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## **2D MODEL OF GROUNDWATER FLOW AND DISSOLVED HCH TRANSPORT THROUGH THE GÁLLEGO RIVER ALLUVIAL AQUIFER DOWNSTREAM THE SARDAS HCH LANDFILL (HUESCA, SPAIN)**

**Javier Samper, Brais Sobral, Luis Montenegro, Joaquín Guadaño, Jorge Gómez, Felipe Delgado, Javier San Román & Jesús Fernández**



# Outline

- Introduction & motivation
- Study area
- Groundwater flow model
- Contaminant transport model
- Conclusions & future work



# Introduction

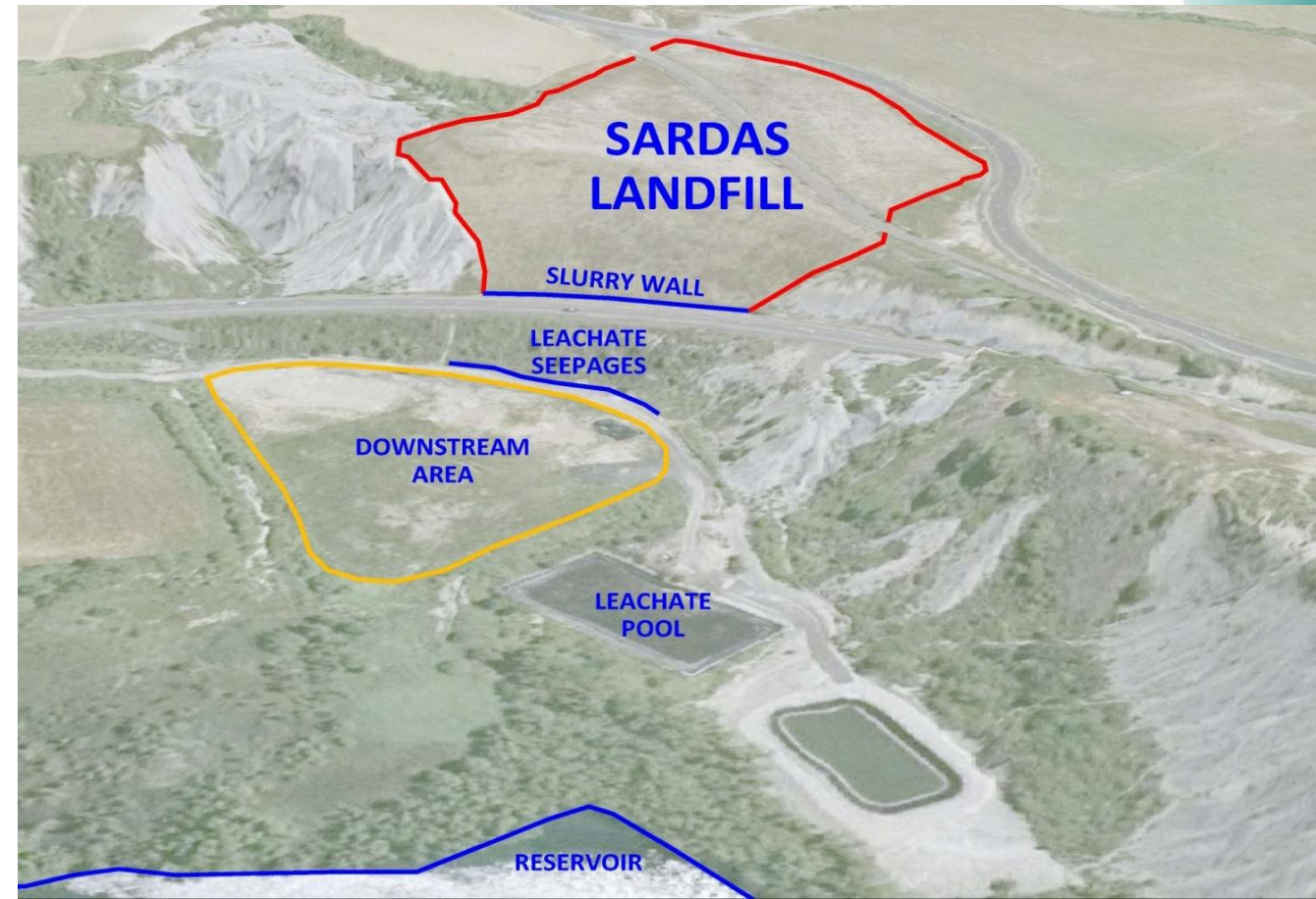
- Sardas site near Sabiñánigo in Aragón, Northeastern Spain is one of the sites affected by INQUINOSA Company which produced lindane
- Lindane is HCH, a persistent organic pollutant (POP): volatile, slightly soluble in water, DNPA
- HCH and other COCs have migrated through the Gállego river alluvial aquifer downstream the Sardas landfill, which is located on the left bank of the Gállego river, less than 500 m from the Sabiñánigo reservoir



# Introduction

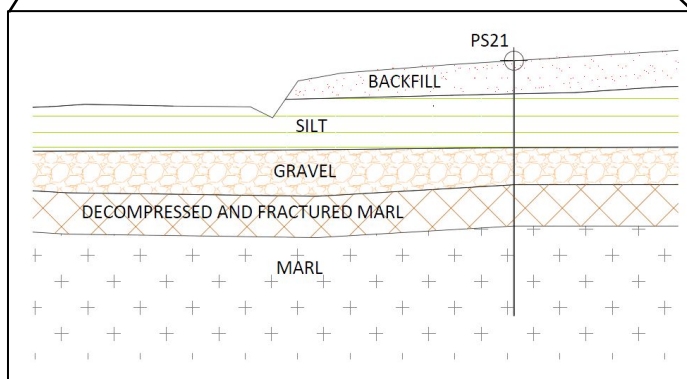
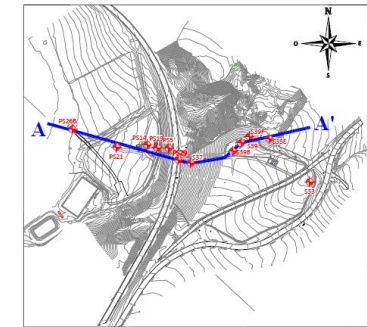
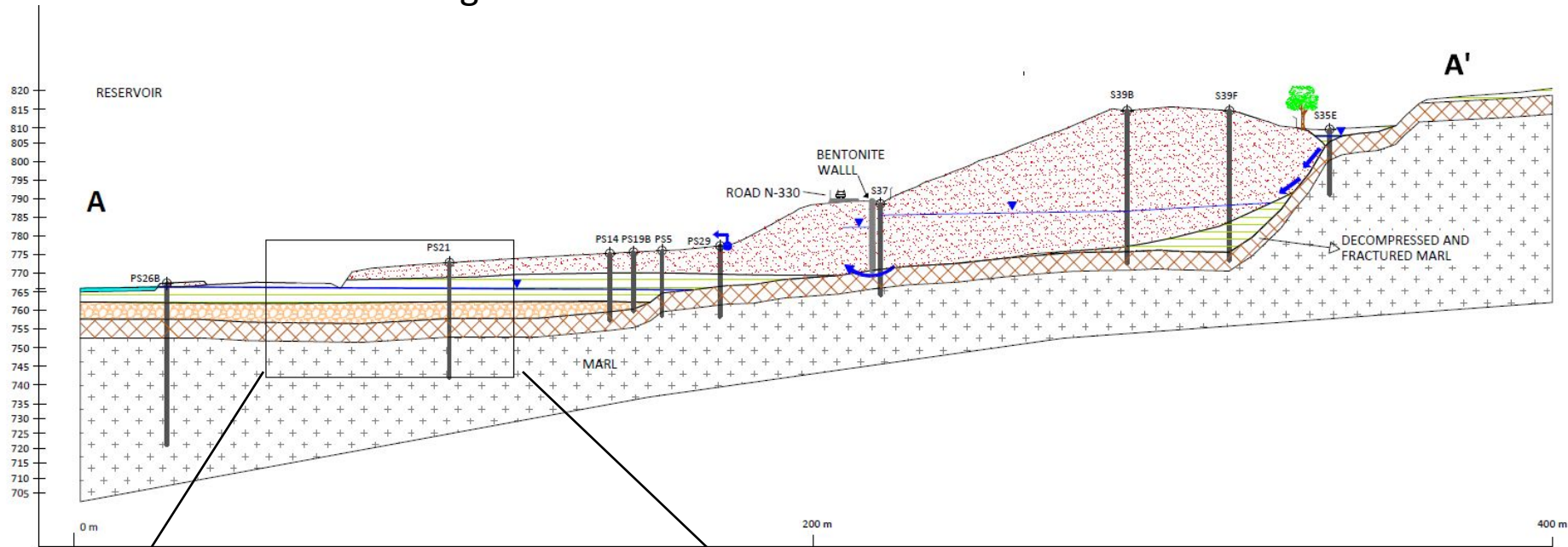
- Sardas landfill and the waste disposed on the alluvial plain pose a risk for Gállego river and the Sabiñánigo reservoir
- Groundwater flow and contaminant transport models of the site are required to
  - Understand the dynamics of the system and pathways of contaminants
  - Quantify fluxes
  - Predict potential impacts
- There is a need to perform groundwater flow and transport models of the Gállego alluvial aquifer

Aerial view



# Study area

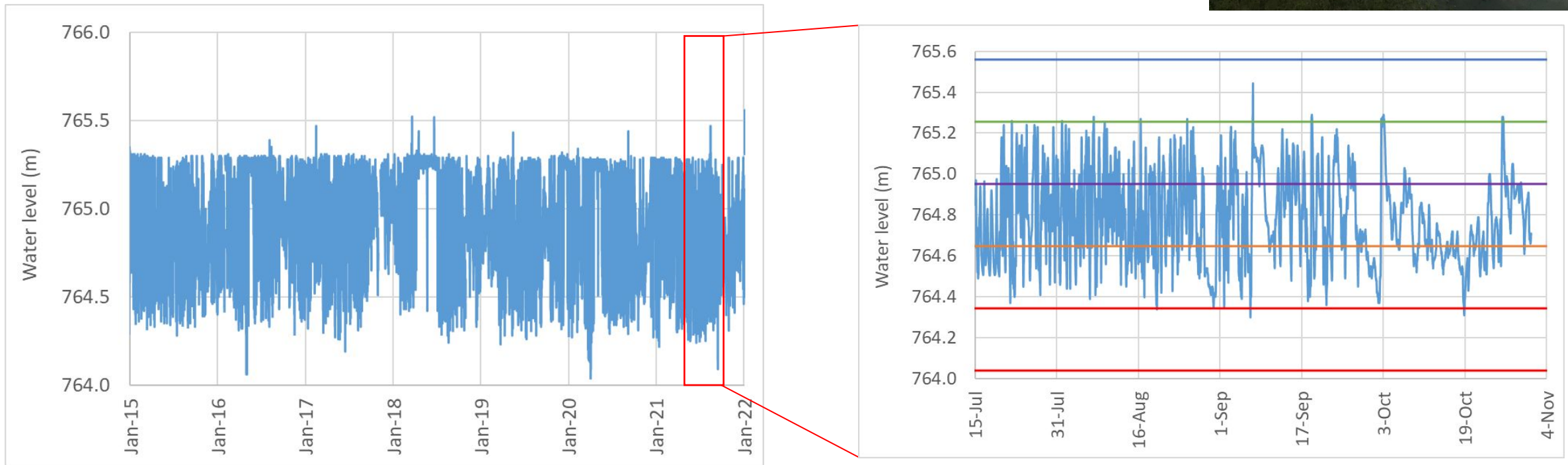
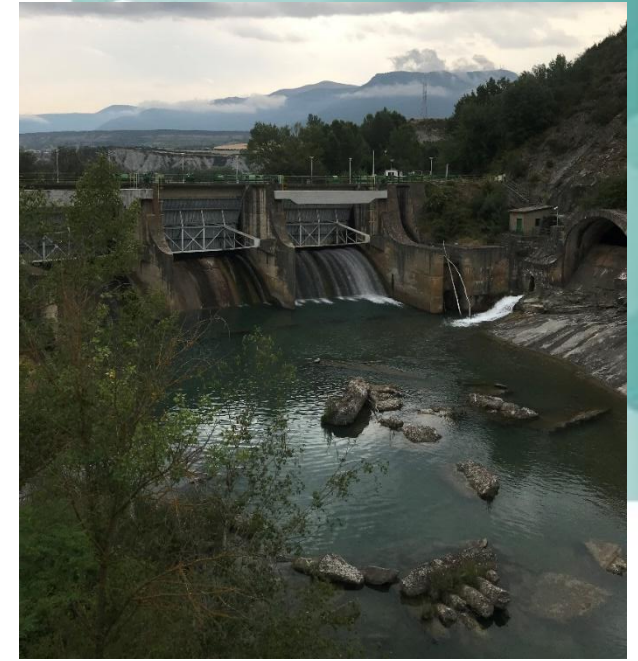
- Conceptual model of the Sardas site
  - Landfill
  - Sabiñánigo reservoir



LEGEND	
	BENTONITE SCREEN
	BOREHOLES
	WASTES
	SILTS
	GRAVELS
	MARLS

# Study area

- Sabiñánigo reservoir for hydropower: daily fluctuations (1 m)

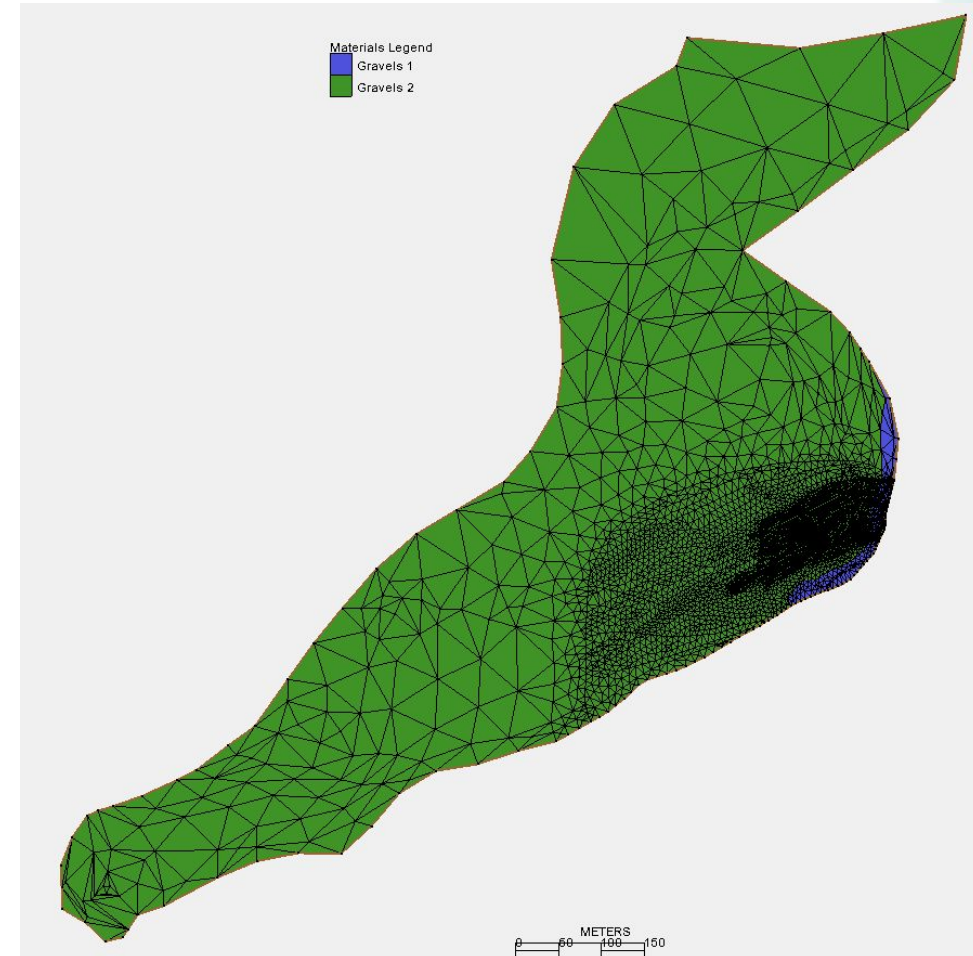


# Study area

- Piezometric measured data show that
  - Hydraulic heads in the alluvial aquifer fluctuate due to the tidal effect produced by reservoir water level daily fluctuations
  - The gradient of the piezometric heads is extremely small = 0.0001
    - 1 cm per 100 m !! (really very small)

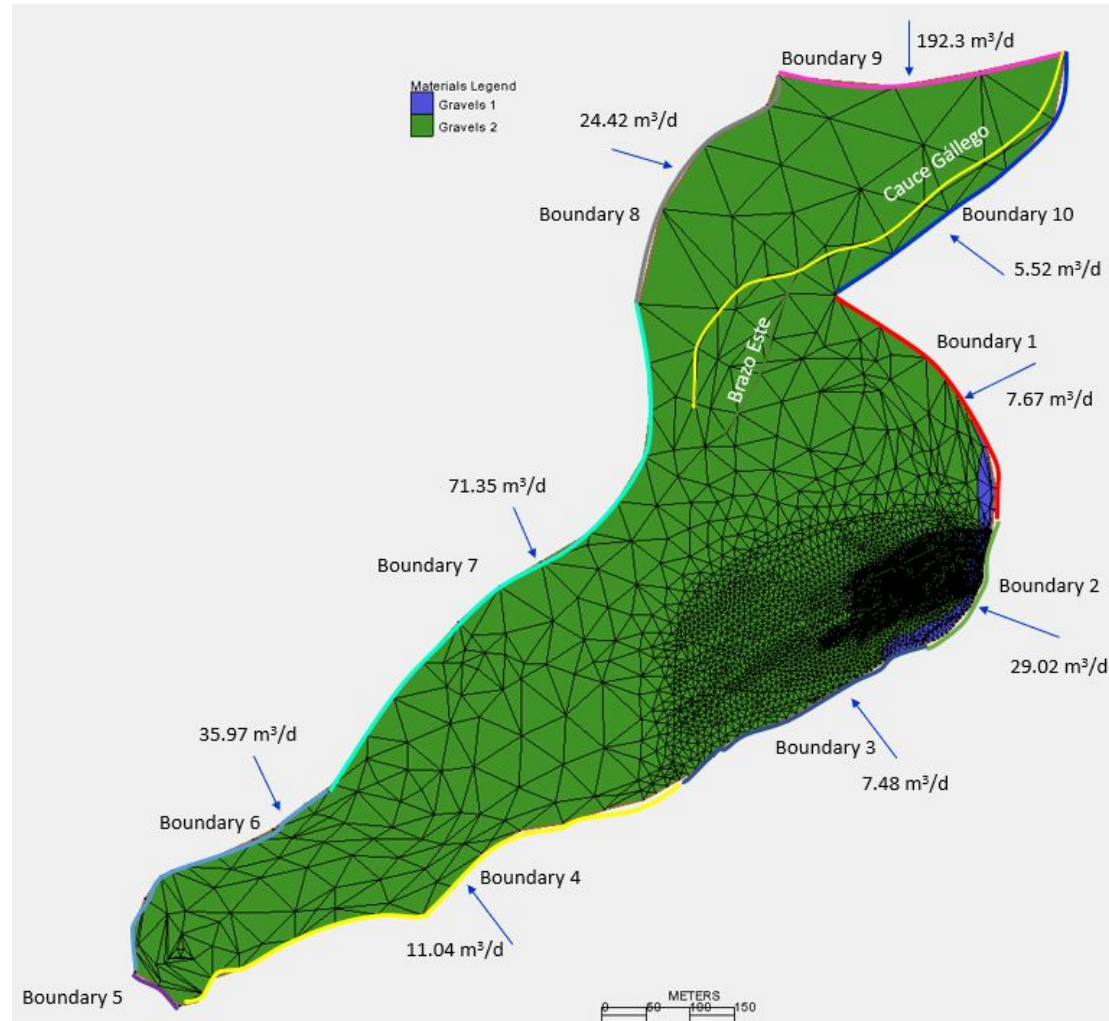
# 2D groundwater flow model of the Gállego alluvial

- Finite element model: Model domain



# 2D groundwater flow model of the Gállego alluvial

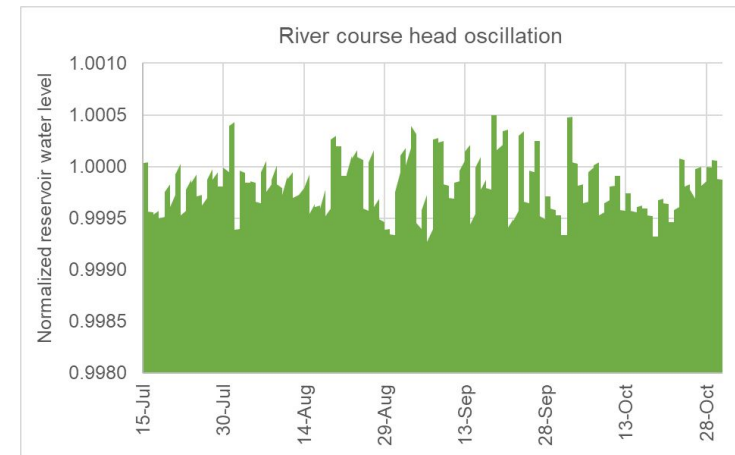
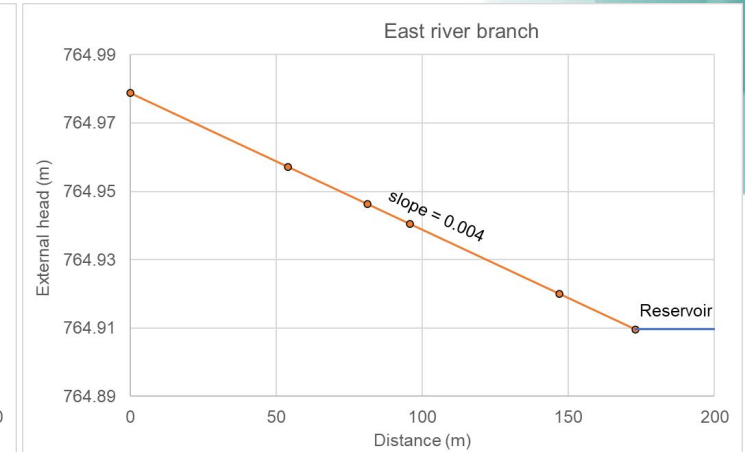
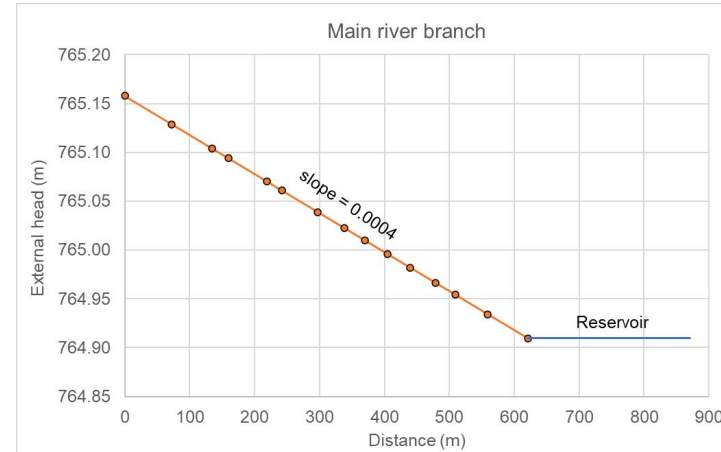
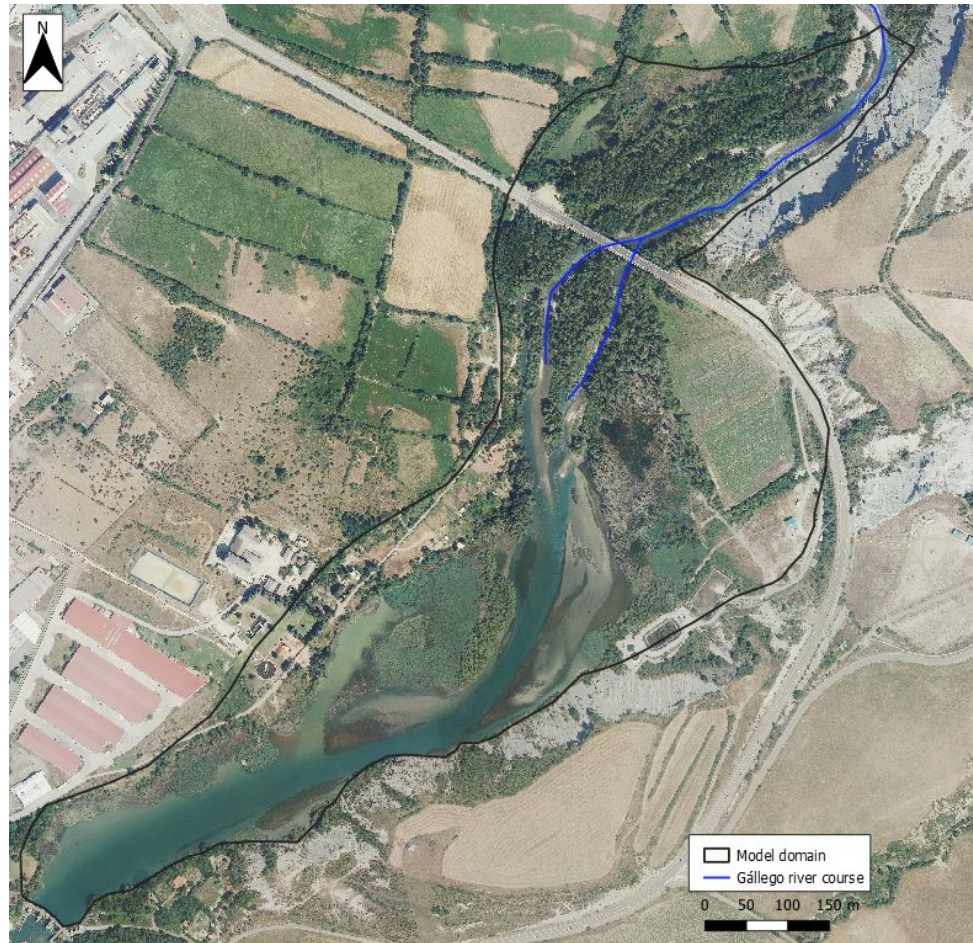
- Finite element model: Boundary conditions and model parameters



Material zones	Hydraulic conductivity, K (m/d)	Specific storage coefficient, $S_s$ ( $m^{-1}$ )
Gravels 1	600	$6 \cdot 10^{-4}$
Gravels 2	300	$6 \cdot 10^{-4}$

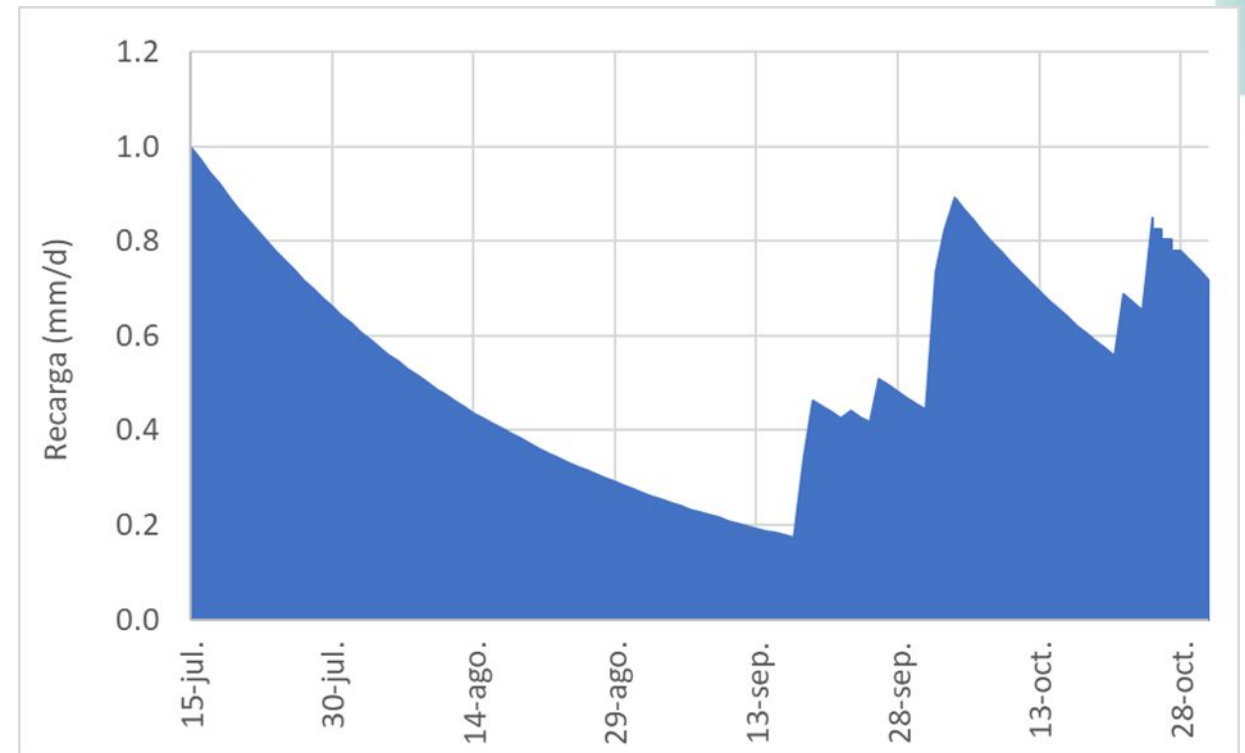
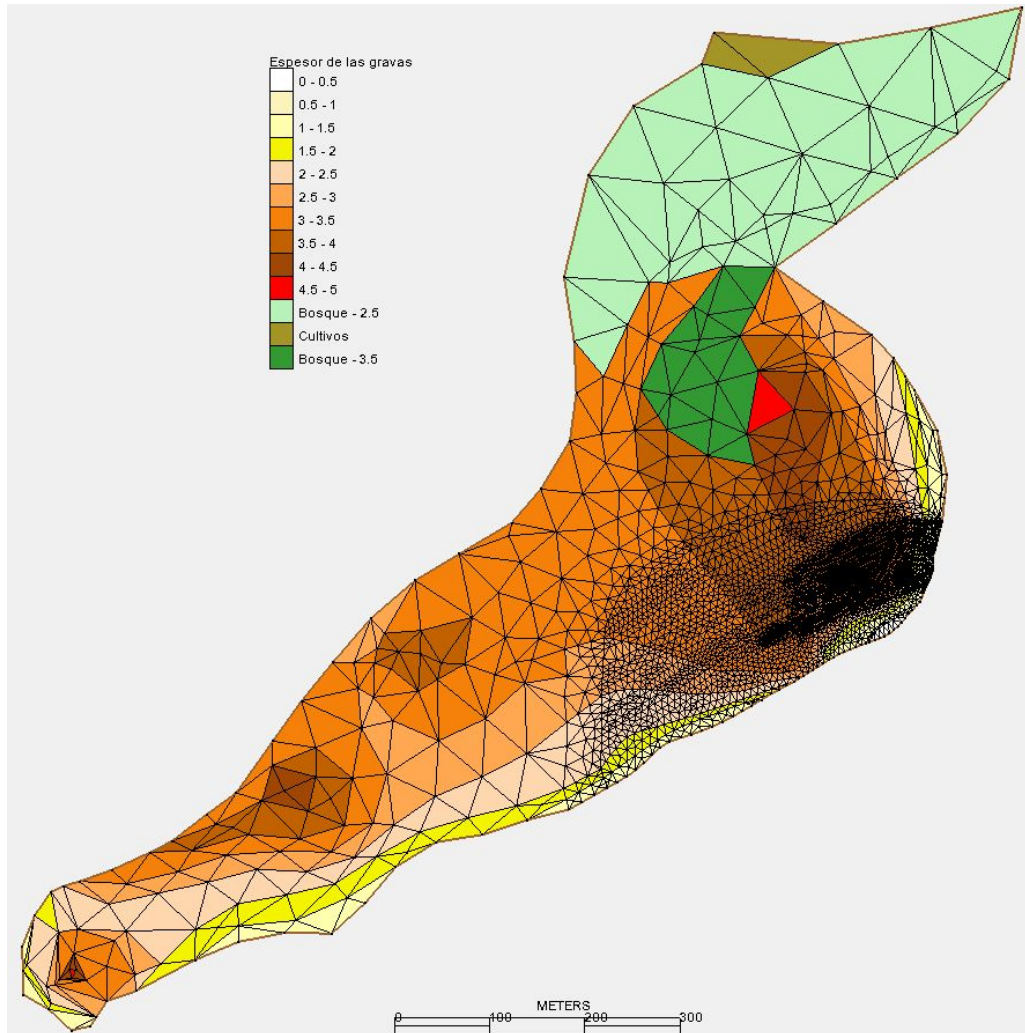
# 2D groundwater flow model of the Gállego alluvial

- Finite element model: boundary conditions along the river and reservoir



# 2D groundwater flow model of the Gállego alluvial

- Finite element model: areal recharge
  - Derived from a hydrological daily water balance model (VISUAL-BALAN)



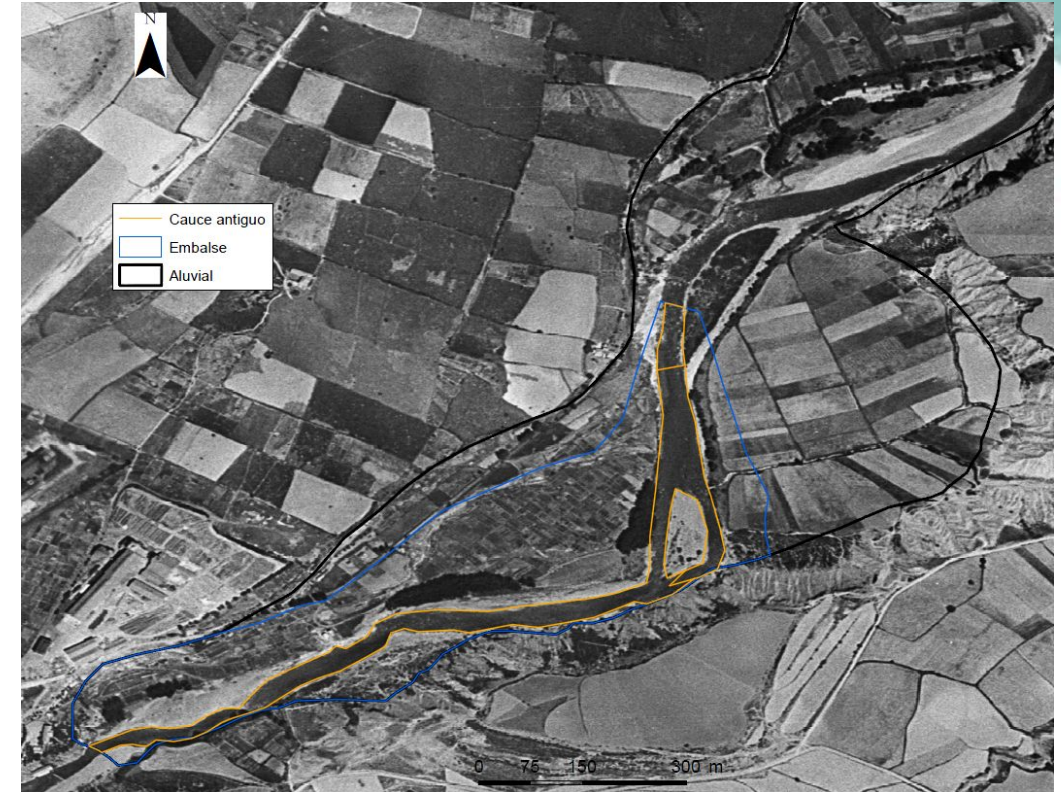
# 2D groundwater flow model of the Gállego alluvial

- Reservoir/aquifer interactions and fluxes
  - Cauchy condition
  - Conductance

$$\alpha = \frac{K_l A_n}{e_l}$$

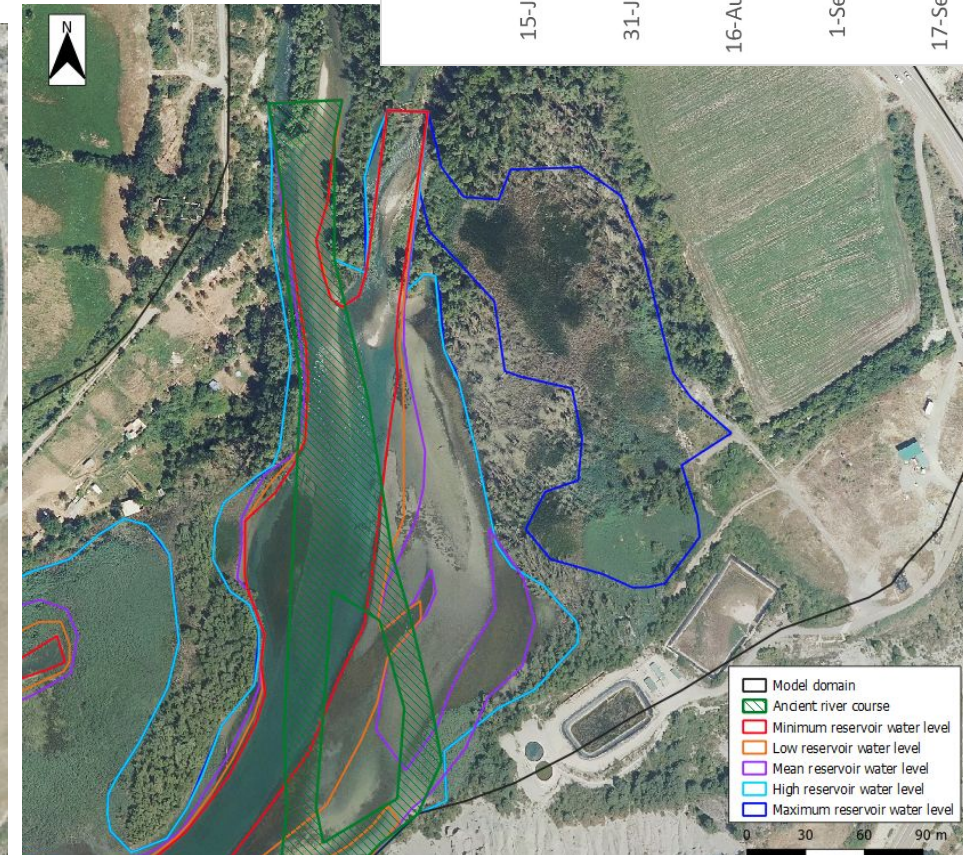
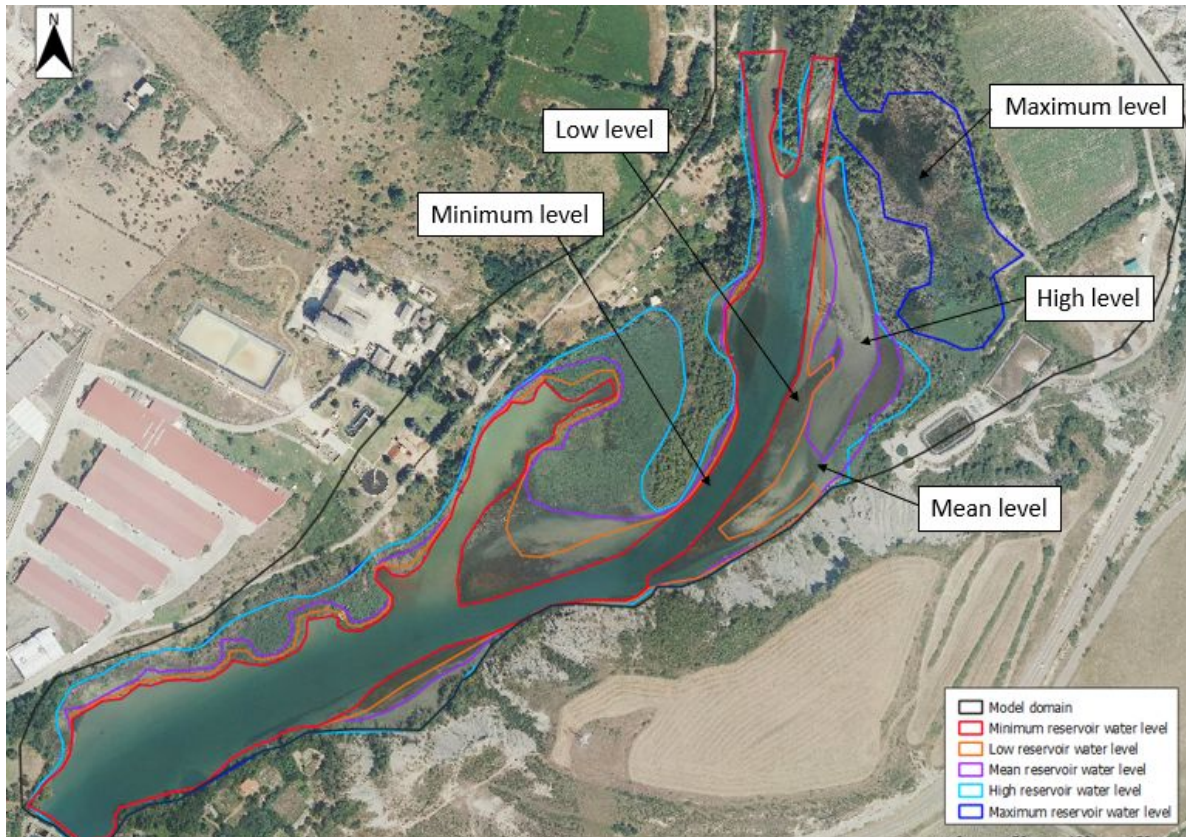
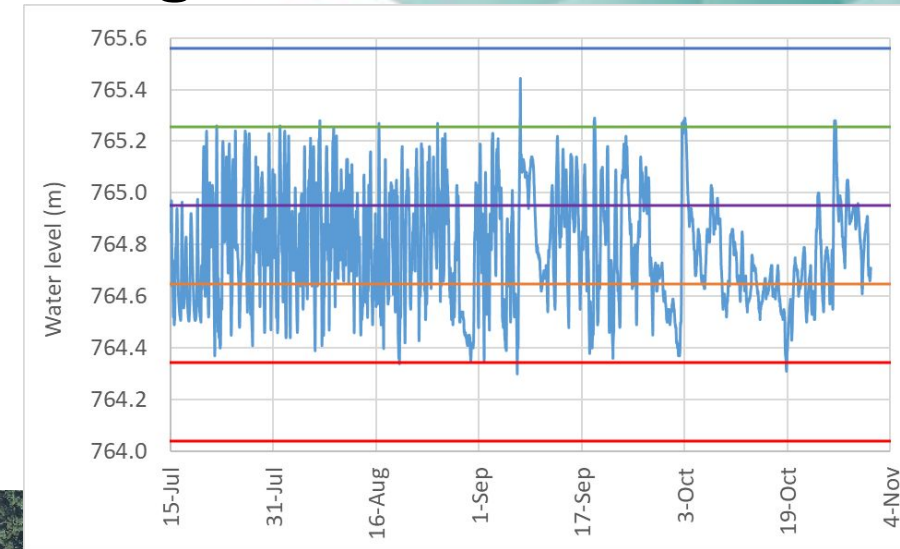
donde:

- $K_l$  = vertical conductivity of the alluvial silts or sediments
  - Silts = 0.01 m/d
  - Sediments = 0.1 m/d
- $A_n$  = nodal area (m<sup>2</sup>)
- $e_l$  = thickness of sediment/silt layer



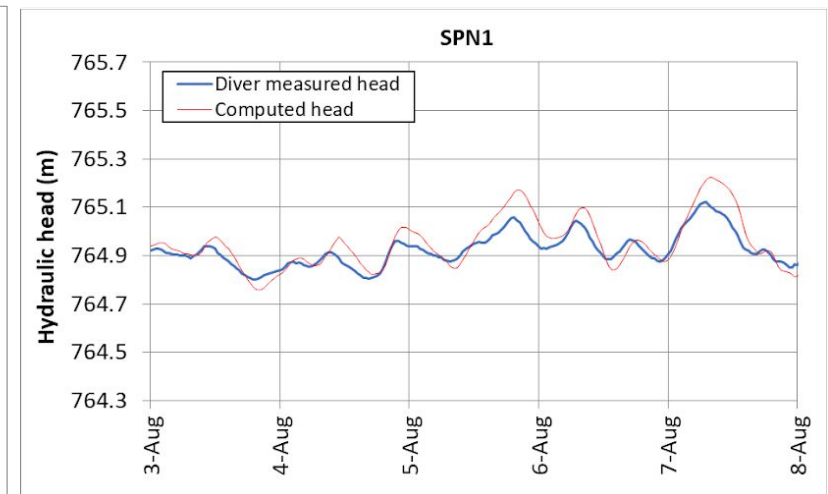
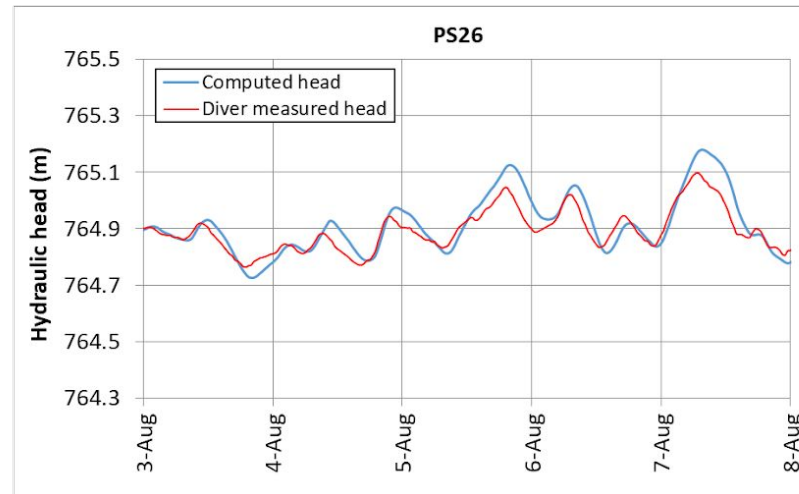
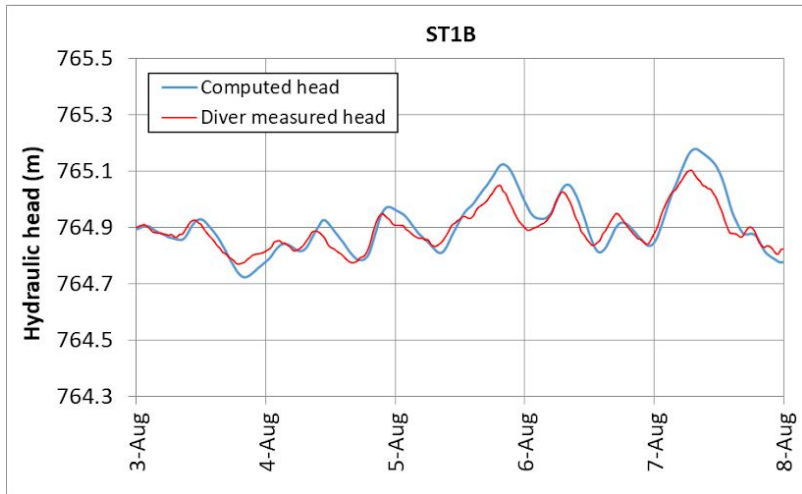
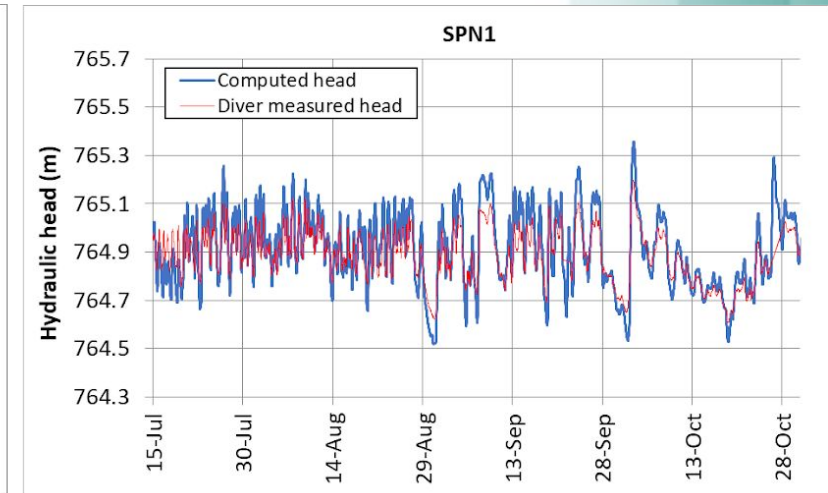
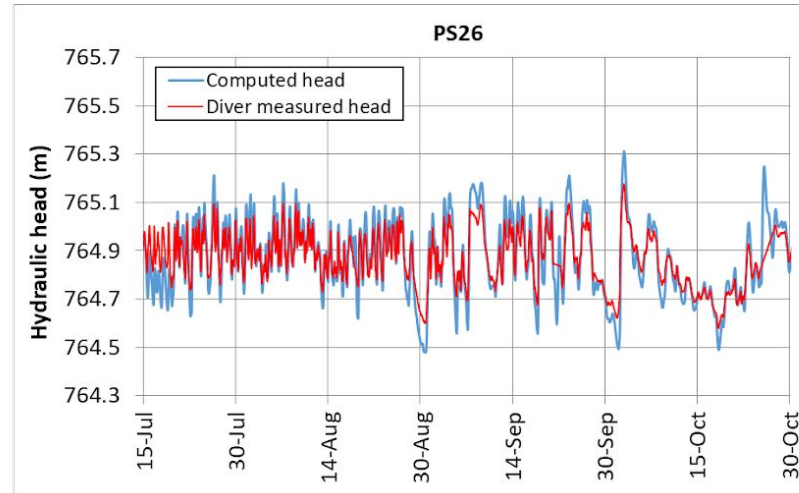
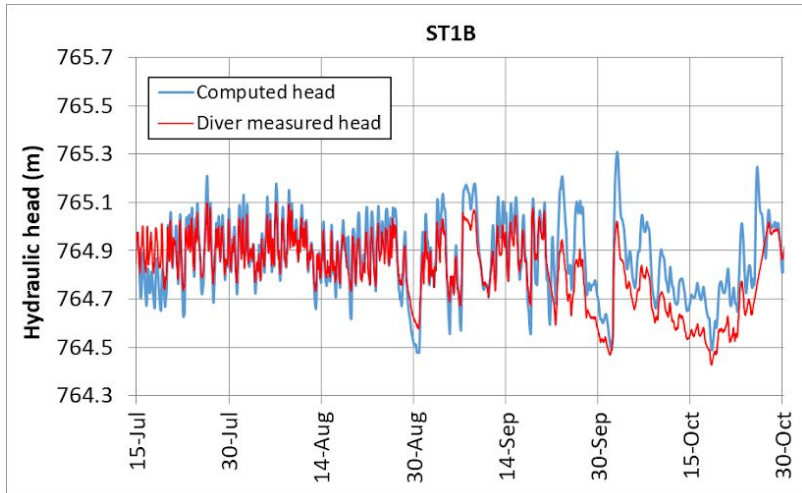
# 2D groundwater flow model of the Gállego alluvial

- Fluctuations of reservoir level
- Changes in reservoir flooded areas



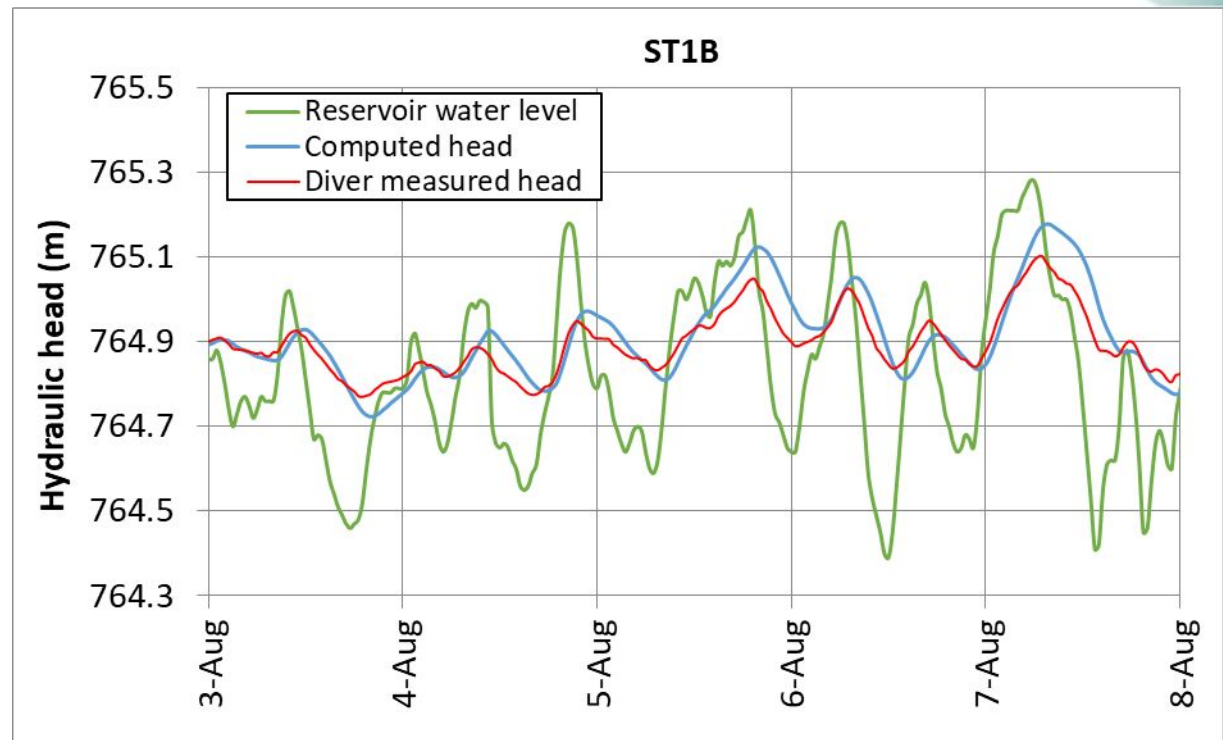
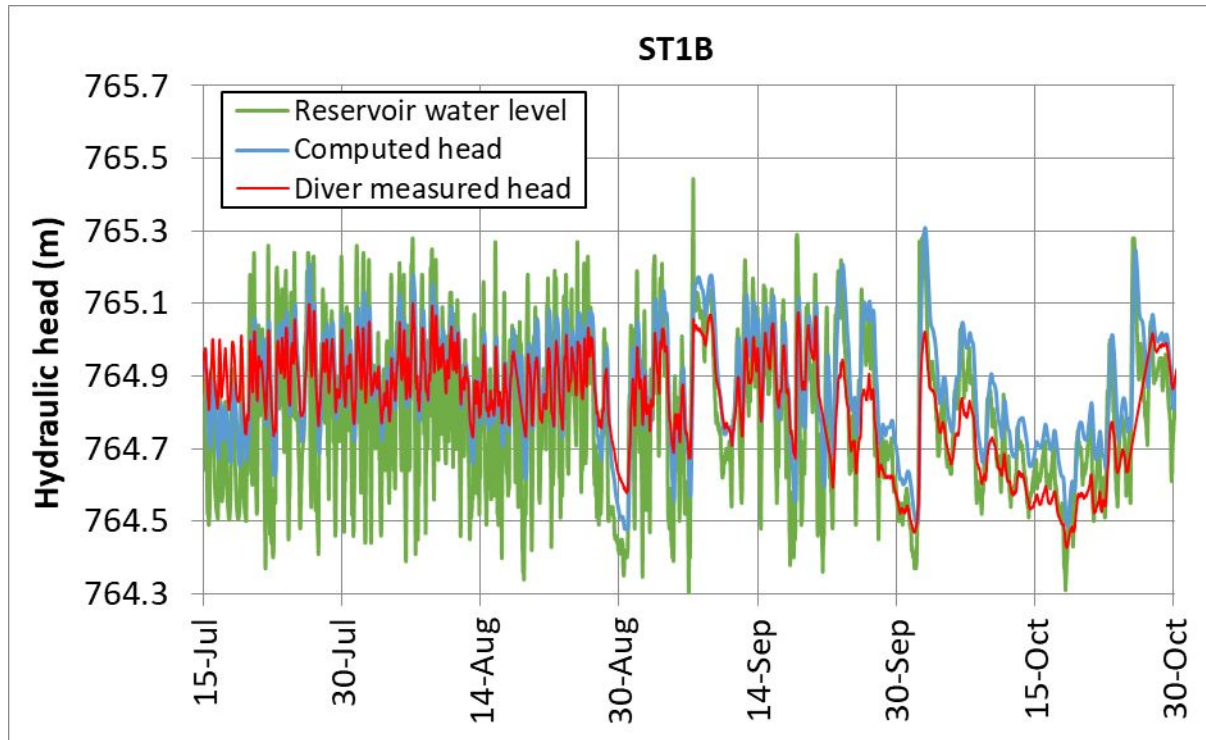
# 2D groundwater flow model of the Gállego alluvial

- Model calibration: fit of measured hydraulic heads



# 2D groundwater flow model of the Gállego alluvial

- Model calibration: fit of measured hydraulic heads: ST1B

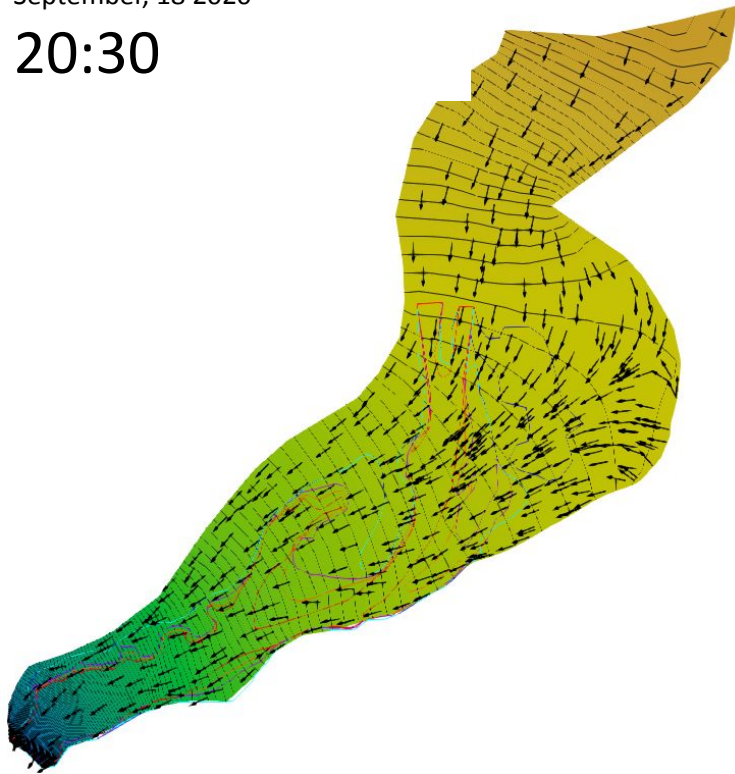


# 2D groundwater flow model of the Gállego alluvial

- Contours of computed hydraulic heads during a period of fluctuation

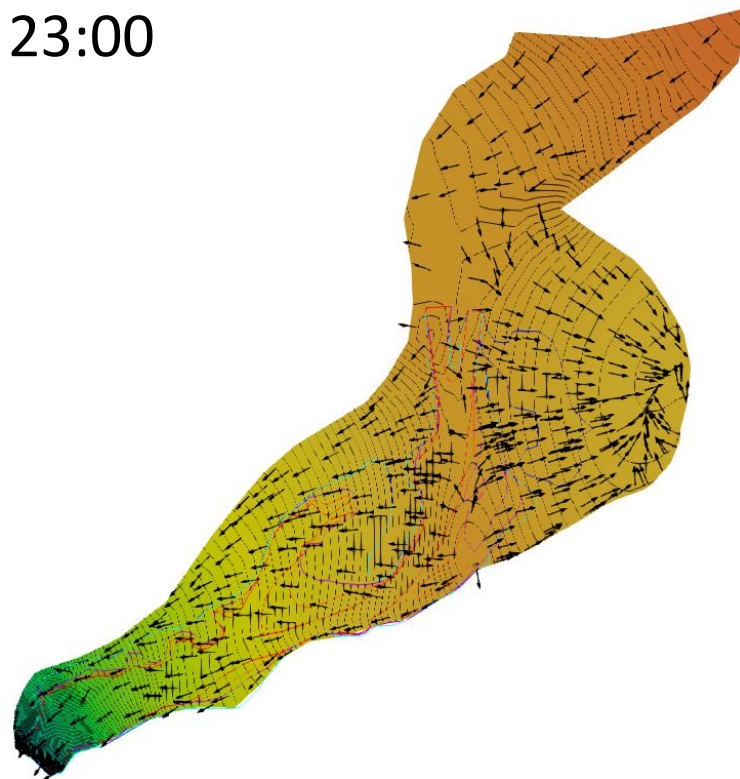
September, 18 2020

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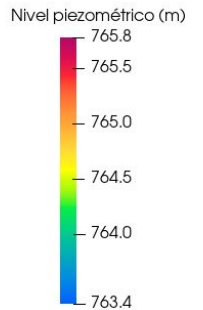
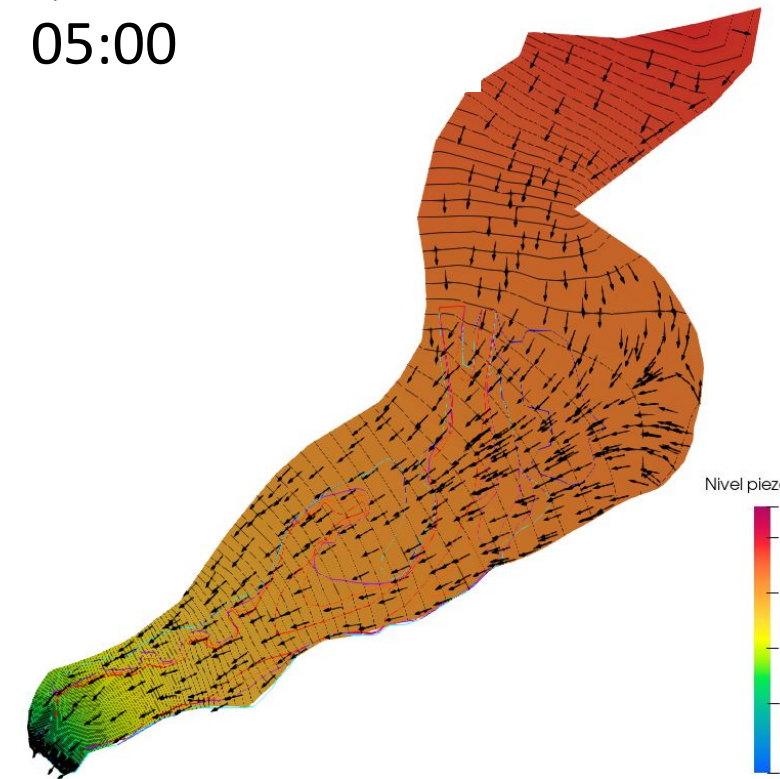
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September, 19 2020

05:00



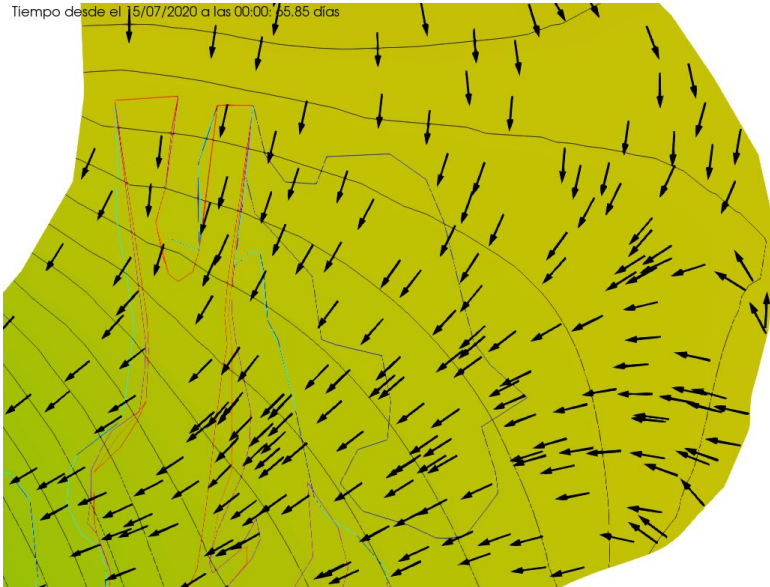
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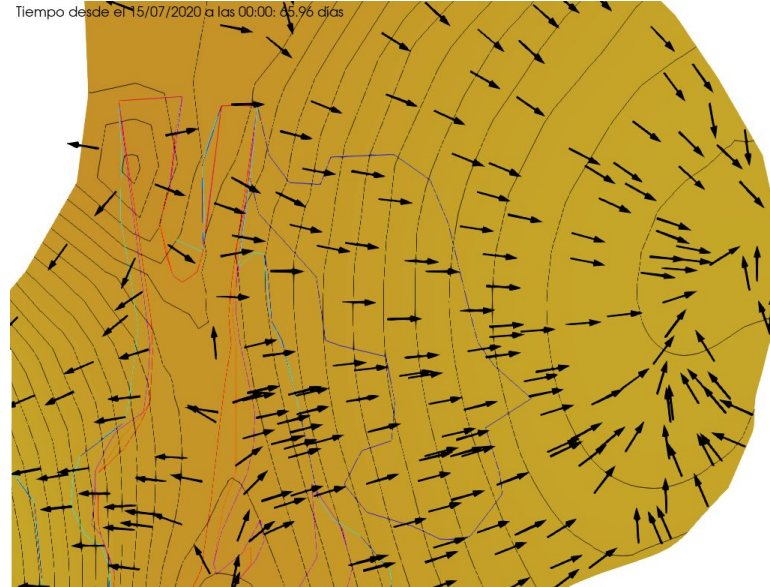
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September, 18 2020

23:00

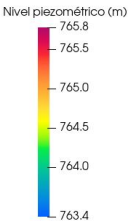
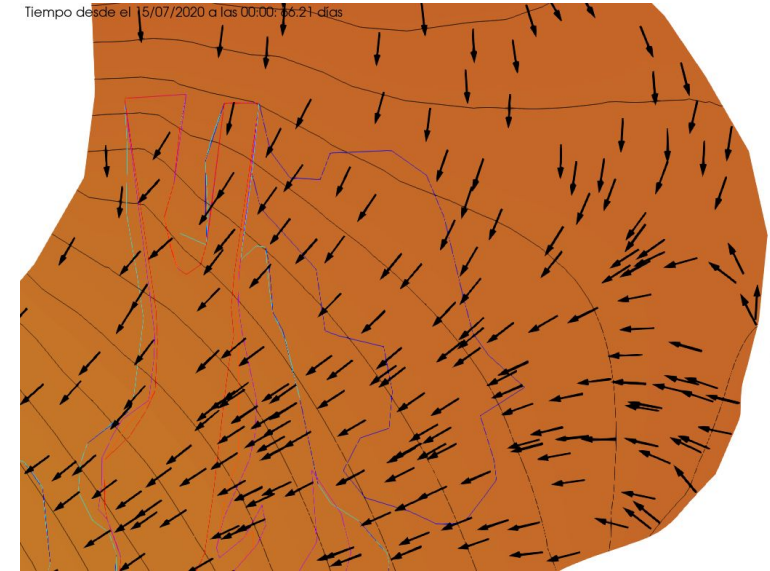
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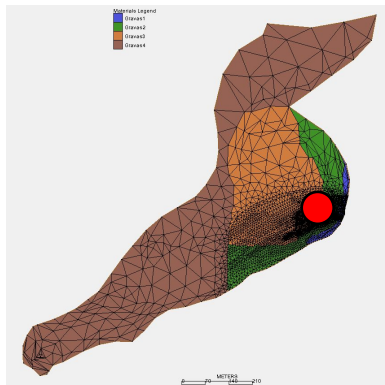
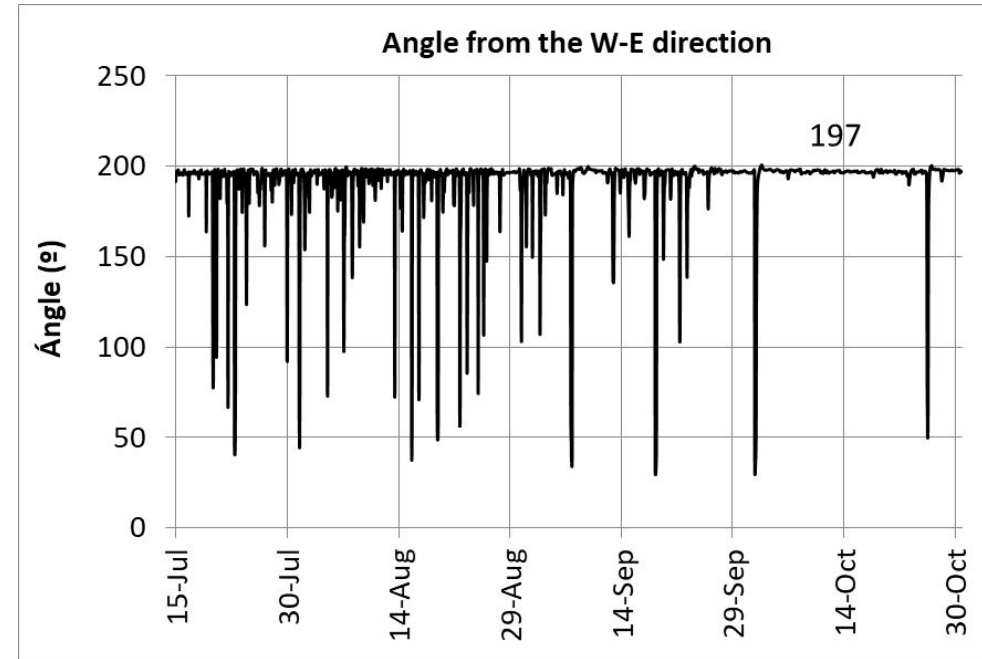
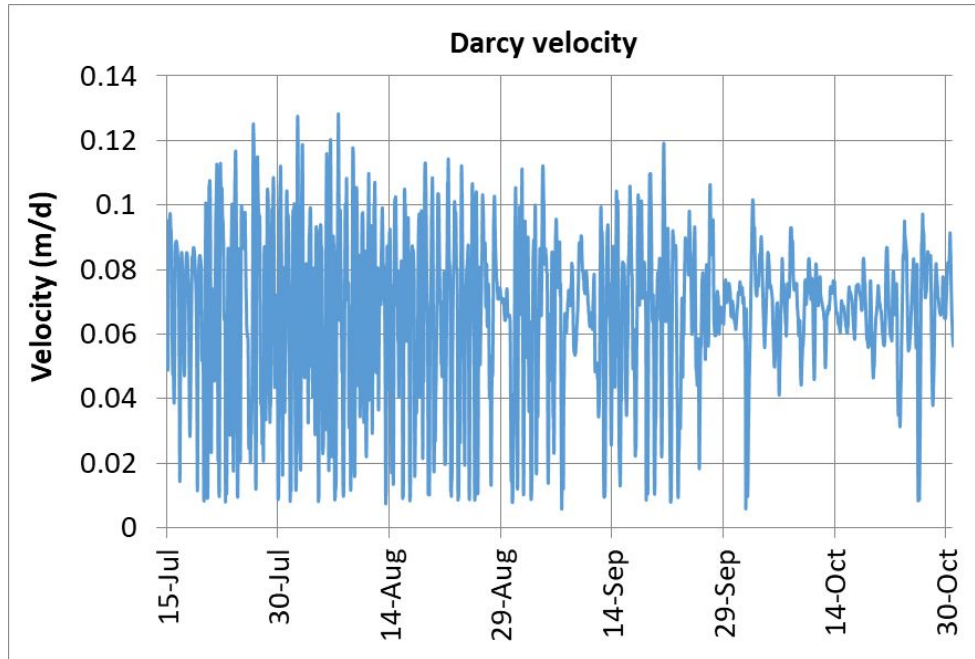
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Tiempo desde el 15/07/2020 a las 00:00: 66.21 días



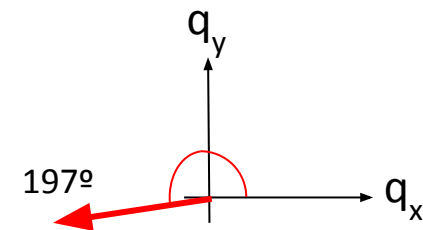
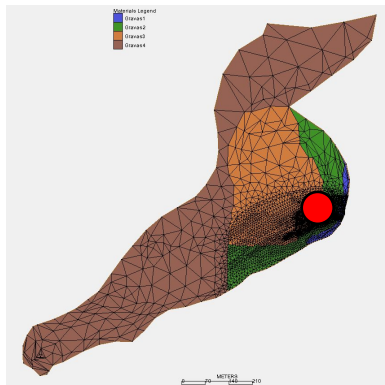
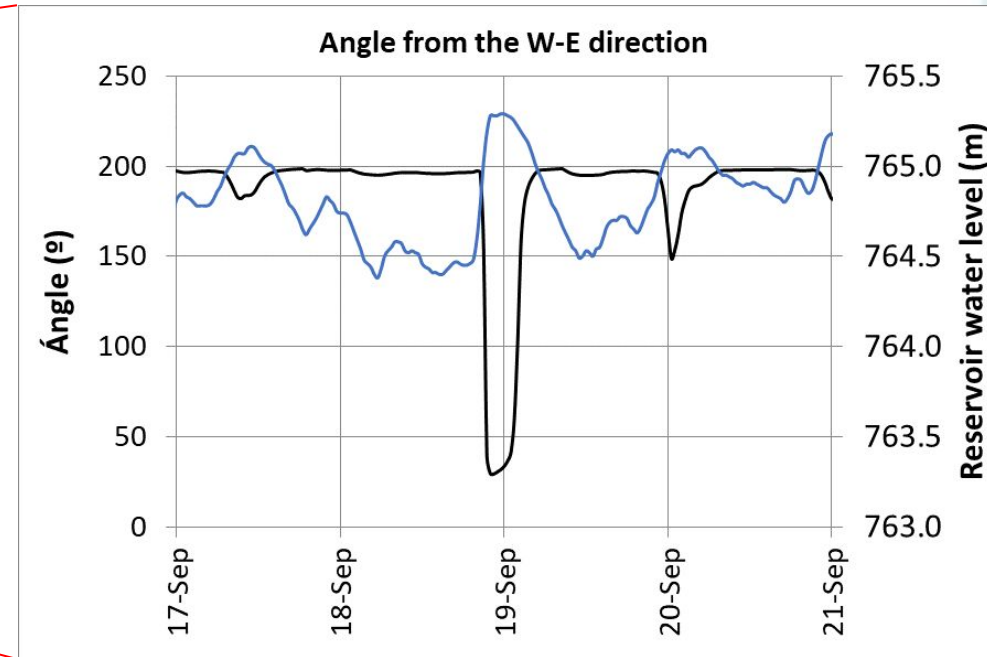
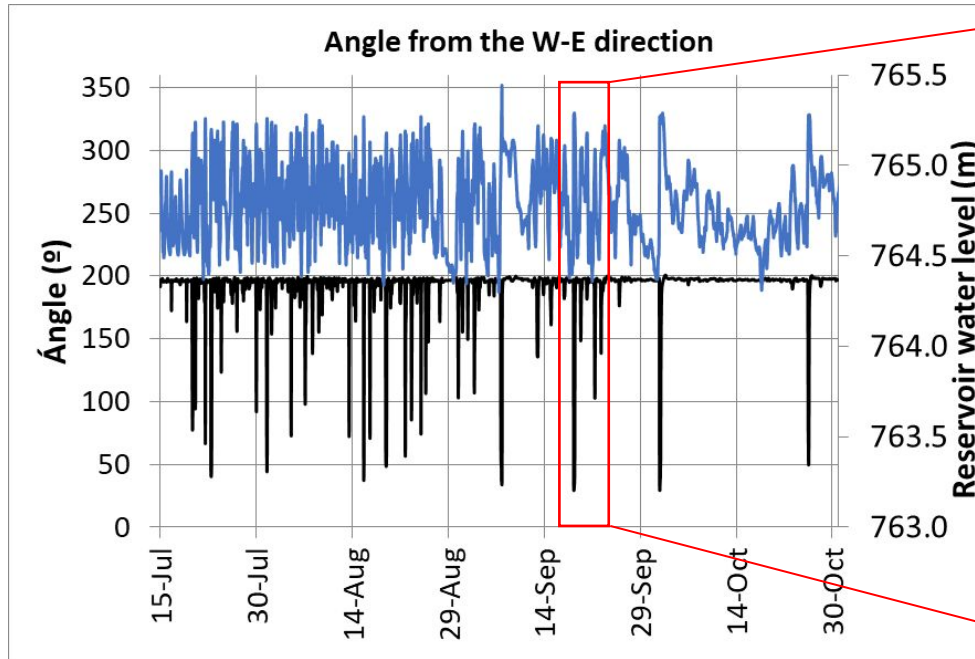
# 2D groundwater flow model of the Gállego alluvial

- Darcy velocity: modulus
- Flow direction: angle w.r.t. E-W



# 2D groundwater flow model of the Gállego alluvial

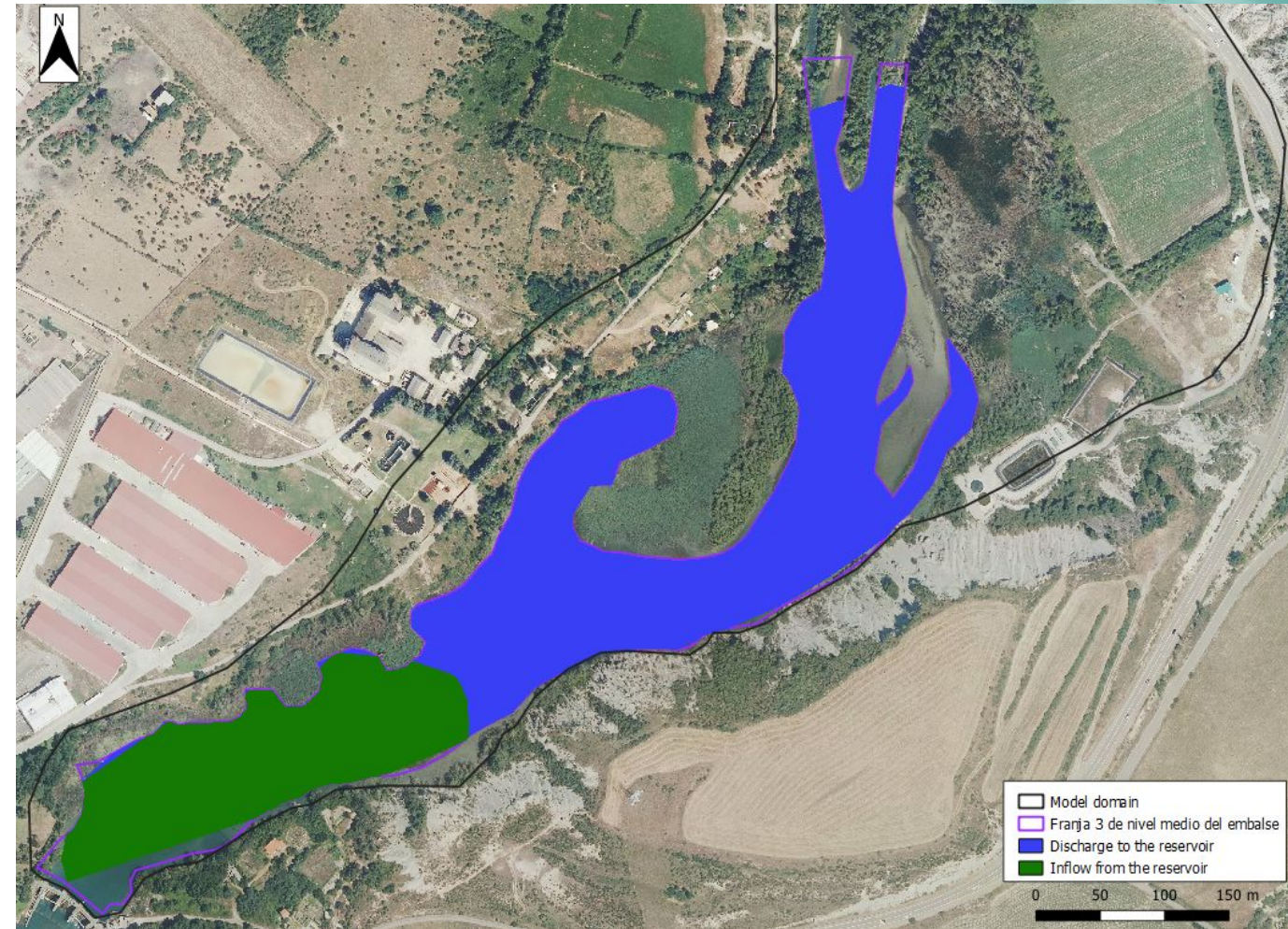
- Flow direction: angle w.r.t. E-W



# 2D groundwater flow model of the Gállego alluvial

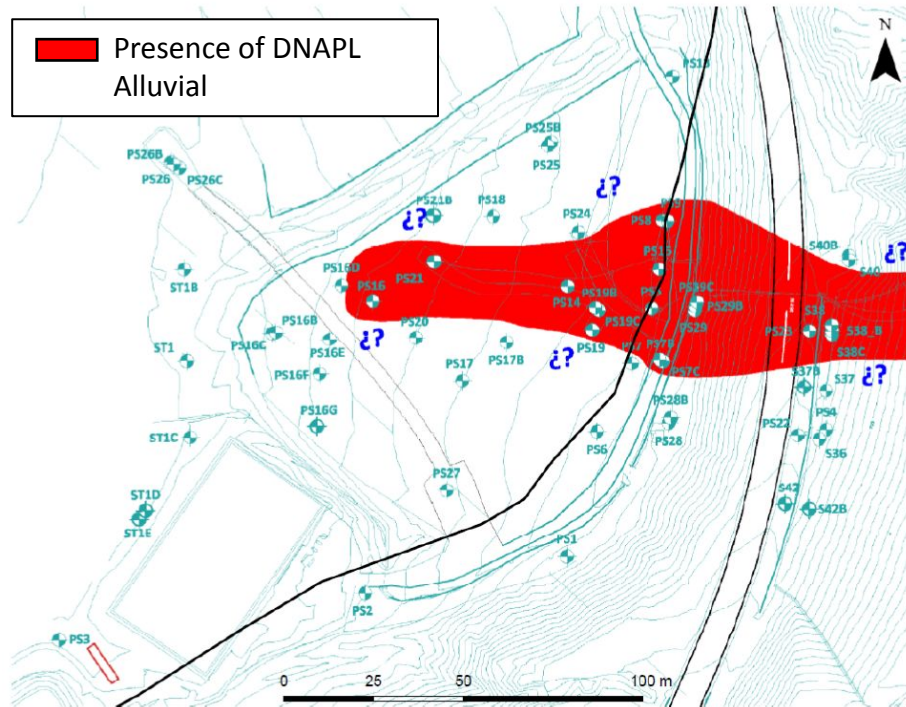
- Aquifer/reservoir interactions

- The alluvial aquifer discharges into reservoir in the upstream part
  - The discharge is very sensitive to the vertical conductivity of the silting sediments
- The reservoir recharges the aquifer in the downstream part near the dam

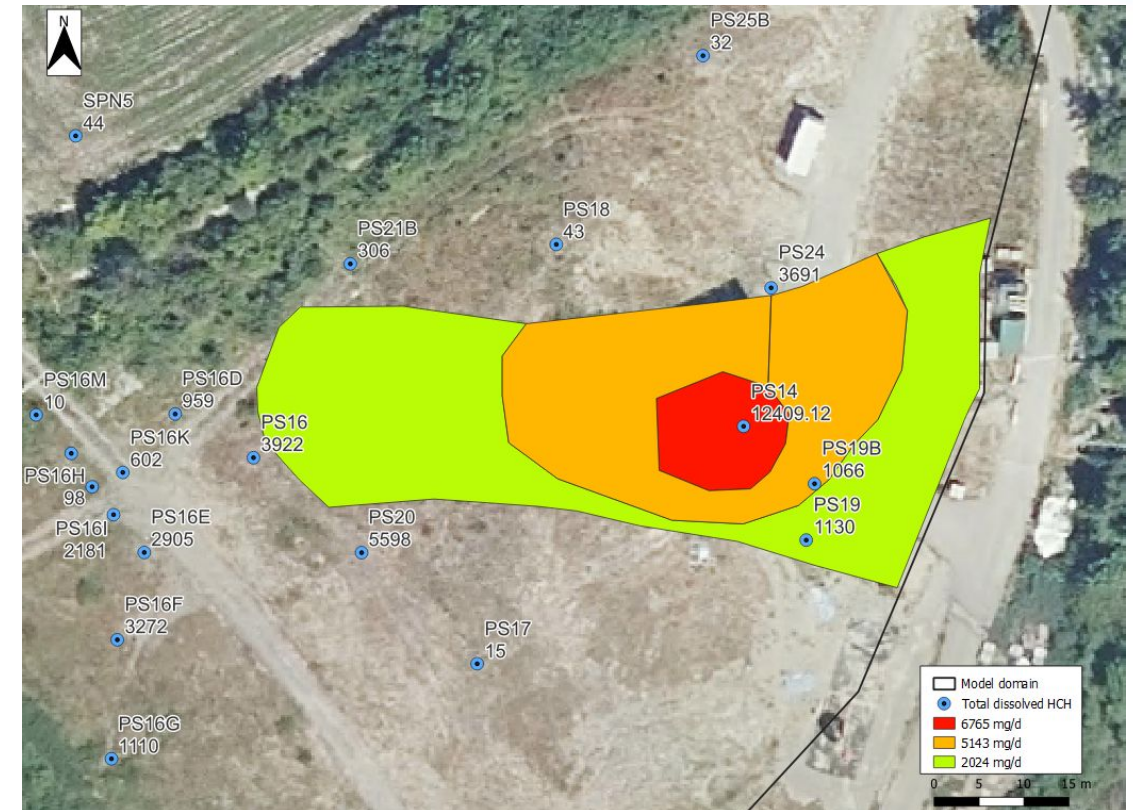


# 2D contaminant transport model

- Transport of total (all isomers) dissolved HCH
- Steady-state flow conditions
- Sources of dissolved HCH
  - Mass inflow from the landfill
  - Source terms in areas where DNAPL has been detected (EMGRISA)



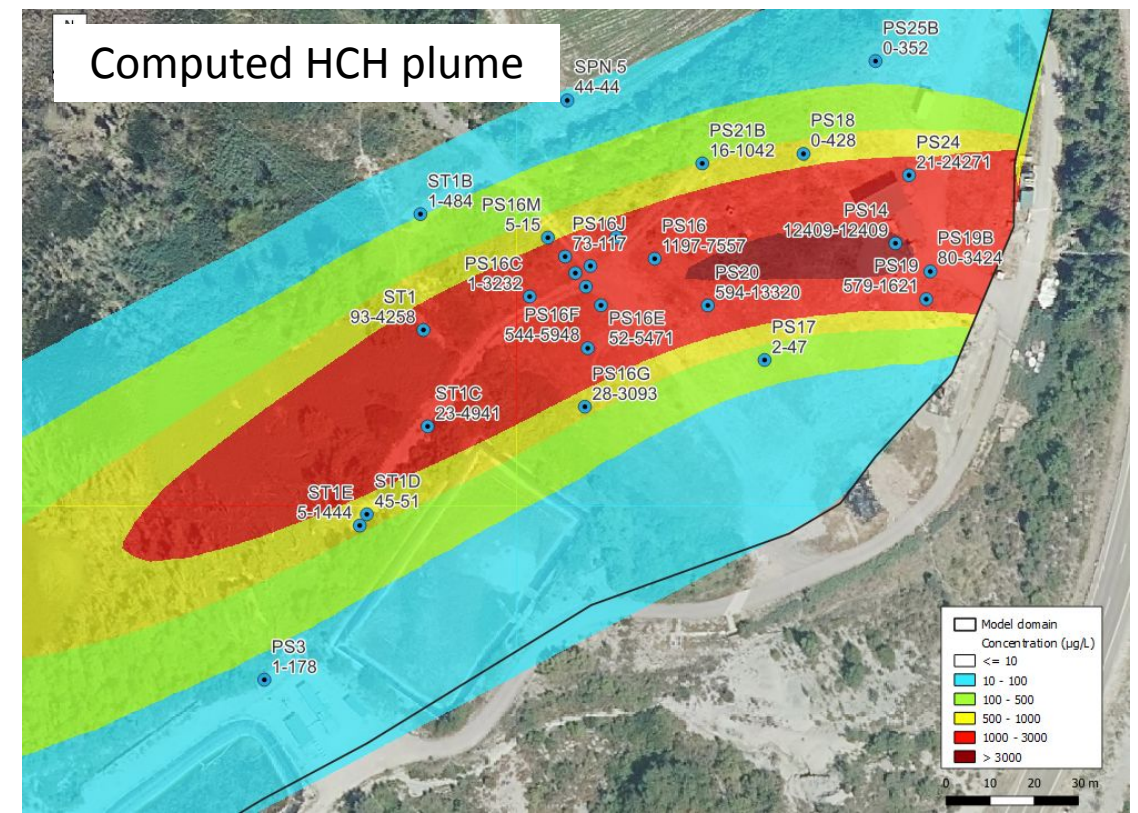
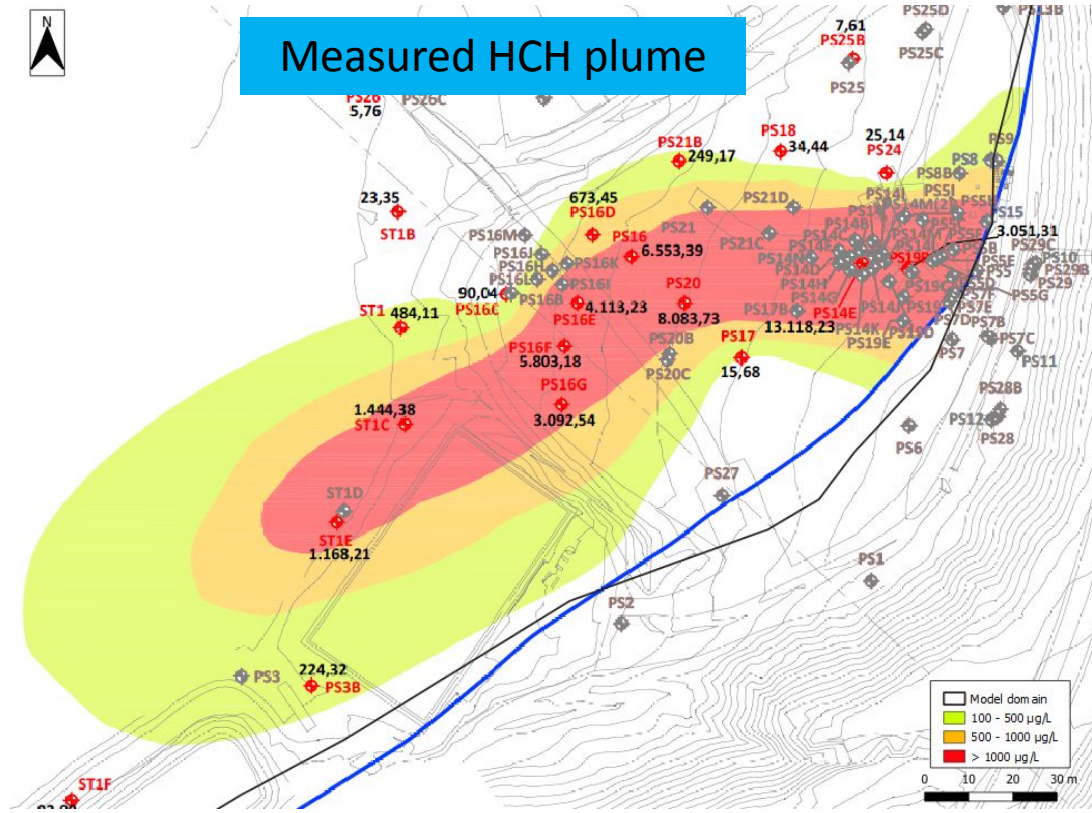
Presence of DNAPL. EMGRISA, 2014.



Dissolved HCH source term.

# 2D contaminant transport model

- Dissolved HCH in equilibrium with the HCH in the solid phase and DNAPL
- Assume a constant distribution coefficient  $K_d$
- The computed plume of dissolved HCH is very sensitive to  $K_d$
- The  $K_d$  calibrated = 3 L/kg
  - Smaller than the values reported by Lorenzo et al. (2020)



# Conclusions & future work

- 2D finite element groundwater flow and total dissolved HCH transport models through the alluvial aquifer of the Gállego river have been presented
- Reservoir level oscillations play a major role in the hydrogeology of the site
  - Oscillations of the reservoir level propagate in a damped way and with delay into the alluvial piezometric oscillations in the aquifer
  - The offset and the damping of the hydraulic heads in the alluvial aquifer CONFIRM unequivocally that the aquifer is not in direct hydraulic contact with the Sabiñánigo reservoir.
- Groundwater flow direction changes quickly in a daily basis in response to the oscillations of the reservoir level
  - Flow mostly in E-W/NE-SW under normal conditions when the head in the aquifer is larger than the level in the reservoir
  - The flow direction reverses to W-E when the reservoir water level rises quickly
- Groundwater flow model results confirm the validity of the conceptual model and reproduce the measured hydraulic heads in the aquifer

# Conclusions & future work

- The contaminant transport model (total dissolved HCH)
  - The computed plume and the mass flux of dissolved HCH are very sensitive to changes in the distribution coefficient
  - The best fit to the measured HCH data is obtained with  $K_d = 3 \text{ L/kg}$
  - The flux of dissolved HCH leaving the site towards the Sabiñánigo reservoir is  $= 2.1 \text{ kg/year}$  for  $K_d = 10 \text{ L/kg}$
- Model uncertainties
  - Lack of hydrodynamic data for the sediments and alluvial silts
  - Lack of HCH data in the silting sediments
  - Sources of HCH
- Future work
  - Include local aquifer heterogeneities
  - Transient flow model for contaminant transport
  - Temperature dependence of HCH solubility
  - $K_d$  dependent on DOM

# THANK YOU FOR YOUR ATTENTION

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<https://cica.udc.gal/group/aquaterra/>

## ACKNOWLEDGEMENTS

Gobierno de Aragón



EMGRISA



CONFEDERACIÓN HIDROGRÁFICA DEL EBRO



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