Anticipation of probabilistic volume constraints

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1. Introduction
2. An asset under many constraints and uncertainties
3. Respect of probabilistic constraints for one reservoir
4. Joint respect of probabilistic constraints for two reservoirs

Introduction

Morgane: EDF’s mid-term stochastic optimization tool for hydropower management

Introduction

The energy source of hydroelectric plants is free… but we cannot refill as we please!

- Future inflows are uncertain.
- Water in the reservoirs must be used timely: use it now, or save it for later (better prices)?
- Some **constraints** on the environment or the hydraulic structures must be **anticipated long in advance**.

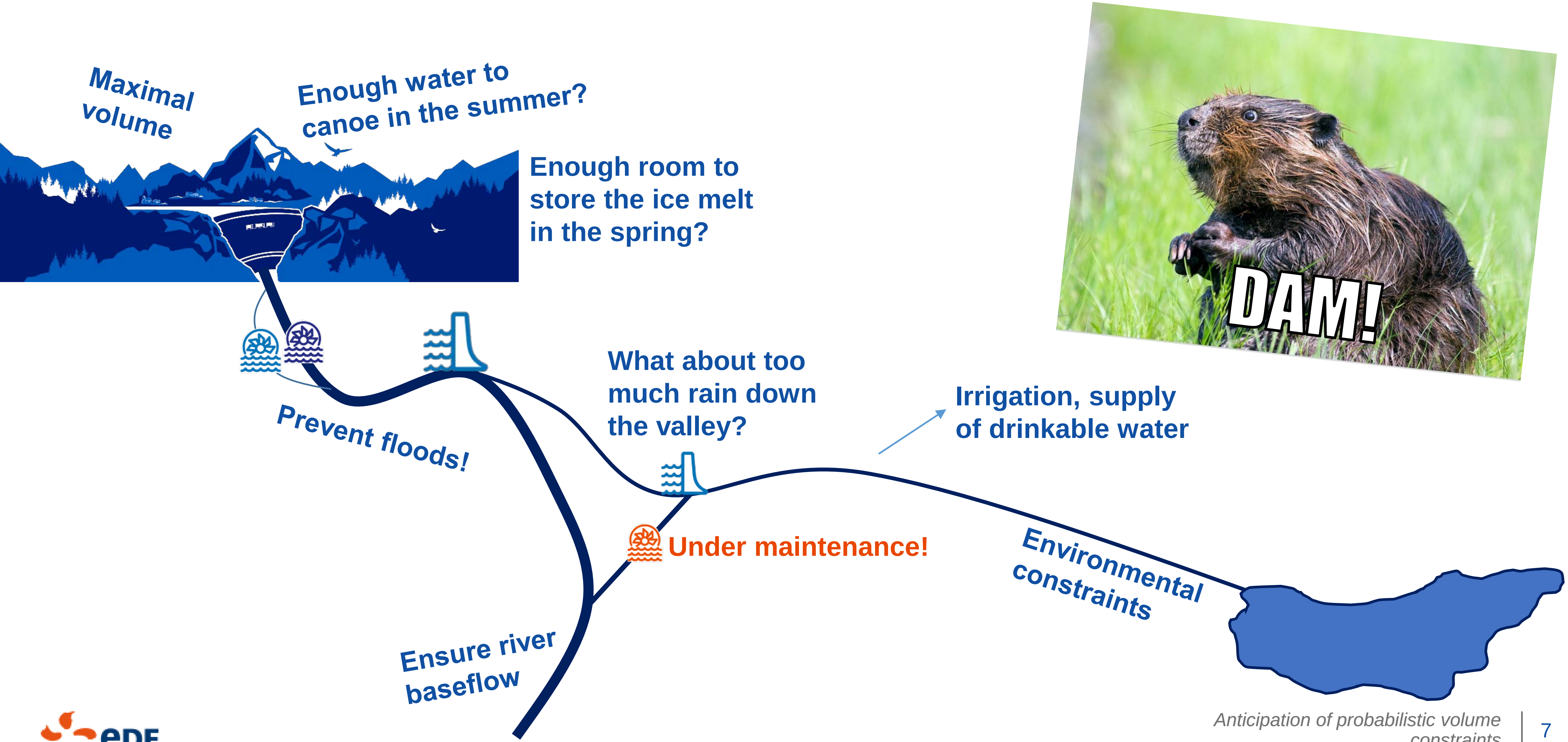
Introduction

Morgane: EDF’s mid-term stochastic optimization tool for hydropower management

- Time horizon of several years
- Uncertain inflows (forecasted, historical data)
- Price-taker: scenarios of marginal costs or market prices to remunerate the power production in each valley
- Detailed valley description using linear problems
- Stochastic dynamic programming to compute optimal management strategies

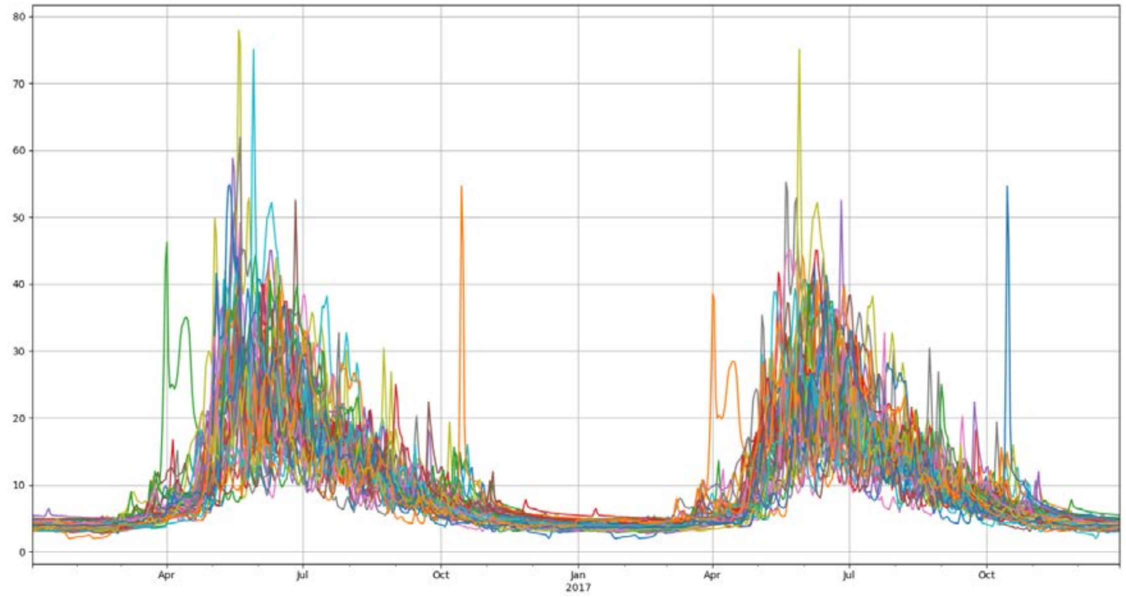
An asset under many constraints and uncertainties

An asset under many constraints…



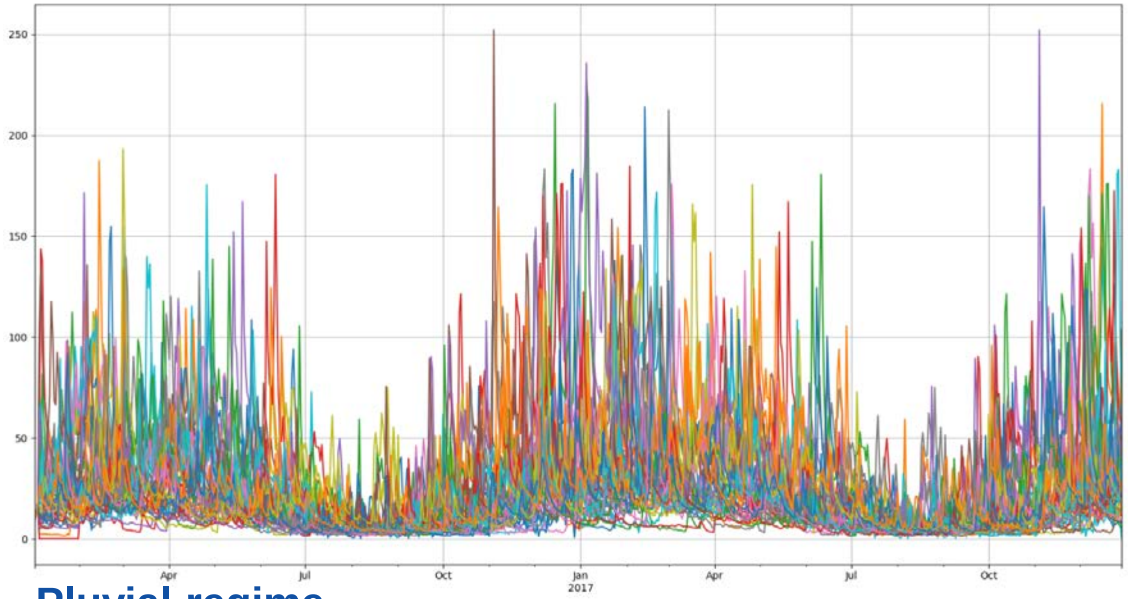
...and uncertainties

Numerous inflow scenarios



Nival regime

A lot of water during spring and summer due to the thawing of snow



Pluvial regime

A lot of water during autumn, winter and spring and summer with a slight decrease during summer

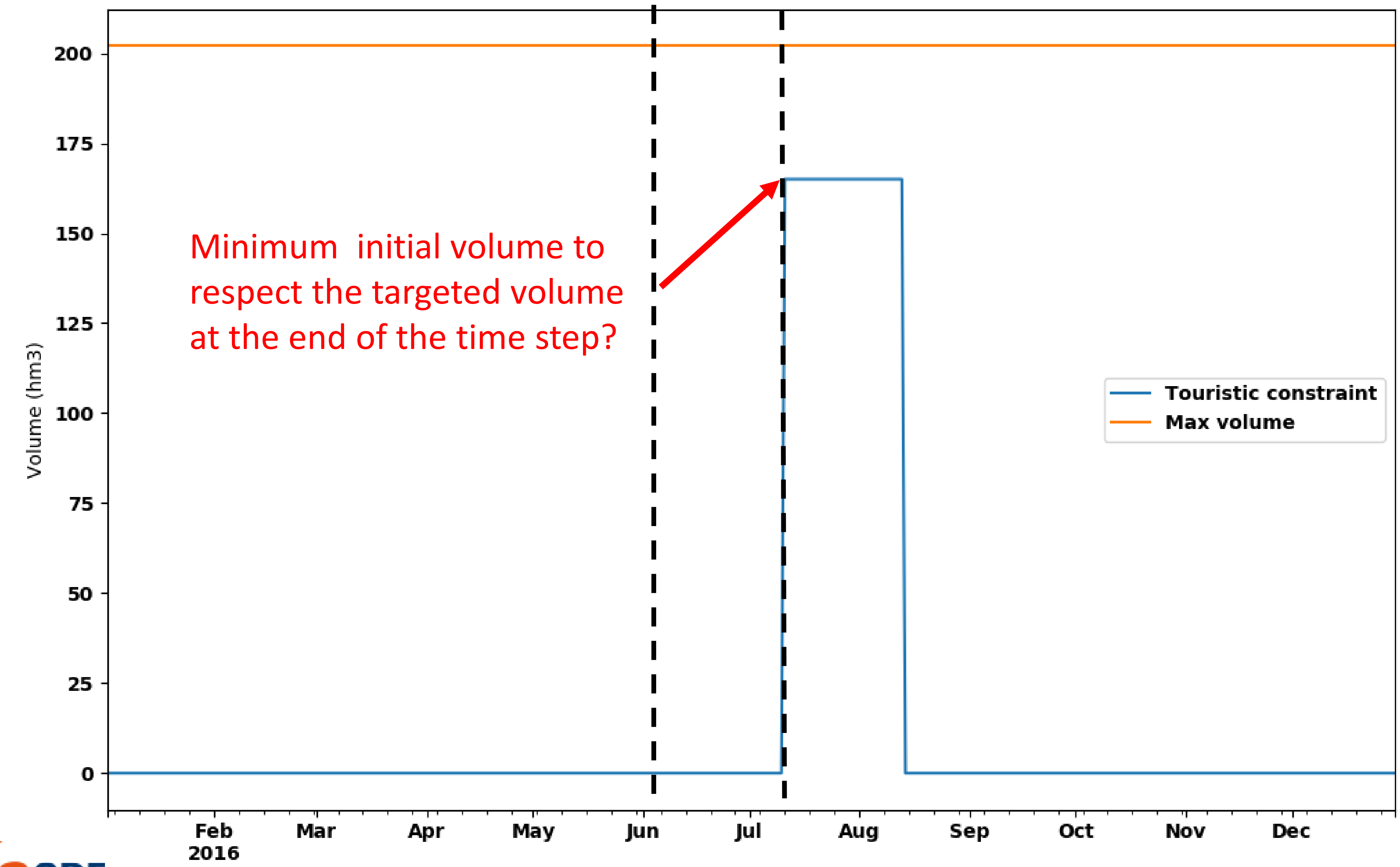
How to respect the constraints in the valley with so much (or so little!) water?

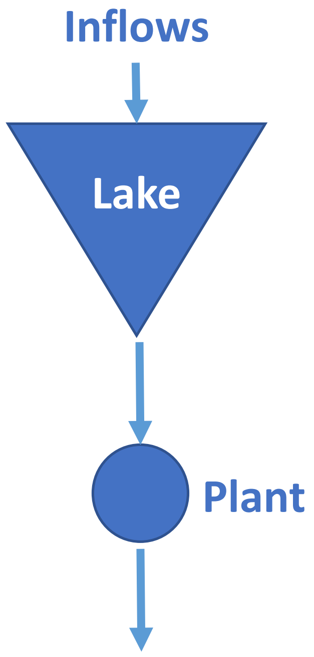
→ Compute **a min volume and a max volume** that ensure the constraints are respected

→ A **corridor** within which the reservoir will be **managed economically**

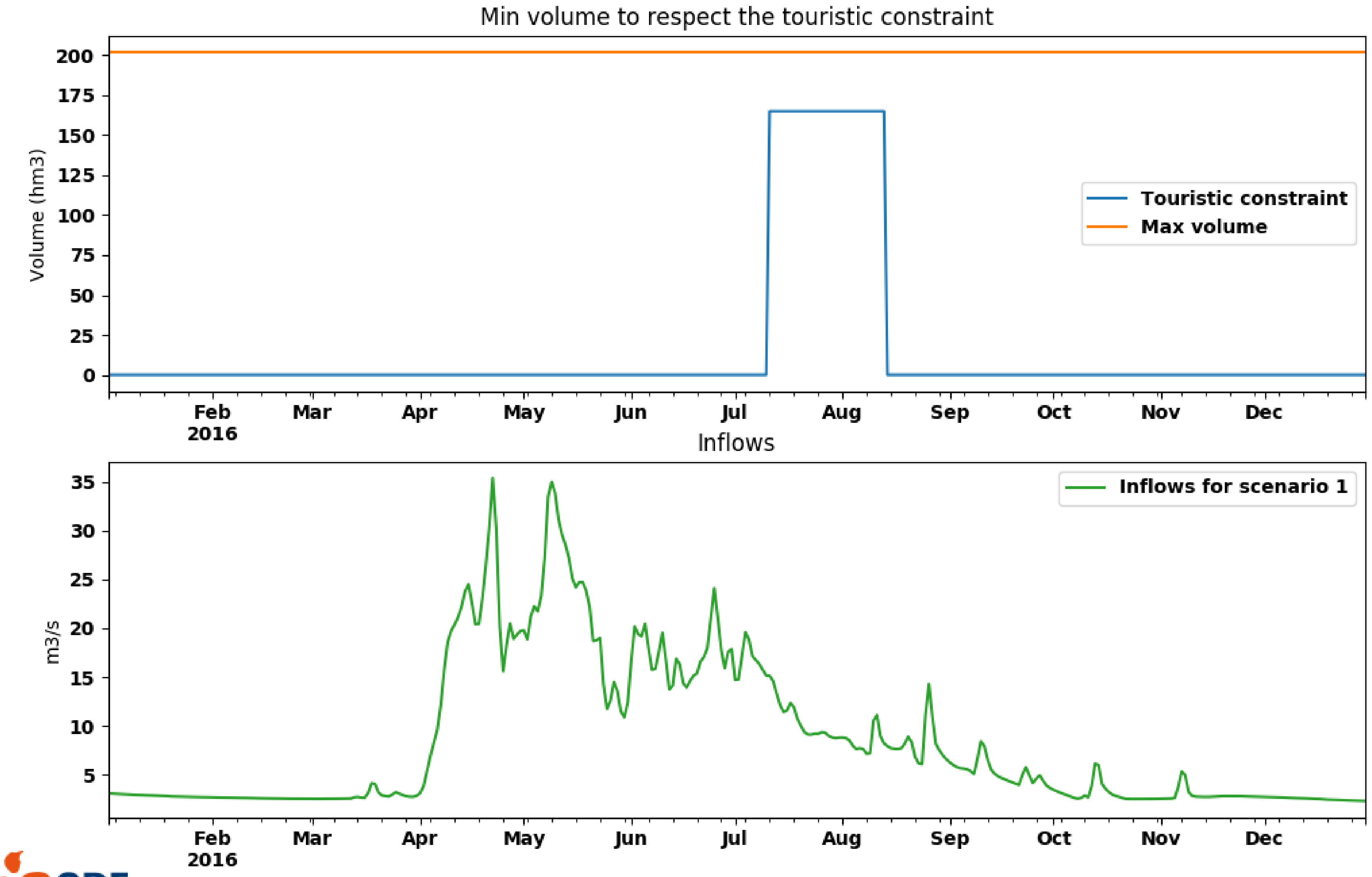
Respect of probabilistic constraints for one reservoir

Respect of probabilistic constraints for one reservoir





Respect of probabilistic constraints for one reservoir



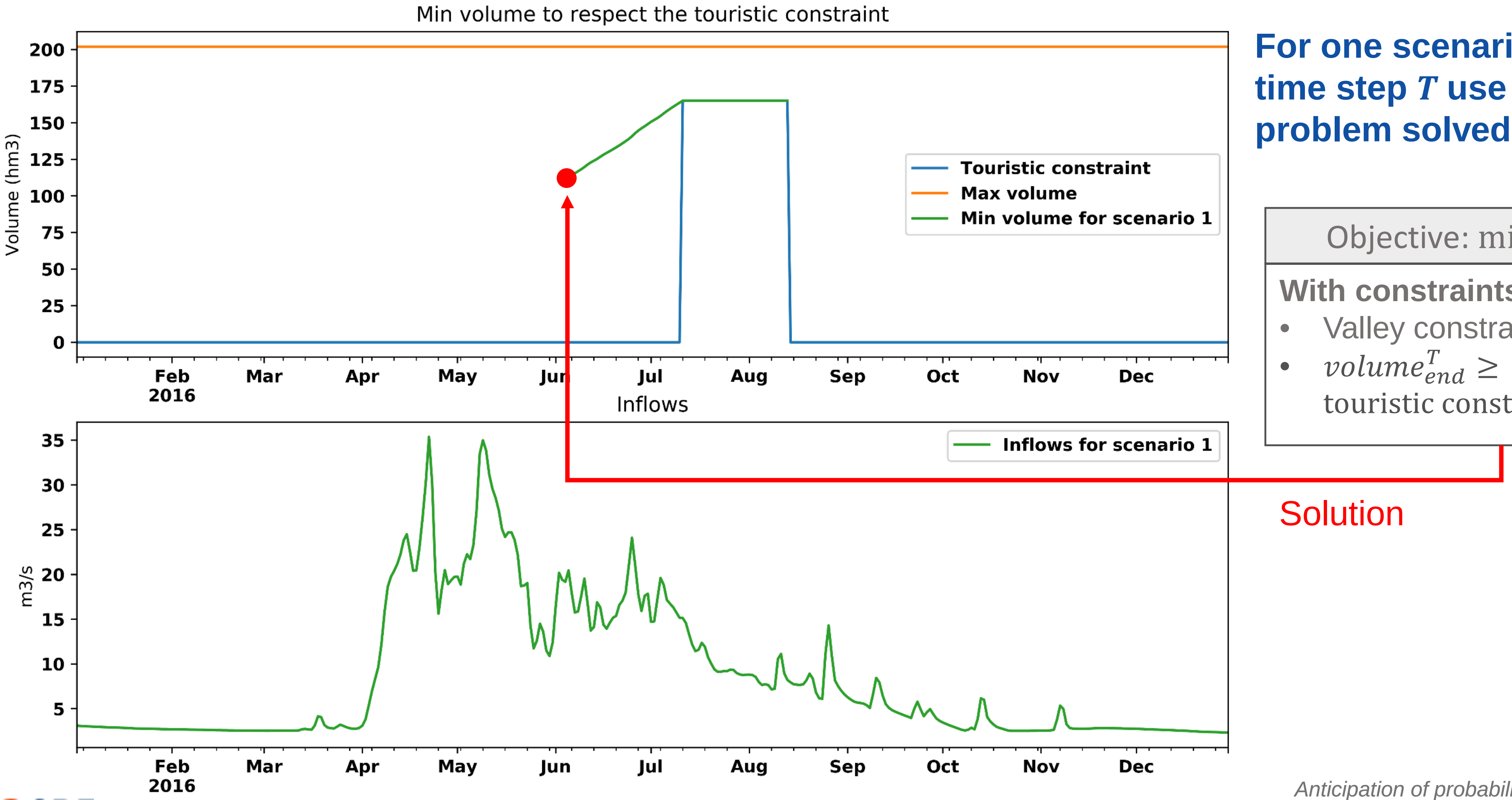
For one scenario, for one time step T use a linear problem solved with a solver:

Objective: $\min volume_0^T$

With constraints

- Valley constraints
- $volume_{end}^T \geq$ touristic constraint

Respect of probabilistic constraints for one reservoir



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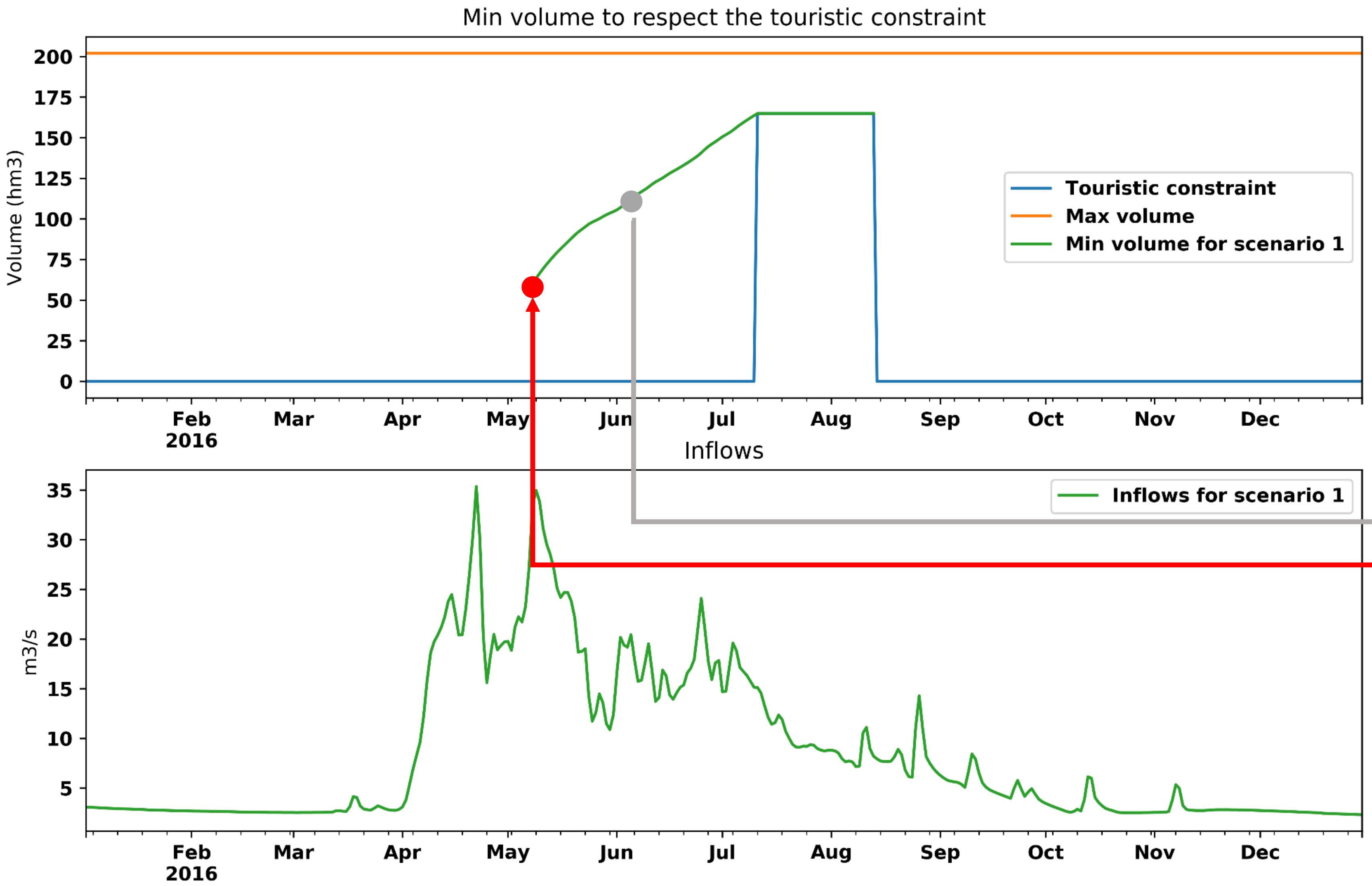
Respect of probabilistic constraints for one reservoir



Backward recursion

Objective: $\min volume_0^{T-1}$

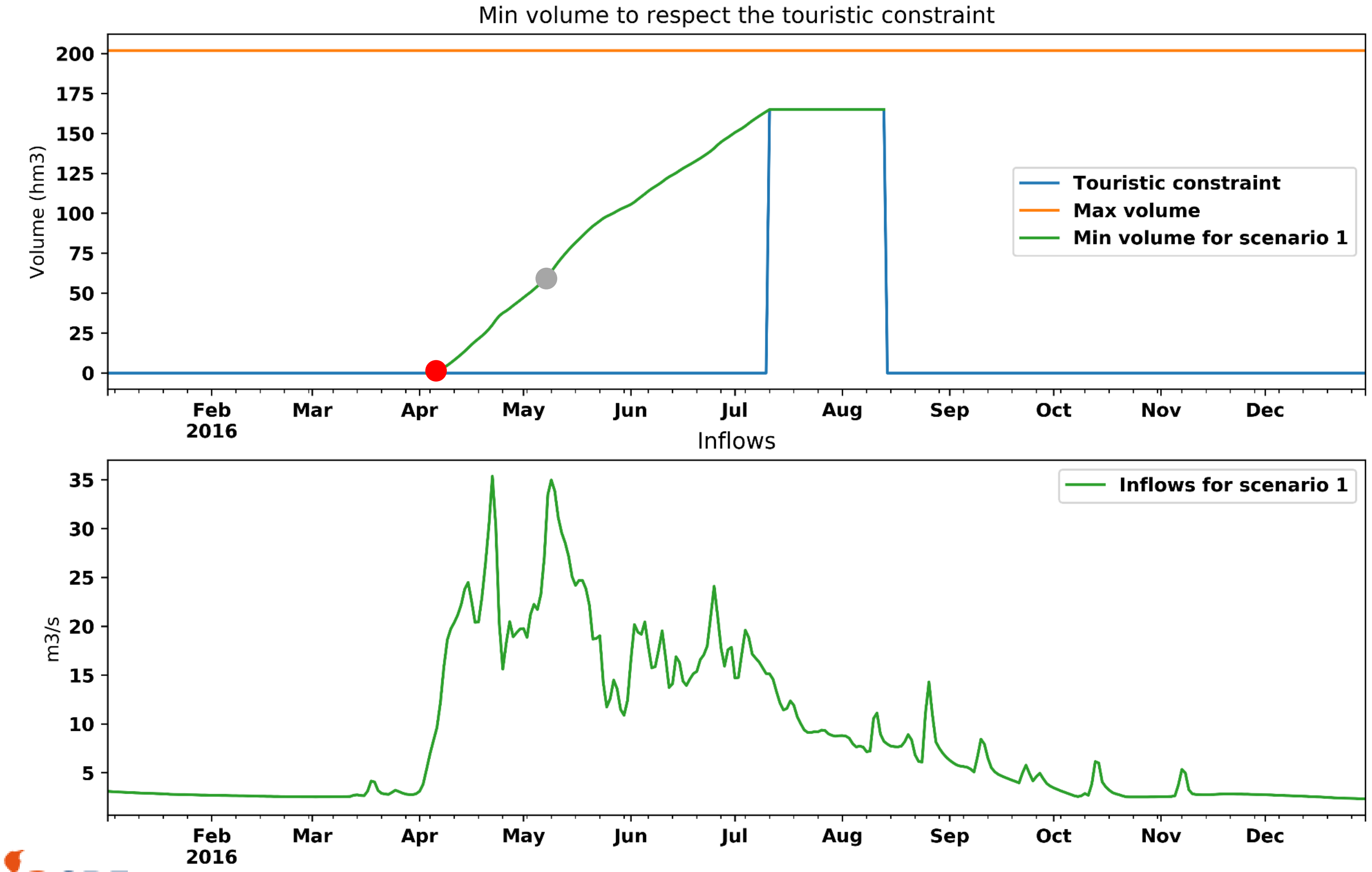
With constraints

- Valley constraints
- $volume_{end}^{T-1} \geq volume{*}_0^T$

Previous solution is new constraint

Solution

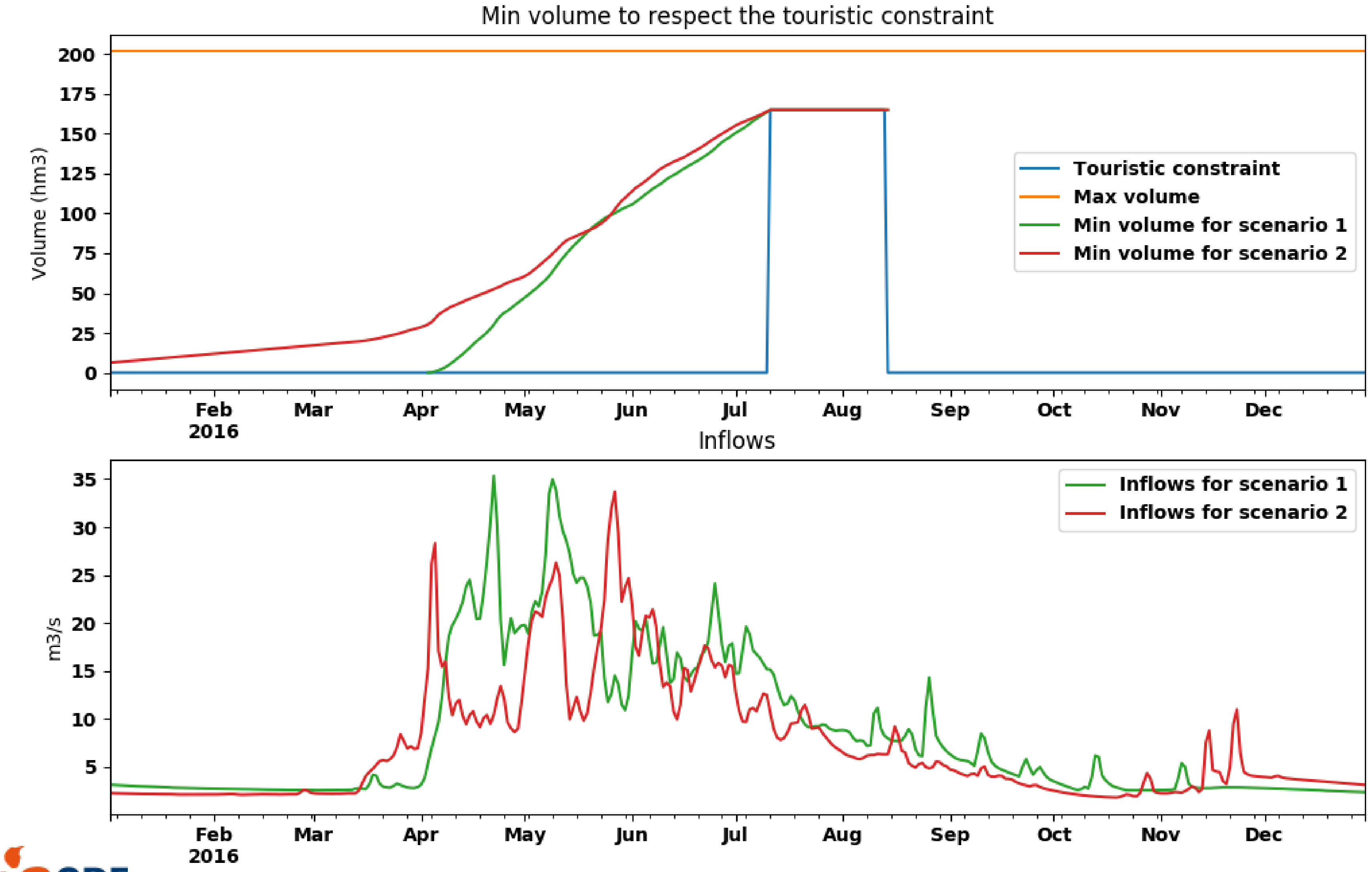
Respect of probabilistic constraints for one reservoir



Backward recursion

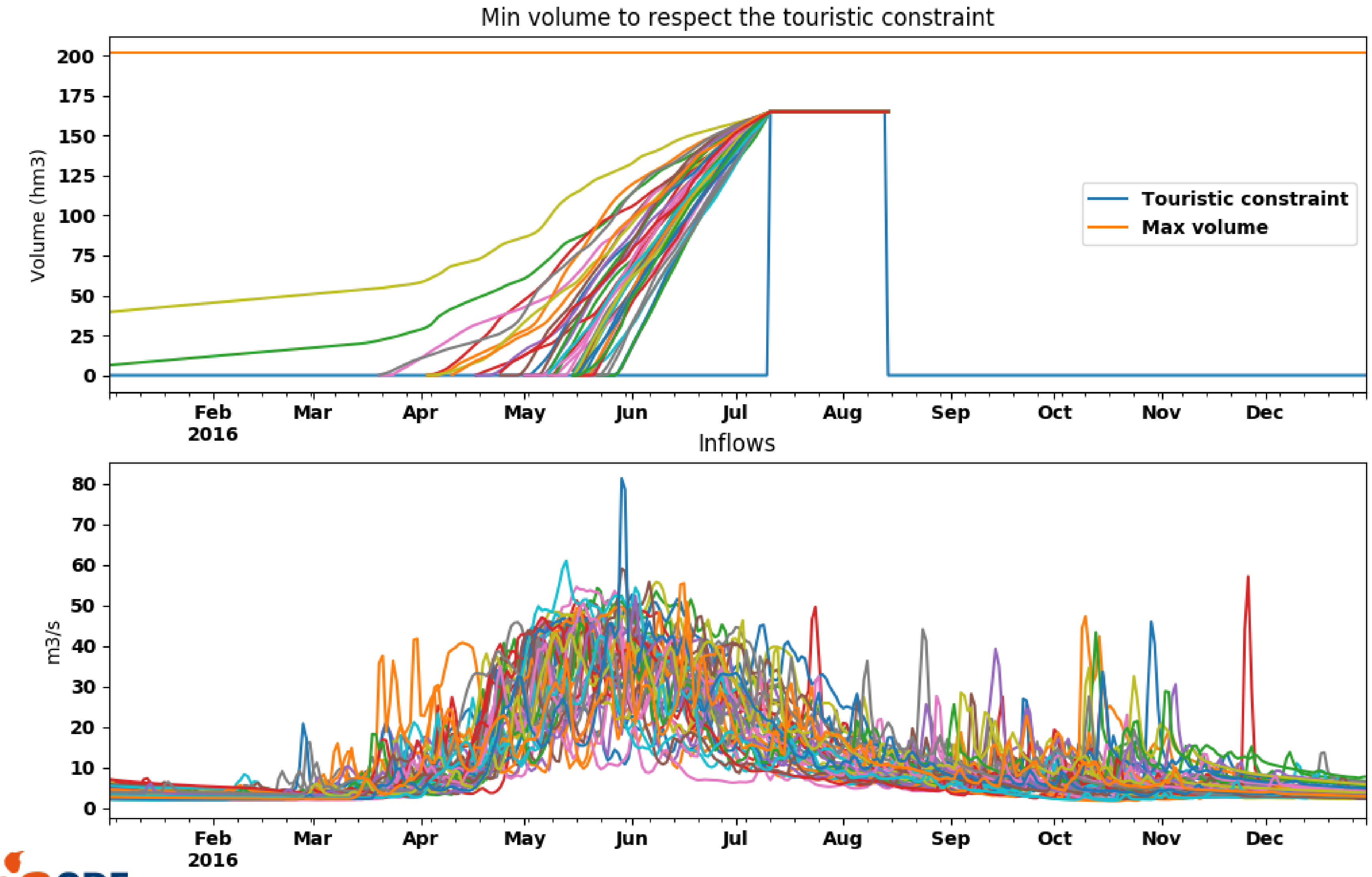
Objective: min $volume_0^{T-2}$
With constraints • Valley constraints • $volume_{end}^{T-2} \geq volume{*}_0^{T-1}$

Respect of probabilistic constraints for one reservoir



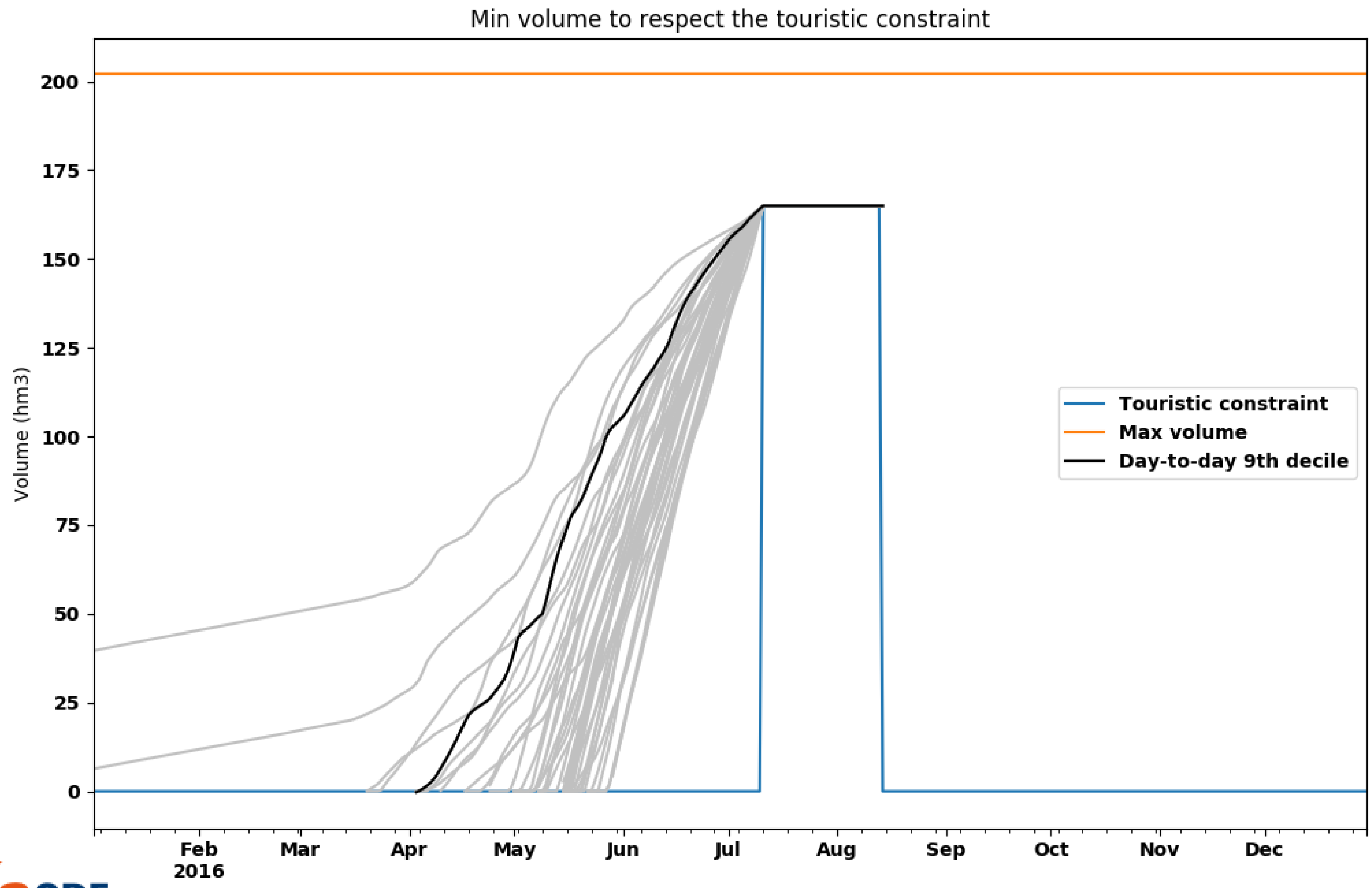
Compute for inflows scenario 2

Respect of probabilistic constraints for one reservoir



Compute for all inflows scenarios

Respect of probabilistic constraints for one reservoir



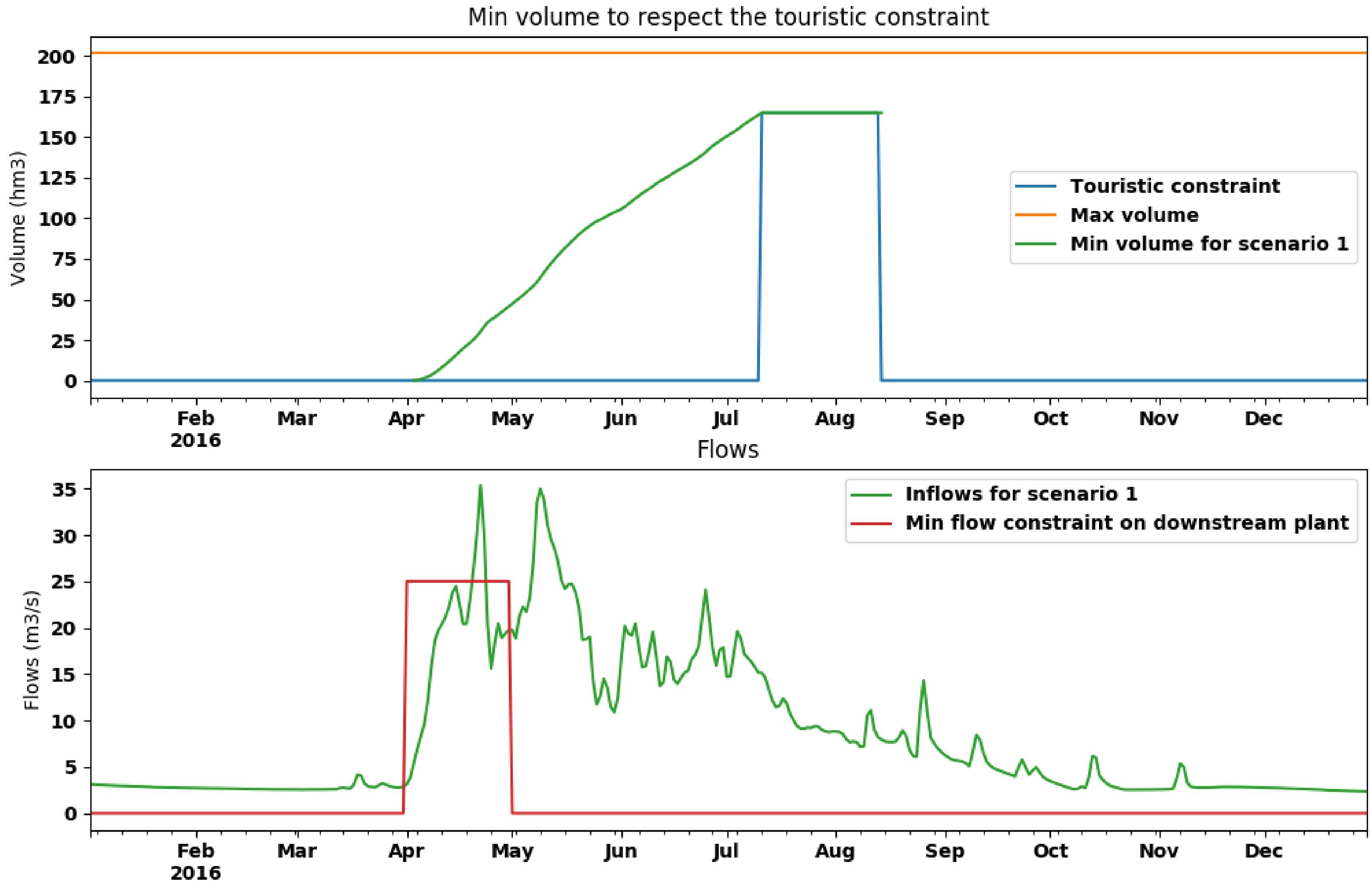
Day-to-day quantile selection

- N inflow scenarios
- Constraint probability p
- Exclude the n most constraining scenarios
- $n = (1 - p) * N$

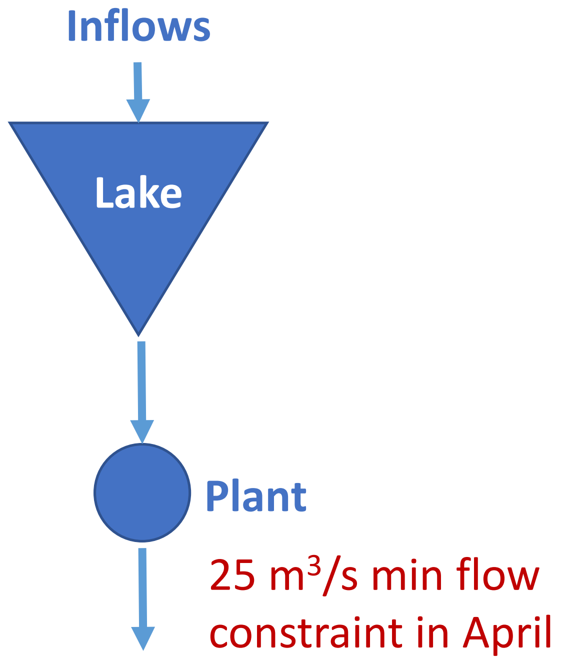
In this example:

- Constraint probability = 90%

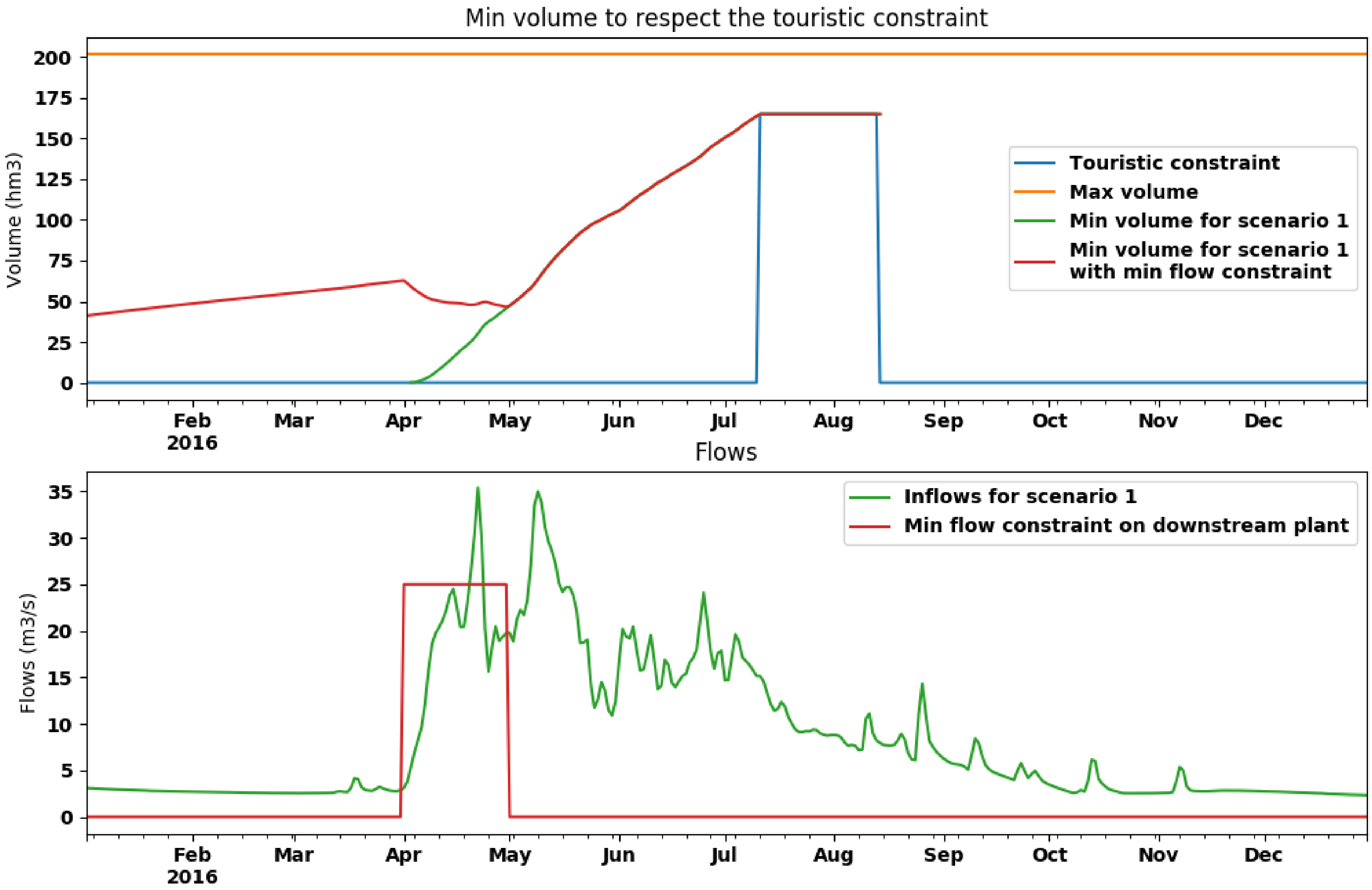
Respect of probabilistic constraints for one reservoir



Using linear problem allows to take into account all the constraints in the valley



Respect of probabilistic constraints for one reservoir



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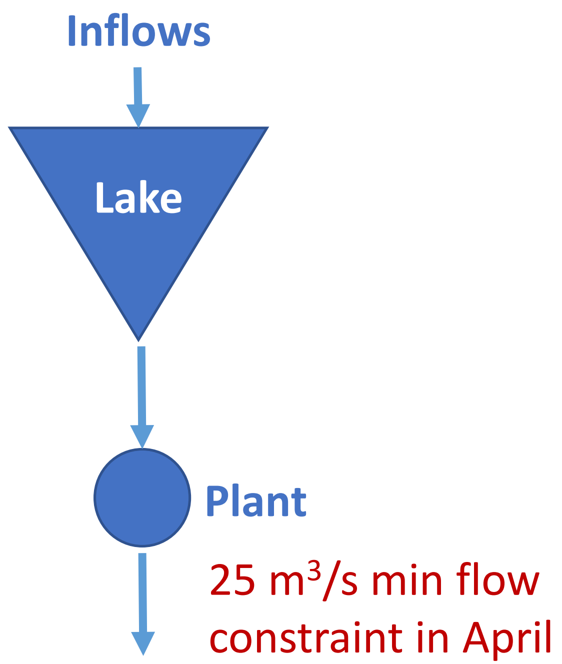
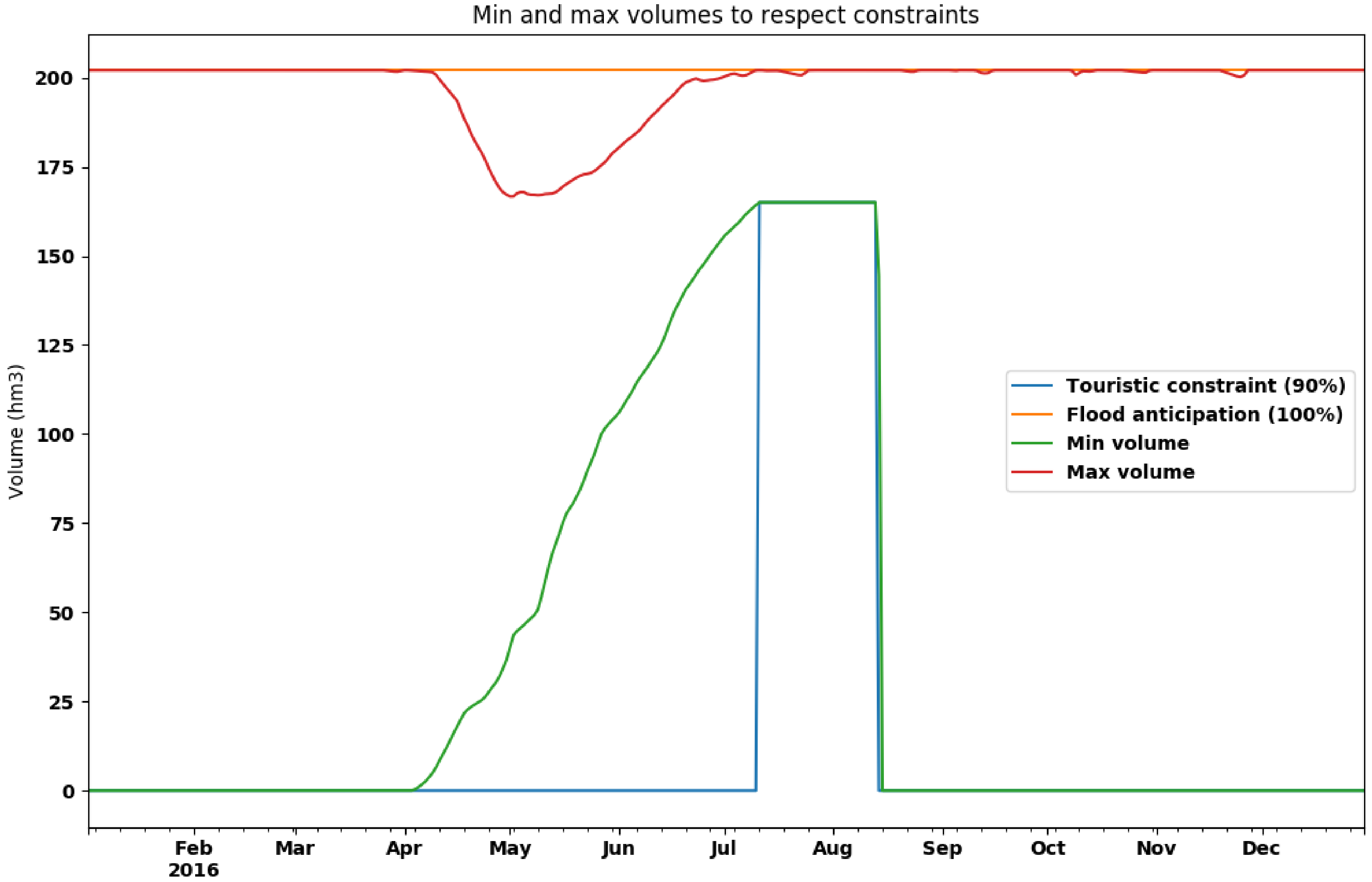


Respect of probabilistic constraints for one reservoir



Volume corridor within which economic stochastic optimization is applied.

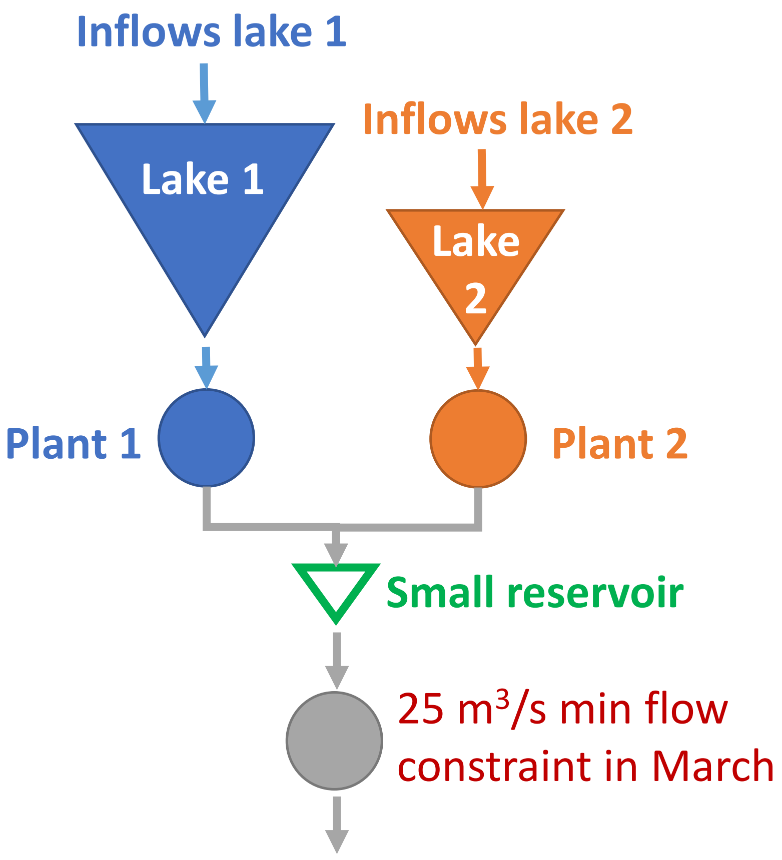
Important mid-term guides to define the hydraulic operations

Separate constraints respect from economic management.

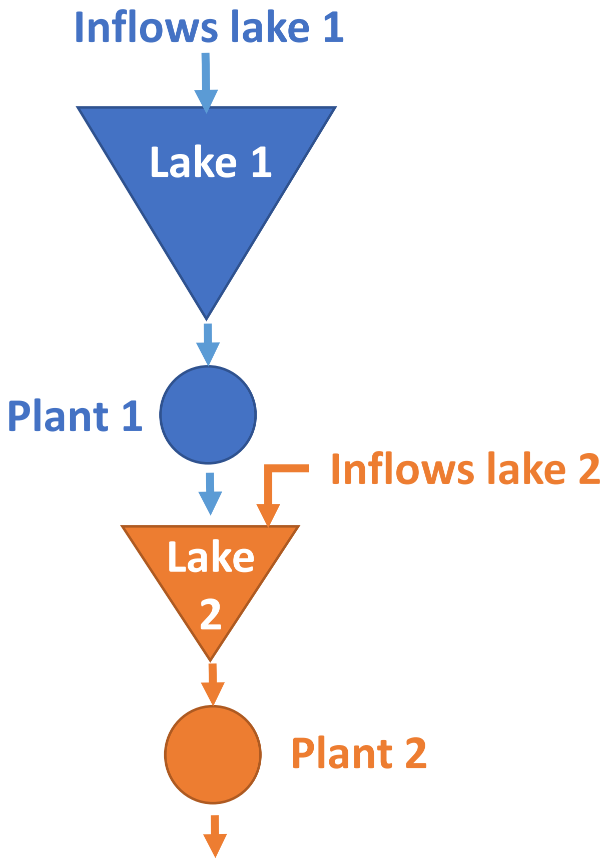
An alternative to chance-constrained programming?

Joint respect of probabilistic constraints for two reservoirs

Joint respect of probabilistic constraints for two reservoirs



Which lake should provide the water to ensure the min flow?



How to best ensure flood control on both lakes?

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Patrice Dhumes

Joint respect of probabilistic constraints for two reservoirs

Idea: add the second lake in the linear problem

Objective: $\min[\text{volume } 1_0^T + \text{volume } 2_0^T]$

With constraints

- Valley constraints
- $\text{volume } 1_{end}^T \geq \text{constraint lake } 1$
- $\text{volume } 2_{end}^T \geq \text{constraint lake } 2$

Problem: several equivalent solutions are possible!

Joint respect of probabilistic constraints for two reservoirs

Solve two problems with a discriminating objective

Objective: $\min[10 * volume\ 1_0^T + volume\ 2_0^T]$

With constraints
- Valley constraints
- $volume\ 1_{end}^T \geq \text{constraint lake 1}$
- $volume\ 2_{end}^T \geq \text{constraint lake 2}$

Solution 1 lake 1
Solution 1 lake 2

Objective: $\min[volume\ 1_0^T + 10 * volume\ 2_0^T]$

With constraints
- Valley constraints
- $volume\ 1_{end}^T \geq \text{constraint lake 1}$
- $volume\ 2_{end}^T \geq \text{constraint lake 2}$

Solution 2 lake 1
Solution 2 lake 2

Combine the solution with coefficients $c1$ and $c2$ $(c1 + c2 = 1)$
- Solution lake 1 = $c1$ $*$ Solution 1 lake 1 $+$ $c2$ $*$ Solution 2 lake 1
- Solution lake 2 = $c1$ $*$ Solution 1 lake 2 $+$ $c2$ $*$ Solution 2 lake 2

A few references

- J. L. Mariën (1984), Controllability Conditions for Reservoir Flood Control Systems with Applications, *Water Resources Research, Vol. 20, N°11- November 1984*

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- André Turgeon (2005), Daily Operation of Reservoir Subject to Yearly Probabilistic Constraints*, Journal of Water Resources Planning and Management Volume 131 Issue 5 - September 2005*

Questions?
Thank you!

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