An uncertainty-based framework for incorporating sediment source fingerprinting into spatially-distributed soil erosion model testing

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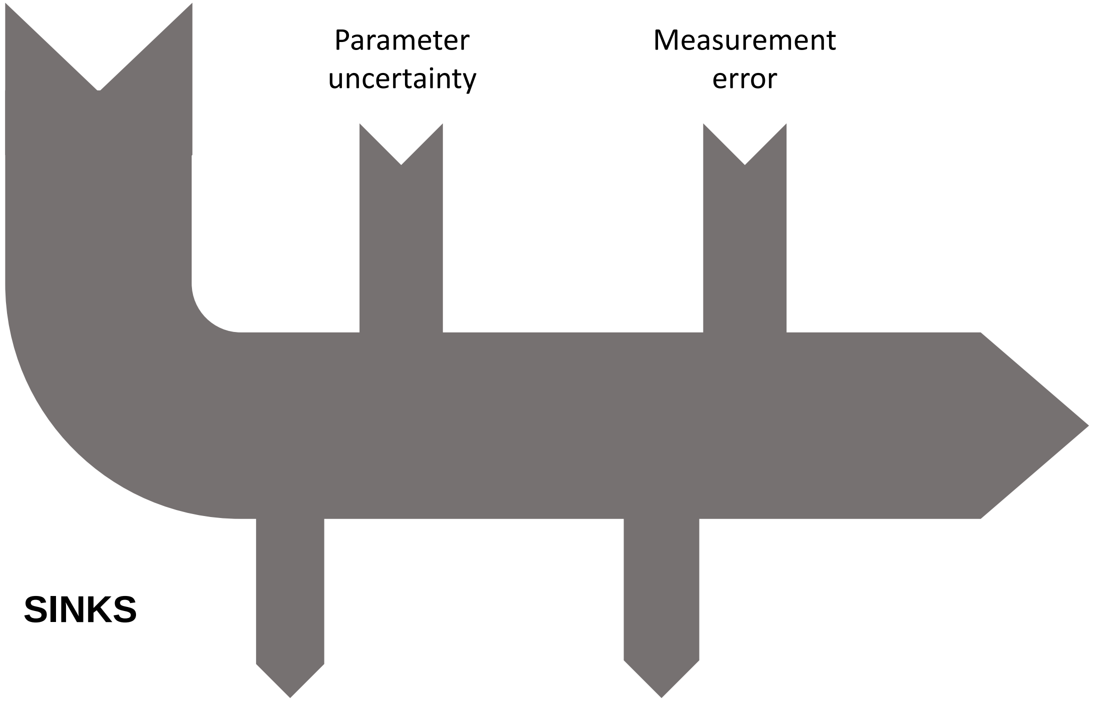

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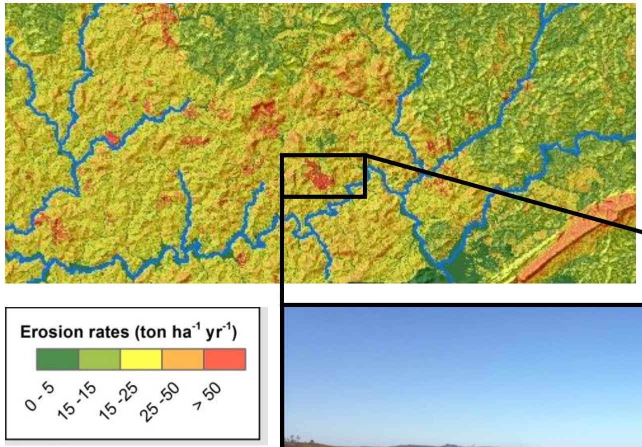
Spatially distributed soil erosion and sediment delivery models can inform us about where, when, and with which magnitude erosion occurs.



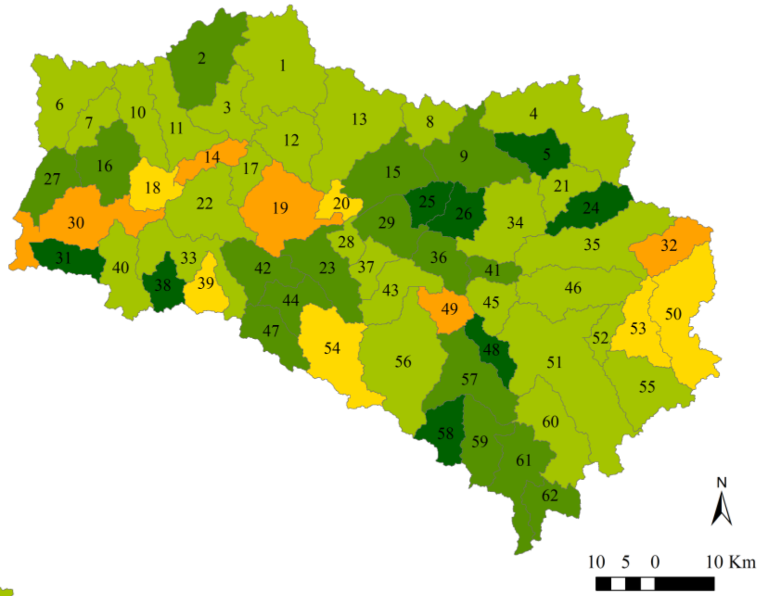
These models also allow us to quantify how much sediment is delivered to water courses and where it comes from.

But how do we test these models? The common approach is to compare modelled and measured catchment sediment loads.

This approach does not allow us to understand if the models are correctly identifying the main sediment sources.

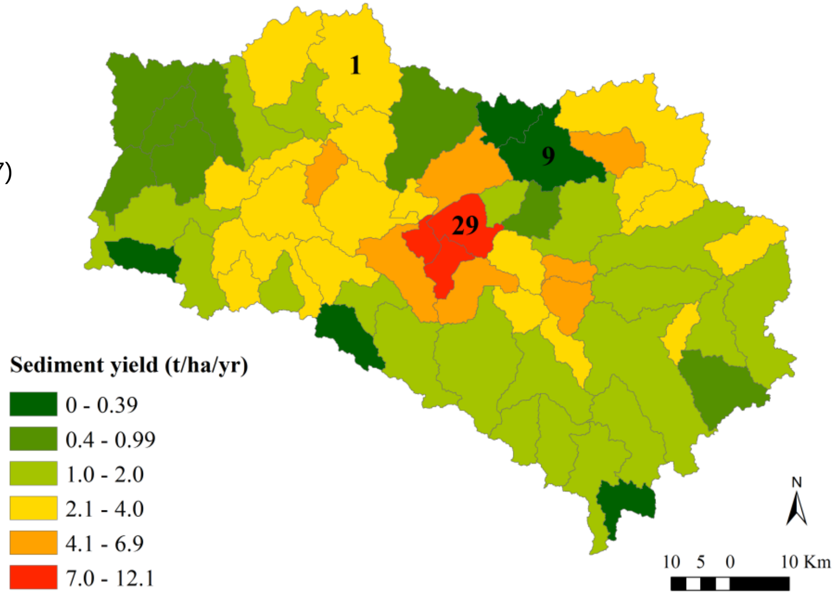
SEDD

Batista et al. (2017)



SWAT

Eduardo (2017)



For instance: both models predict similar outlet transport rates. Which one deviates **farther from reality?**

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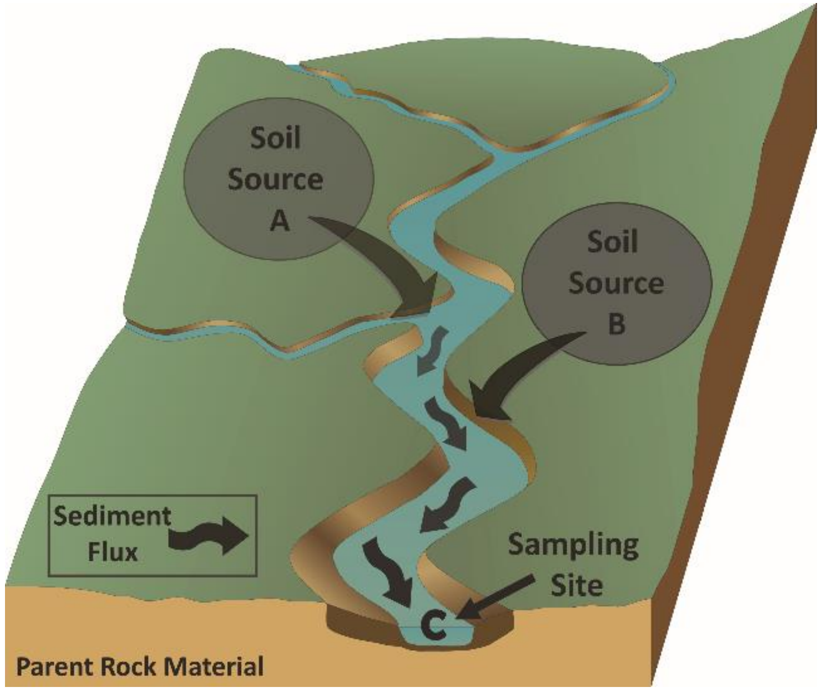
Sediment fingerprinting provides quantitative apportionments of sediment sources.

A comparison between soil erosion/sediment delivery models and fingerprinting source apportionments may be used to evaluate the capability of the models to identify the main sources in a catchment.



Source: Patrick Laceby (personal communication)

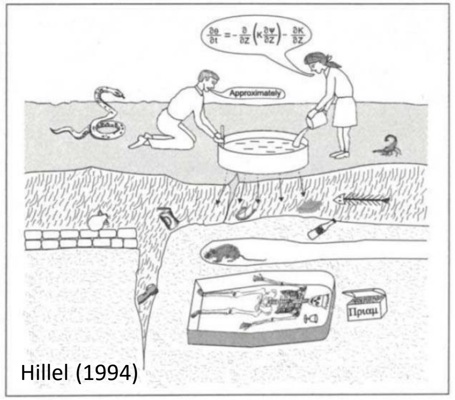
However, testing soil erosion models requires representing the uncertainties associated to:

The system representation:


National Geographic

Reality x Model

Parameter estimation:

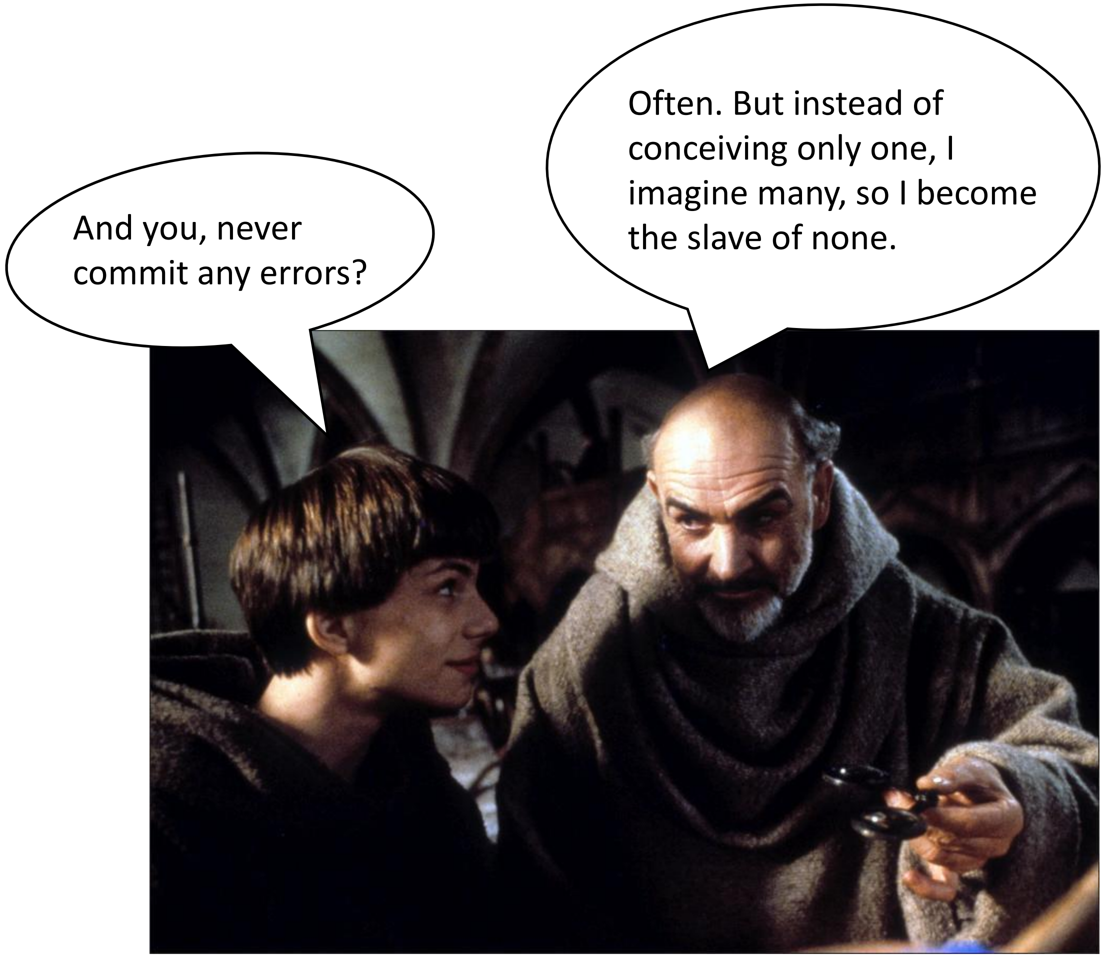

Hillel (1994)

Observational testing data:

The Generalised Likelihood Uncertainty Estimation (GLUE) (Beven & Binley, 1992) provides a framework for testing models, or model realizations, as hypotheses.

The basis of **GLUE** can be summarized in a few decision steps (Beven, 2009):

I. Decide on a rejection criteria **for non-behavioral** realizations (non-acceptable reproductions of the observational data).
II. Decide on which parameters are uncertain.
III. Decide on a prior distribution to characterize the uncertainty of the chosen parameters.
IV. Decide on a simulation method for generating model realizations.



The Name of the Rose, Umberto Eco

Objectives:

- To develop an approach to the evaluation of spatially-distributed soil erosion/sediment delivery models that **incorporates sediment fingerprinting** source apportionments while **representing the uncertainties** in **models and observational** forcing/testing data.

- More specifically:

    - To apply the RUSLE-based Sediment Delivery Distributed (SEDD) (Ferro & Porto, 2000) model within the GLUE methodology at a large catchment in Southeast Brazil.
    - To define limits of acceptability of model error based on the uncertainty of sediment load measurements.
    - To evaluate behavioral simulations against tributary-based fingerprinting source apportionments.

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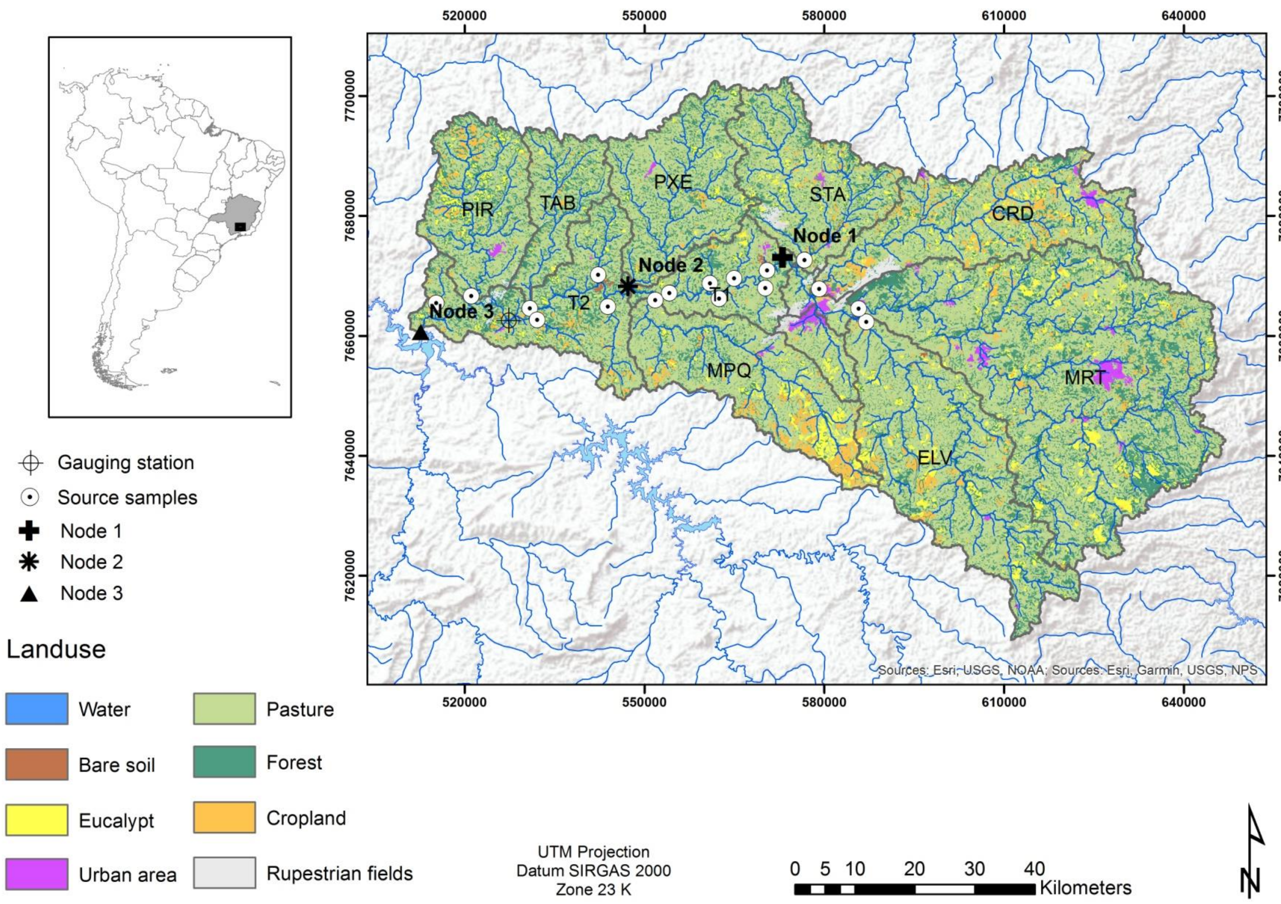
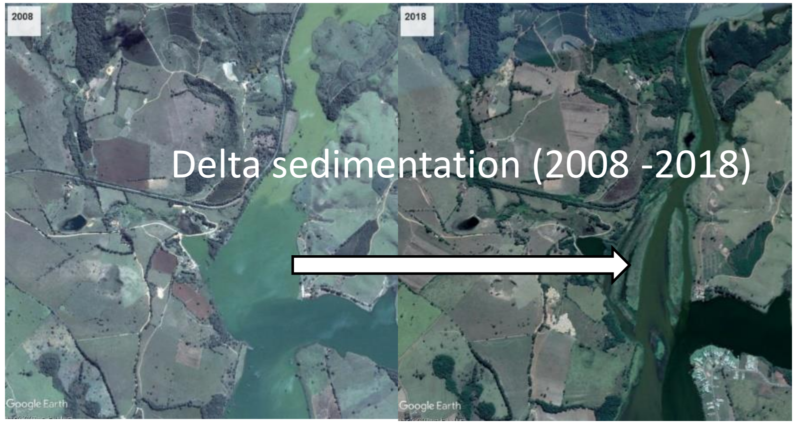
Mortes River catchment:



- ~6600 km^2
- Humid subtropical with dry winters and warm summers (Cwb)
- ~1500 mm yr^{-1}

- Acrisols (48%) and Cambisols (35%) are the main soil classes

- Land use:
  - Pasture: 66 %
  - Forest: 22 %
  - Cropland: 5 %
  - Eucalypt: 5 %



Outlet sediment loads – **forcing data**:

- Sediment concentration and water discharge measurements (2008 – 2012)

Sediment rating curve:

- Log-transformed data
- Ordinary least squares
- Posterior simulations of model coefficients: propagation of regression uncertainty into long-term sediment load estimates (analogous to SEDD outputs).

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Sediment fingerprinting – testing data:

Hierarchical tributary sampling design:

- 20 composite samples of lag deposits per tributary
- Sink nodes sampled during the dry and rainy season

Lab work:

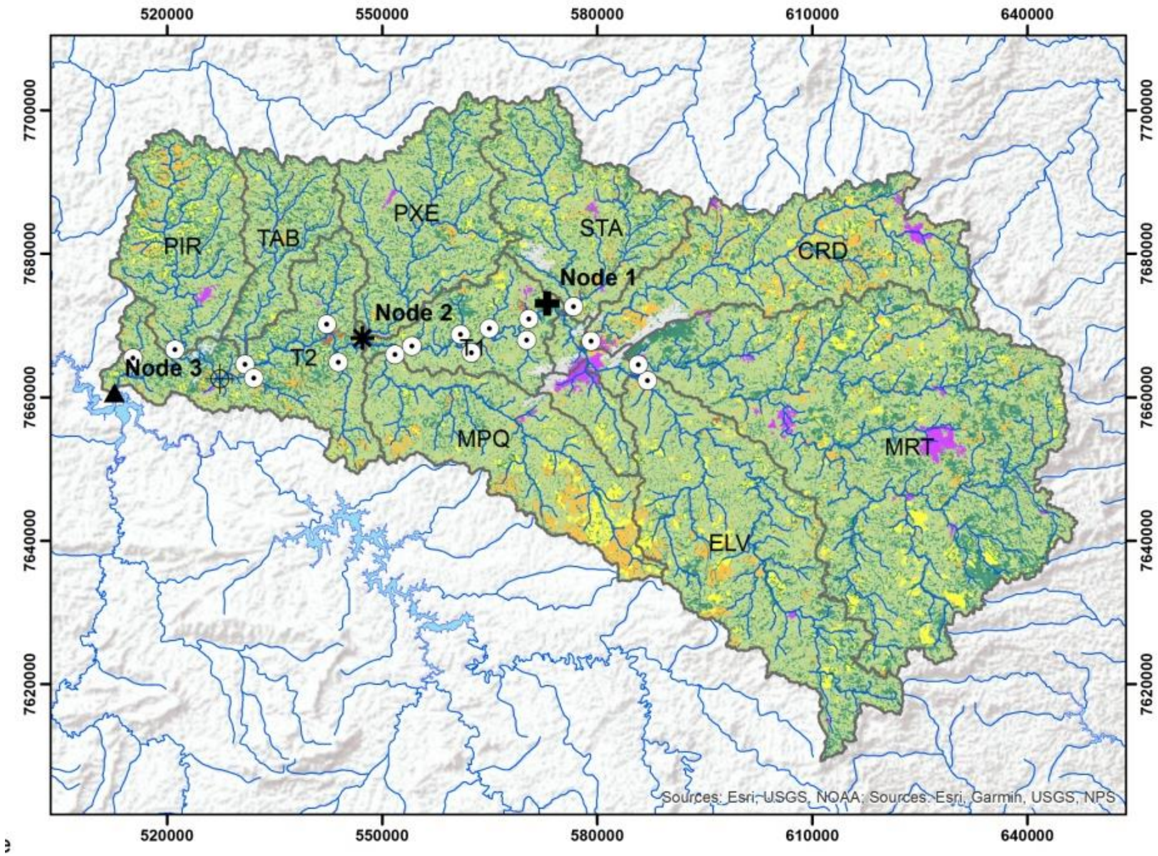
- Sieving < 0.2 mm
- Sediment geochemistry: ICP OES

Element selection:

- Forward step-wise LDA

Un-mixing modelling:

- Monte Carlo simulation sampling from Multivariate-Normal distributions



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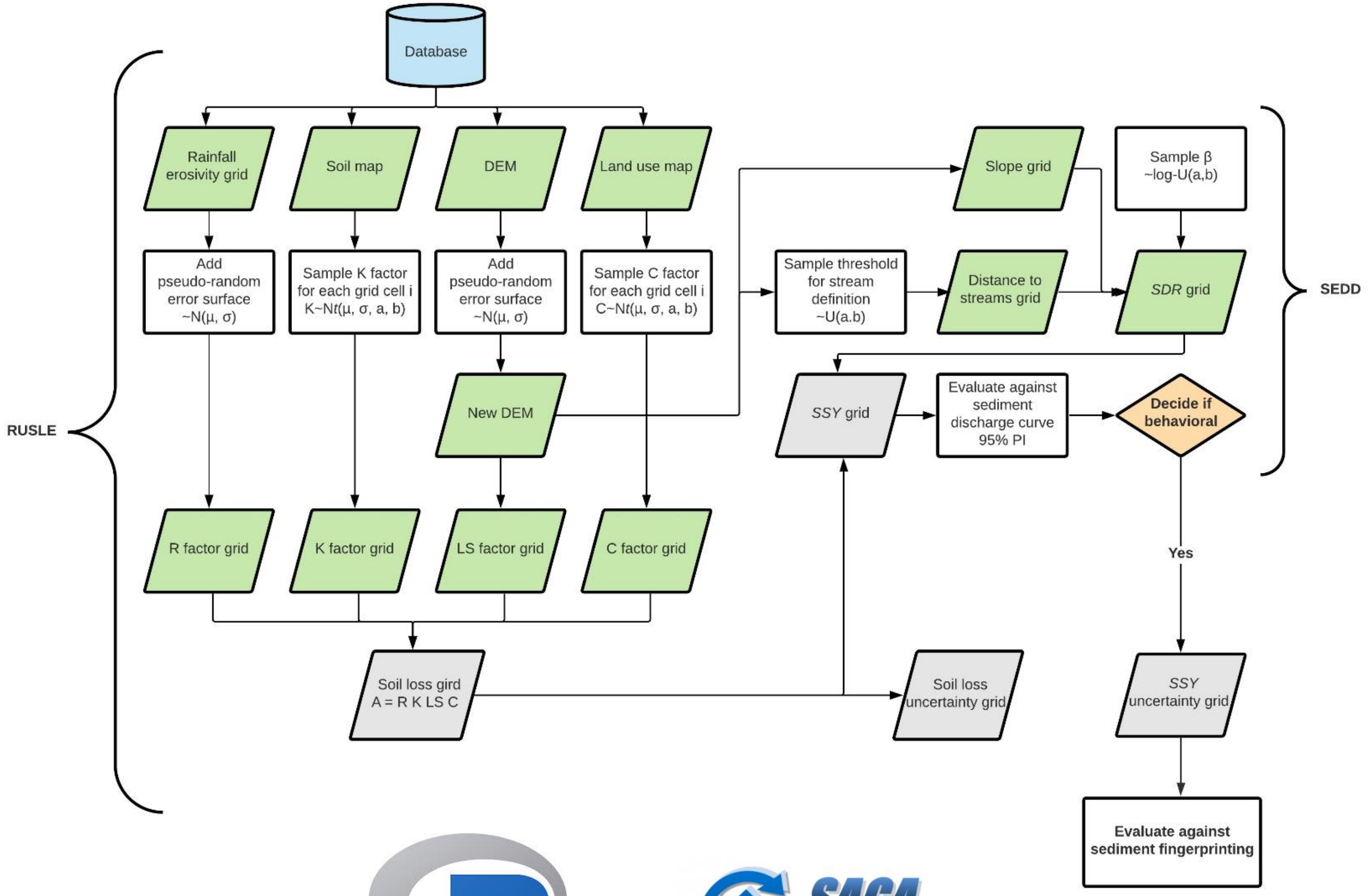
Soil erosion and sediment delivery modelling

RUSLE-based Sediment Delivery Distributed model (**SEDD**):

$$SSY_i = \exp\left(-\beta \frac{l_i}{s_i}\right) * (R\ K\ LS\ C\ P)$$

- Model realizations generated by a Monte Carlo simulation (1000 iterations)
- Rejection criterion: 95% PI of curve-estimated sediment loads (forcing data)
- Evaluation data: sediment fingerprinting source apportionments
- One-way sensitivity analysis: RUSLE factors



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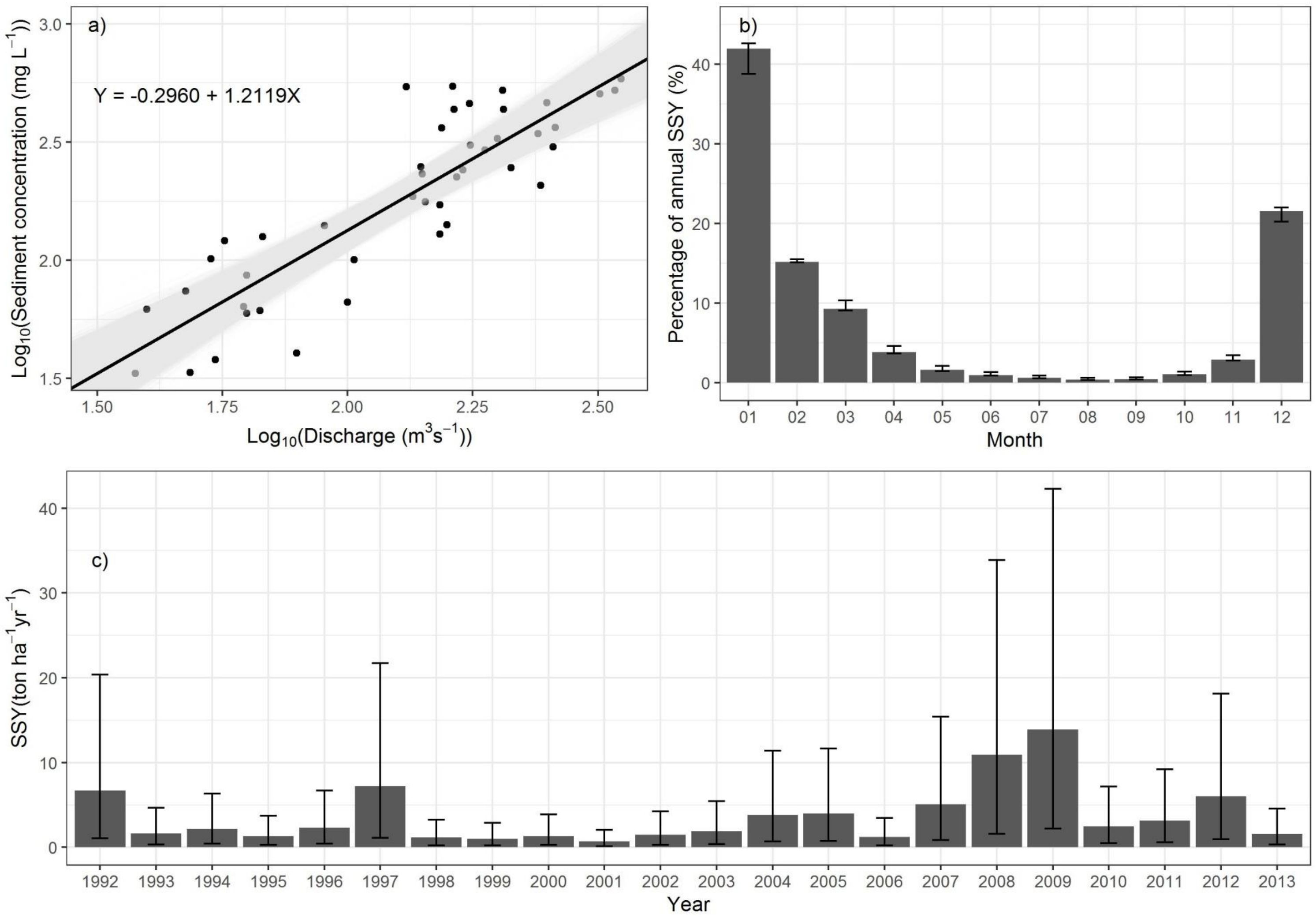
Results – Sediment-rating curve



Long-term average area specific sediment yield (**SSY**):

- **95% PI** = **0.47 – 11.95** ton ha^{-1} yr^{-1}
- **Mean** = **3.45** ton ha^{-1} yr^{-1}
- **Median** = **2.52** ton ha^{-1} yr^{-1}

> 90 % of sediment transport during the rainy season

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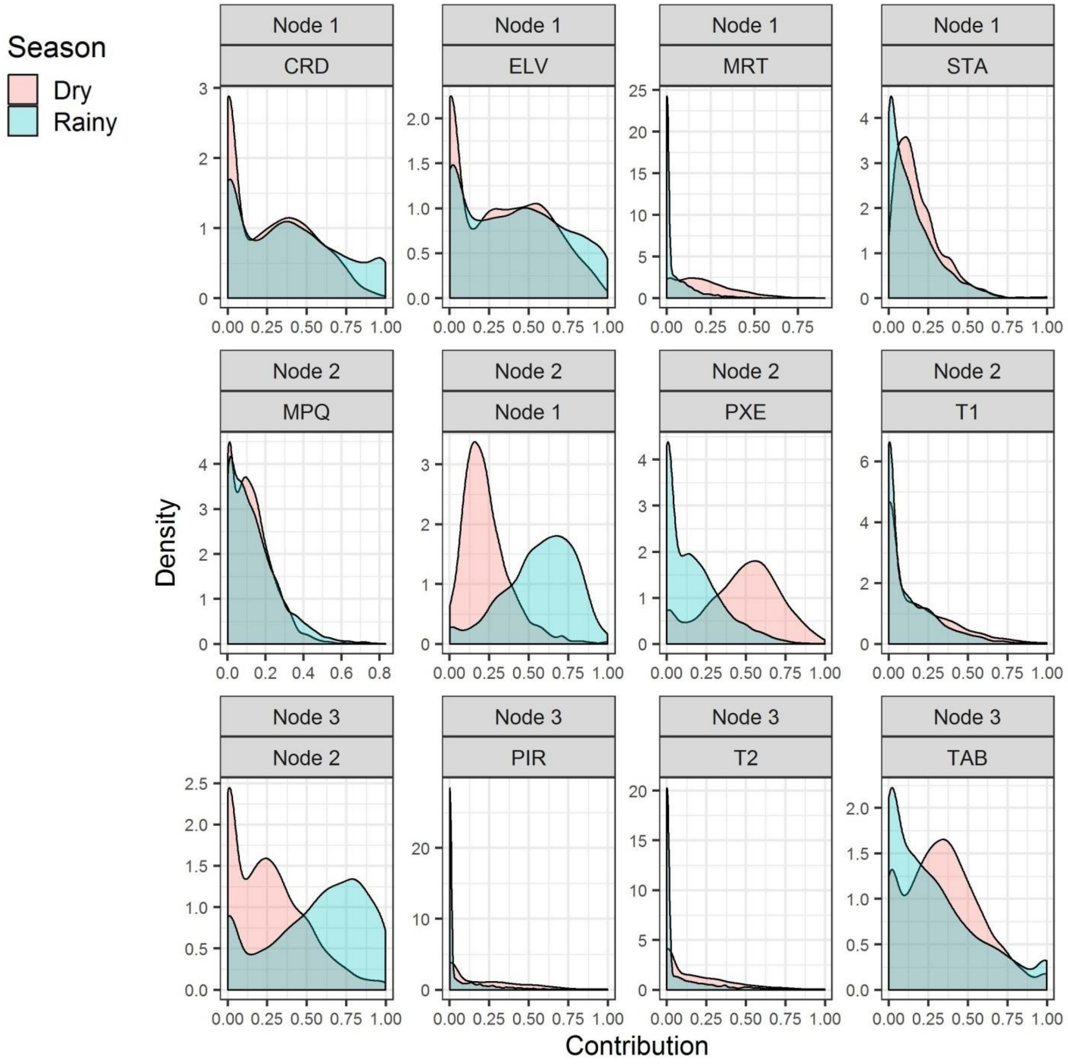
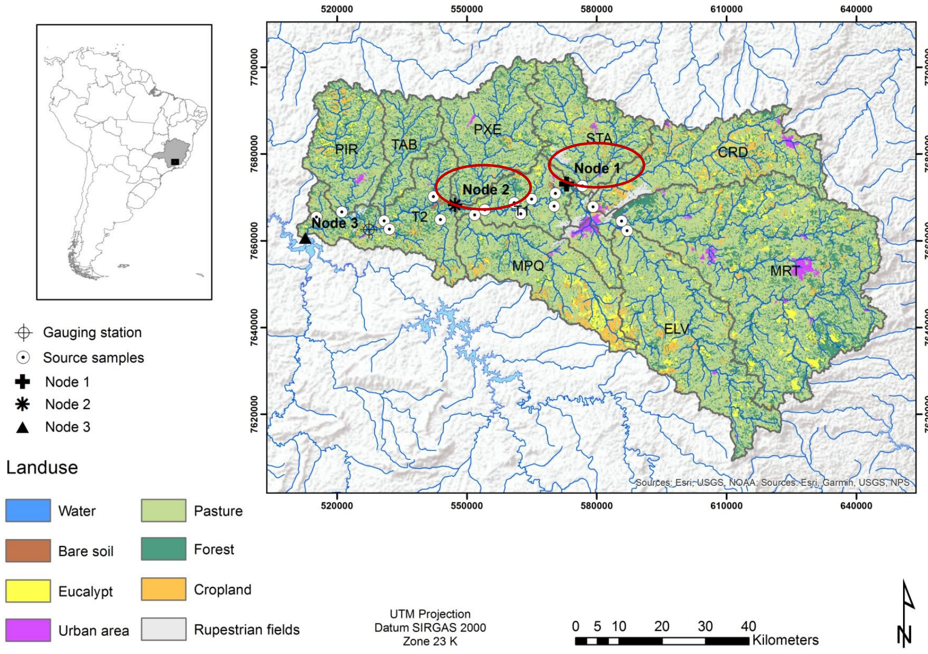
Results – Sediment fingerprinting source apportionments



Increased contributions from **Nodes 1 and 2** during the rainy season (median ~ 60%) in comparison to the dry season (median ~ 20 %). As expected, the catchment is more connected during the rainy season, and upstream tributaries have higher relative contributions. During base-flow, sediments are mainly derived from proximal tributaries (e.g. PXE and TAB).



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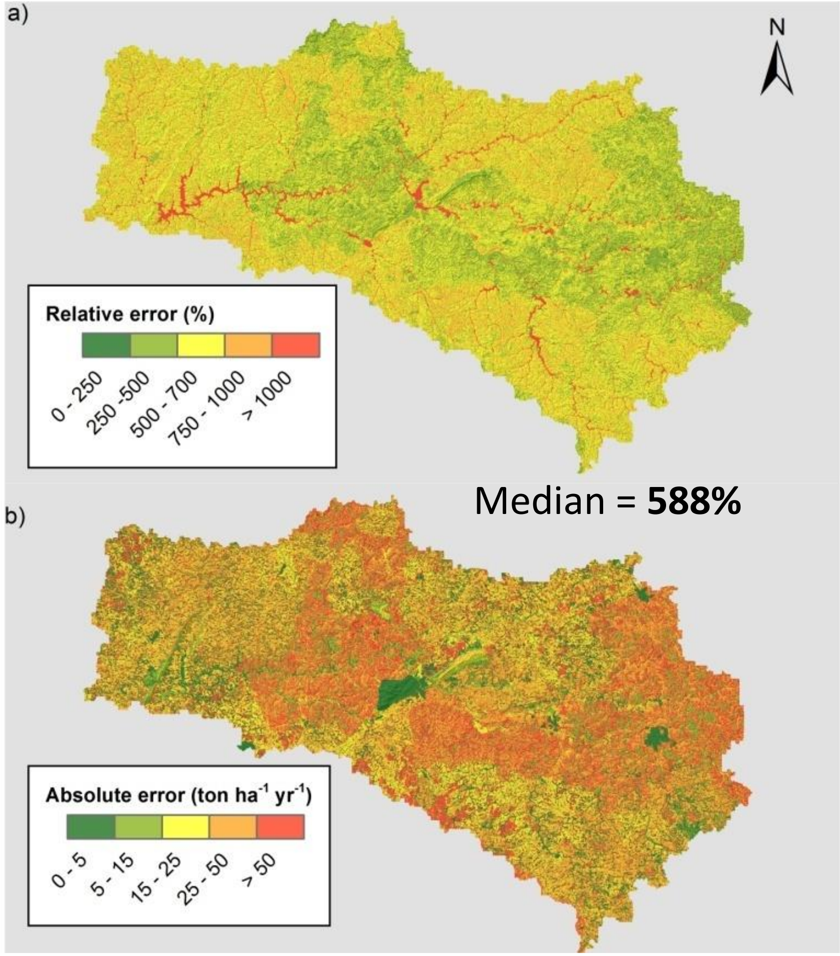
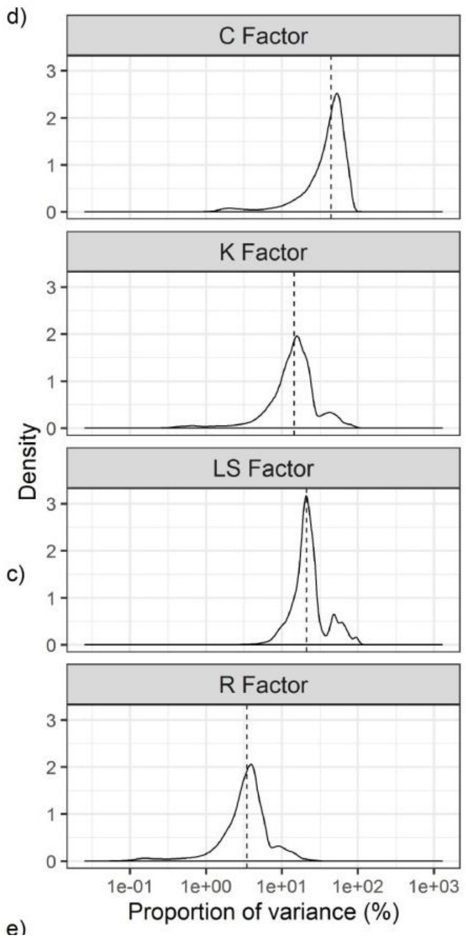
Results – RUSLE uncertainty and sensitivity analysis

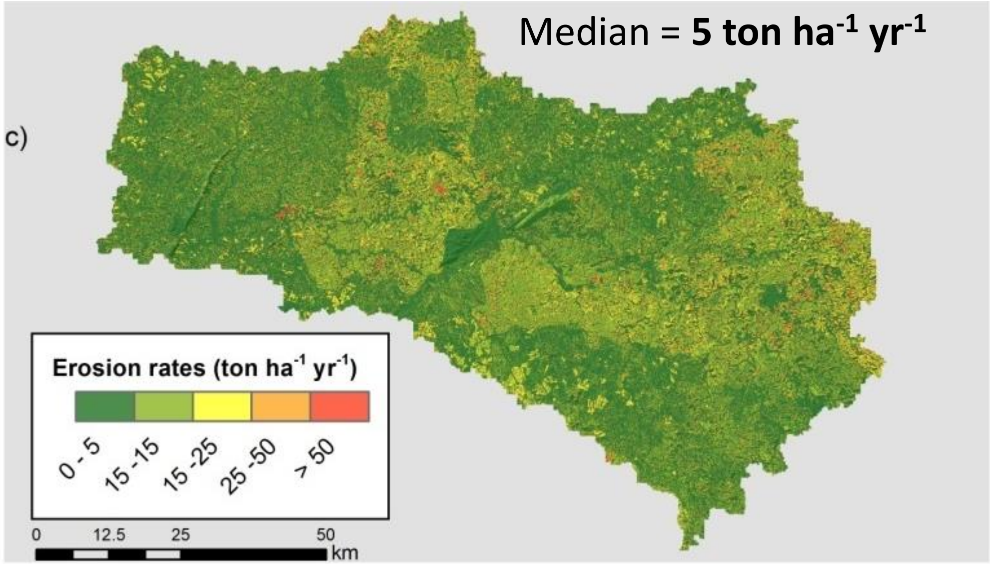


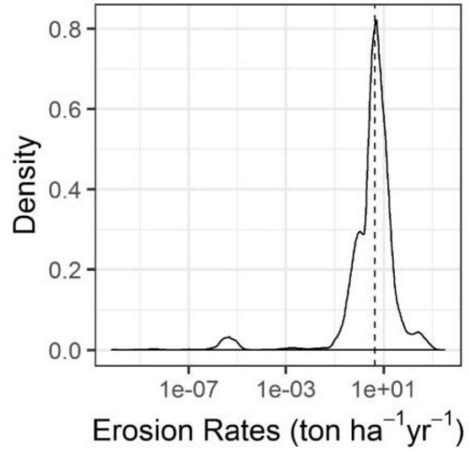
Median = **588%**

Median = **29 ton ha^{-1} yr^{-1}**



Median = **5 ton ha^{-1} yr^{-1}**





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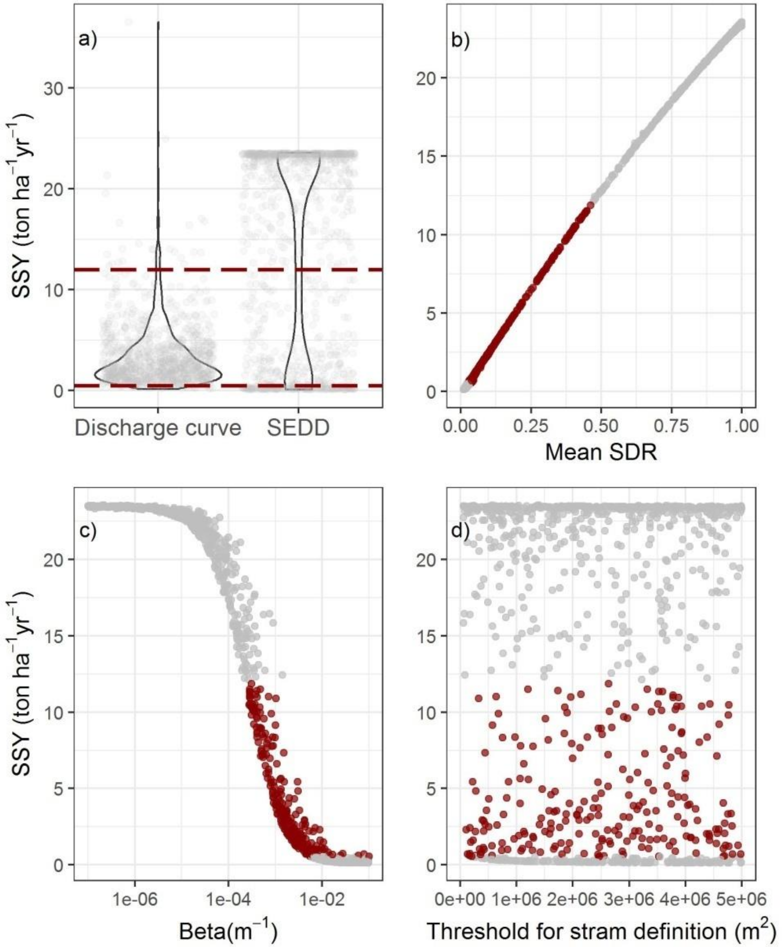
Results – SEDD model

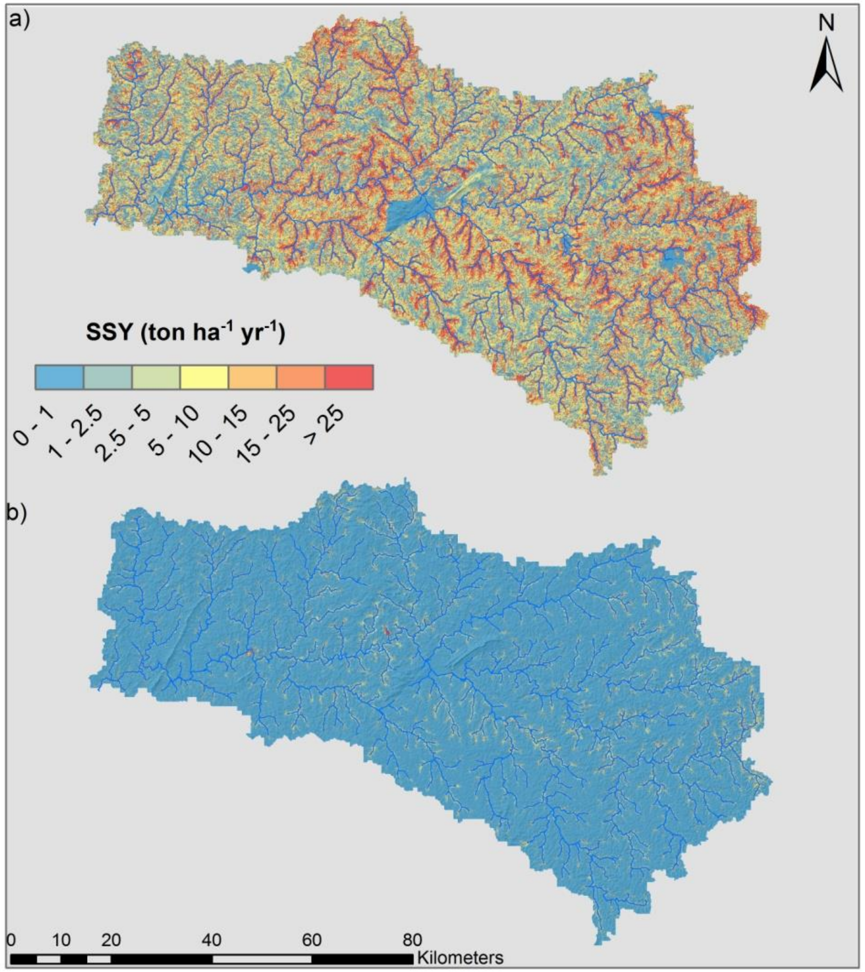
234 behavioural model realizations



Median Absolute Error = **6 ton ha^{-1} yr^{-1}**

Median **SSY = 0.06 ton ha^{-1} yr^{-1}**

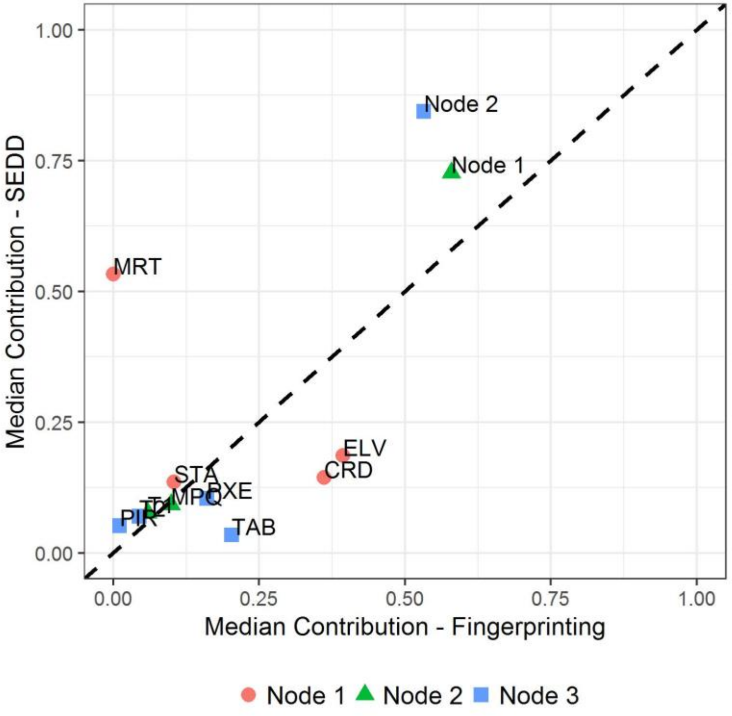
Highly uncertain grid-based model estimates

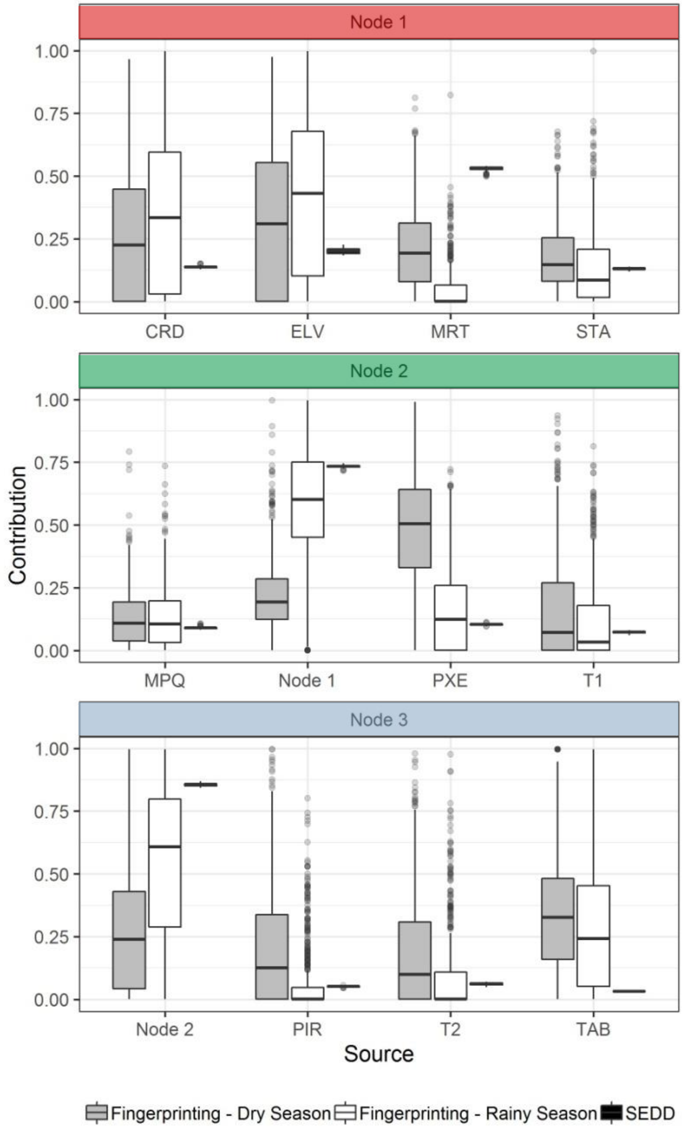


Results – evaluation against sediment fingerprinting source apportionments

SEDD results are far less uncertain when lumped into **relative sub-catchment contributions**.

Fingerprinting and SEDD source apportionments for Node 1 are contrasting.
For nodes 2 and 3, most behavioural SEDD realizations are within the inter-quartile range of the fingerprinting apportionments (rainy season), and both results show a similar pattern.





Conclusions:

- We have demonstrated how sediment fingerprinting source apportionments can be used to evaluate soil erosion and sediment delivery models, while representing the uncertainty in both models and observational data.

- From a **falsificationist** perspective, the SEDD model could not be rejected, as multiple model realizations produced acceptable system representations. However, this was largely facilitated by the uncertainty in the forcing data and the model sensitivity to the empirical parameter β.

- Although grid-based SEDD results were highly uncertain, the evaluation against fingerprinting apportionments indicate the model might be useful for identifying main sediment sources at sub-catchment scale.

- Uncertainty in the RUSLE factors contributed significantly model variance. Uncertainty analysis should become a **standard procedure** for RUSLE model applications.

- We need better data in order to reject models, or model realizations, as hypotheses. This will require honest representations of the uncertainty in models and the observational data.

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Thank you!

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