# Reconstruction of the historical evolution and present-day functioning of a highly impacted river and assessment of sediment injections as a restoration measure:

## a case study of the Péage de Roussillon reach along the Rhône river (France) using the 1D basement model.


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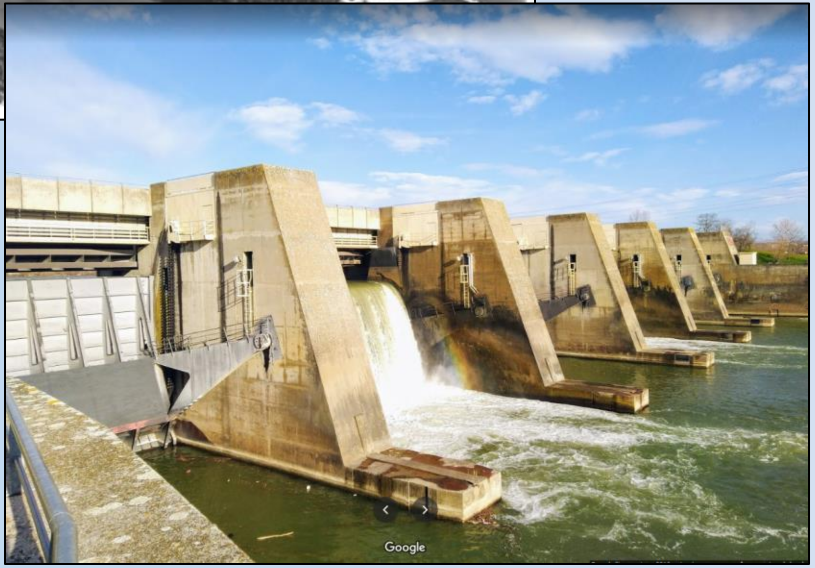
# Context and motivations

- Late 19th century: embankments (narrowing); mid-20th century: 19 successive diversion dams and canals for hydropower

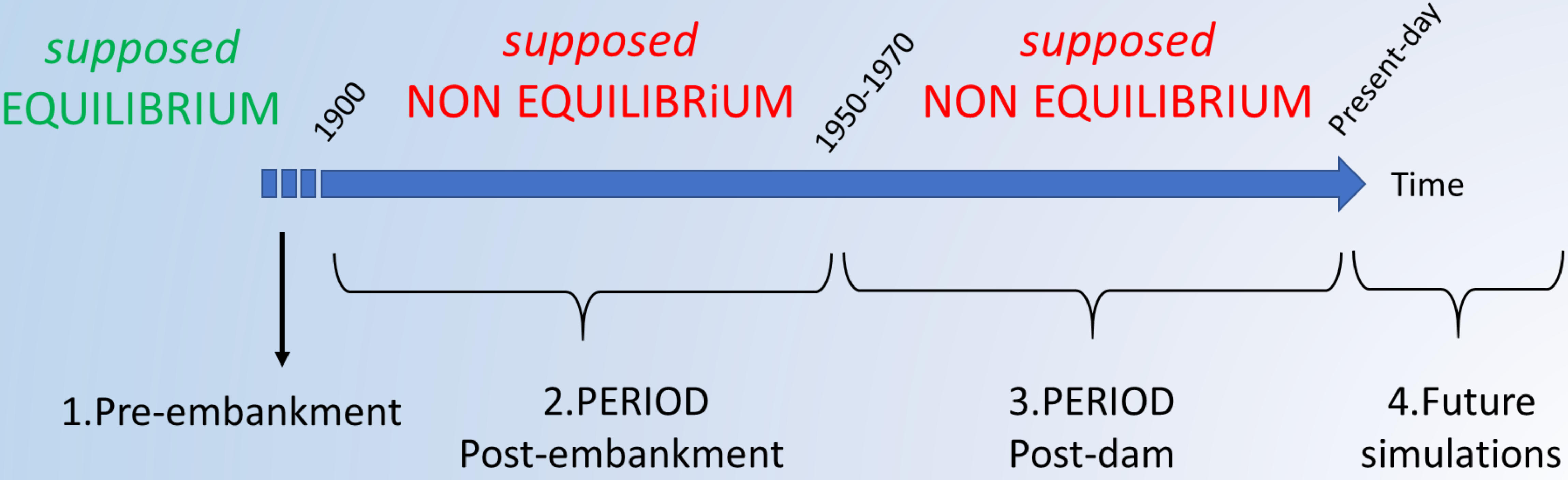


# Context and motivations

- Armored bed, low transport rates → Restoration: reinjections, improve biodiversity
- Objectives of the study:
  - Understanding the historical evolution, relative effects of different time periods
  - Validated 1D morphodynamic model used as a tool for river management (future scenarios)

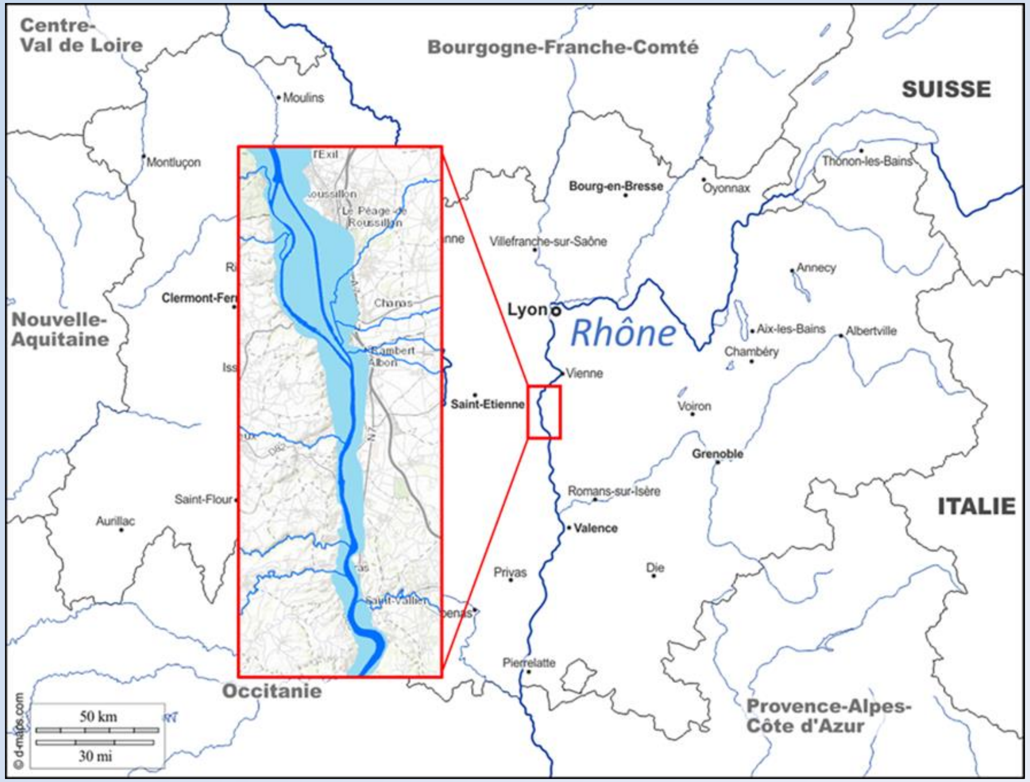
# Modelling approach

- It is unknown if the present-day river bed is in equilibrium considering the long-term impacts of embankments and dams.
- Hypothesis: The Rhone River was in equilibrium prior to channel embankments.

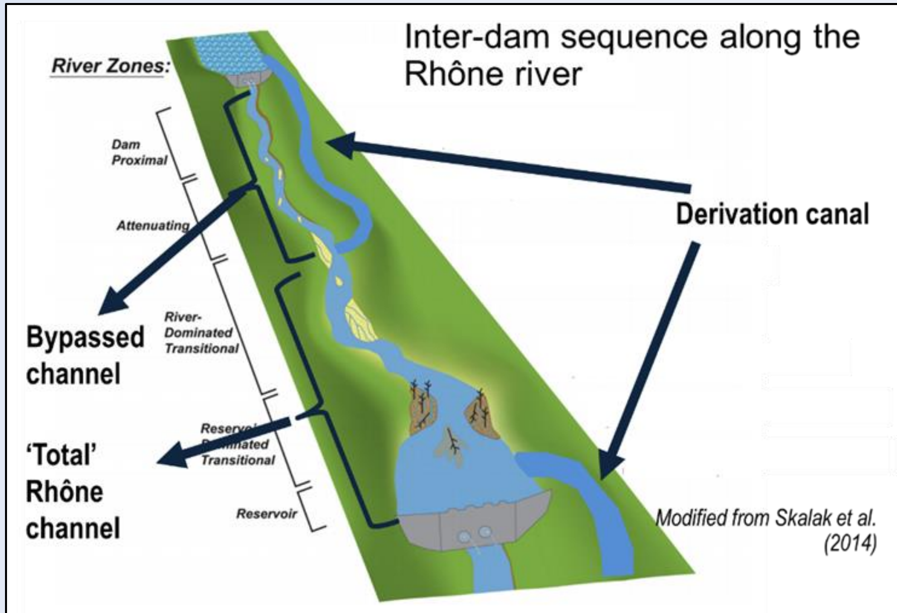


# Study reach Péage de Roussillon

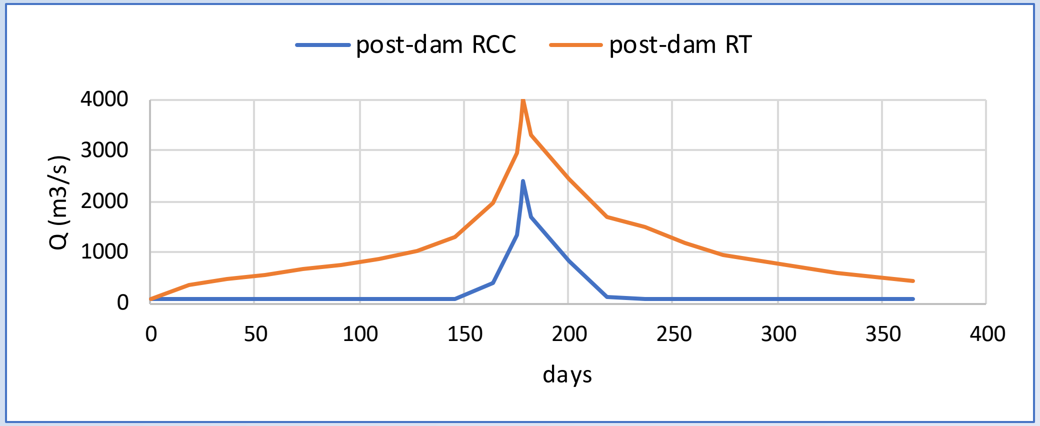
- 50 km downstream Lyon
- 30 km long
- Located between the Saint-Pierre-de-Bœuf dam (in operation 1977) and the Arras dam (in operation 1971)




- consists of a bypassed reach (old Rhône) immediately downstream of the upstream dam that runs parallel to the derivation canal, downstream the confluence is the total Rhône, part of which is within the backwater zone of the downstream dam



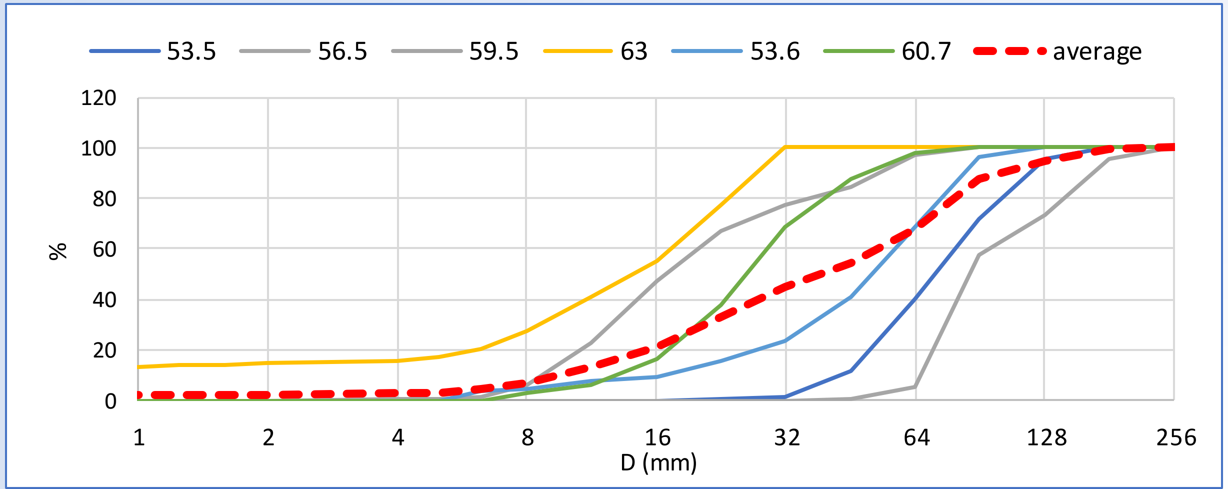
# Data (entire Rhône)




- Bathymetric data (longitudinal profiles, cross sections) and historical maps
- Flow duration curves + hydraulic simulations (Mage software – *Inrae*)
- Grain size distribution (GSD) measured in the channel approximately every 5 km and on sporadic bars (surface and subsurface). There is large variety amongst samples :

**Data acquired through the OSR (reports, theses, papers)**

Grain size distributions at different locations in the old Rhône



# Estimating missing data : sediment load, sediment supply, surface and subsurface GSD

- Hypotheses:
  - The **hydrological regime** (hydrograph) did not change over the past 150 years (reductions in discharge in the old Rhône are only due to flow diversions).
  - The **sediment load** transported by the Rhône River today is a reasonable first-order approximation for the **historical load and sediment supply.**
  - Measurements of the subsurface GSD of bars are a reasonable proxy for the long-term averaged **GSD of the sediment load** of the river.

# Modeling steps

- Used Basement to estimate present day **bedload transport rate** under the conditions of a pre-dam average flow hydrograph, present-day bed elevation and average channel width, and present-day surface grain size.
- Estimated mean annual **sediment supply** from this load: 8.72E-06 m3/s (=275m3/yr) = VERY LOW.
- Implemented this load in the analytical method by Blom et al (2017) to estimate pre-management (equilibrium) **channel bed grain size distribution**.
- Ran a long-term simulation with these inputs until equilibrium was achieved.

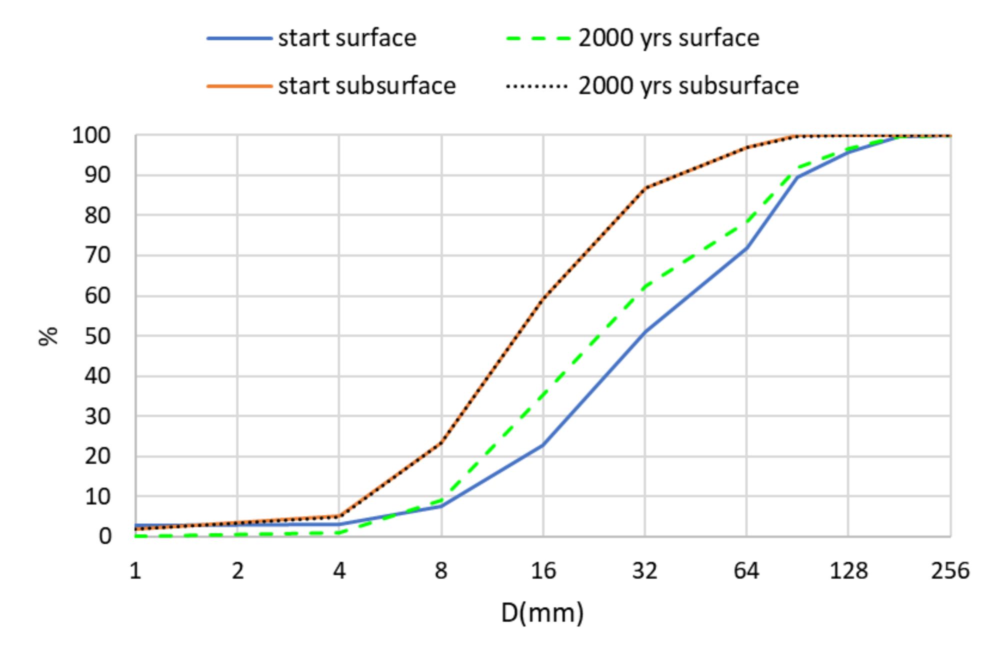
# Model configuration

- 1D grid: rectangular cross-sections with 1 km spacing and fixed average width
- 10 grain classes

| | Width(m) | Bed elevation | Hydraulics | Surface GSD |
|---|---|---|---|---|
| **Pre-embankment** | 300 | fixed slope from LP 1897 | Pre-dam | estimated |
| **Post-Embankment** | 230 | result pre-emankment | Pre-dam | result pre-embankment |
| **Post-Dam** | 150 + 230 | result post-embankment | Post-dam | result post-embankment |

# Pre-embankment (<1900): equilibrium condition

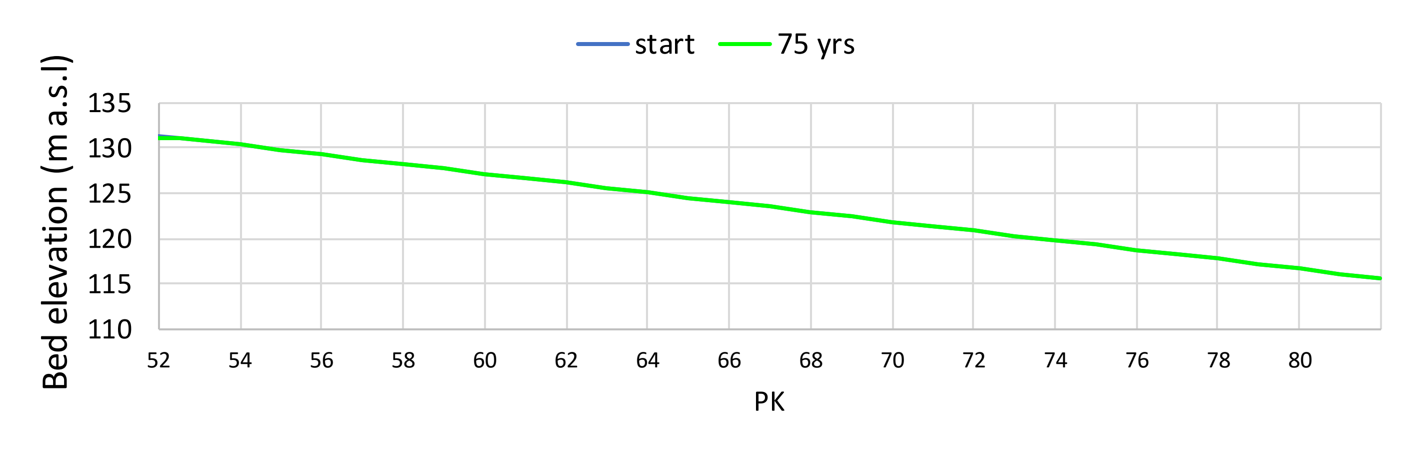
- Stable bed was achieved

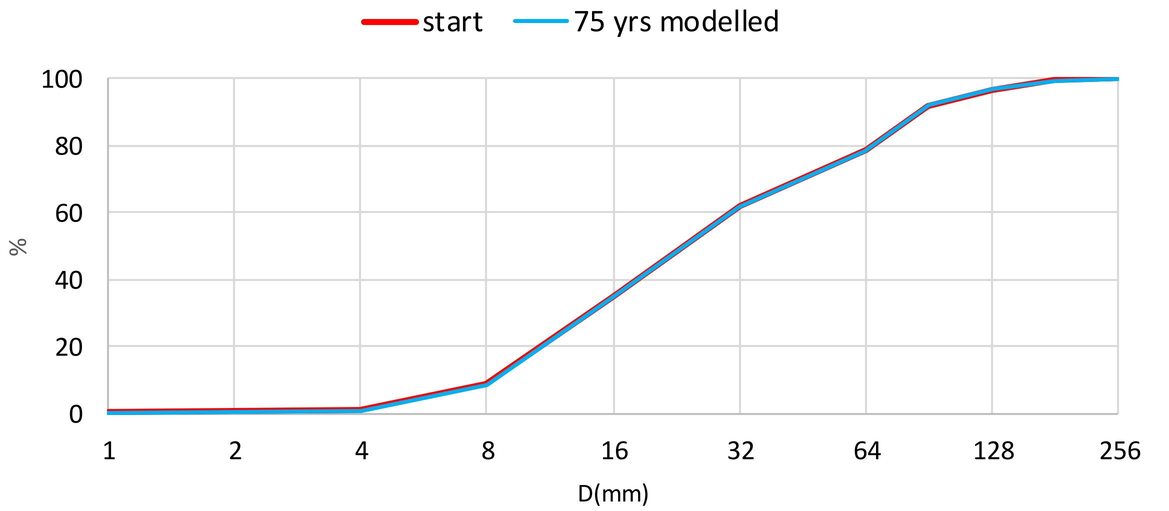

- Surface grain size distribution becomes finer in equilibrium condition

# Post-embankment period (1900-1975)

- Bed remains stable after narrowing (bed elevation and GSD)

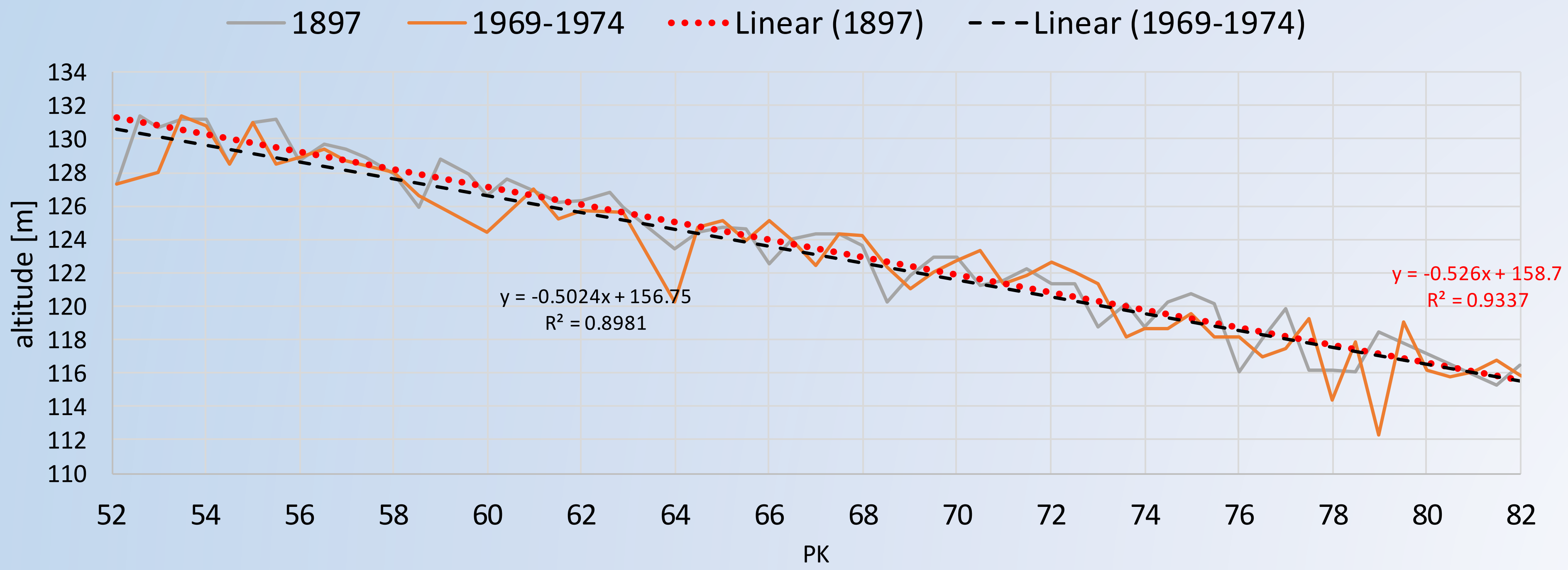



Grain size distribution

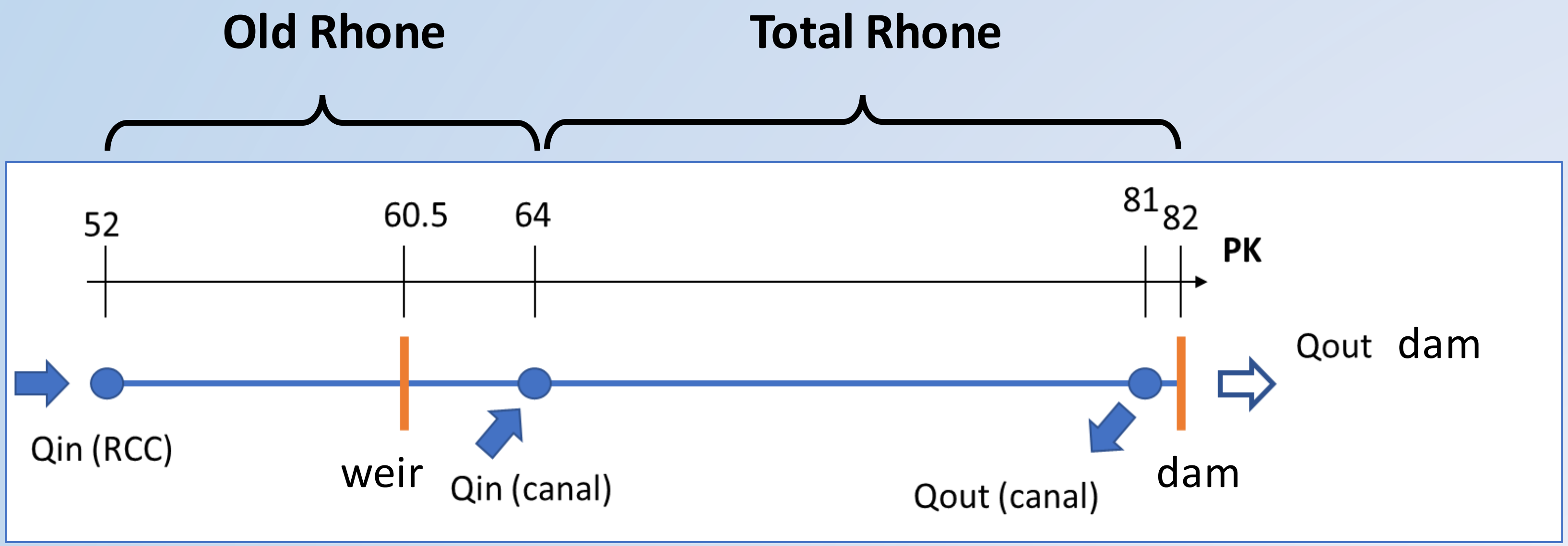


# Post-embankment period (1900-1975)

- Bed remains stable after narrowing (bed elevation and GSD): in agreement with measured data (no change in slope)



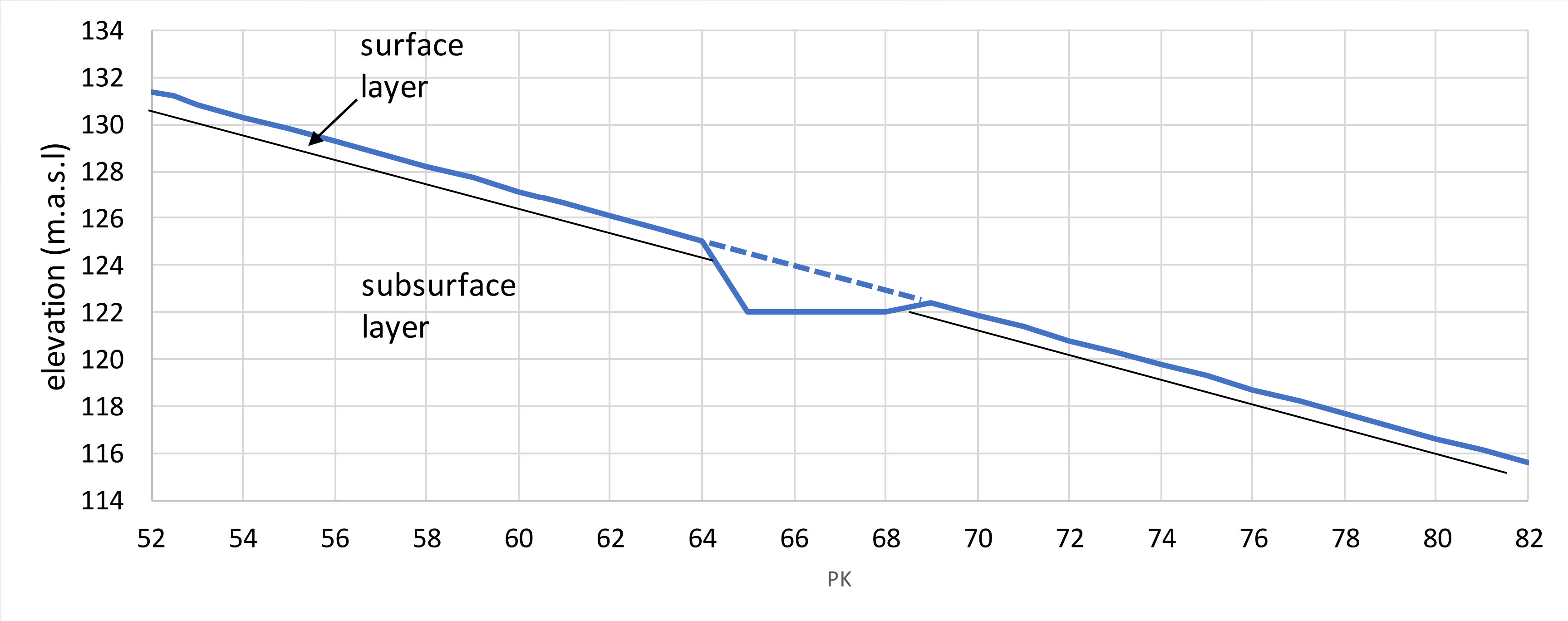
# Post-dam period (1975-2020)




- Weir has fixed height, dam height varies as a function of Q (calibrated with water levels using actual cross-sections)

# Post-dam period (1975-2020)

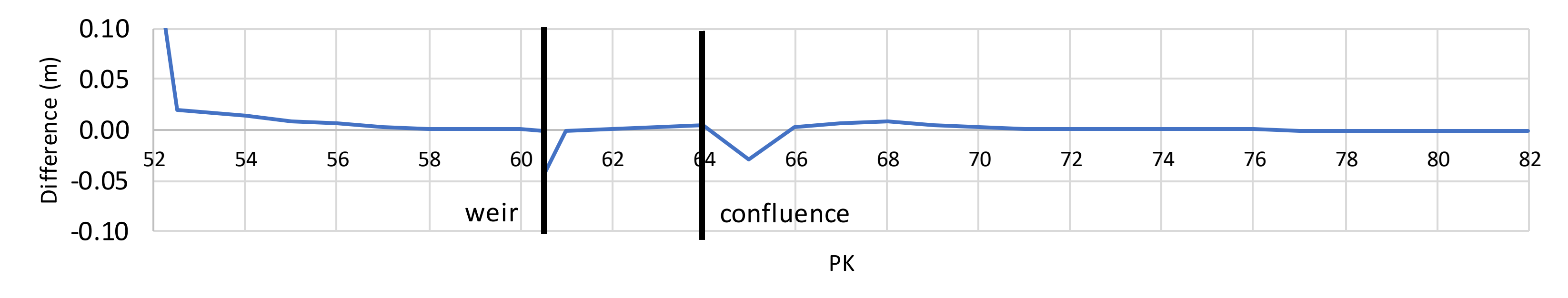
- Dredging: removal of bed material (1979-1985) downstream of the confluence in order to improve functioning of the hydropower station in the canal (“dragage energetique”).



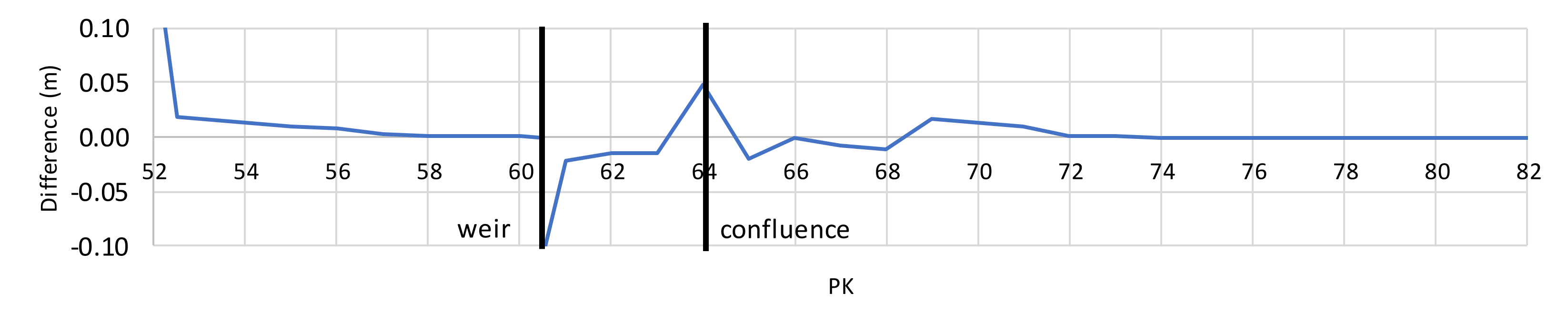
# Post-dam period (1975-2020)

DIFFERENCE IN BED ELEVATION

- Impact dams
  - Minor changes in bed elevation are in agreement with measured data

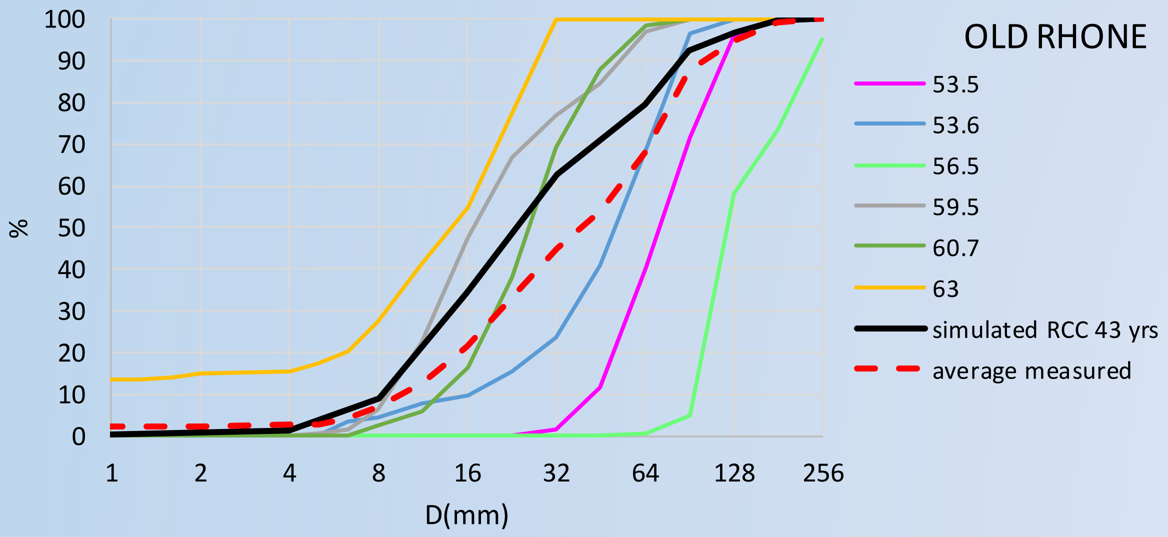


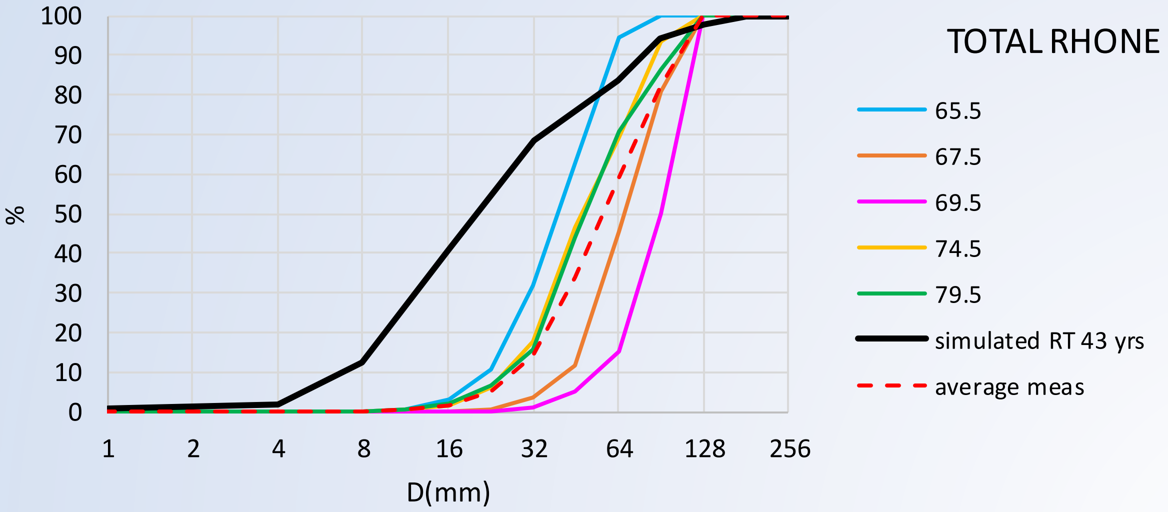

- Impact dams + dredging
  - Minor changes in bed elevation



# Post-dam period (1975-2020)

- GSD dams + dredging: validation with measured data
- Large variability. Old Rhône results are acceptable. Total Rhône shows in simulation larger % of finer materials. (under-representation of finer materials in measurements due to sampling method?)



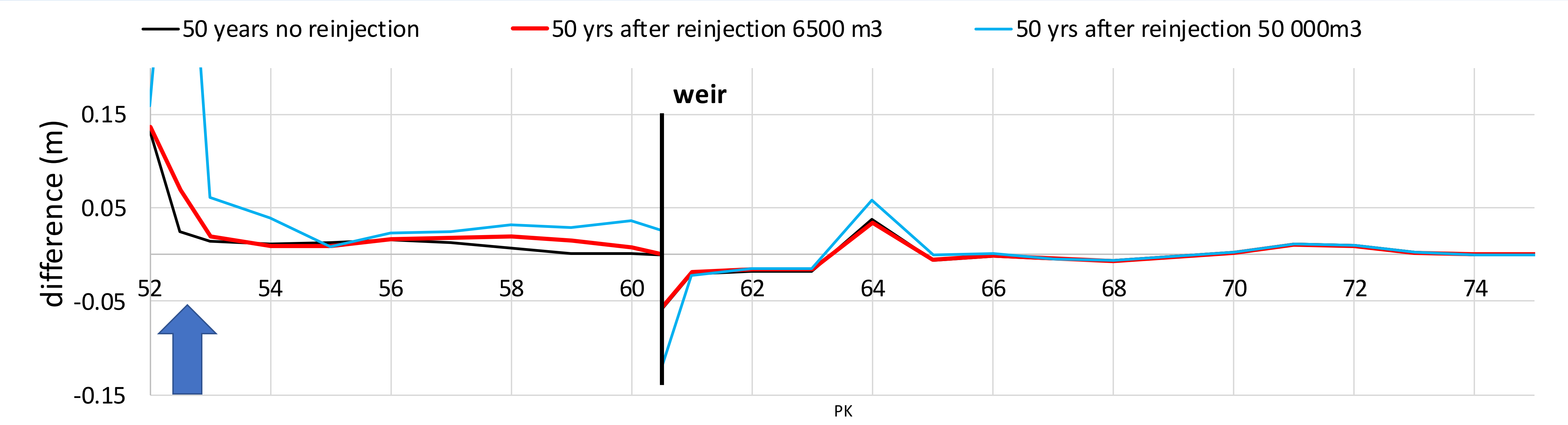
# Scenarios on present-day bed: reinjections

- Actual reinjection volume of 6500 m3 with actual GSD
- A reinjection volume of 50 000 m3 with actual GSD
- A reinjection volume of 50 000 m3 using a single grain size

- Other scenarios not included here: changing hydograph, sediment supply

# Scenarios on present-day bed: reinjections

1. Comparison of different sediment volumes at the end of a 50 years simulation



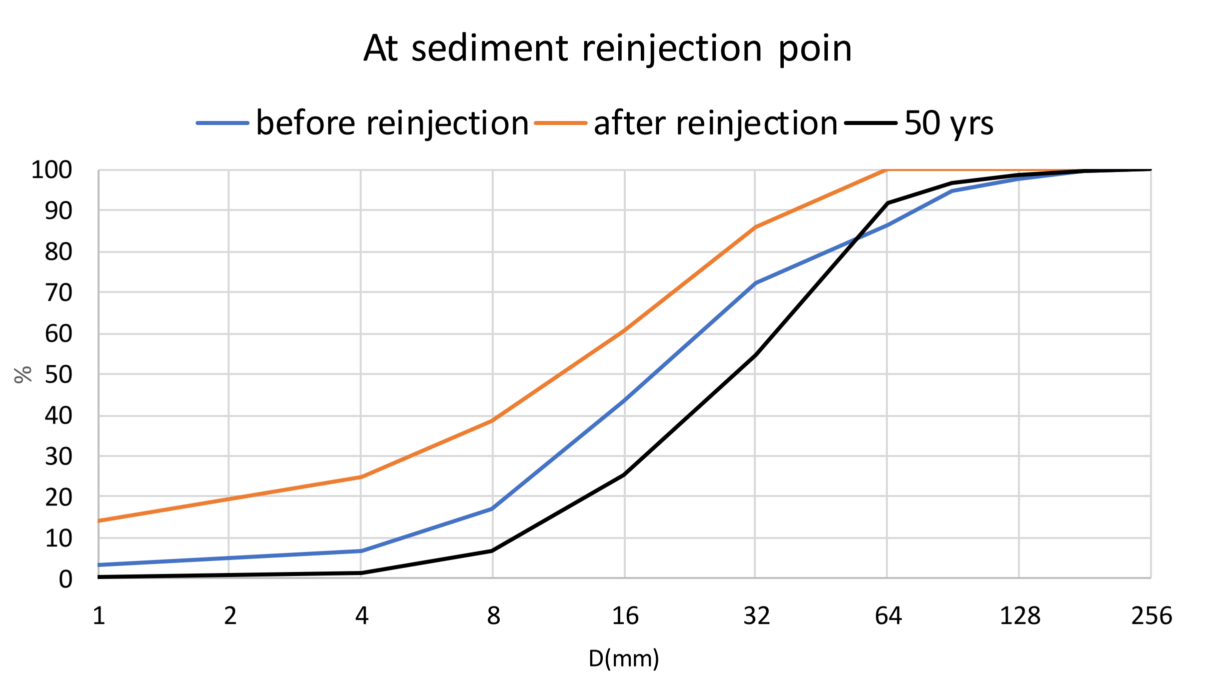

Slow propagation of reinjected sediments (largest in 1st year). Limited and spread deposition. For a 6500m3 reinjection, erosion of the reinjection pile stopped at certain point (possible armouring).

The weir does not allow sediment to pass in the 1D model. The option is considered to implement dredging upstream of the weir and use volumes read-out to inject downstream of the weir.

# Scenarios on present-day bed: reinjections

1. Comparison of different sediment volumes at the end of a 50 year simulation

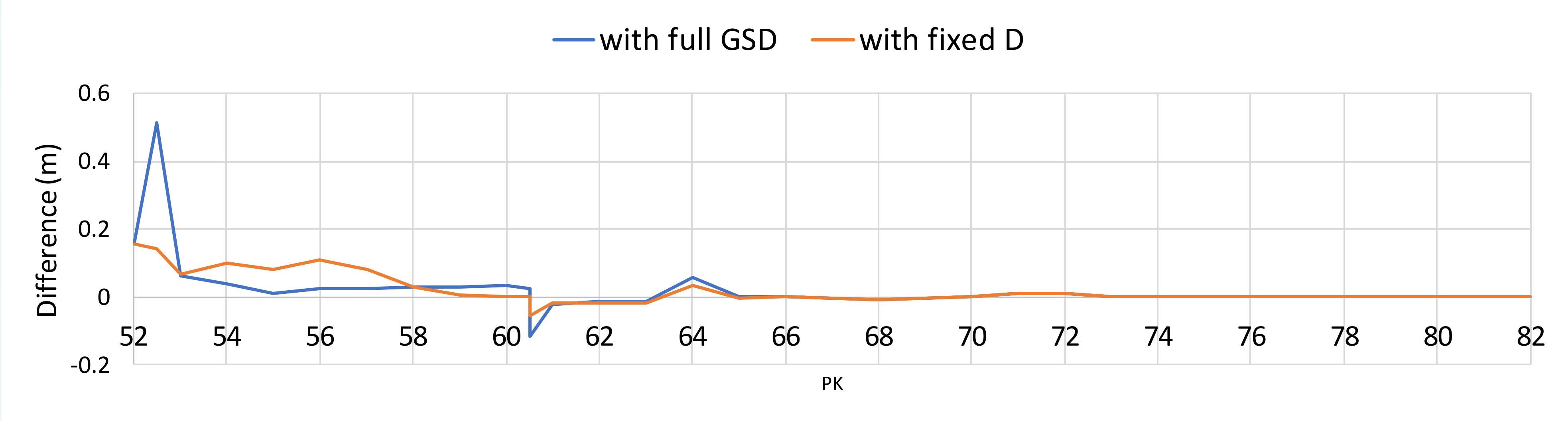
The surface GSD of the pile at reinjection became coarser over time.




More study is needed to compare different types of sediment piles, alter the location of reinjection and use a finer 1D-grid.

# Scenarios on present-day bed: reinjections

2. Comparison of reinjected material of different GSD (50 000m3 reinjected)




the sediment pile eroded much faster when using a single grain size of 22.5 mm. This could be related to the theoretical movement of a single grain size (less cohesion) and lack of armouring as seen with the full grain size distribution. This behaviour highlights the importance of choice of granulometry of the reinjected sediments.

# Scenarios on present-day bed: reinjections

Validation sediment reinjections: comparison with results from RFID tracers study + analytical model on displacement of particles (unpublished). This shows a good agreement on behaviour of river bed after reinjection:

- Slow dispersion (RFID shows maximum measured displacement 1.8 km in 1 year – model shows up to 3.5 km max)
- Majority remains upstream of the weir (analytical model has no restriction of passing the weir – confirming hydraulic impact of weir to be enough restricting passage)

# Conclusions

- Coupling the Basemement 1D software with well designed hypotheses and an analytical model allowed us to reproduce the historical evolution of a reach of the Rhone and achieve a stable model of the present-day system
- The post embankment period confirmed no significant impact of embankments on the bed elevation and GSD (equilibrium)
- The post dam period confirmed minor impact of dams on the bed elevation and GSD (near equilibrium)
- The reinjections confirmed slow propagation downstream and high significance of selecting the GSD for reinjected material
- Perspectives:
  - 1D Comparisons with other reaches
  - 2D modeling to study reinjections and compare in detail with bathymetry and RFID

THE END

THANK YOU