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## Application of a new Maintenance Priority index to support watershed management

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### Abstract.

The monitoring and management of channel control structures have become fundamental in the current context of climate change, marked by extreme events. In mountain basins, there is an increasing need to identify the most critical areas for intervention planning.

The current assessment of the status and functionality of torrent control structures could support the development of watershed management strategies, assess the effectiveness of existing interventions, and foster a more complete decision-making chain. The present work aims to apply a very simple, quick, and user-friendly Maintenance Priority index (*MPi*) that provides a snapshot of the state of the torrent control structures within the mountain basins. Assessing the structure status and functionality using very simple markers in the field offers a quick solution for technicians who conduct constant field monitoring of torrent control structures across numerous basins. It allows them to continuously update the database with operations that are sustainable in terms of cost and time. Moreover, linking an up-to-date *MPi* with sediment morphology dynamics analyses over an extended time window by exploiting topographic information, such as multi-temporal Digital Terrain Models (DTMs) and geomorphic change detection analyses, could offer more complete and quantitative data. This information can be used to prioritize the maintenance intervention and evaluate the effectiveness of the implemented torrent control works overtime, aspects that are normally poorly considered, or developed. In this way, decision-makers can obtain relevant indications on where to invest resources and find more appropriate solutions or address maintenance works.

**Keywords:** Torrent control structures, Maintenance Priority index, Watershed management.

## 1 Introduction

In the last decade with the increasing frequency of extreme weather events, effective and sustainable planning of torrent control structures must be achieved by learning from past mistakes and exploiting all available technologies to support decision-making processes. Although torrent control structures have always been adopted in mountain regions their planning, implementation and above all maintenance remain complicated as interventions must interact with complex natural phenomena [1]. The lack of information on flow and solid transport dynamics in catchments, on the structure damages and the effectiveness of implementing torrent control interventions, can now be addressed by constant monitoring of the mountain landscape exploiting new technologies. The growing capability of producing High-Resolution Topography data (HRT) through multi-temporal surveys (e.g., laser scanning and photogrammetry) greatly simplifies the monitoring of interaction between sediment morphology dynamics and torrent control structures over time [2]. Indeed, thanks to repeated HRT surveys, it is possible to derive accurate multi-temporal Digital Terrain Models (DTMs) and reliable DTMs of Difference (DoDs) useful to quantify the morphological changes and the evolution of erosion and deposition patterns. Once information on the dynamics of the phenomena has been gathered, it becomes essential to correlate this data with the status and functionality of torrent control structures, providing useful and innovative supporting information to prioritize maintenance interventions. These last ones are fundamental for increasing the lifetime of measures and restoring the functional condition [3].

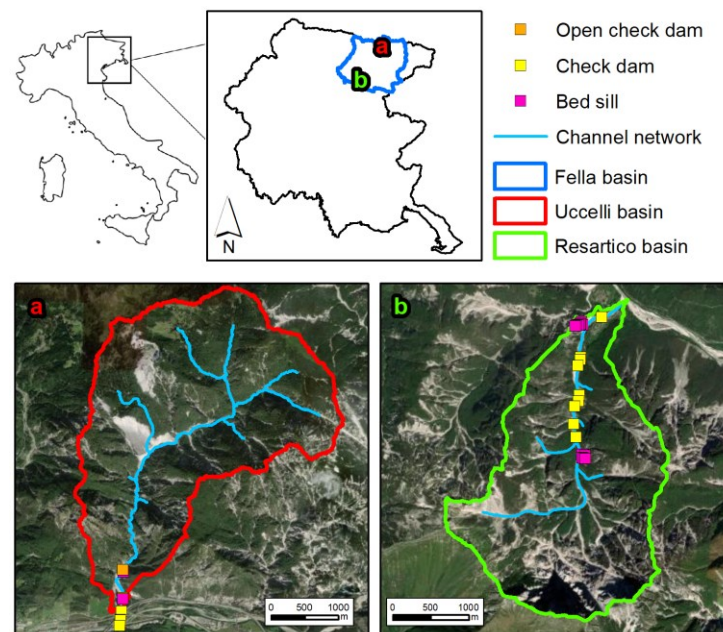
The present work aims to apply a new Maintenance Priority index (*MPi*) to monitor the physical status and functionality of existing structures, integrating this information with sediment morphology dynamics data over large time spans in two mountain catchments. The simple and user-friendly methodology identifies the most critical areas for intervention planning, support the development of watershed management strategies, assess the effectiveness of existing interventions, and foster a more complete decision-making chain.

## 2 Study catchments

To test the proposed methodology, two catchments were investigated, concentrating on specific reaches that play a significant role in the basin dynamics. The Uccelli and Resartico basins are in the Friuli Venezia Giulia Region (Italy) and part of the Fella River basin (703 km<sup>2</sup>; Fig. 1). Their main morphological features are presented in Table 1.

**Table 1.** Main morphological characteristics of the four study catchments.

Catchment	Area (km <sup>2</sup> )	Average slope (°)	Elevation (m a.s.l.)	Channel network length (km)
Resartico	7.05	46.1	324 - 1956	5.1
Uccelli	10.56	38	620 - 2042	13.7



**Fig. 1:** Location of the study basins in the Friuli Venezia Giulia Region (Italy) with the torrent control structures found in the field surveys. (a) The Uccelli and (b) Resartico catchments in Pontebba and Resiutta municipalities, respectively.

In the Uccelli catchment, massive sediment transport processes (e.g., debris flows) are present in the upper part of the basin, where sediment is produced along the hillslopes. Conversely, in the downstream part the stream flows are more confined (Fig. 1a). The main geomorphological feature of the basin is a huge accumulation of chaotic material [4] present on the right side of the upper portion of the valley.

The Resartico basin has sediment sources along very steep slopes (Fig. 1b), causing debris flow phenomena in the upper part of the basin and hyper-concentrated solid transport in the conoid zone, with the latter being a risk factor for downstream infrastructures [5].

### 3 Materials and methods

#### 3.1 Maintenance Priority index (*MPI*) of torrent control structures

Among the several torrent control structures, numerous check dams bed sills, and open check dams have been realized in the Uccelli and Resartico catchments, hence it is possible to assess their interaction with sediment dynamics during a long period (e.g., in this study from 2008 to 2023). To support the development of watershed management strategies, it was important to *i*) localize and classify the torrent control structure present in the case studies analyzed and, according to the existing literature,

*ii*) identify or assume the primary objectives for which the torrent control systems were built and *iii*) assess the status and functionality of structures using simple markers, to be observed during field surveys, and then translate into scores [6]. Exploiting the scores of structural state and functionality, a Maintenance Priority Index (*MPI*; [6]) recently published, was applied as in Eq. (1). Subsequently, it was incorporated into the database, considering the values and color ranks provided in Table 2. This application offers a snapshot of the state of the torrent control structures within the basins.

$$MPI = 1 - \left( Score_{status} \times \left( \frac{Score_{status} + Score_{functionality}}{2} \right) \right) \quad (1)$$

**Table 2.** The *MPI* scores and color ranks are assigned to give a key for reading the index: green-rank (0) indicates the lowest priority of interventions; blue-rank (0.25-0.50) shows that a careful review of the planning process should be carried out; orange-rank (0.63-0.88) where interventions should address the long-lasting durability of the structure itself; and red-rank (0) for interventions that should have the highest priority because structures are destroyed and with any level of functionality [6].

Functionality		Status		
		Destroyed	Damaged	Good
	Score	0	0.5	1
Low	0	1	0.88	0.50
Medium	0.5	1	0.75	0.25
High	1	1	0.63	0

Starting from the Regional Cadastre of torrent control structures realized by Friuli Venezia Giulia Region [7], an updated inventory of all the structures (e.g., dimensions, typology, building material, year of construction, location, and structural and functional states) was carried out in the summer of 2022 and 2023 by field surveys (i.e., through Global Navigation Satellite System – GNSS, laser range and visual inspection) in the Uccelli and Resartico basins, respectively.

### 3.2 Multi-temporal topographic data and change detection analysis

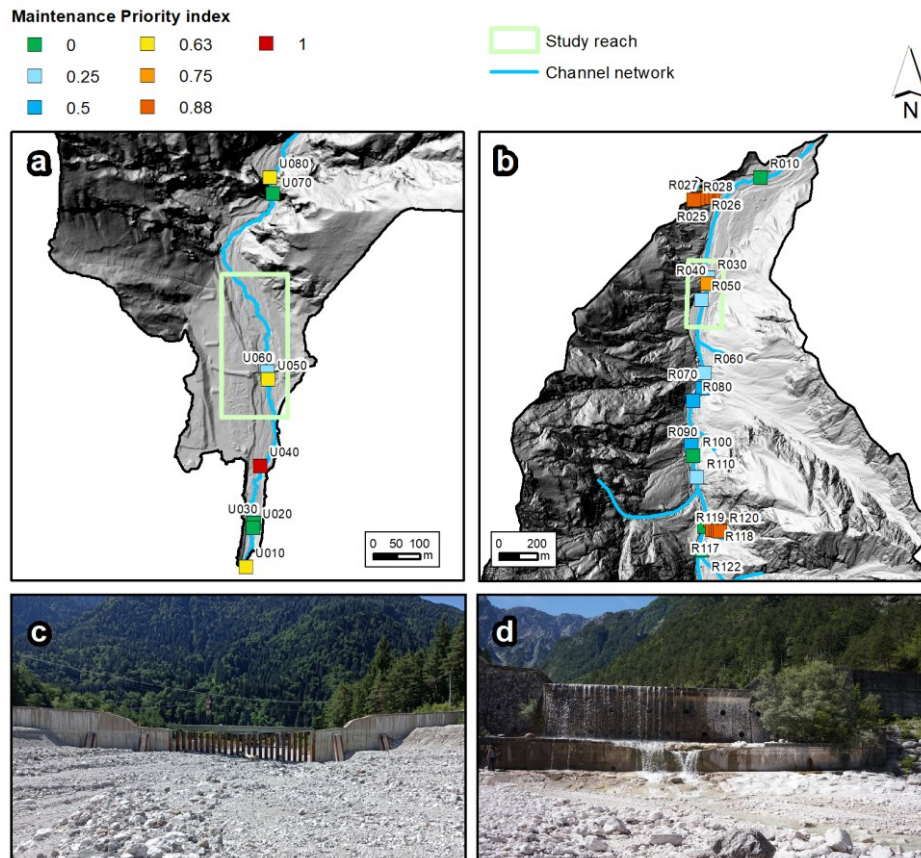
Multi-temporal DTMs at 1 m resolution, derived from Airborne Laser Scanning (ALS) surveys acquired at different epochs (i.e., 2008-2009 and 2018-2019), which allowed the analysis between sediment dynamics and torrent control structures. Old “legacy” DTMs and recent surveys have a different metric quality that often leads to comparison problems [8] therefore the data sets were transformed in the same reference system (RDN2008/UTM-33 N) and co-registered. The multi-temporal DTMs were used to realize a DoD of the channel network for each studied catchment through an analysis of uncertainties and error propagation [9], to discriminate the actual changes in surface elevation from noise. Therefore, using Geomorphic Change Detection (GCD; [9]), the multi-temporal DTMs were compared to obtain thresholded DoD and erosion and deposition volumes for interesting areas close to the torrent control structures.

## 4 Results and discussion

An updated inventory of torrent control structures with the relative  $MPi$  for the two studied catchments was obtained with field surveys (Fig. 2a and 2b). In the Uccelli torrent: 3 check dams, 2 open check dams and 3 bed sills were found in the downstream part of the catchments (Fig. 2a) and were mainly built to regulate solid discharge and to prevent erosion (75%). It is useful to point out that in the Uccelli catchment, 37% of the structures were both operative and in good condition (i.e., green-rank), but the same number of structures were also damaged (i.e., orange-rank). In the Resartico torrent 27 structures were found: 9 check dams along the main channel and 18 bed sills on slopes to consolidate the sediment source (Fig. 2b). The check dams were mainly built to stabilize the channel (56%), retain sediment (33%) and one structure to regulate solid discharge. The check dams were mostly in a good state (78%) and had medium to high functionality, while some bed sills showed signs of damage (39%), and others were in good condition (44%) with average functionality (61%). In the Resartico catchment, the green-ranked structures of  $MPi$  were the majority (41%), but 3 bed sills along slopes needed urgent interventions and other torrent control works have a certain priority (33%, i.e., 0.75 of  $MPi$ ) of maintenance. All these updated data provide a simple snapshot of the state of the torrent control structures and permit to identify the most prone to hazards catchments, helping decision-makers to obtain relevant indications on where to primarily invest resources. Although the proposed  $MPi$  is simpler compared to the few found in the literature [10], it requires less in-depth field surveys and could serve as a guideline and a starting point for further analysis. Therefore, the  $MPi$  wants to be a quick solution for technicians who carry out constant field monitoring of torrent control structures on numerous basins and want to continuously update the database with operations that are cost-effective, sustainable and not time-consuming.

Relevant examples of the  $MPi$  values were found within each catchment's study reach. In the Uccelli basin, the check dam U060 (Fig. 2c) presents a blue-ranked ( $MPi = 0.25$ ), because it shows good status, but a reduced functionality was observed, as the sediment is clogging almost 50% of the filters, impeding correct sediment sorting and retention during intense floods. In the Resartico reach, the check dam R050 (Fig. 2d;  $MPi = 0.75$ ) showed a reduction of its stabilization channel function because upstream of the structure there was a severe bank erosion on the right-hand side, confirmed by field surveys. Moreover, the sediment outflanked the check dam on the left wing and the structure was damaged due to the local scouring downstream on the counter check dam.

The DoDs analysis (Fig. 3a and 3b) realized for the reaches equipped with structures U060 and R050 (i.e., light green frames in Fig. 2a and b) in the Uccelli and Resartico basins, respectively, report an interesting interaction between the structures and sediment dynamics. For example, in the Uccelli reach, after the important flash flood of 29<sup>th</sup> August 2003 (396.2 mm of rain recorded in 24 hours in Pontebba) that caused large and deep erosion upstream of the check dam U060 [6], the 2018-2009 DoD reports mainly deposition upstream the same structure (Table 3).



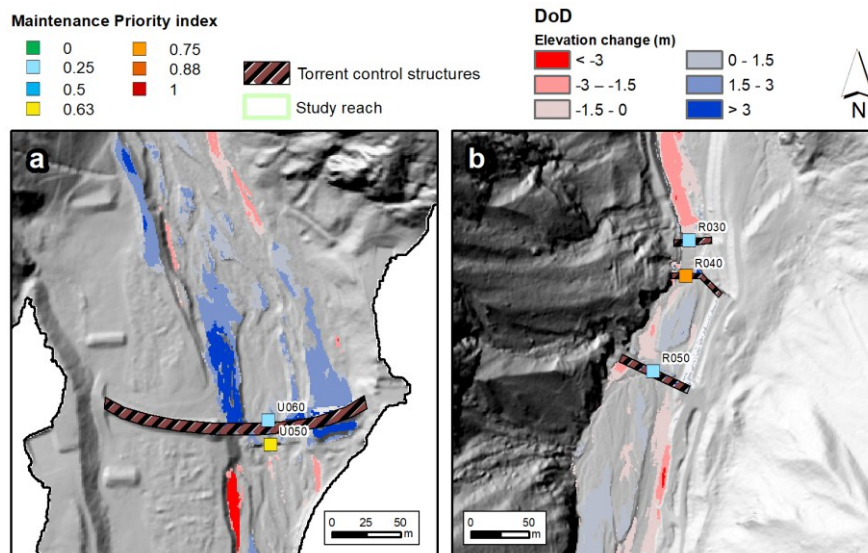
**Fig. 2:** Torrent control structures with (*MPi*) in the Uccelli (a), and Resartico (b) basins. (c) Open check dam U060 in the Uccelli Torrent with 0.25 of the *MPi* (blue-rank). (d) Check dam R050 in the Resartico Torrent with 0.75 of the *MPi* (orange-rank).

**Table 3:** Erosion and deposition process, and net volume change estimations from the different DoDs in the Uccelli reach (Fig. 3a).

Study reach	Downstream check dams n. U060	Upstream check dams n. U060
<b>DoD</b>	<b>2018-2009</b>	<b>2018-2009</b>
<b>Erosion (m<sup>3</sup>)</b>	2746 ± 763	2371 ± 826
<b>Deposition (m<sup>3</sup>)</b>	2578 ± 692	14980 ± 4136
<b>Net Volume difference (m<sup>3</sup>)</b>	-168 ± 1030	12609 ± 4218

This case study is an example of how the data obtained by the DoDs and the *MPi* could be useful in directing the maintenance plans of the open check dam U060, which has lost its filtering capacity due to the huge deposit of material upstream. The structure U060 recently built, underlined the importance of maintenance but also the planning and design of the filter openings in terms of optimal size. As underlined by

[1] and [11] it is important to include maintenance operations as well as the impact of progressive deterioration of existing infrastructures in cost-benefit ratios and risk analyses of managed torrents. The analysis of sediment dynamics using DoDs perfectly reflects the problems found during field surveys close to the check dam R050, showing erosive processes both in the right bank upstream of the structure and downstream (Fig. 3b). These data highlighted how DoDs and *MPi* index could provide useful starting information, for example, for numerical values for risk prediction models. Indeed, the systematic collection of data about the ongoing scouring process downstream check dams is fundamental to monitor seepage filtration phenomena and to develop broader and more effective forecasting models [12]. Moreover, the information obtained from the DoDs can corroborate and enrich the observations made during field surveys, constantly monitoring the undesirable effects of the torrent control structures (e.g., downstream scouring, ill-positioned dams increasing bank erosion, etc.), that could be corrected in further maintenance operations.



**Fig. 3:** Multi-temporal geomorphic changes for the study reach under investigation (Fig. 2) obtained from DoDs (2018-2009): (a) Uccelli and (b) Resartico catchment.

## 5 Conclusions

The Maintenance Priority index of torrent control structures has proven to be very useful in supporting watershed management by facilitating the post-evaluation of interventions effectiveness over time and directing maintenance efforts. Moreover, when coupled the *MPi* with multi-temporal data on the evolution of sediment morphology dynamics (i.e., multi-temporal DoDs), it provides helpful insights for consistently identifying areas most prone to hazards and offers guidance on where decision-makers could best allocate resources.

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