ESTIMATION OF THE OPTIMAL GUIDE CURVE FOR A RESERVOIR, CASE STUDY COPA DAM, BOYACÁ

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INTRODUCTION

2011 Flooding Conditions Downstream La Copa Dam

ESTIMATION OF THE OPTIMAL GUIDE CURVE FOR A RESERVOIR, CASE STUDY COPA DAM, BOYACÁ

The objective of the study is the understanding of the guide curve calculation for the reservoir management releases in order to improve the storage usage which can be used for multi-objective purposes.

La Copa reservoir, located in the upper Chicamocha river basin in Colombia was originally built with the objective of mitigating floods over the valley. An irrigation district was latter established, with the objective of supplying water to farmers.

This study presents the analysis and optimization of operational rules to minimize the likelihood of floods and shortages for the irrigation district considering the uncertainty in the hydrological system.

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GENERAL LOCATION

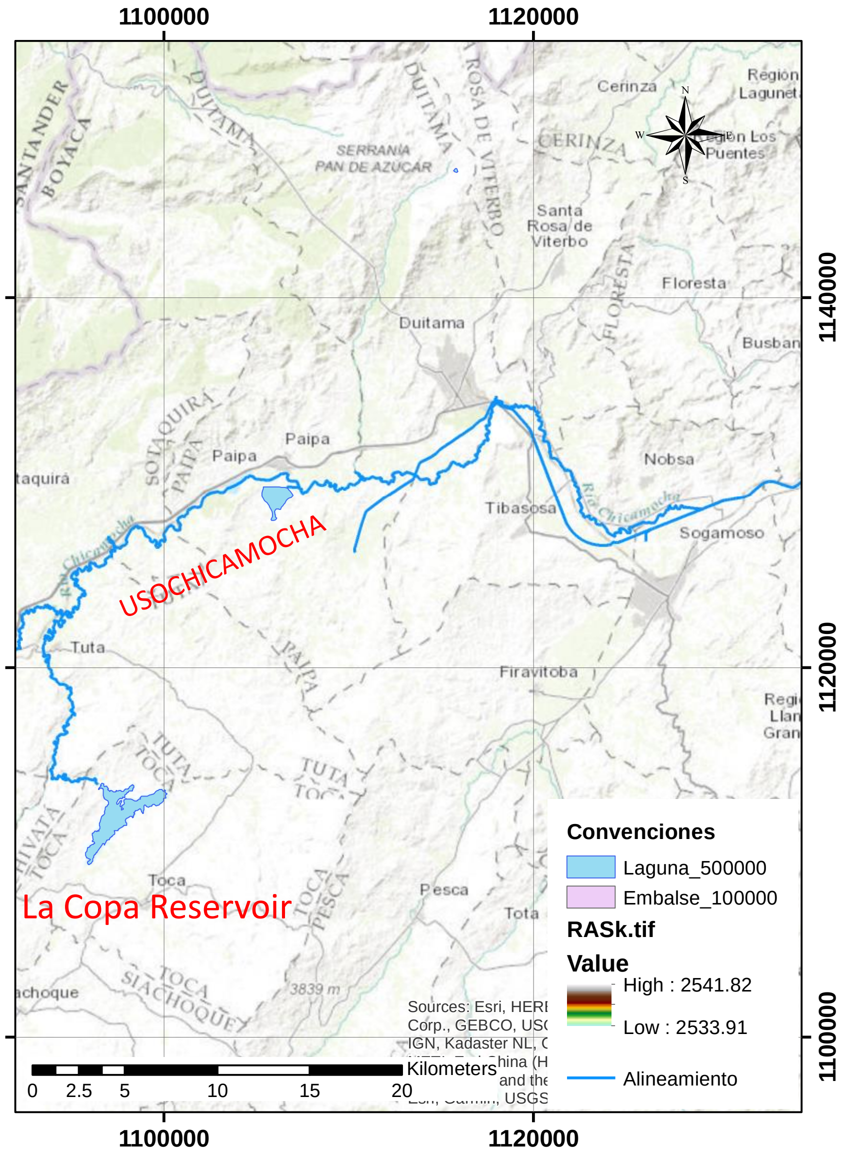
Located in Boyacá - Colombia, La Copa reservoir was built in 1993 to supply the demands of USOCHICAMOCHA irrigation system in the Chicamocha river basin.

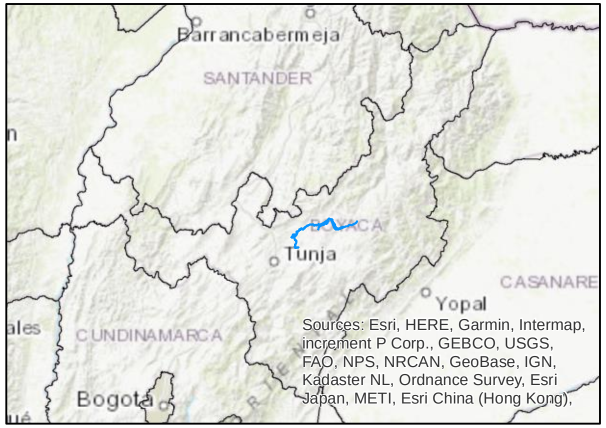
Total Storage: 70 Hm3

Inundation Area: 326 Km2

Storage for irrigation: 34.5 Hm3

Storage for flooding: 5 Hm3





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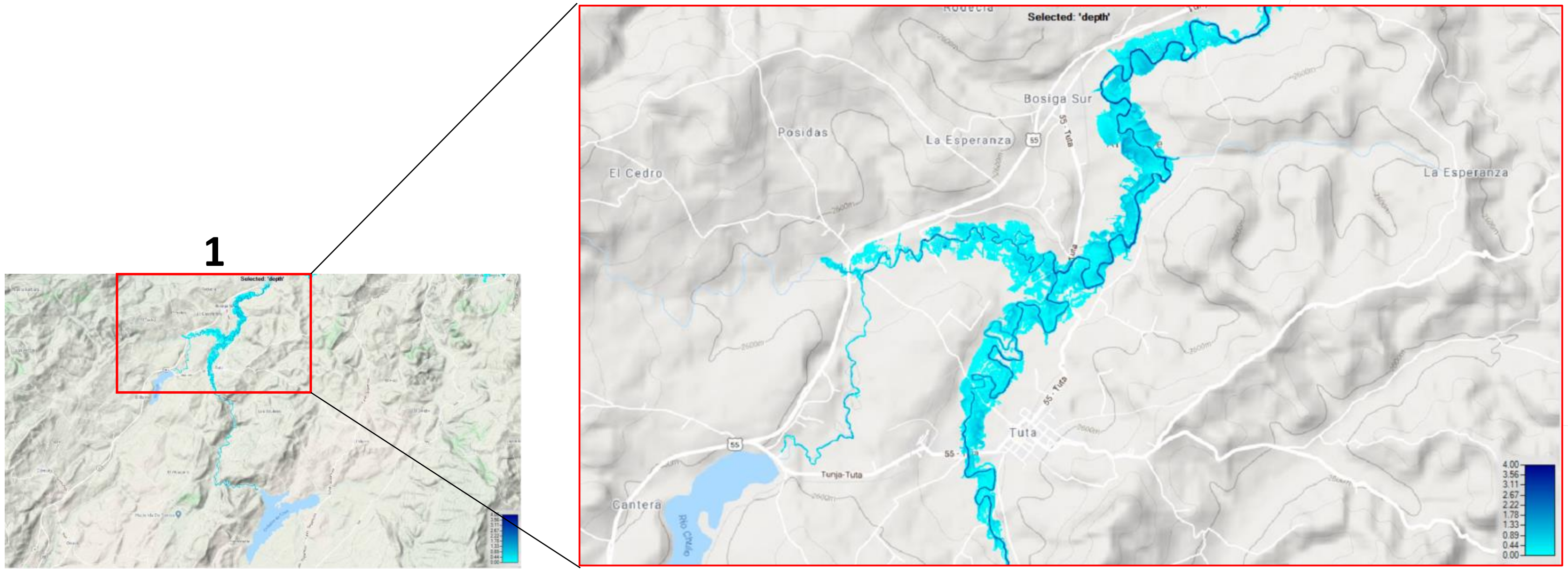
PROBLEM DESCRIPTION

1. **Flooding Boundary 2011 year**
2. **Dam Release (Howell Bunger Valves)**
3. **Detail Dam Embankment**
4. **General View Boundary Reservoir Extent**

1



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PROBLEM DESCRIPTION

Operation of a reservoir must address one or more objectives, those are mainly related to flood control and water supply. While flood control objective requires the most storage capacity available in the reservoir for high runoff volumes, water supply objective requires the reservoir to be as full as possible in order to provide the water demands.

Thus, a methodology was developed aimed to find and optimized guide curve taking into account both flood control and water supply objectives.

Trough a case study, a reservoir simulation model was constructed for a either a critical wet year and a critical dry year. In order to select the appropriate set point for the case study, a set of methodologies where tested and compared.

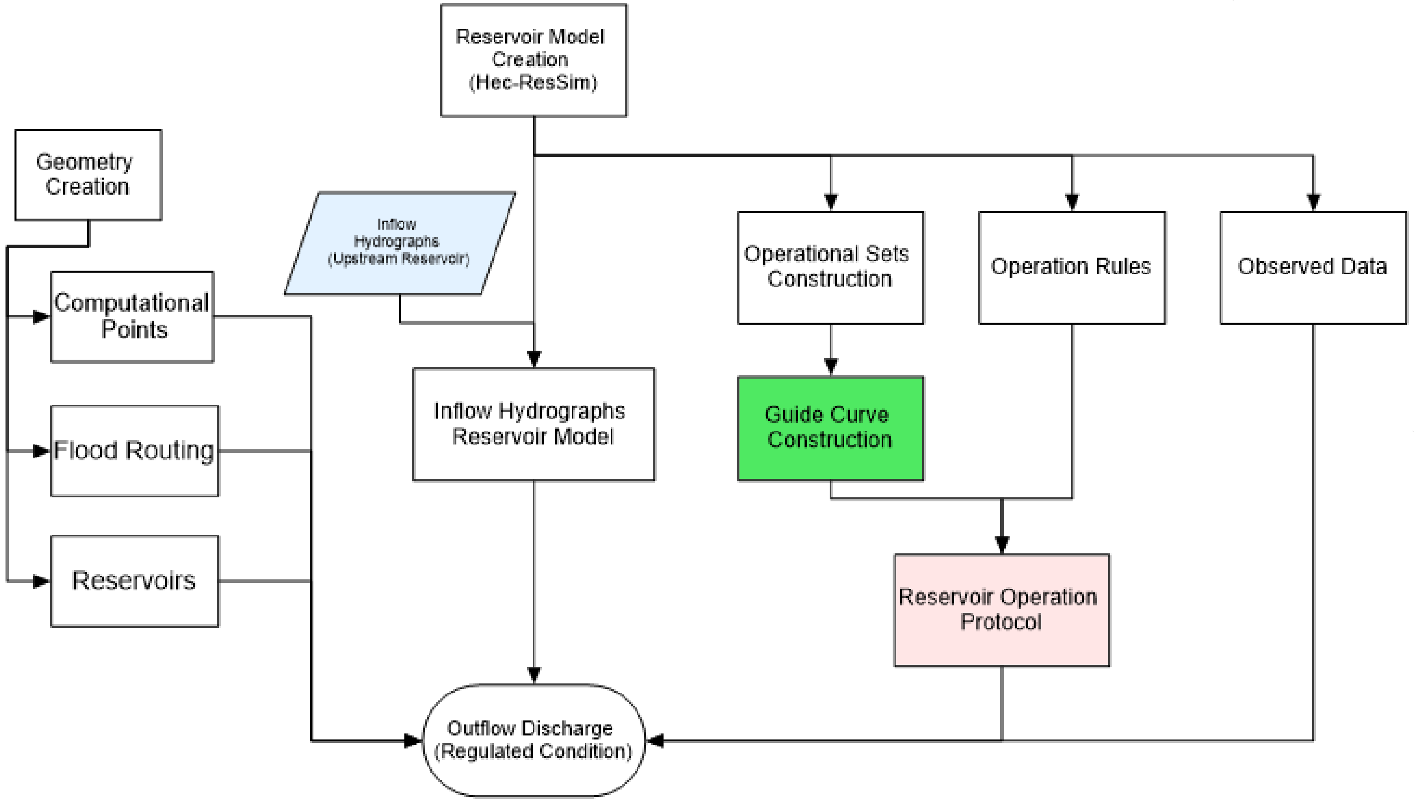
The releases calculated by the decision scheme for the suitable set point were hydrodynamically modelled downstream to validate the reduction of the flood risks for the wet year.

PROBLEM DESCRIPTION

Guide curve is the Setpoint to be reached by the decision scheme at any time step of the simulation period.

Operation rules are the constraints in the simulation model e.g (*full bank discharge downstream*)

Basin partially instrumented, a daily inflow discharges are constructed using semi-distributed model.



Flow Chart of the Operational Water Management Simulation in the Reservoir

COMPONENTS IN THE OPTIMIZATION PROBLEM

- **Objective Function:** Minimize the sum of the excess and shortage volumes expected in the year.

$$\mathrm{OF} = min\ (V_{excess} + V_{shortage})$$

- **Decision Variables:** For the case study are the releases from the dam

- **Constraints:** Physical and environmental restrictive conditions for the variables in the reservoir:
  - *Operational Zone*: Maximum and minimum water levels
  - *Bankfull Discharges:* Maximum downstream flows before flooding
  - *Minimum Discharge*: Echological flow in the stream

- **Setpoint as a guide curve:** Calculated by using different methodologies

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DECISION SCHEMES MODELLED

- DS based in the comparison of guide curve level (setpoint) from the actual month with respect to the reservoir level at end of the precedent month.
- DS based in the comparison of guide curve level (setpoint) from the actual month with respect to the reservoir level at the beginning of the precedent month.
- DS for the reservoir water level prediction at the end of the actual month by using both maximum release and the maximum bankfull discharge downstream.

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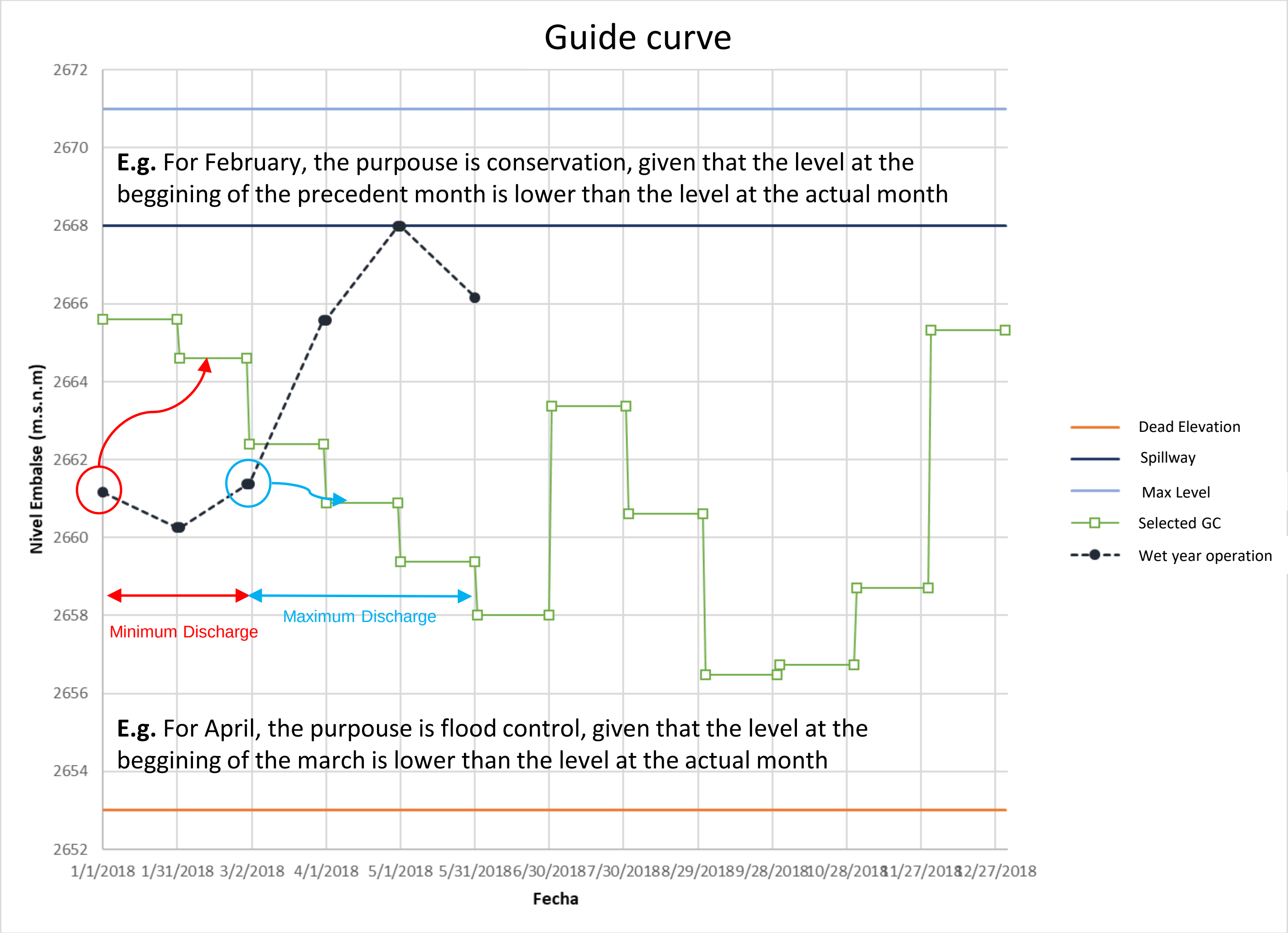

Decision Scheme for Maximum Discharges in Hec-ResSim

PHYSICAL PROCESSES MODELLED

The dam inflow daily discharges were calculated with an Hec-Hms hydrological model.

The reservoir operation was simulated with HecResSim model.

The downstream river condition for the managed releases was tested with Hec-Ras 2D

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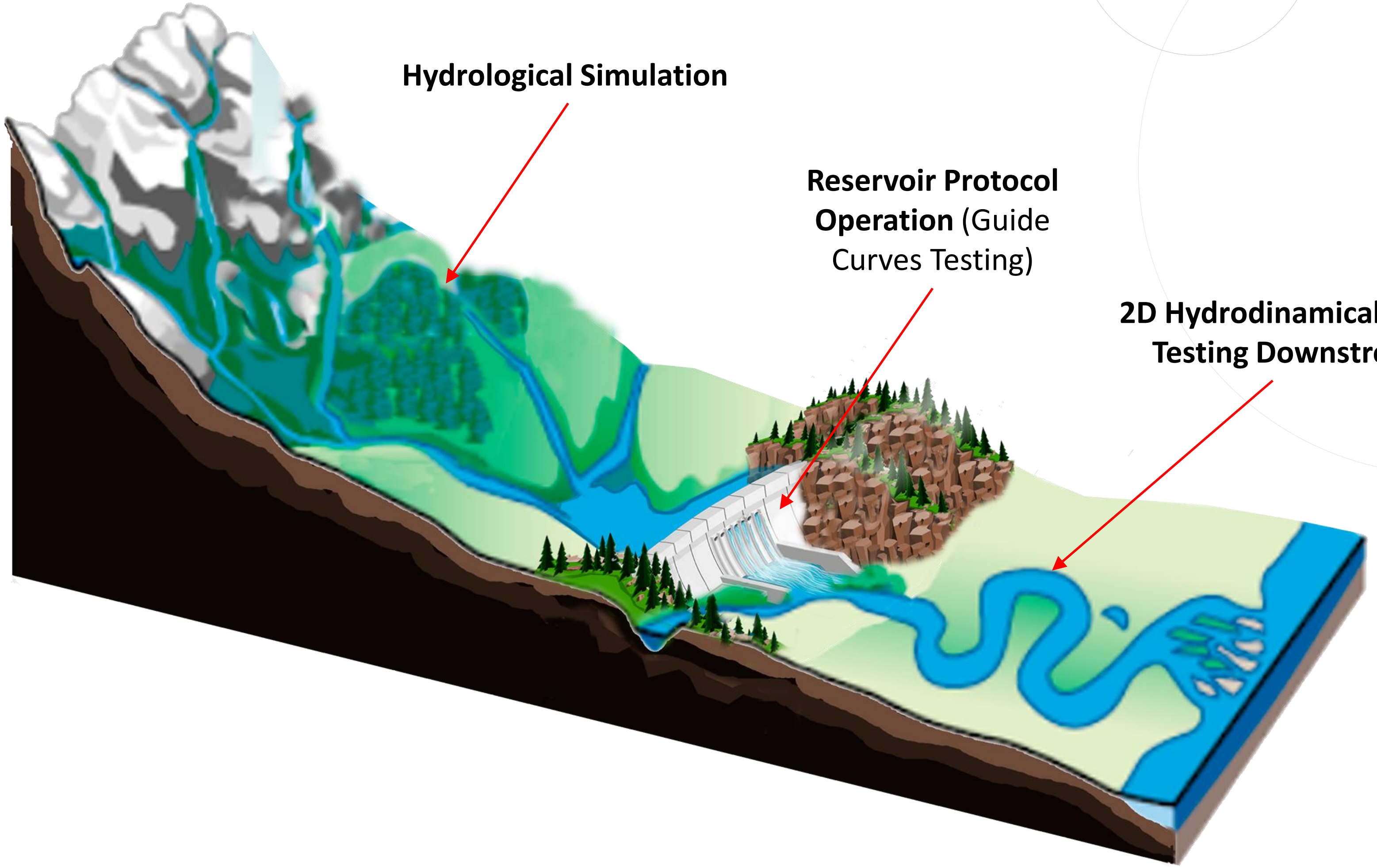


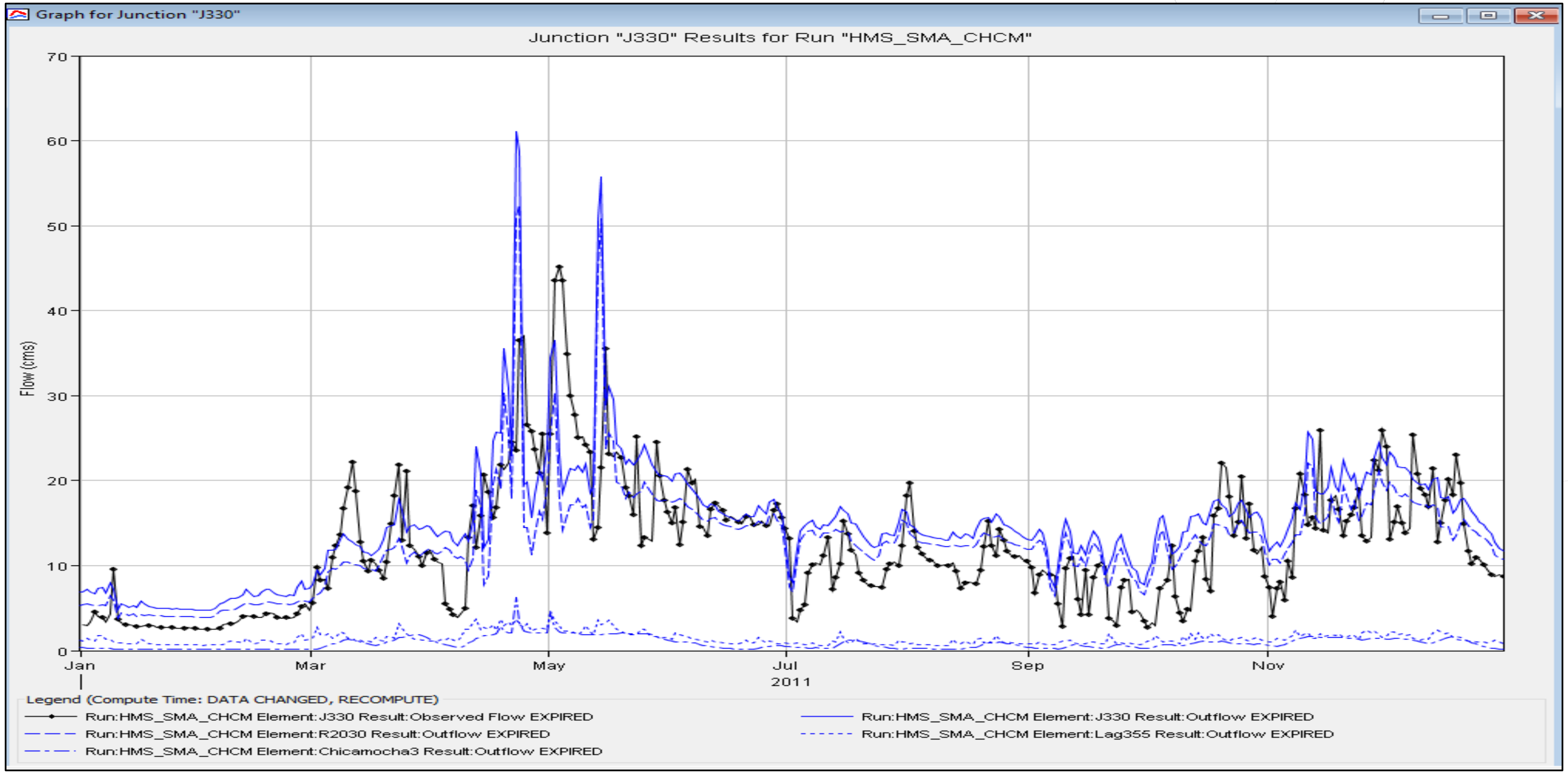
Adapted From Stream Corridor Restoration, 2001.

HYDROLOGIC MODELLING

A continuous semi-distributed hydrological model was created for the basin in the year 2011, which was an abnormal rainy.

SMA (Soil Moisture Accounting) loss methodology was selected.

The model was calibrated with daily discharge measurements.



La Reforma Discharge Station

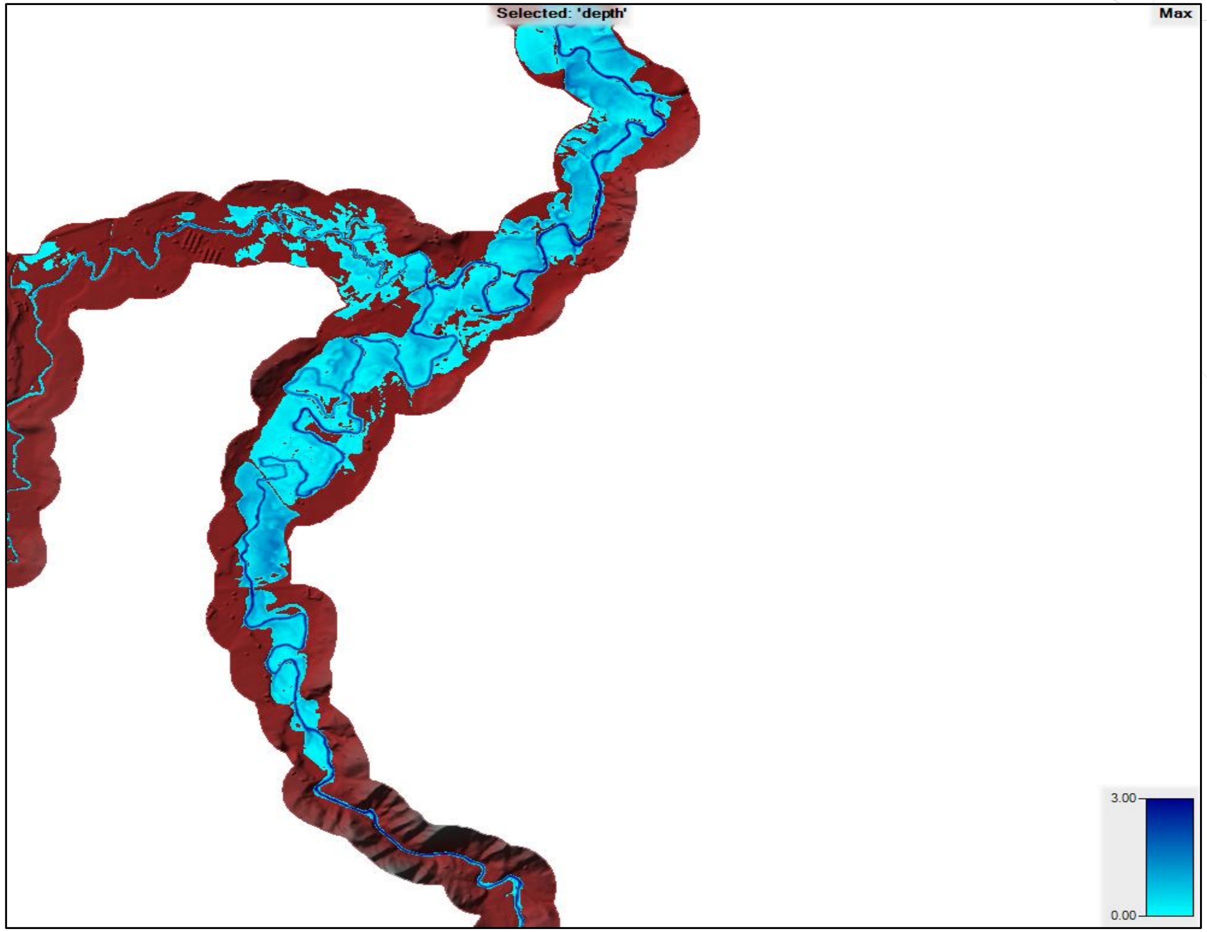
The upstream dam catchment is partially instrumented, the calibrated model allows to estimate the daily discharges in the whole upstream reservoir catchment.

HYDRAULIC MODELLING

To understand the effects of the critical discharges, a 2D hydraulic model was built downstream the dam.

Hec-Ras 2D Model was executed for the 45 days analysis period, where peak discharges occurred.

River flood conditions were observed downstream the dam.



Flooding Conditions Modelled Downstream Dam without Operation

RESERVOIR OPERATION MODELLING

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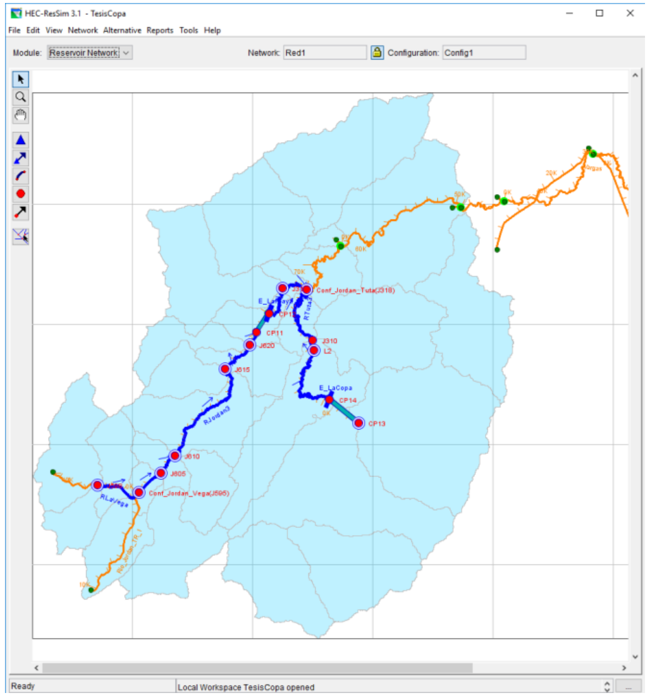
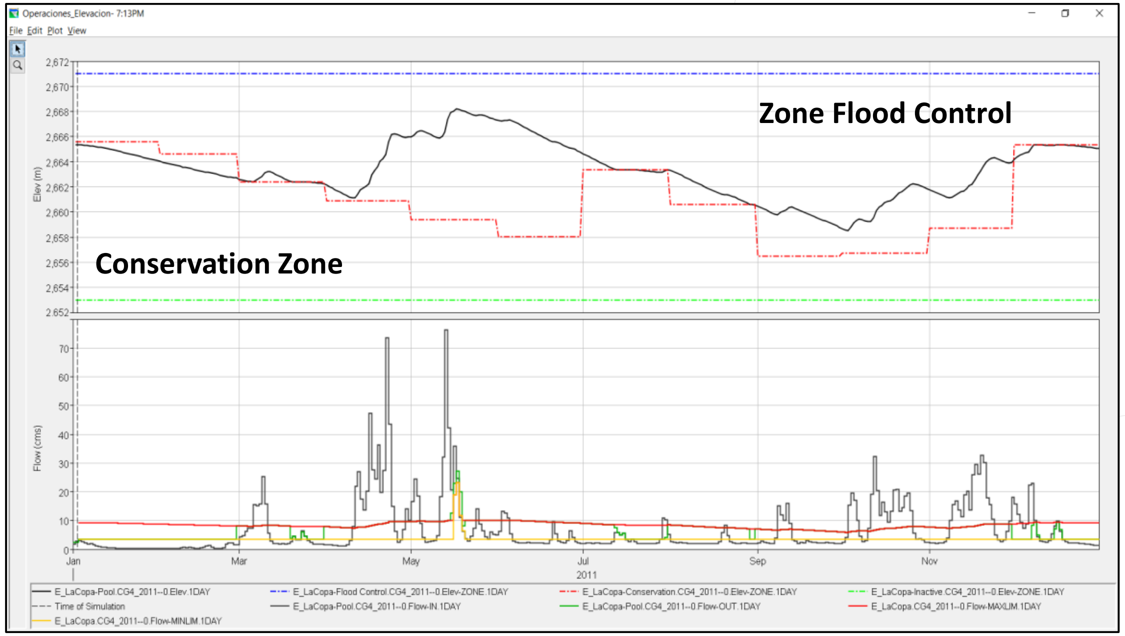
The output discharges from the hydrological model were used to design the reservoir operation model.

Hec-ResSim Reservoir Management Software was used to test the reservoir guide curves performance.

A set of different guide curves were created using different methodologies.



Hec-ResSim Schematic



Hec-ResSim Results

GUIDE CURVE CONSTRUCTION

METHODOLOGIES FOR GUIDE CURVE CONSTRUCTION

- **Using the guide curve software calculation CEH-ECI (2008)**
- Calculating the awaiting and reserve volumes required in each month using statistical analysis
- Using optimization methods

  MES Guide Curve

  Montecarlo method

$$V_f = V_i - (A - D) * N * 0.0864$$

Where,

$$Vf = Reservoir\ volume\ precedent\ month\ (Mm^3)$$
$$Vi = Reservoir\ volume\ at\ the\ end\ of\ the\ actual\ month\ \ (Mm^3)$$
$$A = Mean\ \ monthly\ discharge\ \left(\frac{m^3}{s}\right)$$
$$D = mean\ releases\ at\ the\ actual\ month\ \left(\frac{m^3}{s}\right)$$
$$N = number\ of\ month\ days$$

The given equation is a regressive calculation of the monthly volumes needed to ensure the required releases of the reservoir.

The objective is the calculation of the volumen at the end of the previous month to supply the monthly demands using the affluences and the expected volume at the end of the month.

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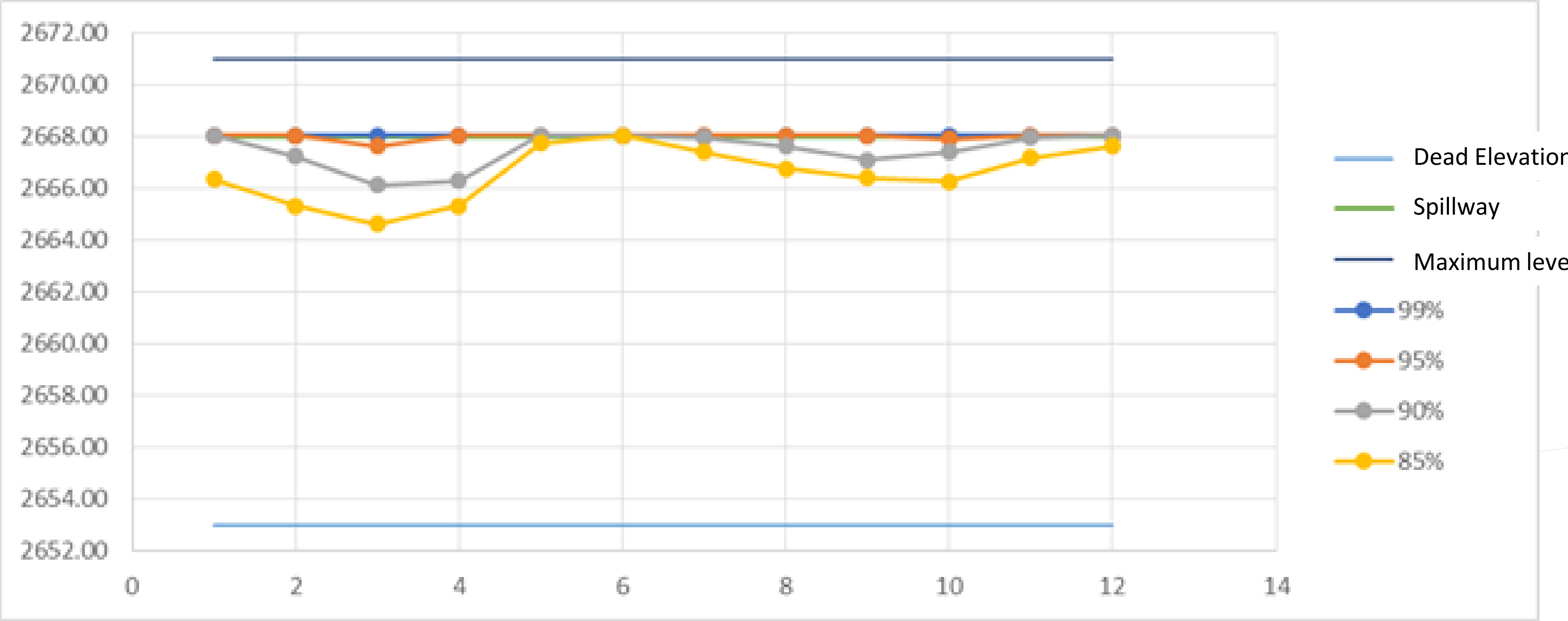

Guide Curve CEH-ECI

CG (EAAB-ESP, 2008) is a software which has capabilities in guide curve construction for monthly reservoir operation by using historic hydrological series (precipitation, discharges, evaporation and infiltration) and basic information from the reservoir as elevation, volume and boundary areas.

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$$q_{i,j} = \bar{X}_j + \frac{\rho_{i,j-1} * S_j}{S_{j-1}}\left(q_{i,j-1} - \bar{X}_{j-1}\right) + Z_{i,j} * S_j * \sqrt{1 - \left(\rho_{i,j-1}\right)^2}$$

Where:

$\bar{X}_j$: Mean historic discharges for month *j* under consideration.
$\bar{X}_{j-1}$: Mean historic discharges for month *j-1* under consideration.
$\rho_{i,j-1}$: First order correlation coefficient between the values in succesive months.
S_j: Standard deviation for the historical discharges in *j* month.
S_{j-1}: Standard deviation for the historical discharges in *j-1* month.
$q_{i,j}$: Discharges at *j* month of the year *i* for the generated discharge sequence.
$q_{i,j-1}$: Discharges at *j-1* month of the year *i* for the generated discharge sequence.
$Z_{i,j}$: Random variable normally distributed applied to the *j* month for the *i year*.

Thomas & Fiering Model

Historic discharge records can be extended using the principle of presistence which indicates the high probability of low flow followed by a low flow due to the storage effect.

GUIDE CURVE CONSTRUCTION

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- Using the guide curve software calculation CEH-ECI (2008)
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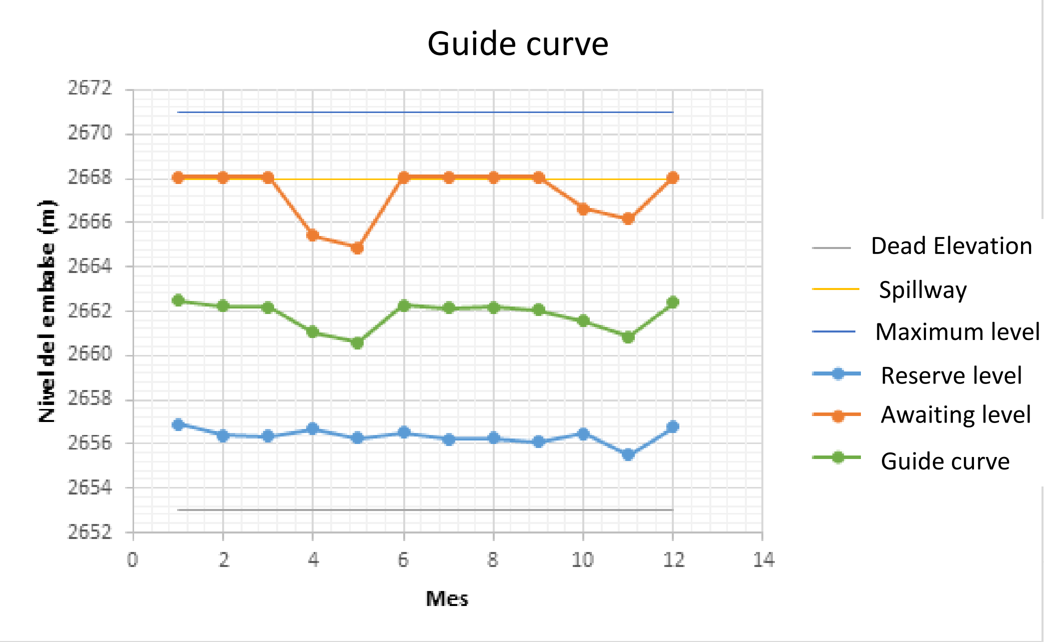
- ***Awaiting and reserve volumes were calculated using the shown equations, and then related to levels at the reservoir in accordance to its shape***



$$Q_{\min} = Q_{eq} + Q_{supply}$$

$$V_{deficit} = (Q_{min} - Q_{nonRegulated}) * T$$

Where:

$V_{deficit}$: Volume shortage to ensure the mínimum discharge en dry periods (Mm³)
Q_{min}: Minimum monthly discharge (m³/s)
$Q_{nonRegulated}$: Monthly inflow average discharge to the reservoir (m³/s)
T: Time monthly period in seconds

Guide Curve Awaiting – Reserve for Minimum Volumes

$$Q_{Max\ outflow} = Q_{maxstream} - Q_{inflow}$$

$$V_{excess} = (Q_{inflowdam} - Q_{Max\ outflow}) * T$$

Where:

V_{excess}: Excess volumen for storage (Mm³)
$Q_{maxstream}$: Maximum bankfull discharge downstream (m³/s)
Q_{inflow}: Monthly Average discharges from the affluent streams between the dam and the interest site (m³/s)
$Q_{inflowdam}$: Monthly average máximum discharges to the reservoir (m³/s)
T: Time monthly period in seconds

Guide Curve Awaiting – Reserve for Maximum Volumes

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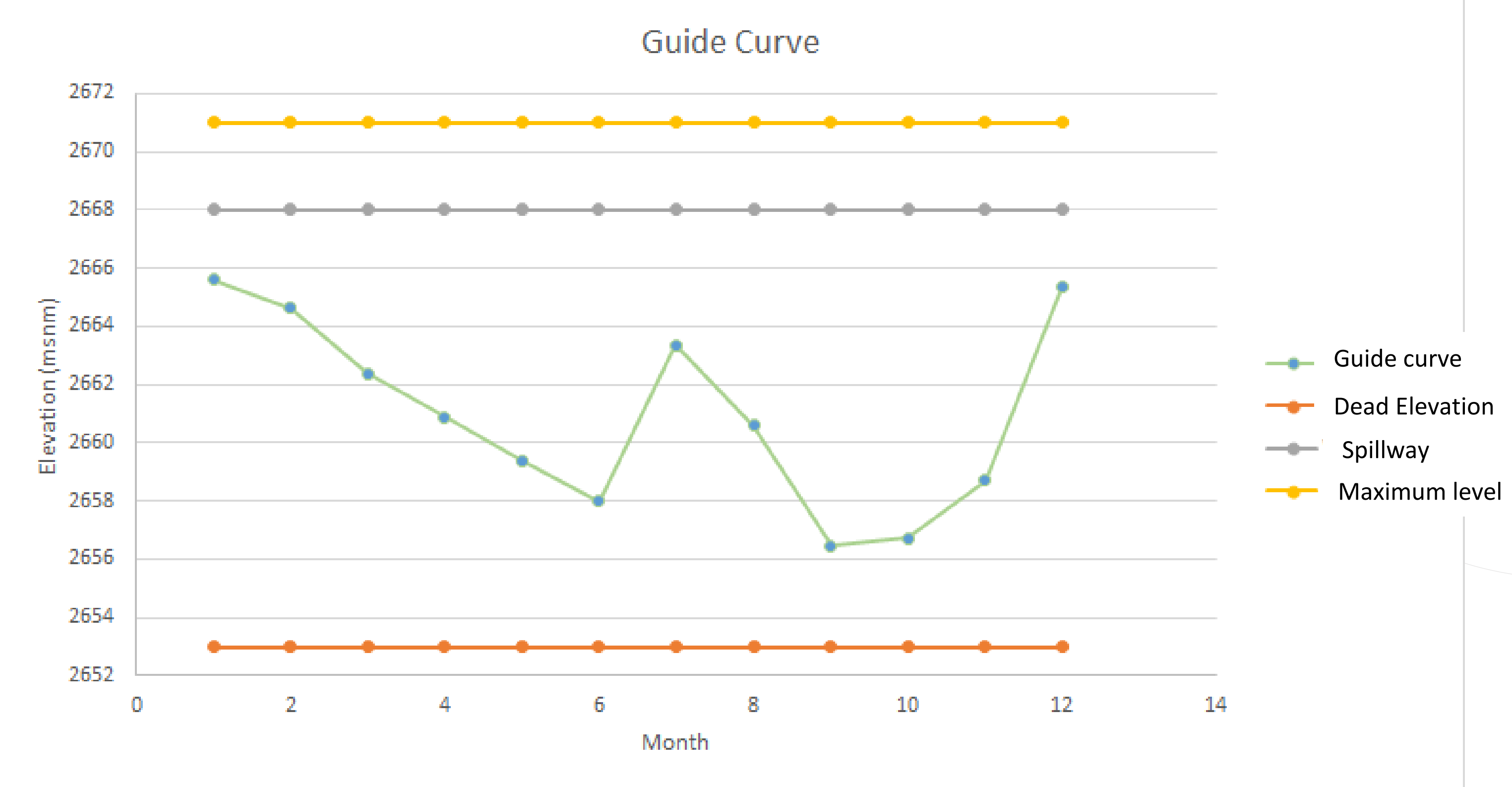

MES Guide Curve

Minimum Excess and Shortage guide curve was created by defining the objective function and the optimal parameters like water levels for each month of the year, it can be constructed a reservoir guide curve, with twelve decision variables. The optimization methods are simple but effective, which find the minimum or maximum value of a real function creating variations in the optimization parameters considering the restrictions for these values.

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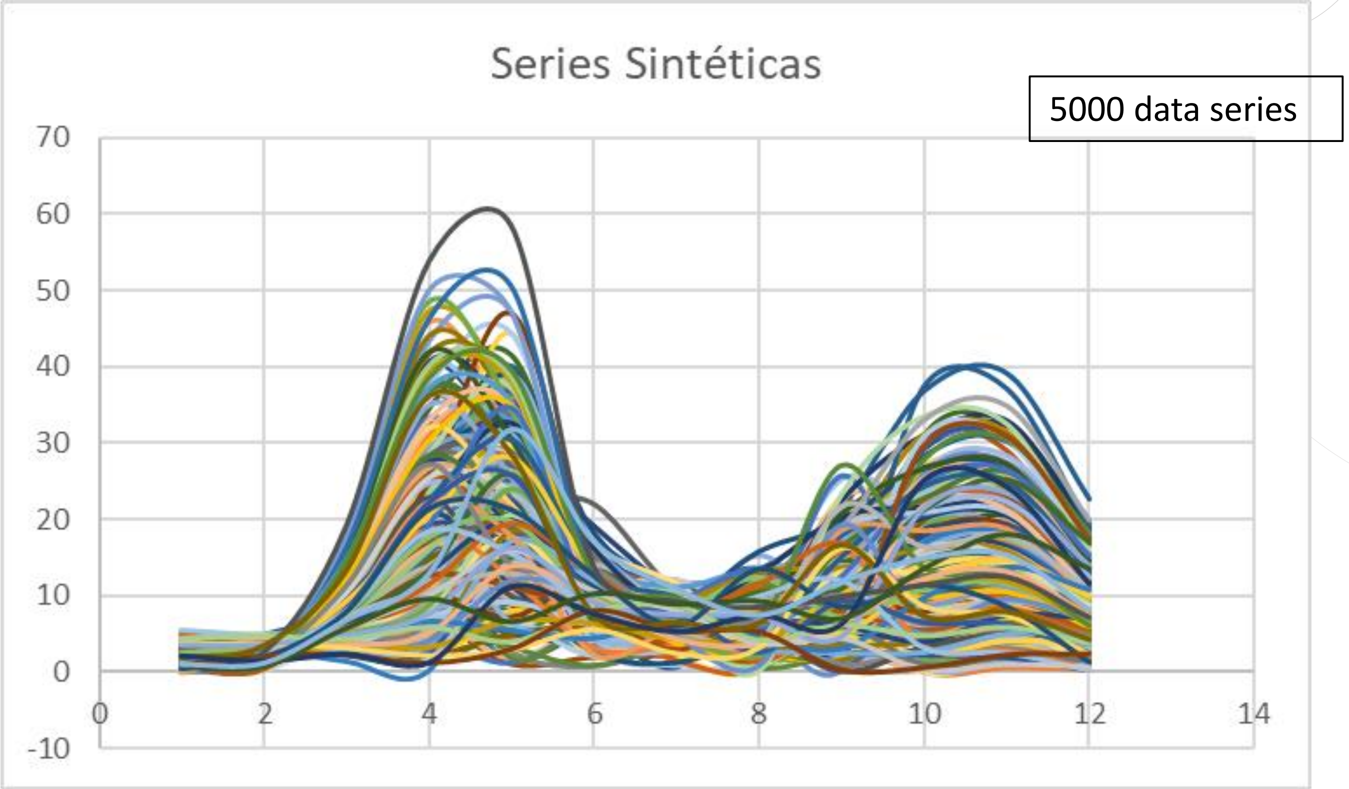

Monte Carlo Method

This method creates a set of random values which can be evaluated in order to estimate the optimal value by a high number of simulations. This method uses the Markov Chain Monte Carlo (MCMC) Algorithms.

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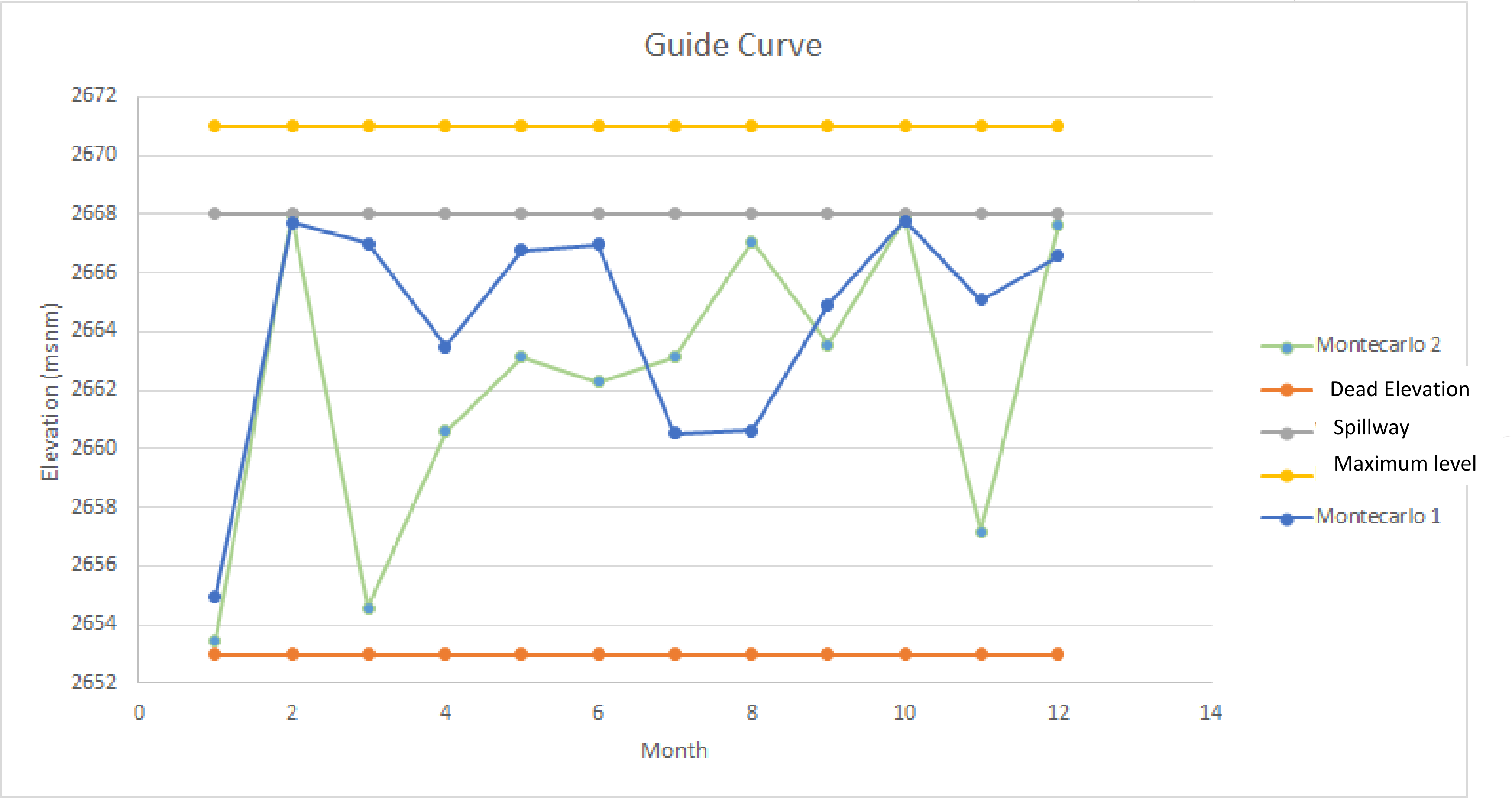


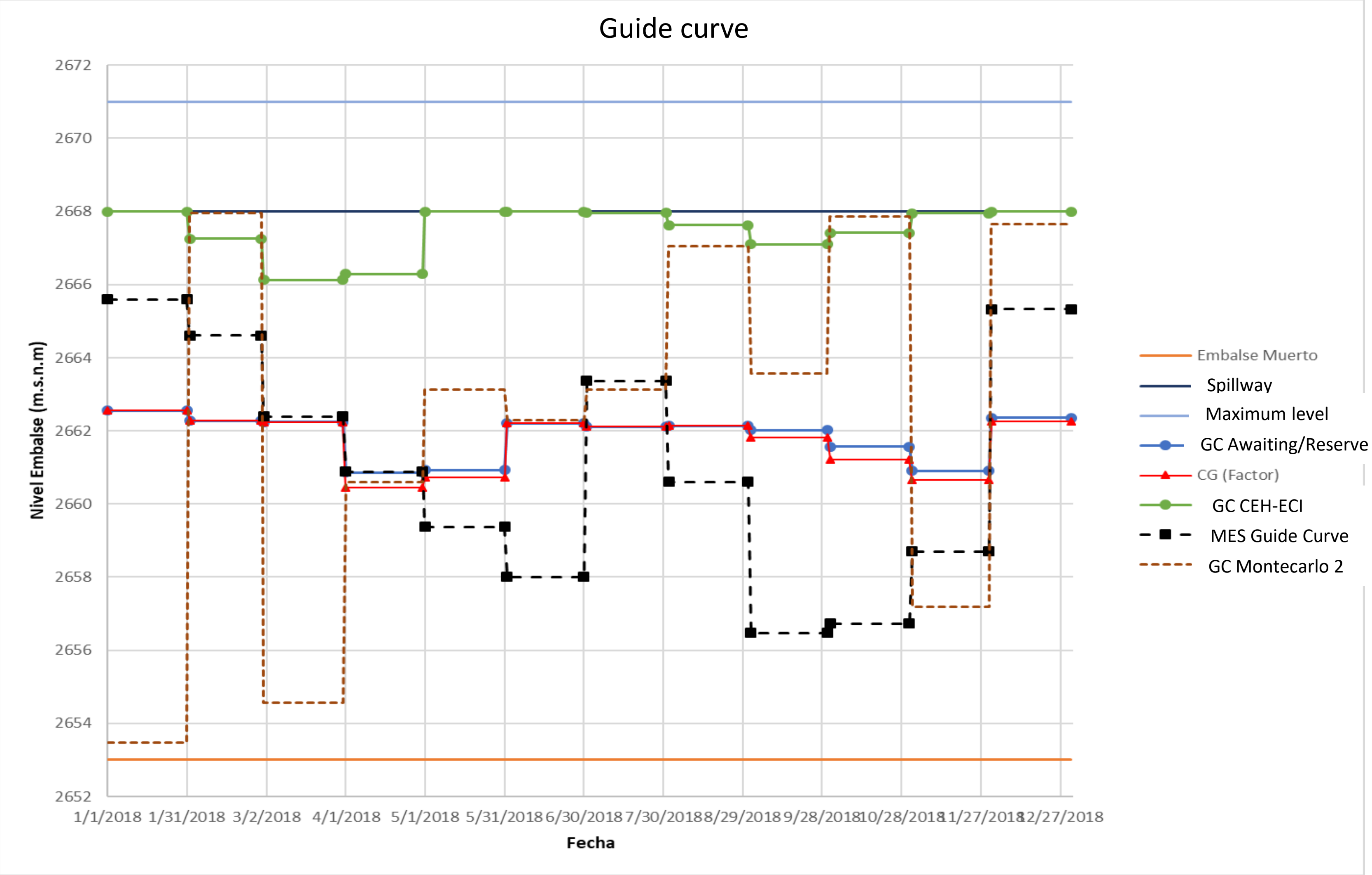
Monte Carlo Method

GUIDE CURVE CONSTRUCTION

Monthly variation of each guide curve calculated using different methodologies

The guide curves were tested with Hec-ResSim in order to verify It's performance. An average failure percentage was calculated for each curve to select the optimal for flooding conditions. The minimum excess and shortage guide curve was selected as the best for the case study.

Using this guide curve were calculated the flood conditions downstream using the hydrodynamical model.



RESERVOIR OPERATION MODELLING

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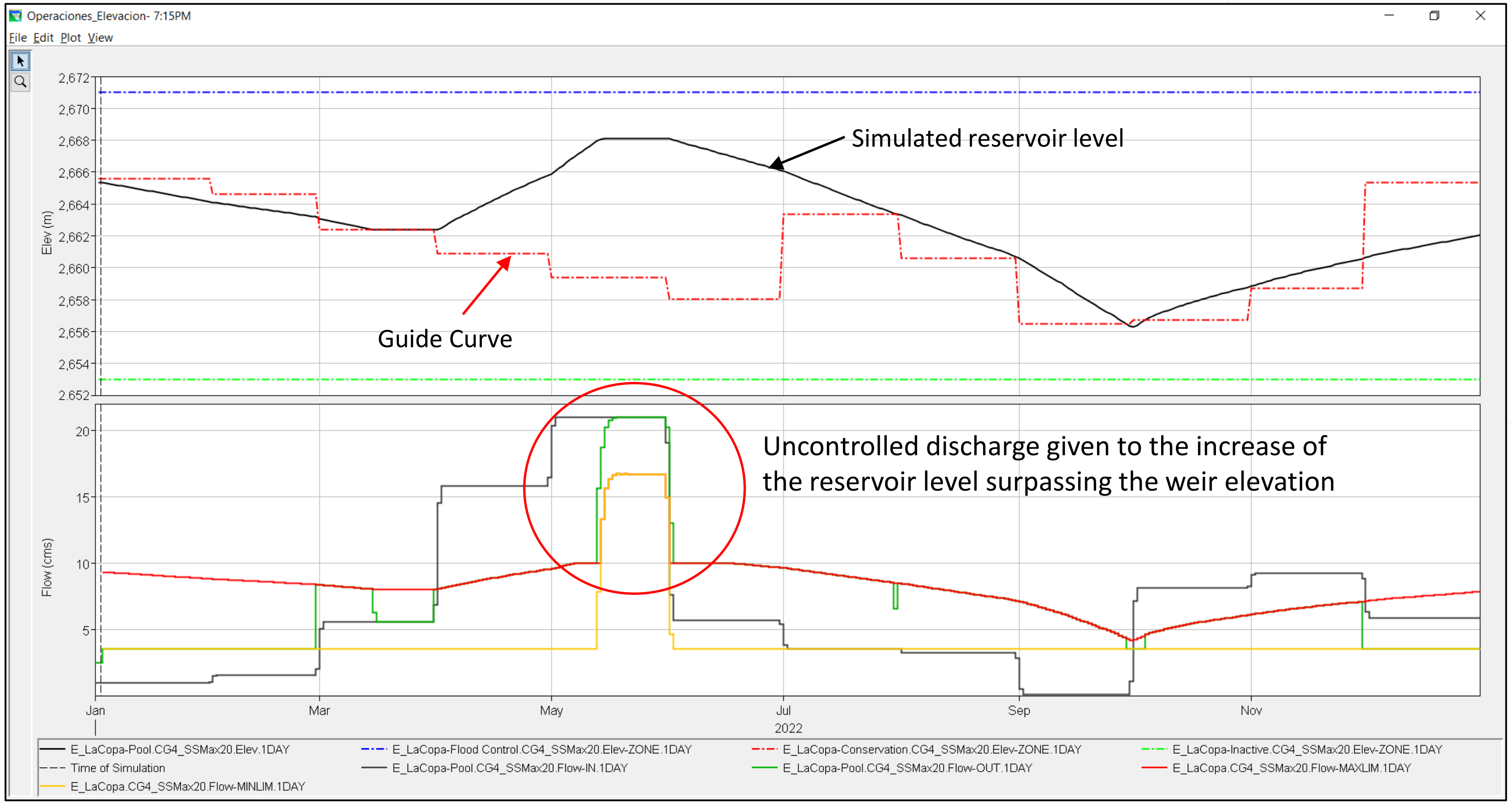
MES guide curve operation for maximum discharges.



Minimum excess and shortage guide curve performance in Hec-ResSim model

RESERVOIR OPERATION HYDRAULIC MODELLING

Results from the operation by using MES guide curve.

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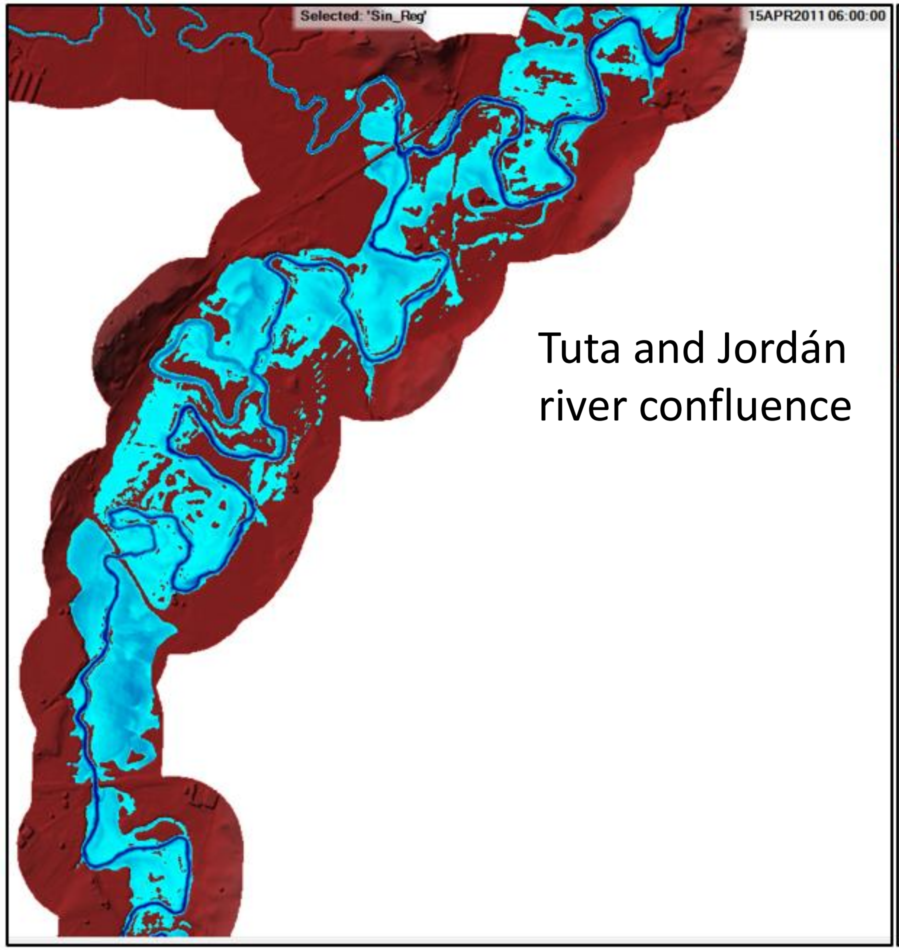

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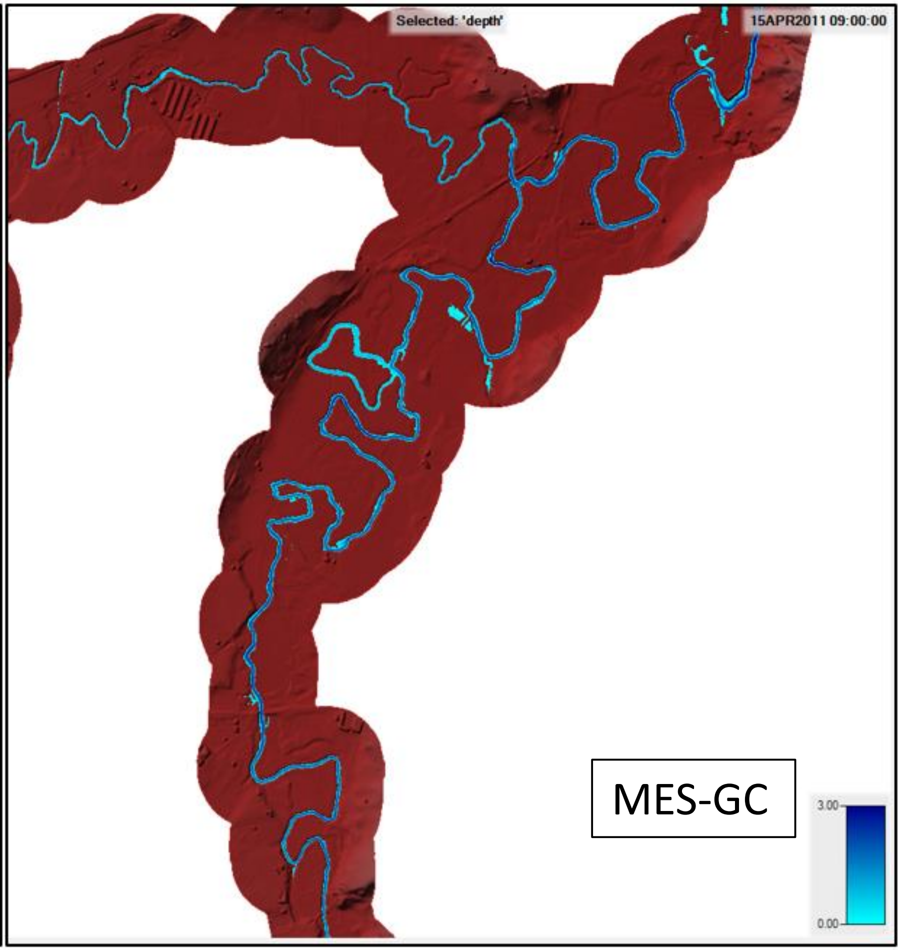

REGULATED
(Guide curves operation)

2D MODELLING – 15Th APRIL

RESERVOIR OPERATION HYDRAULIC MODELLING

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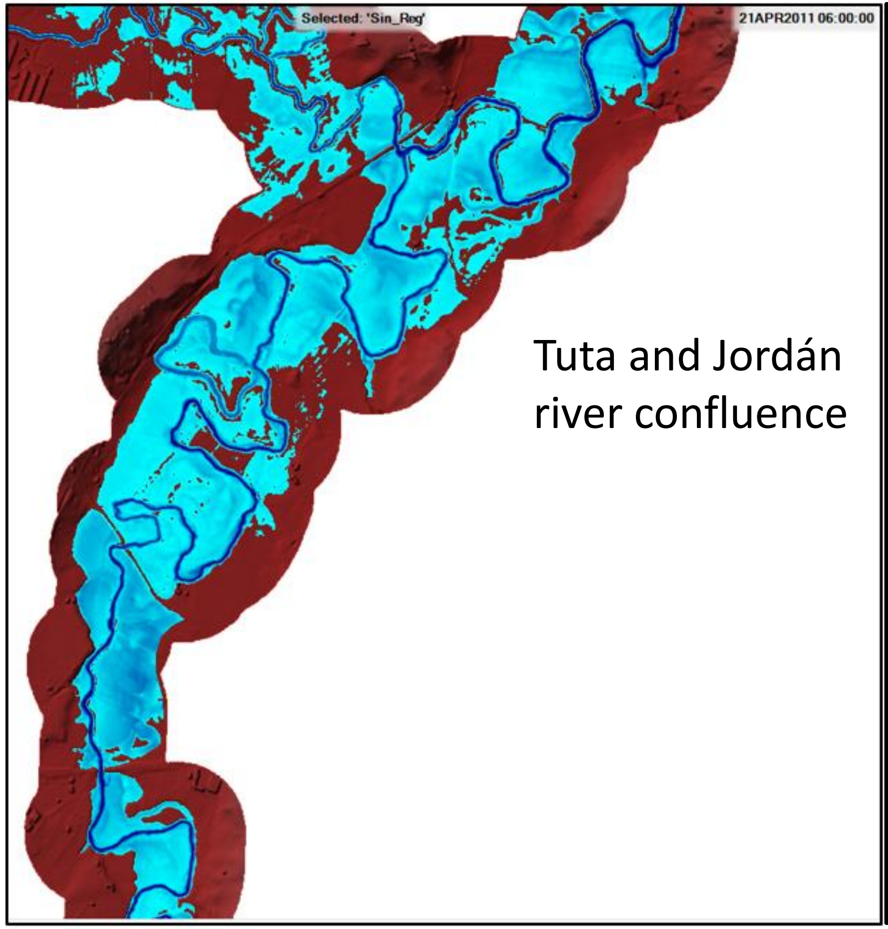

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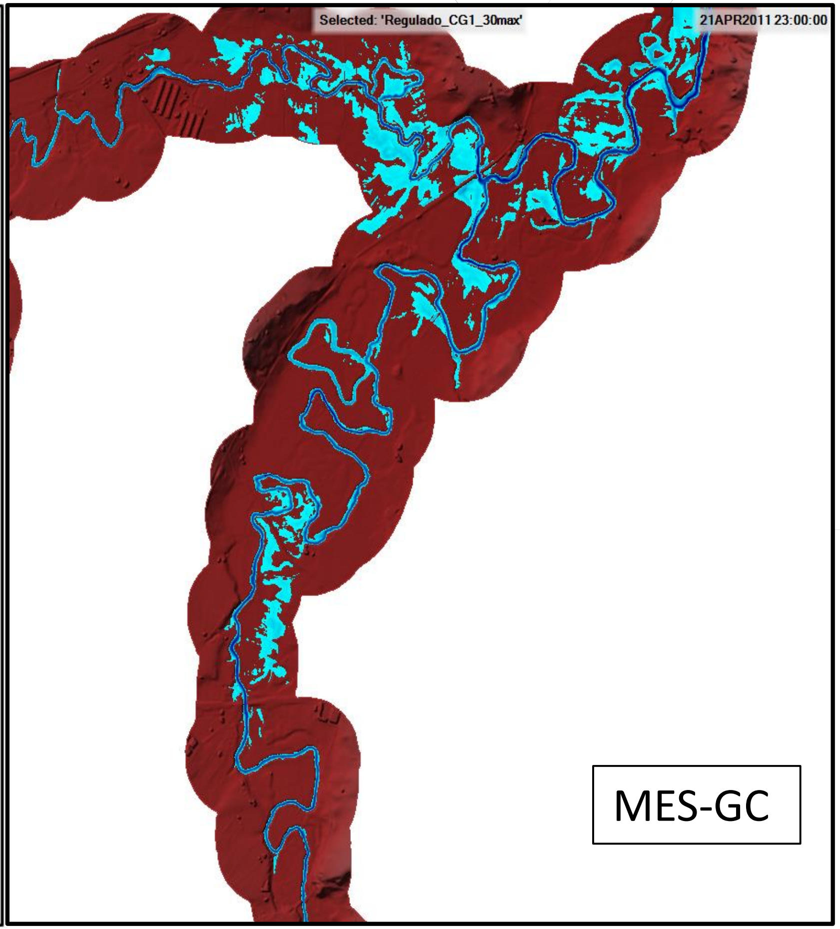

REGULATED
(Guide curves operation)

2D MODELLING REGULATED – 21Th APRIL

CONCLUSIONS

- The calculation of the required volumes does not take into account the peak discharge distribution in each month. This can understimate the required volume for high floods storage which can occur between 10 and 15 rainy days of a wet month.

- The awaiting and reserve volumes method is calculated by the historical affluences to the reservoir for each month separately and independently. This affects the guide curve performance because it considers that at the begining of the month, the resevoir level is able to reach the guide curve level which is not always possible due the antecedent level conditions.

- The optimization methods are the best tool for the guide curve calculation when there are different operational objectives, due to the formulation capabilities and the maximization of the benefits sought.

CONCLUSIONS

- Guide curve selection by optimization is a large technical field. The present study has implemented Monte Carlo methodology and a genetic algorithm by using objective function. However, the decision variables were excess and deficit volumes. Other optimization methods can be used in other cases, whith different objective functions and variables.

- The application of the reservoir operation and control by guide curves is linked to early warning systems in which hydrological short term forecasting can be modelled in the reservoir simulation sofware in order to reduce the effects of flooding downstream by managing the reservoir releases.

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