Simple Reservoir Simulation Problem, and Different Optimization models

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This example is based on the same problem formulation as the model#1, but considers that case of a water scarce situation, where not all demands (Ds) can be always met, and need to be prioritized.

MODEL 2: MINIMUM SHORTAGES (or max water available) WITH PRIORITIZED RELEASES

In real life, there might not be enough water to cover all Ds. In such cases, water managers are forced to prioritize the releases for each use. Here let's assume that the priorities to meet the demands are:

$D_{u,t}$: Priority 1. This is the first one to serve with as much water necessary to cover it. If there is less water, then all releases will be equal to $R_{u,t}$, while $R_{irr,t} = R_{hydro,t} = 0$.

So, $R_{u,t} = D_{u,t}$, and the rest of the water i.e. $S_t - R_{u,t}$, will be allocated to the next priorities (agriculture and hydropower) as follows:

$D_{irr,t}$: Priority 2. This is the second one to serve, depending on the water availability. At a minimum we want to cover the 40% of this demand in t=6, t=7, t=8. (Irrigation for the dry summer months).

$$R_{irr,t} = the\ remaining\ water\ after\ covering\ R_{u,t}, which\ is\ \leq D_{irr,t}$$

$D_{hydro,t}$: Priority 3. This is the third one to serve (after urban and hydropower), depending on the water availability. Otherwise, $R_{hydro,t} = 0$.

The results of the script show the reservoir storage and releases per use for each month of the simulation period, and the respective plots.

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In such a problem setup, the solutions might 'force' the storage to be as 'maximum as possible', at the expense of potential releases for agriculture or hydropower (in this case just at the expense of hydropower, since there is enough water available for irrigation). This leads us to another way to approach this problem: to serve the users (urban, agriculture, hydropower) in order to cover their needs and generate economic benefits from food and electricity, rather than trying to maximize the storage.

This approach aims to maximize releases under stricter constraints (less water available to show the 'competition' among users) – Model #3 below.

MODEL 3: MAXIMUM RELEASES WITH PRIORITIES

Variables:

- S_t: Storage in the reservoir at time t. The amount of water stored in the reservoir.
- I_t: Inflows into the reservoir at time t. The amount of water flowing into the reservoir (from all sources, such as Precipitation, river or other inflows). Indicative data for the sake of the example:

t=1 (JAN) = 3,000,000

t=2 (FEB) = 2,900,000

t=3 (MAR) = 2,700,000

t=4 (APR) = 2,600,000

t=5 (MAY) = 2,000,000

t=6 (JUN) = 1,000,000

t=7 (JUL) = 1,00,000

t=8 (AUG) = 900,000

t=9 (SEP) = 1,500,000

t=10 (OCT) = 1,800,000

t=11 (NOV) = 2,000,000

t=12 (DEC) = 2,500,000

- O_t: Outflows from the reservoir at time t. The total outflow from the reservoir, including spills and losses from evaporation or other unmanaged outflows. Indicative data for the sake of the example:

t=1 (JAN) = 250,000

t=2 (FEB) = 250,000

t=3 (MAR) = 250,000

t=4 (APR) = 500,000

t=5 (MAY) = 500,000

t=6 (JUN) = 500,000

t=7 (JUL) = 500,000

t=8 (AUG) = 500,000

t=9 (SEP) = 500,000

t=10 (OCT) = 250,000

t=11 (NOV) = 250,000

t=12 (DEC) = 250,000

Decision Variables:

Releases (R): The amount of water released from the reservoir to meet the demands of three uses: urban, agricultural, and hydropower.

- $R_{u,t}$: Releases for urban use at time t.
- $R_{irr,t}$: Releases for agricultural use at time t.
- $R_{hydro,t}$: Releases for hydropower use at time t.

Parameters (indicative data for the sake of the example)**:**

- K: Reservoir capacity (maximum storage). K = 100,000,000 m3
- S_0: Initial storage in the reservoir at t=0. $S_0 =$ 5,000,000 m3
- S_{min}: Minimum required storage in the reservoir for safety. $S_{min} = 2{,}000{,}000$
- $D_{u,t}$: Urban demand at time t. Data as follows:

t=1 (JAN) = 1,100,000

t=2 (FEB) =1,100,000

t=3 (MAR) =1,100,000

t=4 (APR) =1,200,000

t=5 (MAY) =1,500,000

t=6 (JUN) =1,700,000

t=7 (JUL) =1,800,000

t=8 (AUG) =1,700,000

t=9 (SEP) =1,200,000

t=10 (OCT) =1,100,000

t=11 (NOV) =1,100,000

t=12 (DEC) =1,100,000

- $D_{irr,t}$: Agricultural demand at time t. Data as follows:

t=1 (JAN) = 1,500,000

t=2 (FEB) = 1,500,000

t=3 (MAR) = 2,000,000

t=4 (APR) = 3,500,000

t=5 (MAY) = 5,200,000

t=6 (JUN) = 5,800,000

t=7 (JUL) = 6,200,000

t=8 (AUG) = 6,000,000

t=9 (SEP) = 4,500,000

t=10 (OCT) = 1,500,000

t=11 (NOV) = 1,500,000

t=12 (DEC) = 1,500,000

- $D_{hydro,t}$: Hydropower demand at time t. Data as follows:

t=1 (JAN) = 900,000

t=2 (FEB) = 900,000

t=3 (MAR) = 900,000

t=4 (APR) = 900,000

t=5 (MAY) = 900,000

t=6 (JUN) = 900,000

t=7 (JUL) = 900,000

t=8 (AUG) = 900,000

t=9 (SEP) = 900,000

t=10 (OCT) = 900,000

t=11 (NOV) = 900,000

t=12 (DEC) = 900,000

Objective: Maximize the releases to serve each user.

Objective Function: $Zmax = \sum_{t}^{T=12}(R_{u,t} + R_{irr,t} + R_{hydro,t})$

Constraints:

1. Storage balance equation: $S_t = S_{t-1} + I_t - O_t$, for all t.
2. Storage capacity constraint: $S_{min} \leq S_t \leq K$, for all t.
3. Release constraints (prioritized – such priorities can be set also with stakeholders):

Priority 1: Urban Demand:
- The model ensures that the release for urban use $R_{u,t}$ is equal to the urban demand $D_{u,t}$ (to meet this demand always first).

$R_{u,t} = D_{u,t}$, for all t.

If there is not enough water at month t to cover all the urban demand, then still all releases will go to the urban demand: $R_{u,t} \leq D_{u,t}$

Priority 2: Agricultural Demand:

The rest of the water RW1[t] will be released for agricultural $R_{irr,t}$ and hydropower $R_{hydro,t}$ at time t.

The rest of the water is $RW1_t = S_t - R_{u,t}$, for all t.

This means that if there enough water available, the priority is given to fulfilling the urban demand, and secondly the agricultural, and thirdly the hydropower. If there is no water available, the agricultural and hydropower releases are set to zero.

If after satisfying the urban demand, there is water available (RW1[t] > 0), then it will be released to serve the agricultural use, fully or just partially per each t.

$RW1_t = R_{irr,t} \leq D_{irr,t}$, for all t.

Priority 3: Hydropower Demand:

If after satisfying the urban and agricultural demands, there is still water available (RW2[t]), it can be released to meet the hydropower demand, fully or just partially per each t.

$RW2_t = S_t - R_{u,t} - R_{irr,t}$, for all t.
If $RW2_t > 0$, then $RW2_t = R_{hydro,t} \leq D_{hydro,t}$, for all t.

The results of the model show the optimized storage, and the optimized releases over time.

If there is not enough water to cover the demands and the minimum storage constraint cannot be satisfied, the model prints “No optimal solution!”.