Doctoral Programme in Civil, Environmental and Mechanical Engineering

Research subjects proposed for the 42nd cycle – second call

Additional positions with scholarships

Curriculum A - Civil and Environmental Engineering

- *Reference persons:* Annunziato Siviglia (UNITN/DICAM), Walter Bertoldi (UNITN/DICAM), Guido Zolezzi (UNITN/DICAM)

Participant: Martina Bussettini (ISPRA, Rome)

A5 - scholarship on reserved topic

Funded by: ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale)

Title: ***Ecomorphodynamic Models for Predicting River Evolutionary Trajectories***

BACKGROUND

River ecomorphodynamics is a rapidly evolving discipline that describes the interaction between vegetation and morphology and identifies the evolutionary trajectories of watercourses. Available modeling tools adequately represent some key processes, but require continuous updates as experimental and theoretical knowledge advances. In particular, simultaneous and physically-based representation of interactions among vegetation, sediment transport, and fluid flow remains an open challenge.

Improving this predictive capacity is essential for assessing river evolutionary trajectories under climate change and anthropogenic pressure, and for supporting river management, restoration, and flood risk mitigation. The development of ecomorphodynamic numerical models that quantify the interaction of relevant physical processes is crucial for predicting the morphodynamics of these areas and for planning sustainable restoration and flood mitigation measures.

MAIN AIM OF THE PROJECT

The primary objective is to develop a multi-scale, physically-based modeling approach for simulating river ecomorphodynamic processes, with direct applications to the implementation of the Water Framework Directive (2000/60), the Floods Directive (2007/60), and the Nature Restoration Law (Eu Regulation 2024/1991). The project will integrate three key components addressing vegetation recruitment at the cross-sectional scale, reach-scale ecomorphodynamic modeling, and application to European river systems with different eco-morphological dynamics.

SPECIFIC OBJECTIVES

The project is structured around three specific objectives, aligned with the three years of the doctoral program.

VEGETATION RECRUITMENT MODELING AT THE CROSS-SECTIONAL SCALE

The doctoral candidate will develop two distinct coupled models. The first, based on the Windows of Opportunity (WoO) concept, describes the short-term recruitment phase: the temporal windows of hydro-morphological conditions favorable to seedling establishment and survival in the first weeks of development.

The second is a deterministic ecohydraulic model describing the subsequent growth of biomass B and root depth z_r on the scale of months to years. Root depth z_r is governed by a physically-based growth law as a function of groundwater dynamics and calibrated through allometric relationships on field data.

The two models are coupled through an erosive criterion: when cumulative erosion, estimated using inundation depth as a proxy, exceeds z_r, vegetation is removed and the system returns to the recruitment phase.

DEVELOPMENT OF ECO-MORPHODYNAMIC MODELS AT THE REACH SCALE

The doctoral candidate will extend BASEveg, an open-source Python module integrated with BASEMENT (2D shallow water model plus Exner equation for bed evolution). The new implementations will include suspended sediment transport, sediment interception by vegetation, and feedback between biomass, hydraulic roughness, solid transport, and bed cohesion. The updated module will be released publicly in a GitHub repository.

APPLICATION AND VALIDATION ON EUROPEAN RIVERS

The modeling approach will be applied and validated on the Tagliamento, Alpine Rhine, and Isère rivers, for which hydrological data, topographic surveys, and aerial imagery are available. Comparison among systems with different eco-morphological dynamics will enable assessment of model robustness, transferability, and predictive capacity.

DISSEMINATION AND IMPACTS

The results will provide operational forecasting tools directly applicable to institutional activities of ISPRA (Italian National Institute for Environmental

Protection and Research) and river basin authorities. Regarding the Water Framework Directive (2000/60), the developed models will support the identification of measures for achieving good ecological status of surface water bodies. Regarding the Floods Directive (2007/60), the reach-scale approach will enable quantitative assessment of vegetation's role in flood risk modulation, supporting Flood Risk Management Plans. Finally, with respect to European Regulation 2024/1991, the developed tools can guide planning of river restoration and riparian ecosystem recovery interventions, contributing to the achievement of nature restoration objectives mandated by the regulation.

CHARACTERIZATION OF THE PhD CANDIDATE

The successful candidate should possess:

- Solid background in environmental or civil engineering, with demonstrated competence in hydraulics and water resources;
- Familiarity with European water policy frameworks (Water Framework Directive 2000/60, Floods Directive 2007/60, and EU Regulation 2024/1991) and their implementation requirements;
- Strong familiarity with mathematical models, including their practical implementation and interpretation;
- Proficiency in basic programming, such as Python and MATLAB for model development and data analysis;
- Ability to work at the interface between theoretical model development and practical application to real river systems, with good balance between theoretical understanding and practical orientation;
- Excellent written and spoken English; strong communication skills;

Initiative and intellectual autonomy in addressing both conceptual and technical challenges.

- *Reference person: Marco Tubino (UNITN/DICAM)*

Participants: Walter Bertoldi (UNITN/DICAM), Niccolò Ragno (UNITN/DICAM), Guido Zolezzi (UNITN/DICAM)

A6 - scholarship on reserved topic

Funded by: Department of Civil, Environmental and Mechanical Engineering (CUP E66C18000340001 - CUP B87H21006450001)

Title: *Sediment transport processes and evolutionary trajectories of riverine ecosystems*

Over the last two centuries, the pervasive channelization and flow regulation of natural river corridors have strongly affected the overall functioning of river systems, especially in developed countries. Rivers are strongly connected with other components of the earth system by exchanging water and sediment and by responding to alterations such as climate change, growth of vegetation, building of in-stream structures and gravel mining activities. This connectivity invariably leads to changing conditions on a multitude of temporal scales, from the daily scale (e.g., discharge variation due to precipitations or water releases), to the scales of decades or centuries (e.g., climate change, alterations of the sediment production in the basin). As a result, rivers are often out of equilibrium and follow morphodynamic trajectories, depending on intensity, duration, and nature of stressors. Their role as fundamental connecting agents of the evolving landscape is underpinned by the morphological dynamics. Channel geometry and patterns reflect the ongoing adjustment to fluctuating flow and sediment yields (bedload and suspended load) and, consequently, the balance of erosional and depositional processes.

Sediment management in fluvial environments is of crucial importance for environmental, productive and safety reasons. The loss of sediment connectivity along river networks is recognized as a major cause of habitat degradation and biodiversity loss, while erosion and deposition processes may severely contribute to flood hazards. Specifically, in alpine regions, the impact of sediment deficits is responsible for riverbed incision and related habitat degradation. At the same time, increase in sediment load and transport is a major problem in regions with soil erosion due to intensive agriculture. Sediment transport management in river systems is relevant for flood hazard prevention, control of bank erosion, channel shift and stability of in-stream structures, land-building processes (e.g. deltas, floodplains), reservoirs management, preservation of transitional environments, river navigation, water exploitation and water quality, and maintenance of ecosystem services and habitat suitability.

In the last 40 years our understanding of morphodynamics has been remarkably advanced through mathematical theories and predictive models, which have received strong validation from laboratory scale experiments and more recently also from field observations. Theoretical models can now benefit from the remarkable support of satellite information, which provides an unprecedented capability of performing quantitative analyses of the spatial distributions of river and deltas characteristics and evolutionary trajectories. The morphodynamic processes that determine the shape of the river have been mainly studied under the assumption that the river system is in dynamic equilibrium. Furthermore, most of the existing morphodynamic models refer to the reach scale, i.e. a hydro-morphologically homogeneous portion of the channel, though processes at this scale are clearly conditioned by those occurring at hierarchically higher scales. Disequilibrium between sediment supply and transport capacity, the role of climate change and land use transitions on evolutionary trajectories, as well as the morphodynamical response to a variable flow regime, such as the hydrological cycle, are still to a large extent unexplored.

Research aims and methodology

With reference to projects currently underway at the Department of Civil, Environmental and Mechanical Engineering, the aim of the project is to develop suitable quantitative, process-based tools to assess sediment production and transport processes of fine and coarse sediments and the related morphodynamical trajectories, detect the potential for restoration accounting for the operational and structural constraints set by the anthropic stressors and advance the present knowledge on key morphodynamical processes to inform river engineering practices aimed at recovering geomorphological and ecological quality of harmed river ecosystems.

The project methodology envisages the integration of mathematical modelling approaches with the collection and analysis of field data in target case studies. Modelling will focus on the development and testing of a nested, multi-scale approach, where a chain of models will be used from the catchment to the reach scale. The field component will integrate the analysis of historical records, existing datasets available at public environmental agencies with those of remotely sensed data and with the collection and analysis of in situ field data.

The ideal candidate will have a background in Environmental Engineering, River Geomorphology or related fields. Candidates should also possess strong computer, scientific, and analytical expertise, have excellent communication (oral and written) skills, have the ability to work independently and as part of a team, self-motivation, adaptability, and a good attitude for critical thinking. Since foreseen activities include model development, the candidate is required to have computational proficiency (or the will to pursue it) preferably in Fortran, R/python/Matlab and GIS products.

Suggested references:

Seminara et al. (2023), Theoretical Morphodynamics: Straight Channels.

Scorpio et al. (2024), Earth Surface Processes and Landforms.

Heckmann et al. (2018), Earth Science Review.

Morel et al. (2023), Nat. Hazard Earth Syst. Sci.

Tangi et al. (2019), Env, Modelling & Software.

Schneider et al. (2015), Water Resources Research.