Matlab Project – Part 2

PROJECT OBJECTIVE

- Optimal Allocation of Water Resources via Simulation and Optimization

The objective of the second assignment is to introduce the students to the concepts of water resources allocation. The assignment aims at optimizing the operation of Lake Como in Northern Italy targeting flood protection to the city of Como located on the lake shores, downstream deficit (relative to agricultural district and hydropower plants) minimization, and low-level prevention (see Figure 1).

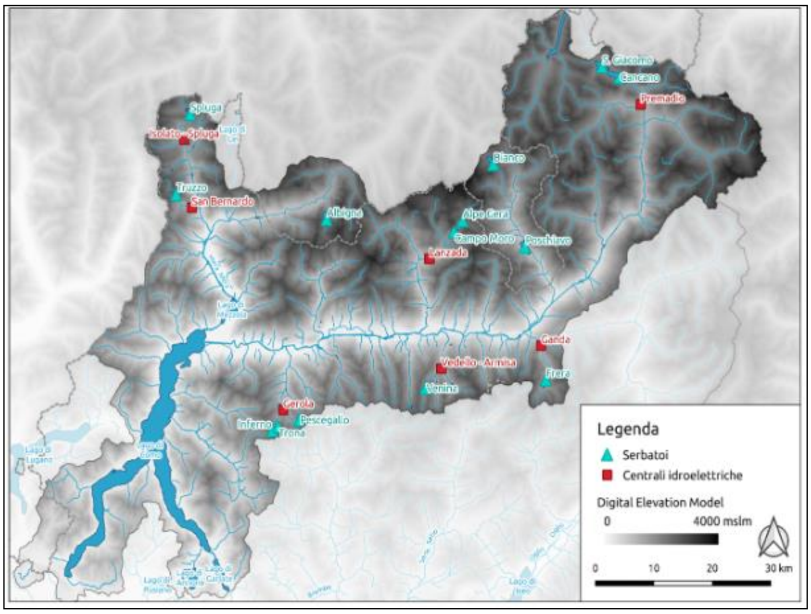

Figure 1: Map of the Adda River basin.

AVAILABLE DATA AND MATERIAL

Mean daily net inflow time series to the lake, q_{t+1}, is provided in [m^3/s] for a period of 11 years (i.e. 1.1.2009-31.12.2019) as a .txt file in the "data" folder in the course page on WeBeep. The model of the system and the optimization algorithm – NSGAII – along with an exemplary MATLAB script are also provided except for few functions to be implemented by the students as described below.

ASSIGNMENT DESCRIPTION

A reference policy for Lake Como management is currently operated for downstream deficit minimization, low-level prevention and flood protection to the city of Como (see Figure 1) using the "standard operating policy", i.e. a piecewise linear function mapping the lake level into dam's release, illustrated by the red line in Figure 2. The policy is constrained by the maximum and minimum release functions, which also depend on the lake level (see dashed and dotted lines in Figure 2): if the level is below -0.4 [m], all dam's gates must be closed; if the level is above 1.1 [m], spillways are automatically opened.

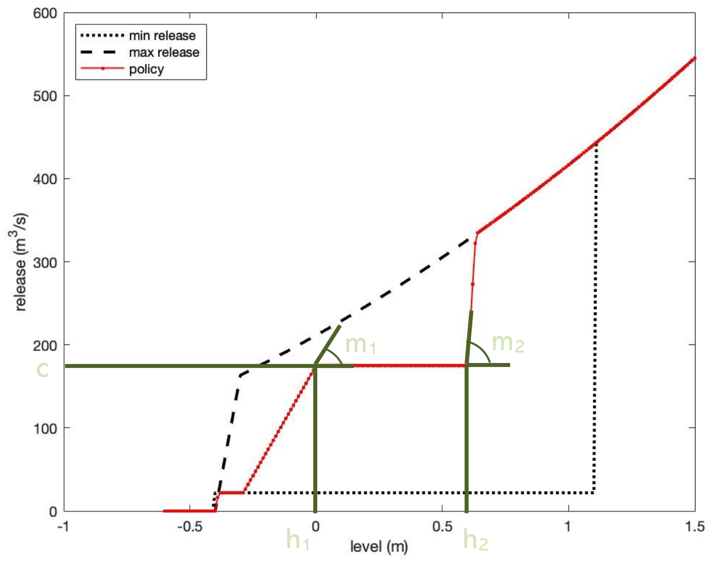

Figure 2: Lake Como standard operating policy.

The parameter values defining the current standard operating policy in Figure 2 are reported in Table 1.

Table 1: Parameter values of the current standard operating policy.

Parameter	Description	Value	Units
h_1	Low reservoir level	0	[m]
h_2	High reservoir level	0.6	[m]
c	Constant release	175	[m^3/s]
m_1	Slope for low level	530	[m^2/s]
m_2	Slope for high level	4900	[m^2/s]

The objective functions of the three operating objectives (i.e. flood control, low-level prevention and downstream deficit minimization) can be formalised as follows:

- Flood control (number of days per year with an exceedance of the flooding threshold):

$$J^{flo} = \frac{1}{N_y}\sum_{t=1}^{H} \Gamma\,(h_t > h^F) \tag{1}$$

where N_y is the number of years of the simulation horizon and:

$$\Gamma(h_t > h^F) = \begin{cases} 1 & if\ h_t > h^F \\ 0 & otherwise \end{cases}$$

- Low level prevention (number of days per year with lake level below low-level threshold):

$$J^{low} = \frac{1}{N_y}\sum_{t=1}^{H} \Gamma\,(h_t < h^L) \tag{2}$$

where N_y is the number of years of the simulation horizon and:

$$\Gamma(h_t < h^L) = \begin{cases} 1 & if\ h_t < h^L \\ 0 & otherwise \end{cases}$$

- Downstream deficit minimization:

$$J^{deficit} = \frac{1}{H}\sum_{t=1}^{H}(w-r)^n \quad (3)$$

where:

$$\text{n} = \begin{cases} 2 & if\ 91 \leq doy \geq 283 \\ 1 & otherwise \end{cases}$$

doy = 91 corresponds to the 1st of April

doy = 283 corresponds to the 10th of October

All variables are listed and described in Table 2.

Table 2: Variables and parameter values for the computation eqs. (1), (2) and (3).

Variable	Description	Value/Units
h_t	Reservoir level at time *t*	[m]
r_{t+1}	Reservoir release in [t ; t+1]	[m³/s]
H	Length of the simulation horizon	[d]
h^F	Flood threshold	1.1 [m]
h^L	Low-level threshold	- 0.2 [m]
w_t	Total water demand in [t ; t+1] (irrigation + hydropower)	[m³/s]

ASSIGNMENT TASKS

1. Current Performance Quantification

Implement the function[1] 'std_operating_policy.m' that, given a value of reservoir level h_t and a structure *policy* containing the parameters *(h_1, h_2, m_1, m_2, c)* computes the release according to the policy illustrated in Figure 2.

Assuming that the reservoir level at the beginning of the simulation period is equal to $h_0 = 0.71\ [m]$, simulate the reservoir operation (i.e. reservoir level, release decision, release) over the horizon 2009-2019 according to the current control policy using the provided function 'simComo.m'[2].

Plot the current control policy in the space level-release (exploring reservoir levels from -0.6 to 1.5 [m]) and the simulated time series of simulated reservoir level, release decision and

[1] Use the script partially provided.
[2] Use the function provided.

release. What is the current performance in the three operating objectives described in equations 1, 2 and 3[3]?

2. Optimization via Evolutionary Multi-Objective Direct Policy Search

Optimize the parameters of the Standard Operating Policy by using the NSGAII algorithm[4] implemented in the Matlab function[5] 'evaluate_objective.m' along with the other functions in the NSGA2 sub-folder to generate a Pareto approximate set of Lake Como policies, i.e. by solving the optimal control problem formulated below using the Evolutionary Multi-Objective Direct Policy Search method[6]:

$$\theta^* = \arg\min_{\theta} \mathbf{J} = |J^{low}, J^{flo}, J^{def}|$$

subject to

$$s_{t+1} = s_t + n_{t+1} - r_{t+1}$$
$$r_{t+1} = f(h_t, u_t, n_{t+1})$$
$$h_t = f(s_t)$$
$$u_t = p(h_t, \theta)$$
$$\{n_{t+1}\} \text{ given } \forall t = 0, \dots, H$$
$$h_0 \text{ given}$$

Visualize the Pareto front of the initial and final populations. Add to the plot the performance of the current operating policy.

Explore the trade-off between flood protection, low level prevention and downstream deficit minimization by selecting few interesting solutions (e.g., best flooding, best deficit, best low level, one compromise policy) and visualizing the policy along with the simulated trajectories of reservoir level and release.

Note that it is possible to extend the analysis to a more complex policy. For instance, nonlinear structures and more input variables[7] can be considered. However, this is **not mandatory** and does not prevent to obtain a full mark for the report. Selecting a different functional form of the control policy could imply the need to change also other part of the code, such as 'simComo.m'.

The dataset provided (2009-2019) does not have to be necessarily used entirely for the training phase. Part of it can be reserved for the validation phase (**not mandatory**). For the contest, however, the optimal policies parameters must be computed considering the entire dataset.

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[3] Use the three scripts partially provided ('g_deficit.m', 'g_flood.m' and 'g_low_level.m').
[4] Deb, K., Pratap, A., Agarwal, S., and Meyarivan, T.A.M.T. (2002). A fast and elitist multiobjective genetic algorithm: NSGA-II. *IEEE transactions on evolutionary computation*, 6(2), 182-197.
[5] Use the script partially provided.
[6] Giuliani, M., J. Quinn, J. Herman, A. Castelletti, and P. Reed (2018), Scalable multi-objective control for large scale water resources systems under uncertainty, *IEEE Transactions on Control Systems Technology*, 26(4), 1492-1499.
[7] The input values have to be known at time *t*, when the decision u_t is taken.

DEADLINES

- The code[8] for contest participation must be submitted **by 04.06.2023 (23:59)**. Students participating in the contest will be required to give a short presentation of the approach they adopted and the obtained results (**08.06.2023**).
- In order to have the final mark registered in a given session, the assignment must be submitted **by the date of the written exam** of that session in the form of a short report (max. 10 pages). A folder with scripts, functions and datasets used have to be submitted as well. The solution procedure should be described in detail (step by step) and the results should be illustrated and interpreted (the developed scripts should be provided as well). Students should justify any assumptions as well as the solution approach.

[8] The folder must contain all the scripts, functions and dataset used. Relative paths have to be properly set. Incomplete submissions and codes that do not run due to errors will be not be evaluated.