Dams on the torrents, why?

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In the upper basins of the Alps, the Pyrenees and the Central Mountains, mountain torrents are equipped with thousands of torrential correction 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 torrential correction dams has emerged and evolved. We will see that a structure as simple as a dam filled with rollers 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 ashlar, 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 containment and canalization 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. Such a project, 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 routes (roads and railways);

more than half a century of activity of a forest 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.

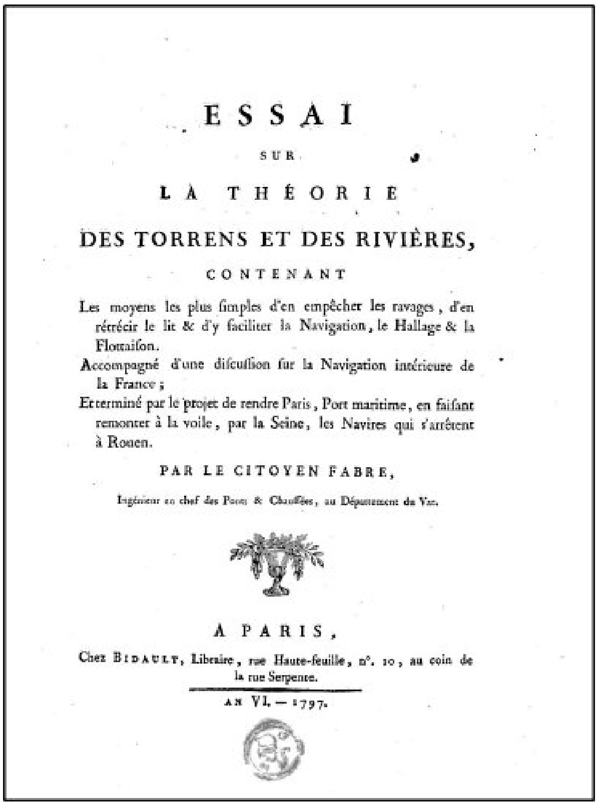
After the fall of the Second Empire in 1870, the Law on the Restoration and Conservation of Mountain Lands (RTM) was proclaimed in 1882. The new republican assembly, listening to the rural populations, reduced the ambitions of reforestation: the work effort would be concentrated where "**restoration 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. This shift was therefore 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 forest engineering, biological engineering for small structures [5] (bundles of branches called fascines & vegetated benches) and civil engineering for dikes, tunnels, sills and dams[2]. These are the most visible and emblematic works in the field of torrential correction 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 deposition ranges [6]. The decision to abandon, maintain or improve a torrent correction 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 torrential correction dams emerged and evolved. We will see that, depending on its location and characteristics, a **structure as simple as a dam filled with rollers**, 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"


ESSAI

SUR

LA THÉORIE

DES TORRENS ET DES RIVIÈRES,

CONTENANT

Les moyens les plus ſimples d'en empêcher les ravages, d'en rétrécir le lit & d'y faciliter la Navigation, le Hallage & la Flottaiſon.
Accompagné d'une diſcuſſion ſur la Navigation intérieure de la France;
Et terminé par le projet de rendre Paris, Port maritime, en faiſant remonter à la voile, par la Seine, les Navires qui s'arrêtent à Rouen.

PAR LE CITOYEN FABRE,

Ingénieur en chef des Ponts & Chauſſées, au Département du Var.

A PARIS,

Chez BIDAULT, Libraire, rue Haute-feuille, n°. 10, au coin de la rue Serpente.

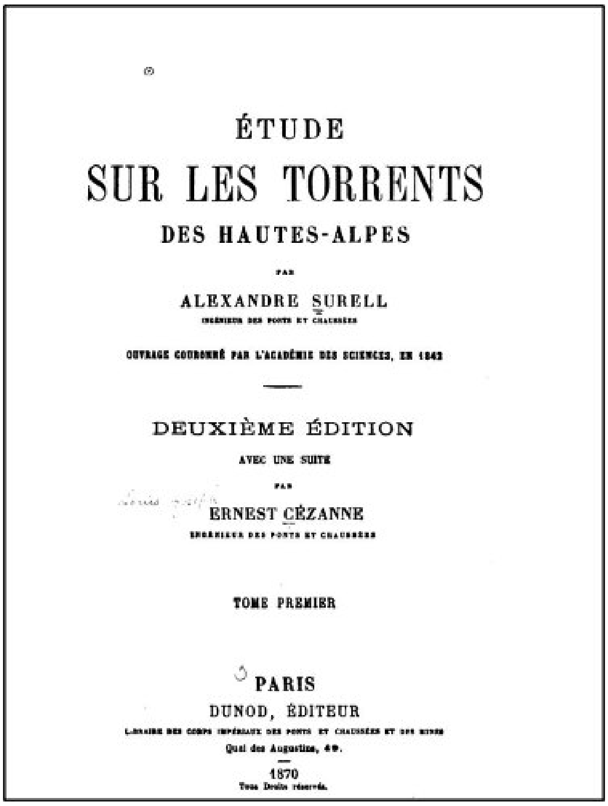
AN VI. — 1797.

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 forest lobby worked to curb uncontrolled deforestation and to initiate mountain regreening [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 fight against erosion [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: **attacking 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.


ÉTUDE
SUR LES TORRENTS
DES HAUTES-ALPES
PAR
ALEXANDRE SURELL
INGÉNIEUR DES PONTS ET CHAUSSÉES
OUVRAGE COURONNÉ PAR L'ACADÉMIE DES SCIENCES, EN 1842

DEUXIÈME ÉDITION
AVEC UNE SUITE
PAR
ERNEST CÉZANNE
INGÉNIEUR DES PONTS ET CHAUSSÉES

TOME PREMIER

PARIS
DUNOD, ÉDITEUR
LIBRAIRE DES CORPS IMPÉRIAUX DES PONTS ET CHAUSSÉES ET DES MINES
Quai des Augustins, 49.
1870
Tous Droits réservés.

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 **torrential correction 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 torrentialcorrection dams. These engineers tried to focus the design of protection structures on flood processes, stressing the need to adapt the protection system to the specificities of the catchment area.

They highlight that, unlike river systems, the origin of hazards in the case of torrents is related to **excess solid transport** rather than **excess liquid flow**. The resulting hazards (mudflows, floods, sedimentary deposits, gullies) are the result of a sediment supply exceeding the transport capacity of the flow, which is strongly correlated to the slope of the sections. Gras and Breton recommend that torrential channels on dejection cones should not simply be dammed; this would simply mean sending the same problem of excess sediment further downstream. The downstream river system (river or agricultural drains), with insufficient slope to transport this solid load, would then tend to become fattened, 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.

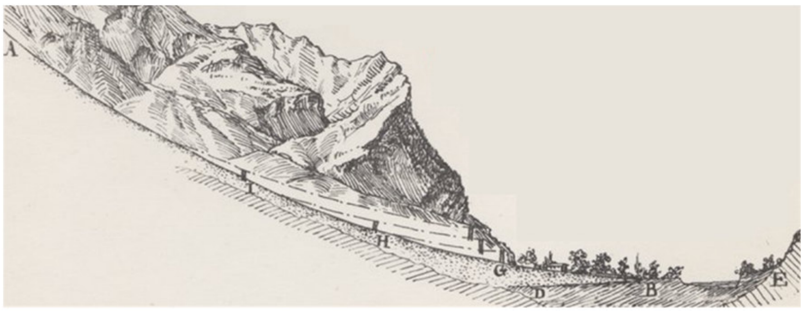


Figure 3. Optimal site for implementing a series of retention dams (at point G) to encourage maximum retention volume in the gorge, i.e. the area between the basin head (upstream of A) and the dejection cone (downstream of G), rather than the dispersion of dams (at points I and H) storing smaller volumes. [© Breton [11]]

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

Figure 4. Hamlet of Bionnay ravaged by the rupture of the Tête Rousse glacier pocket and the torrential lava that formed downstream. Catastrophe which caused 175 deaths in 1892. [© Kuss [19]]

In addition to the channel stabilization role already mentioned by Surell, Gras, Breton and Costa de Bastelica theorized new possible functions of torrential correction dams: (i) **sediment retention** (focus section 4), total trapping in the upstream section, called "landing" in torrential jargon (Figure 3), (ii) **slope consolidation** (focus section 2), the idea being to slow 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 temporarily store solid flows.

3. Waters and Forests

Figure 5. Dams retaining moraine deposits from the basin heads: Arandellys ravine, a tributary of the Griaz River that flows into the Arve downstream of the EDF Houches 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 educators and practitioners who have marked the history of torrential correction and the use of 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 **lake and ice pocket breaks** (Figure 4 & Figure 5), consolidation work on **large landslides and** rock avalanches (Figure 6). They also use drainage or **diversion** systems **and bypass** them (Figure 7).

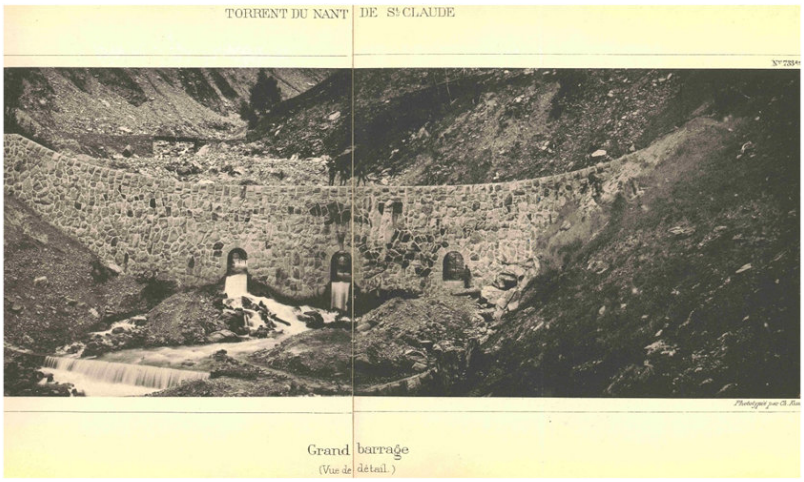


Figure 6. Grand barrage du Nant Saint Claude downstream of a landslide (73). The dam is equipped with openings allowing water to pass through until it fills with materials and thus raises the level of the stream (see Focus on slope consolidation). [© C. Kuss18]

Bernard's courses [15] are a state of the art in understanding torrential morphodynamics and the techniques for controlling it. Torrential correction 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

Slope consolidation

Reduction of bed slopes (read focus,

Sediment retention

Regulation of solid transport

Bed stabilization

Slope consolidation

Reduction of bed slopes (read focus,

Sediment retention

Regulation of solid transport

Figure 7. Downstream outlet of the tunnel bypassing the 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 had to be maintained. The post-war period saw the advent of **two technologies that would revolutionize torrential correction: reinforced concrete and earthmoving machinery** [4]

The use of reinforced concrete made it possible from 1955 onwards to design and build self-stable dams. These are less expensive than masonry weight dams for large dams [2]. Reinforced concrete can also be used to build new structures such as filter dams that close off deposition beaches. The conceptualization and first tests of filtering dams, carried out in the 1950s and 1960s, are considered a world first [2]. The real development 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 Forestry Office in 1966.

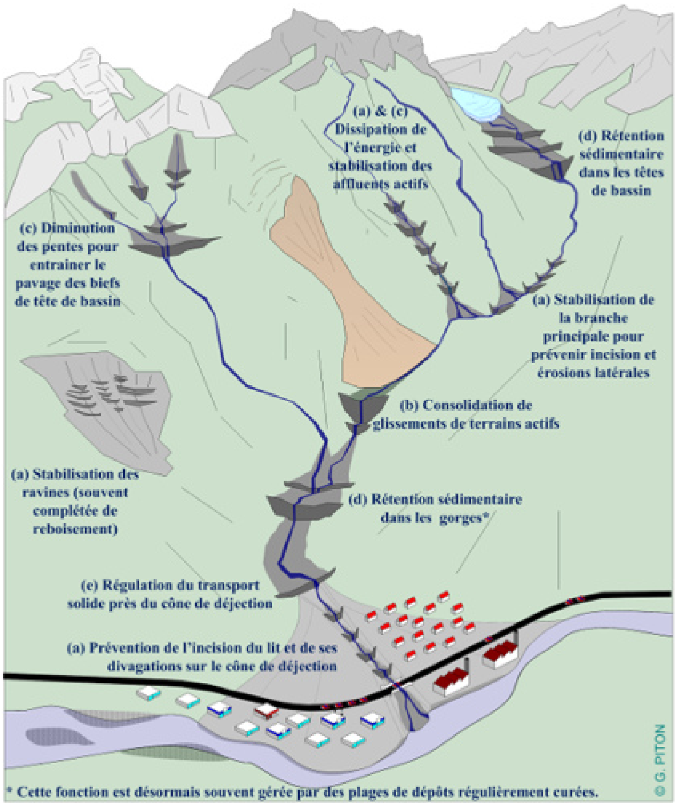


Figure 8. Examples of typical dam configurations and associated main functions: (a) bed stabilization, (b) slope consolidation, (c) slope reduction, (d) retention and (e) regulation of solid transport; additional corrective measures (reforestation, drainage, channelization, embankments and deposition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

4. A huge park of structures to be managed

In 1964, the former Water and Forestry Administration had 92,873 dams and torrential correction thresholds, 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 exodus, decreased grazing, climate change since the end of the Little Ice Age and spontaneous or artificial reforestation have reduced 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 issues and road and rail networks.

The management of torrential correction 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 "domino" effects [23].

The **management of the immense French fleet of torrential correction works therefore requires a better understanding of the potential effects of 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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[6] Structure dedicated to the trapping of solid load (sediment and wood), generally consisting of a sedimentation basin, closed by a civil engineering structure, pierced by openings, called "filtering barrier", see Piton, 2016, ibid. chapters 2 & 3. these areas are regularly cleaned by earthmoving machinery.

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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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