

# Design of two retention basins along the torrent Liera on the Gares Valley (Dolomites, North East Italy) after the storm Vaia

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**Abstract.** A storm called “Vaia” affected the North East Italy and South West of Austria at the end of October 2018. On the Gares Valley (Canale d’Agordo, North East Italian Alps), the abundant runoff triggered several in-channel debris flows that transported hundreds of thousands of cubic meters of sediments on the valley bottom. Some control works for retaining the sediment volume have then been built in the most threatened sites. Herein we show the design of two retention basins that should protect both the Liera torrent and the main road parallel to it. We computed the debris-flow volume to be retained both using an empirical law and simulated solid-liquid hydrographs corresponding to a return period of 300 years. The estimate of the debris-flow volume in the empirical law depends on the basin area upstream of the deposition zone, whereas, in the solid-liquid hydrographs, it depends on the area of the basin closed at the initiation area, as well as on the design rainfall.

## 1 Introduction

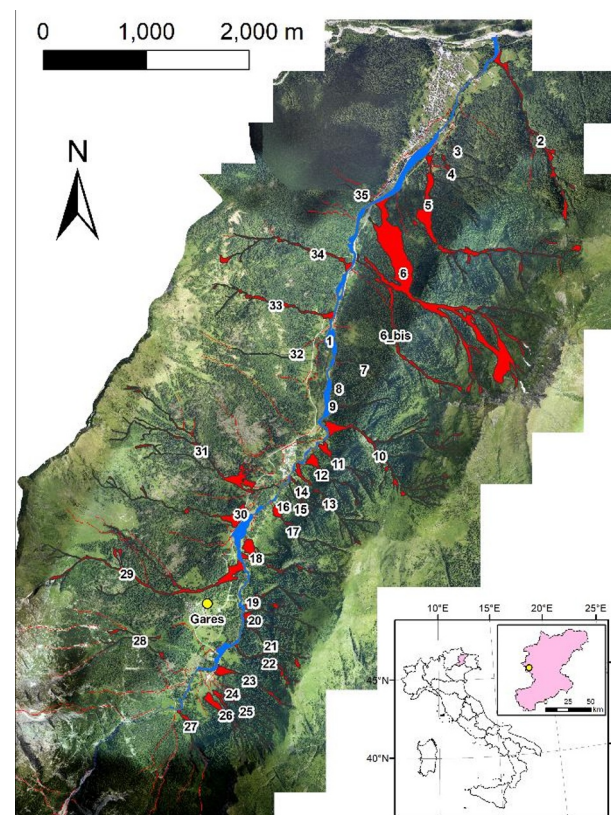
The “Vaia” storm strongly hit the Gares Valley on the Dolomites (North East Italian Alps) at the end of October 2018 [1]. The Gares Valley is a straight and narrow valley in the direction south to north, on which the torrent Liera runs (Figure 1). The slopes flanking the valley are very steep and incised by about 40 channels. During “Vaia”, 33 of them were affected by in-channel debris flows with a total mobilized sediment volume of about 700,000 m<sup>3</sup>. The rain gauge of Gares (Figure 1) recorded two distinct events: a rainfall lasted one day and a half with an average intensity of about 5 mm/h (184 mm), followed by a rainfall long half a day with an average intensity of 11 mm/h (167 mm). The second rainfall event occurred on a saturated terrain and provided the abundant runoff that triggered the 33 debris flows. Most of the channels routed by debris flows ends in uninhabited areas far from the main road of the valley, except for two (channels 33 and 34 of Figure 1) For this reason, two retention basins are designed at the end of the two channels, to protect the main road from debris-flow hazard.

## 2 Material and methods

### 2.1 The site

Channels 33 and 34, located on the left flank of the Gares Valley, are straight (Figures 1 and 2) with an

average slope of 42 and 37% respectively, while the slope of reach of the Liera torrent between them is 4%.



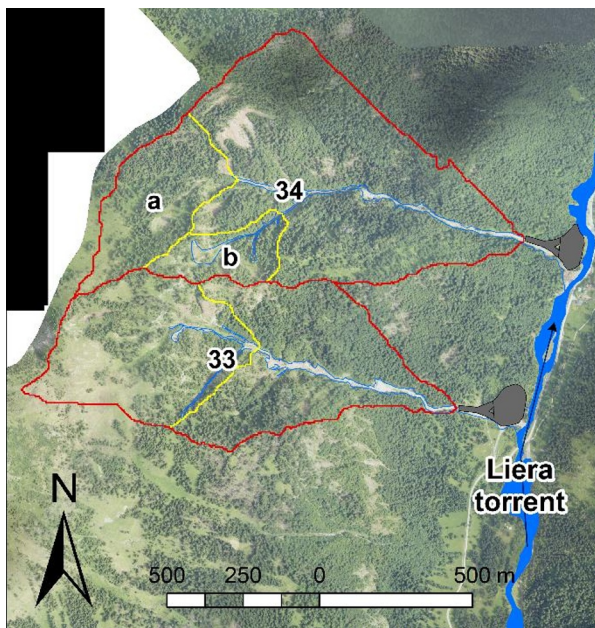
**Fig. 1.** The Gares Valley with channels 2-34 routed by debris flows including the affected areas (red) and the Liera torrent (blue). The yellow circle is the Gares weather station.

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The drainage areas of the triggering zones of channels 33 and 34 are 0.25 and 0.2 km<sup>2</sup> respectively. Figure 3 shows the “Vaia”-related erosion-deposition pattern on the two channels, whereas in Table 1 the sediment volumes mobilized along them during the storm are resumed.

**Table 1.** Solid-liquid peak discharges ( $Q_P$ ) with sediment ( $V_{SED}$ ) and debris-flow volumes ( $V_{DF}$ ) for different events and methods on channels 33 and 34.

Event/Method	$Q_P$ (m <sup>3</sup> /s)	$V_{SED}, V_{DF}$ (m <sup>3</sup> )
<b>Channel 33</b>		
Vaia ( $V_{SED}$ )	-	17360
Equation (1)	-	25300-31100
Equation (4) simulation with maximum peak discharge	11.4	42600
Equation (4) simulation with maximum volume	4.33	47100
<b>Channel 34</b>		
Vaia ( $V_{SED}$ )		15740
Equation (1)		34300-41100
Equation (4) simulation with maximum peak discharge	7.2	23600
Equation (4) simulation with maximum volume	3.95	40050



**Fig. 2.** The two channels 33 and 34 with the drainage areas corresponding to the triggering areas (yellow line) and to the beginning of the deposition zones (red lines). Superimposed the two retention basins.

## 2.2 The design volume of the two retention basins: methods

The design volume for the two retention basins is the debris-flow volume,  $V_{DF}$ . The value of  $V_{DF}$  is searched using two approaches. The former is the relationship of [2] between  $V_{DF}$  and  $A_B$ , the drainage area of the basin at the apex of the fan:

$$V_{DF} = \alpha A_B^\beta \quad (1)$$

where  $\alpha$  and  $\beta$  are two numerical constants that depend on the percentile. [2] examined 809 values of sediment volumes of in-channel debris flows that occurred in the period 1950-2015 in Northeast Italy, and provided a probability distribution. The values of  $\alpha$  and  $\beta$  depend on the chosen percentile of that probability distribution. In the present case, as suggested by the Northeast Italian Alps River Authority [3], it is assumed the 98<sup>th</sup> percentile for which  $\alpha = 52000 \pm 4000$  and  $\beta = 0.94 \pm 0.04$  (4000 and 0.04 are the factors corresponding to the uncertainty estimated using the errors on the measured value of debris-flow volumes and basin areas). The latter approach computes the debris-flow volume according to [4]: the solid-liquid volume, i.e., the debris-flow volume, is the sum of the runoff volume contributing to debris flow,  $V_R$ , with the sediment volume,  $V_{SED}$ , that includes also the water saturating the sediments:

$$V_{DF} = V_R + V_{SED} \quad (2)$$

The runoff volume contributing to debris flow,  $V_R$ , is the runoff volume corresponding to the hydrograph without the parts with a discharge lower than the critical value for debris-flow occurrence,  $Q_{CRIT}$ . The runoff hydrograph is computed by hydrological modelling where the debris-flow surge forms, i.e., in the triggering area. The sediments volume,  $V_{SED}$ , is equal to the solid volume,  $V_{SOLID}$ , divided by the solid volumetric concentration of the dry bed,  $c^*$ :

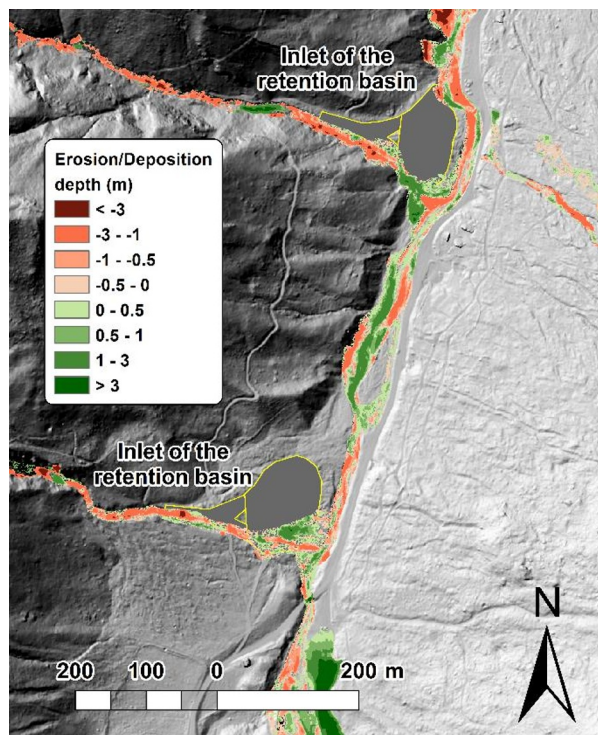
$$V_{SED} = V_{SOLID} / c^* \quad (3)$$

Substituting the second member of equation (3) into equation (2) and posing  $V_{SOLID} = cV_{DF}$  (with  $c$ , solid concentration of the debris flow), yields:

$$V_{DF} = V_R / (1 - c/c^*) \quad (4)$$

Two simulated runoff hydrographs are considered: (a) the first one with the maximum value of the peak liquid discharge because it provides the greater peak for the solid-liquid discharge; (b) the second one with the maximum value of the runoff volume contributing to debris flow, because it provides the maximum solid-liquid volume. The former is obtained by searching the rainfall duration that provides the maximum value of peak runoff discharge using the alternate block method for building the hyetograph [5]. The latter is obtained after computing the simulated runoff volume that contributes to debris flow for increasing rainfall duration and using a constant intensity hyetograph. The

duration of the latter rainfall is much longer than that of the former one.



**Fig. 3.** The deposition-erosion pattern of debris flows occurred on channels 33 and 34 during Vaia storm with superimposed the two retention basins.

### 3 Evaluation of the design volumes

The values of  $A_B$  corresponding to the channels 33 and 34 are 0.52 and 0.71 km<sup>2</sup> respectively. The basins are closed just upstream of the planned works, where the slope of the channels sharply changes from over 25° to less than 15°. In this case the apex of the fan is not recognizable because the stepness of the two channels. In Table 1, it is shown the range of the values of the debris-flow volume computed by means of equation (1) considering the uncertainties. The second method requires the computation of the design rainfall and of the runoff hydrograph, before estimating the solid-liquid volume. The design rainfall for the simulation of the runoff hydrograph is obtained using the depth-duration frequency curve corresponding to a 300-year return period. The curve has been obtained by applying the Peak Over Threshold technique (POT) to the rainfall-event depths recorded by the rain gauge station of Gares in the period 1985-2019 [6]. The rainfall events were determined using the criterion suggested by [7]. The simulations of the runoff hydrograph were carried out by using the model of [8], with the values of the parameters suggested by [9] that allow the best matching between the observed and simulated runoff hydrographs. The runoff volume contributing to debris flow is computed using the value 0.3 m<sup>3</sup>/s as the critical discharge for debris-flow occurrence,  $Q_{CRIT}$ , according to [4]. Using this value in equation (4), it provides the value of debris-flow volume. The parameter  $c$  in the case

of the hydrograph corresponding to the maximum peak discharge is assumed equal to 0.5, the largest experimental value [8,10]. In the case of the simulation with the maximum volume, data about  $c$  are missing. Therefore, it is assumed equal to the values estimated for the storm “Vaia” that had a long duration: 0.30 and 0.42 for the channels 33 and 34 respectively. These values are estimated by dividing the solid volume, i.e. the product of the sediment volume and  $c^*$ , by the sum of the sediment volume and the runoff contributing volume. The value  $c^* = 0.65$  is the average value of four samples of debris deposits. Results are shown in Table 1.

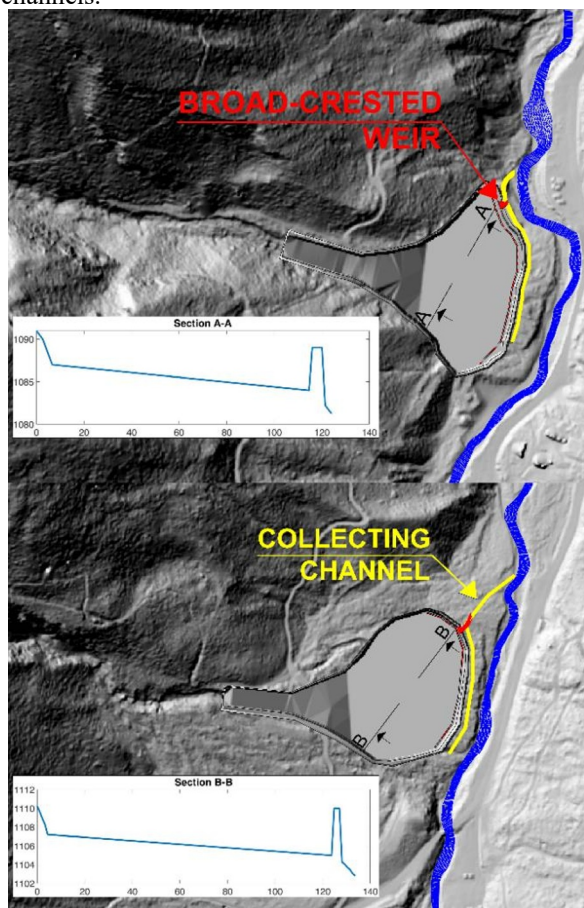
In the case of channel 33, equation (4) provides the largest value of debris-flow volume for the case of the rainfall providing the maximum value of  $V_R$ . In the case of channel 34, equation (1), considering the associated uncertainty, provides the largest value of debris-flow volume. This value is just a bit larger than that provided by equation (4) for the case of the rainfall providing the maximum value of  $V_R$ .

The two approaches for the estimation of the debris-flow volume provide results that seem in contrast. This is explained by considering the quantities involved. The former depends on the basin area upstream of the deposition zone, whereas the latter on the area of the triggering zone. In the present case, the triggering area corresponding to channel 33 is larger than that of channel 34. Vice versa, the basin area of channel 33 is smaller than that of channel 34. This explains the larger value of the debris-flow volume for channel 34 in the first approach and the larger value of the debris-flow volume for channel 33 following the second approach. As a confirmation of the role of the triggering area, Table 1 shows that the entrained sediment volume during the event Vaia on channel 33 is larger than that on channel 34.

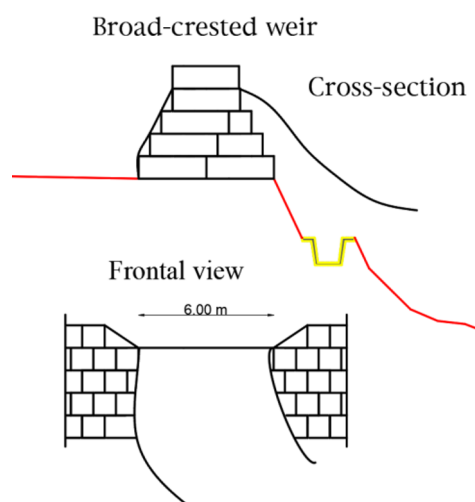
### 4 The two retention basins

The two basins intercept the channels upstream of their confluence with the Liera torrent at the valley bottom. Both are left-oriented where the terrain has a gentler slope and is occupied by a forest stand (Figure 4). The areas of the two basins are 11500 and 9000 m<sup>2</sup> respectively, with an elevation of the retaining wall of 5 m higher respect to that of the basin bottom. The elevations of the level of full filling of the basins are 4.1 and 4.4 m higher respect to that of the bottom respectively. This allows a freeboard of 0.9 and 0.6 m respectively. With the aim of considering the residual risk [11], i.e., the occurrence of a debris flow with the basin already filled by a previous event, a broad-crested weir is built on the left side of each basin, 4 m higher than the bottom level (Figure 5). Both the broad-crested weirs are 6 m long with a maximum hydraulic load of 1 m. The opening and depth of weirs allow the flow of the solid-liquid peak discharges of Table 1. In both cases, the material flowing over the broad-crested weir is collected by a canal running between the retaining wall and the Liera torrent. The two weirs are located on the left side of the basins because the flow in the basins is

left-oriented: the bottom of the basins has a slope in the same sense of the torrent of about 2.5%. However, the spreading of a debris flow on the retention basin could be not uniform because of preferential paths due to the stopping of big boulders. The preferential paths could address the flow far from the weir and the retaining wall could be overflowed. This possibility leads to the upstream elongation of the collecting channels between the walls and the torrent. Moreover, just upstream of the retaining wall, some grids will be arranged to permit the drainage of the debris-flow liquid phase to the collecting channels.



**Fig. 4.** Location of broad-crested weirs and of the collecting channels for the designed retention basins.



**Fig. 5.** Typical cross-section and frontal view of a broad-crested weir.

## 5 Conclusions

The design of two retention basins protecting the main road of the Gares Valley in North East Italy is based on the estimation of the debris-flow volume. This value is computed following two approaches. The former is an empirical law based on a probability distribution obtained thorough 809 observations of deposited sediment volume. The latter is the direct determination of the debris-flow solid-liquid volume corresponding to a 300 years return period rainfall, through the runoff volume contributing to debris flow obtained by hydrological simulations and a reference sediment concentration. Two design rainfalls are considered: those providing the maximum value of the solid-liquid peak discharge and of the runoff volume respectively. In the case of channel 33, the second design rainfall provides the largest value of the debris-flow volume. In the case of channel 34, the second design rainfall provides a value of the debris-flow volume just a bit smaller than that computed through the former approach. After considering the residual risk of a debris-flow event just after the one filling the basin, a broad-crested weir is positioned normal to the main flow direction in the basin. Below the weir, it is located a collector channel joining the main creek downstream of the basin.

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## References

1. L. Giovannini, S. Davolio, M. Zaramella, D. Zardi, M. Borga, *Atmospheric Research*, **253** (2021)
2. L. Marchi, M.T. Brunetti, M. Cavalli, S. Crema, *Earth Surf. Process. Landf.*, **44** (2019)
3. Northeast Italian Alps River Authority – Technical Report of PGRA (2021)
4. C. Gregoretti, L.M. Stancanelli, M. Bernard, M. Boreggio, M. Degetto, S. Lanzoni *Journal of Hydrology*, **568** (2019)
5. M. Bernard, M. Boreggio, M., Degetto, C. Gregoretti, *Science Total Environ.* **688**, (2019)
6. J. Pickands. *The Annals of Statistics*, **3(1)** (1975)
7. J.A. Coe, D.A. Kinner, J.W. Godt, *Geomorphology*, **96** (2008)
8. C. Gregoretti, M. Degetto, M. Bernard, G. Crucil, A. Pimazzoni, S. De Vido, M. Berti, A. Simoni, S. Lanzoni *Water Resour. Res.*, **52(10)** (2016)
9. M. Bernard, C. Gregoretti, *Water Resour. Res.*, **57(3)** (2021)
10. T. Takahashi, *Debris Flow*. Taylor and Francis (2007)
11. S. Hartmann, L. Pedoth, C. Dalla Torre, S. Schneiderbauer, *Int. J. Disaster Risk Sci.*, (2021)