**Geological context**

The Manival catchment is located within the limestone geological zone, on the external border of the Alps. The regional geology is characterized by a Secondary age substratum visible in all the Chartreuse Massif, and later by the influence of the flow of the Isère glacier in the Grésivaudan valley, during the quaternary era.

The Chartreuse Massif consists of a stack of limestone strata, marl and clay limestones surmounted by a strata of sandstones, now eroded. Two strata of limestone are found all along the massif: the Urgonian limestone stratum (about - 110 M years) which is outcropping at the level of the main peaks of the Chartreuse Massif (Dent de Crolles, Granier); the Tithonic limestone stratum (about -140 M years) which forms a group of secondary cliffs, notably at the level of the Saint-Eynard cliffs which constitute the top of the study catchment.

The torrential erosion, very important on this watershed, opened the deep ravine of the Manival. The erosion pushed back the edge of the Tithonic cornice more than 2 kilometers to the north. One of the consequences of the ravine digging and the recession of the Tithonic cornice, is the formation of a huge alluvial fan in an area surrounded by two hillslopes. This is one of the main characteristics of this site.

In the reception basin, the following strata are observed (from the top to the bottom):

- **Tithonic**: it is characterized by massive limestones forming cliffs of about ten meters. Following erosion, it disappeared from the summit of Bec Charvet.
- **Kimmeridgian**: mainly represented by small marl-limestone benches alternating with beds of marls. They are visible under the Bec Charvet.
- **Sequoian and Argovian**: These levels consist of marly limestones, marl-limestone and marls.
The main characteristic of the Manival’s long profile, inherited from the Quaternary era during which the Isere glacier flowed into the valley, is the following: the longitudinal slope directly upstream the confluence with the Isere river, is less than 1%. Thus, sediment produced in the upper catchment and transported during the floods cannot reach the downside part of the catchment and the confluence with the Isere river.

This characteristic can be duplicated for all torrents of the Gresivaudan valley. The problem for torrent hazard management is thus to choose the best places along the profile for bedload and debris flows deposit zones. This has been and still is a very complex task due to: (a) rapid increasing of urbanization; (b) multiples management organizations along the torrent.
Longitudinal profile of the Manival torrent
Some recent history...

Before 1830, the Manival was not equipped with protection works. During the floods, due to bed shifting, the flow invaded the agricultural lands and regularly cut the national road from Grenoble to Chambery.

The first protection strategy was implemented in the middle of the 19th century with levees on the right bank of the torrent. The objective was to protect the village of Verciaux and the national road. For example, in 1831, 7 houses of this hamlet were flooded up to the 1st floor, fields and vines where covered with sediment deposits going up to 1,5m and the national road was cut.

In 1895, following national laws, the French state bought all the upper catchment in order to stop erosion, engage reforestation and build check dams. Despite the very important work done, the 3 communes still were flooded during debris flow events. One of the main causes of failure, was the bed shifting of the torrent at the fan apex, especially occurring on the left side of the fan.

The most effective works, in terms of protection, were carried out in 1929 and consisted of the construction of V shaped dikes. Their objective was to re-center the flow and avoid bed shifting downstream. The levees were built after a second phase of land acquisitions on the fan.

After the Second World War, another dike was built at the fan apex in order to prevent overflows on the left bank. This structure is located at the level of a quick decrease of the longitudinal slope.

Finally, in the 1990's, a sediment trap was built directly at the end of the V shaped dikes. The location already had a storage area where sediment extractions were often done. A concrete dam was added, which has really increased the retention of sediments both in terms of frequency and volume.

Evolution of urbanization, protection works and floods extension (source: SOBOL, 2016)
Hazard mapping

The torrential hazard map is shown below. It compiles the hazard areas defined for each commune concerned by the Manival floods: Saint-Ismier, Saint-Nazaire the Eymes and Bernin.

First, we can see that there is no homogeneity between the 3 hazard maps. In Saint-Ismier, the levees and the sediment trap were taken into account. As a result, no hazard was considered on the right bank of the torrent. For the two other municipalities, Bernin and Saint-Ismier, an opposite approach was chosen. A possible failure of the protection system was considered, but two different levels of hazards were taken into account.

Hazard map (compilation of the documents established for the municipalities of St-Ismier, St-Nazaire les Eymes and Bernin)
EBR study

A study was carried out in 2016 by RTM services on the Manival catchment, in order to proceed to a management review of the torrent. The main conclusions are detailed below.

The reference sediment flow volume, was recalculated. A volume of 30 000 m³, was chosen, according to floods history, statistical and geomorphological calculations. One must note that the capacity of the sediment trap varies between 10 000 and 15 000 m³ depending on the longitudinal slope of deposits considered. With these hypotheses, both observations and numerical modelling of debris flow propagations, showed possible failure of the protection system downstream the sediment trap, in particular at the level of the crossing roads.

Numerical modelling of debris flow propagation – Lave 2D
Another problem identified concerns ordinary floods. Downstream the area managed by RTM services, the bed of the torrent is not fixed with check dams. Due to sediment retention within the sediment trap during several decades, a huge incision of the bed has progressed downstream. According to long profiles comparisons, it has reached up to 10 meters since 1963!

![Image of longitudinal profile evolution downstream the RTM sediment trap]

The main difficulty is thus to manage sediments for two types of floods. Very intense floods, with debris flow events may cause the entire filling of the sediment trap. Half of the flood may propagate downstream, with deposits at the level of the less steep areas, and bed shifting in the residential areas. A first protection strategy would be thus to increase the retention capacity upstream the main stakes. But we thought that we could reach this objective by a combination of increase of sediment trap capacity and with a better regulation of sediment routing during floods.

Indeed, for rare events, by experience it was observed that the dike realized at the fan apex, helps to keep the flows in the main channel and promotes the integral transfer of sediments to the sediment trap. Nowadays, we believe that bed shifting at the fan apex could be a good manner to decrease the potential volume of sediment reaching the sediment trap. In other words, we think that a part of the volume coming from the reception basin will deposit after bed shifting and will not reach the sediment trap. For that reason it was decided to both:

- Increase the sediment trap capacity;
- To promote sediment regulation on the fan by destroying the dike at the fan apex, allowing bed shifting on the fan in the area surrounded by hillslopes, and reinforcing the V shaped dikes built in 1929.

Ordinary floods cause no damage, but are responsible of a huge incision. However, we really fear riverbank collapses which may cause bed shifting near residential areas. A possible strategy would be to fix all the bed downstream the area managed by the state. Another option, is to let more material transit from upstream, changing the conception of the sediment trap. This last option was chosen because it could be done entirely by RTM. In order to achieve this objective, we decided:

- to re-establish a steeper bed into the sediment trap, in order to promote the integral routing of sediments during common floods;
- to build a diversion structure and a storage area to manage the rare floods.
Works carried out in 2018

Following the EBR study, protection works were done in 2018, consisting in:

- the lowering of the dike crest at the fan apex;
- the reinforcement of the V shaped dikes (at the end of the area surrounded by hillslopes) with an enlargement and rise of the crest dike;
- the design modification of the storage area of the sediment trap.

*Location of the different works carried out (2c not done)*
Vol. storage = 15 000 m³ with i = 8%
Addition of a derivation (by-pass) structure + spillway