

# Dams on the torrents, why?

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*In the headwaters of the Alps, the Pyrenees and the Massif Central, mountain torrents are equipped with thousands of torrential check dams. What are they used for? They limit erosion and some of the risks associated with the torrential nature of these rivers. These structures have an important role in protecting mountain societies. They also have an impact on the environment through the stabilization of erosive processes. Their design requires an understanding of their effects on torrent activity and in particular on floods. This article recalls, through references to pioneer publications, how the current vision of the role played by check dams in torrents has emerged and changed through time. We will see that a structure as simple as a check dam filled by pebbles can be built for very different purposes and have very specific effects and functions depending on its location and characteristics.*

## 1. An old need for protection against floods and erosion

Hikers in the mountains near streams and torrents often notice dams filled with gravel and cobbles, especially in state-owned forests. It is **surprising to note the presence of these structures** made of cut stone, masonry or reinforced concrete **so high on watercourses**. Their purpose is not directly related to hydroelectricity or old mills: they **are erosion control and torrential flood control structures**.

Torrential floods cause considerable damage and sometimes casualties. Engineers have long been interested [\[1\]](#) in these phenomena, which originate in the geomorphology of mountains, i.e. the shapes of landscapes and their evolution over time, mainly during floods.

River training and channelization techniques developed on river courses quickly found their limits in the torrential context of Alpine development [\[1\]](#). It was during Napoleon III's Second Empire, established in 1852, that the reforestation of the mountains was launched in France. Such a policy, consisting in reforesting huge areas of grazed and eroded areas, could only be the result of a **combination of several concomitant factors** [\[2\]](#) :

a centralized administration of an authoritarian Second Empire;

projects for major infrastructure works and the securing of strategic transport networks (roads and railways);

more than half a century of activity of a forester lobby [3];

a hydrological crisis in the middle of the 19th century (major floods on most of the major French river systems, see [Hydrometry: measuring the flows of a river, why and how?](#) and associated focus).

This ambitious reforestation program was set out in the 1860 and 1864 laws. This was a first before similar decisions were taken by Switzerland in 1876, Italy in 1877, Austria in 1884 and Japan in 1897.

After the fall of the Second Empire in 1870, the Law on the Restoration and Conservation of Mountain Lands (RTM) was proclaimed in 1882. The new republican assembly, listening to the rural populations, reduced the ambitions of reforestation: the work effort would be concentrated where **"restoration work[would] be made necessary by soil degradation, and the dangers born and present"**. This means mainly torrent beds, gully systems, avalanche corridors and landslides. New project would therefore be based more on civil engineering and less on extensive reforestation operations [4].

The period between 1882 and the beginning of the First World War was the "golden age of the RTM". Generations of engineers working at that time had the means to correct more than a **thousand torrents** using techniques combining forestry engineering, bio-engineering for small structures [5] (bundles of branches called fascines & vegetated benches) and civil engineering for dikes, tunnels, sills and check dams [2]. These are the most visible and emblematic works in the field of check dams and are the subject of this article.

Our mountain societies have inherited thousands of protective structures. The latter sometimes require maintenance operations, are sometimes abandoned or, on the contrary, new structures using new techniques are implemented such as open check dams [6]. The decision to abandon, maintain or improve a torrent control system can only be understood by the populations concerned if they are able, in the first place, to understand the function of this system, i.e. its qualitative effects on floods and on the activity of the torrent. We will begin by recalling, through references to pioneer publications, how the vision of the role played by check dams emerged and changed through time. We will see that, depending on its location and characteristics, a structure as simple as a dam filled with pebbles, filtering or not, can be built for a wide variety of purposes and have specific effects and functions.

## 2. The pioneers

### 2.1. The "foresters"

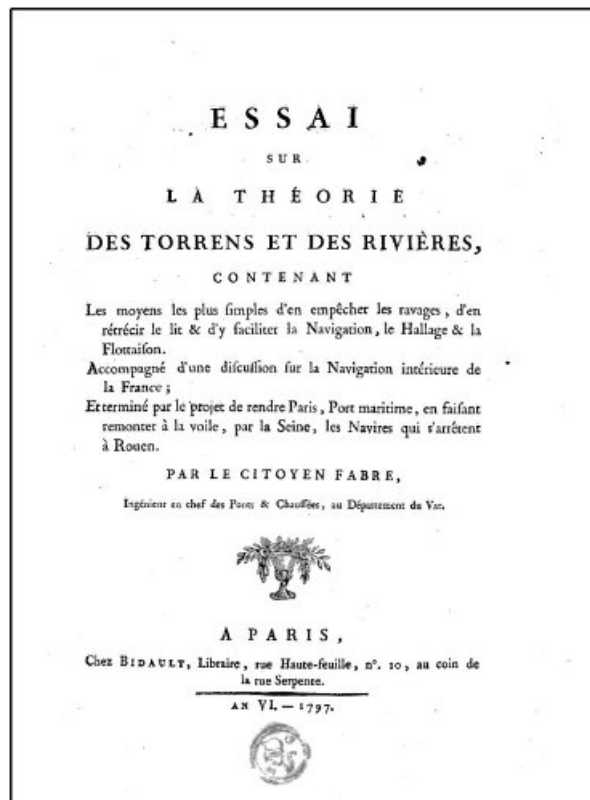


Figure 1. Cover page of Fabre's book (1797), very complete, which seeks to explain the difference between rivers and torrents and how to protect against related risks.

During the 19th century, a strong forester lobby worked to curb uncontrolled deforestation and to initiate mountain greening [3]. The regulatory role of the water regime is a recurrent argument of the different currents that animate it, but a second aspect eventually emerges: the erosion prevention [7].

Jean Antoine Fabre (1748-1834) published a pioneering book [8] (Figure 1). This early geomorphologist points out that a different treatment from that of rivers had to be implemented on torrents: **stabilizing the source of sediments by reforestation** (see focus).

Alexandre Surell (1813-1887) took up and deepened the reflections of Fabre and other authors of the time to write his excellent "Study on the torrents of the Hautes Alpes" [9] (Figure 2). The first part of the book is a high-quality monograph on the origin of torrential activity. The second part is a partisan pamphlet against deforestation of the slopes and a harangue to the authoritarian reforestation of the mountains.

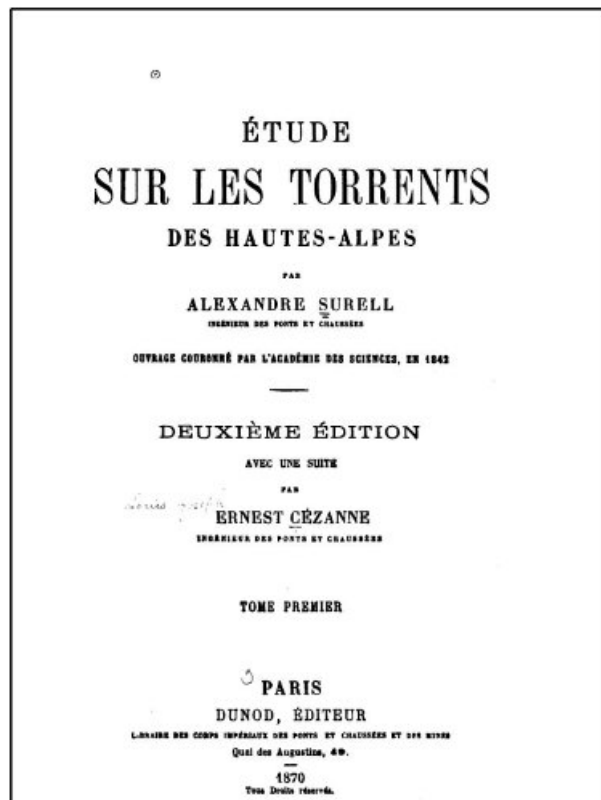


Figure 2. Cover page of the second edition of Surell's book (1871) which will serve science as well because of the depth of analysis on the geomorphology of torrential watersheds as the forest lobby because of the partisan and categorical tone of its author.

Fabre, like Surell, considered the use of **check dams insufficient in itself, but interesting in order to stabilize banks and stream beds** to facilitate reforestation (see [focus](#), section 1).

## 2.2. The barrages makers

Scipio Gras (1806-1873) [\[10\]](#), Philippe Breton (1811-1892) [\[11\]](#) and Michel Costa de Bastelica (1817-1891) [\[12\]](#) later focused on the design and functions of check dams. These engineers tried to focus the design of protection structures on flood processes, stressing the need to adapt the protection system to the peculiarities of the catchment.

They highlight that, unlike river systems, the origin of hazards in the case of torrents is related to **solid transport excess** rather than **liquid discharge excess**. The resulting hazards (debris flows, debris floods, mudflows, floods, sedimentary deposits) are the result of a sediment supply exceeding the transport capacity of the flow, which is strongly correlated to the slope of the reaches. Gras and Breton recommend that channels on alluvial fans should not simply be embanked; this would simply mean sending the same problem of sediment excess further downstream. The downstream river system (river or agricultural drainage ditches), with insufficient slope to transport this solid load, would then tend to aggradated, i.e., increase their bed level, with or without dikes. The increase in the bed level would even be all the more rapid – and therefore more dangerous to manage – if the bed width were constrained by dikes leaving less space to the volume to contain.

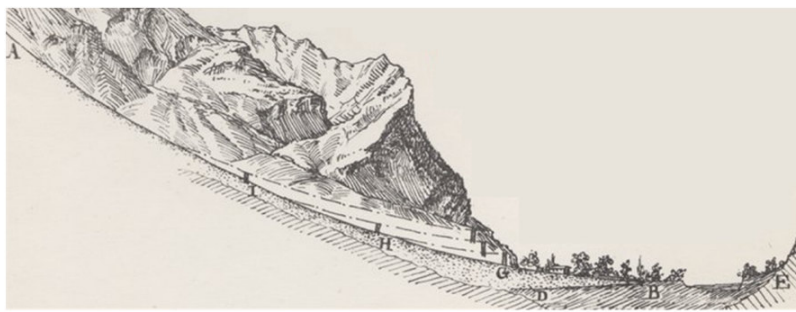


Figure 3. Figure 3. Optimal site for implementing a series of retention check dams (at point G) to encourage maximum retention volume in the gorge, i.e. the area between the basin head (upstream of A) and the alluvial fan (downstream of G), rather than the spreading of check dams (at points I and H) storing smaller volumes. [© Breton [111]]

These authors also considered that the only solution consisted in acting on sediment sources upstream of urban and agricultural areas. **They concede that reforestation can be effective but sometimes insufficient:** (i) because it would take decades to really stabilize torrents through simple reforestation, check dams could be useful for short-term protection, and (ii) in highly unstable basins, reforestation would never be sufficient and should be supplemented by check dams.



Figure 4. Hamlet of Bionnay ravaged by the rupture of the Tête Rousse glacier lake outburst flood and the debris flow that formed downstream. Catastrophe which caused 175 deaths in 1892. [© Kuss [191]]

In addition to the channel stabilization role already mentioned by Surell, Gras, Breton and Costa de Bastelica theorized new possible functions of check dams: (i) **sediment retention** (focus section 4), total trapping in the upstream section, called “atterrissement” or “siltation area” in the technical jargon (Figure 3), (ii) **hillslope consolidation** (focus section 2), the idea being to slow down the activity of landslides that provide the torrent with its solid load by filling the valley bottom with sediments that can form a foot stop and (iii) **solid transport regulation** (focus section 5). Gras (1857) [13], observing the natural tendency of torrential beds to store and release materials, anticipated that structures generating low slope and wide areas would tend to buffer sediment transport by temporarily storing solid transport.

### 3. Waters and Forests



Figure 5. Dams retaining moraine deposits from the headwaters: Ravin des Arandellys, a tributary of the Griez River that flows into the Arve River downstream of the EDF Houches hydro-electricity dam (74). [Source: Waters and Forests 1911 [20]]

The first tests and trials were immediately launched after 1860 by the “Waters and Forests” forestry administration wherever the agents managed to acquire a sufficient area to reforest. Prosper Demontzey (1831-1898), Edmond Thiéry (1841-1918), Charles Kuss (1857-1940), Paul Mougin (1866-1939), and Claude Bernard (1872-1927) are lecturers and practitioners who have marked the history of mountain land conservation and the use of check dams.

The manuals [14] [15] for restoring the Demontzey and Thiéry mountains synthesizing the first techniques will be refined later by Kuss [16] [17] and Mougin [18] in the particular cases of torrents prone to **glacial lake outburst floods** (Figure 4 & Figure 5), consolidation work on **large landslides and** rock avalanches (Figure 6). They also use drainage or **diversion systems and bypass** such large scale instabilities (Figure 7).

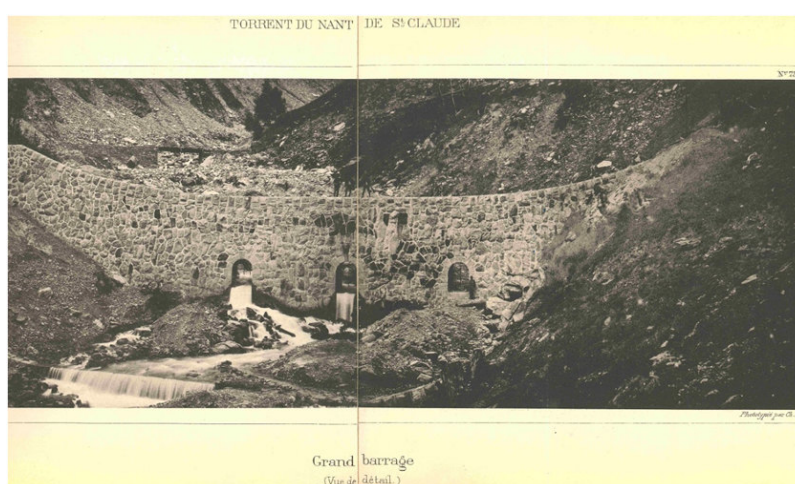


Figure 6. Grand barrage du Nant Saint Claude downstream of a landslide (73). The dam is equipped with openings allowing water to pass through until it fills with materials and thus raises the level of the stream (see Focus on slope consolidation). [© C. Kuss18]

Bernard's courses [15] are a state-of-the-art book in understanding torrential morphodynamics and the techniques for controlling it. Check dams are an important part of it and the **list of the many functions** that these dams can have then has its current form:

**Bed stabilization**

**Hillslope consolidation**

**Reduction of bed slopes** (read [focus](#), section 3)

**Sediment retention**

**Regulation of solid transport**

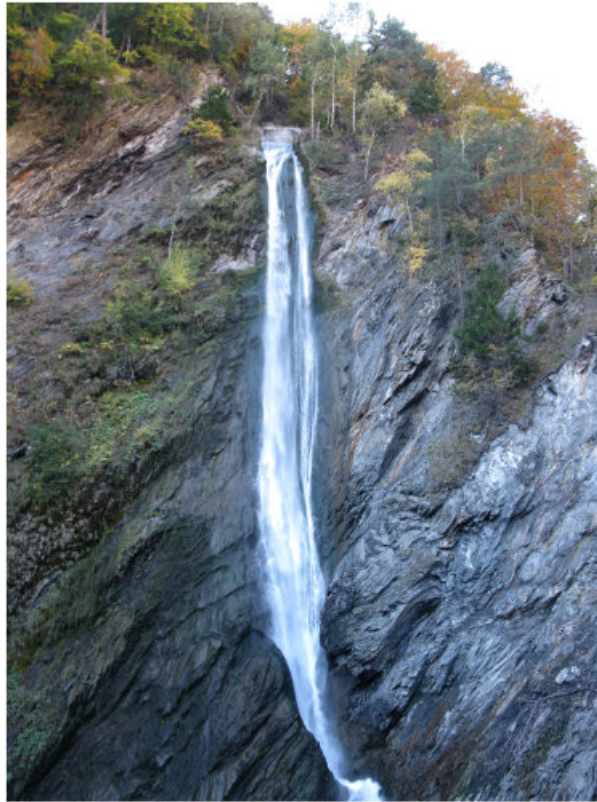
**Bed stabilization**

**Hillslope consolidation**

**Reduction of bed slopes** (read [focus](#), section 3)

**Sediment retention**

**Regulation of solid transport**



*Figure 7. Downstream outlet of the tunnel bypassing a landslide on the Morel torrent (Aigueblanche, 73). The tunnel, drilled in the stable slope opposite the landslide, diverts the stream from the bottom of the landslide (located on the other side of the valley shown on the right of the photo) and prevents the stream from eroding the bottom of the unstable mass and loading itself with sediments that it would carry downstream over high stakes areas. [© G. PITON]*

Figure 8 shows a symbolic watershed in which the main functions associated with these dams are distributed.

The number of new projects decreased between the two world wars, and the large number of structures yet built had to be maintained. The post-war period saw the advent of **two technologies that would revolutionize torrent control: reinforced concrete and earthmoving machinery** [4]

The use of reinforced concrete made it possible from 1955 onwards to design and build cantilever check dams. These are less expensive than masonry gravity check dams for large dams [2]. Reinforced concrete can also be used to build new structures such as filter dams and open check dams that close off debris retention basins. The conceptualization and first tests of filtering dams, carried out in the 1950s and 1960s, are considered a world first [2] The mainstreaming of these structures in France took place a little later, after the transfer of the former responsibilities of Water and Forests to the new National Forest Office in 1966.



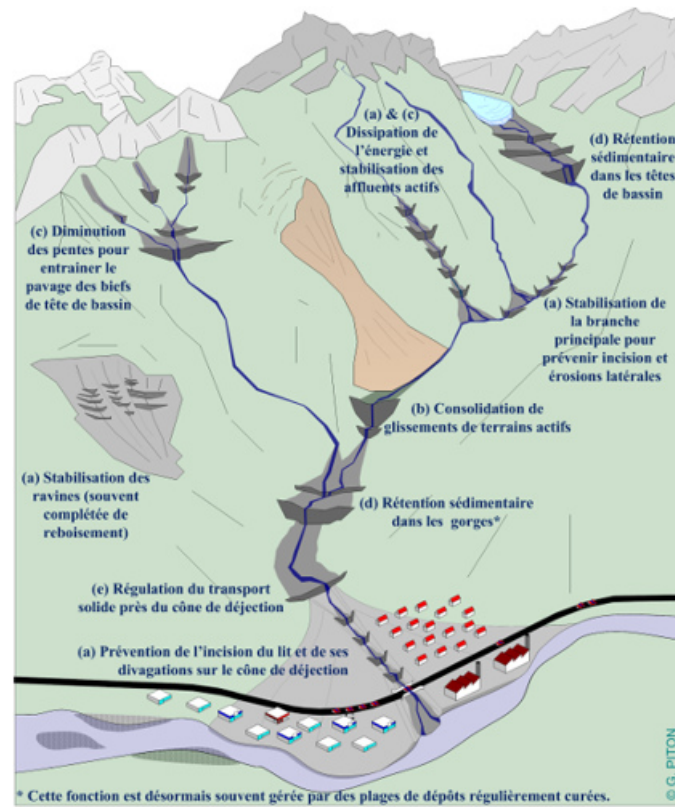


Figure 8. Examples of typical check dam configurations and associated main functions: (a) bed stabilization, (b) hillslope consolidation, (c) slope reduction, (d) retention and (e) regulation of solid transport; additional corrective measures (reforestation, drainage, channelization, embankments and deposition ranges) as well as functions and side effects were not mentioned for the sake clarity. [© G. PITON]

## 4. A huge park of structures to be managed

In 1964, the former Water and Forestry Administration had 92,873 check dams and weirs, 10 diversion tunnels, 736 km of drainage networks built in the 26 French departments in accordance with RTM laws [21]. In 1966, the management of these structures was transferred to the ONF: Office National des Forêts (with a partial and temporary transfer to the DDA: Directions Départementales de l'Agriculture), and in 1971 in some departments to the care of a specific Service de Restauration des Terrains de Montagne at the ONF [22] (ONF-RTM).

**Only a part of these works is regularly monitored on behalf of the State** in the 11 mountain departments of the Pyrenees and the Alps, which still include an ONF-RTM service [21]. Rural depopulation, decreased grazing, climate change since the end of the Little Ice Age and spontaneous or artificial reforestation have reduced erosion activity in many watersheds. Others that are still very active are still regularly the subject of maintenance and investment work to protect populations as well as the various downstream assets, road and rail networks.

The management of check dams is now being considered in terms of the effectiveness of the structures (adequacy between objective and capacity achieved) and their efficiency (adequacy between overall effectiveness and cost). These analyses aim, in parallel with other criteria, to optimise investment and maintenance funds; but their implementation is hampered by the complexity of torrent morphodynamics, the difficulty of characterising the capacity of a structure (its quantified effect on flooding), as well as the cumulative effects with risks of ruptures and potential cascading effects [23].

**The management of the immense French fleet of torrent control works therefore requires a better understanding of the potential effects of check dams by all stakeholders (ONF-RTM, State, local elected officials, populations, risk managers).** Although the quantification of these effects and their aggregation is a complex subject requiring professional expertise, we advocate that everyone can understand their general principles. This paper provides a first overview.

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[22] ONF-RTM services are specialized services that exist only in certain areas of the territory. Today, the NFB is represented in the territories by territorial agencies whose scope of action is larger than the department (51 agencies). Then there are 320 territorial units for representation throughout the country.

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