Allegato al bando: descrizione del progetto di ricerca / Research project description

This position is funded through the SEDMORNET - PRIN 2022 research project, funded by the National Italian Ministry for Scientific Research (MUR). It corresponds to the postdoctoral research position at the University of Trento as described below.

The candidate is expected to work full-time on the research activities foreseen in the project for the University of Trento, and to give a substantial contribution to the project management, as described in detail below.

Applicants can choose two of the three research questions (RQ) of the project as described below to develop his/her research proposal for the application, focusing on the activities of the University of Trento

SEDMORNET - Multi-Scale sEDiment transport and MORphodynamic conNEcTivity in rivers

SEDMORNET focuses on river morphodynamics, the science of physical processes that studies changes in river forms, which represent a fundamental control of the integrity of many freshwater ecosystems and related biodiversity, and are at the base of river management for flood protection and risk prevention. Achievements of nearly 40 years in river morphodynamic studies mainly refer to unit processes occurring at specific scales under equilibrium assumption between flow and sediment transport, while non-equilibrium, unsteadiness and connectivity across multiple scales are essential drivers of the actual evolutionary trajectories of the river morphology.

To address this fundamental gap, the main goal of the research to be developed is to investigate the relation between sediment connectivity across and within scales and morphodynamic processes.

Considering that variability in streamflow and sediment supply are the external drivers of morphodynamics, which reflect climatic or anthropogenic changes acting at larger scales, the project will take a multi-scale approach aiming to:

1) quantify the connectivity properties of wet and active riverbed areas in multi-thread rivers at different flow stages;

2) formulate a conceptual and quantitative model that links the statistical properties of streamflow and sediment supply with the consequent space-time variability of connectivity;

3) develop quantitative, process-based nested morphodynamic models to predict reach-scale evolutionary trajectories of river morphology in response to anthropic and climate changes in the river basin.

The project will integrate the complementary expertises of the two Research Units of the University of Trento and of the Polytechnic of Torino: physics-based analytical morphodynamic modelling, integrated with field/remote sensing observations (University of Trento - UniTN), and stochastic, analytical modelling of river processes (Politecnico di Torino - PoliTO). The strong modelling focus will be complemented with laboratory experiments on a large mobile-bed flume and the analysis of already collected large morphodynamic datasets by the Research Units. Novel methods for river morphodynamics will be also capitalised from other fields of science (complex network models, scale-nested modelling). Two postdoctoral young researchers will be recruited by UniTN and PoliTO to work full time on the project, supervised by 2 permanent staff in each unit and supported by 4 already enrolled PhD students, ensuring a fair balance between the research activities, the specific skills needed and the effort required.

Results of SEDMORNET can support effective planning and implementation of investments on river restoration foreseen in the Next Generation EU and PNRR programmes, contributing to social and economic well being and to more resilient river ecosystems. Achieving the project's potential impact on the scientific community, students, stakeholders and the general public is supported by a dedicated dissemination strategy.

RESEARCH QUESTIONS (RQ)

The three scientific gaps identified in the previous section allow to draw the main project roadmap and to formulate the specific Research Questions (RQs) that the SEDMORNET project aims to address.

Spatial fluvial connectivity depends on the geometry of the riverbed and on the hydraulics of the stream that flows through it. Both these components strongly depend on the external forcing of discharge fluctuations. It follows that river connectivity exhibits marked heterogeneity in both space and time.

RQ1: HOW DOES THE CONNECTIVITY OF MULTI-THREAD RIVERS CHANGE WITH FLOW STAGE?

We then aim to formulate a quantitative model that links the statistical streamflow properties (probability distribution, temporal correlation structure, seasonality, extremes, temporal memory, etc.) with the consequent space-time variability of connectivity. We aim to statistically describe connectivity, focusing on basin-scale connectivity and connectivity in braided rivers.

RQ2: HOW DOES UNSTEADINESS (AND STOCHASTICITY OF) THE FLOW REGIME AND UPSTREAM SEDIMENT SUPPLY AFFECT CONNECTIVITY OF MULTI-THREAD RIVERS?

River evolutionary trajectories are associated with non-equilibrium effects, which derive from processes at larger scales, which in turn are connected with the reach scale through sediment connectivity, and partially, also through hydrodynamic connectivity.

RQ3 HOW CAN REACH-SCALE RIVER EVOLUTIONARY TRAJECTORIES ASSOCIATED WITH NON EQUILIBRIUM EFFECTS BE PREDICTED THROUGH PHYSICS-BASED MODELLING APPROACHES?

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CROSS CUTTING ELEMENTS OF THE PROJECT

MULTI-SCALE APPROACH. To address the above research questions, a multi-scale approach is needed (Figure 1). At the reach scale we will investigate spatiotemporal connectivity patterns induced by the interplay among random discharge fluctuations, morphological processes in multi-thread rivers (WP1.1, WP2.2). At lower scales, we will address the dynamic response of channel loops (bifurcations-confluence units) to stochastic flow variability, while at the catchment scale we will couple a network-theory based, catchment-scale sediment connectivity model with river trajectory predictors at the reach scale (WP3.1), and with the connectivity model for multi-thread rivers (WP3.3). A similar, nested 1D-2D approach will be developed to predict the dynamic response of meandering rivers to changes in reach hydraulic geometry (WP3.2).

METHODOLOGIES AND THEIR INTEGRATION. the use and application of methods that have been traditionally employed in morphodynamics (analytical theories, laboratory scale models) and to integrate them with scientific approaches complex network models; automated analysis of large remote sensing datasets), which already find an extensive application in other fields [3,21,29,27,33,35,50], whose potential in morphodynamics has been unexploited so far. Comparison with observations from satellite data and existing datasets will demonstrate the effectiveness of these coupled approaches.

TARGET RIVER TYPES. The project will specifically focus on gravel bed rivers typical of the mountainous and piedmont areas, thus representing the great majority of rivers in Italy. In these environments, most of the sediment is transported as bed load, so that the effect of suspended sediment transport on river hydrodynamics and on the riverbed morphological evolution is almost negligible. Furthermore, most of the studied river morphologies will be multi-thread, which also include meandering rivers with secondary

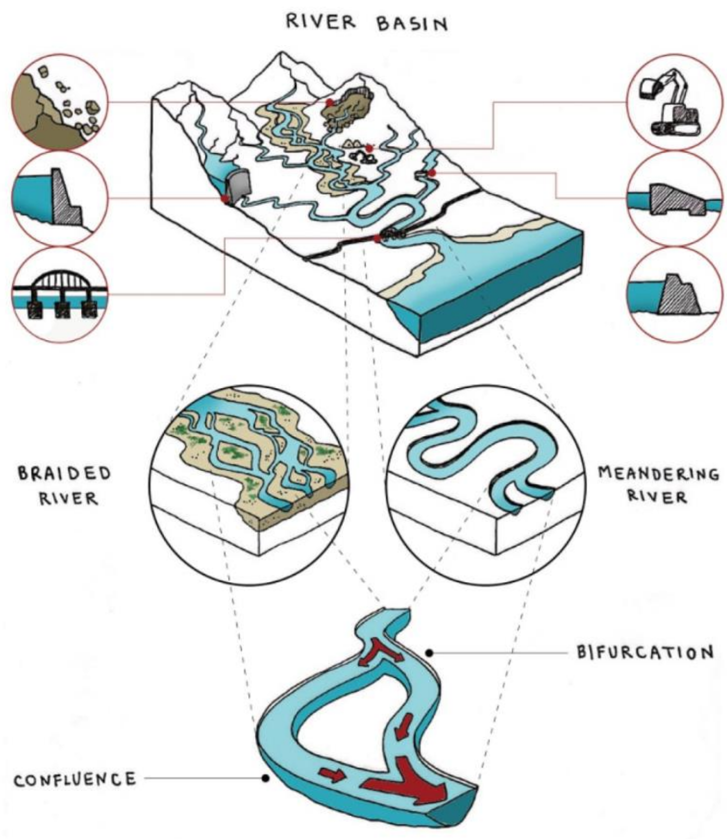

Figure 1. Conceptual diagram of the mult-scale approach to sediment connectivity and morphodynamic processes on which the SEDMORNET project is based, from the entire river basin, to the typical river reaches in mountainous and piedmont areas (braided and meandering rivers), to the individual unit processes (bifurcation and confluences).

WORKPACKAGES DESCRIPTION

The project activities are organised into 3 scientific Work Packages (WP1-3), plus one management / results dissemination Work Package (WP4):

- WP1: RIVER CONNECTIVITY AT THE REACH SCALE
- WP2: NOISE-INDUCED PHENOMENA AND NON-EQUILIBRIUM CONNECTIVITY
- WP3: MULTI-SCALE NESTED MODELLING OF SEDIMENT CONNECTIVITY AND RIVER EVOLUTIONARY TRAJECTORIES
- WP4: PROJECT MANAGEMENT AND RESULTS DISSEMINATION

In the following we describe each WP and the related task breakdown in detail.

<u>The selected candidate is expected to focus on the tasks under the responsibility of the University of Trento, which are highlighted in the GANTT Chart reported in Figure 2 below.</u>

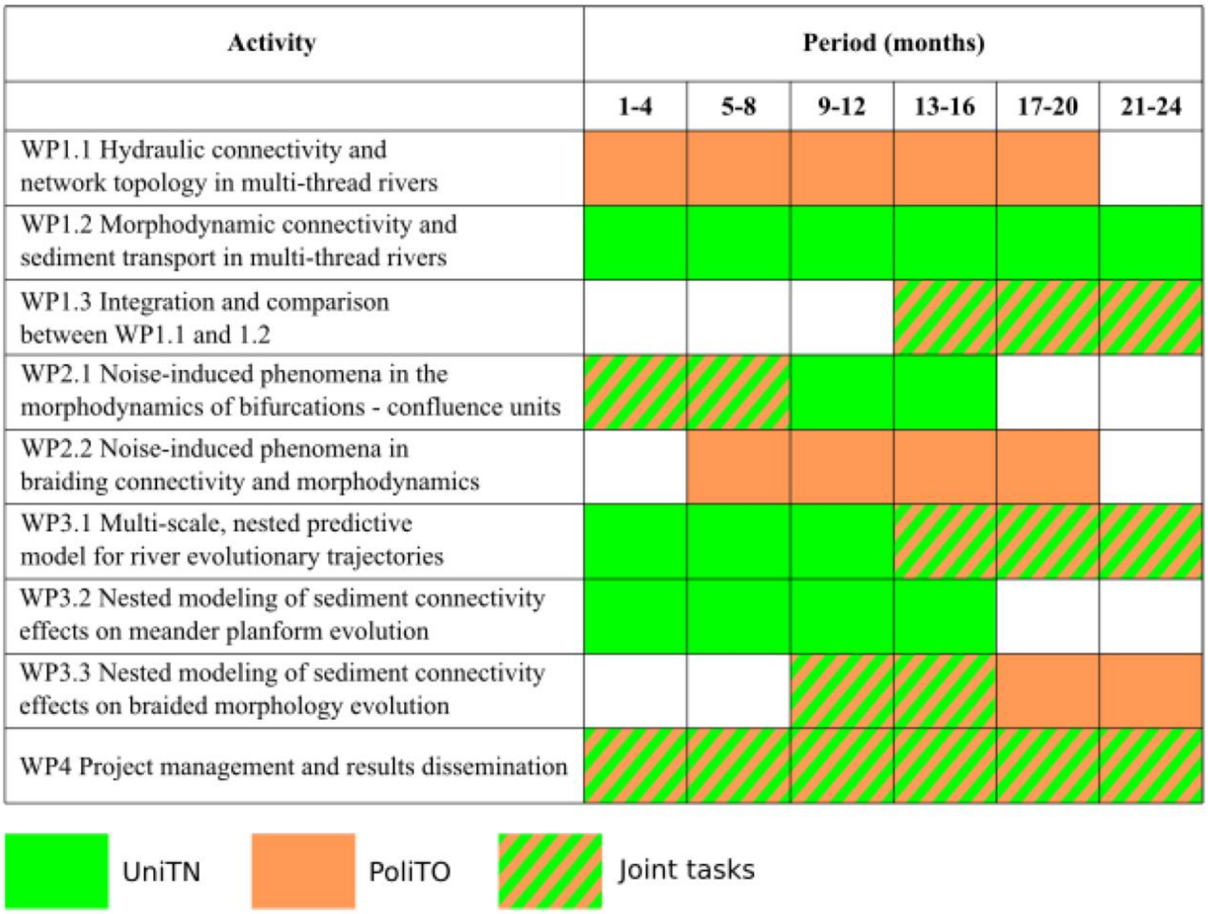

Figure 2. GANTT chart of the project. Colour codes illustrate the main responsibilities of each Research Unit and the joint activities

WP1 RIVER CONNECTIVITY AT THE REACH SCALE

We focus on multi-thread river systems (braided, anabranching, wandering, secondary channels) which are paradigmatic cases for addressing connectivity, because of the wide range of link properties and network topologies that these systems develop at varying flow stages. Furthermore, they represent a wide class of reference, near natural morphologies for gravel-bed rivers. Two complementary types of connectivity (WP1.1 hydraulic - with fixed bed; and WP1.2 morphodynamic - with mobile bed) will be first analysed separately, and then (WP1.3) examined jointly to detect their mutual relations.

WP1.1 Hydraulic connectivity and network topology in multi-thread rivers (PoliTO)

Detailed field data about the morphology, hydrology and vegetation distribution of some emblematic braided rivers in NW Italy (Borbera, Orco, and Pellice rivers) will be collected, and already available datasets for the same rivers will be exploited as well. Bed and floodplain morphology will be measured by drone-mounted lidar and high-resolution camera, possibly taking advantage of drought periods with the driest conditions of the river bed. Vegetation will be recognized and separated through suitable data processing techniques and direct field observations. Fixed-bed hydraulics in such real riverbeds will be numerically simulated at different discharges, and the effect of variable water stage on the connectivity pattern will be studied. To this aim, classical and innovative analyses will be adopted. The former include channel and bifurcation numbers, island and channel properties (size, shape, wetted perimeter, etc.), probability density and spatial correlation structure of water depths and topographic elevation, etc.. The latter refer to the complex network approach: the flow pattern will be described like a directed, weighted network and its topology and link properties will be investigated by suitable network tools (local and global centrality metrics, hub occurrence, node and link betweenness, shortest path statistics, percolation-based analyses, etc.). Different link weights (and multilayer formalism) will be adopted to take into account different link/channel properties (flow velocity, water depth, and transversal area). For instance, two morphological nodes may or may not be connected (i) depending in the depth (or/and the depth-averaged stream velocity) of the channel that connects them, which may or may not be accessible to a fish species, or (ii) depending on the shear stress which may or may not involve sediment transport. In this sense, the network topology and its properties change according to the specific focused connectivity and the hydraulic properties of the potential links. Data collected in the past for the same rivers will give snapshots of the bed morphology and vegetation pattern at different times, by allowing us to repeat the analyses in different (real) morphological conditions highlighting possible different coupling between discharge regime and bed morphology, and its impact on connectivity patterns.

WP1.2 Morphodynamic connectivity and sediment transport in multi-thread rivers (UniTN)

Morphodynamic connectivity and sediment transport in multi-thread channels will be modelled through a series of laboratory experiments at the hydraulic laboratory at UniTN. These experiments will be performed by means of an already-available, large experimental facility (25x3 m) equipped with a mobile-bed flume, where self-formed braided networks can be reproduced in miniature [7]. We plan to perform at least five experiments with the same channel slope and bed material but different values of water discharge. In each experiment the discharge will be kept constant and the bed will be allowed to freely evolve for a long time (in the order of 100 hours), to ensure that channel morphodynamics attains a statistically stationary state. Our recent developments in image analysis techniques [31] will be employed for a detailed, continuous tracking of sediment transport activity within the entire network of channels. This will enable us to monitor the sediment distribution and bifurcations, the propagation of sediment pulses within the channels, and identify erosion and deposition sites. This information will allow us to build a complete image of the connectivity of the active riverbed areas at each time and the intrinsic, autogenic temporal variation of the bed morphology at the reach scale.

WP1.3 Integration and comparison between WP1.1 and 1.2 (UniTN - PoliTO)

Results from the analysis of hydrodynamic and morphodynamic connectivity developed in WP1.1 and WP1.2 will be finally integrated to detect their possible relations and combined effects, analysing the combined effect of different water stages and morphological adaptation on the connectivity at the reach scale. We will focus on a single river site, a reach of the Tagliamento RIver near the Pinzano Gorge (Friuli), for which a 15-years record of continuous (hourly) oblique images is available, thanks to two automatically controlled reflex cameras installed by the research group of UniTN [43]. The time variation of relevant metrics - such as bifurcation and channel numbers, statistical features, and topological network quantities (WP1.1) - will be analysed to identify the respective role of discharge variability and morphological adaptation.

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WP2 NOISE-INDUCED PHENOMENA AND NON-EQUILIBRIUM CONNECTIVITY

Analysis in WP1 focuses on intrinsic connectivity under constant forcings (flow and upstream sediment supply). Here we investigate how the systems connectivity and morphodynamics responds to the typical irregular, stochastic variability of the flow and sediment Ministero dell'Università e della Ricerca supply, which we refer to as “Noise-induced variability” as in many environmental and physical sciences applications [32]

WP2.1 Noise-induced phenomena in the morphodynamics of bifurcations - confluence units (UniTN)

We will investigate the effect of noise-induced phenomena on the dynamics of the key unit elements that constitute the channel network: bifurcations, confluences and their channel loops. Upstream streamflow and downstream water level variations will be treated as an environmental noise that may strongly affect the non-linear dynamics of bifurcation and confluences. The evolution of the system will be modelled through a one-dimensional scheme for the transport of water and sediment, coupled with nodal point relations that quantifies the effect of the mass and momentum exchanges at the nodes of the network. This approach has been proved to be capable of reproducing the key dynamical processes that are crucial for reproducing the interaction with the environmental noise: (i) the instability of the flux partition at the bifurcation; (ii) the possibility of multiple stable states; (iii) the interaction between the downstream confluence and the upstream bifurcation made possible by backwater effects. Results from the one-dimensional scheme will be validated by means of dedicated laboratory experiments at the hydraulic laboratory of the University of Trento, where the dynamics of bifurcations and confluence loops will be simulated considering different geometrical and flow conditions. Specifically, we plan to build a reduced scale physical model of a symmetric channel system consisting of a bifurcation and confluence unit with fixed banks but mobile bottom. An already installed automated system allows for applying prescribed hydrographs and sediment feed rates, while the output sediment flux is monitored through a system of load cells. Finally, a monitoring system based on two reflex cameras, a dedicated illumination system, and a specific image processing software that we have already developed [31], enables us to continuously monitor the spatial distribution of sediment transport activity within the channels.

WP2.2 Noise-induced phenomena in braiding connectivity and morphodynamics (PoliTO)

The aim is to investigate the spatiotemporal dynamics of braided morphology when it is forced by stochastic streamflows. The presence of a wide range of scales and a number of nonlinear processes (e.g., shear stress thresholds for the sediment transport and bifurcations) induces the occurrence of noise-induced phenomena - i.e., structural changes of the dynamics with respect to the deterministic behaviour - triggered by the stochastic discharges. Taking advantage from findings obtained in WP1 and in the parallel WP2.1, morphodynamic models with different levels of complexity will be adopted to investigate the coupled action of discharge regime and river morphology in the braided network shaping. Simple, but realistic, models of riparian vegetation dynamics will be also implemented, in order to elucidate the impact of interactions between abiotic and biotic processes (e.g., vegetation-induced changes of soil erodibility and hydraulic roughness, enhanced sedimentation, uprooting and anoxia, etc.) on shaping braided morphology. Discharge will be described as a shot noise with different decay shapes, in order to simulate different noise intensities and temporal correlation structures. The occurrence of noise-induced processes - e.g., stabilisation of deterministically unstable points, stochastic resonance in bistable dynamics - will be investigated. Similarly to WP1.1, the water stage-dependent hydraulic and morphological behaviours of the networks will be studied deeply, using classical statistical approaches (spatio-temporal correlations, pdfs, spectra, etc.), nonlinear time/space sequences analyses (mutual information, entropy information, etc.) and complex network-based methods. This latter point of view will allow us to capitalise the very recent advances in this field to extract novel information about braided river dynamics and their impact on riverine transport processes.

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WP3 MULTI-SCALE NESTED MODELLING OF RIVER EVOLUTIONARY TRAJECTORIES

Evolutionary trajectories represent changes in river morphology over the medium and long-term (several years to decades) and are a useful tool to guide decision making in river management. However, so far only the reconstruction of past trajectories has been achieved [8], while predictive models for morphological trajectories are largely missing. In this WP we will develop multi-scale nested modelling to predict morphological river trajectories able to account for the non-equilibrium between flow and sediment supply regimes occurring at larger than the reach scale. Modelling outputs will be compared with already remotely sensed datasets of river morphologies.

WP3.1 Multi-scale, nested predictive model for river evolutionary trajectories (UniTN)

Under this WP a nested, multi-scale modelling approach to predict the river morphological trajectories will be developed. The starting point will be the freely available sediment connectivity model CASCADE, which yields upstream average sediment supply rates that feed every reach in a catchment, modelling the sediment cascade. Its outputs will be used as inputs for semi-analytical models predicting the evolution of channel width and mean bed elevation at the reach scale (e.g. [39], which will be extended to braided morphologies). Finally, outputs of these cross-sectional evolution models will be used as inputs of rational and empirical channel pattern predictors. The output will be a multi-scale, nested model able to predict the morphological trajectories of target river reaches in response to changes in sediment connectivity at catchment scale associated with different sediment management choices, such as dams, weirs, sediment mining or land-use changes.

WP3.2 Nested modelling of sediment connectivity effects on meander planform evolution (UniTN)

We aim to include the overlooked, albeit crucial effect of variations of the channel hydraulic geometry in evolutionary models of river meanders. A nested modelling strategy will be used, whereby the reach-averaged values of channel width, depth and slope are computed by means of a 1D model that accounts for the different evolutionary stages of single meander loops and for variations of the sediment supply. These average hydraulic conditions then provide the required information for modelling the local flow field, bed evolution and channel migration rate by means of a semi-analytical 2D model. This nested strategy is expected to provide a suitable tool for analysing the role of the alterations of flow and sediment regime due to river damming, change in land use and climate change. Model results will be compared with field observations based on the custom developed Pyris software which allow us to perform quantitative multi-temporal analyses of meander evolution [25], taking advantage from the recent progress in satellite geosciences.

WP3.3 Nested modelling of sediment connectivity effects on braided morphology evolution (PoliTO)

Coherently with WP3.1 and WP3.2, the morphodynamic braiding models developed, refined and used in WP1.1 and WP2.2 will be embedded (like a sort of "core brick" in a wider hydraulic and sediment chain) in the CASCADE model at basin scale. The aim is to investigate how changes of water and sediment discharges along the basin affect the evolution of braided reaches, in terms of topology and hydraulic and topographic features. Both idealised and real conditions will be investigated. The first case will allow us to systematically investigate different combinations of increase and reduction of upstream water and sediment rates (e.g., simulating different management rules of reservoirs, water/sediment uptakes, etc.). In the real cases, we will focus on the same basins (i.e., Borbera, Orco and Pellice basins) where the braided reaches considered in WP1.1 and WP2.2 are located, studying the impact of the upstream reservoirs on their evolution. The ultimate purpose of this activity will be to demonstrate – by the paradigmatic case of braided reaches – the great importance to pursue a multiscale (in space and time) approach to sediment dynamics and river morphologies.

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WP4 – PROJECT MANAGEMENT AND RESULTS DISSEMINATION

UniTN as lead partner will be responsible for the administrative management of the project.

The entire project team will meet at the beginning of the project and every 6 months (with at least 2 meetings in presence) to facilitate a smooth and well-coordinated execution of the research activities and to keep an overall control of the research progress in the different tasks. More frequent informal meetings will take place, mainly online, by smaller groups collaborating on the joint tasks highlighted in the GANTT chart (Figure 2). An online workspace will be created to facilitate data and information sharing between the Research Units.

A first dissemination strategy will consist of setting up a project website at the start of the project; it will be progressively filled with the key outputs and developed tools. Links to open repositories (Github, Bitbucket, Zenodo) will be reported in a dedicated page to allow easy and reliable access to usable digital tools and open datasets. The results dissemination strategy will be based on combining a set of actions tailored to different target groups: the scientific community, graduate students, practitioners in river management (public authorities, private consultants) and the general public

Results dissemination to the scientific community will take place: through participation of project partners to international conferences and through publications on peer-reviewed international journals (minimum target: 4 submitted papers by the end of the project, with more expected given its highly innovative character).

Dissemination to graduate students will be achieved in the 2nd project year by developing PhD-level scientific seminars for young researchers presenting the project outputs. These seminars will build on long-lasting collaborations among the Research Units in doctoral education on river morphodynamics. Uptake of recent scientific and technological innovations within the scientific community and by practitioners is often limited by the availability of digital tools that are ready to use, robust and accessible. Specifically, theoretical morphodynamic models developed in the past decades have been hardly made available beyond the model developers, and their use is often limited to a restricted number of scholars who focus their research on this specific sector. For this reason a key action in the dissemination of project results will be the development of a web-based digital Theoretical RivEr Morphodynamics modelling TOol (TREMTO), which will integrate a suite of codes developed under the modelling tasks (mainly WP1.1, WP2.2, WP3.1) into a web-based, user-friendly application to extend their use to interested researchers and practitioners.

together with a dedicated user manual and application tutorial based on the practical case studies of the project. At the end of the project, a one-day workshop will be organised to present the project outcomes to the key stakeholders at national, district and local levels: The language of the workshop will be Italian in consideration of the target audience.

Dissemination to the general public and other stakeholders will benefit from the project webpage hosted at the UNITN website, allowing public access to the scientific findings and providing information about the practical implications of the research activities related to the project. An informative, short video on the project outcomes using non-technical language will be realized in the second year and distributed via the project website and institutional social media of the two research units.