Study of groundwater contribution to floods in Mediterranean mountainous watersheds

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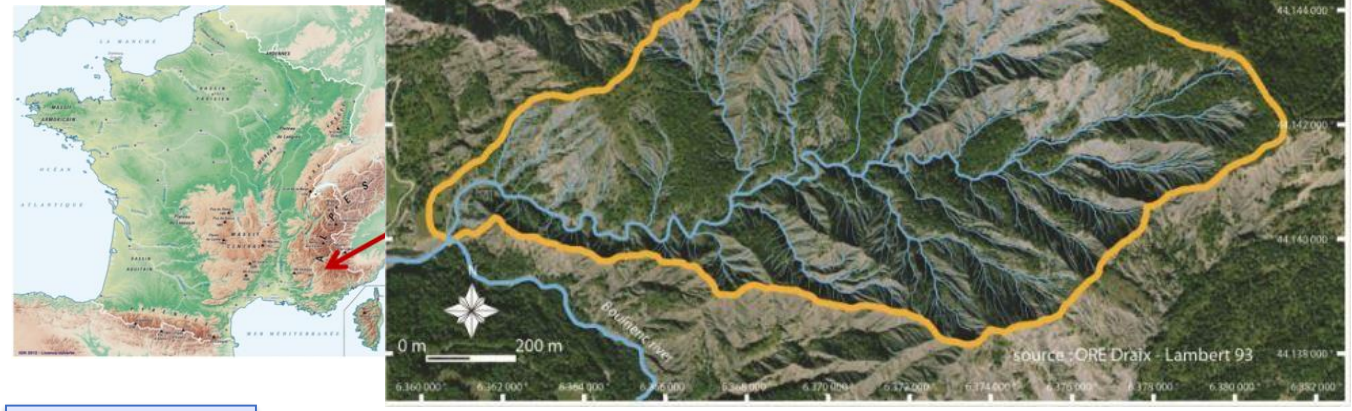
Study site : the Laval catchment of the Draix-Bleone observatory



Parshall flume at the Laval station

Geology

- Succession of limestone, marly limestone and **marl layers** from the Jurassic period, partially covered by Quaternary deposits.

Geochemistry

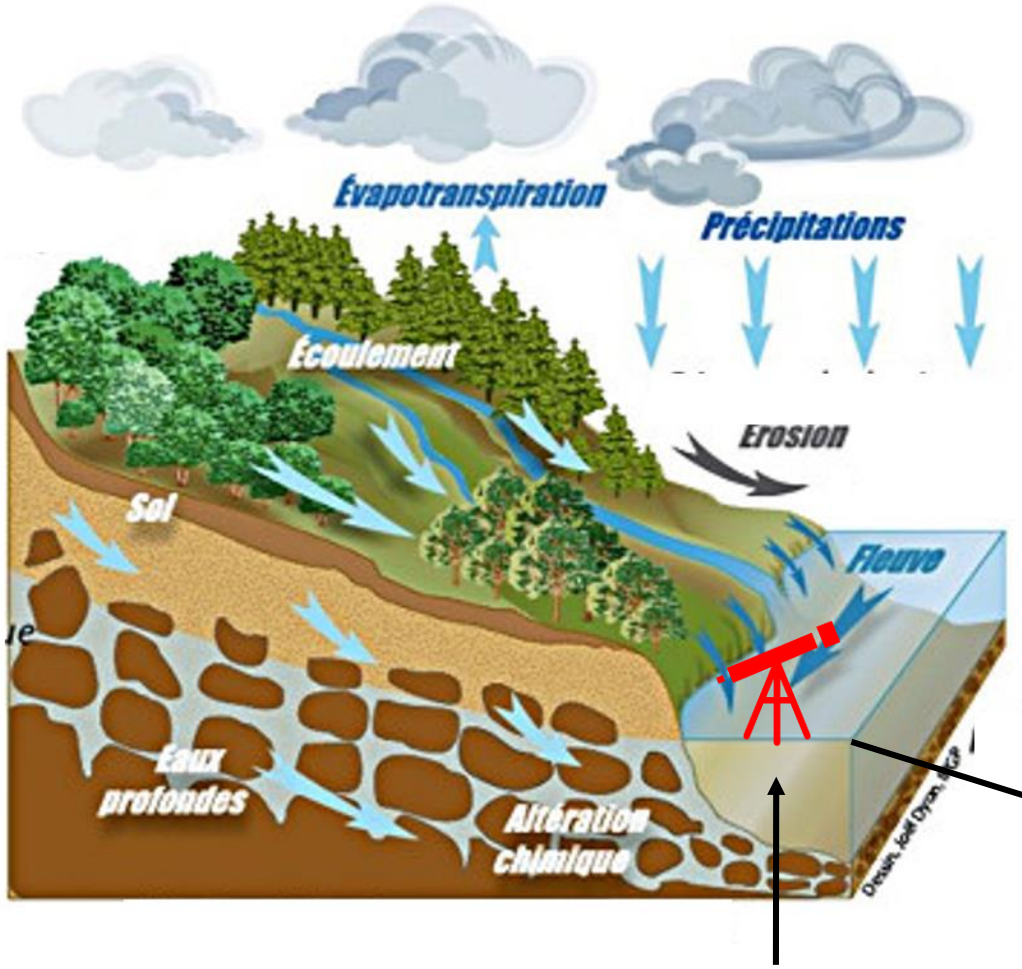
- **High mineralization** (mean conductivity of $0.9\ mS/cm$), dominated by sulfate ions.
- Water ionic load is primarily due to **sulfate salts, calcite, and clay minerals** hydrolyzed by meteoric water.

Data acquisition

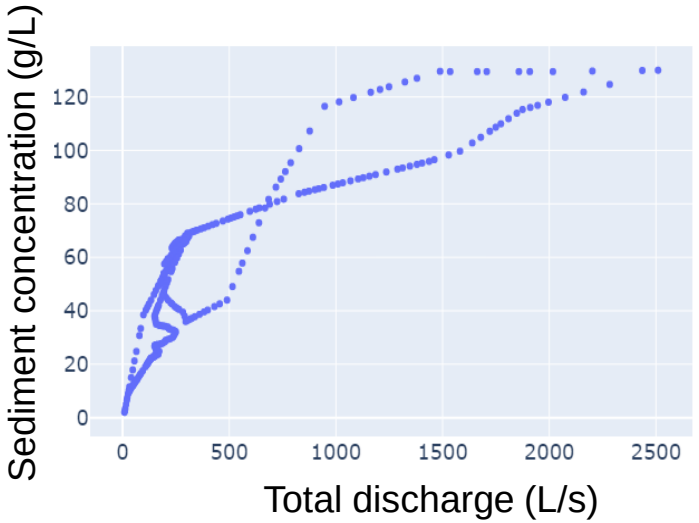
Temporal chronicles of :

- Water discharge
- Water concentration in fine suspended sediments (SS)
- Water conductivity from 2015
- Water major ion ($SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-}$) concentrations during some floods, monitored by Cras (2005), Mallet (2018) and Ogric (2021).

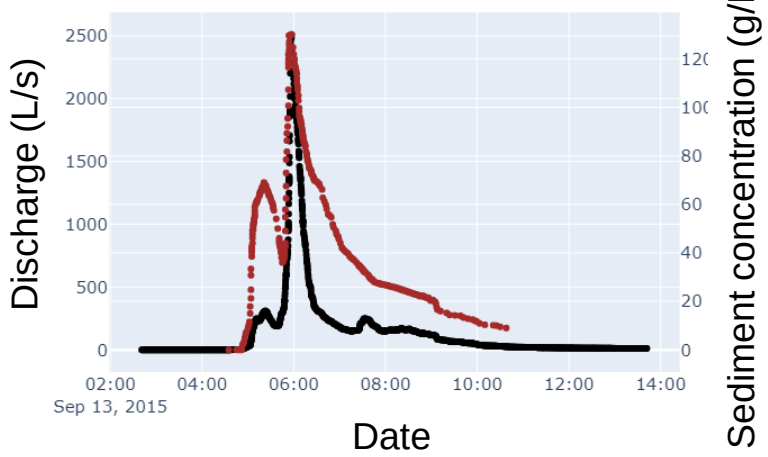
Context : study of erosion dynamics



Hydrological station

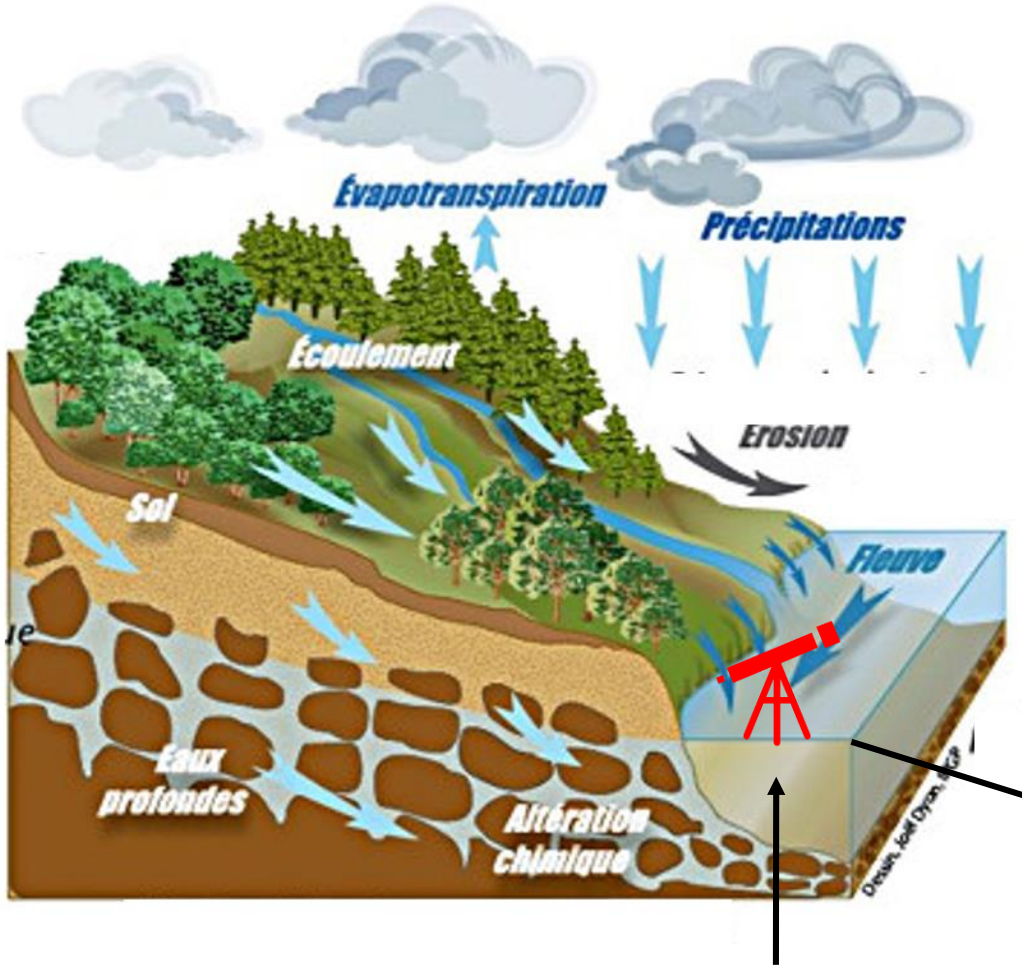


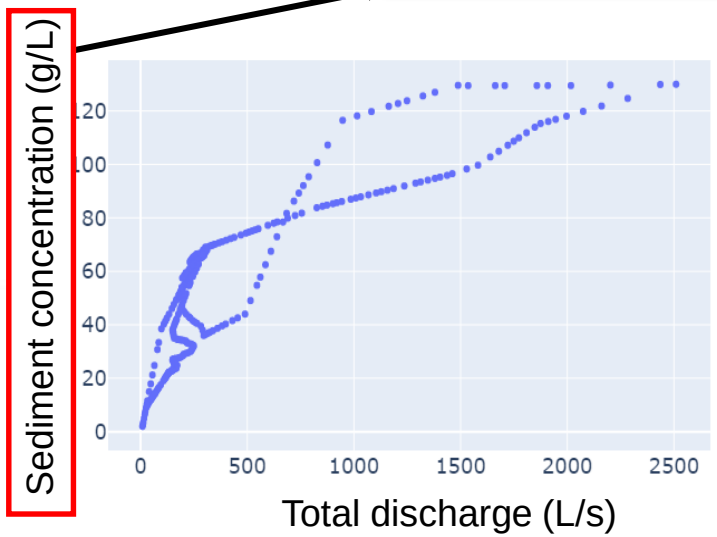
Flood hydrograph



Context : study of erosion dynamics

Origin of particles,
limited supply of sediments ?





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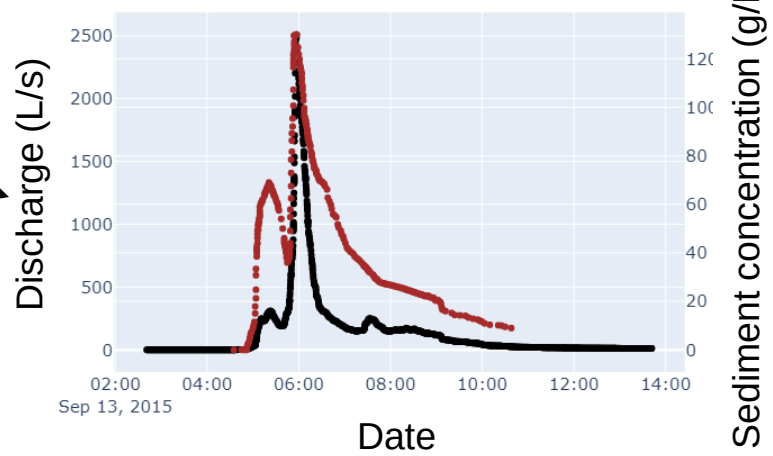

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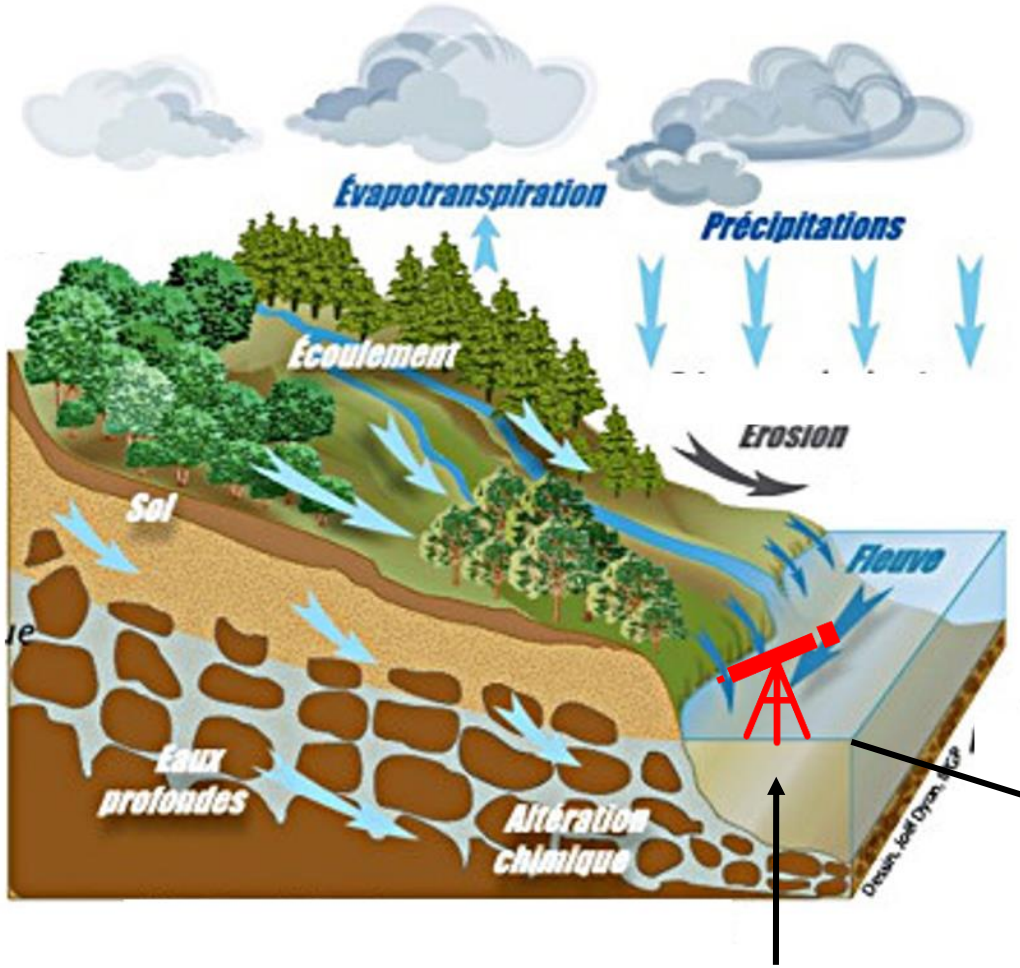

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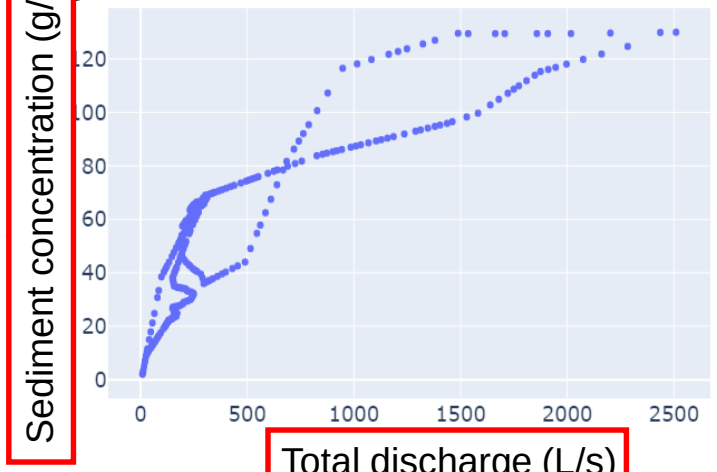

Origin of water ?

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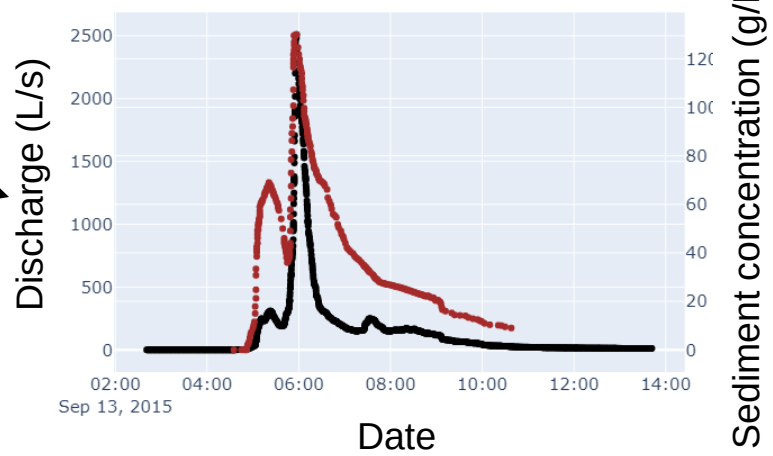

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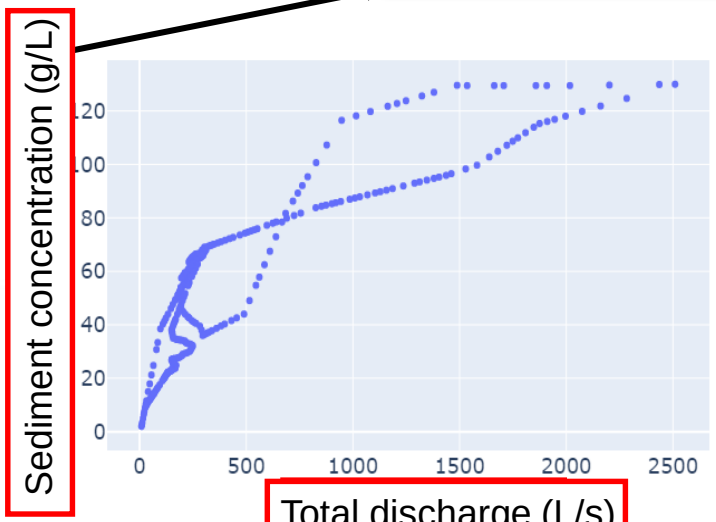

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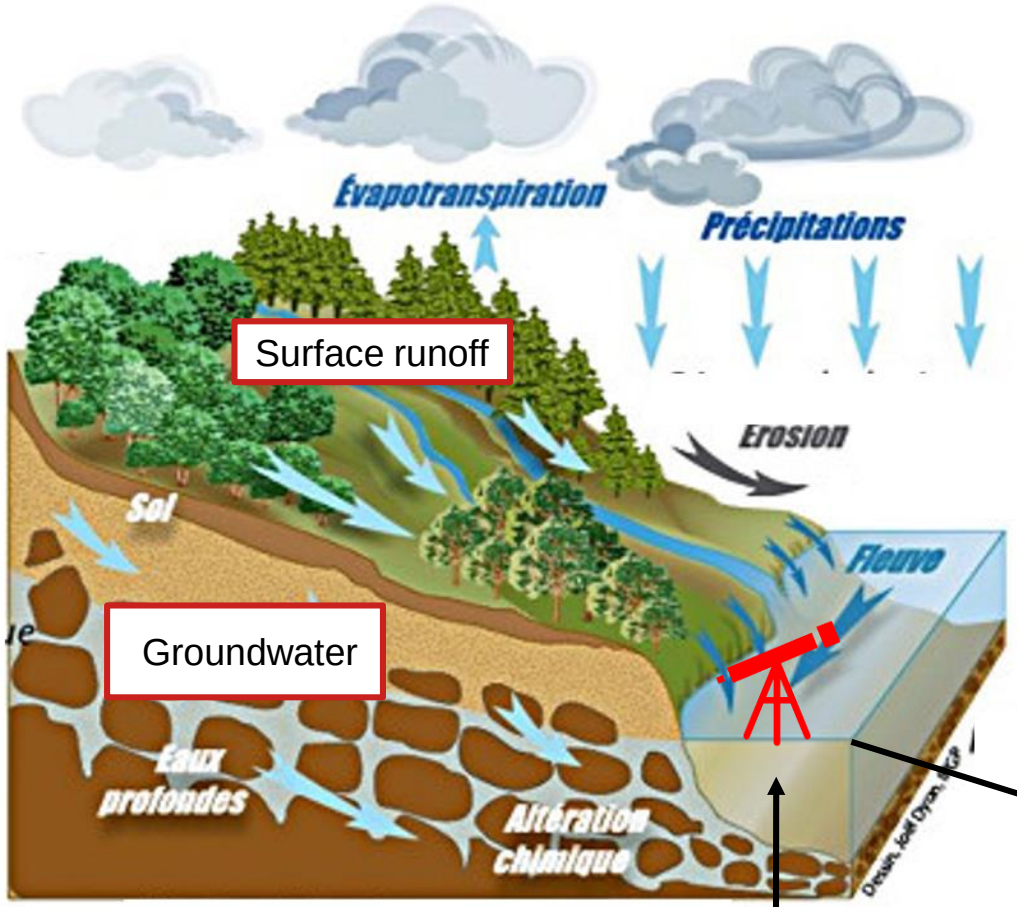

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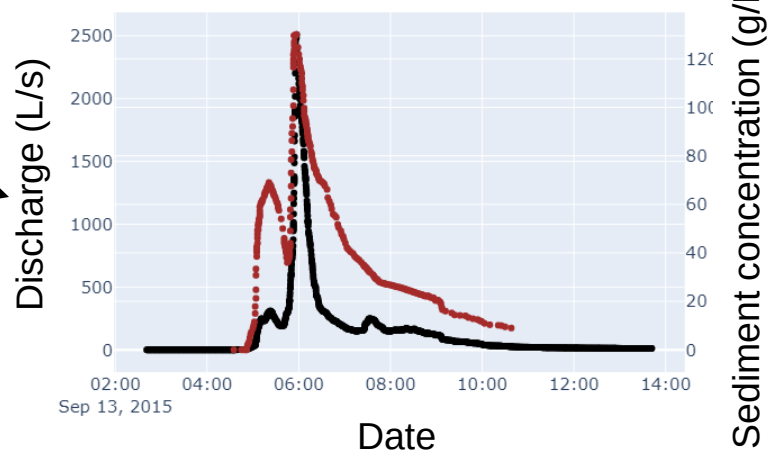

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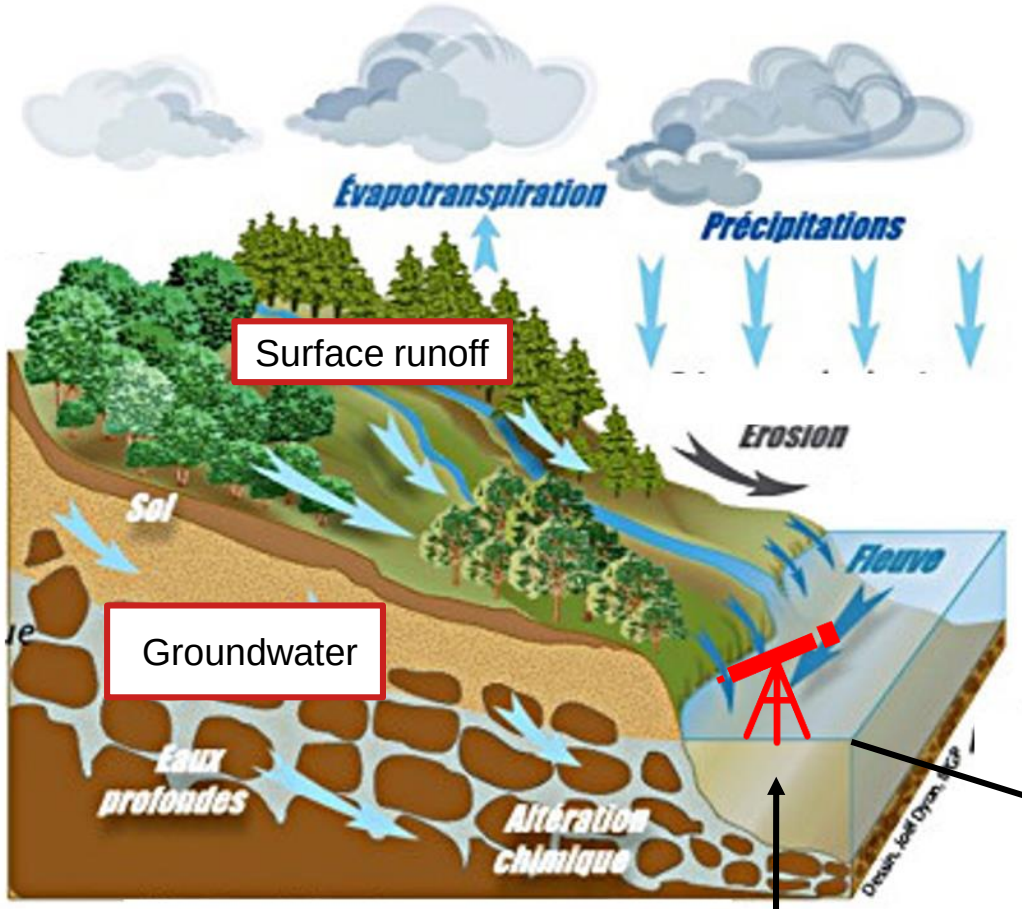

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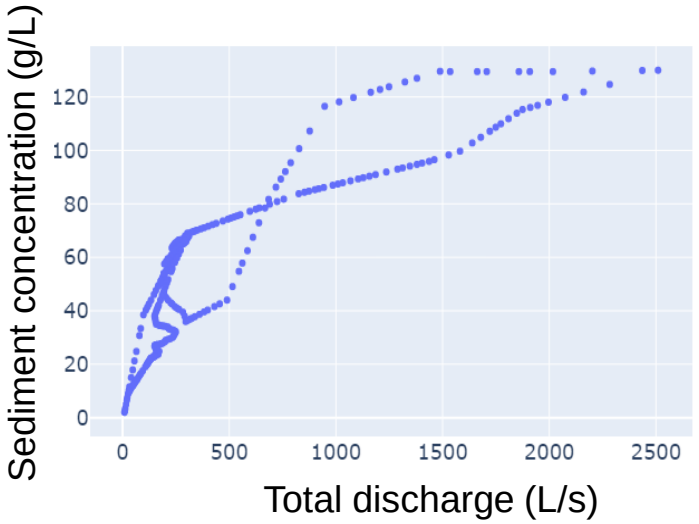

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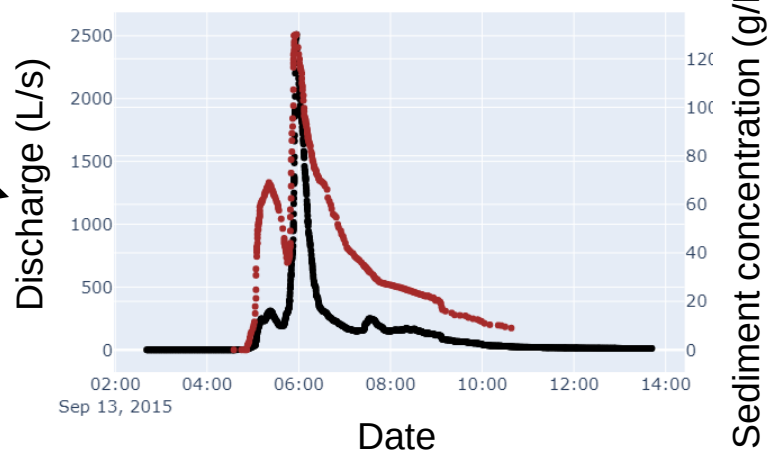

Hydrograph decomposition

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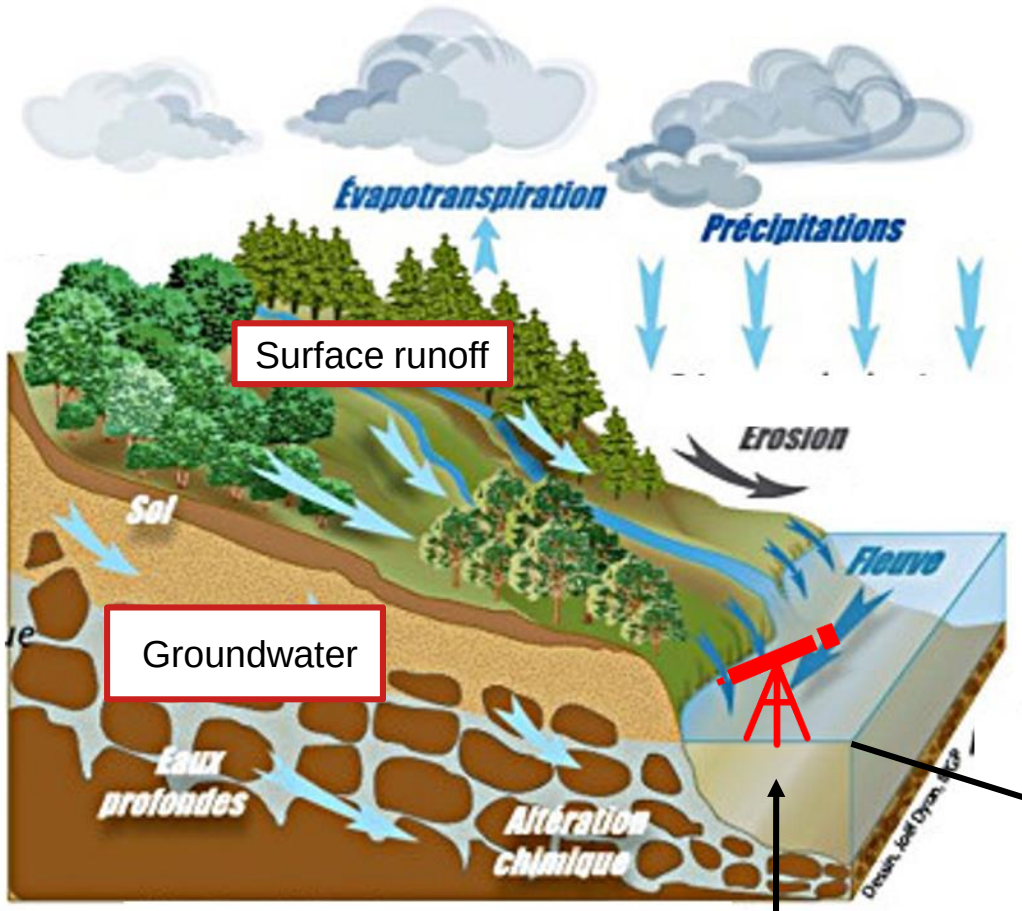

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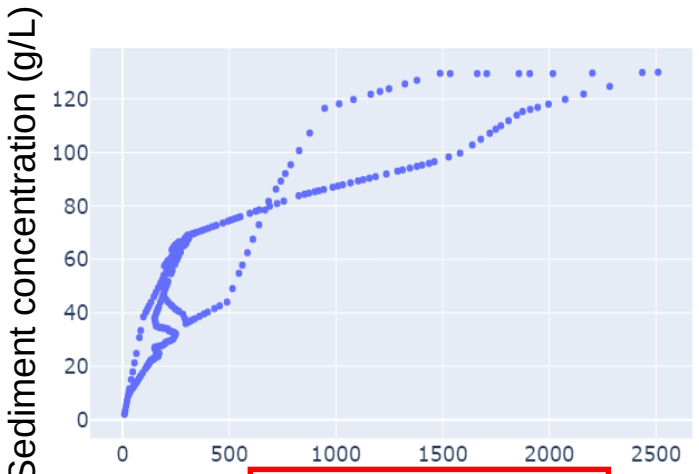

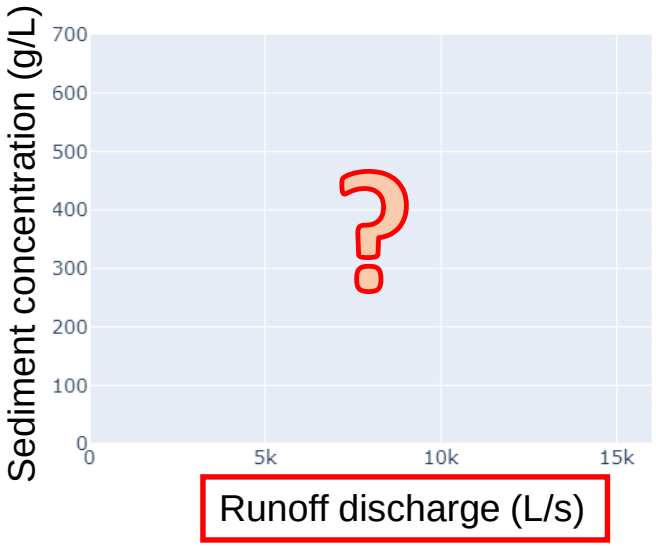

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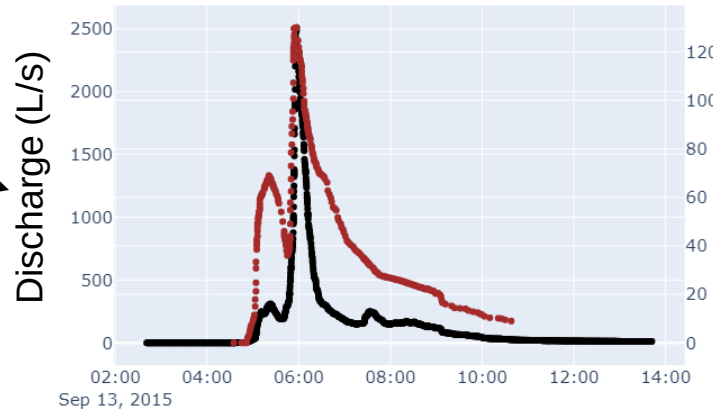
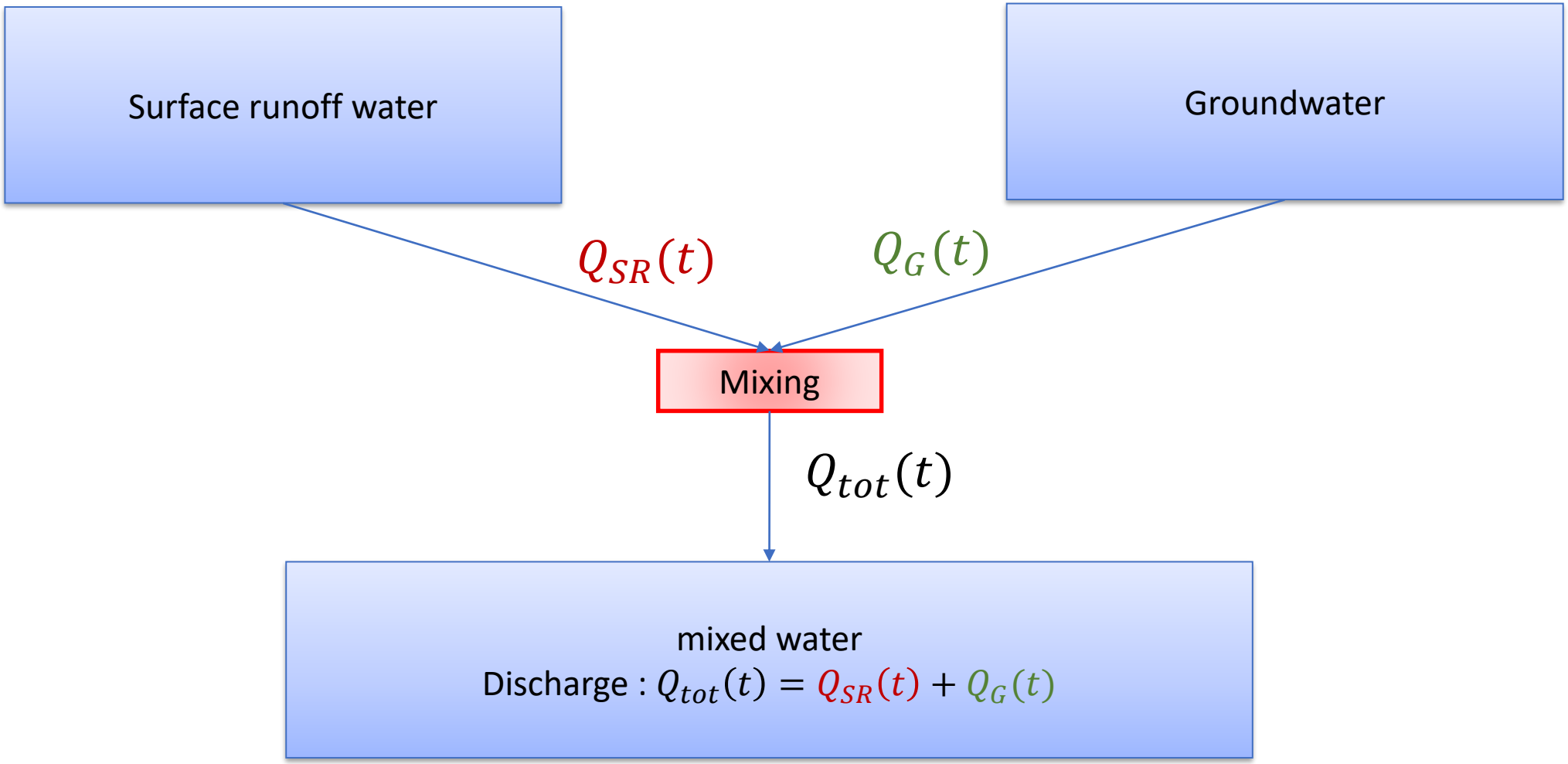


Sediment concentration (g/L)

Hydrograph decomposition

The End-Member Modelling Analysis (EMMA)



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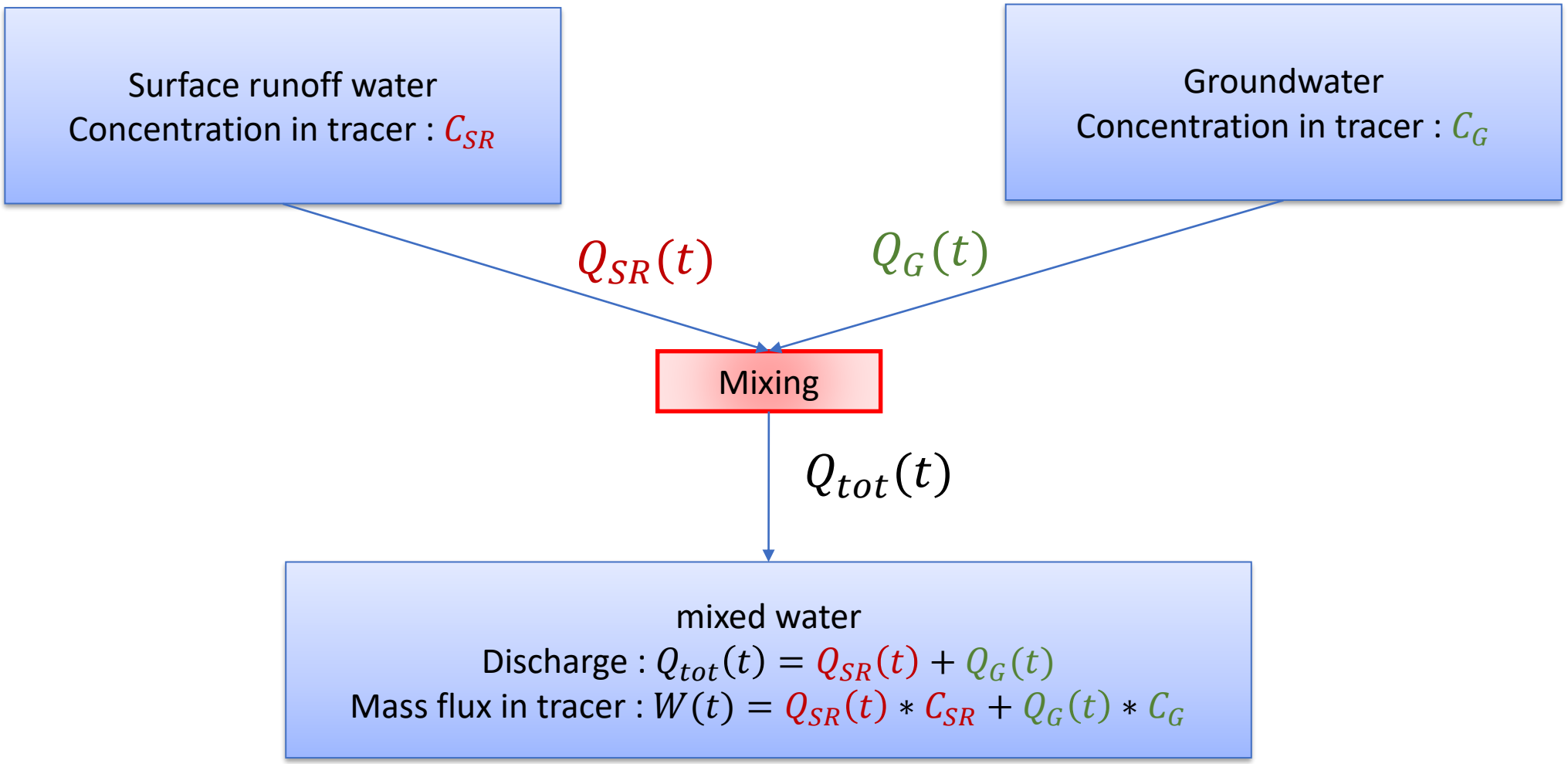

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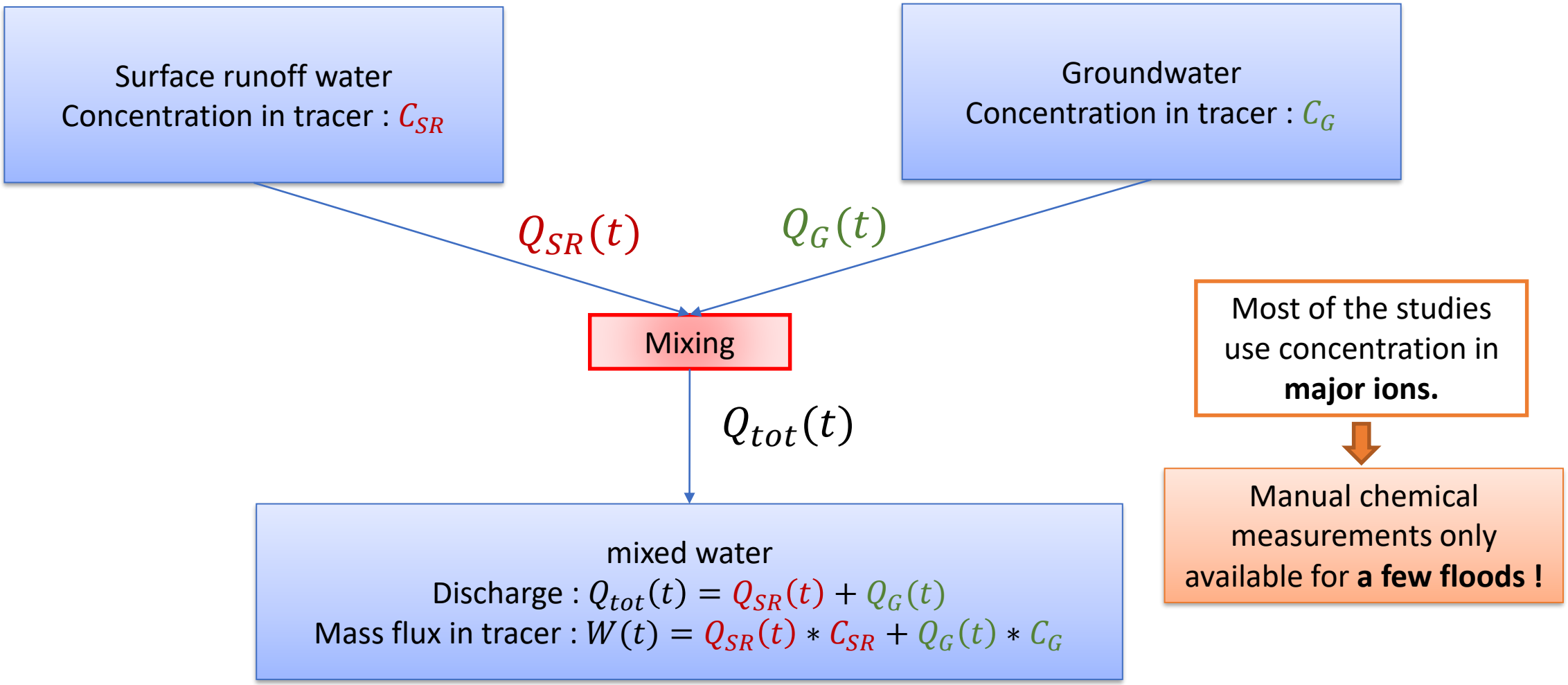

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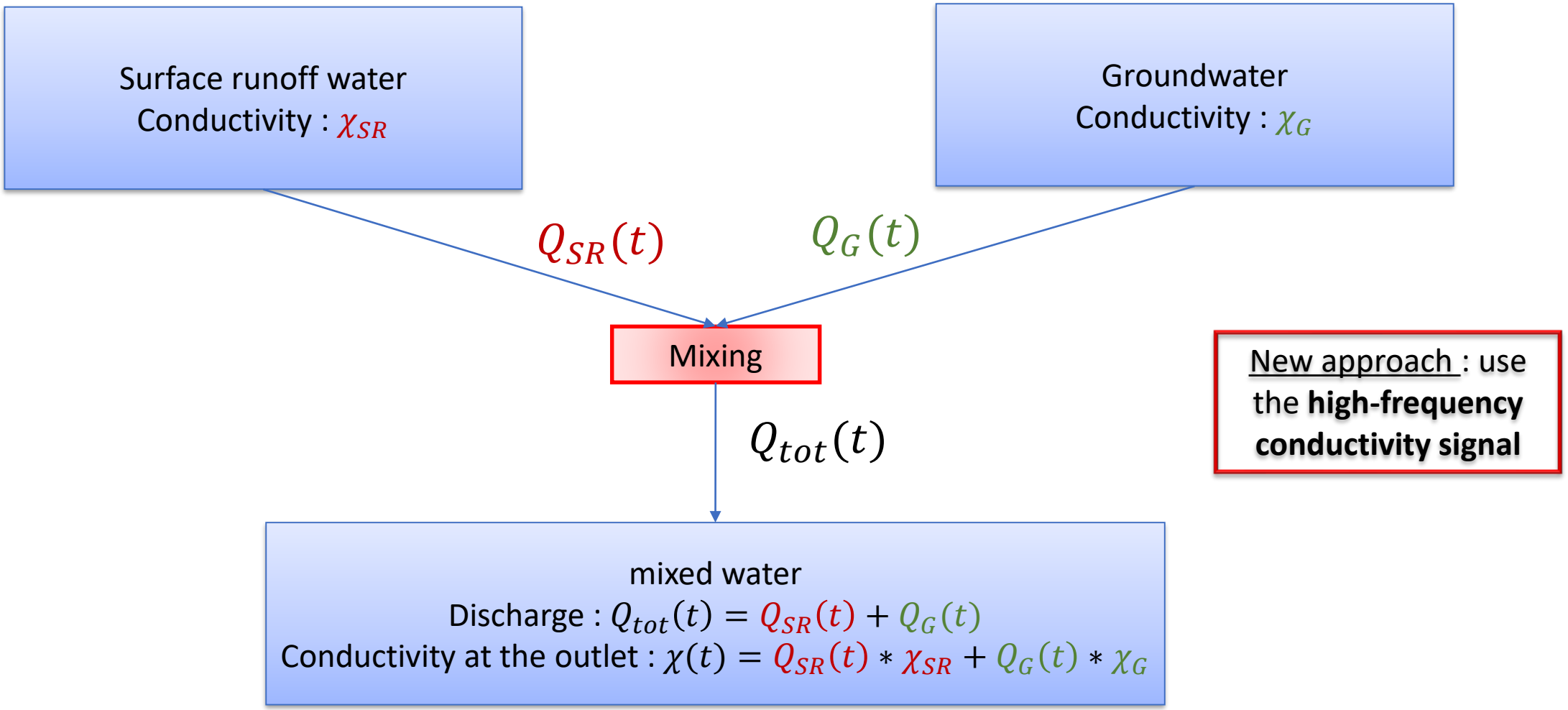

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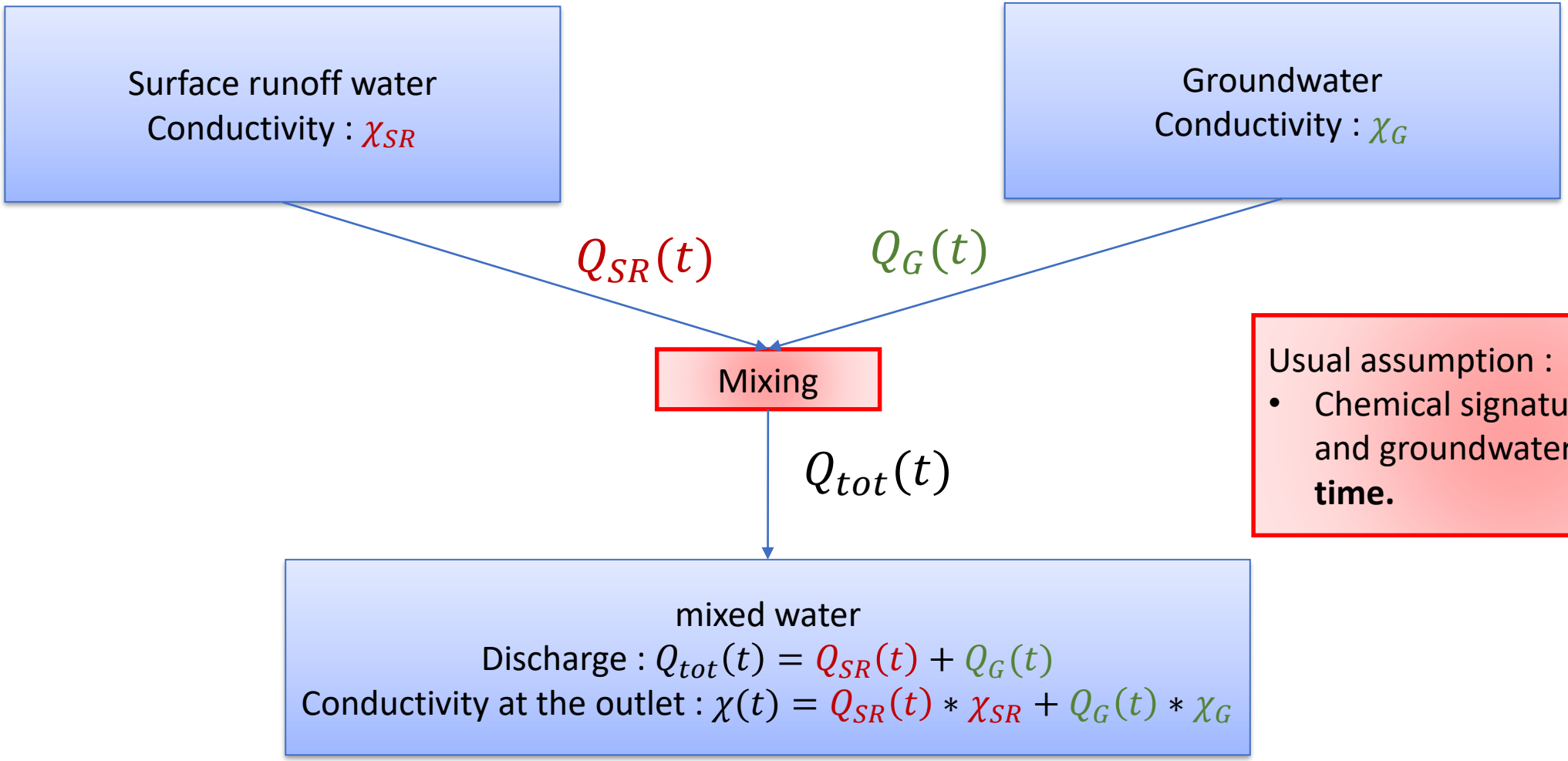

Usual assumption :

- Chemical signature of runoff and groundwater **constant in time.**

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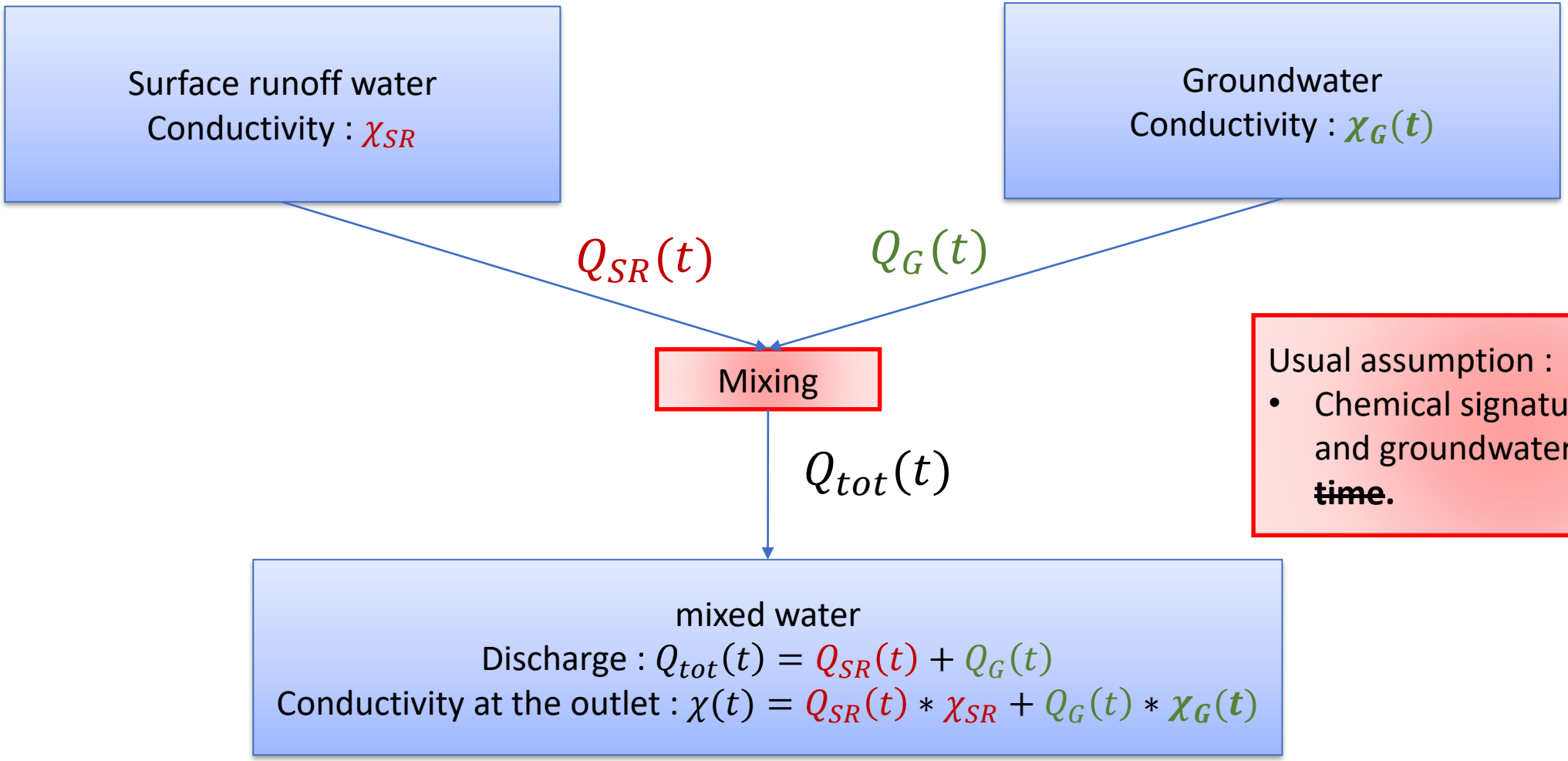

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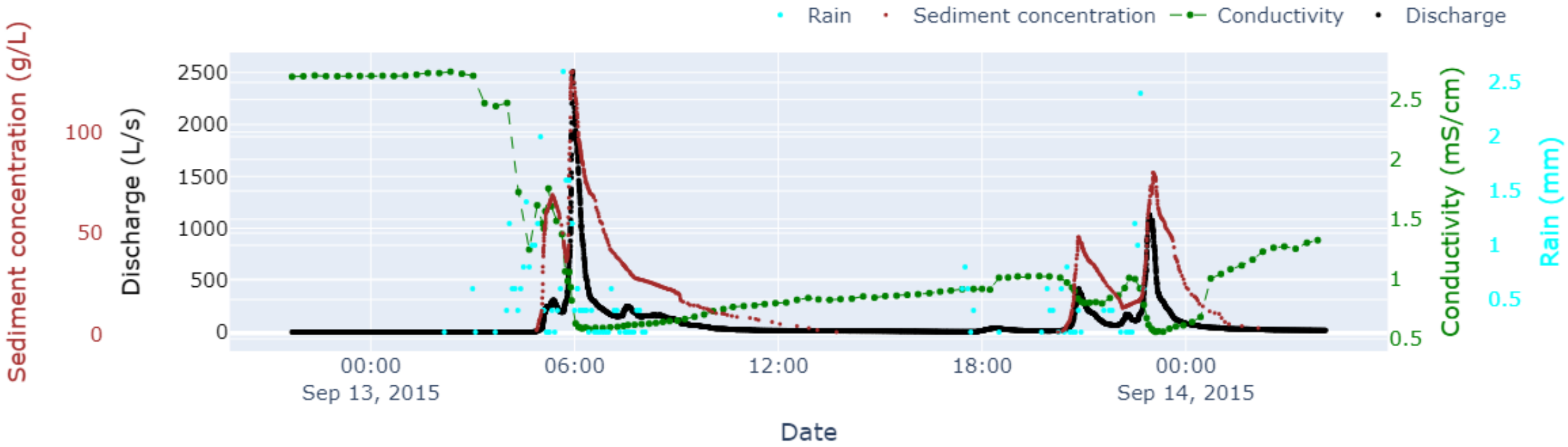
Construction of the EMMA methods



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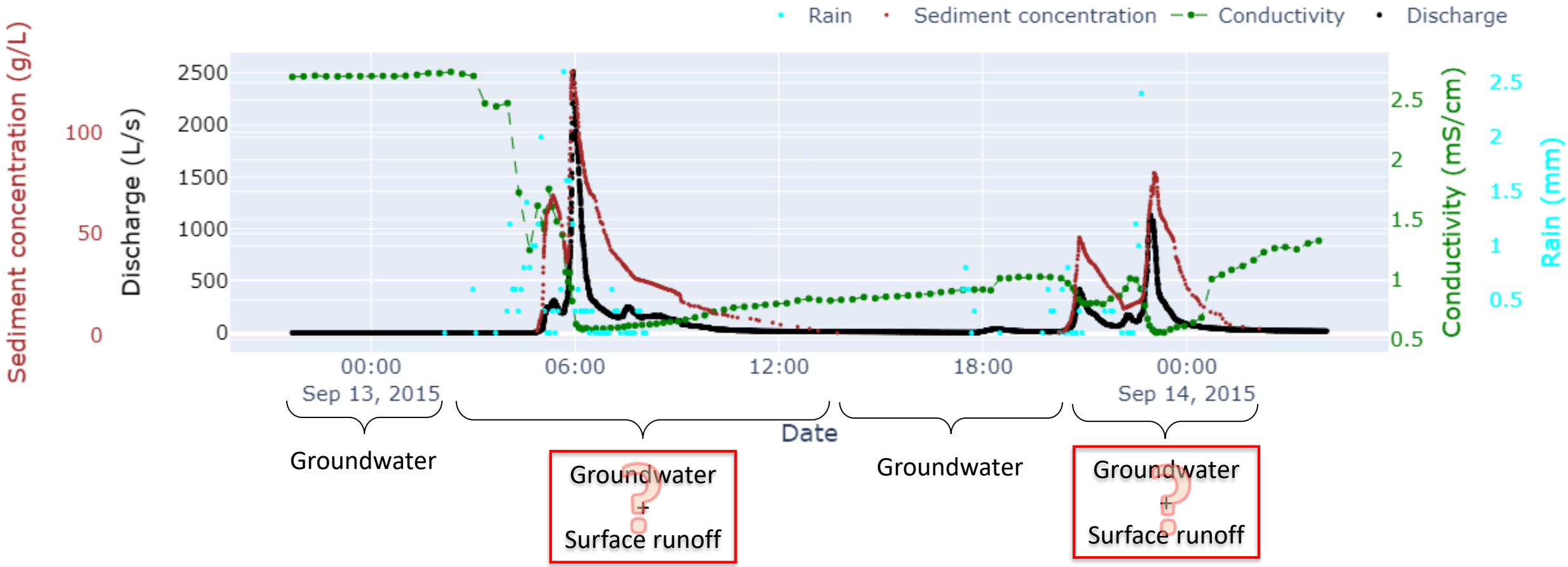

Groundwater more mineralized than surface runoff : $\chi_G \gg \chi_{SR}$

Definition of the end-member chemistry

- **Surface runoff** : chemical measurements of runoff water on surface plots performed by Cras (2005)

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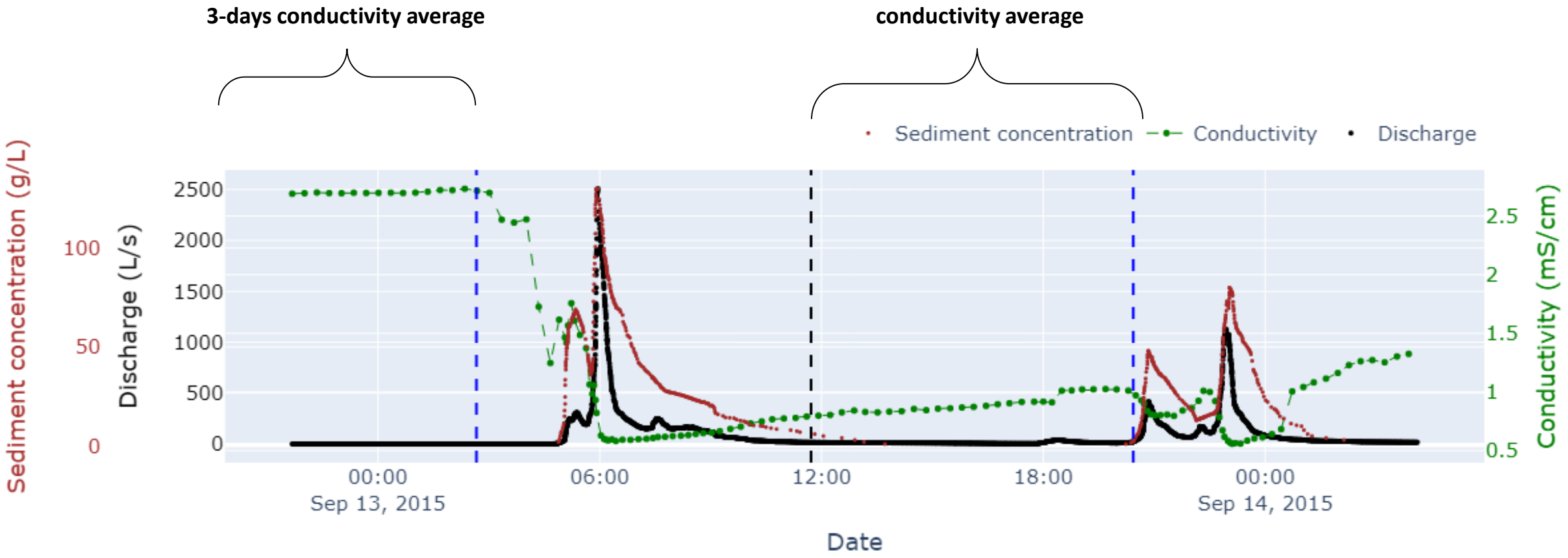

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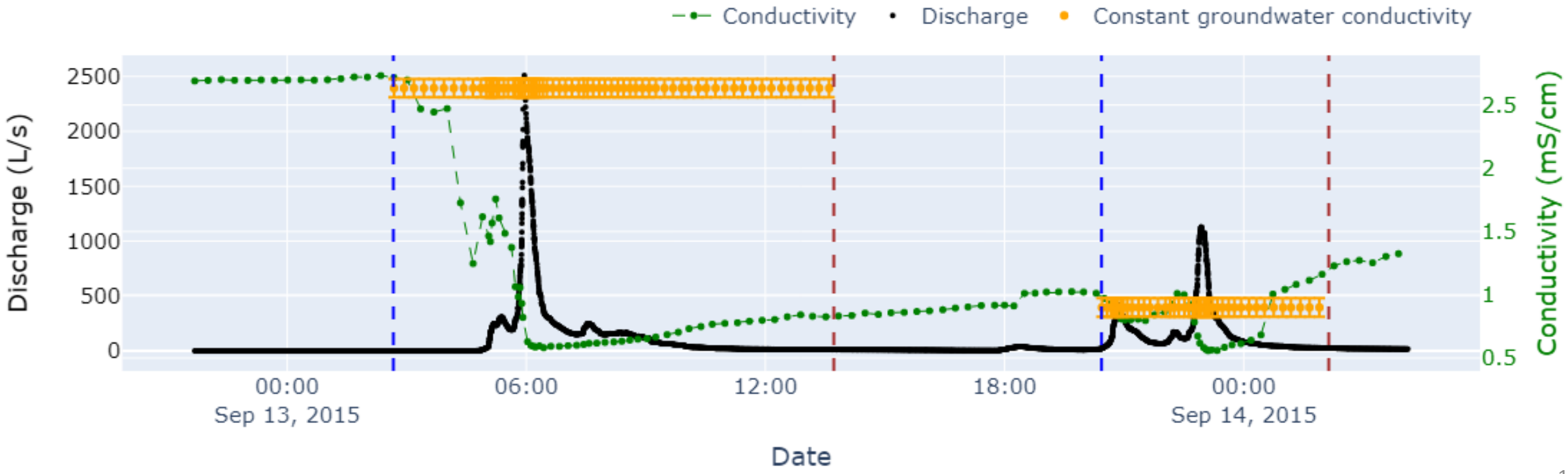

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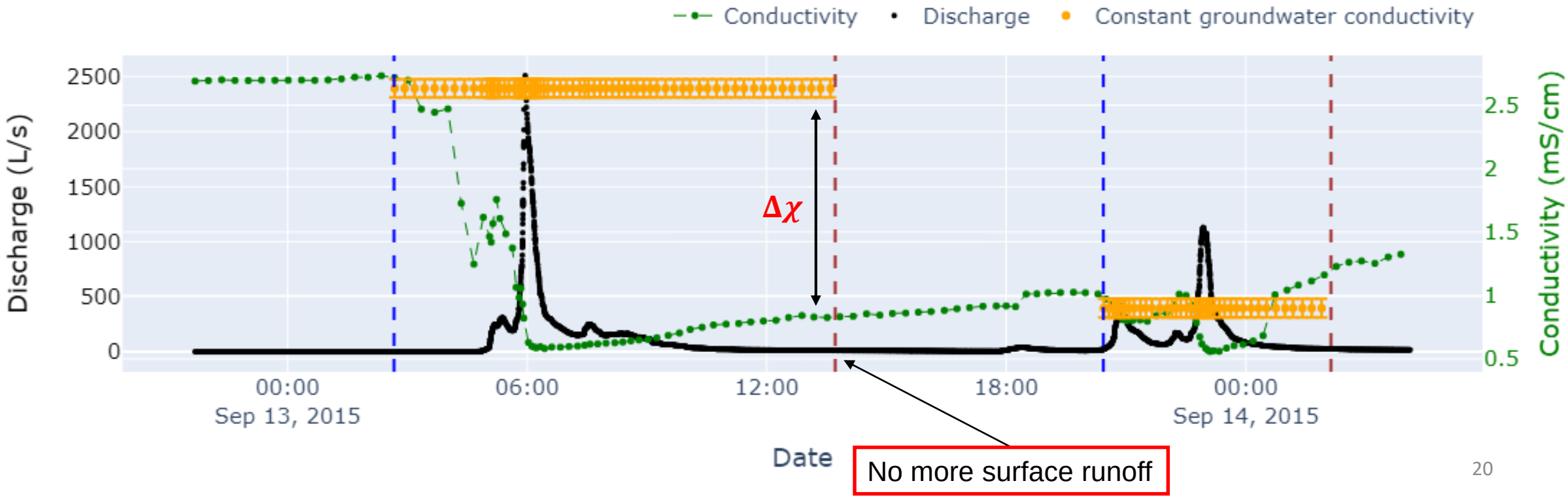
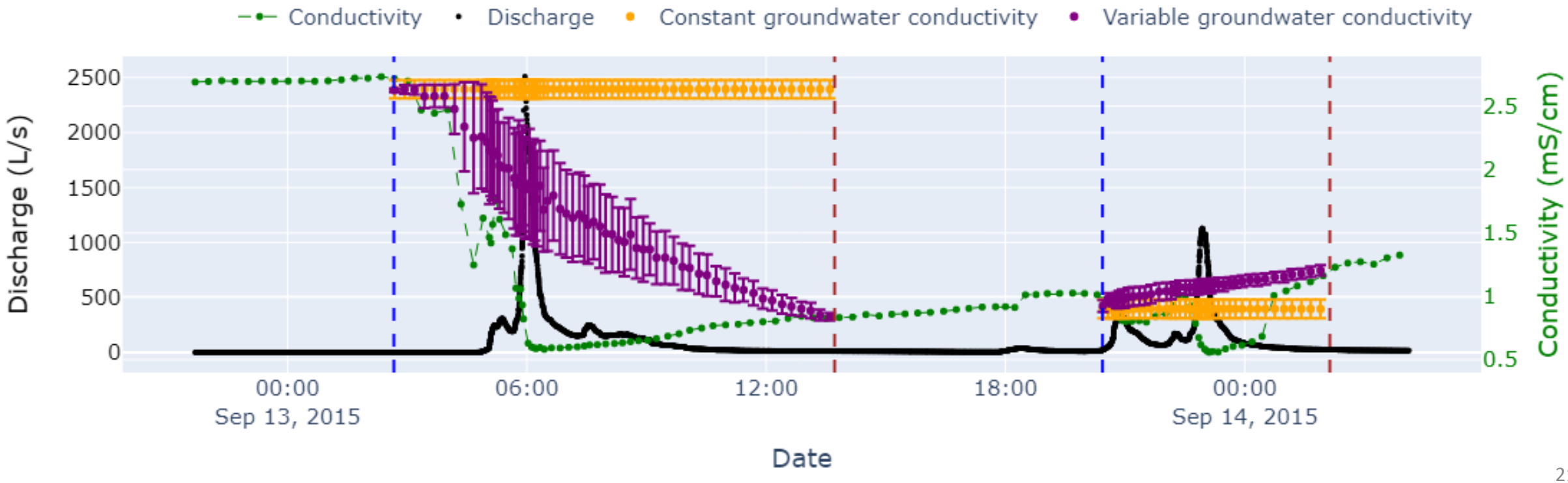


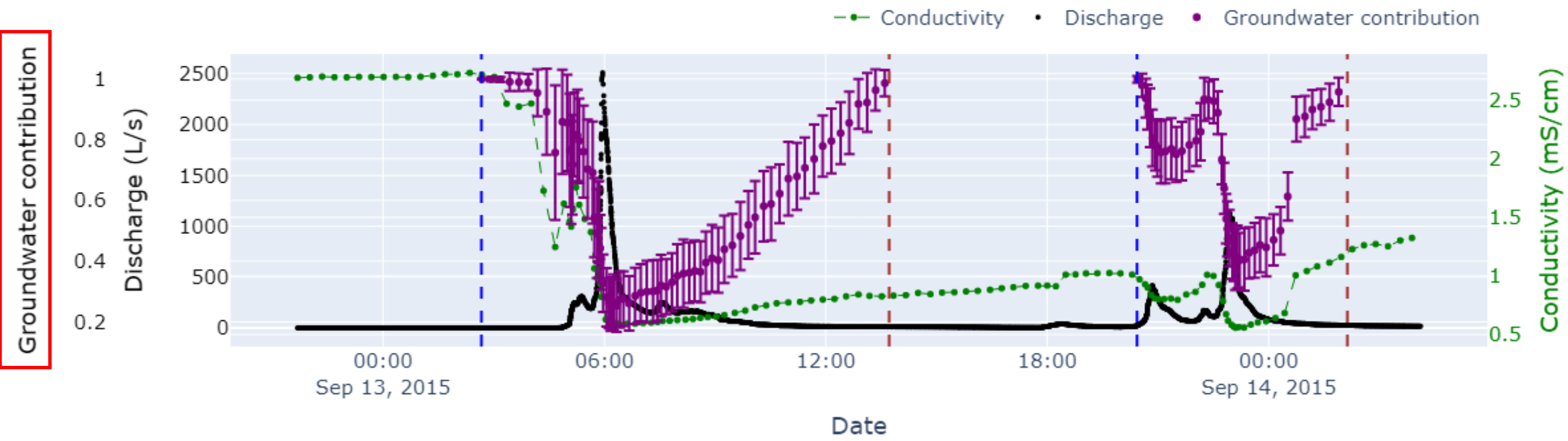
Definition of the end-member chemistry

- **Surface runoff** : chemical measurements of runoff water on surface plots performed by Cras (2002)
- **Groundwater** : pre-event conductivity measurements
  - ❖ Methods with a **varying or constant groundwater conductivity** during the flood



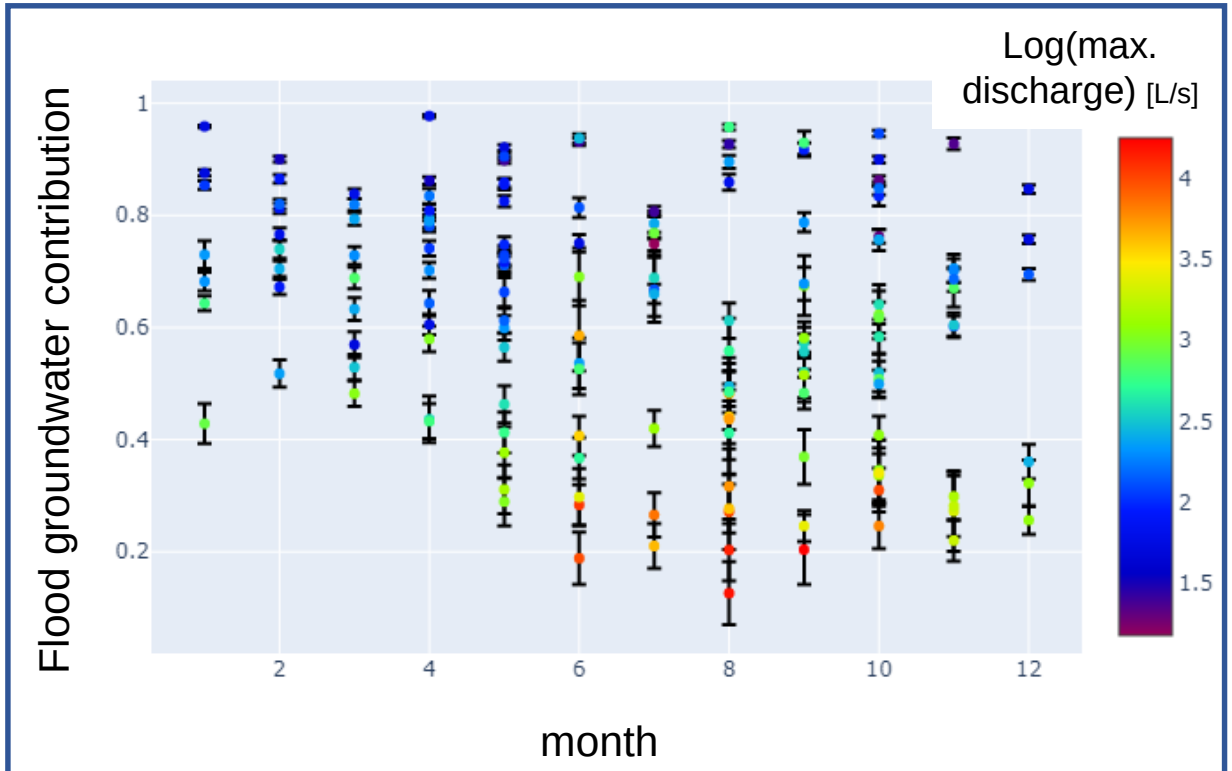
Results of the EMMA methods for the two successive floods

- **Quantification of uncertainties** : Monte Carlo algorithm

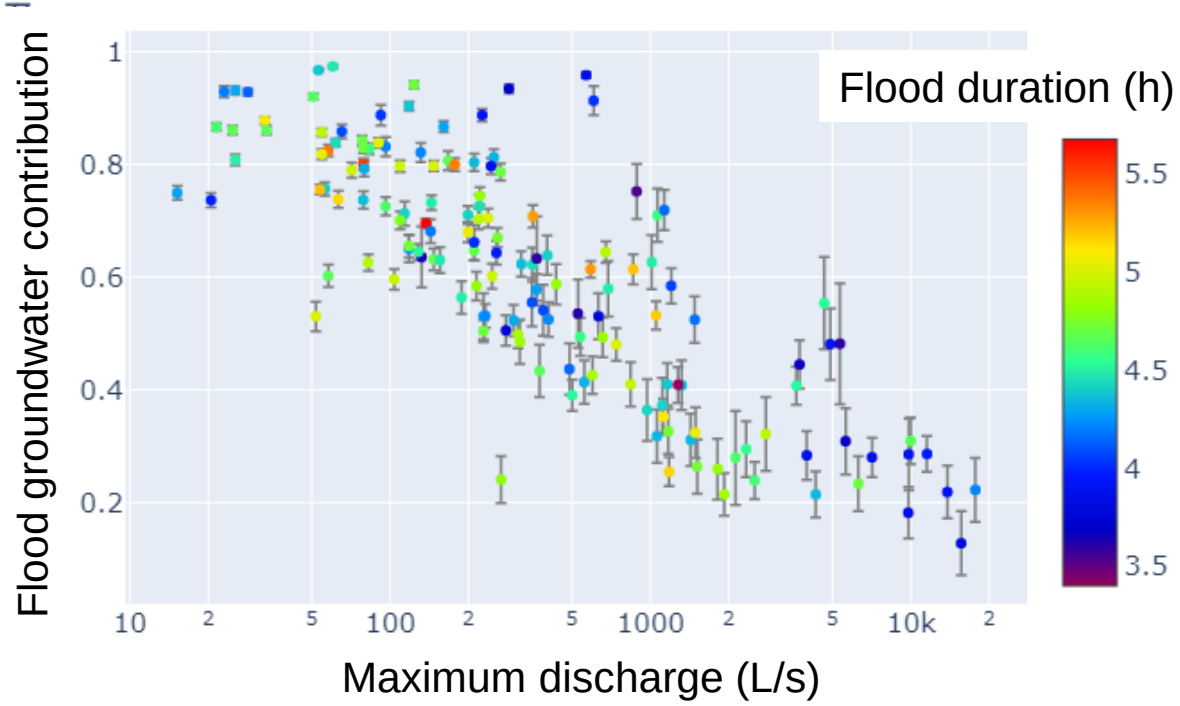


Total groundwater contribution to the flood = $\sum_{t,flood} \frac{Q_{G,t}}{Q_{tot,t}}$

Results of the flood hydrograph decomposition calculated with the conductivity signal for the 165 floods between 2015 and 2020 : a) *controlling factor analysis*



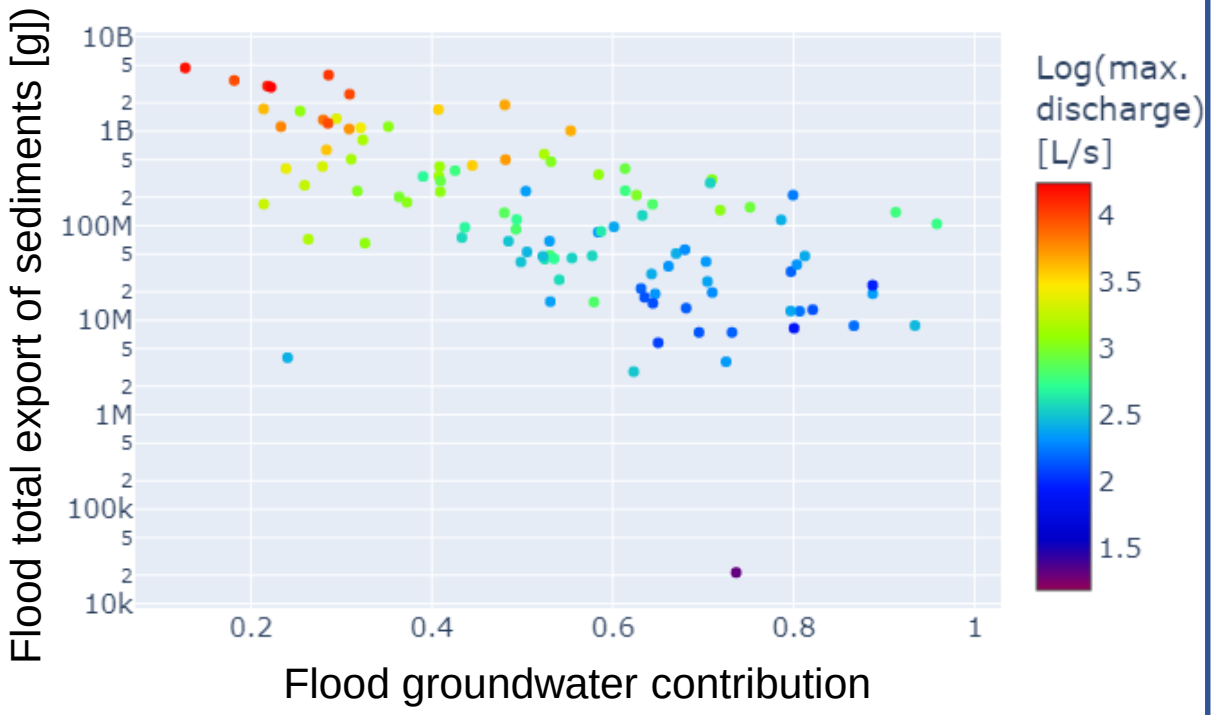
- **Higher variability** in the results in **summer**, that seems to be correlated with a **higher discharge variability.**



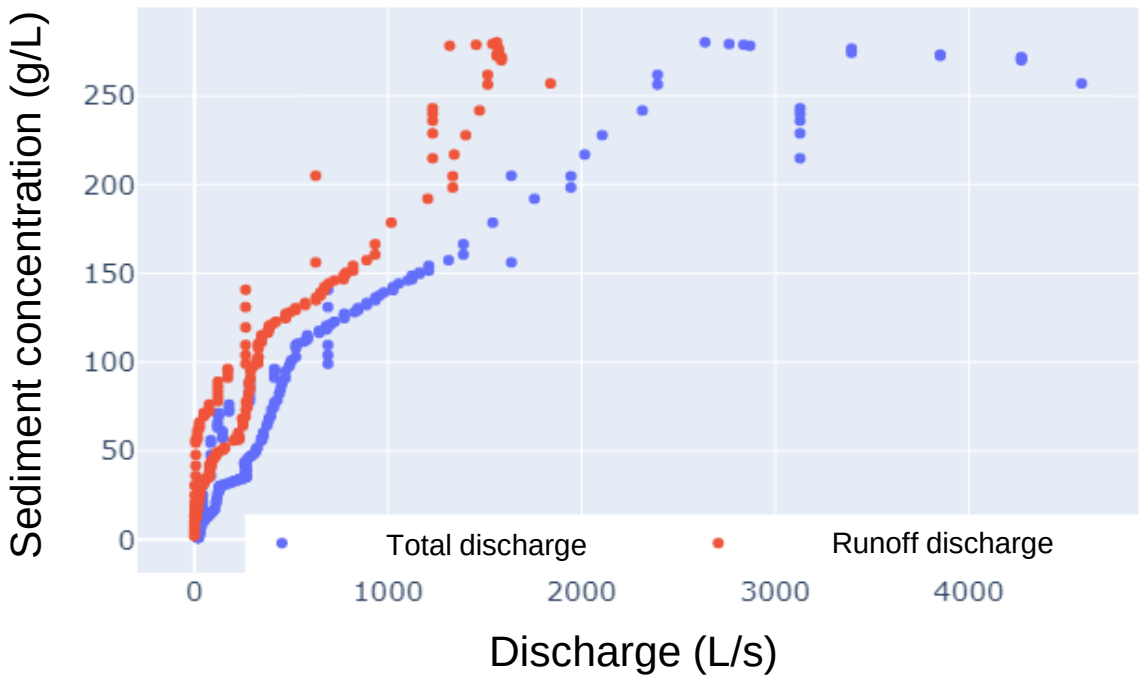
- Groundwater contribution **decreases exponentially with maximum flood discharge.**

- seasonal variations in the groundwater contribution mainly due to the climatological characteristics of the catchment :
  - **high-intensity, short-duration floods** in summer and autumn result in a **low groundwater contribution**.
  - **low-intensity, long-duration floods** in spring and winter result in a **high groundwater contribution**

Results of the flood hydrograph decomposition calculated with the conductivity signal for the 165 floods between 2015 and 2020 : *b) Link with suspended sediments*



- **Floods generating the most sediment** are those with **the highest contribution of runoff**, and are associated with **the highest peak flows.**



- Usual interpretation : stabilization of sediment concentration at high flows → **due to a limitation of sediment supply during peak ?**
- Alternative interpretation : stabilization is probably due **to the dilution effect of groundwater.**

Conclusion

- Use of the high-frequency conductivity signal seems to be suitable for the hydrograph decomposition in the Laval watershed.
- Groundwater contribution to floods exhibits **seasonal patterns that appear to be primarily linked to the climatological characteristics of the watershed.**
- Taking into account the dilution effect of groundwater **modifies the interpretation of the dynamics of hydrosedimentary processes in the watershed.**

Perspectives

- Reduce uncertainties in EMMA decomposition results, in particular by **improving our knowledge of the chemical signatures of surface runoff and groundwater end-members.**
- examine more precisely the role of groundwater in sediment transport dynamics by further **analyzing the relationships between sediment concentration and total runoff rate.**
- perform these hydrograph decompositions in **other catchments of different sizes or with different vegetation cover**, in order to assess the impact of these aspects on the contribution of groundwater to flooding.

Bibliography

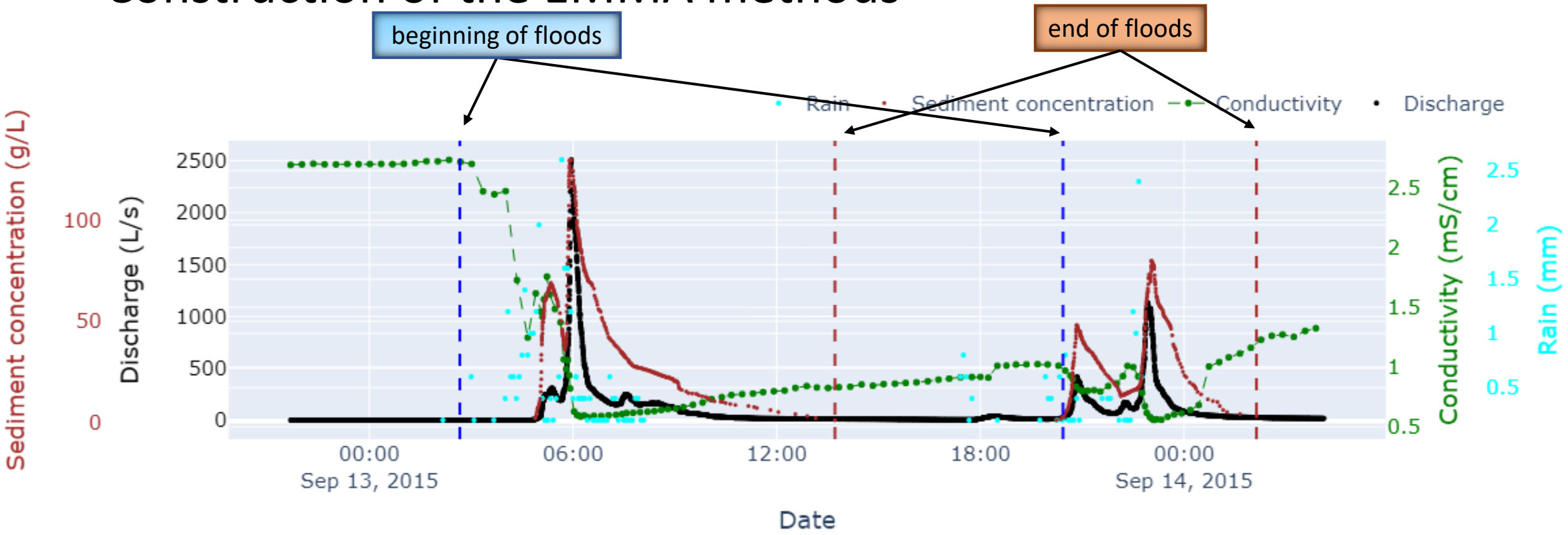
- Cras, A. (2005, January). *Etude et modélisation de la dynamique de fonctionnement hydrologique des bassins versants torrentiels marneux, apport du traçage naturel: application aux bassins versants de recherche et d'expérimentation (BVRE) de Draix, Alpes-de-Haute-Provence, France. Avignon.*

- Mallet, F. (2018). *Spatialisation et modélisation de l'état hydrique des sols pour l'étude des processus de formation des écoulements en contexte torrentiel: application au bassin versant marneux du Laval (ORE Draix-Bléone, Alpes-De-Haute-Provence, France)* (Doctoral dissertation, Université d'Avignon).

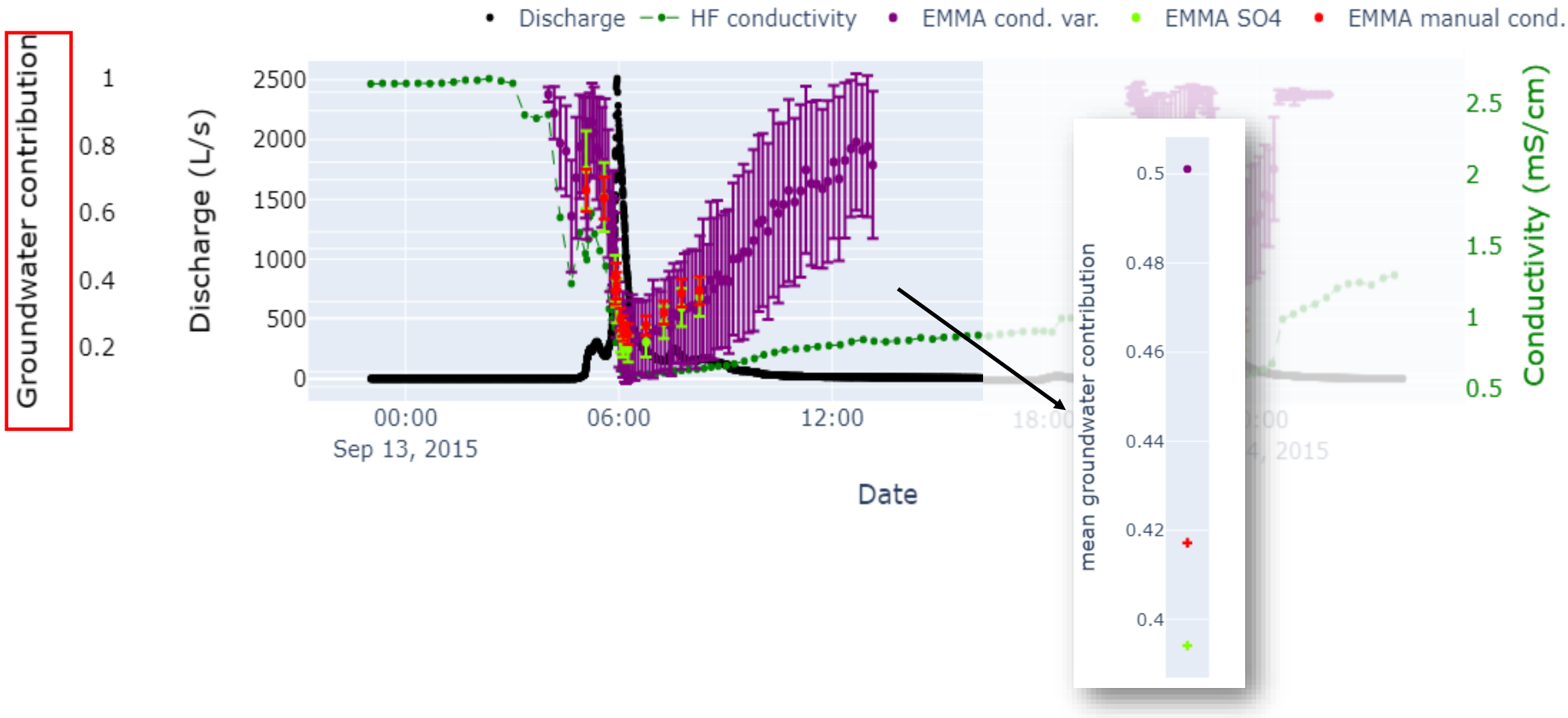
- Ogric, M. (2021). *Chemical weathering of sedimentary rocks as a source of carbon dioxide to the atmosphere* (Doctoral dissertation, Durham University).

Thank you for your attention !

Construction of the EMMA methods



Results of the EMMA methods for the two successive floods



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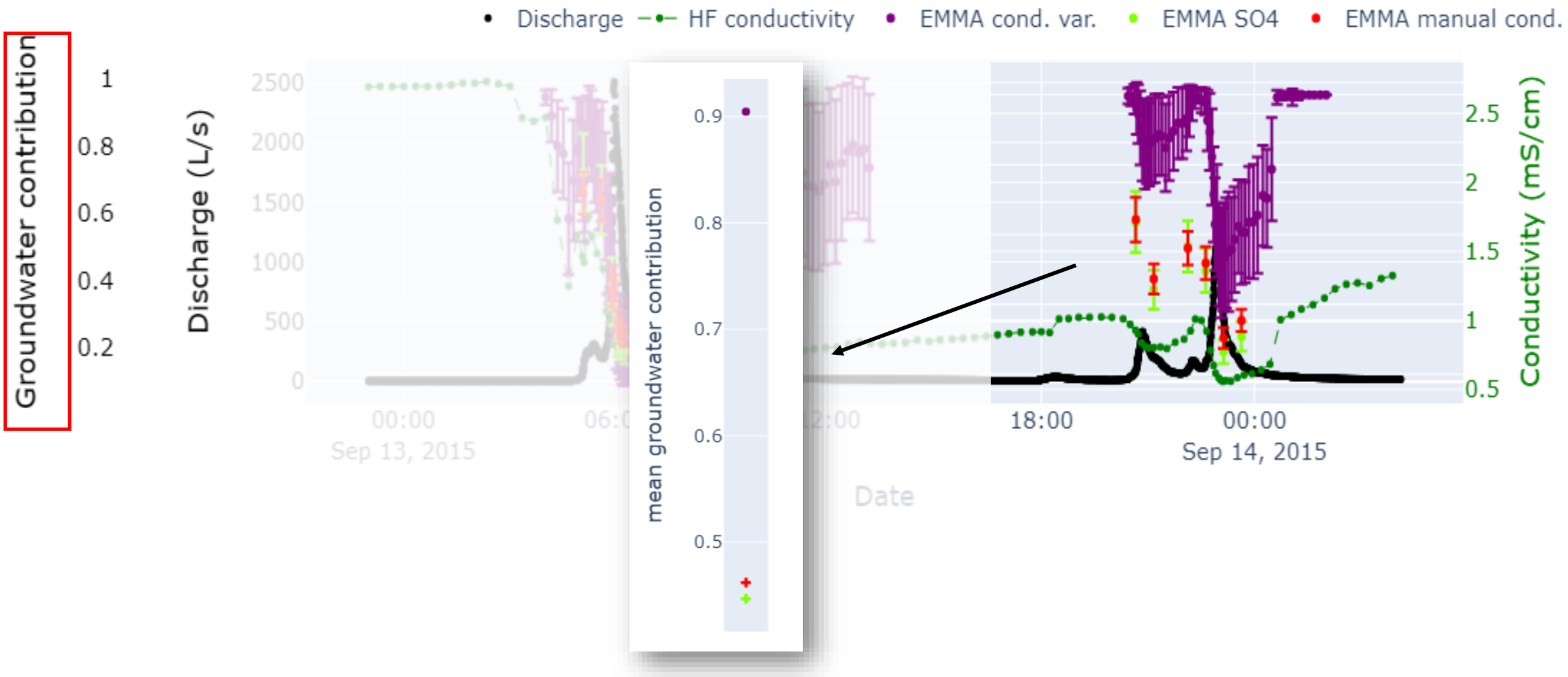

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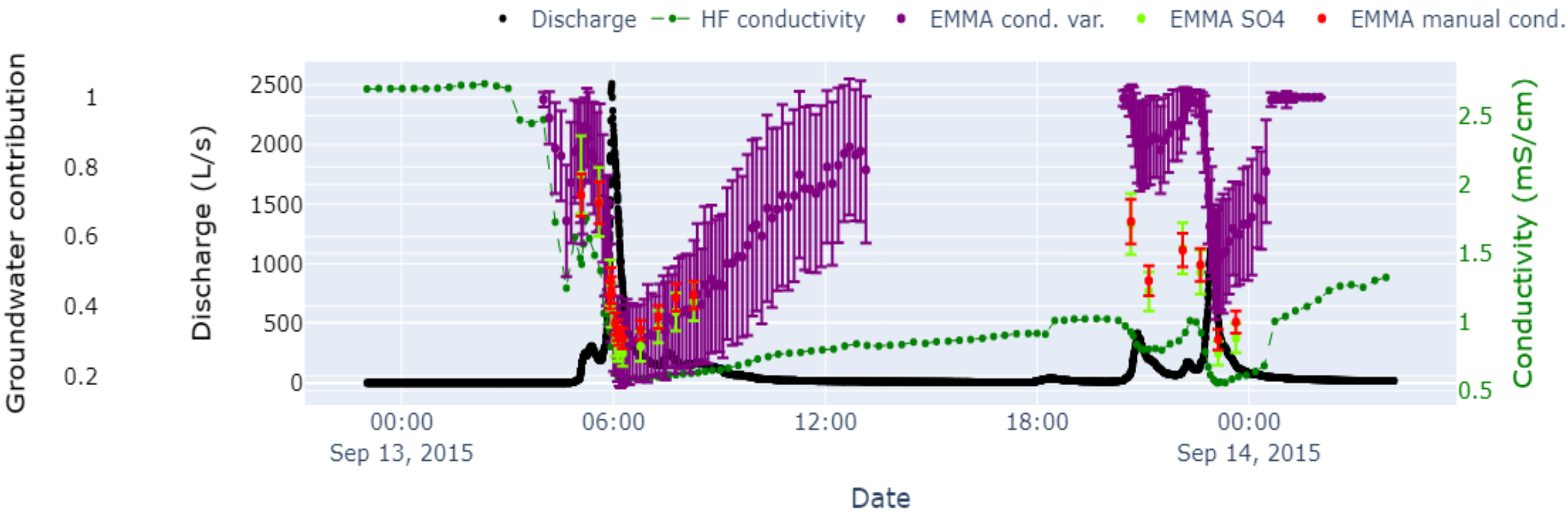
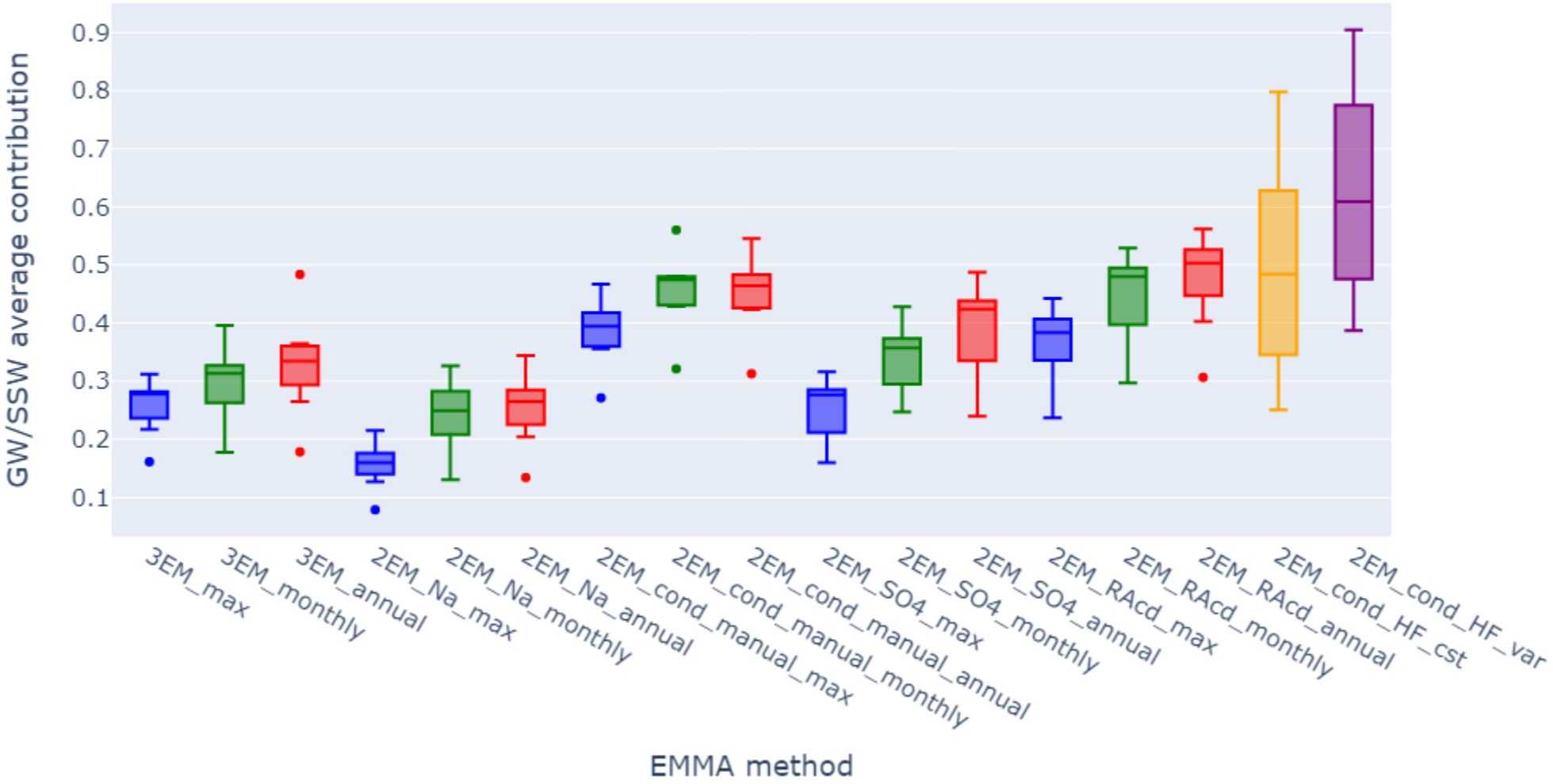
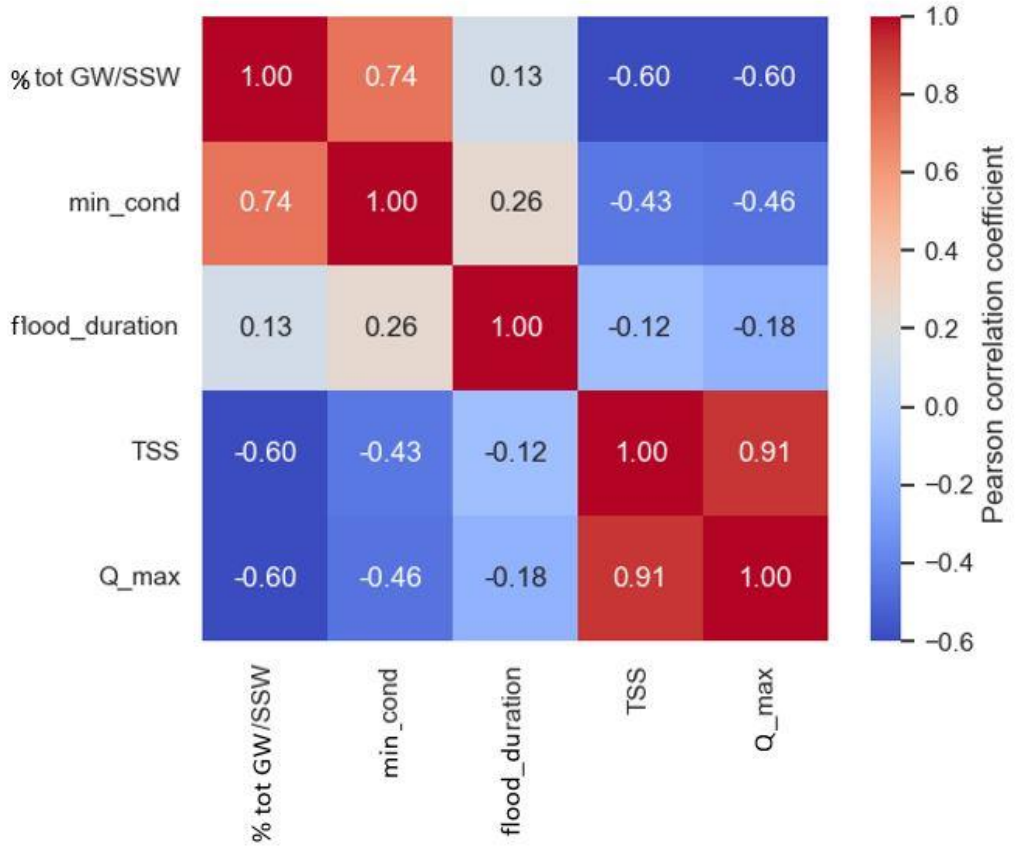


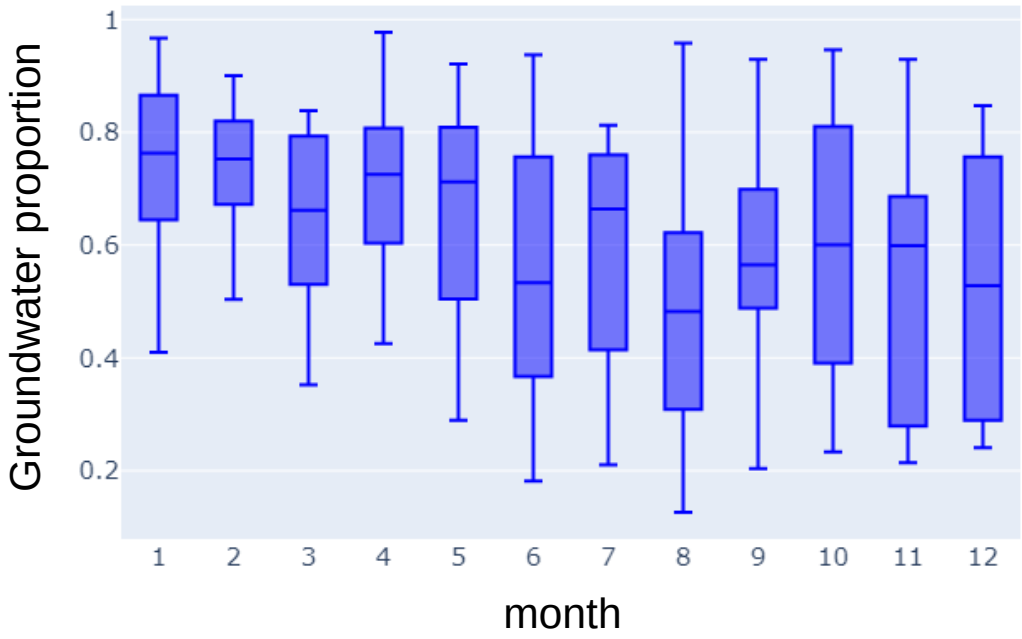
- **The adaptability** of the method using the high-frequency conductivity signal **to pre-event hydrological conditions has a major influence on decomposition results.**
- The use of the high-frequency conductivity signal as a tracer in the Laval watershed **seems promising.**



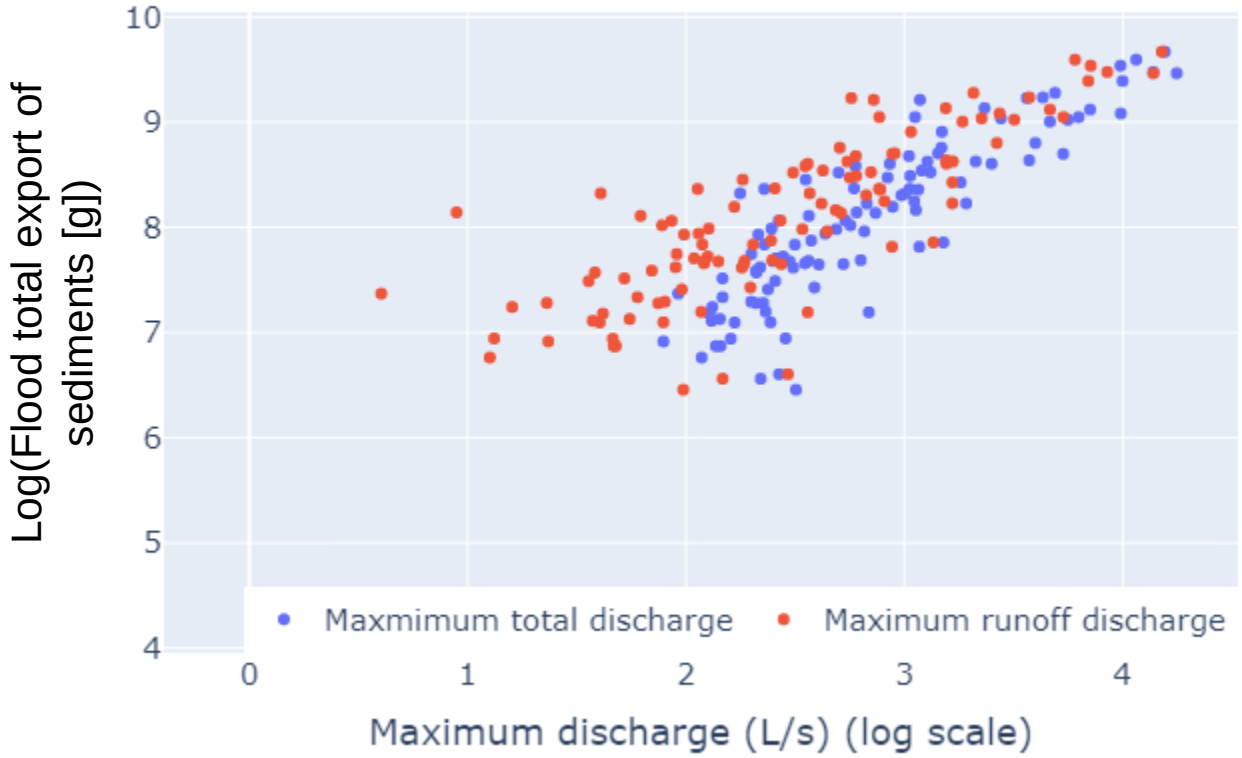
Box plot of the average GW/SSW contribution depending on the method for all floods monitored by Mallet [2018].



Pearson correlation coefficients between the flood total groundwater contribution (% tot GW/SSW) and the flood minimum conductivity (min_cond), duration, total export of sediment (TSS) and maximum discharge (Q_max).

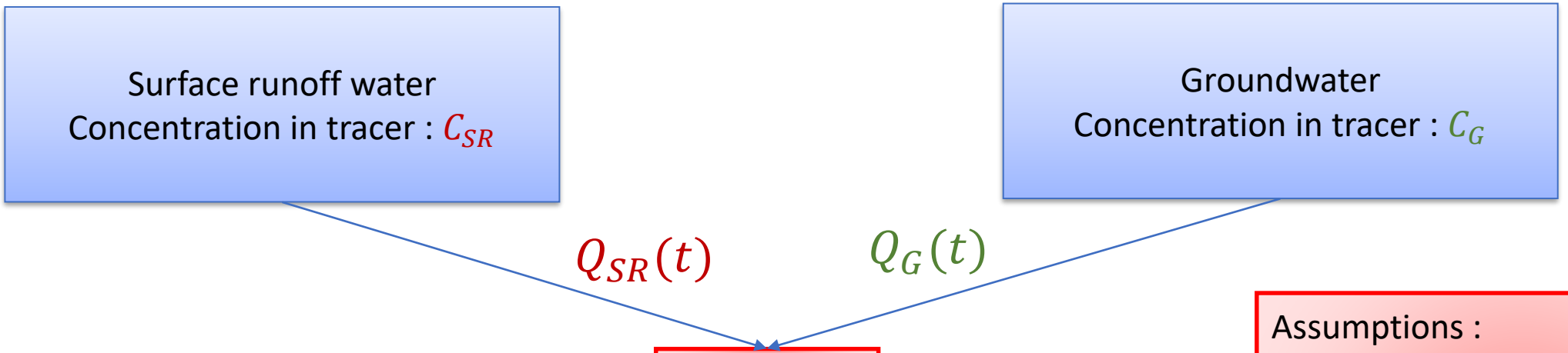


Box plots of the total groundwater contribution to each flood from 2015 to 2020 as a function of the month.



Flood total export of TSS depending on the maximum total discharge or the maximum runoff discharge of each flood from 2015 to 2020.

The End-Member Modelling Analysis (EMMA)



Assumptions :

- **Conservative chemical tracers** (no interaction with the bed during flow)
- **Conservative mixing** (no chemical reaction during mixing)

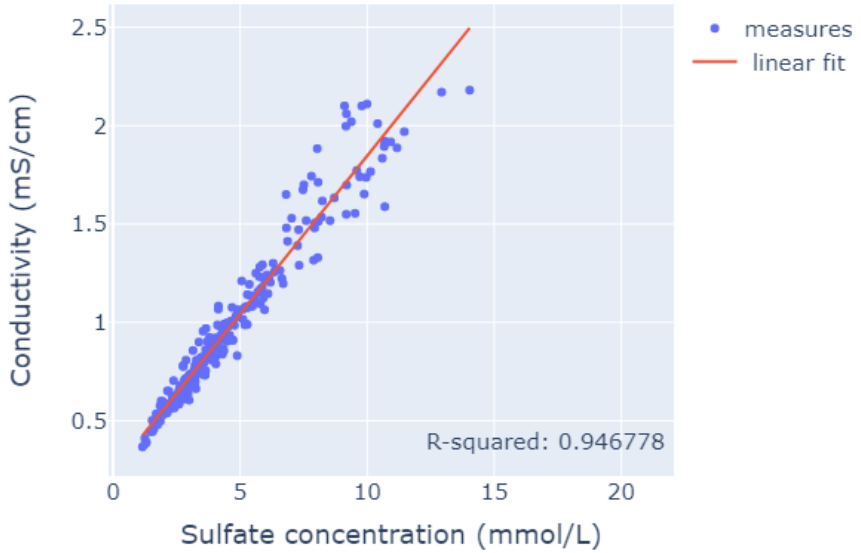
Choice of the tracers for the EMMA methods

- Most of the studies use concentration in major ions
- Needed properties : dynamics not controlled by saturation, strong concentration differerence between runoff and groundwater
- In the Laval catchment : SO_4^{2-}, Na^+

Manual chemical measurements only available for a few floods !

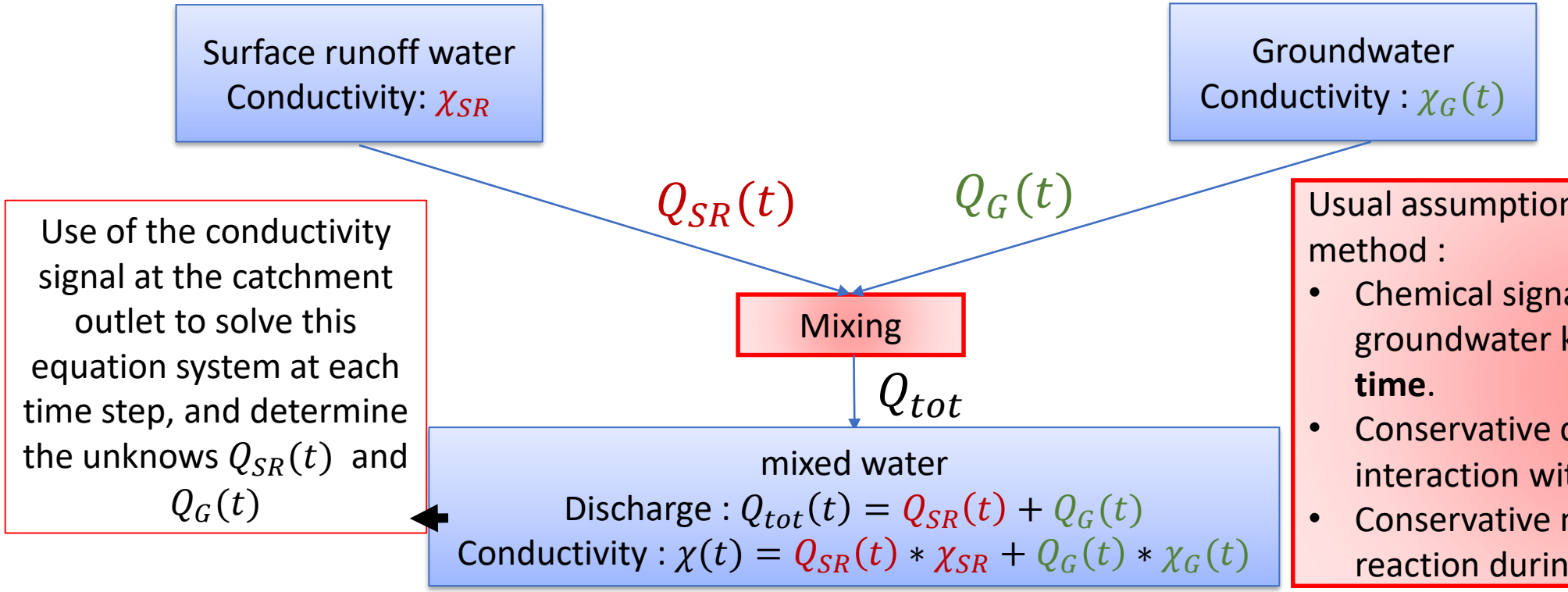
New approach : try to use the **high-frequency conductivity signal** to **decompose a high number of flood hydrographs**

- Correlation between sulfate concentration and conductivity



First objectives of this internship :

- Developp EMMA methods using the HF conductivity signal as tracer.
- Compare these methods with the one using manual ionic concentration measurements.



Use of the conductivity signal at the catchment outlet to solve this equation system at each time step, and determine the unknows $Q_{SR}(t)$ and $Q_G(t)$

Usual assumptions of the EMMA method :

- Chemical signature of runoff and groundwater known and **constant i time**.
- Conservative chemical tracers (no interaction with the bed during flo
- Conservative mixing (no chemical reaction during mixing)

Particularity of the EMMA method constructed in this study : **variability in time of the groundwater conductivity $\chi_G(t)$.**

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Introduction

The EMMA method

Analyse of the results