

Reconstructing Reach-Scale Sediment Regime Shifts Across Successive Stages of Industrialization

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Abstract:



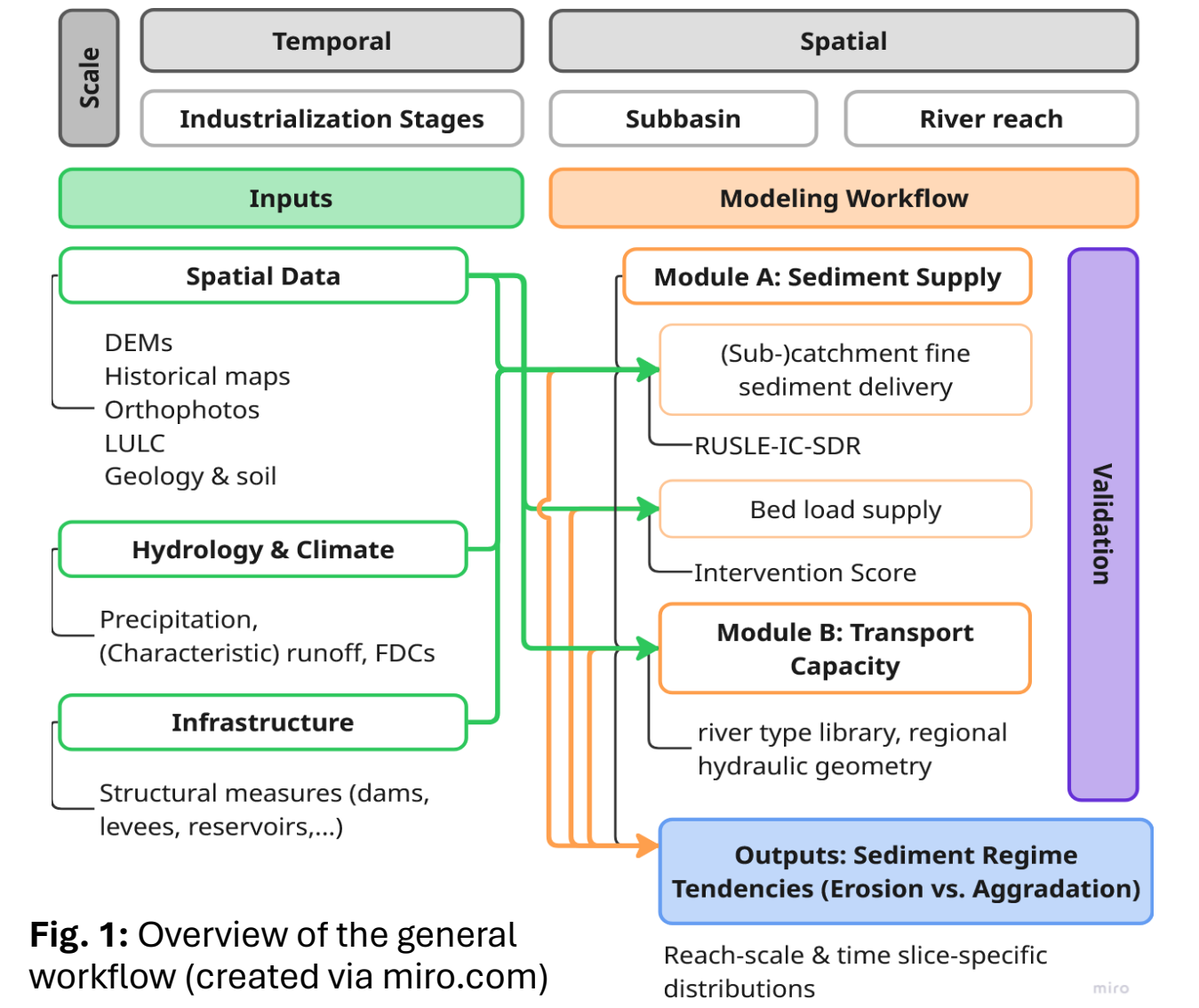
Introduction

Fluvial systems are inherently dynamic. By conveying not only water, but also sediment, they act as links between catchment-scale processes and geomorphic development. Over the course of human history, landscapes - including rivers - have undergone substantial changes. Industrialization has initiated particularly rapid transformations, not only via structural measures or the direct harnessing of resources, but also through changes in the whole catchment and the functioning and connectivity of the drainage network, **altering the availability, transport, and storage of both water and fluvial sediment**^{1,2,3}. The consequences of these sediment budget disruptions are far reaching: incision and the loss of channel stability may threaten adjacent infrastructure; changes in bed material composition - be it excessive accumulation of fine sediment and the clogging of pore space, or the development of armouring layers - compromise ecosystem functioning. Understanding historical river systems builds on analyzing the **dynamic interplay between sediment sources (S), transport capacity (C), and human intervention**. To study these large-scale processes that are highly heterogeneous in space and time, we focus on multiple rivers across modern Austria, allowing us to control for variable national economic structures while still capturing wide gradients of physical and human boundary conditions.

Theoretical Foundations

The proposed framework accounts for the complex network of drivers of fluvial sediment dynamics by synthesizing established geomorphological principles like **regional hydraulic geometry**⁴, and quantifiable processes of soil erosion to understand available **fine sediment supply**^{5,6}. We harness the results of these physically based models to map historical sediment regime tendencies across distinct industrial periods⁷. The goal is not to predict absolute sediment fluxes, but to account for the relationships between human interventions and sediment budget, described by supply and transport capacity.

Overview



Problem Statement

The reconstruction of past conditions is one of the major challenges in fluvial geomorphology. Conventional approaches require detailed bathymetry and continuous runoff measurements. This **data is**, however usually **sparse** or unavailable for periods prior to the mid-20th century, making a precise quantification of historical sediment mass balances unachievable. For this reason, a systematic evaluation of historical sediment states must shift its focus from calculating absolute fluxes to **inferring relative sediment regime tendencies (aggradation vs. erosion) based on available proxies**.

Aim: Our central aim is, therefore, to develop and validate a probabilistic framework that systematically assesses how historical human forcing (LULC, structural changes, water abstraction,...) influences the potential for sediment regime shifts across diverse river types. Instead of attempting deterministic calculations of sediment balances, we account for uncertainties in our assumptions by producing probability distributions of potential sediment fluxes.

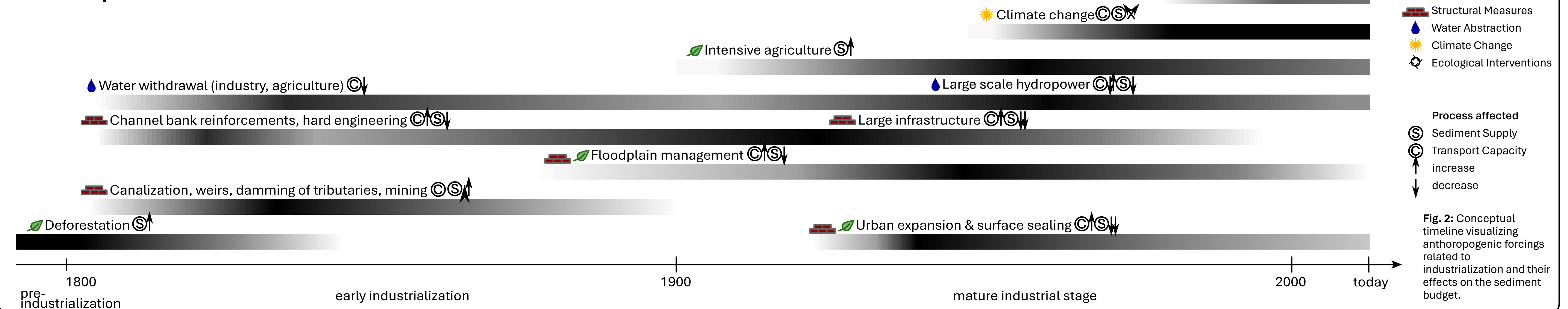
Hypothesis: We hypothesize that systemic industrialization leads to measurable shifts in the sediment regime that vary in direction both spatially and temporally based on (i) river type, (ii) industrialization stage, and (iii) geographic boundary conditions.

Synthesis, Output and Scientific Impact

The final stage of the framework integrates the proxy outputs from Modules A and B into a **cascade-style model**. In this process, each reach acts as a dependent node. System continuity is maintained by blancing the modeled distribution of transport capacity (C) against local supply (S) and upstream inputs ($I_{u,s}$) to determine relative, reach-scale sediment regime tendencies (**erosion vs. aggradation**). By doing so, we can identify critical geomorphic constraints, such as persistent deficits, which indicate a state of high instability and potential for major regime shift. We quantify the degree of uncertainty and address model **sensitivity** to determine the most influential physical parameter(s) for modeled sediment regime shifts.

The presented probabilistic framework shifts our focus from quantifying absolute historical sediment fluxes to systematically assessing the **relative likelihood of sediment regime state transitions under reconstructed (historic) boundary conditions**. Color-coded **Regime Tendency Maps**, indicating the modeled likelihood of instability, allow us to visualize potential hotspots of erosion or aggradation over time. Future work will couple these outputs with models of ecological and infrastructural vulnerability, allowing us to map the **cumulative socio-ecological consequences** resulting from past human activities.

Conceptual Timeline

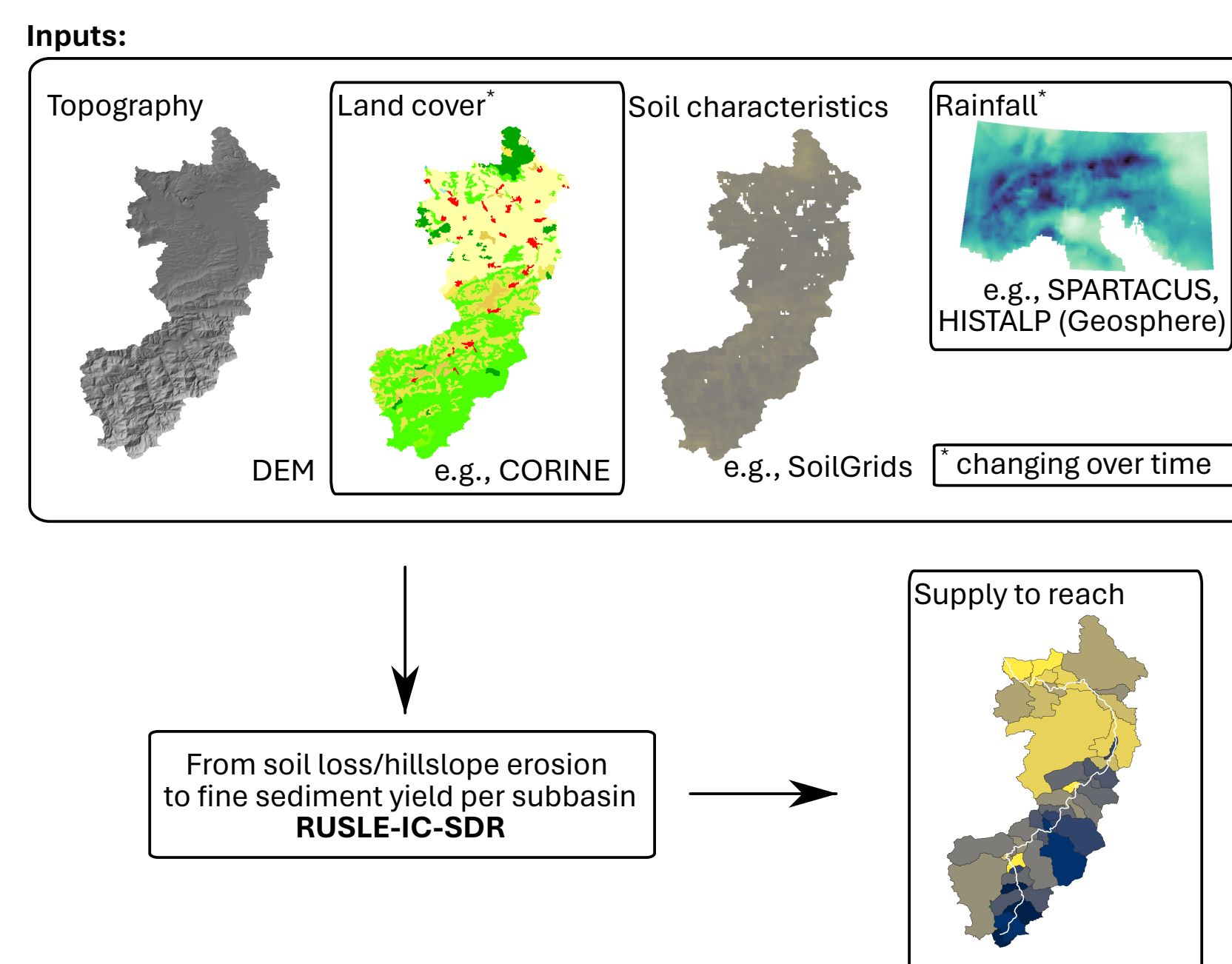


Methods

Our approach tackles traditional data limitations by building a **process-based proxy framework**. This methodology systematically converts complex historical evidence into quantifiable estimates of **sediment supply S** and **transport capacity C**, allowing us to model sediment regime tendencies.

Module A₁: Fine Sediment Supply

We estimate local fine sediment supply by applying the **RUSLE-SDR**^{5,6} scheme and **reconstructing historical inputs**: historical land cover is reconstructed from historical cartographic surveys; reach-scale flow duration curves (FDCs) are reconstructed by applying regionally calibrated rainfall-runoff models from modern data combined with a pattern-scaling approach that employs HISTALP (GeoSphere) climate reconstructions.

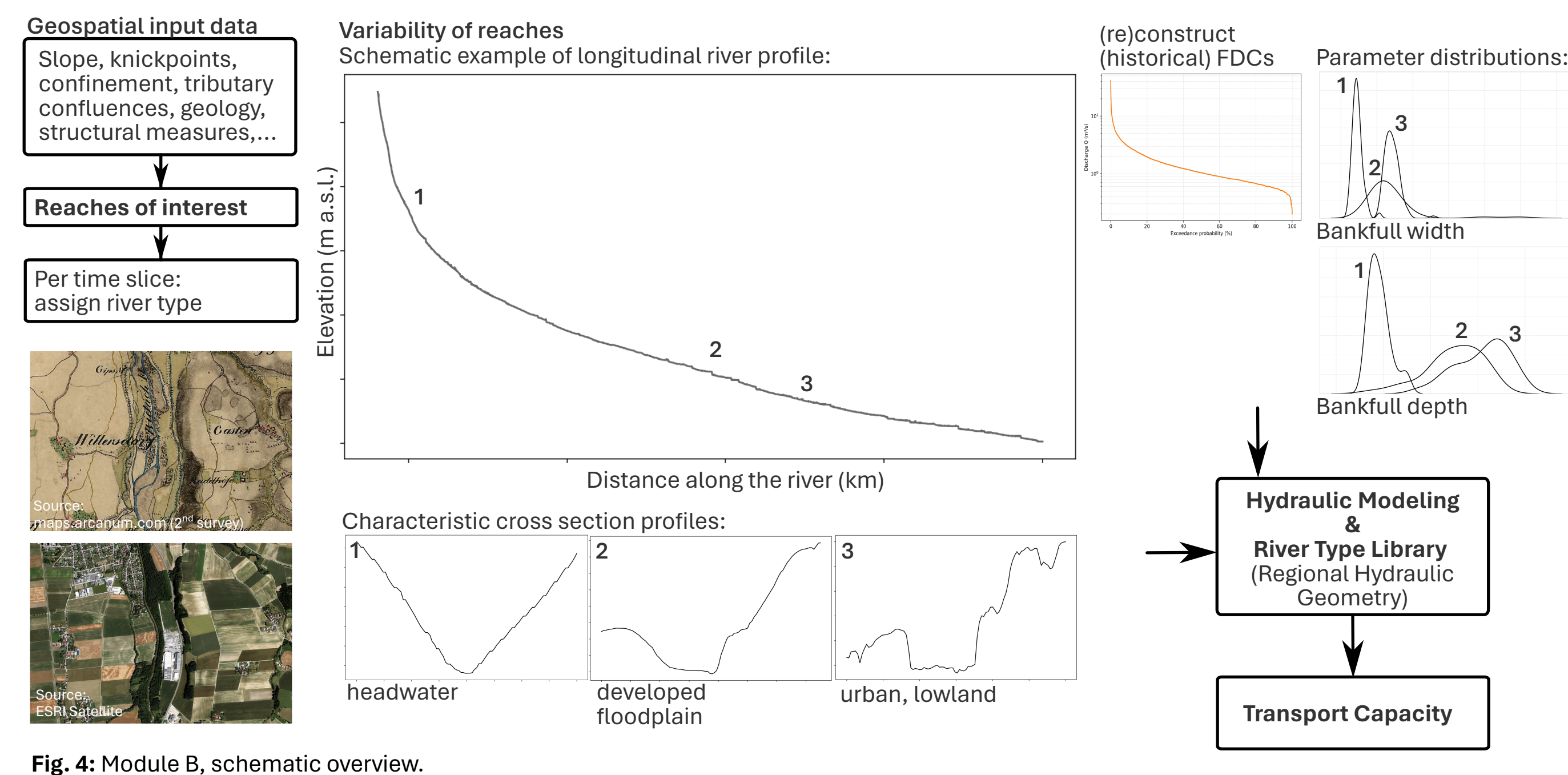


Module A₂: Coarse Sediment Supply

To account for coarse sediment dynamics, we introduce an **Intervention Score** as a proxy that quantifies the disruption caused by human activity. This score is derived from historical mapping data and captures density metrics related to major structural barriers (dams, weirs), point sources (mining sites), or localized bank reinforcements. By analyzing these quantifiable interventions across different time slices, our model **tracks how anthropogenic forces disrupt the natural balance of coarse sediment supply and routing potential**, enabling us to assess changes in geomorphic constraint without requiring direct measurements of historical sediment fluxes.

Module B: Transport Capacity

Transport capacity is determined by calculating the probabilistic shear stress (τ) of the channel. To bypass the need for historical bathymetry, we establish a **River Type Library** based on map-derived planform geometries (width, slope) and physiogeographic boundary conditions. This library is compiled from modern reference reaches to define characteristic relationships of **Regional Hydraulic Geometry** to provide reliable parameter distributions for the historical time slices. Computing transport capacity (C) against **reach- and time slice-specific FDCs** allows us to assess transport capacity for various probability thresholds, providing a robust, probabilistic estimate of sediment transport potential.



Contact

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I am looking forward to discussing this work. Feel free to get in touch!



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