# UNRAVELLING THE POTENTIAL OF CONTEXT-BASED STORYLINES:

## Towards ecosystem-based land use planning for the Tagliamento River, northeastern Italy

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Chiara Scaini

National Institute of Oceanography and Applied Geophysics, Udine, Italy
<saetachiara@gmail.com>

Anna Scaini

Department of Physical Geography, Stockholm University and Bolin Centre for Climate Research, Stockholm, Sweden <anna.scaini@natgeo.su.se>

**ABSTRACT:** Land use changes can pose threats to natural ecosystems already challenged by anthropogenic pressures and increase societal exposure to river-related risks such as floods. In the Tagliamento river basin, a reference ecosystem for the restoration of Alpine rivers, land use planning was identified by locals as a major flood risk management issue. Here, we present evidence of the evolution of land use in the basin and explore the synergies between river conservation efforts and ecosystem-based land use planning. We present two storylines, one about a village that moved across the river and a second about a village that became an island. The analysis of the two storylines suggests a narrative that highlights (i) the preservation of natural regulatory functions in the middle course and (ii) the reactivation of fluvial corridors and wetlands in the lower course. Past documents highlighted that land use plans should account for threats posed by multiple hazardous phenomena (e.g., floods and droughts) to natural and human assets. We provide suggestions for future land use plans in the river basin integrating local knowledge and historical evidence into context-dependent storylines to convey risk-related concepts to the public.

**KEYWORDS:** ecosystem services, nature-based solutions, land use planning, exposure assessment, disaster risk reduction, river conservation, context-based storylines

### 1. Introduction

The occurrence of disasters caused by droughts and floods is projected to increase in the future, mostly due to human-induced alteration of the water cycle, disruptive land use patterns and climate change (Dottori et al., 2020; Cammalleri et al., 2020; Kreibich et al., 2022; Zhai et al., 2020). Floods and droughts are strongly interrelated, and the increasing impacts caused by droughts are shifting the focus towards a more holistic management of interrelated water-related risks (Barendrecht et al., 2024; Ward et al., 2020). Risk management decisions depend on the definition used for droughts and floods, as both definitions have been associated with perception biases (e.g., Glantz and Katz, 1977). Infrastructure-based measures (e.g., levees, dams) can increase or decrease long-term flood and drought risks (Di Baldassarre et al., 2013; Barendrecht et al., 2024), and infrastructural failure can lead to disruptive consequences (Tobin, 1995). Public debate and decision-making on risk-related concepts are often focused on the impacts of disasters rather than their prevention, and on short-terms (a few decades) rather than long-terms (100+ years). Short-term adaptation measures can therefore lead to long-term maladaptation if the systemic dimension is overlooked (Biella et al., 2024). In turn, reconnecting rivers with their floodplains has been proven beneficial for alleviating the effects of both floods and droughts (Ward et al., 2020). More work on how to balance combinations of short- and long-term actions is needed to avoid the dominance of short-term solutions which do not address the long-term problem (Biella et al., 2024).

The analysis of past disasters can be beneficial to identify causal chains and key factors for future risk mitigation (Balch et al., 2020; Atun et al., 2024). Studying past events allows for identification of two main behaviours of riverine communities after major floods: moving settlements away from the river and increasing hydraulic defences (levees, dykes, dams) (Di Baldassarre et al., 2013; Nakamura et al., 2024). The regulatory role of ecosystems is increasingly recognised as beneficial for disaster risk reduction (Crowley et al., 2022). The benefits and services provided by nature have been conceptualised within the ecosystem services framework and further elaborated through nature's contributions to people (Millennium Ecosystem Assessment, 2005; Díaz et al., 2015). Despite some critiques (e.g., Kadykalo et al., 2019), the ecosystem services framework is the most integrated in land use planning.  Ecosystem-based planning looks into solutions that instead are based on reconnecting and reactivating ecosystem services, such as regulatory ecosystem services provided by wetlands (Thorslund et al., 2017), including flood attenuation (e.g., Turyahabwe et al. 2013; Zedler and Kercher, 2005). Nature-based solutions encompass a range of ecosystem-based approaches, including restorative actions, ecosystem-based disaster risk reduction, integrated management and protection. The nature-based solutions approach goes beyond the ecosystem-based one to include additional aspects such as large- and multi-scale analysis, integration with other types of solutions and policy development (Cohen-Shacham et al., 2019). The implementation of nature-based solutions has been proposed in contrast to the so-called ‘grey’ infrastructure or within hybrid implementations (i.e., combinations of nature-based and grey infrastructure), but their adoption is limited by several challenges, including the uncertainties related to their definition and effectiveness (Anderson et al., 2022; Sowińska-Świerkosz and García, 2022). Significant efforts are required to draw lessons from major floods of the past in order to develop effective ecosystem-based and nature-based solutions.

Scientists play an increasingly relevant role in facilitating societal interaction processes (Köhler et al., 2019; Schneider et al., 2019; Turnheim et al., 2020) but also face critiques for their lack of engagement (Gardner et al., 2019). The development of storylines, i.e., “physically self-consistent unfolding of past events, or of plausible future events or pathways” (Shepherd et al., 2018) has been identified as key to making risk-related concepts more evident to societal stakeholders (Fuller et al., 2023; Sillman et al., 2021). Storylines can exemplify the potential interaction with other emerging hazards (Zaccaria et al., 2024) and, more broadly, anthropogenic climate change (Shepherd et al., 2018; Baulenas et al., 2023; Caviedes-Voullième and Shepherd, 2023). Also, they can be a starting point for the integration of local knowledge into a broader understanding of anthropogenic climate change impacts and to the identification of adaptation strategies (Chambon et al., 2024). However, there is still a gap in transferring knowledge of interacting hazards and lessons from the past to societal stakeholders for practical actions.

The Tagliamento river (Figure 1), often referred to as the 'King of Alpine rivers', is a reference ecosystem for international academic groups, providing a model for the restoration of degraded rivers, because of its morphological characteristics and functions (Müller, 1995; Tockner et al., 2003). Riverine communities have experienced numerous historical floods in the past (Spaliviero, 2002), with an ongoing debate focused on potential disaster risk reduction measures based on infrastructural intervention (Brusarosco et al., 2010; Osti, 2019). Ever since the last historical flood (1966) conflicting values related to flood risk and river conservation have exacerbated: part of the community urges the government to build additional flood risk mitigation measures, while other groups wish for the riverine ecosystem to be preserved. A questionnaire distributed to more than 4000 residents of the Tagliamento basin gathered citizens' perception of the river, identifying pronounced cultural values across the entire basin (Scaini et al., 2022). In addition, the questionnaire revealed a non-homogeneous perception of flood risk across the basin (Scaini et al., 2021b). Most respondents agreed that the river can be preserved while mitigating flood risk and mentioned land use planning as a major issue in the management of river-related risks (Scaini et al., 2021b). Citizens were correct: disaster risk depends not only on the frequency and magnitude of river-related hazards, but also on the number, type and economic value of exposed assets (i.e., the exposure) (Pittore et al., 2017). The distribution of exposed assets is, in its turn, defined by land use plans, which are one of the main governing instruments of contemporary landscapes (Hudson and Middelkoop, 2015). Land use planning has therefore the power to increase or decrease the overall societal exposure to river-related risks (Paprotny et al., 2024). For this reason, it is paramount to identify land use patterns that can mitigate disaster risk rather than exacerbating it.


Figure 1 – Location of the Tagliamento river in north-eastern Italy.[1]

This work starts from the aforementioned premises to collect evidence of past flood events around the Tagliamento river. We analyse the onset of disasters and the land use dynamics associated with them. The collected historical evidence is structured into context-based

[1] https://commons.wikimedia.org/wiki/File:Tagliamento_river_location.png

storylines for further dissemination and co-creation activities with stakeholders. We identify patterns of land use change and lessons learned in order to develop ecosystem-based land use plans that, leveraging riverine ecosystem services, mitigate long-term disaster risk. Below, we summarise the available historical evidence and reconstruct past flood events and land use patterns in the river basin (Section 2) and develop two context-based storylines (Section 3). Based on the storylines, we discuss their implications for the Tagliamento river basin and for the development of long-term, ecosystem-based disaster risk reduction plans (Section 4).

## 2. Analysis of the evolution of past floods and land use change

Despite preserving most of its features, the morphology of the Tagliamento river has been affected by human actions, including land use and construction of levees and bridges. Figure 2a shows the boundary between the lower, middle and upper courses. In the middle course, where the riverbed is very wide (reaching almost 2 km), the levees were maintained at a reasonable distance from the river, despite some partial narrowing due to bridge construction. The boundary between the middle and lower courses is characterised by a morphological change from braided channels to meanders. In the lower meandering course, the levees were constructed very close to the river. The presence of villages constructed on the river shore disrupted the natural dynamics. After the levees were constructed, multiple floods happened in the lower course.

In this study, we collect information on past floods using documentation from publications (e.g., Corbanese et al., 1987) and maps from historical archives, such as those Von Zach Kriegskarte, developed between 1798 and 1805 (Von Zach, 2005), and the Habsburg empire military map developed between 1818 and 1826. The Von Zach map is a military map developed by the Austrian Empire upon taking control of the area of northeastern Italy that nowadays corresponds to Friuli Venezia Giulia, Veneto and parts of Istria (currently part of Croatia). Historical documents (e.g., the Von Zach notes associated with the map) relate the consequences of floods for the communities. Historical information on floods is available starting from 1420 (Corbanese et al, 1987) and a synthesis can be found in Spaliviero (2002). Since 1798, floods have occurred mostly in the lower course (with a total of 8 floods) and in the valley of Fella, the northeastern, main tributary of the Tagliamento. Recent floods follow the same pattern, with major events in the lower course (1966) and the mountain basin (1996 and 2003). Information on recent floods was extracted from the records of Friuli Venezia Giulia's civil protection organisation.[2] Figure 2 shows the location of documented historical floods for three main periods: 1420-1798, 1798-1914 and 1915-2024, depicted with blue, purple and red dots respectively.

Levees have been progressively constructed to protect communities from river floods but information on their construction is scattered across multiple sources, making it difficult to reconstruct their detailed evolution. Here, we have collated data on levees from the historical data with their approximate construction periods (Figure 3). The first levees were constructed before the 18th century to protect medieval settlements affected by floods, under the order of local governments, as described in the Von Zach notes. In the second half of 1700 construction started in a more structured way, under the coordination of 'defense consortia' established in the middle and lower course, and the decisions were taken based on projects developed by local technicians. The historical documents specify that the levees construction was demanded by the local population to mitigate flood risk. The Venetian

[2] See https://www.protezionecivile.fvg.it/it

Republic gathered the funding (also by increasing taxes to riverine communities) and appointed the technicians responsible for the project. Historical evidence was collected from documentation in the Joppi Public Library (Biblioteca Civica Udinese Joppi) in Udine, in particular from the collection Stampe Presidenza Tagliamento - riparazione argini contribuzioni vari paesi, available at the Joppi Public Library in the miscellaneous section. This collection includes all the documentation associated with the levees' construction under the Venetian Republic.

Large historical floods created river channels outside the riverbed, reaching villages located several kilometres away from the river, and incorporating other rivers (e.g., the Stella river). The three arrows in Figure 3 show the main breeches of the past floods. Currently, the Cavrato (blue arrow) is still operational, while the other two (the Masato and Mucose, depicted with transparent arrows) have been closed since the reconstruction of the previously existing levees in the 19th century (Altan et al., 1990). Levees in the middle and lower courses were finalised by the end of the 19th century. Since the early 2010s, levees in the lower course have been strengthened by the use of concrete diaphragms, reaching their current state.

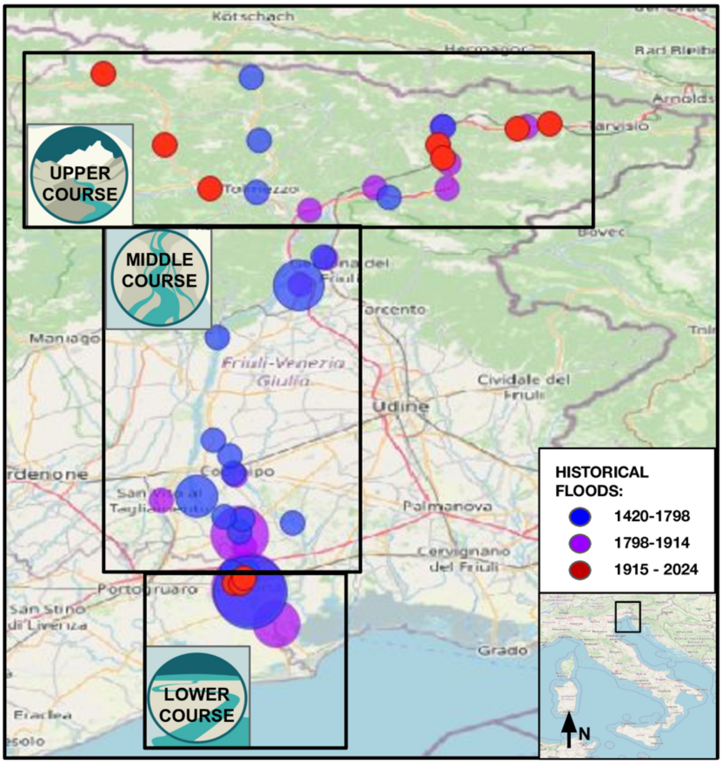


Figure 2 - Map of the Tagliamento basin, distinguished between upper, middle and lower course, characterised by different morphologies, and location of historical floods in 1420-1798 and 1798-1914 and 1915-2024, depicted with blue, purple and red dots respectively), with dot size proportional to the number of events occurred in each location.[3]

[3] Background map data extracted from OpenStreetMap, https://www.openstreetmap.org

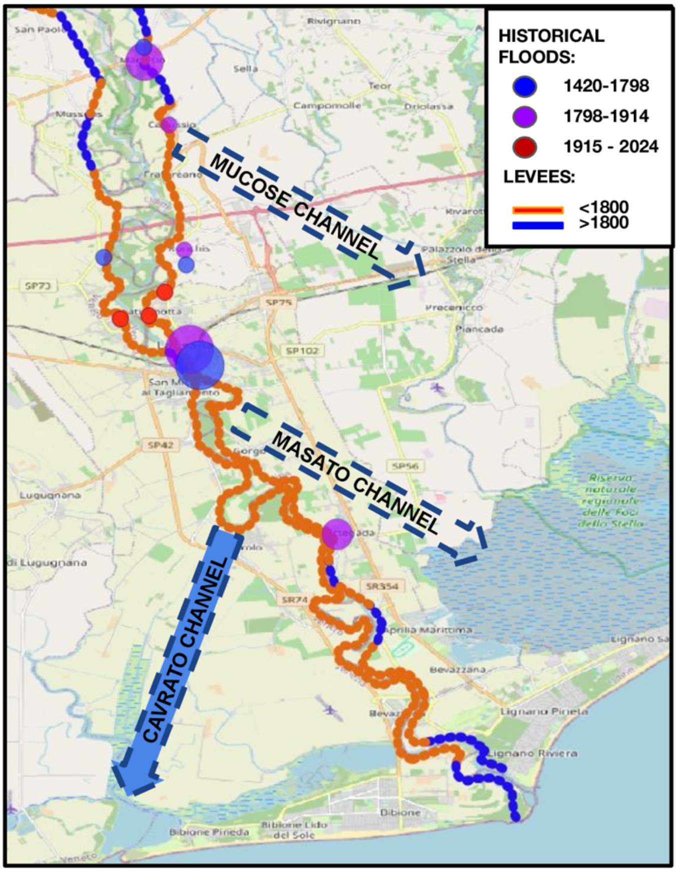


Figure 3 – Current levees in the lower course of the Tagliamento associated with their approximate age of construction (orange and blue, respectively for levees constructed before and after 1800). The arrows correspond to the main breeches in the lower course, one of which (Cavrato, filled in blue) is currently in use, while the other two (Mucose and Masato) were closed with the reconstruction of the previously existing levees.[4]

Based on the previous analysis, we identified patterns of interaction between the river and the communities during floods. We performed a qualitative comparison between the floods' location, the damages that occurred to the communities, the construction of levees and the land use choices made over the last decades. In particular, we identify three main patterns (Figure 4):

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[4] Background map data extracted from OpenStreetMap, https://www.openstreetmap.org (© OpenStreetMap contributors 2023; distributed under the Open Data Commons Open Database License [ODbL] v1.0.).

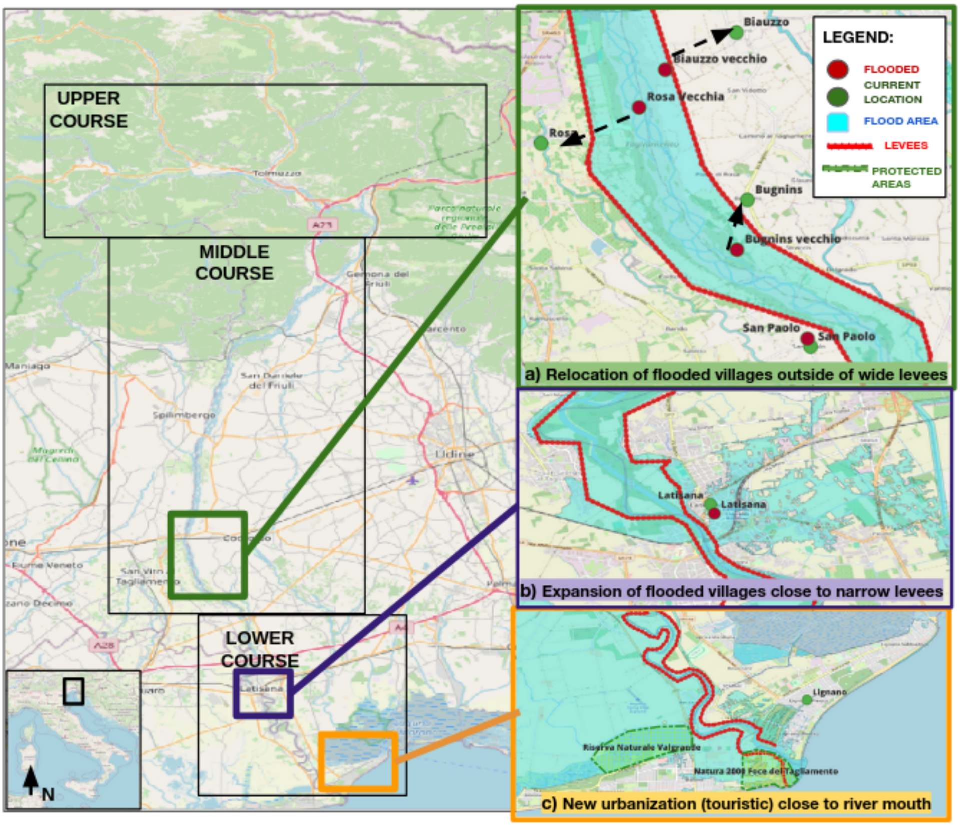


Figure 4 - Examples of land use patterns in the Tagliamento river basin: a) relocation of flooded villages (e.g., Biauzzo Vecchio to Biauzzo, Bugnins Vecchio to Bugnins) with construction of wider levees in the middle course; b) urban expansion of flooded villages (e.g., Latisana) in the lower course, with construction and strengthening of levees; c) new urban and touristic expansion (e.g., Lignano) in previously non-urbanised areas in correspondence to the river mouth. The location of protected natural areas on the eastern side of the river is also shown. The flood area extent corresponds to the latest version of the official flood hazard map computed by the Italian Institute for Environmental Protection and Research (ISPRA) and represents the envelope of flood area obtained for different rainfall scenarios defined based on historical data for a return period of 30 years (Trigila et al., 2018; Autorità di bacino distrettuale delle Alpi Orientali, 2021).[5]

♦**The relocation of villages in the middle course, characterised by braided channels (Figure 4a).** The Tagliamento braided channels moved largely across the floodplain in historical times, up to the second half of the 19th century, when levees were constructed. In this time span, several villages were subjected to floods in the middle course, and some of

[5] Background map data extracted from OpenStreetMap://www.openstreetmap.org (© OpenStreetMap contributors 2023; distributed under the Open Data Commons Open Database License [ODbL] v1.0.).

them were progressively relocated further away from the main river channel. Figure 4a shows the displacement of three villages in the middle course (Biauzzo, Bugnins and Rosa) from their original locations (Biauzzo vecchio, Bugnins Vecchio and Rosa Vecchia[6]). All three villages were relocated further from the river's active course between the second half of the 16th and the end of the 19th century. The names of the old villages are still used to identify the area where they were originally located. Towards the end of 1700, levees were constructed, and the villages remained in the current configuration.

♦ **The reconstruction and expansion of flooded villages in the lower course, characterised by meandering morphology (Figure 4b).** Several villages were subjected to floods in the lower course, with subsequent construction of levees (between the 18th century and the end of the 19th centuries) and their progressive strengthening (up to 2022). With the presence of levees, many villages were reconstructed and experienced expansion in tandem with Italy's economic and population growth after World War II. The town of Latisana is the main village in the lower course and suffered significant damage from multiple historical floods, the last one being in 1966 (Altan et al., 1990). The 1966 flood was followed by reconstruction and urban development including the construction of new residential areas. Urban expansion also occurred in areas close to the historical breaches of the Tagliamento after they were closed (Figure 4b).

♦ **Substantial urban expansions close to the river stream in upper and lower course (Figure 4c).** World War II was followed by urban expansion including new industrial and tourism areas. Figure 4c shows an example for the town of Lignano, constructed after 1950 in a previously uninhabited area. Nowadays it hosts more than 3.5 million tourists per year. Historical documents show the presence of sand dunes and pine woods that protected the shore from marine hazards. On the opposite side of the Tagliamento river mouth near the town of Bibione, some natural areas were maintained, e.g., the Natura 2000 site Foce Del Tagliamento (Natura 2000 code IT3250033), established in 1995, and the natural area of Valgrande.[7] Another example of new expansion is Tolmezzo, in the upper course, where industrial development occurred very close to the river.

## 3. The development of context-based storylines

We present two storylines based on the patterns presented in the previous section. Both take place in the middle course, in the area identified by the green rectangle, where the villages of Rosa and San Paolo are depicted (Figure 4a). Each storyline is exemplified by a causal chain of events and presented using maps and images to convey specific risk-related concepts.

### 3a. *Storyline 1:* Rosa: the village that moved across the river

Among the villages that were relocated between the 17th and the 19th century, the town of Rosa (Figure 4a) is perhaps the most notable example. In this period, the town was progressively moved four times to reach its current position (Sclippa, 1997). The reason for this progressive relocation was the floods that repeatedly hit the town due to a west-to-east progressive movement of the river (Figure 5). The relocation was documented by the

[6] *Vecchio* means 'old' in Italian and is used to highlight the old location of these villages in historical maps.
[7] https://www.bibione.com/it/scopri/natura/valgrande/.

reconstruction of the village church (with destruction and reconstruction dates recorded in official church registers), which testifies the willingness of the inhabitants to relocate. The remains of the first church, which was destroyed in 1698, occasionally become visible in the riverbed. These 'appearances' were documented in 1995, 2005 and 2010 (Figure 5a), giving rise to the oral legend of the 'church that crossed the river'. The story of Rosa shows multiple displacements required for the community to co-exist with the river. This storyline exemplifies:

♦ The dynamics of a free-flowing river, whose braided channels move across the floodplain, causing floods to nearby villages.

♦ The option for communities to promote adaptation, e.g., by relocating further away from the river, highlighting the need to allow adequate space to rivers and thereby mitigate flood risk for communities.

♦ The importance of land use planning and the need for understanding long-term riverine dynamics, exposure patterns and potential risk mitigation actions to reduce disaster risks.

2b. *Storyline 2:* San Paolo: the village that became an island

The village of San Paolo (Figure 4) suffered the consequences of the Tagliamento floods but remained in the same location. However, its story is special with regards to the other villages: for 100 years, Sao Paulo was separated from the mainland on a riverine island. In 1596, a flood created a secondary river stream that separated the village from the mainland, as testified by historical maps of the time (Figure 5B). Almost 100 years later a second flood occurred, caused by the break of a landslide-induced river obstruction in the Tagliamento upper course (the Borta landslide in 1692, Bonnard et al., 2011; Dykes et al., 2013). During this landslide-induced flood, the river debris closed the secondary river stream and the village was returned to the mainland. The dry stream was occupied by the river during other floods, the last of which occurred in 1966. The village still maintains some traditions developed during the period of partial isolation, e.g., it is said that cooking goats for the annual festival of the village comes directly from the new habits acquired during their period of partial isolation (Floramo, 2017). San Paolo supports many initiatives devoted to the river's historical, cultural and environmental values, such as hosting river-related cultural events and publishing river-related books. The river dynamics described in the storyline also affected the towns of Mussons and Bolzano, also visible on the historical map of the Tagliamento river (detail shown in Figure 5, bottom right). The original map represents the Tagliamento river middle and lower courses, showing the location of the main river channels and the villages (most of which still exist today). The story of San Paolo conveys that despite the distinction between upper, middle and lower course, riverine dynamics (and associated risks) can only be understood and managed looking at the entire river basin. This storyline also exemplifies:

♦ The relevance of considering cascading impacts in a multi-hazard context, with identification of causal effects between strong rainfall, mountain landslides, river obstruction and floods for braided channel rivers;

♦ The different temporal scales of hazardous phenomena that can happen in a range from frequently (e.g., landslide or flood occurrence) to very rarely (valley obstruction with resulting lake generation) and how they affect riverine communities (e.g., by forcing relocation or temporary isolation).

♦ The occurrence of past disasters leaves a memory in the riverine community but does not necessarily encourage them to relocate, nor it disconnects them from the river.

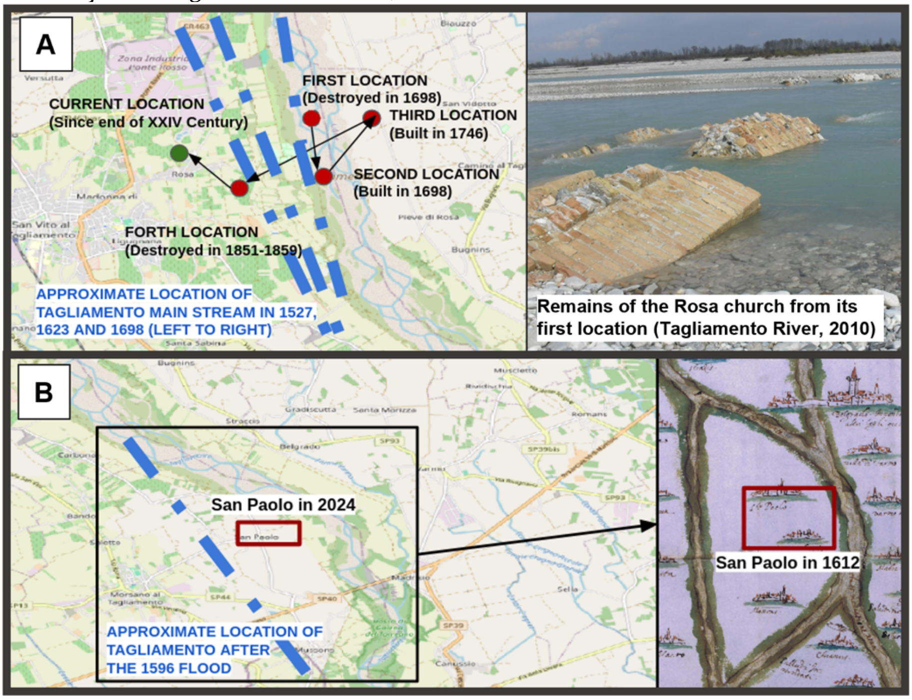


Figure 5 – A: map of the progressive relocation of Rosa and picture of the old church emerging from the current riverbed (Wikicommons).[8] B: map of the current location of San Paolo and detail of an historical map of 1612 and authored by Conte Savorgnan Vettore, in which the village is located on a riverine island.[9]

The theoretical conceptualisations developed by the scientific community should be validated and enriched through the analysis of specific contexts. Figure 5 shows material developed to present the two storylines to the public. The San Paolo storyline was used for outreach activities performed in 8 locations in the upper, middle and lower course (from North to South: Venzone, Pinzano al Tagliamento, San Martino al Tagliamento, Codroipo, Camino al Tagliamento, San Vito al Tagliamento, Gradiscutta, San Paolo and Lignano, see Figure 6). The story of the relocated villages, including Rosa, was mentioned as an example of community adaptation to floods. The dissemination initiatives were organized in collaboration with local associations, municipalities, and private stakeholders, attracting approximately 100 participants to each activity. The potential of these storylines was evident

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https://it.wikipedia.org/wiki/Rosa_(San_Vito_al_Tagliamento)#/media/File:Rosa_(San_Vito_al_Tagliamento)_-_resti_chiesa_Villa_di_Rosa_-_2010_-01.JPG under the CC-BY-SA license

9 Digital reproduction of the original, available at the Archivio di Stato di Venezia. Background map data extracted from OpenStreetMap: //www.openstreetmap.org (© OpenStreetMap contributors 2023; distributed under the Open Data Commons Open Database License (ODbL) v1.0.).

from the participants' attention and feedback, further enhanced by the presence of historian Prof. Angelo Floramo, who served as co-presenter.


Figure 6 - Left: Map showing the location of the dissemination activities where context-based storylines were presented. The areas where infrastructures (in particular, flood retention basins and filtering dams) were proposed in the last decades are shown with black squares. All infrastructures were planned in the middle course, where the morphologies of braided channels are still preserved. Right: photos taken during the activities.[10]

## 4. Discussion

### 4.1 Learning from the past a new paradigm for the management of the Tagliamento river

In this article we have shown two examples of the relationship between land use planning and disaster risk, e.g., *Storyline 1:* Rosa: the village that moved across the river and *Storyline 2*: San Paolo: the village that became an island to prove the validity and usefulness of the context-based storylines theoretical framework. Both context-dependent storylines underline the role of land use in mitigating long-term risks. The critical interpretation of these storylines and the associated historical evidence provides hints for future land use planning in the Tagliamento basin and in riverine landscapes. The storylines rely on the analysis of historical documents, of which we provide here only a limited extract. The information available on historical documents and maps is paramount for understanding the multiple relationships between communities and rivers (e.g., conflicts on the levees' location) and the land use patterns (e.g., existence of wetlands drained during land reclamation projects). They also point out the existence of different opinions regarding the

[10] Background map data extracted from OpenStreetMap: //www.openstreetmap.org (© OpenStreetMap contributors 2023; distributed under the Open Data Commons Open Database License (ODbL) v1.0.).

river management, including notions of river morphology and proposals for renaturation processes. The analysis of historical evidence deserves more attention in the current disaster risk reduction practice and should be more systematically integrated into more holistic and less anthropocentric risk assessments.

Structural measures such as water retention basins are currently planned in the Tagliamento river to prevent flood risk in the lower basin (Figure 6), where only a limited amount of discharge can pass without causing damages to communities. Such structures have been under discussion since the last damaging flood in the lower course, in 1966, but faced strong opposition from both the riverine populations (Osti, 2019). However, building new infrastructure is not the only option to mitigate flood disaster risk. Different possibilities have been developed in the last decades and mostly relate to two concepts:

a) The preservation of the middle course and its natural regulatory functions.

Despite being considered among the most preserved free-flowing rivers in the Alps, the riverbed has been heavily modified by humans, including narrowing of the floodplain in correspondence of bridges, and land use changes favouring human settlements, industry and agriculture. In 1870, the hydraulic engineer Giuseppe Rinaldi pointed out the importance of maintaining riverine forests, which are gradually disappearing but play a relevant role in reducing flood speed and increasing water infiltration (Rinaldi, 1870). The management of the middle course should account for trade-offs between human activities and ecosystem conservation needs, ensure riverine connectivity (or at least avoiding infrastructures that disrupt such continuity) and maintain riverine ecosystem services (including cultural ones) (Scaini et al., 2022). Flood mitigation engineered or non-engineered infrastructure are often designed as single-purpose measures, disrupting river connectivity and failing to address the multi-risk challenges for which regulatory ecosystem services are key. Nature-based solutions or hybrid interventions that favour river connectivity, conservation and restoration, mitigating multiple risks at the longer term should therefore be favoured. However, so far, no one has estimated how much water the middle course could retain across its 80 km length if the floodplain area between the current levees could be reactivated. In the middle course, the floodplain includes mainly agricultural land and riparian forests: here, the river's regulatory capacity could be enhanced through nature-based solutions (Harrak et al., 2023). Multiple management scenarios can be defined to quantify the volumes of water that can be retained under a range of simulated flood events, with the primary purpose of "natural" flood risk management (Hartmann et al., 2019; Thaler et al., 2021). Any proposed flood retention project should be critically revised in light of these considerations and meet the expectations of local communities (Anderson et al., 2022).

b) The reactivation of fluvial corridors and wetlands in the lower course.

Spaliviero (2002) describes the option of recovering ancient fluvial corridors to be used for expanding the capacity of the Tagliamento river during large flood events. This idea comes from the past. It was originally proposed in the end of the 19th century, as reported by Croci (1899) in the engineering journal *Giornale del Genio Civile*. The publication describes the successive phases of levee construction and states that it would have been beneficial to have the river lower course in its natural state, including the presence of natural expansion areas (the original wetlands of the riverine delta). At the time, there was a common practice of keeping river breeches open for flood mitigation purposes in order to submerge agricultural areas instead of the towns (Croci, 1889; Altan, 1990). Croci (1889) indicates that (literal translation carried out by the authors):

> *on the 9th of April 1838, a decree by the district commissioner [i.e. the local authority appointed by the Austrian government to manage the river] obliges the landowners to destroy the private levee arbitrarily constructed to close the Masato break, motivated by the fact that this breech, together with the Cavrato, would contribute to maintaining the equilibrium of the main Tagliamento channel.*

Some projects developed in the 19th century even hypothesised the partial or total deviation of Tagliamento into one or more of the channels opened by past floods (marked with blue arrows in Figure 3), of which one, the Cavrato, is still functioning today (see Figures 3 and 7 and text for details). Reggiani and Verschelling (2005) showed that, under specific hydraulic conditions, the use of the Cavrato channel combined with targeted measures in the lower course can allow the peak flood to pass without inundation.

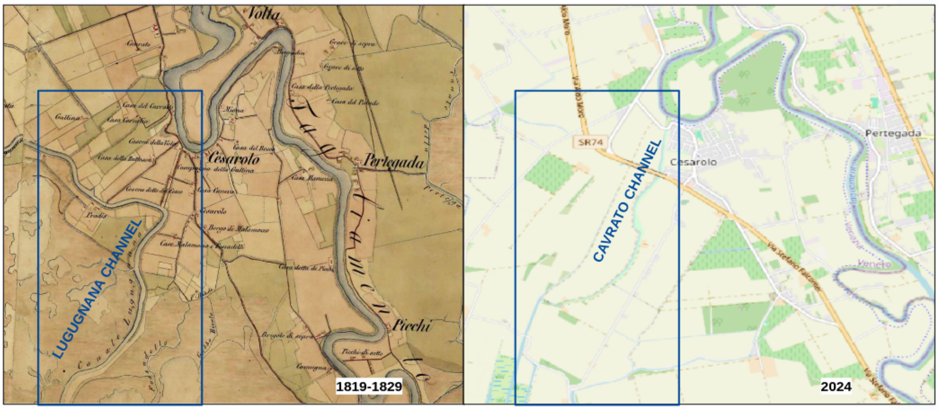


Figure 7 - Habsburg Empire military map (left, 1818-1829[11]) showing the Lugugnana river channel which later was used for constructing the Cavrato channel (see Figure 1 for its location within the river basin). The Cavrato channel nowadays (right, 2024[12]) conveys water from the river to the lagoon and is operational when a flood occurs. Originally, the Lugugnana channel drained water into the wetlands (in particular, into one area named Valle Grande della Lugugnana ('Large wetland of the Lugugnana') visible in the Habsburg military map) which was progressively converted into agricultural land.

The opening of additional channels for peak discharge has also been proposed in 2024, as an alternative to flood retention basins. These interventions were sometimes defined as "nature-based solutions", without a justified positive or neutral impact on river connectivity. The impact of any of the human-made infrastructures associated with the channel's construction and maintenance have not been evaluated. Unfortunately, since the last flood in 1966, exposure has increased in the lower basin, with residential, touristic and agricultural land

[11] Habsburg empire Military map developed by the Habsburg army during their II military survey of northeastern Italy, available at: https://maps.arcanum.com/en/map/europe-19century-thirdsurvey/?layers=160%2C166&bbox=1422747.3246267214%2C5720261.160736699%2C1496126.8717804905%2C5748772.172287069

[12] Background map data extracted from OpenStreetMap: //www.openstreetmap.org (© OpenStreetMap contributors 2023; distributed under the Open Data Commons Open Database License (ODbL) v1.0.).

use, making it more difficult to implement these potential solutions. In addition, transboundary issues could arise as the river is an administrative boundary between two regions (Friuli Venezia Giulia and Veneto). Also, the usage and reactivation of external channels for peak discharge should be pondered to account for the trade-offs and impacts on the marine ecosystem (e.g, the lagoons where such channels would flow) and human activities. Potential interventions should also account for the effects of climate change (e.g., variation of precipitation patterns, on evapotranspiration, groundwater table and presence of snow/ice). Finally, the lower course is subjected to the combined effects of subsidence, saline intrusion and sea level rise. The subsidence in the lower plain is due to a combination of natural and anthropogenic causes. In particular, it is accelerated by water extraction, land reclamation and building load (e.g., Tosi et al., 2009, 2010; Floris et a., 2019). The indirect impacts of anthropogenic climate change can also contribute to accelerate these phenomena (e.g., drought that accelerates subsidence and saline intrusion). The lower Tagliamento basin coastal area is therefore exposed not only to river-related hazards, but to multiple processes at different temporal and spatial scales, which demand for "solutions" that can mitigate more than one threat instead of focusing on single hazards. A single-purpose infrastructure in the upper course would not prevent these processes to happen, and therefore would not fully mitigate the river-related risk in the lower course.

A solution suggested by Croci (1889) and potentially feasible today is to reactivate the wetlands that were originally present in the lower course and drained through land reclamation (visible in historical maps up to the beginning of 1800, Von Zach, 2005). Croci writes about the levees in the lower course, asserting that:

> *The levees in the lower course have serious shortcomings, in particular the fact that they are very narrow and that they follow the path of the meanders. If levees were constructed at larger distances, they would have left more space to the river flood, allowing its natural flow with clear advantage for the peak discharge. It would have been preferable to avoid building levees in the lower course, stopping their construction at the level of Cesarolo and Pertegada (on the right and left shore, respectively). Lower to these locations, the arable wetlands are mostly marsh and swamps, and during the progressive river flooding, they would have been naturally dried up by the contribution of river sediments, if it was left free to expand in the surroundings.*

The lower course could still accommodate ecosystem-based and nature-based solutions and would be able to offer multiple co-benefits such as water retention, biodiversity conservation, prevention of subsidence and saline intrusion (Thorslund et al., 2017). A notable example is the Natura 2000 Foce del Tagliamento site and the recently established Valgrande nature reserve (Figure 4c) which could increase the retention capacity during a flood. The reactivation of wetlands is also strongly aligned with the EU Nature Restoration Law (European Commission, 2024) and would represent a strong step forward reducing long-term disaster risk in the Tagliamento river basin. The aforementioned concepts are alternatives to the currently proposed infrastructures, which are designed based on purely hydraulic considerations at the expense of the last free-flowing Alpine river. The long-term objective should instead be to allow the river its space within the floodplain and reduce exposure, not only with regards to floods but also droughts and other hazardous phenomena, in particular in the delta, prone to coastal storms, surges and meteo- and seismically-induced tsunamis (Peresan and Hassan, 2024).

In the Tagliamento river, the need to ponder any intervention considering the whole basin dynamics and the multiple dimensions of the river, including its ecosystem services and the relationship with communities has been considered (Scaini et al., 2022). Work is ongoing to explore the relation between land use, exposure and risk, developing adaptation strategies that also account for the aforementioned aspects (Aminjafari et al., in prep.). Flood attenuation solutions are nonetheless needed to accommodate more water and retain and/or delay floods without compromising the long-term regulatory services of the river and wetlands (e.g., regulation of groundwater table and surface temperature and humidity). In particular, altering the river's natural course might have negative impacts, for example increasing the subsidence rate and facilitating saline intrusion. Nature-based solutions could be developed by learning from the past and, in particular, from the context-based storylines presented here, as recently highlighted with regard to the role of forests as nature-based solutions to water scarcity (Suman et al., 2024). The focus is gradually shifting from one single infrastructure to distributed nature-based solutions for both multi-hazard risk reduction (including flood retention, drought prevention through groundwater recharge) and climate change mitigation through regulatory ecosystem services (e.g., carbon sequestration, Taillardat et al., 2020).

4.2 Context-based storylines to communicate river-related risks on the Tagliamento

The progressive urbanisation of the lower course of the Tagliamento river has highlighted several unresolved challenges (Osti, 2019). The interaction between societies and the fluvial environment has, so far, included some degree of riverine conservation efforts, which might allow for it to become a flagship case-study for developing a community-driven strategy that entails both flood risk mitigation and river conservation. The relationship between river conservation and long-term disaster risk reduction is often overlooked in the media communication within the region, with a debate dominated by hydraulic infrastructure and their supposed role in providing "safety" (Scaini et al., 2021a). This polarisation of media coverage insists on the perception of scientists that information on the media is prone to errors (Besley and Nisbet, 2013). This narrative needs to change: the context-dependent storylines developed here can bring the debate to a different level, conveying risk-related concepts to the community (Figure 6). The approach presented here, based on past evidence and context-based storylines, can help better communicate the concepts around nature-based solutions implementation also to the general public, preventing negative perceptions (e.g. Anderson et al., 2022) and supporting the existing belief that river conservation is compatible with risk mitigation (Scaini et al., 2022). The recently created website tagliamento.org, which brought more attention to ecosystem-based planning, represents a step forward, emphasising the role of all riverine ecosystem services, including cultural ones (Scaini et al., this volume). The community meetings (Section 3) and the questionnaire developed by Scaini et al. (2021b) identified that riverine populations want to preserve the river and are not in favour of infrastructures that can disrupt its natural characteristics. The role of scientists is pivotal to developing an evidence-driven communication and dissemination strategy to improve awareness. Unfortunately, though, outreach and dissemination activities are often under-valued by academic institutions (Calice et al., 2022), probably causing the scientific community to be less engaged than they could (Dablander et al., 2023). Context-based storylines and active and inclusive community engagement act as 'breadcrumbs' to co-create context-dependent adaptation measures and contextualise the production of scientific knowledge.

### 4.3 New narratives for ecosystem-based planning

Long-term, ecosystem-based land use planning can shift the focus from specific events (i.e., based on one or more historical floods) to multiple interacting hazards (Di Baldassarre et al,. 2013; Ward et al., 2020). In particular, droughts and floods in the Mediterranean are increasingly impacting human societies (Masseroni et al., 2021), with recent examples in northeastern Italy (Straffelini and Tarolli, 2023). Ecosystem-based land use plans should be developed at river basin scale, accounting for threats posed by multiple hazardous phenomena, including floods and droughts, to both natural and human assets. This also implies long-term assessments that go beyond single short-term infrastructural actions, also considering climate change scenarios and their evolution (see IPCC, 2022).

The synergies between river conservation efforts and ecosystem-based land use planning are evident: ecosystem services are a necessary tool to mitigate long-term risks. Local studies such as this one can provide general suggestions for future ecosystem-based planning, demonstrating its practical importance for a case-study of European relevance. The methodology is exemplified here for the Tagliamento river but highlights the potential benefits of integrating local knowledge and historical evidence in assessing exposure to different river-related hazards. The approach presented here highlights that combining participatory approaches with lessons learned from the past can be key to developing novel and inclusive narratives (with enhanced awareness) for ecosystem-based planning.

Storylines are used for communication, dissemination and co-creation purposes, and they allow collecting historical, scientific and geological knowledge together with local traditions and memories. The storylines rely on the availability of historical information, which in this case is taken from governmental historical archives and land use maps. Having this type of information available to the scientific community is of utmost importance for developing future strategies based on historical and scientific evidence. In addition, storylines can be combined with physics-based modeling (e.g., Bonasia et al., 2021, Ceragene et al., 2023) in order to develop scientifically sound scenarios and convey the results of risk assessments to the public. Combining storylines with modelling requires a combination of disciplines including risk-related, historical, cultural, and traditional dimensions of landscape. A strong component of local knowledge is also needed. Collaborative efforts can facilitate the process, particularly when local scientists are involved such as in this case (Taylor et al., 2021). Participatory, bottom-up approaches such as questionnaires, focus groups, and a collaborative knowledge hub are currently being extended to other study areas and point out the importance of multidisciplinary knowledge including historical, cultural and traditional dimensions of landscape studies.

## 5. Conclusions and outlook

We have developed context-based storylines that relate the history of the Tagliamento river and its communities. The storylines are based on past evidence on floods and their impacts and highlight the need for considering past river dynamics and impacts when pursuing flood risk adaptation. We provide particular emphasis on land use management, levee placement and urban development choices, which are main drivers of flood risk. The analysis of past floods' occurrence unravels potential adaptation strategies that are nowadays overlooked and might conciliate river conservation efforts with disaster risk reduction in exposed areas. In particular, we highlight that the lower river basin could accommodate nature-based solutions to recover the regulatory ecosystem services of the river floodplain, with beneficial outcomes for the entire river basin and its communities. Historical sources highlight that focusing on a single hazard (e.g., floods in the case of the Tagliamento river) should not overlook compounding and cascading hazards (such as droughts and coastal hazards) and their consequences. The use of historical data and storylines is discussed in light of current and future co-creation work and highlights advantages for future ecosystem-based land use planning within this and other case studies.

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