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Tour du Valat

CENTRE DE RECHERCHE SUR LA BIODIVERSITE ET L'ENVIRONNEMENT

INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

MODELING SOIL TO RIVER CESIUM-137 CONCENTRATIONS

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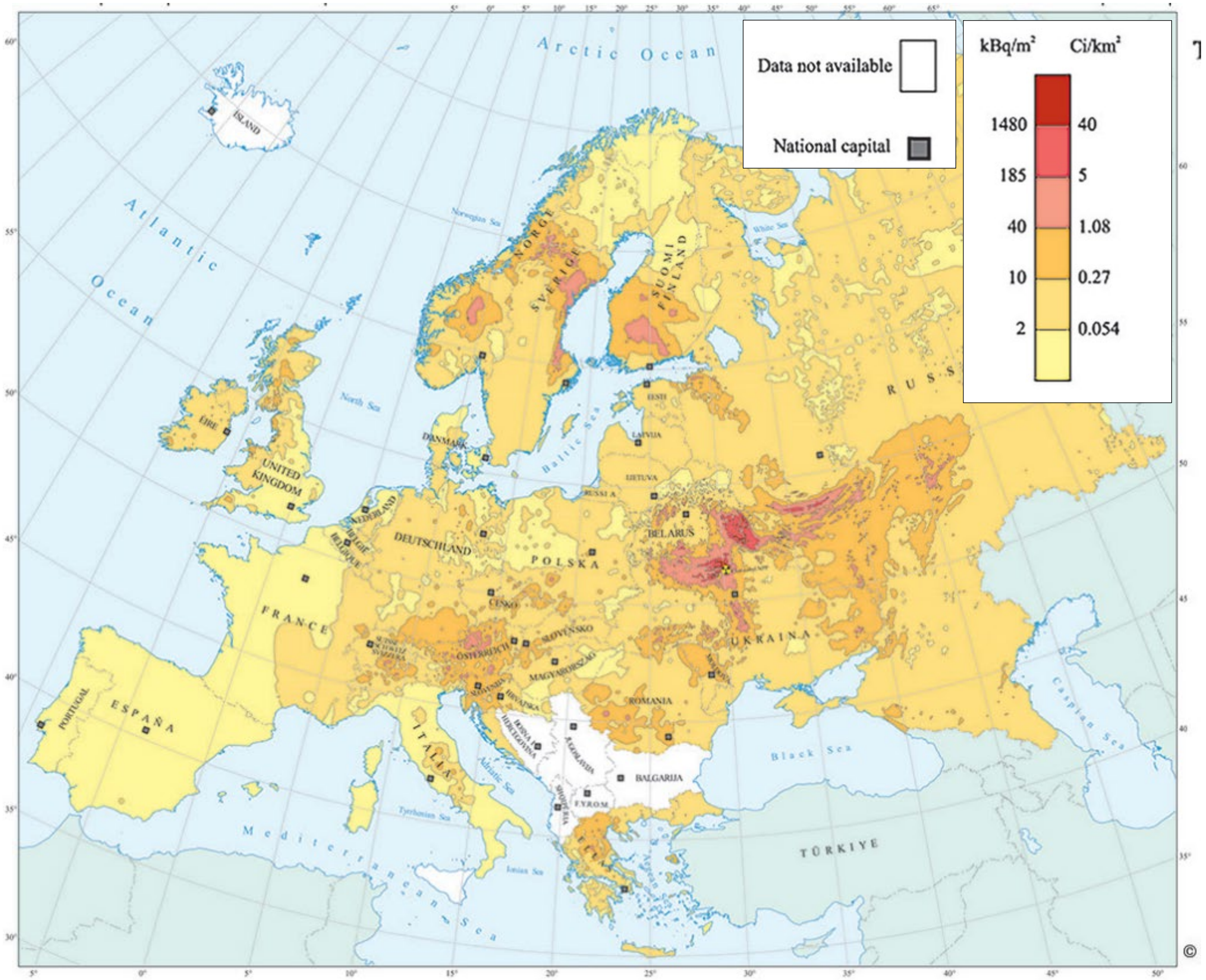
MEMBRE DE ETSON

[HAVING MODELS TO PREDICT THE TRANSFERS OF RADIOACTIVITY

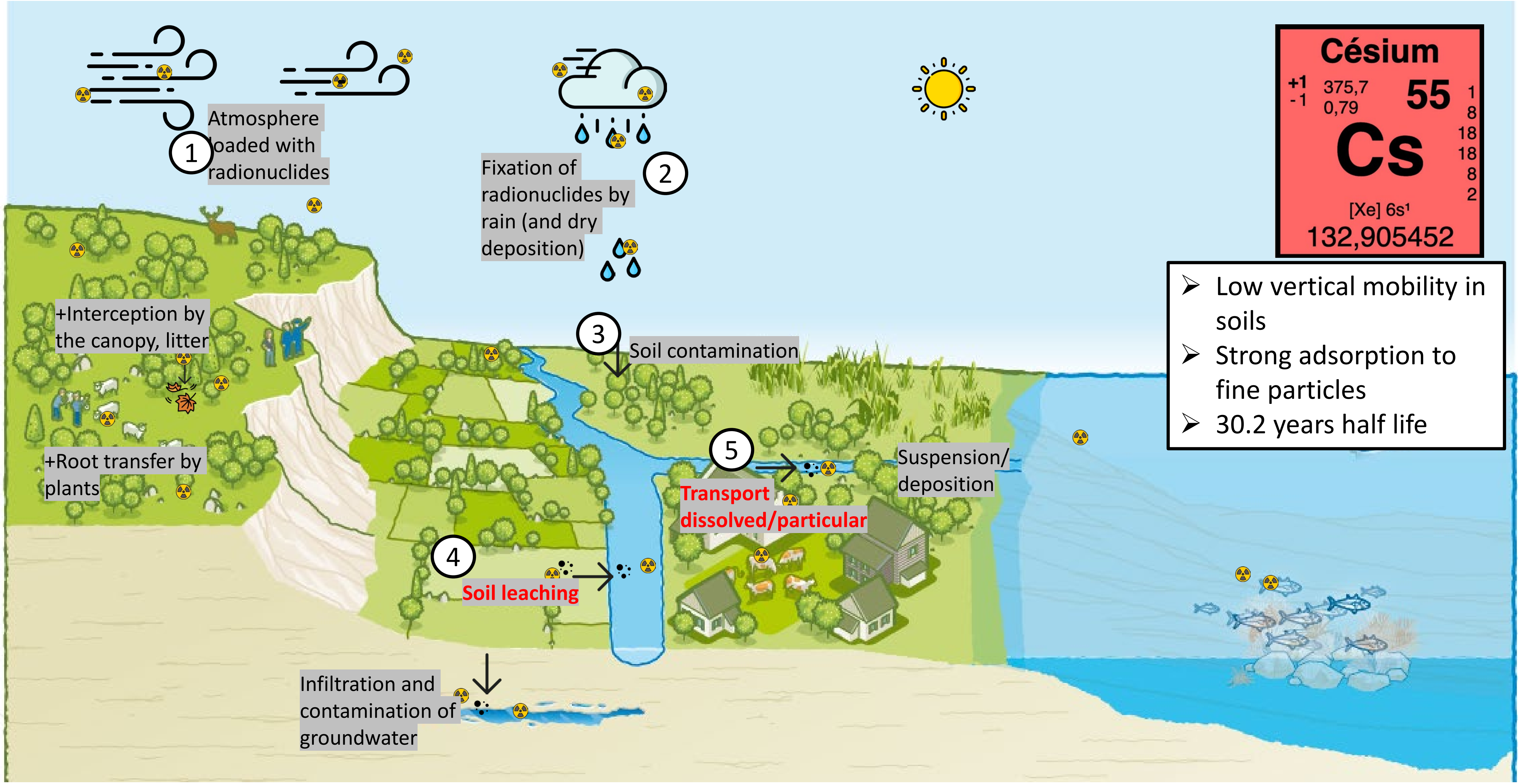
French nuclear facilities location map

EDF, CEA

EC/IGCE, Roshydromet 1998

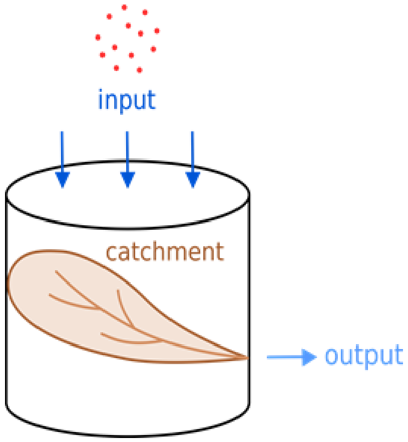


Nuclear accidents release lots of Cesium-137, its very persistent in the environment ($T_{1/2}$=30.2years) and harmfull

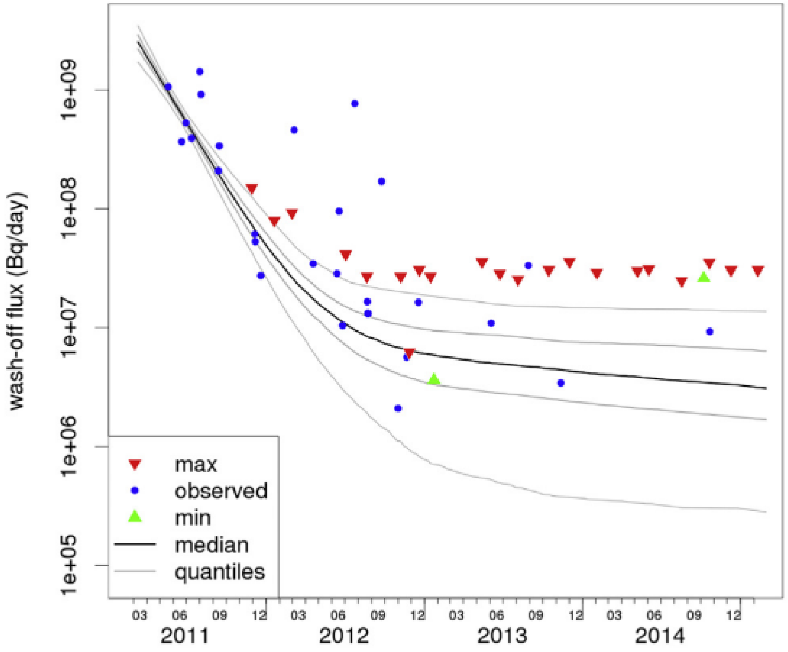

Atmosphere loaded with radionuclides
1
Fixation of radionuclides by rain (and dry deposition)
2
Césium
+1
- 1
375,7
0,79
55
Cs
1
8
18
18
8
2
[Xe] 6s¹
132,905452
Low vertical mobility in soils
Strong adsorption to fine particles
30.2 years half life
+Interception by the canopy, litter
+Root transfer by plants
3
Soil contamination
5
Transport dissolved/particular
Suspension/ deposition
4
Soil leaching
Infiltration and contamination of groundwater

The IRSN model already deployed: transfer functions (Delmas et al. 2017)

- 1D black box model



Chow *et al.*, 1988



+	-
Very quick to deploy, requires minimal input data, cost-effective	Excessive simplification, no spatial dispersion, does not consider geographical environmental data, no transfer processes

NEED TO DEPLOY A NEW MODEL

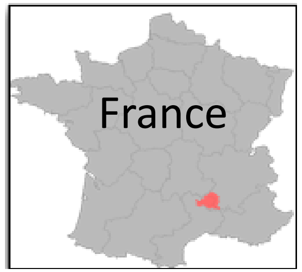
IRSN objectives

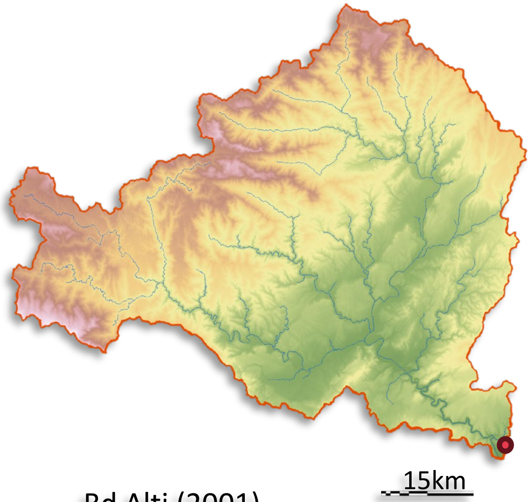
- **Spatialization** of transfers based on environmental parameters
- Consideration of **temporal fluctuations**
- Integration of **remediation practices** (adaptive)
- **IRSN made** model
- Relevant for monitoring, crisis response, expertise, and research

Soil & Water Assessment Tool SWAT

Project development

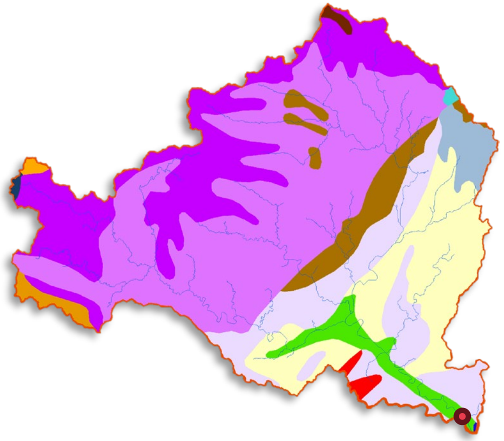
[A SMALL WATERSHED : THE ARDÈCHE RIVER (2200KM² - FRANCE)





Bd Alti (2001)

Corine Land Cover (2012)



European soil database (2001)

SAFRAN (1980-2022)
(grided meteo France data)

Discretization : 5679 HRUs and 283 sub-basins

Hydrological calibration → Cesium-137 modeling using SWAT outputs

Sediment calibration

Calculation of Cesium-137 concentrations in suspended solids

BASED ON A TRACE METALS EQUATION (TOMCZAK ET AL. 2021)

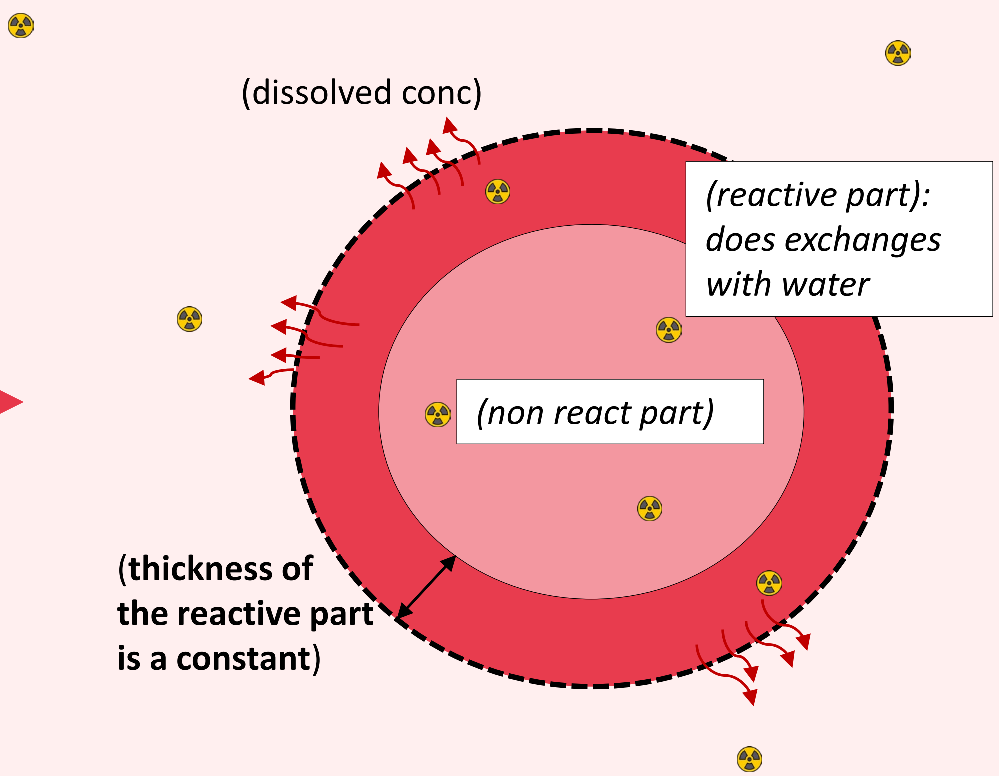
Yellow: modeled with SWAT

For Cs-137 particulate concentrations:

- **Flow** (m^3/s)
- **Suspended solids concentration** (g/L)
- **Particle size** (µm)
- **Dissolved particular ratio KD** (L/kg)

- **Source term** (Bq/kg):
  - **Soil erosion** (t/ha)
  - **Soil contamination** (Bq/kg)
    - Soil sampling campaign

In the formula every particle is described with *two phases*



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Soil sampling campaign

A KD of 68 000 means :

The number of bequerels in 68 000 liters of water

=

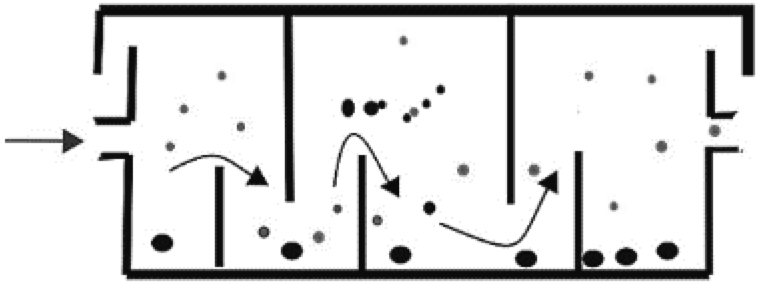
The number of bequerels in 1 kilo of matter

Is the same as

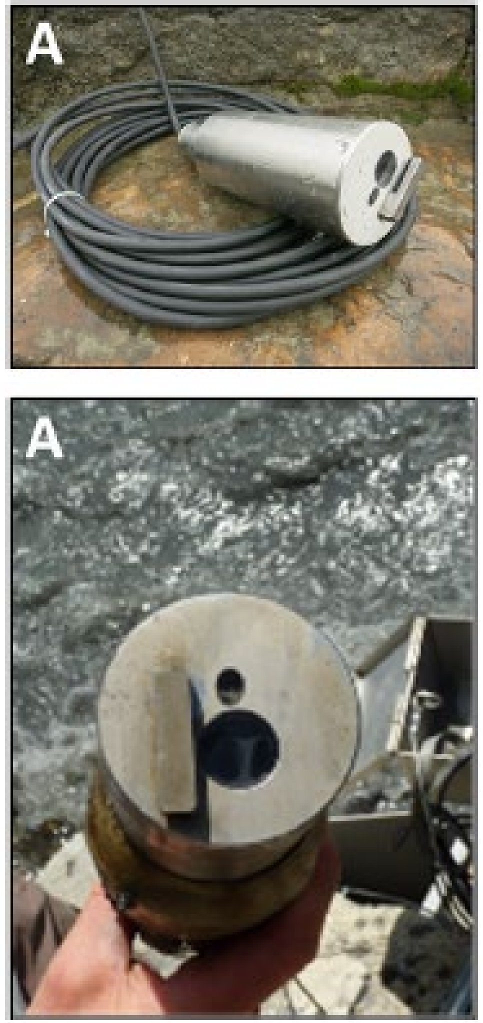
Material and methods

Observatoire des Sédiments du Rhône

DATA FROM FRENCH RIVER MONITORING AND THE OSR (RHÔNE SEDIMENTS OBSERVATORY)



- Hydrology (1980-2022): calculated by converting water height into flow
- Suspended sediment concentrations (2016-2022) : calculated using a turbidity meter (A) calibrated with sediment concentration manual sampling.
- Sediment trap (C) for Cesium-137 values 2016-2022).
  - Submerged for 3weeks-1month to have enough matter to do measures



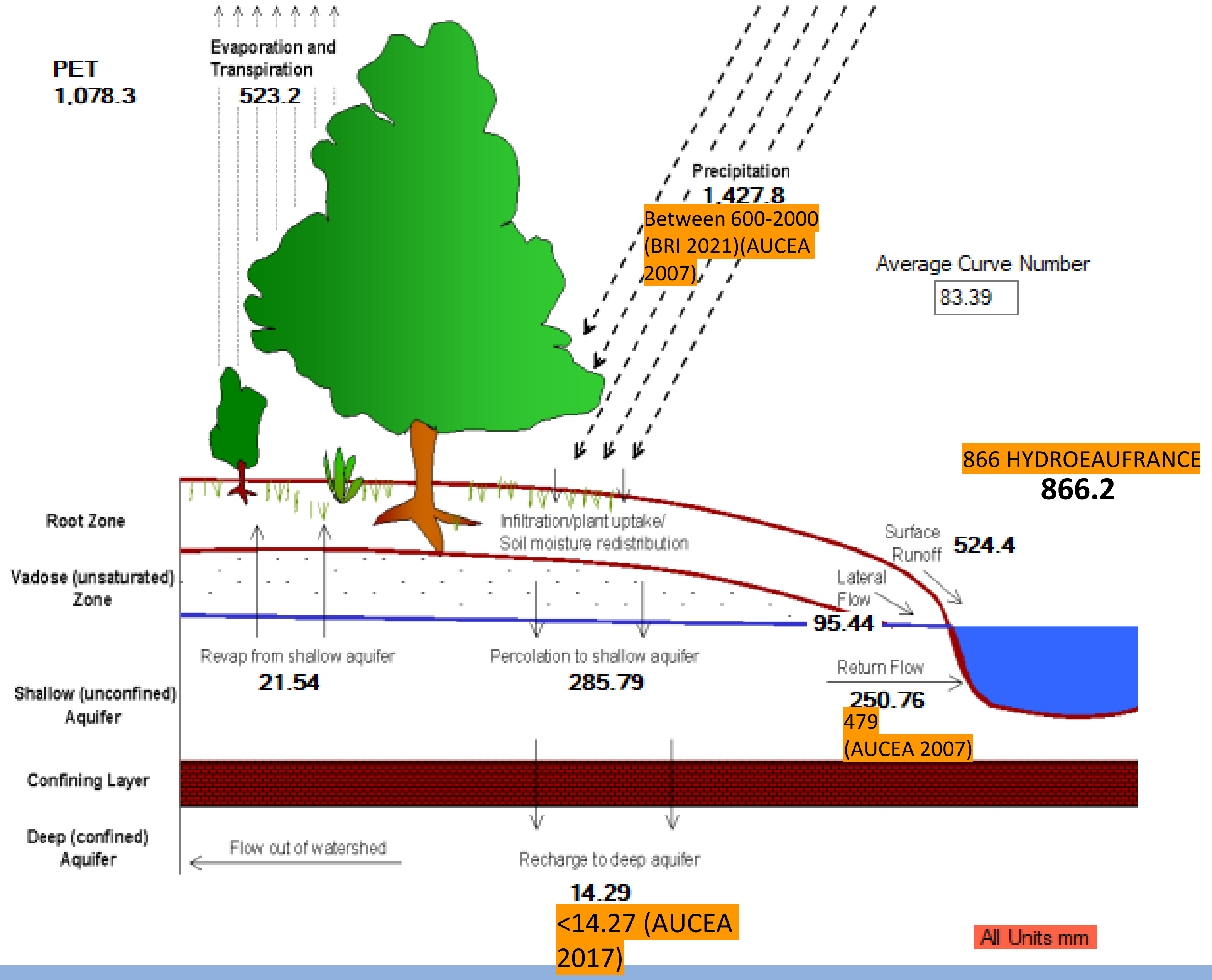
Lepage et al. 2021

SWAT Soil & Water Assessment Tool

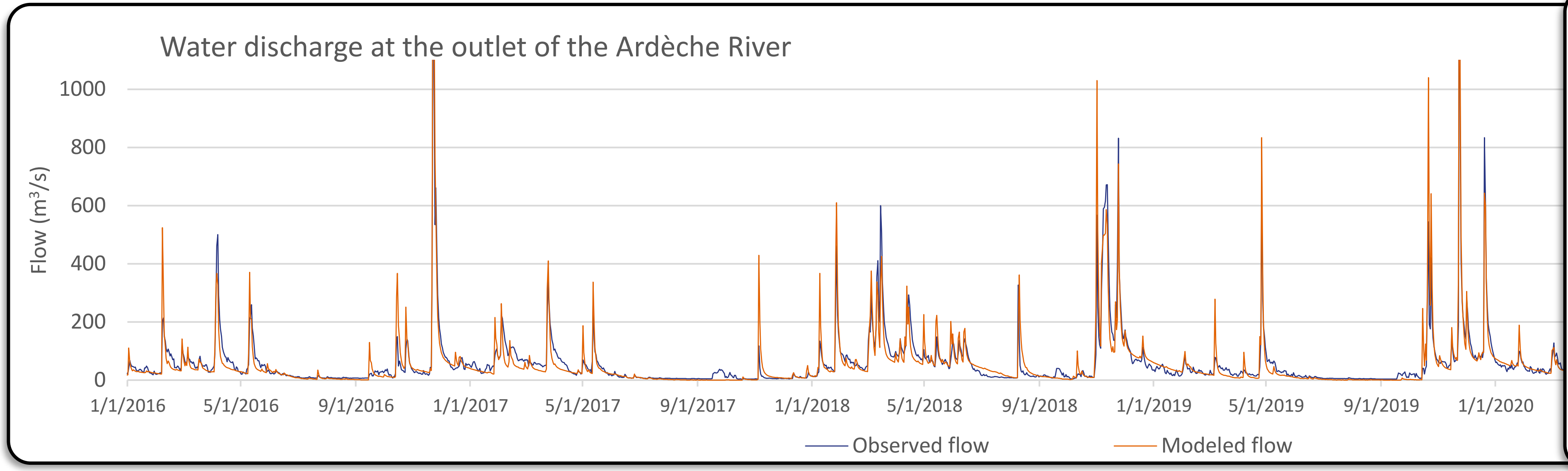
SWAT modelling

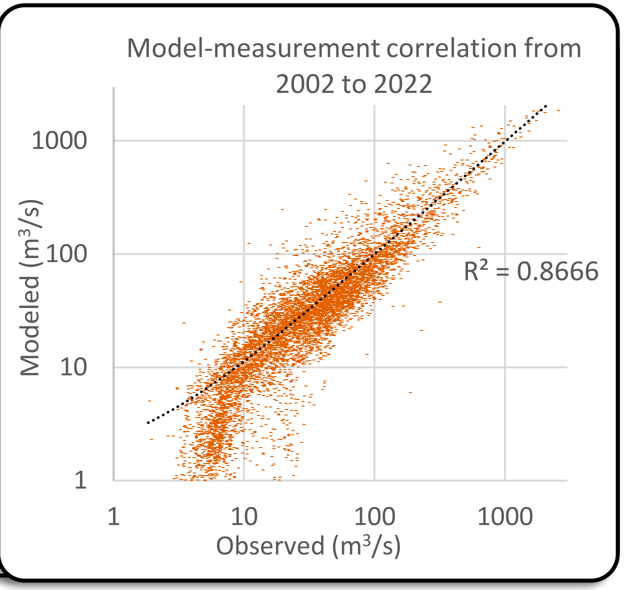
[HYDROLOGICAL BALANCE

1980-2022

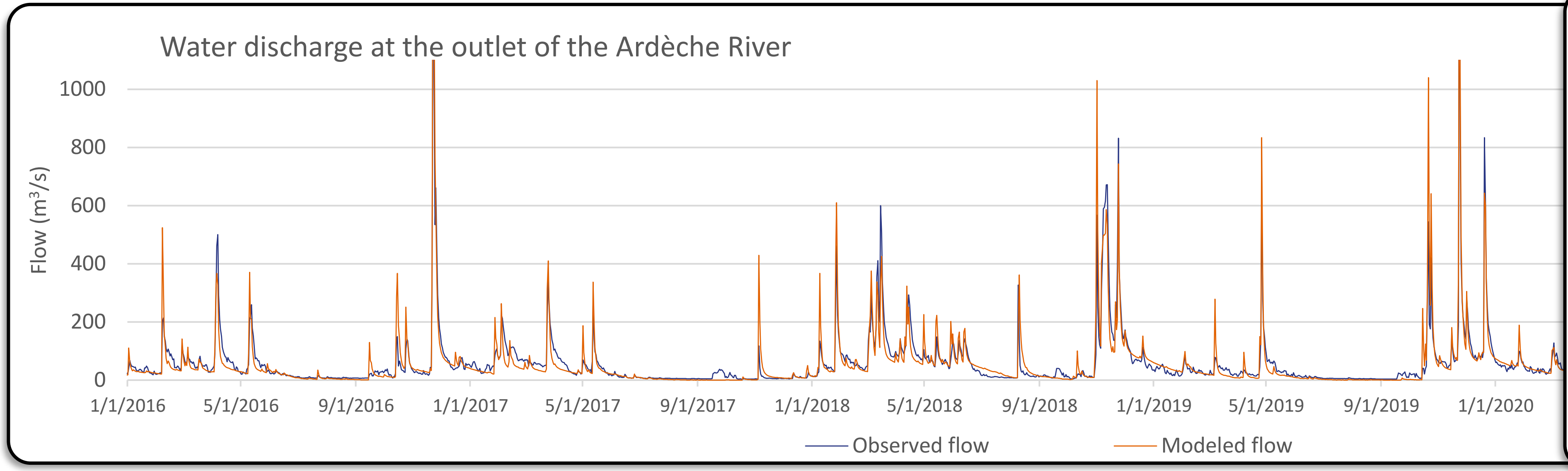


FLOW

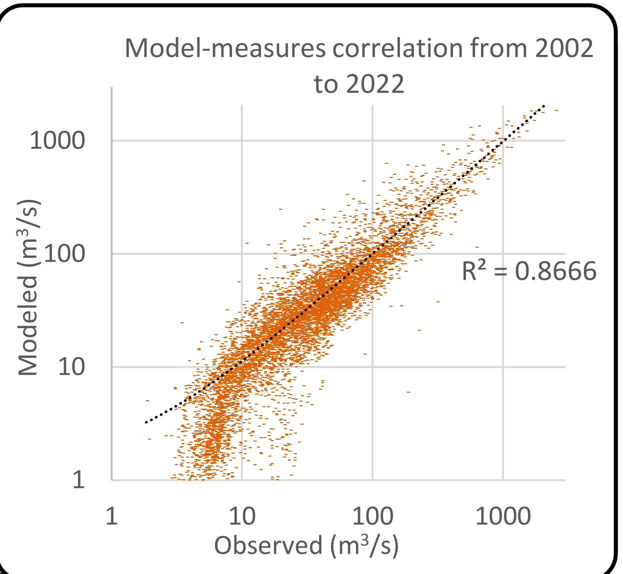

Water discharge at the outlet of the Ardèche River
1000
800
600
400
200
0
Flow (m³/s)
1/1/2016
5/1/2016
9/1/2016
1/1/2017
5/1/2017
9/1/2017
1/1/2018
5/1/2018
9/1/2018
1/1/2019
5/1/2019
9/1/2019
1/1/2020
Observed flow
Modeled flow


Model-measurement correlation from 2002 to 2022
1000
100
10
1
Modeled (m³/s)
R² = 0.8666
1
10
100
1000
Observed (m³/s)

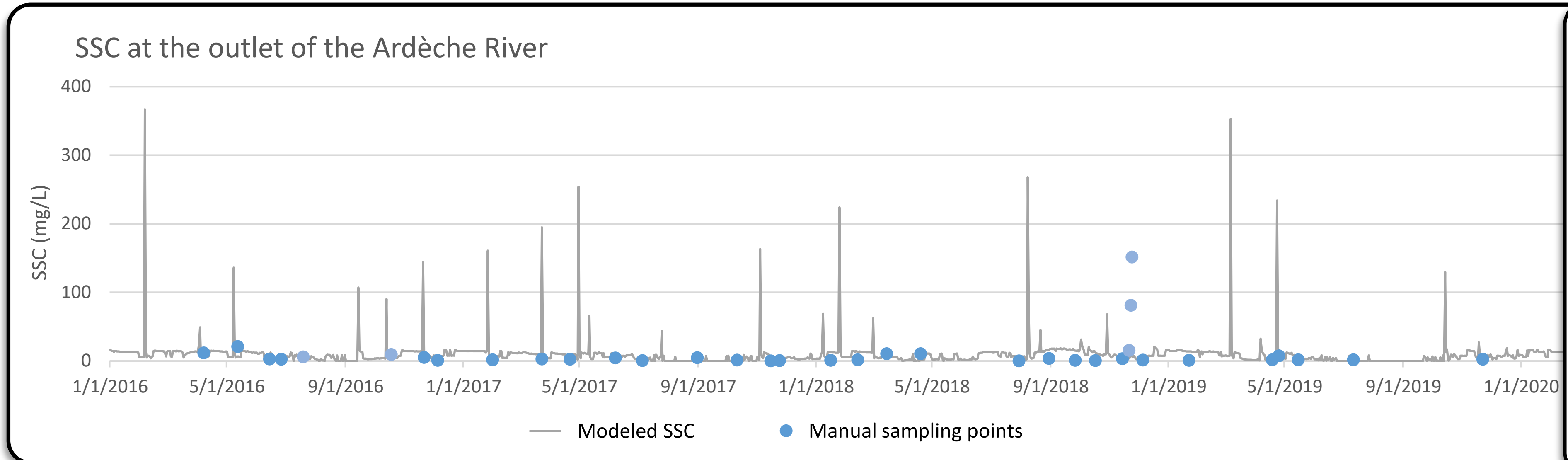
FLOW



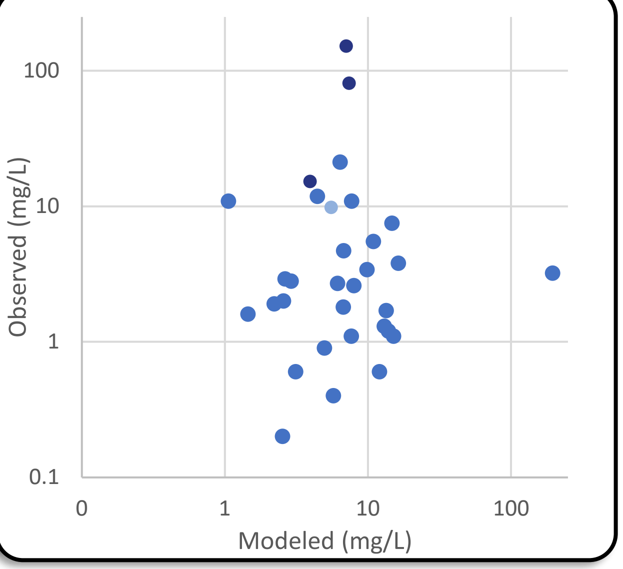
Water discharge at the outlet of the Ardèche River
Flow (m3/s)
1000
800
600
400
200
0
1/1/2016
5/1/2016
9/1/2016
1/1/2017
5/1/2017
9/1/2017
1/1/2018
5/1/2018
9/1/2018
1/1/2019
5/1/2019
9/1/2019
1/1/2020
Observed flow
Modeled flow



Model-measures correlation from 2002 to 2022
Modeled (m3/s)
Observed (m3/s)
1
10
100
1000
R² = 0.8666



SSC at the outlet of the Ardèche River
SSC (mg/L)
400
300
200
100
0
1/1/2016
5/1/2016
9/1/2016
1/1/2017
5/1/2017
9/1/2017
1/1/2018
5/1/2018
9/1/2018
1/1/2019
5/1/2019
9/1/2019
1/1/2020
Modeled SSC
Manual sampling points



Observed (mg/L)
Modeled (mg/L)
0.1
1
10
100
0

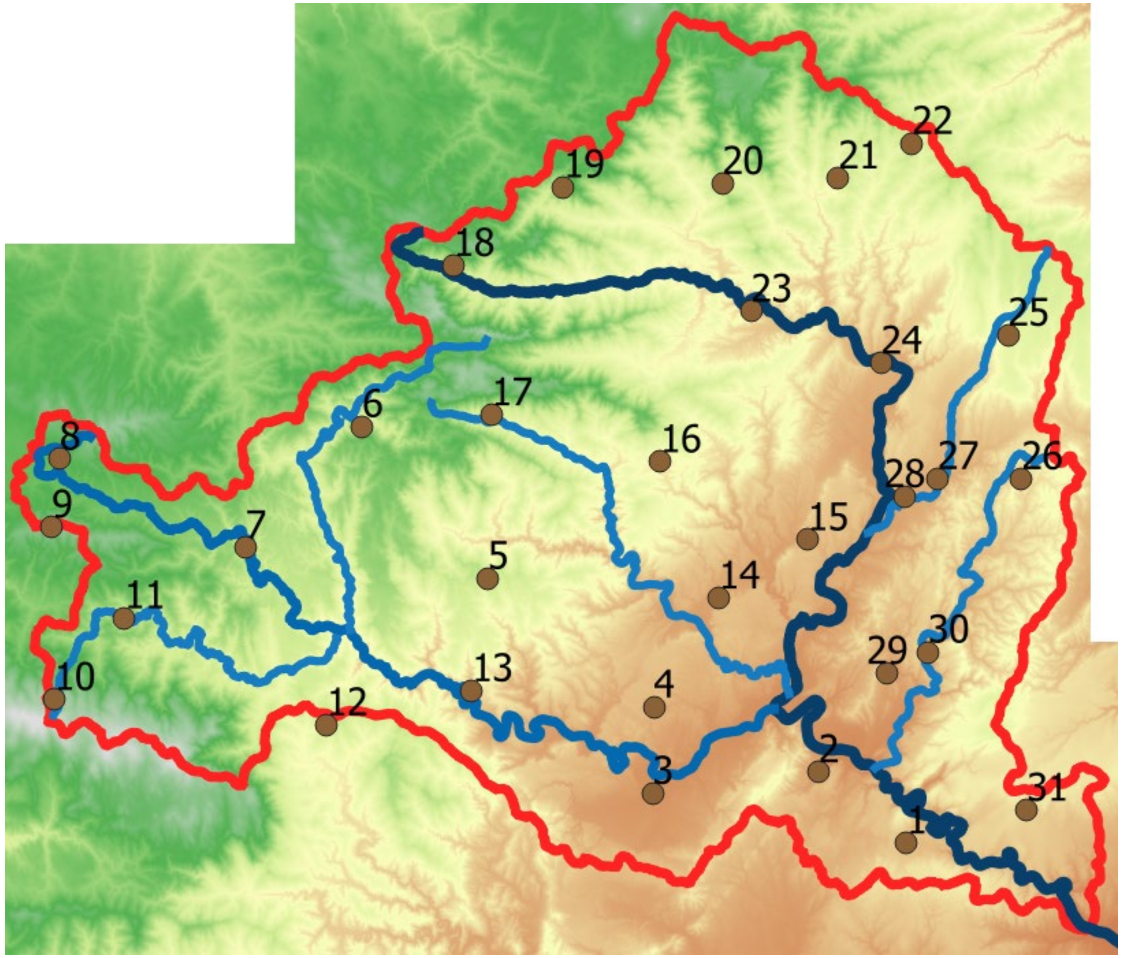
Defining a source term to model Cesium-137

FIELD CAMPAIGN AND LABORATORY ANALYSES (PHYSICOCHEMICAL PROPERTIES OF PARTICLES)

Cultivated (grapes, land generic, orchard..)
Forested (deciduous, evergreen and mixed)
Natural (garrigue, hay, range brush, grasses..)

- 31 cores, cibling 3 major types of land use (Forests, cultivated soils and natural/ untouched)

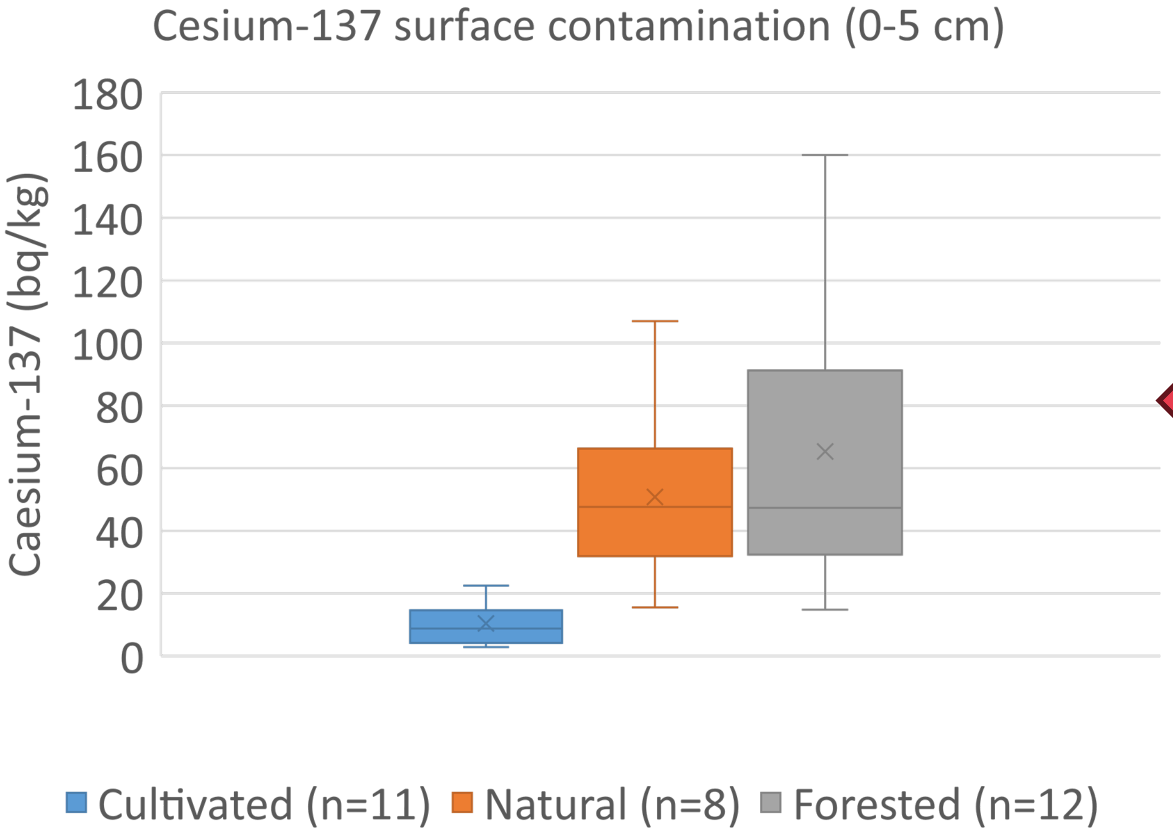
©François GUILLORY

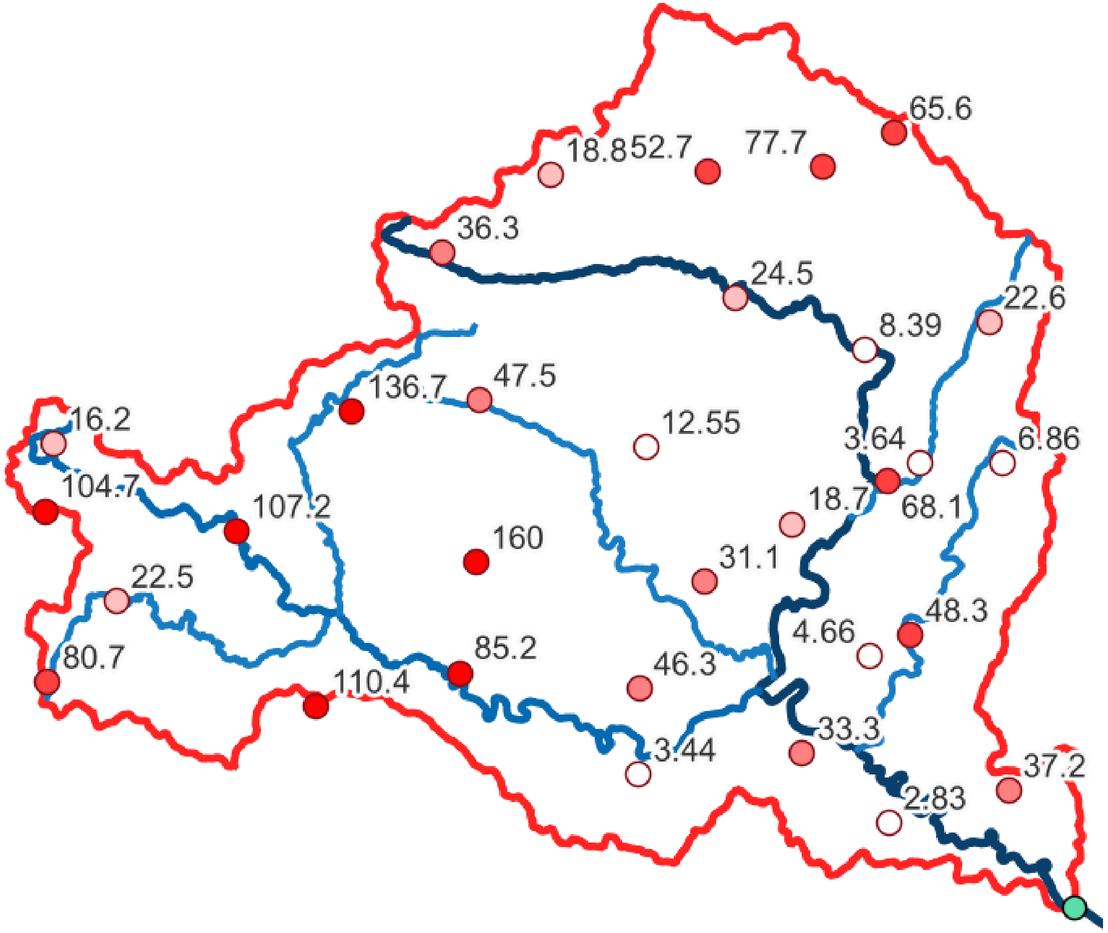


Defining a source term to model Cesium-137

FIELD CAMPAIGN AND LABORATORY ANALYSES (PHYSICOCHEMICAL PROPERTIES OF PARTICLES)

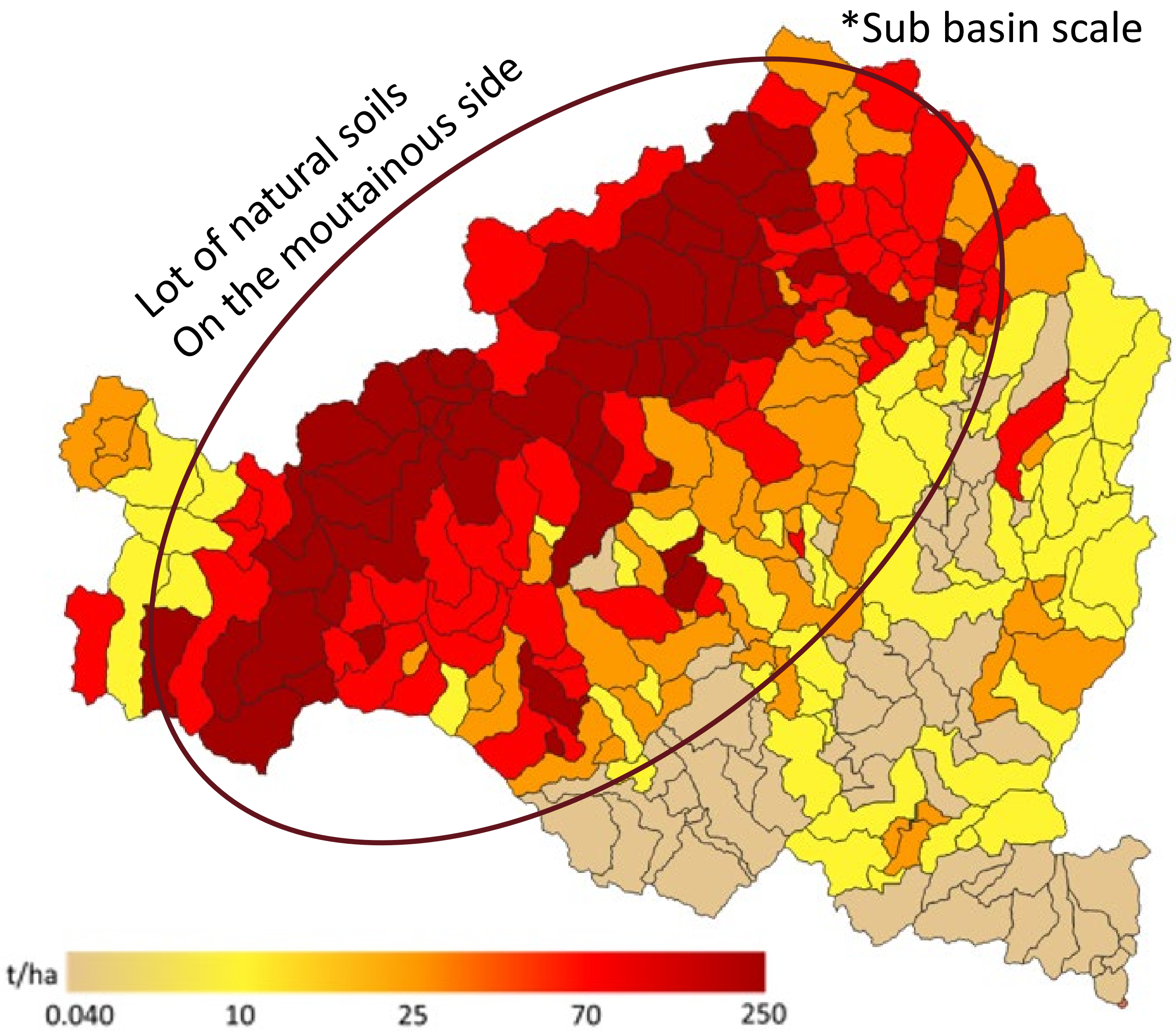
CAMPAIGN RESULTS

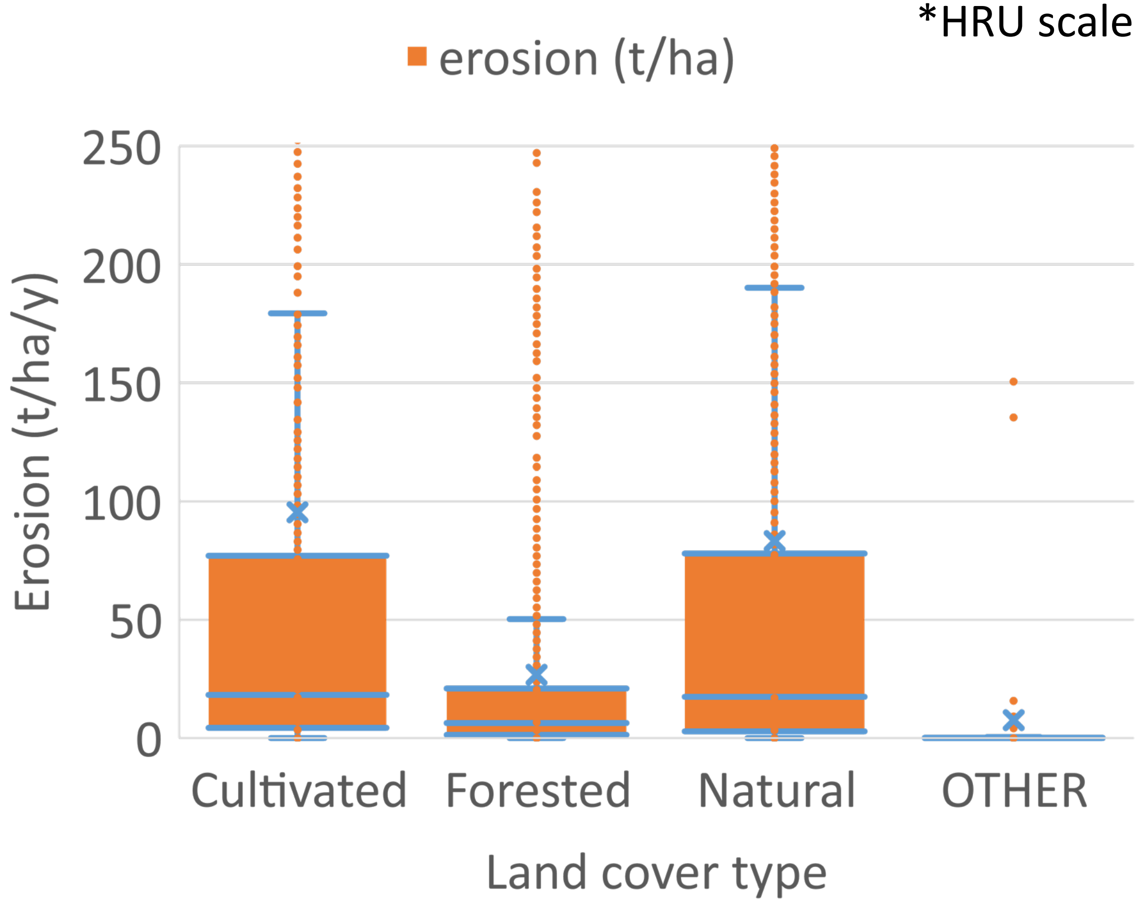




SWAT outputs

[EROSION RATE (.HRU -> SEDTH)





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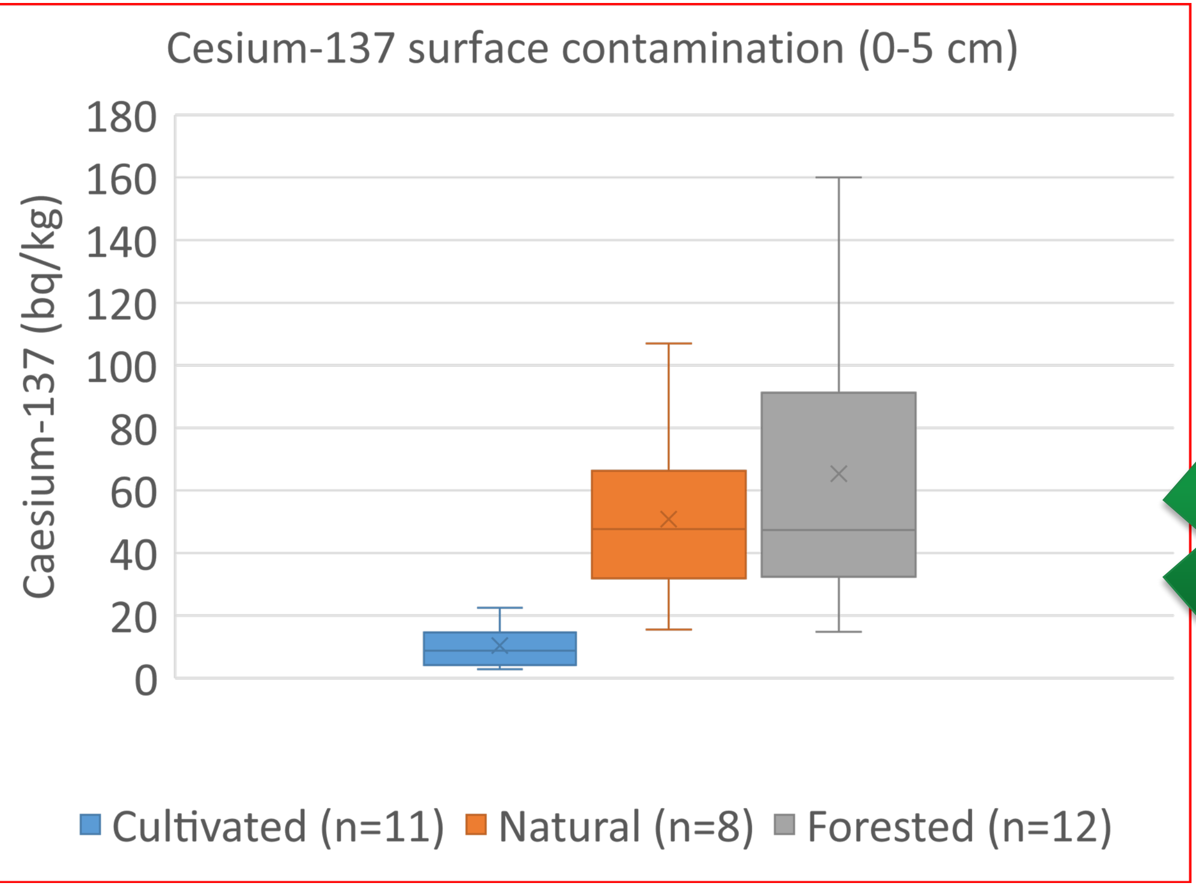
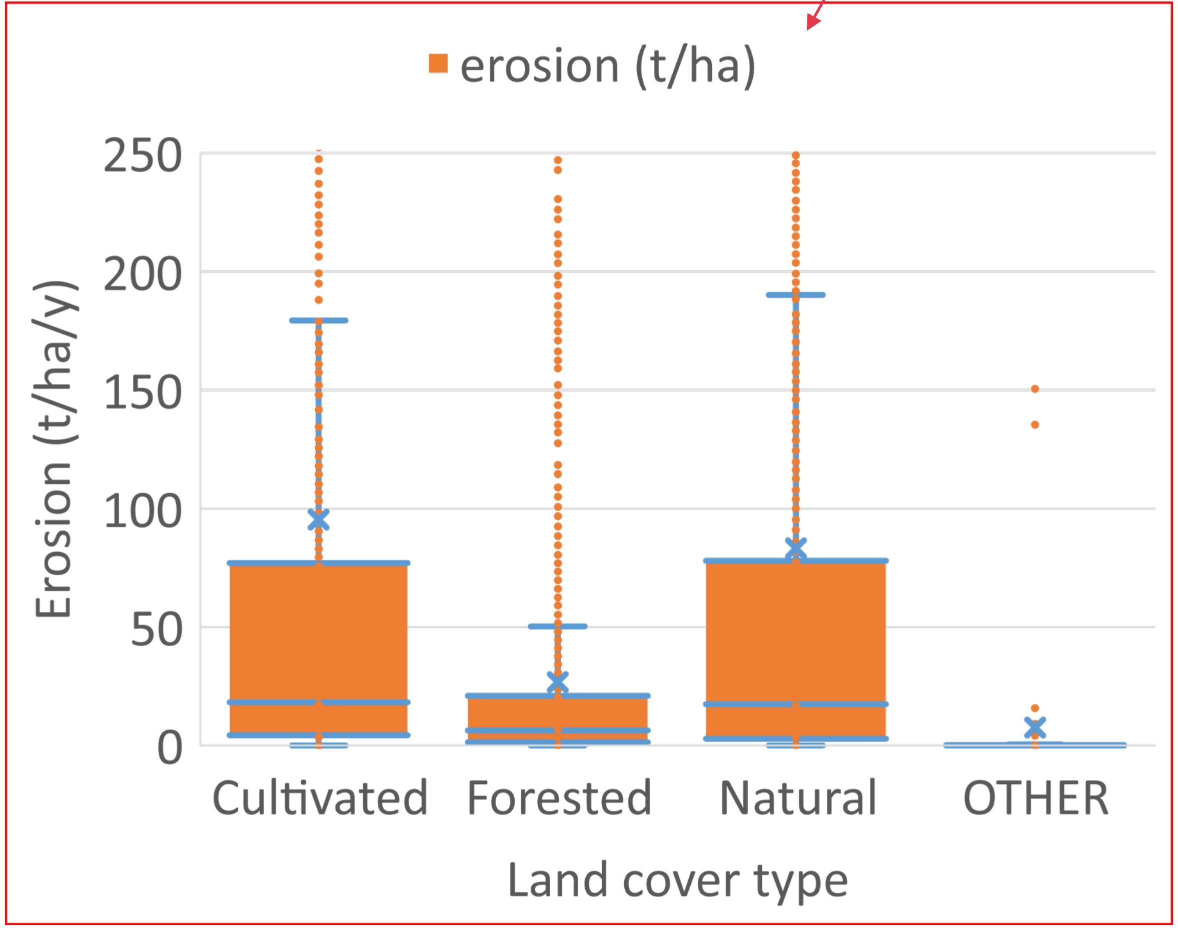


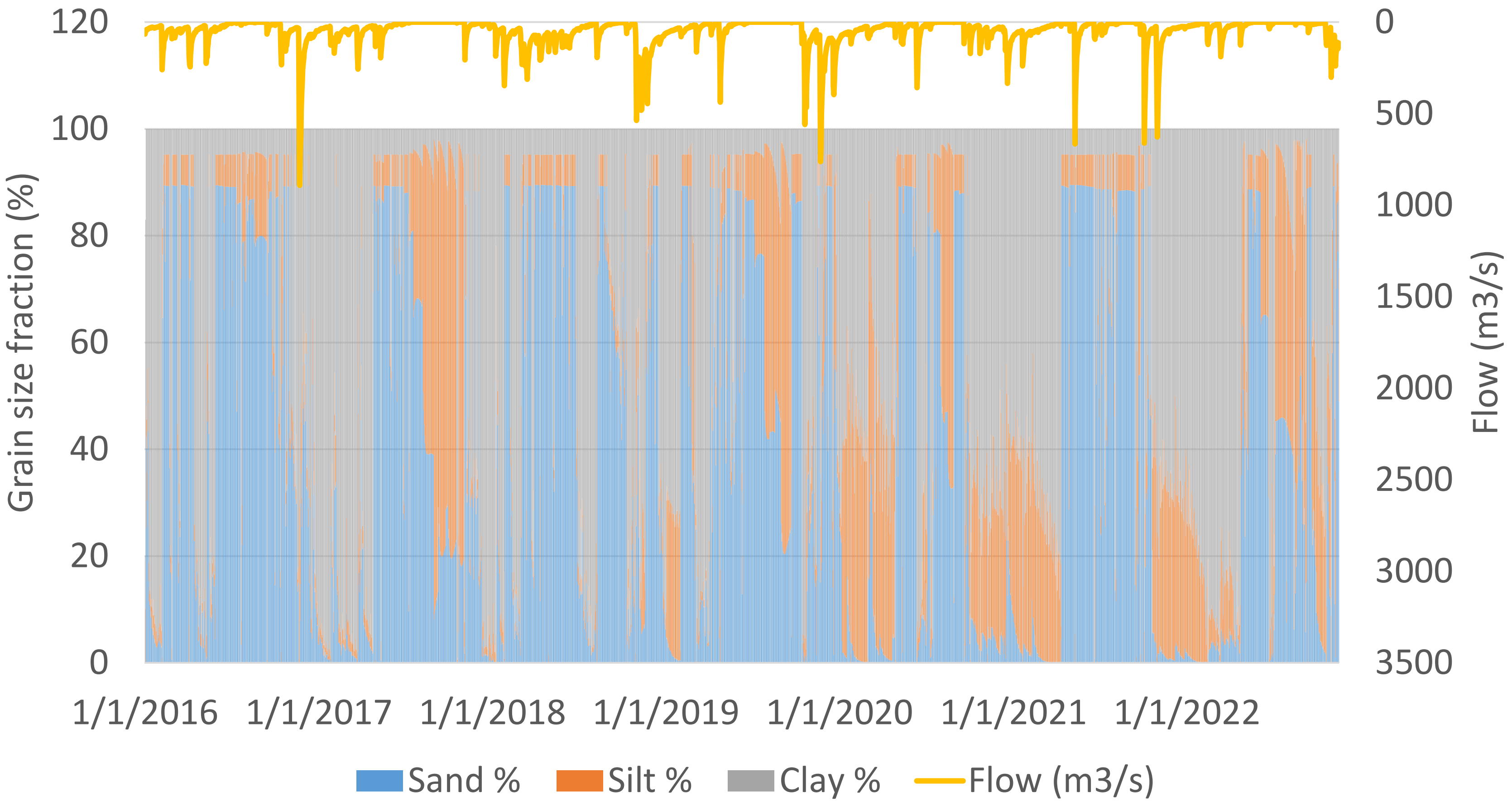
Converted to % contribution

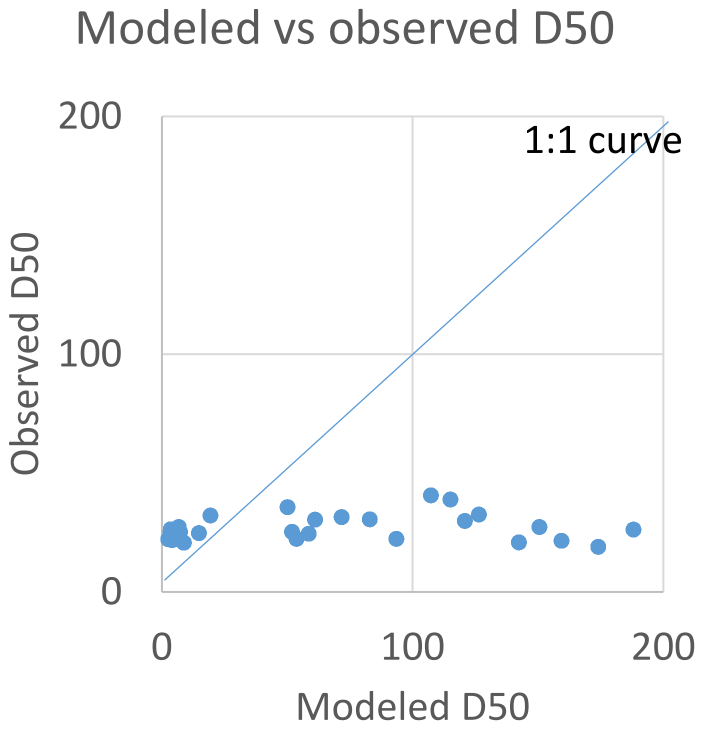


Source term of 29.1 Bq/kg

PARTICLE SIZE

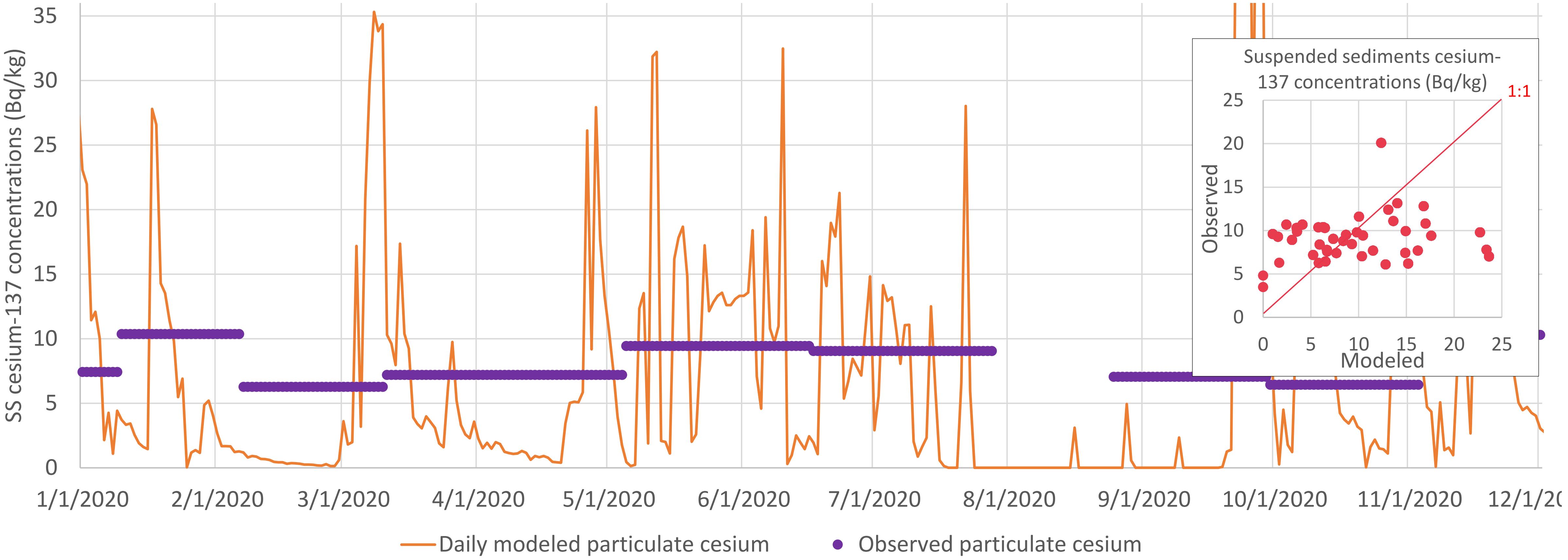
-We averaged what goes in and out of the last hydrographic section (.sed)





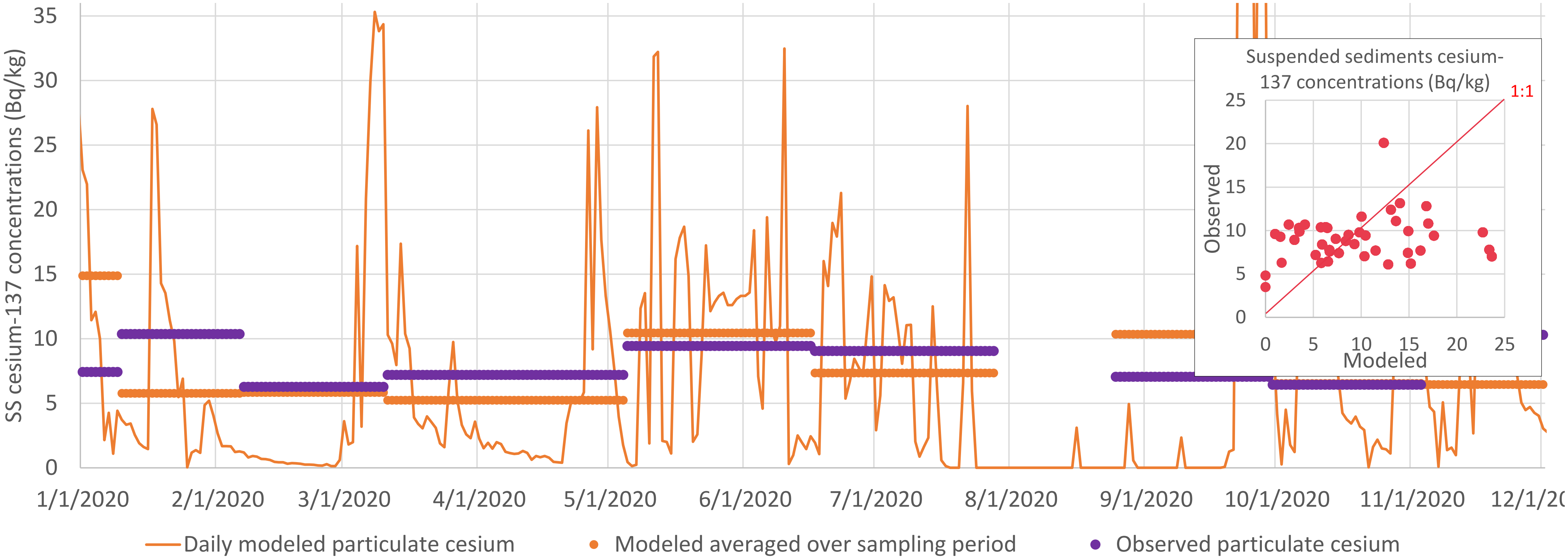
Cesium-137 transfer formula

RESULTS



Cesium-137 transfer formula

RESULTS



Conclusion

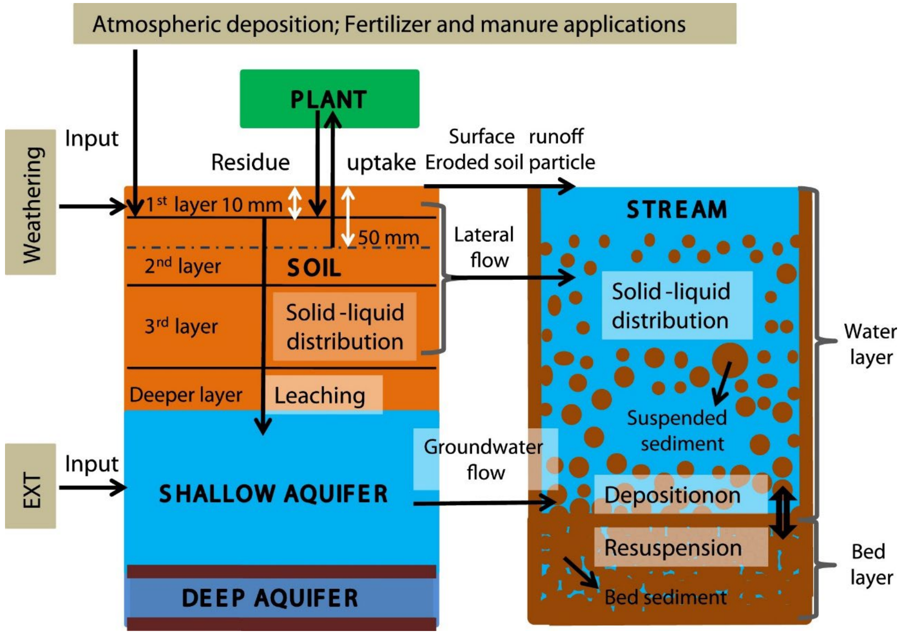
- Cesium-137 concentrations were modelled using SWAT outputs (flow, SSC, particle size, erosion rates)
- Particular and dissolved phase concentrations are in the same magnitude order despite doubts on SS and particle size

CRITICS

- Suspended sediments modelling
- Are erosion rates and particle size valid ?

WHAT WE WORK ON

- Adding more dynamism : working with each HRU's features/ add plant transfers
- Coupling it with a nuclear power plant discharge model
- Setting a new project in Japan's contaminated watersheds
- Maybe using a potassium module (an analog of the Cesium)



Thanks for listenning

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Transfer formula

$$Kd_{\varrho} = 68\ 000$$

$$[SS_p]_r = (1 - \gamma p)[SS_p]$$
$$[SS_p]_{nr} = \gamma p[SS_p]$$

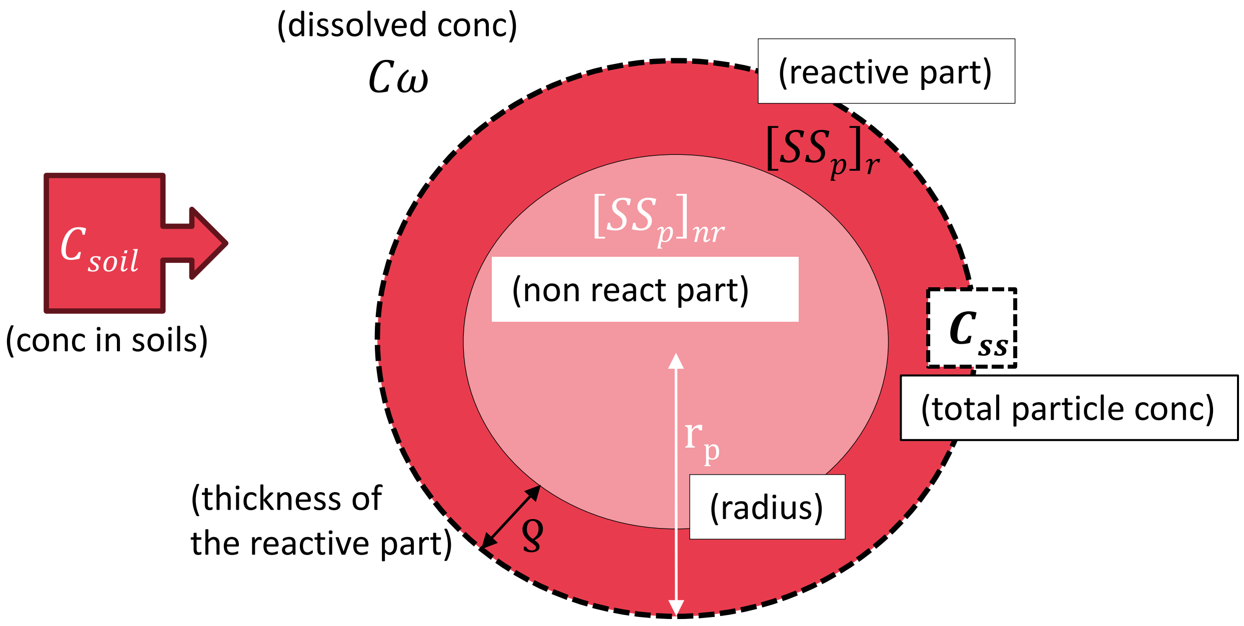
$$avec\ \gamma p = \left(-\frac{\varrho}{r_p}\right)^3\ si\ r > \varrho \text{ et } \gamma p = 0 \text{ si } r_p \leq \varrho$$

$$\boldsymbol{C_{ss} = \sum_p [SS_p]\,.Css_{,p}}$$

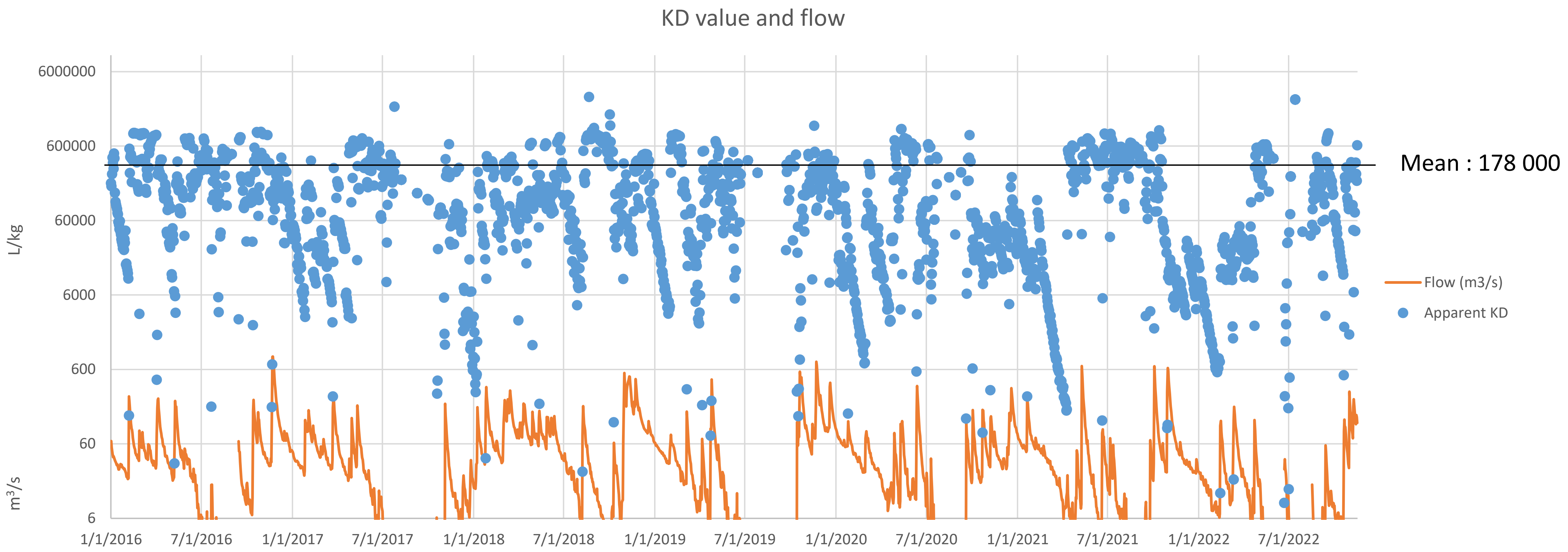
$$\boldsymbol{C_{ss,p} = \frac{(Kd_{\varrho}.C\omega.[SSp]_r + Csoil.[SS_p]_{nr})}{[SSp]}}$$

$$C\omega = \frac{\sum_P [SS_p]_r.Csoil}{1 + Kd_{\varrho}.\sum_P [SS_p]_r} \quad ; \quad C_{ss,r} = Kd_{\varrho}.C\omega$$

$$Kd_a = \frac{C_{ss}}{C\omega}$$



$$Kd_a = \frac{C_{ss}}{C\omega}$$



- KD increases when disharge goes up, although there are more particles, they are less contaminated as they are bigger (bigger transport bigger particles)

- 98.4% of the Cesium-137 mean annual flux comes from particular discharge