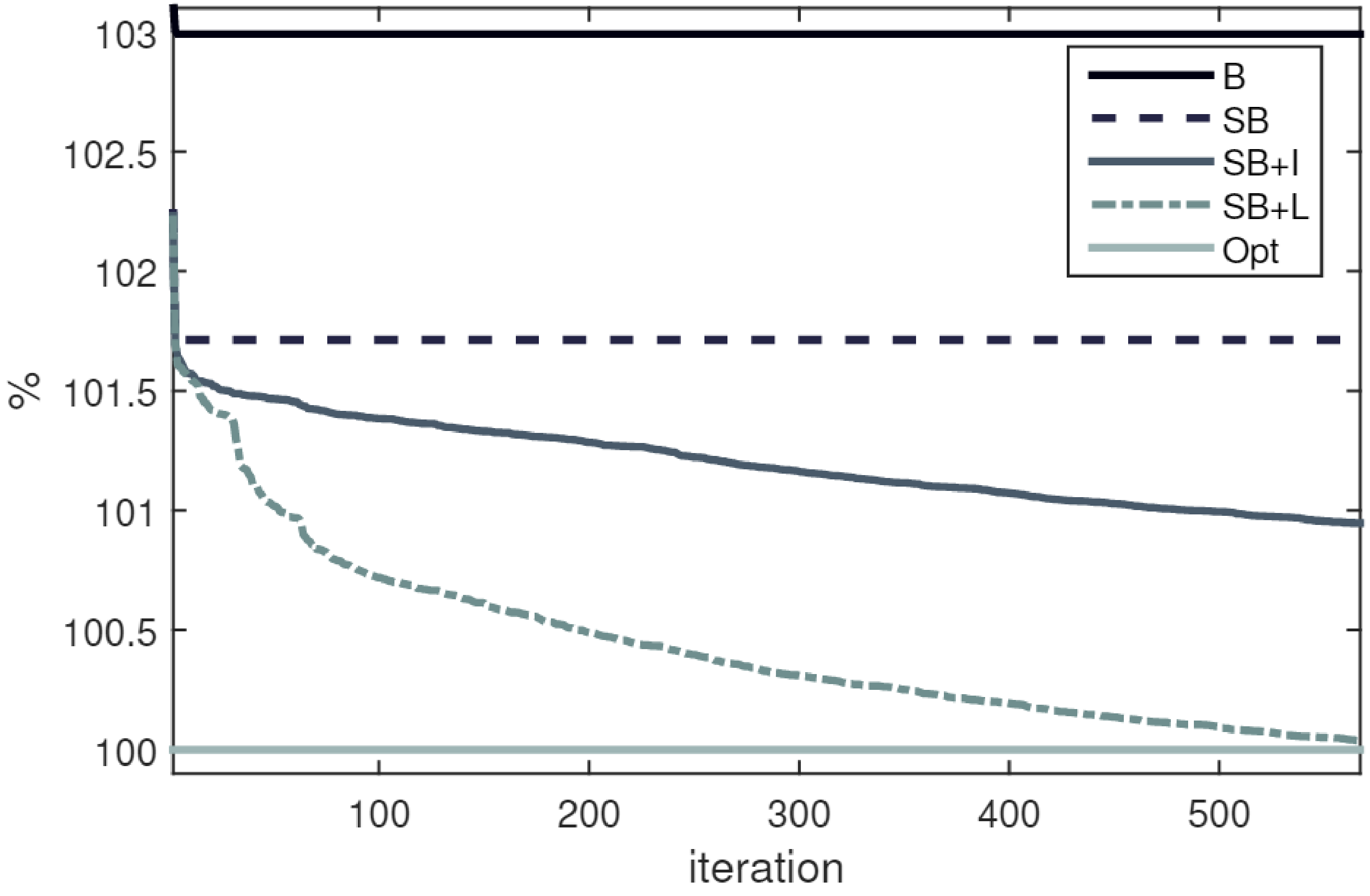
M. N. Hjelmeland, J. Zou, A. Helseth and S. Ahmed, "Nonconvex Medium-Term Hydropower Scheduling by Stochastic Dual Dynamic Integer Programming," *IEEE Transactions on Sustainable Energy*, 2018.

- Sales of both energy and reserve capacity
- 2 years
  - Weekly decision stages
- Uncertainty of inflow and energy price
  - VAR-1 model
  - McCormick Envelopes for bilinear terms
- Nonconvex generation function
  - Only dependent on discharge
- Minimum generation limits
- Spillage
- Reservoir operation



Results

Validation of SDDiP with a Test Case



- Lagrangian cuts too comprehensible.

TABLE I
CASE I, INFLOW UNCERTAINTY. SDDIP (TOP) AND APPROXIMATE PROBLEM (BOTTOM).

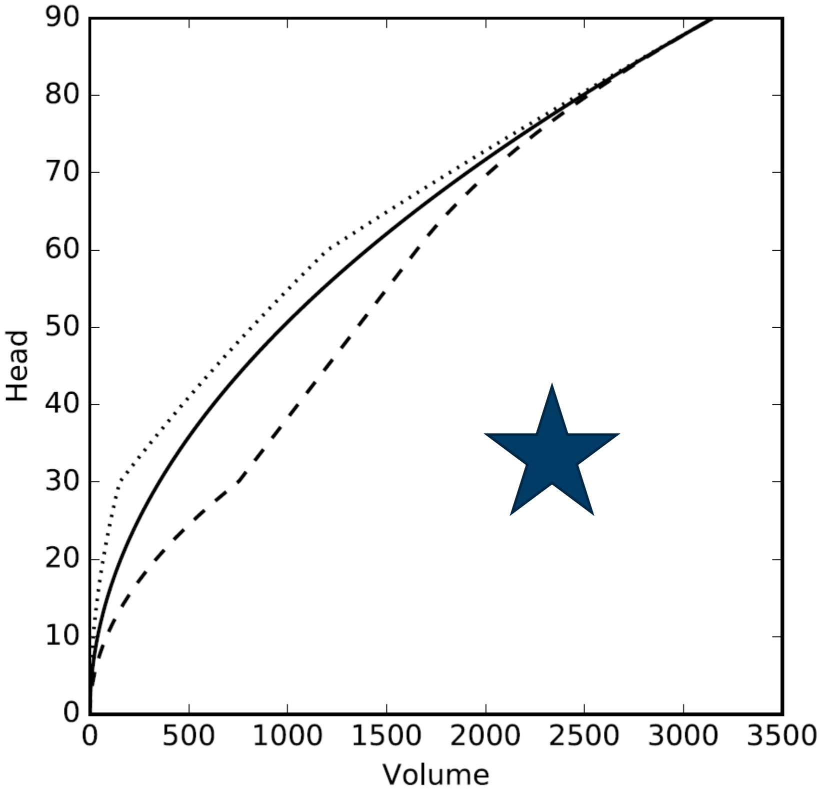
	UB [kEUR]	stat. LB [kEUR]	gap [%]	time [s]
B	47 353.72	40 776.87	13.89	16 792
B-SB	42 907.58	41 135.43	4.13	17 716
B-SB-I	42 854.80	41 197.25	3.87	30 277
B	47 030.08	40 973.28	12.88	742
B-SB	42 906.90	41 350.85	3.63	1 176

TABLE II
CASE II, INFLOW AND ENERGY PRICE UNCERTAINTY. SDDIP (TOP) AND APPROXIMATE PROBLEM (BOTTOM).

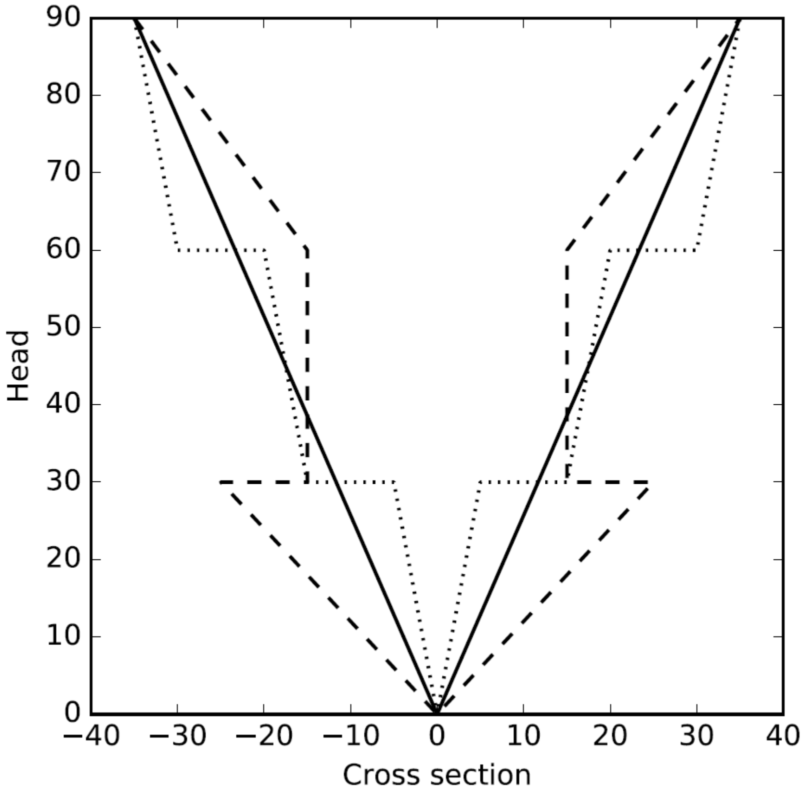
	UB [kEUR]	stat. LB [kEUR]	gap [%]	$\underline{\text{gap}}$ [%]	time [s]
B	107 469.94	42 276.74	60.66	11.24	11 788
B-SB	84 380.16	43 802.85	48.09	7.37	13 896
B-SB-I	84 291.78	43 748.69	48.10	7.50	18 966
B	107 449.36	42 444.20	60.50	10.80	2 279
B-SB	84 367.26	43 891.43	47.98	7.15	2 869

Adding Head Dependencies

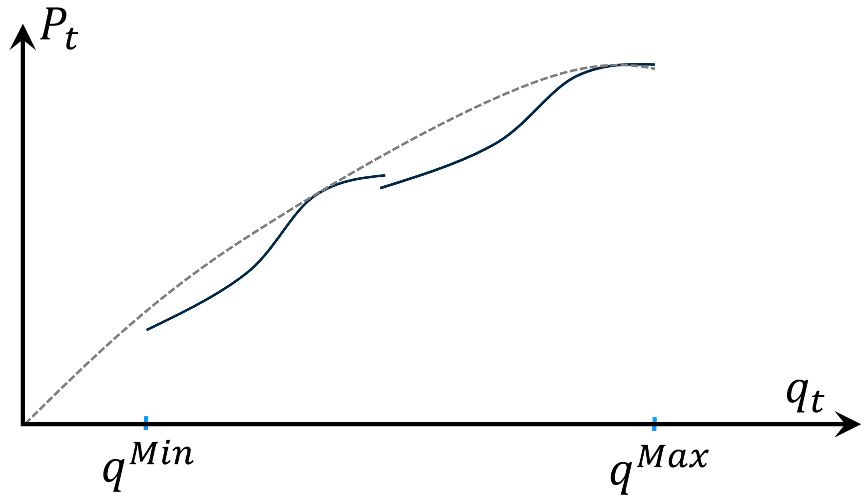
Head(Volume)

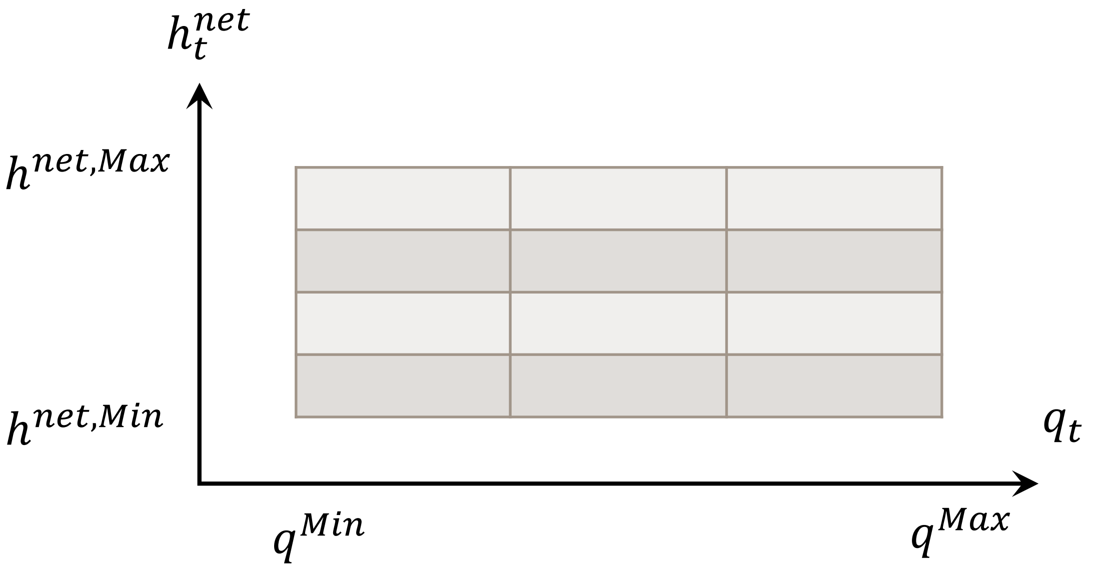


Head(Cross section)



- Multiple turbines
  - Adding to the nonconvexities
- Splitting the generation function into convex segments
  - Efficient way of doing this?

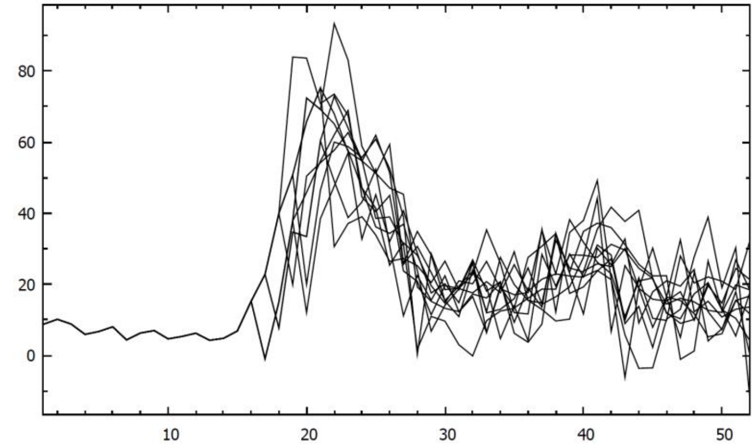




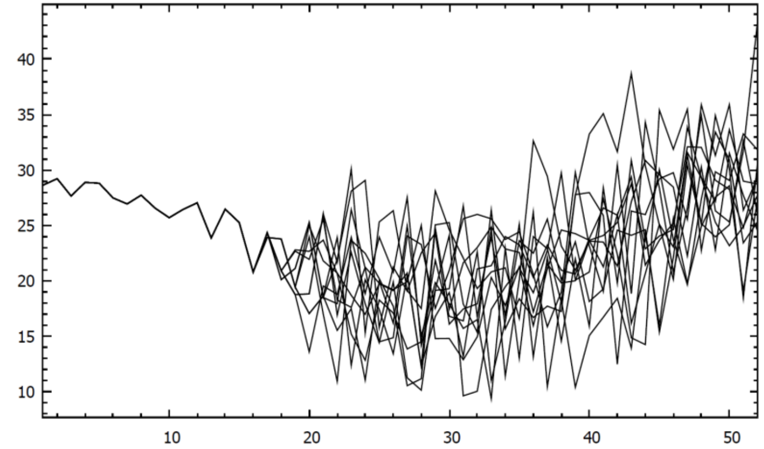
Visualization of the EFP Function

- Simple Idea
  - Solve the extensive form of the problem
  - Iterate over different starting reservoirs
  - Add different nonlinearities and observe

Inflow

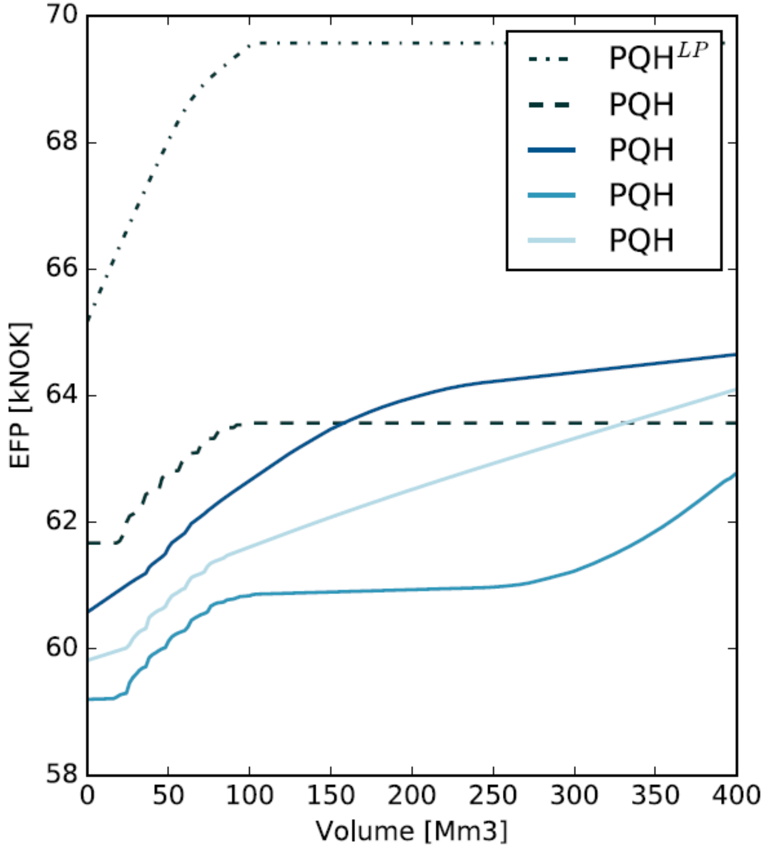


Energy Price

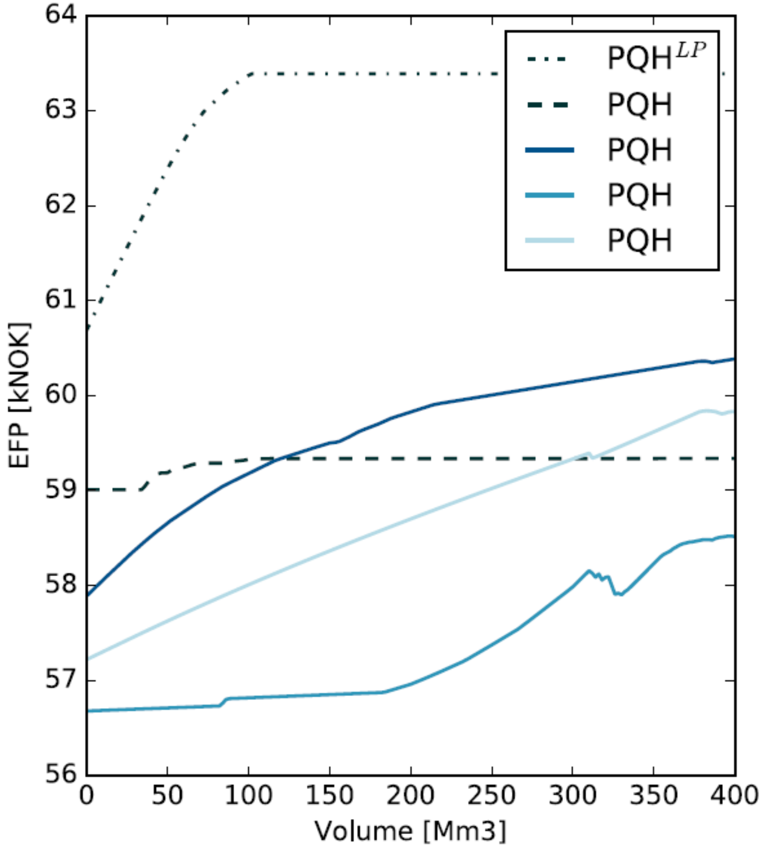


Visualize the EFP Function

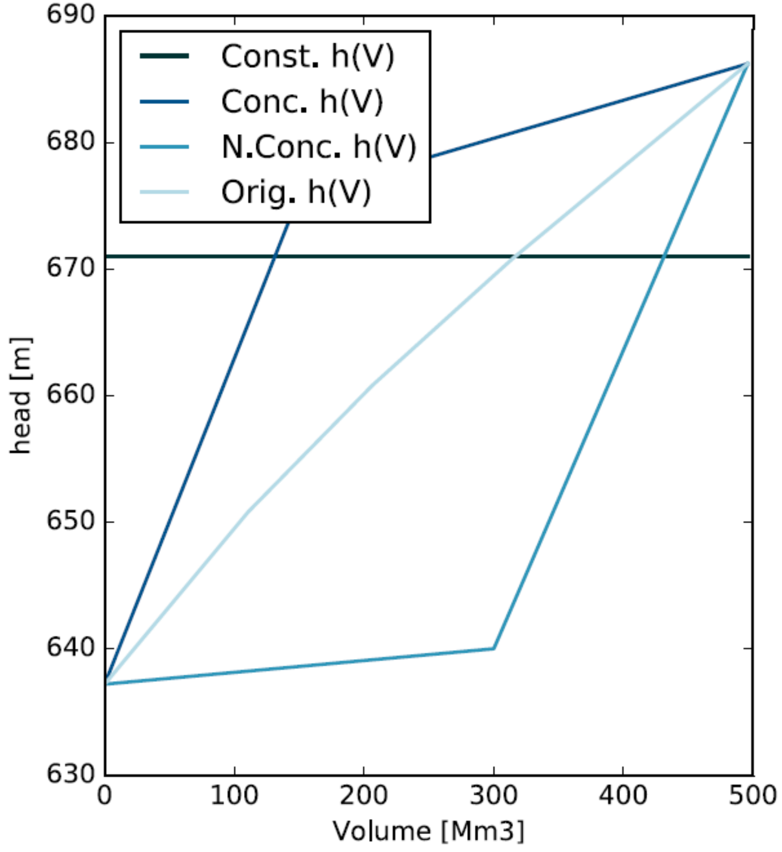
Energy & Capacity Reserves



Energy



Head Function



Case Study 2.0

- Sales of both energy and reserve capacity
  - A. Downward, 2018
- 2 years
  - Weekly decision stages
- Uncertainty of inflow, energy & capacity price
  - VAR-1 model
  - ~~McCormick Envelopes for bilinear terms~~
- Nonconvex generation function
  - Dependent on discharge and head
- Minimum generation limits
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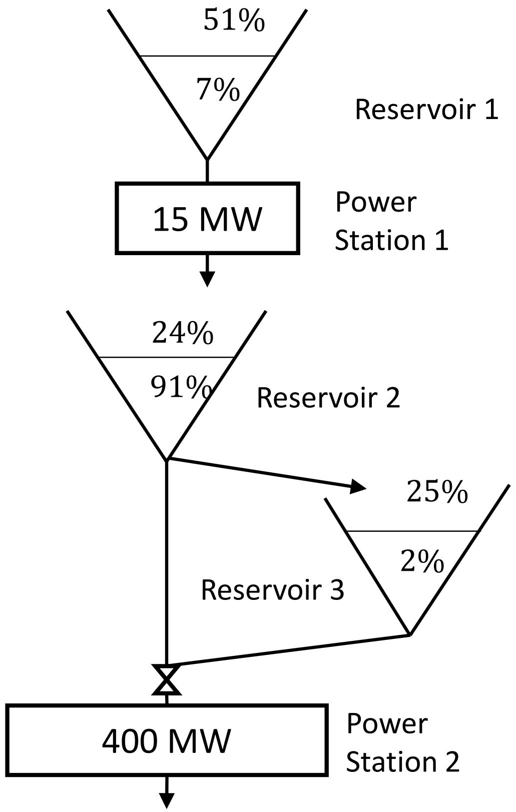
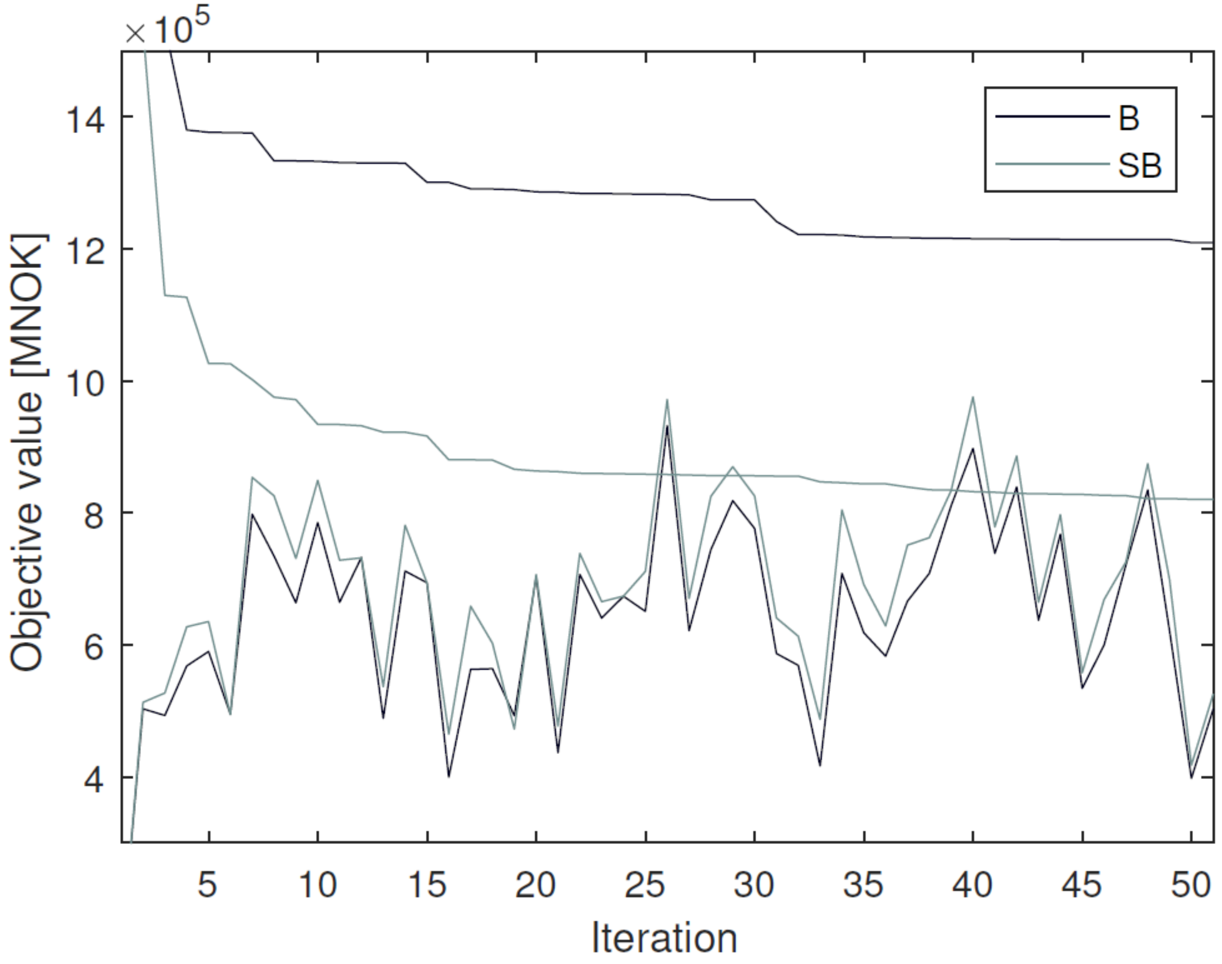
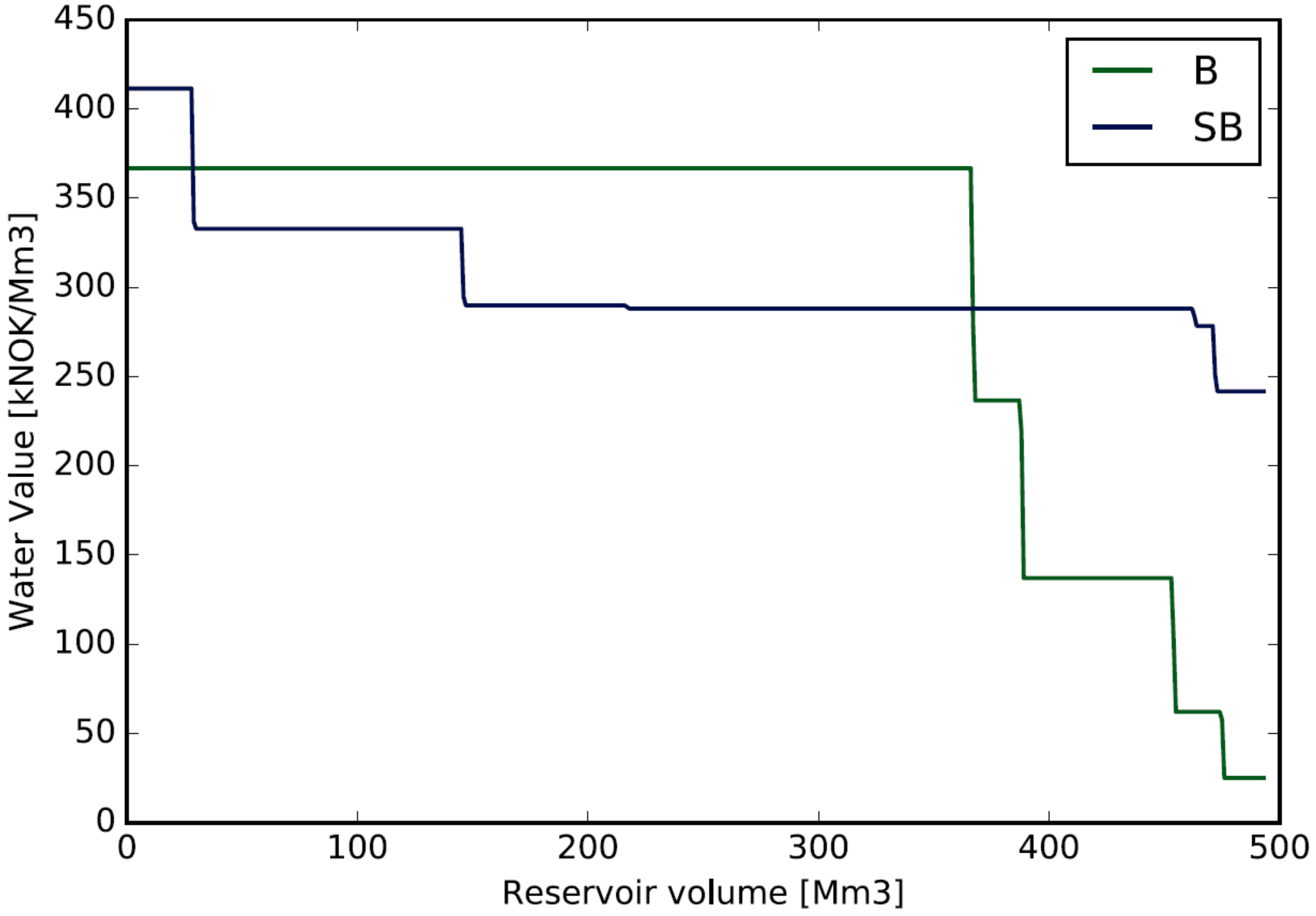


Convergence B vs SB

- Significantly improved Gap
- Slightly improvement of policy



- Assuming all but one reservoir fixed
- Water values for a given week using either B or SB
- Generally lower water values by SB
  - Does not imply lower operating states
  - Need more testing and validation




Thank you for your attention!

References

- J. Zou, A. Sun and S. Ahmed , "Stochastic dual dynamic integer programming," *Mathematical Programming,* Mar 2018.
  - ICSP 2016 Presentation on SDDiP by Shabbir Ahmed: https://www.youtube.com/watch?v=Ewr2Boj0Jgs
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