1.1 GEOGRAPHICAL DESCRIPTION

Cervo Valley is located Biella province, a region in the north-west of Italy. It has an extension of about 100 km^2.

The valley is delimited on three sides by the mountain ranges that define the watershed of the Cervo stream catchment. To the north it borders with the Valle del Lys, to the east with the Val Sessera and to the west with the Valsesia. Then, heading south, the Valley continue till the confluence of the Oropa Stream, close to Biella.

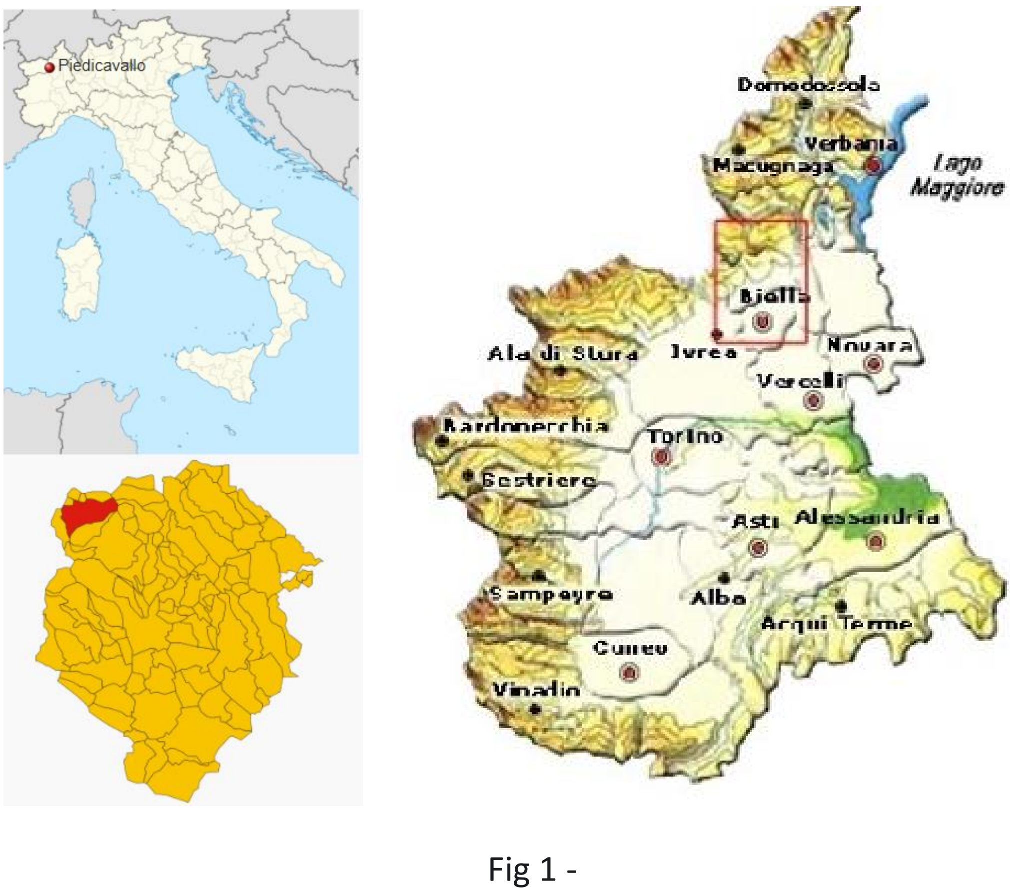


Fig 1 -

1.2 GEOLOGICAL DESCRIPTION

The Cervo Valley is characterized by the presence of typical intrusive volcanic rocks.

Syenite is the main intrusive rock, but monzonites and granites are present as well. All these rocks compose the Cervo Valley' Pluto, which is a body of igneous rocks that was formed 30 million years ago, during the Oligocene.

During the Oligocene, a strong magmatic activity took place all around this area. In fact, the collision between Europe and Africa led to the creation of the Alpine chain. Since it is free from metamorphism, the Cervo Valley's Pluto is subsequent to the main structuring phase which built up the Alpine chain, which mean that it was crated at the end of the Oligocene.

The Pluto has a characteristic sub-concentric ring structure, created by subsequent intrusions. It is present a granite core with a median band of syenite and an outer ring of monzonite. The contact area between the Pluto and the outer metamorphic rocks is well defined due to a marked difference in temperature between crystallizing magma and encasing rock. That means the intrusion occurred at relatively shallow depths (4-7 km from the surface). As aforementioned, the Cervo Valley's Pluto is intruded in rocks of metamorphic origin. Metamorphic rocks are rocks that have undergone to a transformation with respect to the original conditions due to the different conditions of pressure and temperature to which they have been subjected in depth before emerging to the surface due to erosion and tectonic forces. In the Cervo Valley it is possible to find gneiss and mica schists.

Moreover, volcanic and metamorphic rocks are often covered by eluvial debris, sometimes even of high thickness. These deposits derive from the erosion of the rocks that make up the substrate of the whole valley.

(((carta geologica)))

Fig 2-

1.3 GEOMORPHOLOGICAL DESCRIPTION

The area around Biella close to the mountain is characterized by small and medium-sized hydrographic basins. These basins are cyclically affected by flood events, which occur whenever rainfall intensity overcomes typical thresholds. The most critical flood events are related to storm cells that affect mainly a single catchment and then tend to have lower intensity in the surrounding ones. Since the concentration of urbanized areas is high for an alpine region, the risk for human activity and people safety is always high. Moreover, due to the conformation of the area, urban and industrial centers are often located near streams and riverbeds. That entails a higher probability of damage to the infrastructure.

The Cervo valley has a partially glacial and fluvial origin. In fact, in the upper valley region it is possible to recognize small glacial origin basins which constitute secondary hanging valleys， alternating with more engraved sections that, instead, have been dug by the action of stream-water.

The Cervo stream itself originates from a glacial lake and then wedges itself into an alternation of segments carved into the rock and segments in large valley sections dug by the action of glaciers. For instance, between Rosazza and San Paolo Cervo the morphology of the valley varies, leaving most of the space at the bottom of the valley and then shrinks again. This is due to the lithological differentiation characteristic of this area: in correspondence with the widening of the valley the granites, which are alterable and easily crumbled rocks, emerge. Granites are then followed by syenites, more compact rocks, that give rise to overhangs and steep walls.

In conclusion, Cervo Valley can be morphologically divided into two macro-areas: Alta Val Cervo and Bassa Val Cervo. The upper side of the valley is the area enclosed within the mountains that define the watershed. These mountains have a homogeneous height of about 2000m and Punta del Bo is the highest peak (2556m). Here the Cervo stream is mainly dug into the rock, therefore, the valley results narrow and engraved by numerous side valleys up to the Bogna Gorge, where the Bassa Val Cervo begins. Instead, here the valley is characterized by wide spaces and here the Cervo stream flows in coarse alluvial deposits.

Fig 3 –

Fig 4

1.4 General picture of instability processes and induced effects

The Cervo Valley, such as many others Alpine valleys, is subjected to a series of soil movements that tend to be activated during important meteorological events, when the soil becomes saturated.

The most common landslide phenomena of this area are:

- collapses and overturning landslides (approximately 54%). This kind of landslide occurs due to detachment of rock masses from face rock-walls. Its movement is extremely rapid and the mass that falls down is usually composed by medium/big blocks;
- shallow landslides (approximately 39%). This kind of landslide is caused by saturation and subsequent partial (shallow landslide) or total (mudflow) fluidification of the soils exposed to precipitations. Shallow landslides are rapid and characterized by medium/important soil mobilization.

In the valley there are also other kind of landslides, such as rotational sliding and big complex landslides, but they are present in a smaller percentage and do not affect consistently the instability process consequences in the valley (Fig).

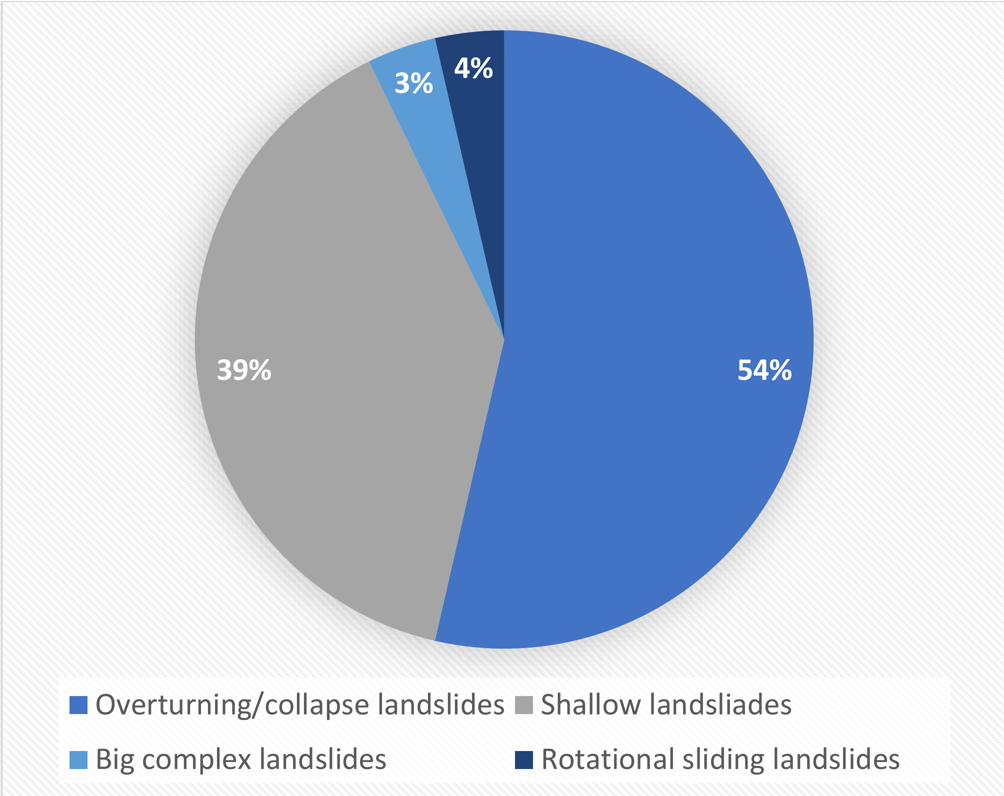


Fig 5 –

This gravitational phenomena's type picture reflects the lithological differentiation of the valley. In fact, in presence of compact rocks, such as gneiss at the head of the valley or syenite in the middle valley, landslides mainly occur due to collapse and or overturning; while shallow landslides occur wherever soil deposits, generated by mica schists and granites (rocks more easily alterable by meteoric degradation processes), are present.

Another condition that produces important damages to the environment and to the man-made structures is represented by flood. During flood events, the solid material movement mobilized due to surface instability causes solid transport processes along the entire hydrographic network which is already overloaded due to substantial water supplies. The combination of processes occurring on the slopes and processes along the hydrographic network increases moving downstream, where the subsequent confluence of the secondary watercourses causes always greater water and solid supplies. The damage caused by this phenomena are amplified by the interference between the anthropic works and the natural water flow.

Shallow landslides cause the solid transport in the hydrographic network. In some case such landslides can lead to mudflow or debris flow. They are flow of water that contains large amounts of suspended particles and silt. If the particle dimension is very low, mudflows are generated, while debris flows are produced when rock blocks are interested too. These kind of phenomena are characterised by a higher density and viscosity than a common streamflow and can deposit only the coarsest part of its load; this causes irreversible sediment entrainment (https://www.britannica.com/science/mudflow). These events are very dangerous for structures and people as they are difficult to predict, very fast and possess a great energy that allows them to raze whatever they encounter along their path.

It is possible to identify two different types of shallow landslides in Cervo Valley. A first group is triggered in the alteration layers with a prevalent silty-clay component. They are typical of not very steep slopes. These landslides are usually limited in magnitude and do not cause significant direct damage to structures and infrastructures, but the mobilized material partially saturates the hydrographic network. Therefore, bank erosion, transport and accumulation of debris in the riverbeds occurs.

The other group interest debris layers having larger grain sizes (coarse grains) making up the Syenite rocks Cervo Valley’s Pluto coverings. Such landslides are typical of steep slopes and cause significant direct damage to infrastructure as they have an high energy. In addition to direct damage, this king of phenomena causes solid transport of the hydrographic network too.

(((add picture)))

1.5 Historical flood event description and annual precipitations analysis

For the purpose of this analysis, both the rainfall data recorded by the Piedicavallo, Campiglia Cervo and Biella stations, and the historical data present in the municipal archives (appendix A) have been considered. Therefore, it was possible to reconstruct the evolution of the Cervo Valley flood events starting from 1666, when it is recorded in the Piedicavallo's municipal archives a deposition regarding the damage caused by the flooding of the Sevro stream, a tributary of the Cervo.

It is important to underline the evolution of the available data. In fact, until 1925 only testimonies and descriptions of the main events recorded in the archives of the Cervo Valley's municipalities and Biella are available. This mean we only have news of those events that caused damage to the population, while we have no trace of all those events that, although exceptional, did not cause problems. Since 1925 the data relating to the rainfall regime of the Cervo stream are available. In fact, 3 rain gauge stations, located in Piedicavallo, Campiglia Cervo and Biella, were built. Therefore, more accurate rainfall distribution assessments can be done.

Finally, for June 2002 and October 2020 flood events, a relevant amount of data is available since technologies for the data harvesting increasingly improved in tha last 3 decades and a digital data storage system is now present.

Analyzing the annual Cervo Valley rainfall distribution, it is possible to identify a bimodal trend with two maximums, in spring and in autumn, and two minimums, in winter and in summer. May turns out to be the rainier month, followed by November and October, but high rainfall values are also present in September (Fig.). This trend is typical of Alpine areas.

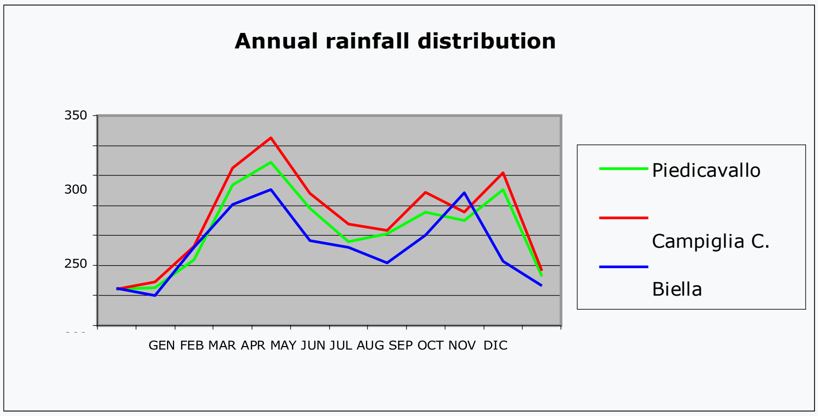


Fig –

Comparing the monthly rainfall trend recorded at different rain gauges with the monthly distribution of damage in the period 1666-2000, a close correspondence in the maximum and minimum values of the graphs can be identified.

In October and November, high precipitation values lead to an important number of damages. That is due to the fact the autumn meteoric events affect large areas, causing extraordinary floods of the main waterways. In fact, all the catchment is subjected to the rainfall, therefore, the whole hydraulic network tend to be saturated. In May, despite the average amount of rain is greater than in the other months of the year, there is a lower correspondence between the amount of rainfall and the number of damages, probably because the rainfall is more widespread in time but it has a limited intensity. In summer, the meteoric events have high intensity and are localized on small areas. These phenomena can trigger extremely violent instability processes in secondary basins that cause huge damages in limited portion of the catchment.

As previously suggested, on the basis of historical archived data it is possible to reconstruct the evolution of exceptional flood events that caused damages to the infrastructures. It is important to point out how many of these events have affected just localized areas of the basin, affecting repetitively especially some minor basins: Pragnetta, Mologna, Chiobbia and Piaro.

A table showing the principal flood events since 1666 is reported below (Tab):

DATE	DAMAGE
26th September 1666	Cervo stream destroyed twenty houses and removed land and things. No victims.
27th September 1827	Only the upper part of the basin was hit, causing victims and damaging some houses in Piedicavallo and Rosazza
June 1840	Rio Piaro caused the flooding of the town of Campiglia and damaged the river embankment and a bridge
October 1910	roads and hydraulic works in the upper side of the Cervo Valley have been flooded
30th May 1923	Cervo stream eroded the foundations of some houses, caused the partial collapse of the Piedicavallo’s bridge and partly removed the provincial road.
28th October 1928	Relevant rainfall event with 250mm/24h
29th November 1930	Relevant rainfall event with 290mm/24h
14th-17th May 1927	Cumulated rainfall heights of 845mm in just 4 days were recorded in the Biella station, the highest value ever recorded
November 1951	Significant rainfall, but lack of information regarding damages to structures
November 1968	In the basins of Valle Strona, Valle Mosso and Val Sessera, the most catastrophic event of the twentieth century took place. Cervo Valley have been badly affected too
October 1977	Flooded houses in Piedicavallo, Montesinaro, Rosazza. Landslides has damaged the provincial road to San Paolo Cervo
October 1979	The flood arrived till Biella, where industrial sites were flooded and part of river embankments were destroyed.

21st – 22nd September 1881	The upper basin of the Cervo stream and the Chiobbia stream were mainly affected. Piedicavallo station recorded a precipitation height of 250 mm in 16 hours
November 1994	Relevant rainfall event
4th – 6th June 2002	Damages along all the valley. Some bridges were demolished, and the main valley road was flooded and covered by landslides in multiple points. Different houses and industrial areas were flooded. River embankments were seriously damaged all along the river
15th October 2020	Damages in all the valley: river embankments, bridges, roads, houses were hit. San Giovanni D'Andorno monastery was hit by a landslide.

Tab 1 – Historical flood events

Two points need to be highlighted. First of all, in addition to the damages reported by man-made structures, environmental damages must be taken into account as well. In fact, the saturation of the soil frequently leads to landslides, whose consequences represent a predisposing factor for future flood events.

Furthermore, as pictured in table 1, it seems that up to 1900 there was a lower frequency of flood events. This is essentially due to the data availability. In fact, starting from the first twenty years of the '900, rainfall measurements have been added to the simple historical data. That allows to identify more events that overcome some defined thresholds. Surely climate changes of the last decades has influenced the frequency and the magnitudo of these events, but this factor do not deal with the lack of information available until 1900.

In conclusion, it is possible to state that Cervo Valley is repeatedly hit by flood events having a return period of 8-9 years and about every 25 years one of these events have a significant higher impact.

2. BEST PRACTICES ON FLOOD PREVENTION, PROTECTION AND MITIGATION.

Until the first decade of the 21^{st}q century, the common approach to prevent flood damage consisted of trying to avoid any flood event by creating structures that can protect human activities from flood consequences. This strategy cannot be always successful. In fact, flood protection is never absolute since nature is unpredictable and a residual risk must be always taken into considerations (bestpractice pg4). It is not possible to design a defence structure that can protect from every flood event, since it is not possible to define an absolute maximum threshold for precipitation height.

This approach to natural hazard requires a change of paradigm.

Nowadays, the focus is no longer just on defensive actions, but it moved on the management of global conditions that affect a flood. Floods are climatological phenomena influenced by the geology, geo-morphology, relief, soil, and vegetation conditions (bestpractice pg4). In that sense, it is of vital importance not to consider just protection, but also prevention and mitigation.

Protection includes all the set of actions that play a role to avoid direct damage during the flood event. Usually they are structural measures that limit the natural water flow in order to defend human activities. They could be, for instance, riverbanks or dams. (more specifications about this argument will be given in chapter 111111).

On the other hand, non-structural measures are divided into prevention and mitigation. Mitigation is represented by all the activity that can be implemented during the flood event in order reduce the damage probability. Basically, it is the plan of action that the authorities have to follow during a flood event. Mitigation starts with a proper and on time weather forecasting that lead to a reliable alert to the local population.

Prevention consists of all the measures that can help to limit the flood magnitudo. The measures can be both structural and non-structural. For instance, they could involve a proper maintenance of the drainage and hydraulic.

The new strategy for flood management is mainly based on non-structural measures since they tend to be potentially more efficient and long term far more sustainable (bestpractice). Risk analysis is at the base of the modern approach. The risk is estimated as the product of damage probability and amount of possible damage (source). Therefore, the higher is one of the two factors, the higher is the flood risk. In that sense it is important to reduce not just the damage probability by creating defence structures, but also reduce the human vulnerability by limiting the interaction between human activities and water flow.

In the past being close to a water source as a river was fundamental for the economy of a small to medium community. It brought more advantages than disadvantages since it was not easy to transport water away from its natural course (source). But nowadays that advantages do not justify anymore damages caused by floods. Where possible, it is more convenient to move away human construction and activities from flood plain and restore the rivers natural flow. That allows to reactivate wetlands and areas where the rivers do not always flow, but effectively belong to it. This new approach gives more importance to prevention and mitigation rather than protection.

Climate changes have highlighted the need of a different plan. As precipitations become less spread in time and more intense, it is no longer enough just to rely on structural defences. Try to act on what it is possible to be directly controlled, such as prevention and mitigation, is more efficient than just trust on defensive structures that can undergo to failure with a more dangerous event than the one they have been designed for.

Due to the increment of flood damage recorded all around the European states since the nineties, the European Union (EU) has decided to create common directive in order to reduce the economic and social flood issues. In the 2000, the meeting of the Water Directors of the European Union agreed to consider the prevention, protection and mitigation of flood events as a core problem that need to be solved similarly in the whole EU. Moreover, the importance of comparison and exchange of knowledge between all the EU States has been recognized as a core point to improve flood management.

In the 2000, United Nations and Economic Commission for Europe Guidelines (UN/ECE) wrote a paper about sustainable flood prediction that have been continuously updated. On the 23rd October 2000 the Water Framework Directive (WFD), a set of suggestions and rules regarding proper actions in the field of water policy, was finally adopted.

2.1 Structural measures

In order to analyse globally the consequences of a relevant precipitation event, it is important to consider both water flow and soil control. The interaction of water and soil during extreme events generates more damages since the impact energy of a mixture of water, mud and rocks is much higher than the only water. Therefore, the following two aspect must be guaranteed:

1. limit water flow energy
2. reduce as much as possible the inclusion of rocks and soil in the hydrographic network

These two goals can be assured both with structural and non-structural measures. Usually, a combination of the two is the best option.

2.2.1 Limit water flow energy

Limit water flow energy is a challenging problem in mountain flood-prone valleys. In this scenario, a drop of water that falls on the watershed covers a high height difference in a limited horizontal distance. That drop of water has an incredible high potential energy at the top ($U = mg\Delta h$, where m = mass (kg), g = 9.81 m/s^2, h= height (m)), since the altitude is high. The potential energy is almost completely converted into kinetic energy during its travel across the valley. Therefore, as kinetic energy is defined as $K = \frac{1}{2}mv^2$ (where m = mass(kg) and v= speed (m/s)), the water velocity is equal to $v = \sqrt{2g\Delta h}$. Water speed is linked to the capability to generate damage to structures and infrastructures and in an alpine region it tend to be very high as the height gradient Δh is high all around the valley (in some cases the partial height gradient can be reduced with appropriate interventions that will be analysed later in this chapter).

Usually this problem is solved creating structures whose aim is to retain, store and drain part of the water. In alpine areas that is not always possible due to limited spaces. Since retain and storing water could be very difficult and even dangerous in narrow valleys, quite the opposite, it is often useful to pass through the water to level ground areas where these operations are easier and more efficient. On the other hand, it is always possible and convenient to act on the draining.

Soil is a good space were to retain water. But, as it will be analysed in more detail later, saturated soil is more inclined to mechanical failure. Failure means soil movement, which likelihood lead to the introduction of solid phase into the hydraulic network. For this reason, in mountain areas it is better to move downward the water and do not retain it. In order to do so, some prevention practices, such as cleaning of the riverbeds and channelling of the surface waters, are very useful.

Instead, store water is possible wherever the valley shape allows to create an artificial basin. By means of dam construction, it is possible to store part of an extreme event water directly in locus. That allows to slow down the effect of a fast flood and to reduce the flow energy. In fact, a basin represents a spot where the water can be initially stored and then realised slowly in time and with a lower energy.

On the other hand, a dam represents a potentially dangerous situation. It can fail or be overtopped due to, for instance, a lateral slope collapse that cause the introduction of a huge amount of soil in the basin. Therefore, in mountain regions, it is better to avoid the construction of big dams, while it is preferable to create smaller ones.

The following structure can be built to limit flow energy (https://www.tulane.edu/~sanelson/eens1110/streams.htm):

- soglia: it is an easy structure that avoid stream cutting. It is composed by a horizontal section, usually built in concrete, that is followed by a drop, at whose feet are inserted big rocks that do not allow water to dig the riverbed.
  This kind of structure allows to have almost flat sections, where the flow energy is low, followed by section where most of the energy is dissipated.

It operates similarly to a common weir (Fig. x).

Fig x – Soglia followed by a common weir

- selective weir (or comb-weir): as for soglia, the purpose of a weir is to limit the energy of the water flow along its path. Moreover, a selective weir has some fixed steal bars on its top. They allow the passage of water, but block every solid element, such as rocks or trunks.

  Selective weir may have different shape and bar separation. All these properties are defined in design stage.

  They are very useful in areas where debris-flows are frequent, but they need to be put back to state of art after every flood event. Moreover, weirs are commonly built in low slope areas, where flow energy is lower, in order to have less impact energy on the bars. It is common practice to cgtuinsert a series of soglia before a weir, in order to normalize the flow.

Fig x – Selective weir before and after a flood event

Fig x – different types of weirs

- dams: Dams can be used to hold water back so that discharge downstream can be regulated at a desired rate. Human constructed dams have spillways that can be opened to reduce the level of water in the reservoir behind the dam. Thus, the water level can be lowered prior to a heavy rain, and more water can be trapped in the reservoir and released later at a controlled discharge.
- Retention pond: it serves a similar purpose to dams. Water can be trapped in a retention pond and then released at a controlled discharge to prevent

flooding downstream. This option, with the same space, store less water than a dam.

2.2.2 Reduction of solid inclusion in the hydrographic network

Reduce as much as possible the amount of solid phase into the water flow during a flood event permit to reduce the impact energy of the water flow and to sedimentation. In fact, sedimentation causes long term problems since it changes the riverbed shape and discharge, but also short-term ones. The solid phase, usually composed by mud, rocks and trunks, can create a natural dam. If it fails when the flood regime is still in act, it severely amplifies the damages since a flood wave is generated.

Landslides are the principal cause of solid materials intrusion in the hydraulic network. Therefore, it is fundamental to prevent their formation.

The stability condition of a slope can be evaluated with numerical methods or with the limit equilibrium limit method (LEM). The main difference between the two possibilities is that LEM assumes the factor of safety as constant along the whole sliding surface, while numerical methods allow to analyse the progressive failure conditions, from the triggering to the final stable or unstable configuration.

LEM method allows to simplify the problem obtaining reliable results. The Factor of Safety, F_S, that is the ratio between the shear strength of the instable soil volume and the acting shear stress along the sliding surface, is the governing stability equation (ADSGE):

$$F_s = \frac{\int \tau_R(\sigma_n)dl}{\int \tau dl}$$

Equation 1

If $F_S \leq 1$, slope failure occurs. Usually, a reliable value for F_S in order to be in a safe condition is ≥ 1.6 (source).

As suggested before, landslides are the main cause of solid materials intrusion in the hydraulic network. In particular, big and complex landslides can create stream blockages that act as natural dams. This is a very dangerous situation because, as the dam fails, a huge amount of water mixed with rocks and mud spills downward. On the other hand, shallow landslides affect directly the water flow.

Big-complex landslide need to be identified and continuously monitored with instruments and technique that will be described in CAP X. Shallow landslide, since they are usually spread all around the valley, need to be limited with prevention and structural measures.

In fact, saturated soil has a lower safety factor than dry one. Using the Mohr-Culomb strength criterion in equation 1, it is possible to verify that, as the pore water pressure u_0 increases, it reduces the soil strength:

$$F = \frac{\tau_r}{\tau_{acting}} = \frac{c' + (\sigma_n - u_0) \cdot tg\varphi'}{\tau_{acting}}$$

Equation 2

Drainage can be used to reduce the amount of water in the soil.

Different methods to drain the water are available. They are divided into large and small diameter, where the diameter is the pipe diameter or the equivalent diameter of the draining structure.

The large diameter drains are wells, trenches and tunnels, while small diameter drains are constituted by a series of sub-horizontal pipes that carry the water out of the slope.

Wells

Wells have great effectiveness but high costs. They are excavated starting from the surface of the slope by means of appropriate machines. Dig issues show up when compact rock masses are intercepted. Therefore, a perfect knowledge of the geo-structural conditions of the rock mass during design phase is required.
It is preferable to choose wells when the following condition are present:

- underground water conditions are not known exactly;
- the soil to be drained is constituted by the alternation of horizons having different permeability characteristics;
- the slope has a low permeability and, consequently, the time necessary for lowering the piezometric level lasts for long;

Wells use the different permeability materials to move the water inside the soil. In fact, a well is composed by a vertical pipe surrounded by gravel. The gravel permeability is much higher than the soil one. That cause the movement of the water in pipe direction. Here the water is collected and usually pumped out in order to keep the slope in proper piezometric conditions.
Pumps work can have a drawback. In fact, during heavy rainfall pumps must be kept constantly running, but in these predicaments electrical faults could take place, vanishing their aim.

Trenches

Trenches are elongated structures, generally of rectangular section, excavated to approximately 5-6 m (maximum 10 m) deep and slightly less than 1 m wide.

They are arranged parallel to the direction of the maximum slope gradient.

Trenches are constructed performing narrow slot cuts. If the depth of the trench is greater than that of the used digging machines, it is possible to make an enlarged section to support the machine. Their construction is not easy on steep slopes.

The bottom of the draining trench is equipped with a concrete channel with a pipe perforated in the upper section. It allows to move water away. All the aligned trenches end up with a perpendicular collector (Fig. x).

Fig x – Example of trenches and collector (ANPA, 2002)

The upper part of the trench must be protected by a layer of compacted clay with a thickness between 50 cm and 1 m and a width equal to that of the trench. This layer prevents the direct infiltration of surface water and the transport of fine material inside it. It is preferable to use a type of clay with medium-low plasticity, less subject to shrinkage phenomena.

As for wells, draining trenches perform their draining function through the filling material, consisting of coarse-grained soil, such as pebbles and gravel.
The great difference in permeability between the on-site and the filling soil, as well as the easiness with which the drained water is removed by gravity (unlike wells), implies that the pressure inside the trench is atmospheric. For these reasons, the construction of a drainage trench system allows the immediate reduction of the piezometric level in the stratum, with a consequent reduction of pore water pressures and, therefore, an increase in friction resistance.
Trenches must be excavated from the lowest part of the slope to be stabilized. In this way:

- it is possible to remove the drained water without further intervention on the slope;
- its draining function is carried out from the beginning, even during the phase of construction.

Drainage tunnels

Tunnels are extremely expensive works they usually have a diameter from 1 to 3m and have to be adopted just for the stabilization of large and complex landslides: they are constructed when there is the need to capture considerable concentrated water flows along preferential paths (fault zone or intense fracturing, contacts between rocks and cover soil, etc.).
Drainage tunnels requires an accurate design and preliminary investigation aimed at precisely reconstructing the landslide model. Particular attention must be paid to the determination of the underground water circulation and the identification of preferential drainage areas, in order to optimally locate and design the drainage tunnel and any sub-horizontal network connected to it. In

fact, on the drainage tunnel contour some small diameter drains are installed with radial direction to catch the water from a larger area.

The bottom of drainage tunnels is generally located deeper than the preferential level of water collection, while their crown reaches this level. That allows to increase more the slope safety factor.

Finally, at the outlet of the drainage tunnels, spillways are placed to measure the flow of drained water and, consequently, to verify the good operating of the drainage system.

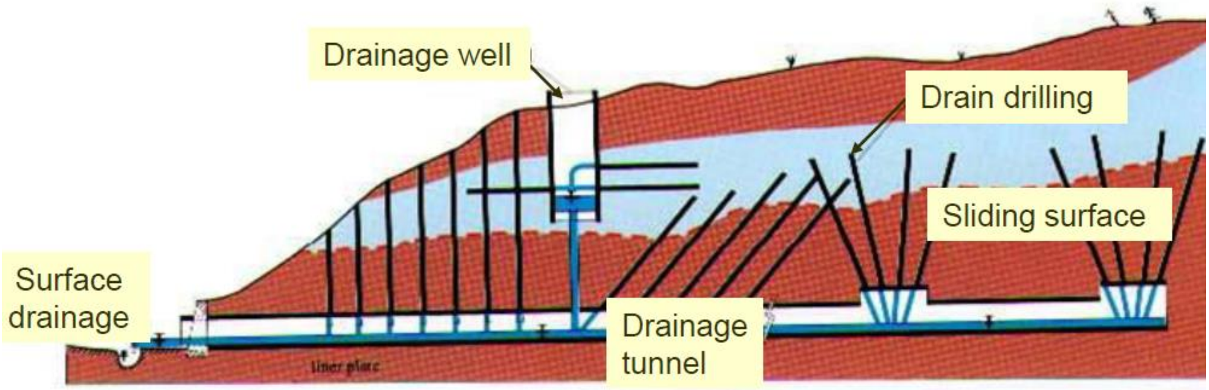


Fig x - Example of a drainage system with a drainage tunnel (G. Bottino, 2005)

Large diameter drain structure are useful to prevent the collapse of medium to big landslides. For shallow landslides or even bigger ones that interest just short soil thickness, small drains system is the best choice.

Small diameter drainage systems

Small diameters drainage systems reduce water pressures in the slope facilitating its removal by gravity. Therefore, the underground water circulation has to be investigated a priori to guarantee an efficient installation.

A small diameter drainage system is a set of pipes, whose hole diameter varies from 40 to 200 mm, dig sub-horizontally (from 5° to 10°) into the slope by means of conventional drilling equipment.

The pipes must be enough long and oriented in such a way to intersect both the potential slip surface and the maximum number of water-carrying fractures (fig. x). In fact, just a very little water is contained within the intact rock, while it is mainly contained into the soil cracks.

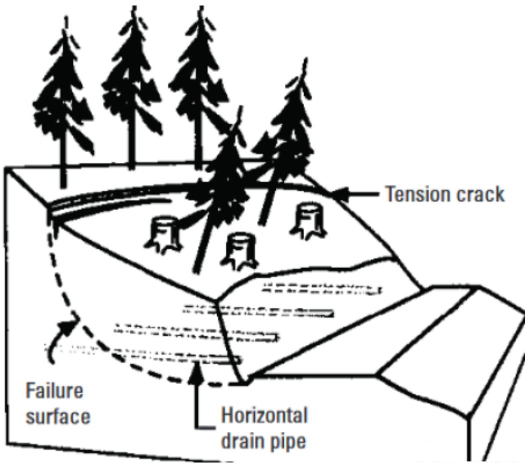


Fig. x – scheme representing a right pipes positioning: the failure surface is intercepted

The whole set of pipes can be arranged parallelly to each other or radially, depending on the slope shape. The spacing between holes is defined during design phase. It is based on the amount of water that have to be driven outside the slope, but usually it ranges between 5 to 15 m. More than one level of pipes is generally required.

Pipes material must assure corrosion resistance. For this reason, the tubes are generally made of plastic or anodized aluminium.

The spilled water must be appropriately moved away from the instable area to the hydraulic network.

The design is made a priori, but once that the drainage system is finished, it is appropriate to monitor its efficiency by means of piezometers. Therefore, on the basis of piezometric measurements, engineers can determine if the drainage is sufficient or if additional drains are needed.

Moreover, pipes should be covered with a geotextile membrane in order to limit the infiltration of fine particles and prevent the occlusion of the pipes and a periodic maintenance to prevent clogging is required. It is performed cleaning the pipe with water or pressurized air.

Fig. x – example of small drains drainage system

Considering equation 2, the effectiveness of a drainage intervention is strictly related to the variation of interstitial pressure in the slope. The amount of water removed, the lowering of the water table or the drying of the soil are consequences. They do not govern drainage.

Therefore, the aim of a drainage system is to reduce the term u_0 (with a reduction $\Delta u = u_0 - u$). Ideally, u_0 should be reduced to 0 in order to obtain the best condition. But practically it is not possible.

Anyway, if the pore water pressure is reduced, the slope safety factor increases. In fact, the new safety factor is expressed as in equation 3:

$$F_{afterdrainage} = \frac{\tau_r}{\tau_{acting}} = \frac{c' + \left(\sigma_n - (u_0 - \Delta u)\right) \cdot tg\varphi'}{\tau_{acting}}$$

Equation 3

The new nominator is higher that the previous one as the term u_0, that reduces the second term of the nominator, is lowered by Δu. Therefore, $F_{afterdrainage}$ is higher too.

The final safety factor reduction is (equation 4):

$$\Delta F = F - F_{afterdrainage} = \frac{c' + (\sigma_n - u_0) \cdot tg\varphi'}{\tau_{acting}} - \frac{c' + \left(\sigma_n - (u_0 - \Delta u)\right) \cdot tg\varphi'}{\tau_{acting}} = \frac{(-\Delta u) \cdot tg\varphi'}{\tau_{acting}}$$

Equation 4

The efficiency of a drainage system is defined by the hydraulic efficiency E. it is the relationship between the reduction of pore water pressure Δu and the maximum obtainable pore water pressure u (Equation 5).

The hydraulic efficiency is also a function of time. In fact, as the drainage system is ended, the pore water pressure dissipation is not immediate, but need time to reach a stable regime condition.

$$E(t) = \frac{u_0 - u(t)}{u_0}$$

Equation 5

As suggested so far, drains are ruled by pore water pressure. The distribution of interstitial pressures is not an easy factor to be determined a priori since it is influenced by many different factors, such as:

- precipitation regimes
- infiltration levels
- presence of discontinuity surfaces
- lack of homogeneity and permeability anisotropy of soils.

That fact affects consistently the real situations modelling. Obtain an accurate result during the design phase is very complex and difficult. For this reason, empirical methods to design drains have been created, such as *Di Maio's model* (1988, source). Knowing some properties of the soil (depending on the method) and the interstitial pressure, the geometric features of the drainage systems are easily evaluated by means of charts or easy formulas.

Rock-fall protection

In order to reduce the possibility of rock inclusion the hydrographic network, it is also important to mechanically stabilize the rock volumes that could collapse. As for soil landslides, even rock blocks are more prone to fail when the cracks are saturated.

All the unstable rocks that threaten structure, infrastructure or human activity need to be put in safe condition. The risks during a flood event are two:

- rock collapsed blocks damage buildings or roads. Especially road network is generally subjected to damages in the moment when connections are more important for the mitigation phase;
- Unstable rocks near to the primary or secondary streams could obstruct

the water flow and create dangerous water reservoirs.

In order to prevent rock collapse, it is possible to increase mechanically the factor of safety by adding some forces in the opposite direction of the resultant of the forces acting on the rock block.

As for common soil landslides, even rock blocks stability can be evaluated with numerical methods or limit equilibrium analysis. Both methods allow to determine the stability of the rock mass, but with numerical methods, such as FEM (finite element method) or FDM (finite difference method), it is also possible to define the probable rock blocks trajectory. These methods are commonly implemented on almost every landslide design software. As for LEM, it is necessary to identify a priori the rock blocks detachment source area. Then, basing the analysis on the block kinetic energy and defining empirically a set of parameters, it is possible to define the probable trajectory. These parameters are:

- Real slope topography;
- Blocks shape. It defines the kind of motion: sliding or rolling;
- Rock blocks dimensions;
- Initial velocity;
- Restitution coefficient. It defines the soil capacity to dissipate energy and is defined as the fraction of blocks velocity after and before the impact;
- Vegetation effects (it will be analysed afterwards).

In any case, a rockfall analysis cannot be done without a previous back analysis. Taking into account previous rock blocks detachments in the same area, it is possible to validate the numerical model. It means that, for instance, the restitution coefficient have to be defined a priori, but as close as possible to the one defined empirically by means of the back analysis.

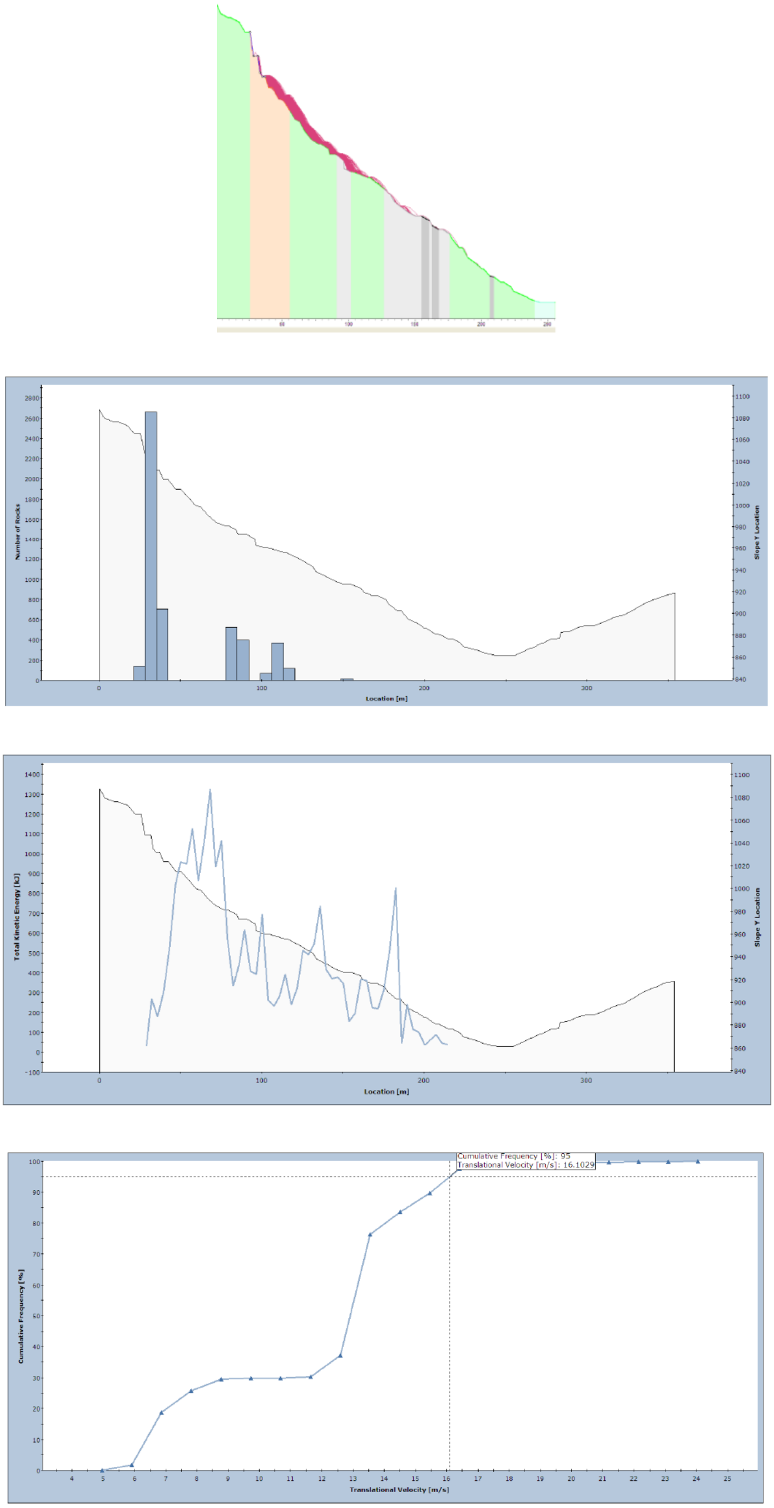


Fig x – example of a 2D dimensional model

(((describe what they are. If possible, re-do them with a real case in cervo valley)))

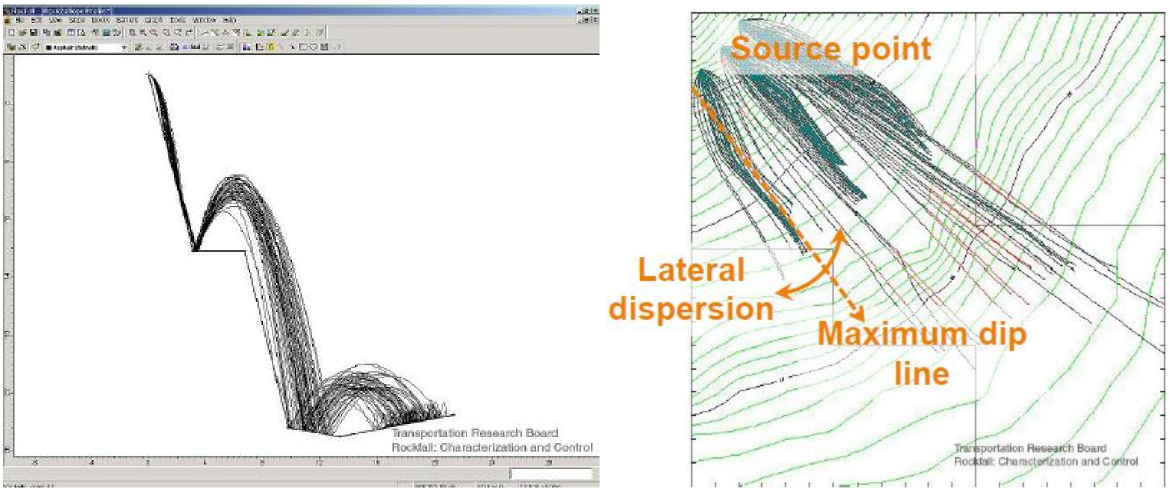


Fig x – example of the final trajectory result by means of a 3D dimensional model

On the other hand, limit equilibrium analysis perfectly describes the operating instability principle, but it does not take into account the motion of the blocks.

With LEM a safety factor is defined considering the equilibrium of the forces acting on the rock block. As for landslide, the safety factor is computed with Mohr-Coulomb strength criterion. It is the ratio between shear strength of the instable soil volume and the acting shear stress along the sliding surface (equation 1).

The forces acting on the block are the following ones (fig. x):

- block weight (W);
- hydraulic pressures into the tension crack and sliding plane interfaces (V e U, respectively);
- generic external force (E) with an inclination **β** with respect to the sliding plane;
- stabilizing force (T) with an inclination θ with respect to the sliding plane.

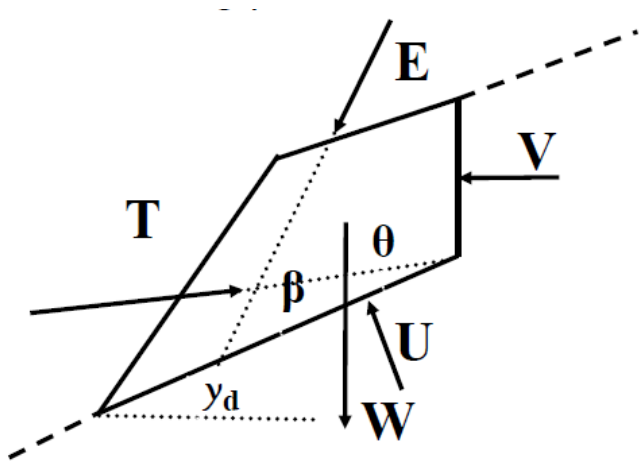


Fig. x – Forces acting on a generic rock block

Therefore, the factor of safety is calculated by solving the equilibrium equation along the sliding direction. It results to be equal to:

$$F = \frac{R}{S} = \frac{[N \times tg\varphi] + [c \times A]}{S}$$

Equation 6

Where N is the net force of the normal components of the acting forces. With the cohesion term represents the stabilizing forces. Instead, S is the net force of the components of the acting forces in the sliding direction. It represents the un-stabilizing forces.

Rewriting N and S with the effective forces acting on the block, the generic formula for the safety factor of an unstable rock block is (equation 7):

$$F = \frac{c \times A + [(W \times \cos\psi_d - U - V \times \sin\psi_d + T \times \sin\vartheta + E \times \sin\beta) \times tg\varphi]}{W \times \sin\psi_d + V \times \cos\psi_d - T \times \cos\vartheta + E \times \cos\beta}$$

Equation 7

As visible in figure xprevious, this formula is valid for a block sliding along a plane. In the case of rock-fall, the failure could also happen with the sliding of a wedge along the line of intersection between two planes (fig. x). In this case, the final equation is empirical. It is more complex because all the projection factors along the 2 planes (q, r, s, x, y, z, $m_{W,5}$, $m_{V,5}$, $m_{T,5}$) need to be taken into consideration (equation 8).

$$F = \frac{c_A A_A + c_B A_B + (qW + rV + sT - U_A) tg\varphi_A + (xW + yV + zT - U_B) tg\varphi_B}{m_{W,5}W + m_{V,5}V + m_{T,5}T}$$

Equation 8

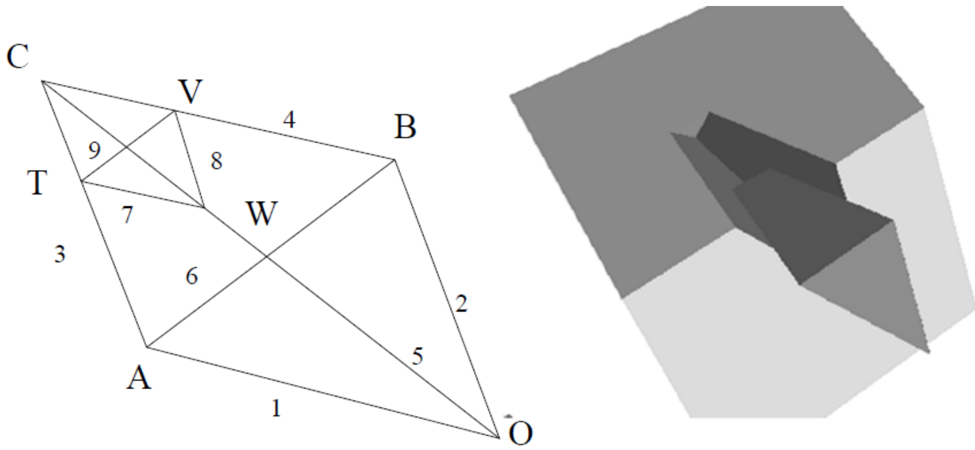


Fig. x - Sliding of a wedge along the line of intersection between two planes

The stabilizing force T is introduced by means of different types of stabilization systems. They could be passive or active. The active systems generate a force that acts permanently. They are anchors and bars. The passive one acts only when unstable volume moves by increasing the material strength. They are bolts and nails. They need to be correctly design and installed.

(((parlare o no del design degli ancoraggi e chiodi???))).

In conclusion, figure x helps to understand how to design correctly defensive structures. In fact, in order to minimize the consequences of a flood event it is necessary to integrate structures that limit water flow with others that allows to avoid soil movement into the hydrographic network.

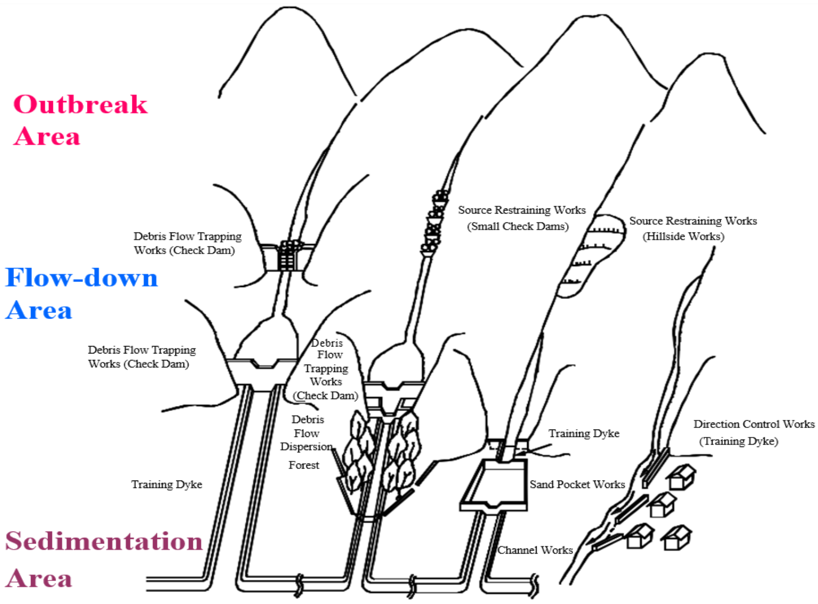


Fig. X – some examples of integrated defensive approaches

2.2 Non-structural measures

2.2.1 Introduction

In Nature, there is no flood damage. Floods only lead to damage when human activities interact detrimentally with rivers. The more intensively and the less suitably the flood basin is used, the greater the potential for damage when the flood occurs.

Moreover, society has become more vulnerable to natural hazards. Although floods are natural phenomena, human interventions into the processes of nature, such as alterations in the drainage patterns, agricultural practices and

deforestation, have considerably changed the situation in whole river basins. In the same time, exposition to risk and vulnerability in flood-prone area have been growing constantly due to climate changes.
Considering the evolution and trends (see chapter 2.2.2), the approach to natural hazards requires a change of paradigm. It must shift from defensive action to management of the risk and living with floods.

In order to reduce flood damages, a good combination of structural measures, preventive measures and operative measures during floods is still necessary. But it is more long term efficient to act on prevention and mitigation rather than just protection.

Building codes and legislation to keep structures away from flood-prone areas, appropriate land use, adequately designed floodplains and flood-control structures, early-warning systems, correct risk communication and preparedness of the populations how to act during floods will be the main future interventions. In some cases, even relocation of extremely endangered activities and buildings may be advisable.

Therefore, it is important to develop a preliminary flood management strategy that include evaluation of costs associated to repetitive damages (not just common events, but even extreme one with a return period greater than 100 years), technical feasibility assessment and environmental impact assessment. The water management policy and spatial planning efforts in the long run must concentrate towards attaining an equilibrium stage between economic development and urbanisation on one hand and the needs to allocate more space to water for flow retardation and water retention on the other hand.

The exigencies of flood prevention must become one of the guiding principles in spatial planning.

2.2.2 Climate changes

As mentioned before, in the last decades society has become more vulnerable to natural hazard. This is mainly due to two reasons. Firstly, the population growth has led to urbanization of areas more vulnerable to natural hazard. Then, the climate change caused an increase of frequency and intensity extreme meteorological phenomena, especially in that areas that have a temperate climate (climate with moderate annual average temperatures and rainfall well distributed throughout the year. It belongs to the two areas of the earth's surface between the tropics and the polar circles (Wikipedia)), like Italy.

It is precisely climate change that, record after record, does not stop its race and has highlighted the inadequacy of just a defensive policy against extreme events, suggesting a greater use of prevention measures. In fact, the higher intensity of precipitations caused the failure or the non-functioning of protection structures.

Italy is no exception. In fact, as the report 'Il Clima è già cambiato' (Legambiente Webinar, 2020) shows, in the last decade (2010-2020) 946 phenomena distributed in 507 municipalities were recorded in Italy. What is important to note is their constant increment year after year.

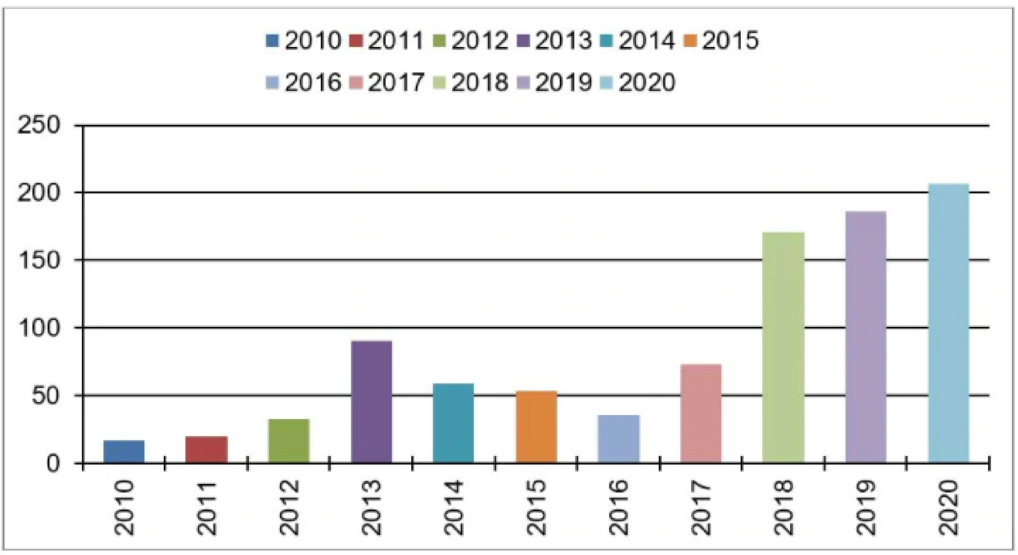


Fig. - Extreme meteorological phenomena distribution from 2010 to 2020 in Italy (Legambiente webinar, 2020)

The precipitation events with high intensity is increased as well (ISTAT, 2020). Therefore, the constant increment of extreme events that causes damages is strictly related to the climate changes.

The figure X graph is not only explained by a rise of high intensity precipitation events. As the precipitation intensity increase, the structural defences to water flow start to fail. The concept of residual risk cannot be overcome, and this is the reason why prevention and risk mitigation are fundamental. They guarantee to manage the risk instead of limiting it.

2.2.3 Risk management

Flood risk management aims to reduce the human and socio-economic losses caused by flooding.

In order to manage the risk that derives from a certain scenario, it is fundamental to define it by means of a risk assessment procedure. That allows to know all the possible consequences and their probability.

A variety of methods have been implemented, both for natural and man-made disasters (see e.g. Cox, 2001; Horlick-Jones et al., 1995; Vose, 2000; Drau-Fersina, 1999). The common approach for the flood risk can be resumed throughout the accomplishment of the steps in figure X:

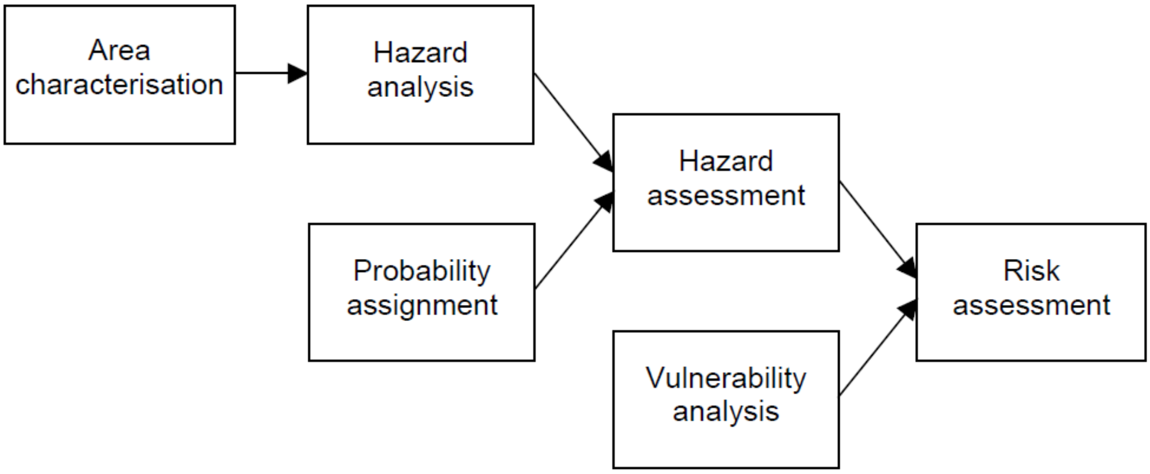


Fig. – Risk assessment steps (Guidelines on Flash Flood Prevention and Mitigation, Alessandro G. Colombo, Javier Hervás and Ana Lisa Vetere Arellano, 2002)

1. Data collection is necessary for the area characterizatio. It must include all the information regarding the considered domain: geography, geology, geomorphology, hydrology, vegetation cover, land use, river engineering and historical floods analysis.
2. Hazard analysis includes the definition of hazard scenarios and the choice of the level of detail of the analysis (map scale and hazard intensity scale). Before starting the data collection, both the map scale and the hazard intensity scale must be selected. The two scales are linked. The choice is usually made between the following two alternatives: medium level of detail (map scale in the range 1:10,000 to 1:100,000 and hazard intensity scale subdivided in 3 degrees), or high level of detail (scale in the range 1:1,000 to 1:10,000 and hazard intensity scale subdivided in at least 4 degrees) (European guidelines, 2002).
3. Based on the hydrological information, flooding frequency and water levels of a certain time of occurrence are defined. A probability level is then assigned to each hazard scenario, like in the following figure.

Probability level	Return period T (years)	Frequency (w)
very high	T < 10	w > 1/10
high	10 ≤ T < 30	1/10 ≥ w > 1/30
medium	30 ≤ T < 100	1/30 ≥ w > 1/100
low	T ≥ 100	w < 1/100

Fig. – Probability level scale of a hazard scenario (flood event)

4. Now it is possible to assess the considered hazard by means of an hazard level scale. An hazard level scale is defined on the basis of a combination of the hazard probability scale and hazard intensity scale. The resulting hazard level scale will have five different hazard levels (very low, low, medium, high and very high). On the basis of these classes it is possible to subdivide the whole considered area in sub-risk-zones.
   An example related to Cervo Valley will be given in chapter 5, while the following figure resume how the hazard level classes are graphically obtained.

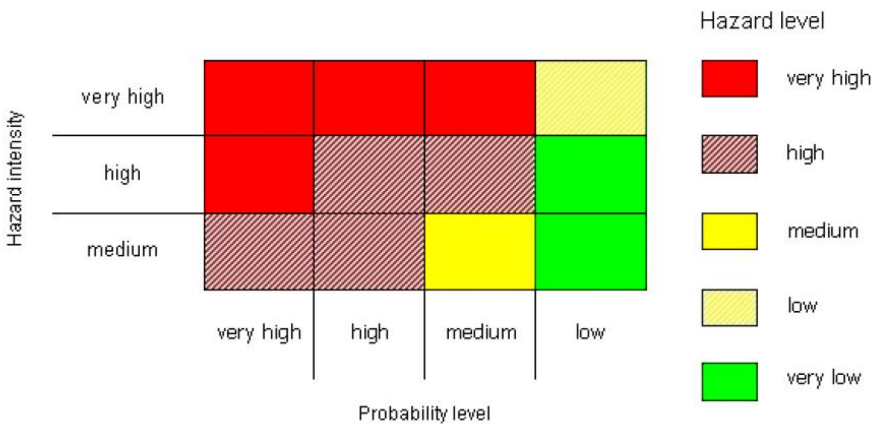
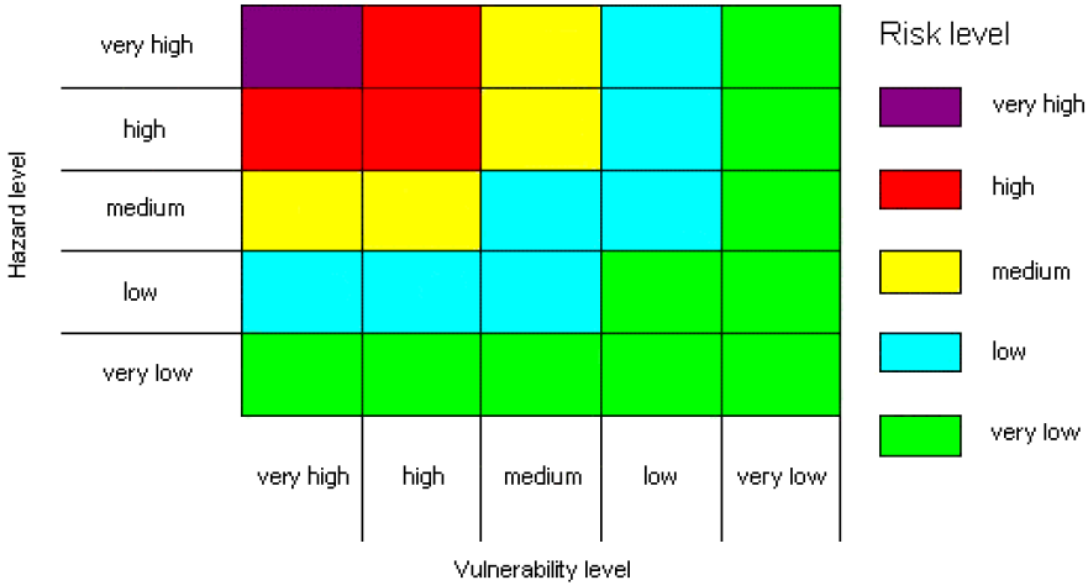


Fig. – Hazard level scale

5. On the basis of the obtained risk-zones and the effective presence on the territory of structures or human activities, it is possible to classify the more vulnerable areas into vulnerability levels.
6. Finally, matching again the hazard level with the vulnerability level, the final risk is obtained. It is a function of the global damage probability and the actual likelihood of causing harm.



Pre-flood activities	*"During-flood" activities*	*Post-flood activities*
Flood risk management for all causes of flooding and disaster contingency planning.	Detection of the likelihood of a flood forming (hydro-meteorology).	Relief for the immediate needs of those affected by the disaster.
Construction of physical flood defense infrastructure and implementation of forecasting and warning systems.	Forecasting of future river flow conditions from the hydro-meteorological observations.	Reconstruction of damaged buildings, infrastructure and flood defenses.
Land-use planning and management within the whole catchment.	Warning issued to the appropriate authorities and the public on the extent, severity and timing of the flood.	Recovery and regeneration of the environment and the economic activities in the flooded area.
Discouragement of inappropriate development within the flood plains.	Response by the public and the authorities.	Review of the flood management activities to improve the process and planning for future events in the area affected and more generally, elsewhere.
Public communication and education of flood risk and actions to take in a flood emergency.		

Once that the areas more prone to be damaged are identified, it is necessary to intervene to protect them. The structural measures have been explained in chapter XXXX, while the non-structural measures can be grouped into two categories: risk acceptance and risk reduction measures.

2.2.3.1 Risk acceptance

An acceptable risk is defined as the "degree of human and material loss that is perceived by the community or relevant authorities as tolerable in actions to minimize disaster risk" (UNISDR Glossary, 1992).

Risk acceptance implies that the local community and regional or national administration accept the degree of human and material loss in the short, medium and long term.

The strategies used in the field of risk acceptance are toleration, emergency response systems and insurance.

Toleration of risk implies that the occurrence of all the floods below a certain threshold, and the associated damage, is tolerate. This principle is based on the resilience capacity of a community to react to a hazard. It is an inherent quality in every community, but it is important to set the most appropriate boundary between what can be supported or not by the population. To set the acceptability threshold, the risk analysis of the interested area is compulsory. A problem arises from the fact that, although risk analysis is gradually gaining ground with competent Authority routines, it still needs to become common practice (Disaster Preparedness and Resilience for Rural Communities, Naim Kapucu, Christopher V. Hawkins, and Fernando I. Rivera, 12/2013).

The use of emergency response systems implies that the competent institution is aware of every area prone to floods of their jurisdiction. All emergency plans (regional, district, local, etc.) should be based on a national emergency plan, in order to carry out the same doctrine within a particular country in a concerted manner. Therefore, each task group, e.g. police, fire brigade, hospitals, etc. must have a well-structured emergency organization that guarantee a quick and effective cooperative response. More details about emergency and evacuation plans will be given in chapter 2.2.3.2, as a prompt response allows to reduce the hazard risk.

Finally, a compensation system that support the victims of flood disasters should be furthered. Besides public and individual measures, insurance can be an important factor in increasing the awareness and reducing the financial risk for individuals and enterprises. Proper insurance can considerably mitigate the effects of extreme events. In fact, insurance companies or public compensation organizations make a contribution to better arrangements so that future events will be less harmful and, at the same time, prevent people from being ruined. However, many countries still do not consider using flood insurance, due to its high costs. This is mainly due to different views on the role of the state in managing the flood risk and diverging perceptions of the dangers posed by flooding.

2.2.3.2 Risk reduction

Usually flood risk is not acceptable. If economic or social activities and structures are threatened by flood water flow, the risk of being damaged must be reduced as much as possible. Unfortunately, it is not possible to eliminate it, as there could always be an event of greater magnitude than the hypothesized one.

Therefore, the objective of prevention and mitigation is to cooperate with structural defences to manage all the events that could make them fail and improve a long-term sustainable approach to flood protection. Consequently, risk reduction is one of the main goals in flash flood management. It can be dealt with in two ways: prevention and mitigation strategies.

2.2.3.2.1 Prevention

The following paragraphs are key examples of non-structural prevention strategies.

Mapping

Flood maps help to identify and reduce the existing risks and to prevent the build-up of new ones by means of an adequate planning. Generally, flood maps are used to set up a regional or local hazard management strategy.

Flood maps differs on the base of:

- Scale factor: local or regional maps
- Content: risk or vulnerability maps
- 1D, 2D or 3D maps

The scale factor determines the area represented in the map. It divides the maps into regional (1:100000 to 1:500000) and local (1:5000 to 1:10000). As a local map represents an area 20 times smaller in the same paper, it contains more specific information than a regional one. Regional maps are used to manage great extension precipitation phenomena that hit more valley, when it is necessary to have a global view of the interested domain. Usually, a particular focus is made on the road network, as it is fundamental to guarantee a full cover for the emergency operations. A comparison between regional and local map is made in table X.

Level / scale	Use of flood maps	Readership / Complexity	Content of flood maps:	
			Essential parameters	Desirable parameters
National / regional 1:100,000 - 1:500,000	• High-level spatial planning • Allocation of land for development • Suitability of land for different types of development • Planning of national infrastructure	• Decision makers • Land-use and spatial planners • Simplified maps	• Flood extent • Flood risks • Sites of environmental vulnerability • Pollution risks • Assets at risk	• some indicators (to define) allowing to evaluate the hazard (considered useful if available or derivable, although a requirement in some contexts)
Local 1:5,000 - 1:25,000 (cadastre level)	• Specific city or village planning • Watershed management • Meeting specific needs of planners as a basis or guidance for decisions (e.g., provide for land zoning that forms the basis of planning decisions, support local flood risk assessments for development, determine appropriate land uses and development types, assessment of individual planning applications).	• City, village planners • Rural planners • Local authorities • Simplified maps	• Flood extent (typically for a range of event probabilities) either ignoring flood defences or assume a breach of defences	• Various flood parameters (e.g., depth, velocity, duration, erosion and debris accumulation, defended areas, etc.) and / or Hazard classes (in terms of probability and intensity), particularly where the planning process is linked to this type of information

Table x – Regional and local flood maps differences

Flood maps show how a single parameter vary along the considered area. For this reason, normally there are several flood maps. They could represent, for instance, the variation of flow speed along the river course, the evolution or damages of past floods or the presence of flood defences.

As already described in chapter 2.2.3, the most common flood maps are the risk and vulnerability maps. They contain the analysis along all the considered area of a single hazard. Risk maps represent the flood risk due to the valley morphology. It is a general parameter that is not influenced by the human activity, but only by hazard intensity and probability. On the other hand, the vulnerability maps link the general hazard risk with the effective presence of structures and infrastructure on the territory.

Both are used to determine the most risky and vulnerable areas in order to decide a strategy to protect them from flooding and organize an emergency strategy.

Nowadays it is also possible to have a 2D or 3D view of the evolution of a predefined flood event. There are several software that permit to study a priori the water flow propagation along a valley just setting the valley topography and flood parameters (precipitation equivalent height, soil water absorption, …). A huge number of simulations are performed by the software and, on the base of a statistical analysis, the probable flood evolution is represented by means of 2D graphs or even 3D models.

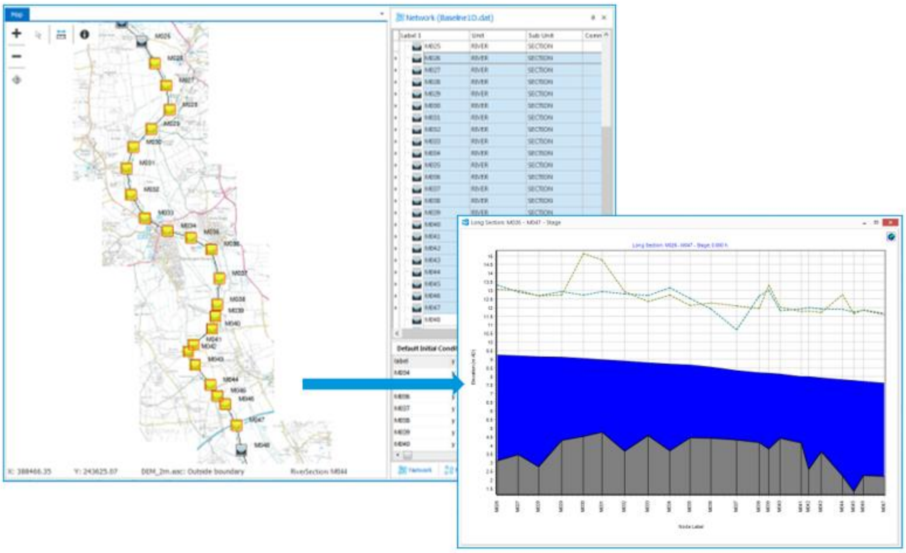


Fig. X – 2D flood analysis performed with Flood Modeller. Each section represents the change in riverbed shape and water height.

Land use policies

First of all, once that the flood-prone vulnerable areas have been individuated, it is fundamental to ensure that they are exploited only for activities that are compatible with the water regime in order to improve flood discharge and bed load transport, which also allow to head off future remedying interventions. A passive control method is the best way to avoid flood damages. In fact, keep flood discharge areas clear of buildings and essential activities guarantee to head off the need for remedying intervention and cut down economic losses.

(((Bridges need a particular attention as they compulsory have to occupy the floodplain. Bridges have to guarantee the passage of water heights related to exceptional flood events, do not present an obstacle for debris carried by the current (large span between the pillars are required) and be designed in order not to undergo to sub-excavation of the pillars.)))

Secondly, improve the soil capacity to store part of the precipitation water must be encouraged. In that sense, it is important to avoid proofing of the soil in the more urbanised areas and promote the presence of wetlands and forests. it is important to consider that water in soil can lead to landslides. Therefore, it is important to take in mind the considerations of chapter X.

Land reclamation and Maintenance of hydrographic network

A tool to limit the damages caused by floods is the care of the alpine environment. Keep the riverbed clean, take care of the vegetation and maintain the slopes that can cause shallow landslides is key to reduce flood damage.

Often, the presence of debris into the hydrographic network due to past flood events is one of the main causes that provoke damages. If the original river section is not preserved, the flow rate is reduced and the water height is increased, favouring the flow of water out of its natural course. During a flood event, the high energy of the flow causes the transport of solid material which settles in the riverbed when the flow energy is no longer sufficient to transport it. Therefore, after every flood event the riverbed must be cleaned and restored to its original condition.

In order to limit solid material transport into the hydrographic network it is necessary reclaim and maintain all the lands that can cause it. The material that goes into the streams derives from shallow landslide and vegetation. Promote land reclamation and vegetation maintenance gives value to the alpine areas and, at the same time, protect them from future flood events.

Legislation/regulation

Legislation related to flood-prone areas should be promoted at all levels (European, national, regional and local) and created where it is not present. Furthermore, it is necessary that legislation is keep updated. This should be a continual process whereby legislation should be re-examined after each flash flood disaster in order to incorporate every learnt lesson into the existing legal framework.

A proper legislation must ensure that flood catchment areas are exploited only for activities that are compatible with the water regime. This is to preserve and improve flood discharge and bed load transport to consequently head off remedying intervention.

The following aspects have to be considered into land regulation:

- Flood zonation based on hazard and risk maps, as seen in chapter X
- Incentive policies on limited building in flood-prone areas in order to move buildings in safer areas
- Maintenance flood structure and riverbed plan
- Introduction of Integrated Water Resources Management (IWRM). It implies the coordinated development and management of water, land, and related resources by maximising economic and social welfare without compromising the sustainability of vital environmental systems (GWP, 1997).

Forecasting

The use of cutting-edge technologies, such as satellite detection or radar scanning, and the improvements of mathematical models allow today to have very accurate estimations of precipitations, both in time and in quantity.

Know the amount of water poured into the hydrographic network during an extreme event and its evolution in time is powerful tool to manage the emergency. These data permit to evaluate in advance if the defensive structure can confine the water flow into the natural riverbed or if more interventions, and even a preventive evacuation, are necessary. For this reason, weather forecasting is essential for prevention and mitigation, but it needs to be inserted into a wider methodology that comprehend the collection, analysis and elaboration of real-time data (see chapter 3).

2.2.3.2.2 Mitigation:

Wheater alert

Evacuation plan

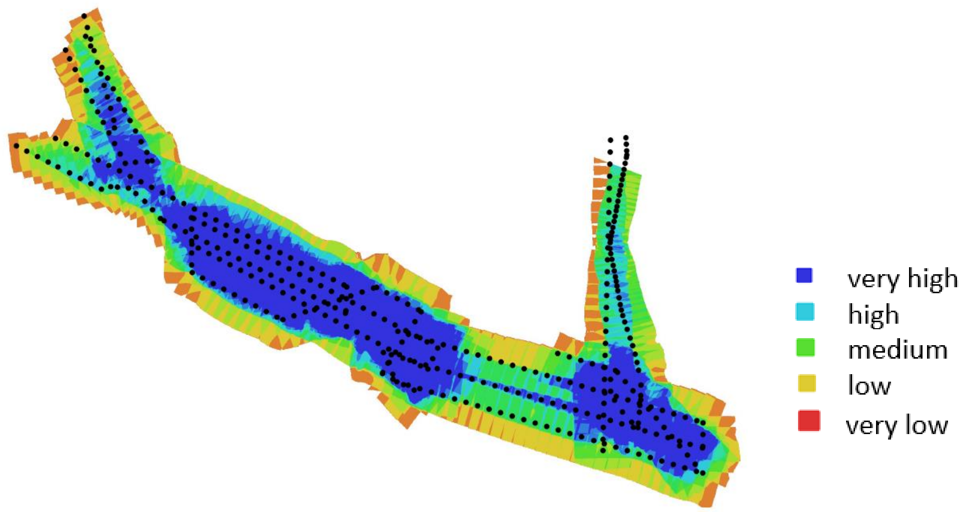
3. Innovative and future instruments for flood management (digital twin)

Bim, gis, pc, …

Technologically speaking, the recent advancements of data acquisition sensors, the introduction of satellites data, the improvements of BIM and GIS methodologies, the Internet of Things (IoT) and the evolution of big data analysis technologies (BDA) and machine learning (ML) have provided an open opportunity to innovate data harvesting, aggregation and processing procedures. Furthermore, the combination of these technologies will allow to create new tools for emergency response. In fact, nowadays information coming from heterogeneous sources are easily collectable in real-time. If this huge volume of data is properly managed, it allows to respond promptly to an extreme event.

First of all, it is necessary to evaluate the risk assessment of the considered region. That allows to be acquainted with the valley and recognize the more vulnerable zones. On the basis of the area evaluation it is then possible to decide which are the most suitable recording instruments to be employed and their amount, remembering that data collection is fundamental for a reasonable system response. IoT allows to create a real-time database that can be directly associated with a digital twin of the valley, where all the general information is stocked. The digital twin is created taking advantage of the interoperability between BIM and GIS systems. Finally, it is necessary to analyse collected data in order to fit them in a pre-defined function that permits to find the most suitable scenario. In that sense, BDA and ML must be implemented to obtain a prompt response and to improve it step by step.

4.Applications to cervo valley



very high
high
medium
low
very low

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