Torrent Control With Check Dams: Historical Evolution in France

Workshop "Flood hazard, mitigation works and residual risks: how can we manage changes over time?"
Trento, Italy, Oct. 9-10 2023

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Prepared with the help of
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Early XIXth century

End of the Little Ice Age, widespread deforestation

Hydraulic engineering managed by the "Corps des Ponts et Chaussées" (Bridge and road engineers)

- Flood protection techniques defined according to the vision of the civil engineers in charge of the large lowlands rivers → rely on dikes
- Investments to protect strategic transportation axis (roads and railways), e.g. connection with the Italian border
- Pioneering works (Fabre 1797, Surell 1841, Gras 1848, 1850) paying attention to sediment transport and stressing its importance

Gras (1850) reports aggradation of 8cm/yr of the Romanche River channel bed since the dikes construction in the Bourg-d'Oisans plain (royal road Grenoble – Briançon)

Grollaz (Northern Alps ©Archives of ONF-RTM)

Queyras (Southern Alps ©Archives of ONF-RTM)

Pioneer studies of torrent control and the use of check dams in France

Surell (1813-1887) provides the first monography on 1841 explaining why torrents behaves differently from rivers and thus dikes won't work

→ We must fight erosion in the headwater, let's plant millions of trees!

Gras (1806-1873) advocates for simultaneous use of check dams and reforestation

→ To create sediment traps (1850)

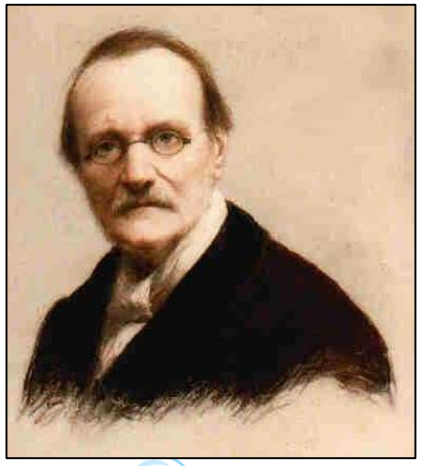
→ To buttress sediment at cliff toe and regulate sediment transport (1857)

Breton (1811-1892) pushed forward the ideas regarding retention check dams (1867) as complementary with reforestation

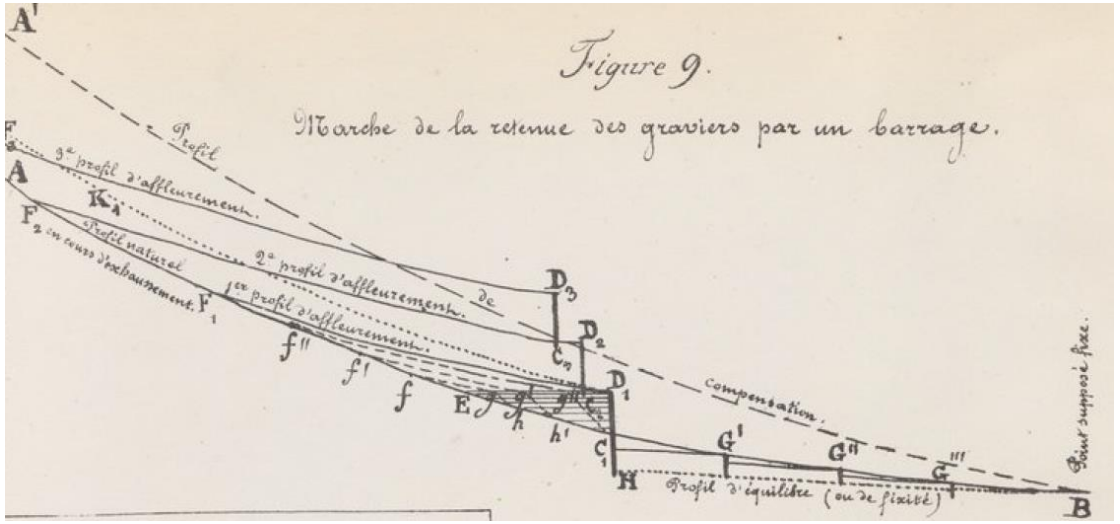
→ Would be more readily effective, though only until filling, then build new structures

→ Anticipate the downstream incision by hungry water effect, can be used to increase channel capacity, but should be stabilized at some point

Source Image http://www.bibliotheque-dauphinoise.com/alexandre_surell.html



Source Image © Muséum de Grenoble



Breton (1867) p. 79

Similar ideas emerged in the central and eastern Alps (e.g. von Zallinger 1779, von Aretin 1808 & Duile 1826)

Mid XIXth century: flood crisis

In a context of an authoritarian political power

"Forester lobby" promoted reforestation of mountain areas (e.g. Surel 1847)

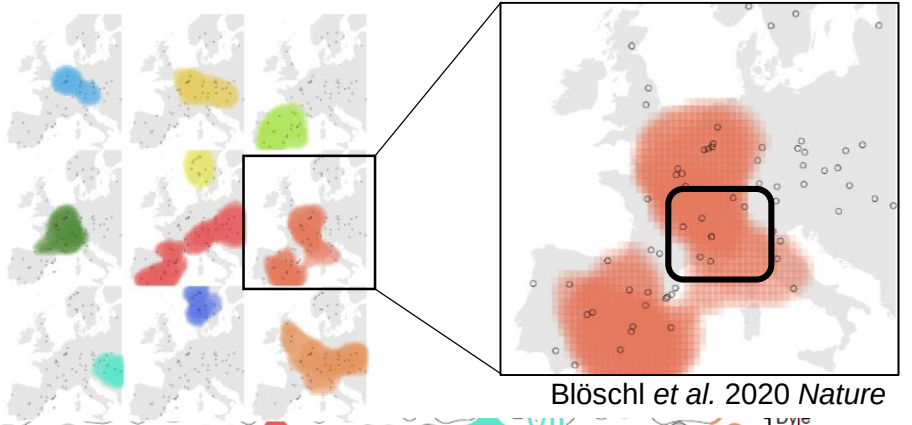
Napoléon III, elected, became Emperor of France (1852 – 1870)

Flood crisis at the same time (2nd strongest in Europe on 1500 – 2020, Blöschl et al. 2020 *Nature*)

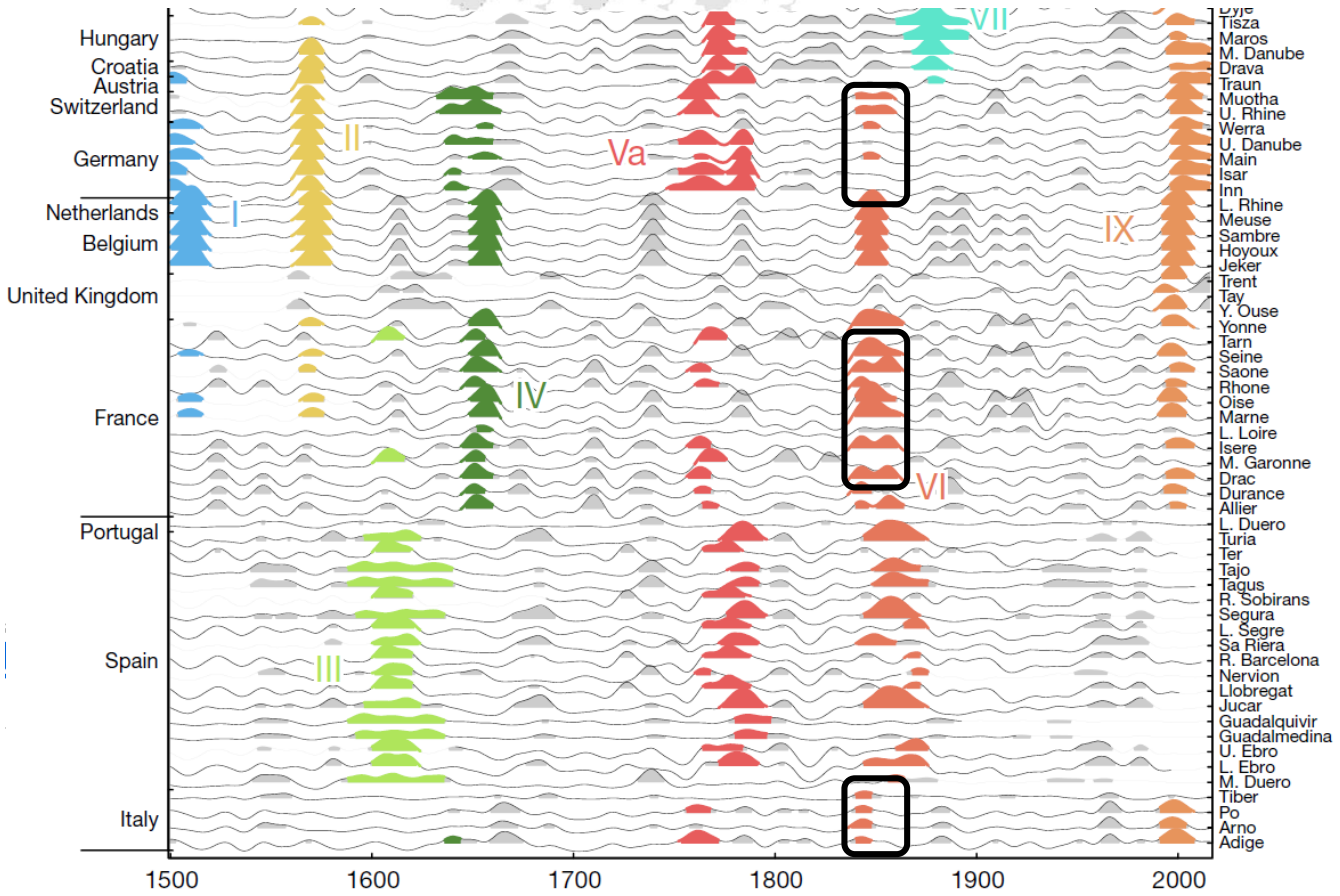
→ Ambitious reforestation law on 1860

- Targets 11 000 – 12 500 km² of reforestation
- Main official objective is hydrological: reduce floods in large rivers

→ Trigger strong contestation and even riots, adjust the ambition with a new law on 1882



Blöschl *et al.* 2020 *Nature*

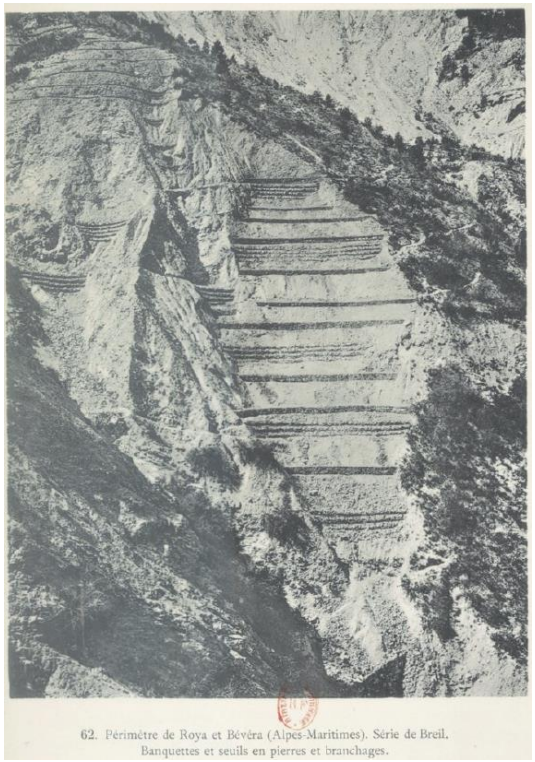


Forester golden age until WWI: 1st generation of engineers

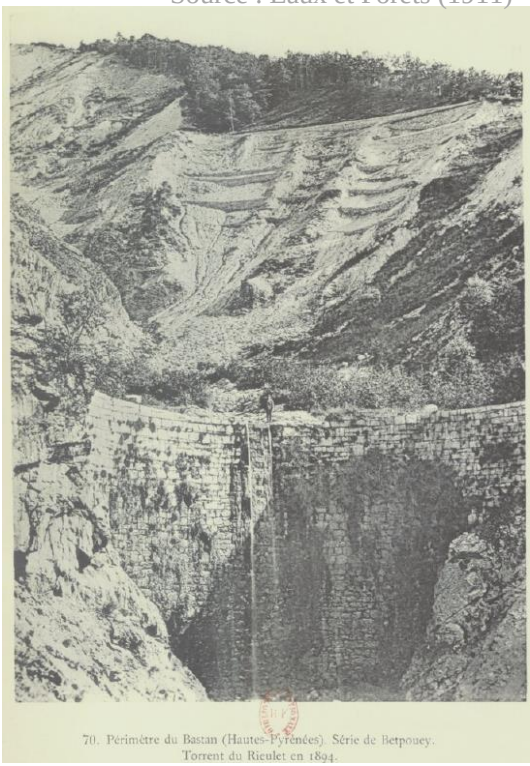
Demontzey (1831–1898) and Thiery (1841–1918): pioneers in implemanting reforestation masterplans

Source : Eaux et Forêts (1911)


92. Périmètre du Var Supérieur (Alpes-Maritimes). Série d'Entraunes. — Seuils en pierre sèche avec fascines.


62. Périmètre de Roya et Bévéra (Alpes-Maritimes). Série de Breil.
Banquettes et seuils en pierres et branchages.

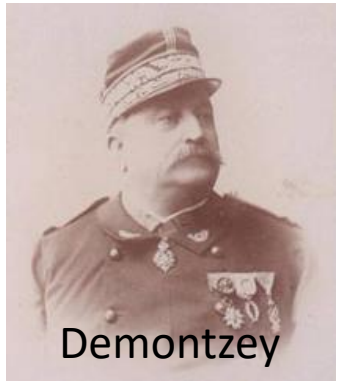

3. Périmètre de l'Ubaye (Basses-Alpes). Série de Faucon.
Partie inférieure du torrent du Bourget en 1887.


70. Périmètre du Bastan (Hautes-Pyrénées). Série de Betpouey.
Torrent du Rieulet en 1894.

Publishes in 1882 a comprehensive treatise on torrent control where check dams are key measures to stabilize banks and hillslope the time it takes to reforest them

In due time some of those structures can be abandonned

→Focus check dam use on stabilization, no mention to other functions

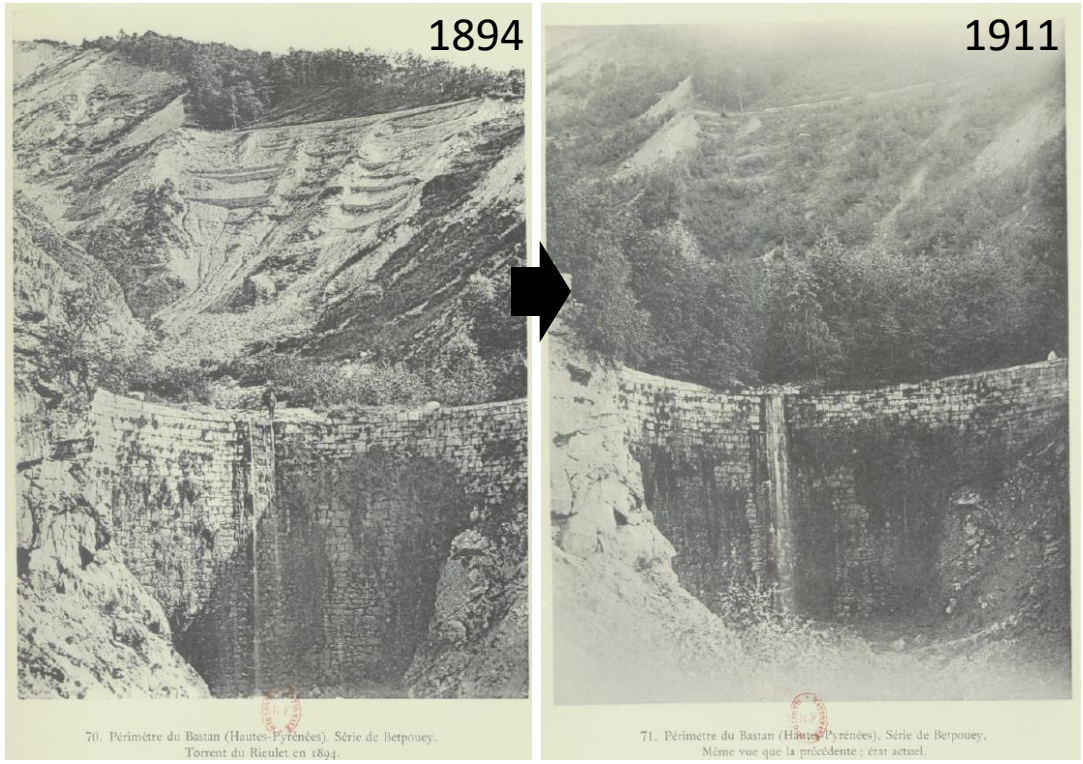

Demontzey

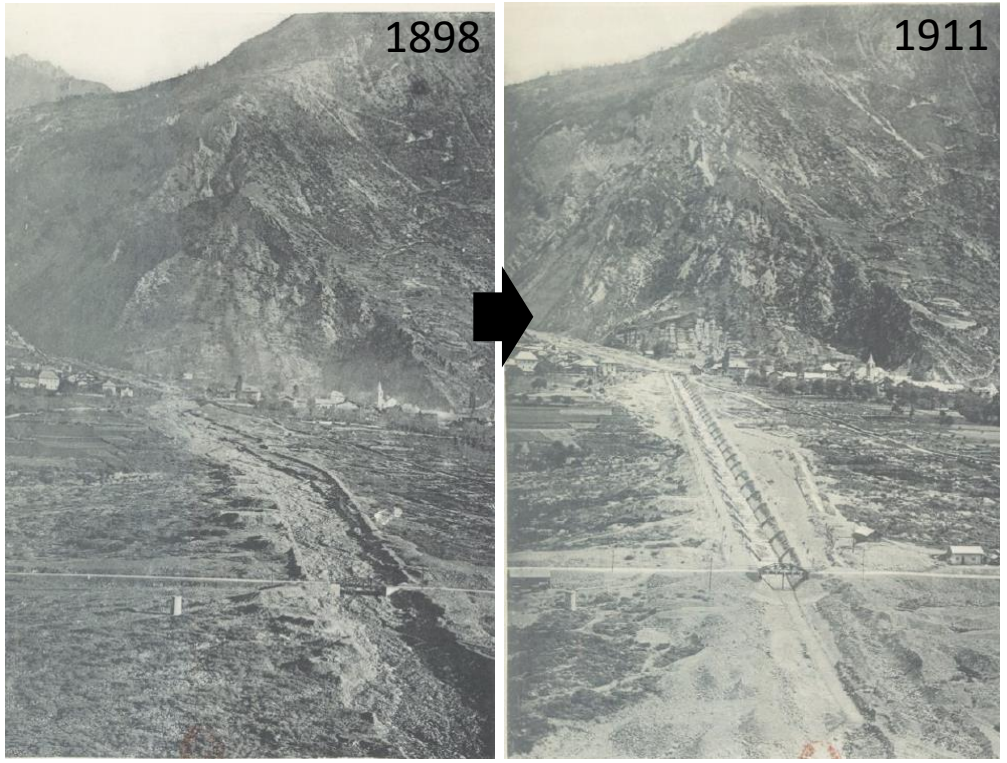
Source : http://ubaye-en-cartes.e-monsite.com/pages/hommes-celebres/prosper-demontzey.html

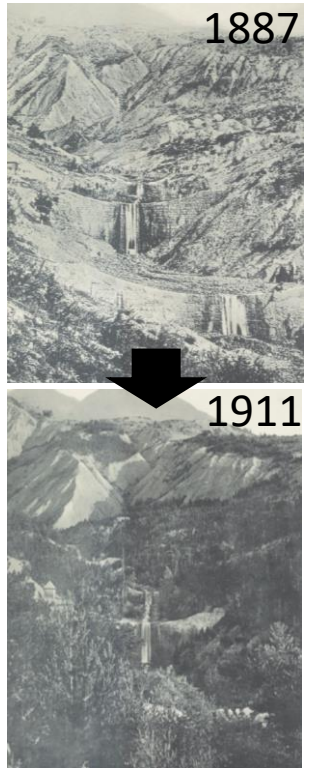
Forester golden age until WWI: 2nd generation of engineers

Paul Mougin (1866–1939), Charles Kuss (1857–1940), and Claude Bernard (1872–1927)

Source : Eaux et Forêts (1911)







Implement torrent control works in 1000⁺ torrents and 100⁺ landslides in the Alps

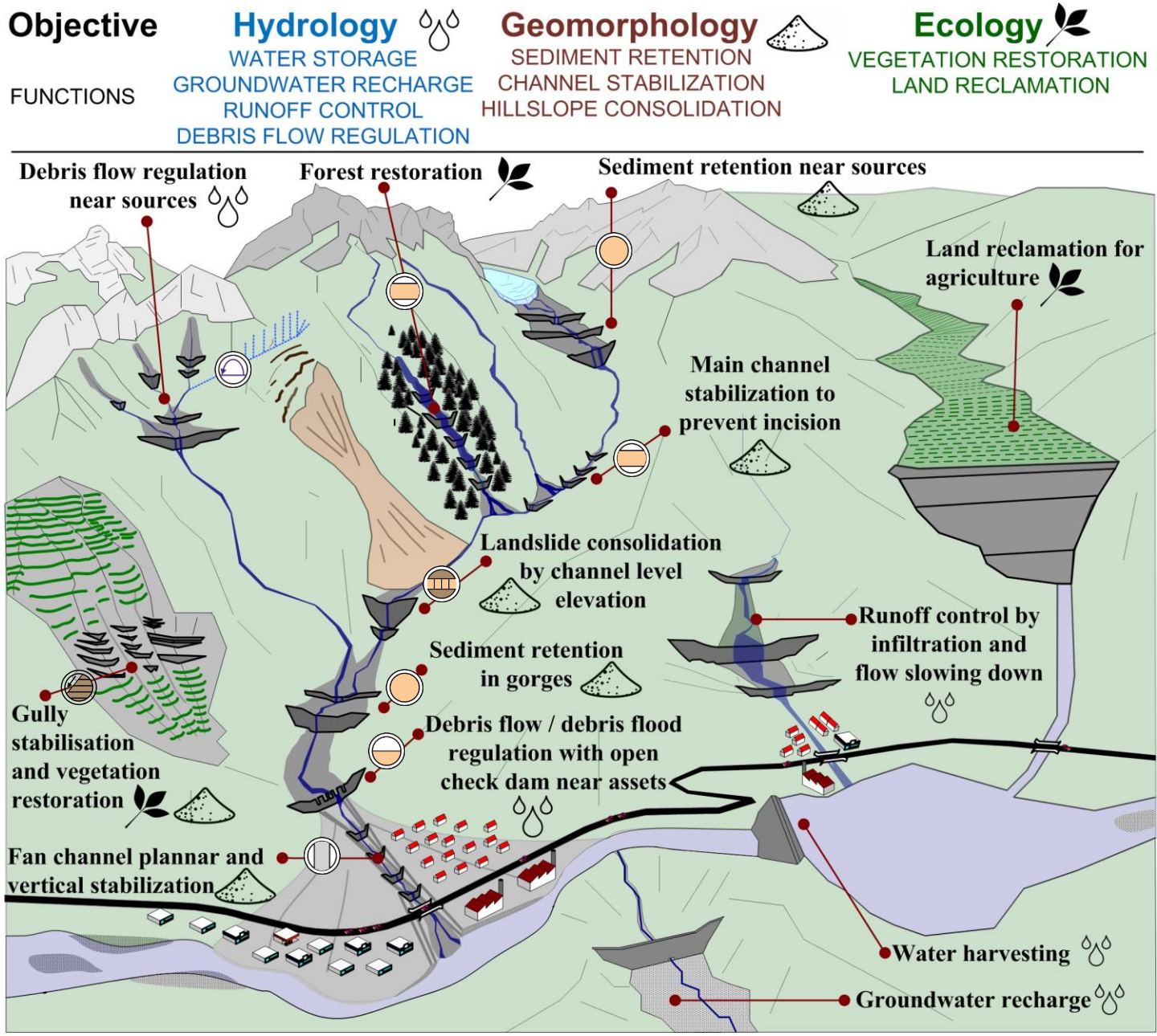
Build complementary measures: diversion tunnels with subterranean check dams, canals, etc.

Improved design and construction techniques, start studying landslides, avalanches, archives

Measure functions

Fully defined in Bernard (1926)

Function	Effect on the processes
Soil conservation	Prevent erosion on hillslopes using vegetation protective capacity
Channel stabilization	Prevent long term incision (temporal) and extented channel erosion events (spatial)
Hillslope buttressing	Decrease sediment supply by decreasing landslide or rock avalanche movements
Diversion	Divert runoff and channel flows from erosion-prone areas toward stabler areas
Debris buffering	Transiently store solid transport to reduce solid peak discharge
Debris deposition	Trap a certain volume of sediment
Conveyance	Convey flows along a chosen path

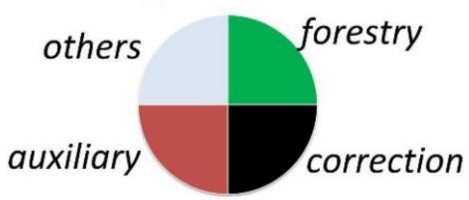


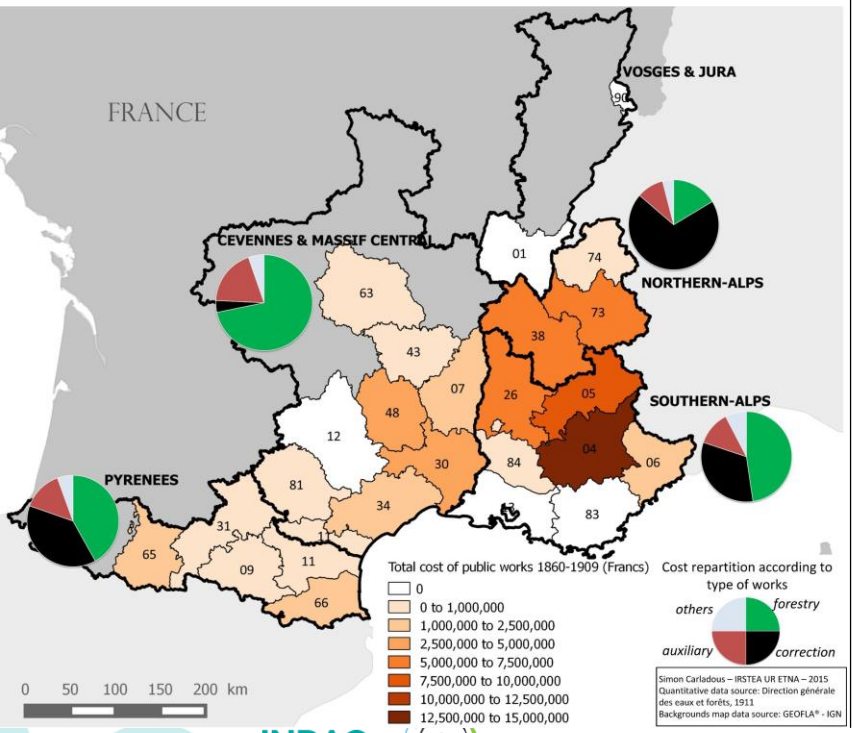
Piton et al. 2017 *ESPL,* Lucas-Borja et al. 2021 *CATENA*

Achievement in 1909 and 1964

Carladous *et al.* 2016
Interpraevent Conf. Proc.

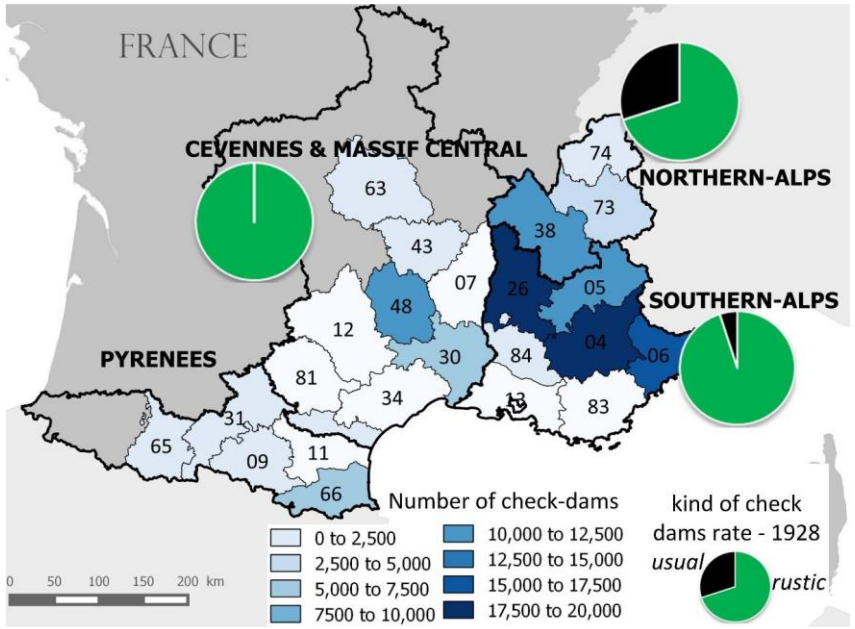
Cost of public works 1860 - 1909

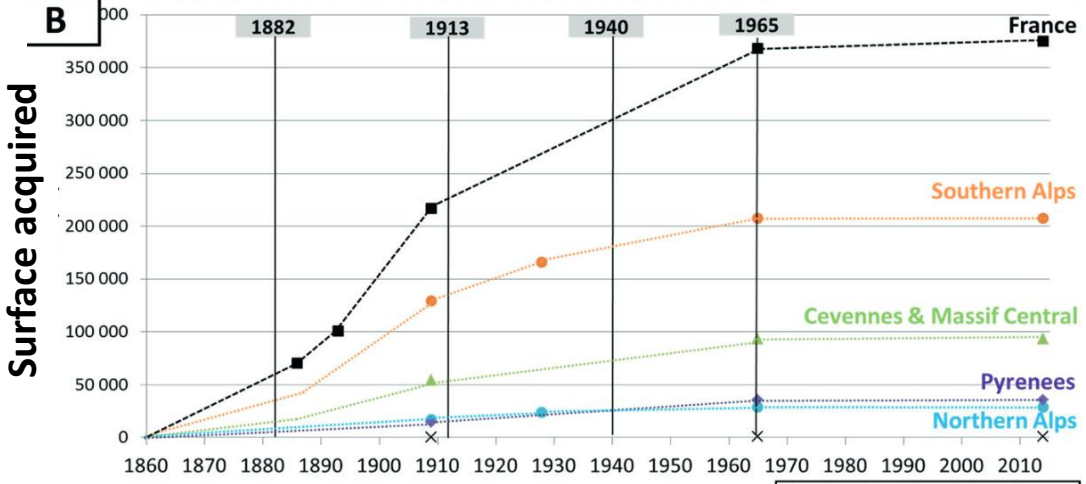




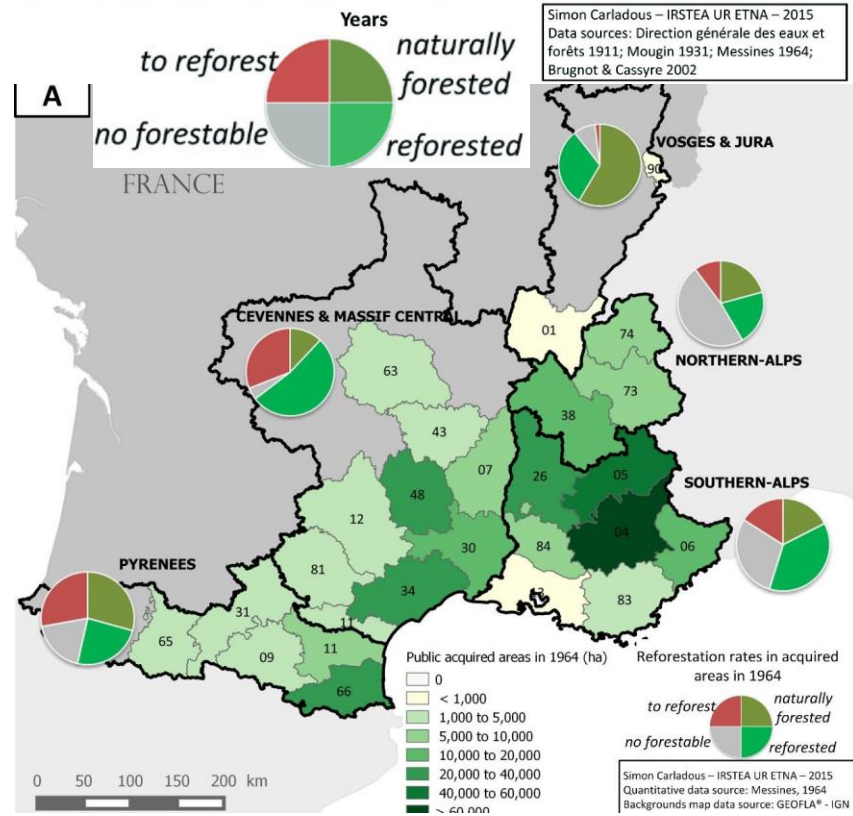
Number of check dams in 1964

Total > 100 000





Simon Carladous – IRSTEA UR ETNA – 2015
Data sources: Direction générale des eaux et forêts 1911; Mougin 1931; Messines 1964; Brugnot & Cassyre 2002



Simon Carladous – IRSTEA UR ETNA – 2015
Quantitative data source: Messines, 1964
Backgrounds map data source: GEOFLA® - IGN

Surface publically acquired in 1964

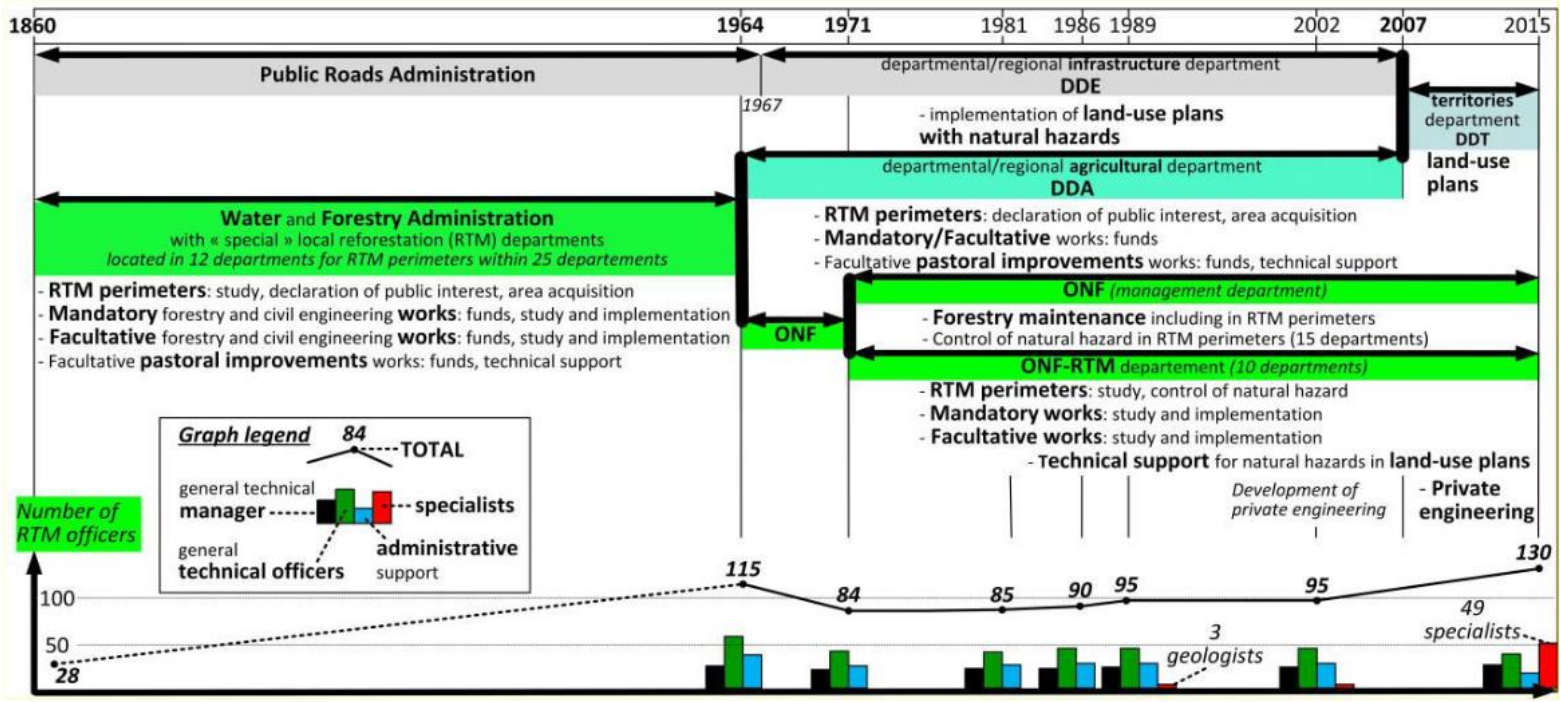
Total > 3 800 km²

and also 28 km of channels and tunnels,
663 km of landslide drains, etc.

WWII to nowdays: time of maintenance and new technology

Changes in the administration organisation

Reorganisation in 1964 where the Water and Forestry administration disappeared, protection forest and torrent control works were transferred to the newly created Forest National Office, with a dedicated Torrent Control Service (ONF-RTM)



Carladous *et al.* 2016 *Floodrisk Conf. Proc.*

New technologies enabling new structures and management

Reinforced concrete

→Make possible to build higher dams and dams with orifices

Earth moving machinery

→ Make possible to dredge deposits

Source: Wikipedia

Emergence of open check dams used as sediment traps

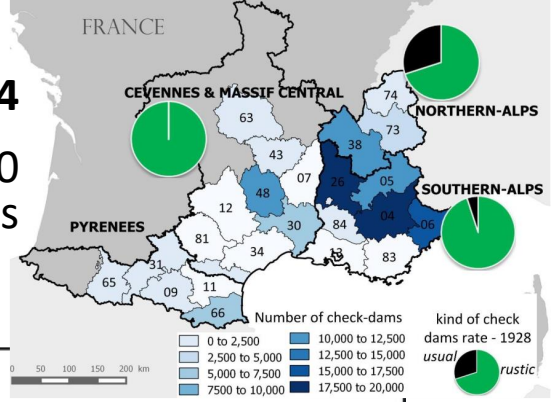
Current organization and maintenance policy

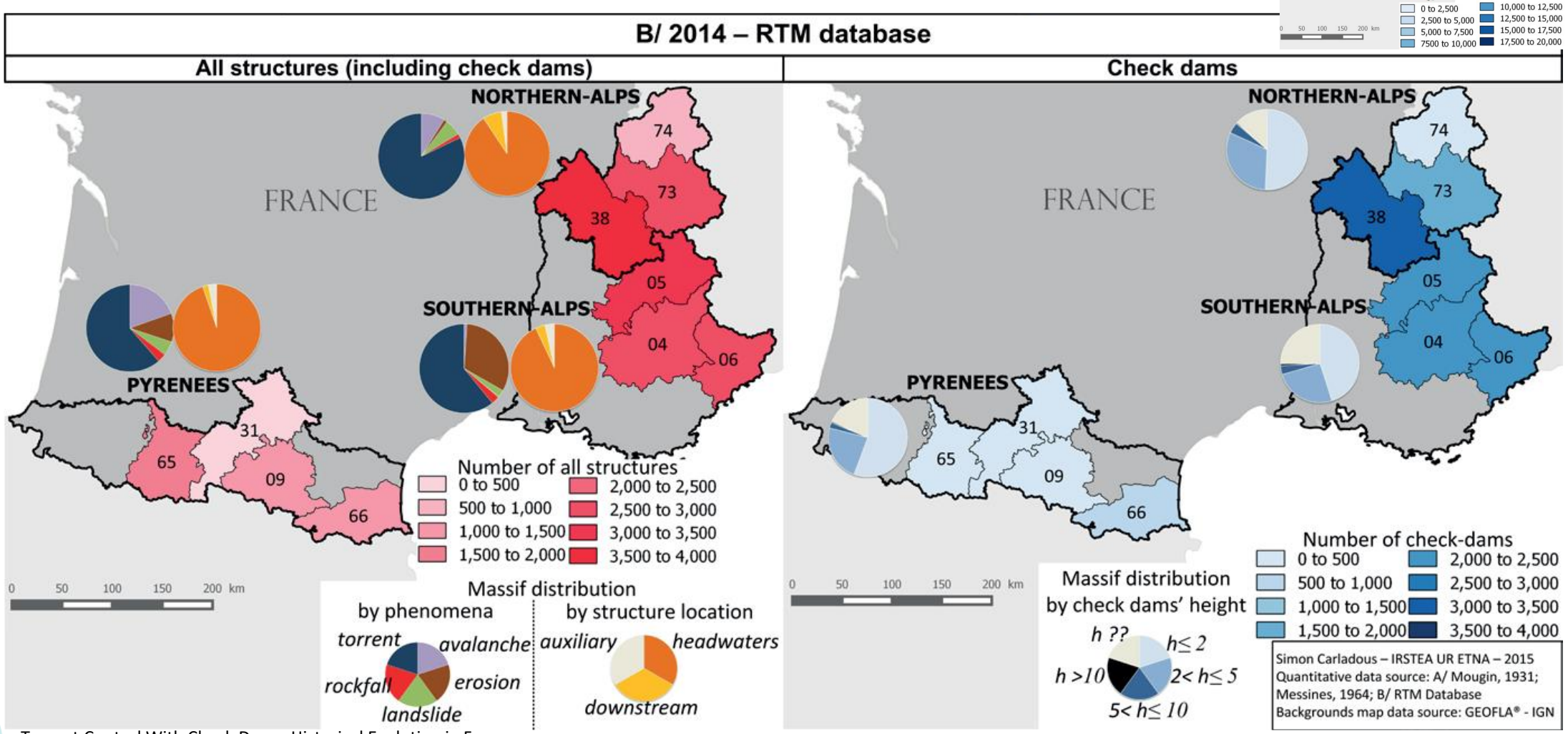
Torrent control services only in the Alps and Pyrénées

Managing State-owned structures mostly located in headwaters

1964

> 100 000 check dams





Carladous *et al.* 2016 *Interpraevent Conf. Proc.*

2014 ~14 000 check dams, being 85% of the structures

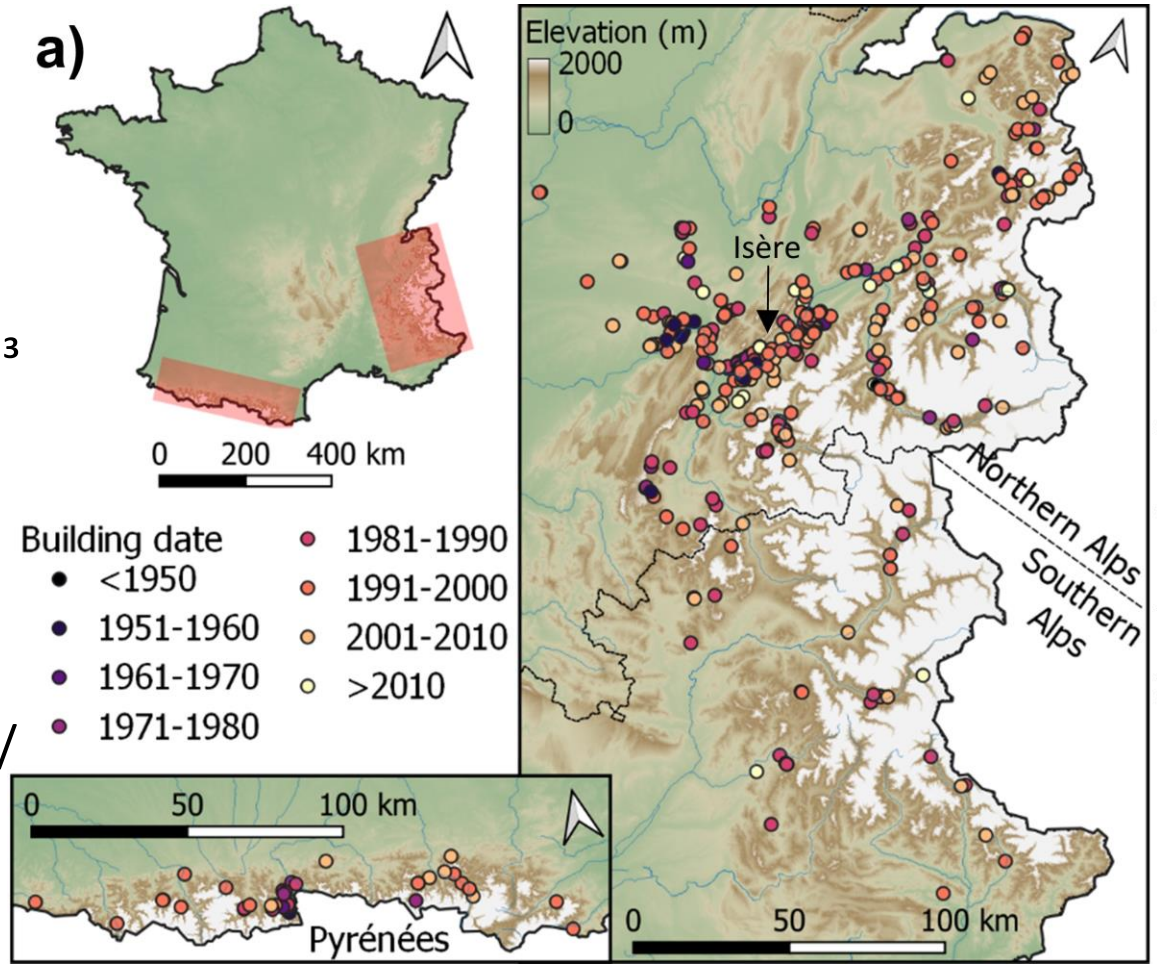
Open check dam inventory

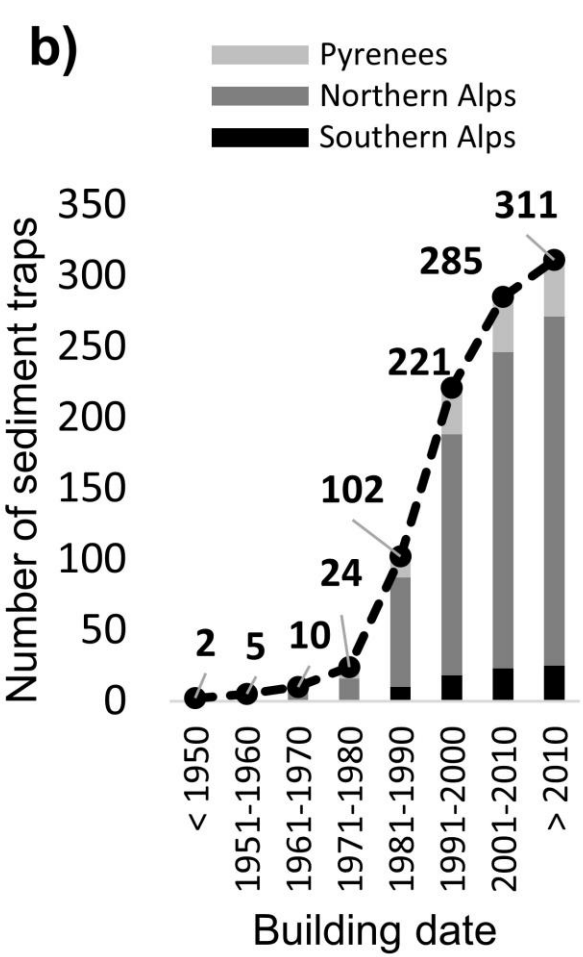
Carladous et al. 2022 Chap. 13 of *Check Dam Construction for Sustainable Watershed Management and Planning*

Inventory of open check dams

- 330 structures found (many small structures missing)
- 50%: $V_{retention} < 1000\ m^3$
- 22%: $1000\ m^3 < V_{retention} < 5000\ m^3$
- 26%: $5000\ m^3 < V_{retention} < 50000\ m^3$
- 2% : $V_{retention} > 50\ 000\ m^3$

→ 115 Interviews of managers regarding location, type of structure, processes at work, protected assets, maintenance / dredging and failures / malfunctioning

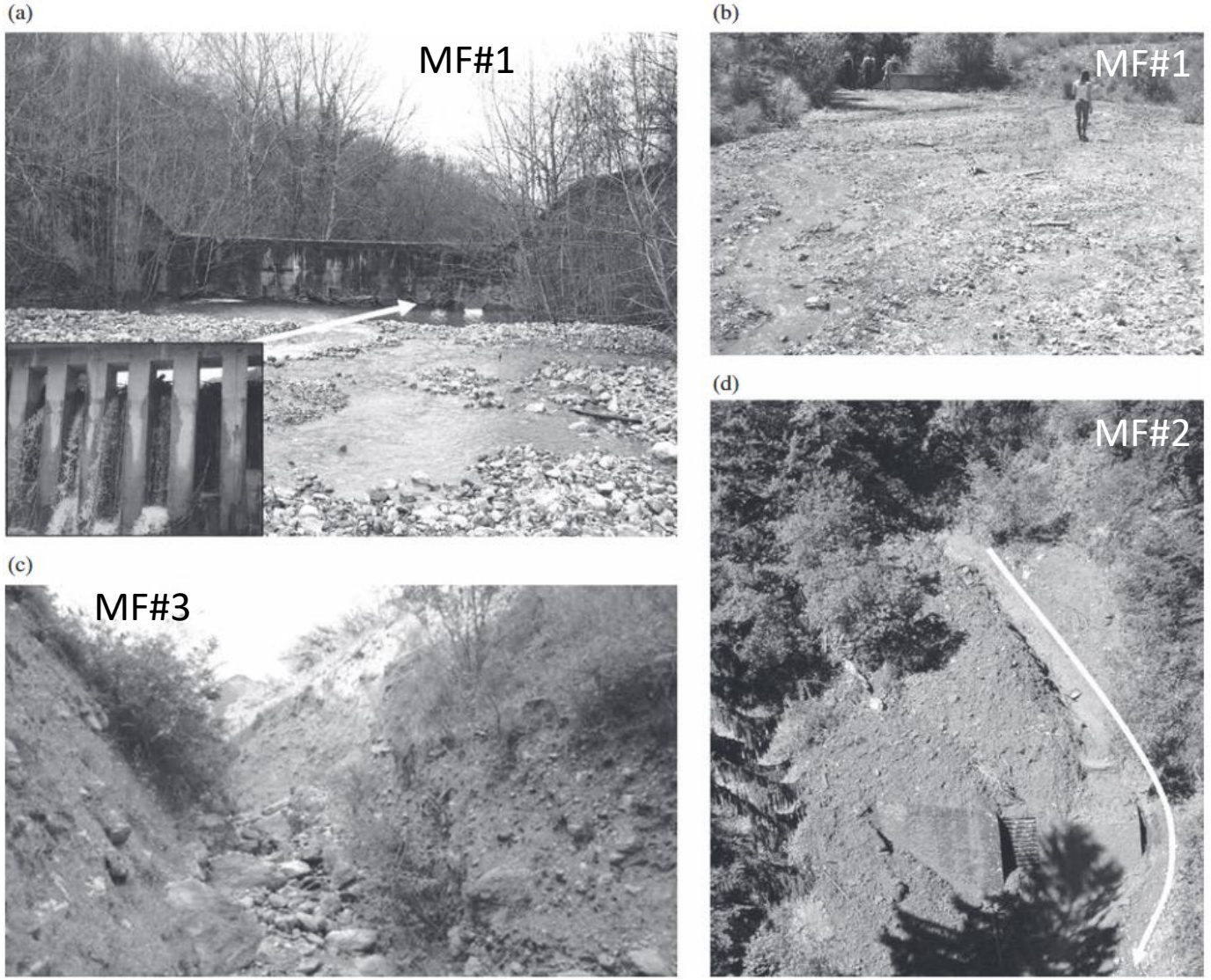




Open check dam inventory

Carladous et al. 2022 Chap. 13 of *Check Dam Construction for Sustainable Watershed Management and Planning*

Malfunctions	Causes	Consequences	freq
MF#1 **Trapping excess:** stopping of materials and filling for routine event	Opening too small and/or basin too flat	Downstream incision + expensive maintenance + lower retention capacity	**33%**
MF#2 **Outflanking of the barrier**	Ill-design barrier	Trapping failure (full or partial)	**18%**
MF#3 **Location too far upstream of element at risks**	Complicated land acquisition	Same than for MF#1	**7%**
MF#4 Structural damage on the open check dam	Impact of boulders and debris flows	Lower durability or stability	**6%**
MF#5 Insufficient storage capacity	Many!	Insufficient protection efficacy	**5%**



Event and structure databases

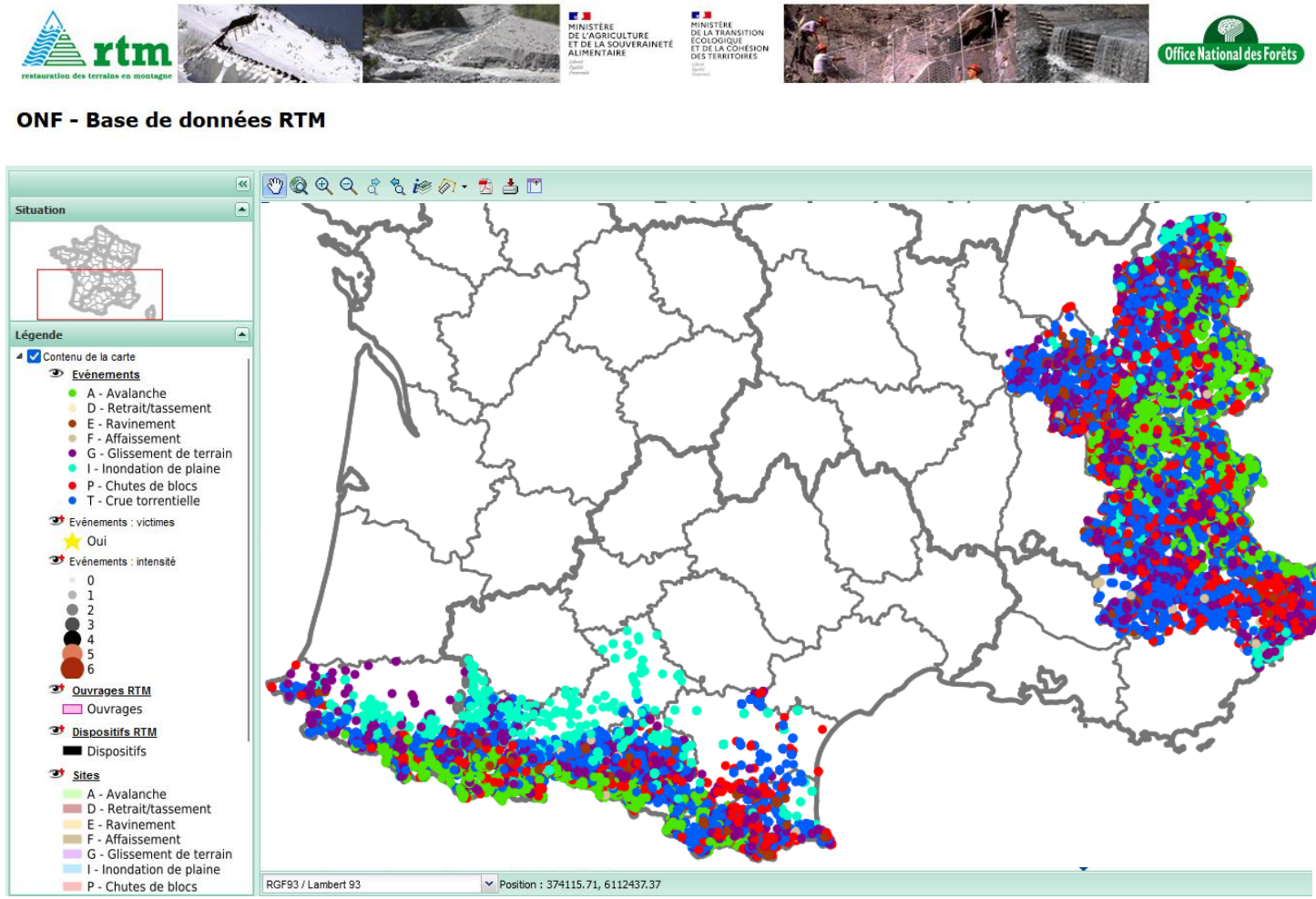
Online databases freely accessible for practionners: https://carmen.carmencarto.fr/105/ONF_BDRTM.map#

Events

- 17 000⁺ torrential floods ,4000⁺ river floods, 900 hillslope gullying, 5000⁺ landslides
- Old (XIXth century) and very old (XVIIth century) major events taken from historical archives
- Most events of the XXth century with information of date, triggering event, location, extension, damage, fatalities

Protection structures

- Only those managed by the ONF-RTM
- 21 000 structures in 2000⁺ basins
- 14 000⁺ check dams



Protection structure database

Online databases freely accessible for practionners:
https://carmen.carmencarto.fr/105/ONF_BDRTM.map#

Online content

- Location, type, owner, construction date
- Material, main geometrical features
- Function, importance

Private content

- Structural and functional status, pictures
- Efficacy of protection systems

From regular inspections at frequency: 1|3|10 year

In case of large event or worrying changes, detailed inspections are organized

Saint antoine in Modane © RTM73

Riou Bourdoux in Barcelonette (Ubaye)

Check dam, retaining wall, open check dam
Drainage system, canal
Consistent protection system

0 500 1 000 m

Legal organisation of structure ownership

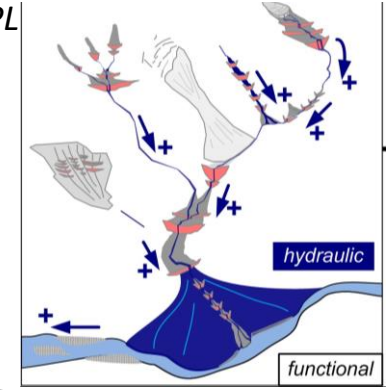
Owned by	The State	Communities
Real estate	Acquired by the central administration	Local public terrains
Location	Mostly in the headwaters	Mostly on fans and river banks
Management	By the ONF-RTM	By basin agencies (GEMAPI law)
Funding	By the Agriculture Ministry	By local tax + up to 50% funding by the State
Investment	Very few new structures	Upgrading of dikes and bank protection, creation of a few flood or debris basins
Maintenance	In 2022, 4.2M€ made internally + 6.8M€ subcontracted to private companies	Not enough,… but dredging basins, reparation of dikes and bank protection after events

Organisation of structure maintenance and investment

General objective	Function	Typical owner	Structure type	Effect on hazard*
Prevent sediment supply	Soil conservation	State	Aforestation, bio-engineering	No
	Channel stabilization		**Check dams**	No
	Hillslope buttressing		**Check dams**, retaining walls	No
	Diversion		Drainage systems, canal, tunnel	No
Change certain features of the processes	Transformation	State & Com	Open check dam	Difficult
	Wood filtration		Open check dam	Yes
	Debris buffering		Open check dam, **check dam**	Difficult
	Debris deposition		**Check dam**, open check dam	Yes
	Water retention		Flood basin	Yes
Guide flows	Conveyance		Dikes, bank protection, **check dams**, bridge, apron	Yes
	Deflection	Com	Berm, open check dam	Yes

*Feasability to assess in detail the effects of the structures on the hazard intensity at the asset locations

Piton *et al.* 2017 *ESPL*



Comprehensive torrent control study for each basin (EBR: study of risk basin) by the ONF-RTM + Multi-year work program at national scale

Cost-benefit analysis of avoided damage by consulting companies at river basin scale p. 16

Studies of risk basins

Currently the standard way to plan torrent control works

- Launched in 2012 with funding by the Ecology Ministry (in charge of natural hazards)
- >250 basins already studied
- Comprehensive appraisal of :
  - Geomorphology of the basin
  - Description of the active processes (landslides, gullying, debris flows, bedload)
  - Archive analysis (past events, location of damages)
  - Protection measure (type, date of works, function, status, maintenance)
  - Hydrology, hydraulics and sediment transport computations
  - Risk analysis and protection efficacy
  - Assessment of past maintenance and construction policy and proposal for the future
- Proof that protection structures are useful and efficiently managed

  → increase of funding for maintenance and investment by several M€

Concluding remarks

- Check dams can be used to interfere with natural processes to achieve many different functions.
- The understanding of check dam effects emerged along with the understanding of the specificities of torrential processes.
- In France, about 100 000 check dams were built to reforest the mountain, 14 000 are still regularly maintained.
- Studying the distant and long term protection effects of check dams remains complicated.
- Open check dams are interesting alternative, that are however ineffective in controlling some key processes (e.g. landslides).
- Maintenance must be done on regular basis by skilled managers and builders.

Thanks for your attention!

Saint Antoine – Modane (Savoie)