Coupled Modeling of Hydro-Sedimentary Transfer Processes and Socio-Economic Dynamics Evaluating Public Policies to Control Runoff and Erosion: Case Study in Normandy (France)

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November 22, 2022

Abstract

Watersheds are complex systems with multiple interactions between physical processes and human-induced socio-economic dynamics. Since the 2000s, numerous flooding and mudslide events have affected the territory in Normandy (France), leading to significant damages. Therefore, a public policy was adopted with the aim to reduce runoff and erosion, it includes: (i) the building of 4,000 hydraulic infrastructures (dams, fascines, hedges, etc.), (ii) the creation of turbidity water-treatment plants and, (iii) the conduction of animation and protection programs on soil and water resources. These investments are co-funded by several local authorities. This original research project aims evaluating the effectiveness of the above-mentioned public policy. Therefore, two complementary approaches are applied: (i) at the regional scale, the investments and damages between 2000 and 2017 were assessed and, (ii) for a pilot small scaled watershed (la Lézarde, 212 km^2) a coupled modeling was conducted, taking hydro-sedimentary processes (flood envelopes, diffuse and concentrated erosion, karstic transfers) and associated socio-economic dynamics into account. Our results suggest that over the study period, at the regional scale 500 M\euro were invested to reduce erosion/runoff impacts and, 300 M\euro of damage were caused. Nevertheless, the effectiveness of the public policy since 2000s must be evaluated at the watershed scale using a Cost-Benefit Analysis (CBA) according to two main scenarios: S1 = pre-development (2000), and S2 = post-development (2017). The processes that govern the surface transfer are modeled for different design floods (Q10-50-100) coupling two semi-dynamic models (MikeSHE and Watersed), and the karstic transfer using a deep learning algorithm (Tensorflow). Additionally, three long-term scenarios (until 2050) are modeled taking into account the effects of climate change (RCP scenarios), the change in land use (-33% of grassland areas), and the modification of agricultural practices that limit runoff. These projections provide key elements for decision-makers to guide future public policies controlling runoff and erosion in this territory.

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AGU 100 FALL MEETING

NO PHOTOS « Only beer is allowed »

Context & Objectives

- Normandy region is located in the European loess belt, and therefore, very sensitive to runoff and erosion → 0.5-10 t/ha/yr (Cerdan et al., 2010)
- Excessive density of muddy flooding → 10-20/km² (Boardman et al., 2019)
- Since 2000, high financial support from several public institutions to reduce erosion and runoff impacts (flooding, damages to infrastructures, turbidity in drinking water, etc.)

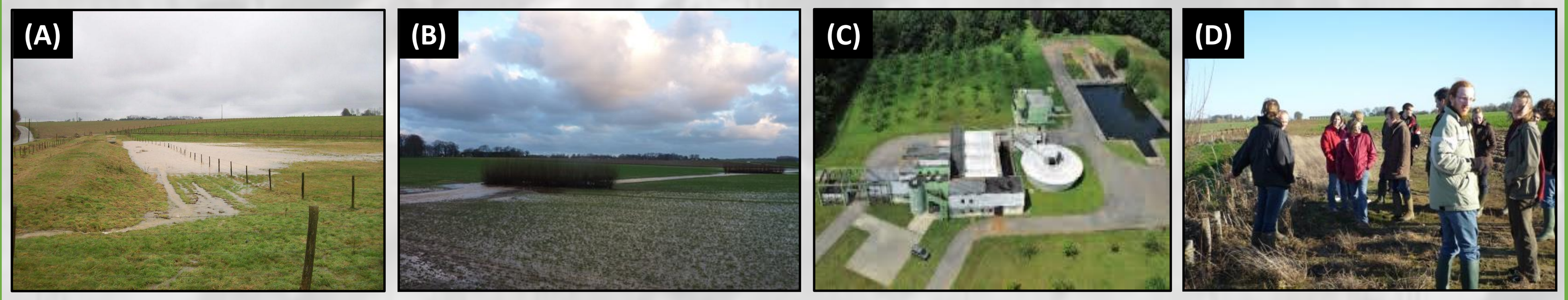
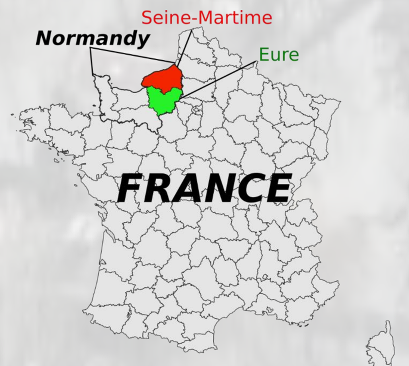


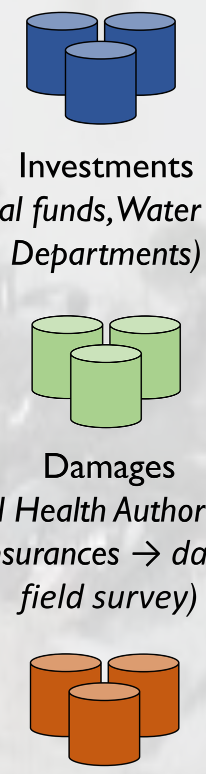
Fig.: (A) Retention pond, (B) Fascines, (C) Water treatment, (D) Animation on the field (credits: AREAS)

I. **Economic performance analysis** of assets for **flood and erosion/runoff** mitigation
II. **Provide key-elements for future public policies** through hydro-sedimentary processes and socio-economic dynamics modeling



Methods & Data

Collecting Data



Investments (Regional funds, Water Agency, Departments)

Damages (Regional Health Authority, French Railway, Insurances → databases + field survey)

Erosion Control Measures (CASTOR – regional database)

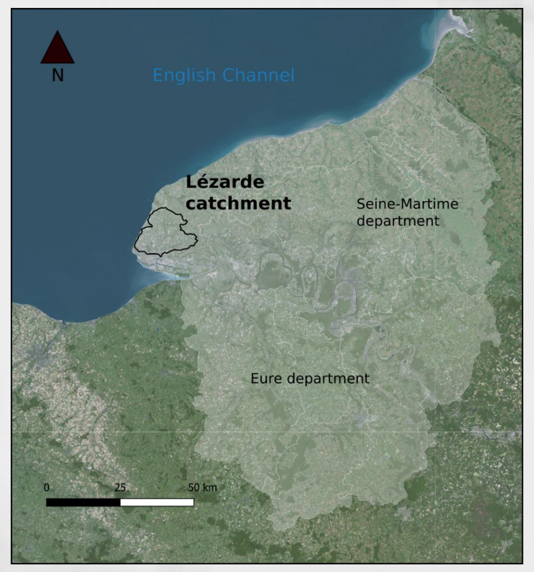
Data Mining & Analysis

Investments :
- Extract subsidized projects linked to erosion/runoff (*n = 4086*)
- Cross-checking for co-financing
- Building typology → classification
- Estimate real volume of public investment (€)

Damages :
- Flooding/mudflow events in *CatNat (French reinsurance; n = 1379)*
- Records on drinking water prohibition (*n = 408*) → cost with local case studies
- Aggregate annual overall damage costs to transport network based on surveys

Maintenance Cost (MC) :
- Dimensions + implementation year
- Annual MC evaluation → literature review
- Adjusting for inflation

Downscaling & Flood Scenarios



i. Rainfall Frequency Analysis
- DDF curves → Meteo France (1996-2006)
- P_{10}=52 , P_{50}=75, P_{100}=87 (mm d^{-1})

ii. Building Scenarios
- Baseline (2000) and Actual (2017)
- Climate change (RCP4.5/8.5)
- Ploughing up 33% of grassland
- Best farming practices (+20% infiltration)
- More, and more, hydraulic infrastructures

2050

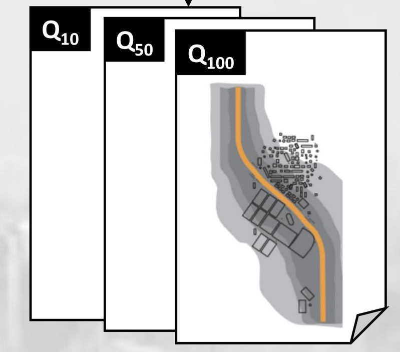
Complex Modeling Chain

Runoff/Flood Hazard modeling
- WATERSED (Landemaine et al., 2015 – BRGM)
- MIKE Hydro River 2019

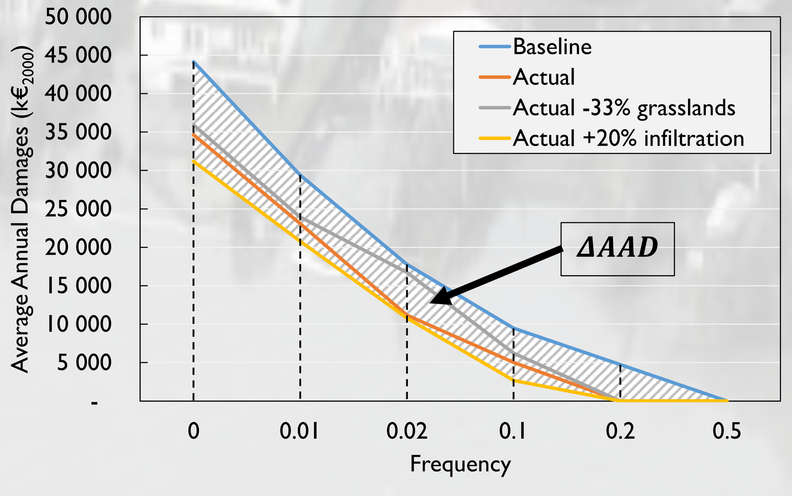
Runoff/Flood Hazard exposure
- Housing/Economic activities/Public institutions
- Cultivated lands

Methods:
- Land-Use database (RPG, cadastral maps, etc.)
- Google Street view + Field Survey

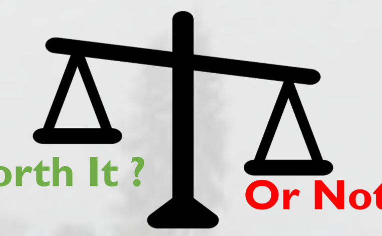
Damage estimation
- *Damage functions (CGDD, 2018)*
- **NEW = sediment management function**



Cost-Benefit Analysis



- Calculate Net Present Value (NPV; €)
- Benefit-Cost Ratio (BCR)
- Identification of sensitive parameters

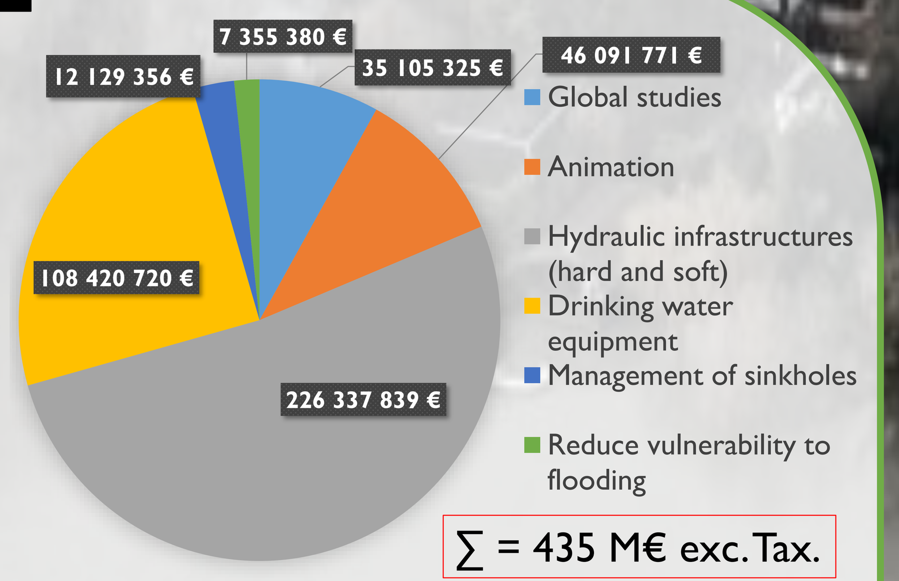


Regional scale — Catchment scale

Economic Overview

i. Investments

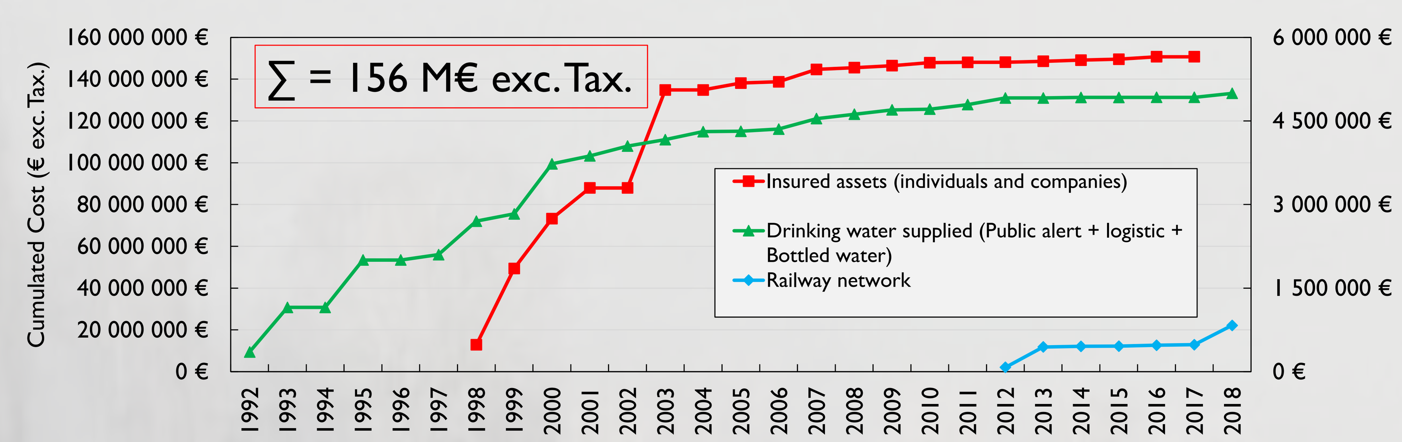
- Seine-Maritime and Eure departments
- Temporal frame: 2000-2017
- 4 public funders (Water Agency, Regional council, Department councils)



∑ = 435 M€ exc. Tax.

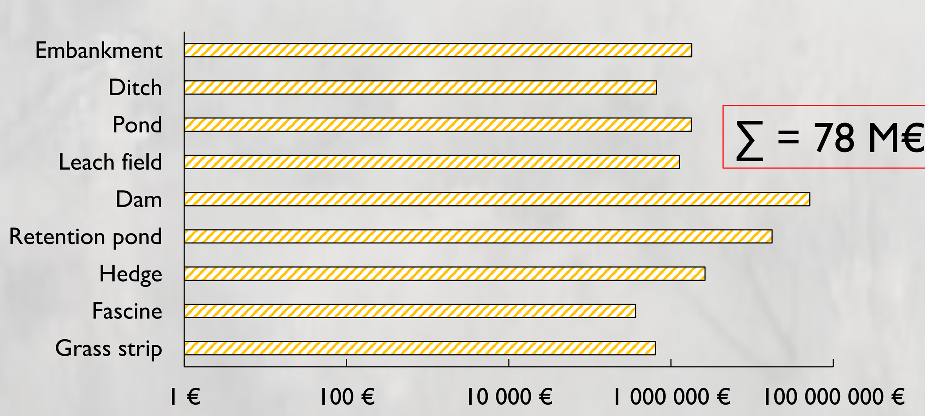
ii. Damages

- CatNat French database (Individuals = 102M€; Companies = 48M€)
- Impacts on railway network → mudflow, landslide, flooding
- Excessive turbidity in drinking water induced by erosion/runoff



iii. Maintenance

- 774 dams/retention ponds
- 211 km of hedges
- 19.2 km of fascines
- 105 ha of grass strips
- 1427 leach field/pond/ditch/embankment



∑ = 78 M€ exc. Tax.

Flood & Runoff Modeling

- Coupled modeling : *WATERSED* (Erosion/Runoff) + *MIKE* (Flood)
- Damages cost is influenced by both the surface of asset flooded and the height of water

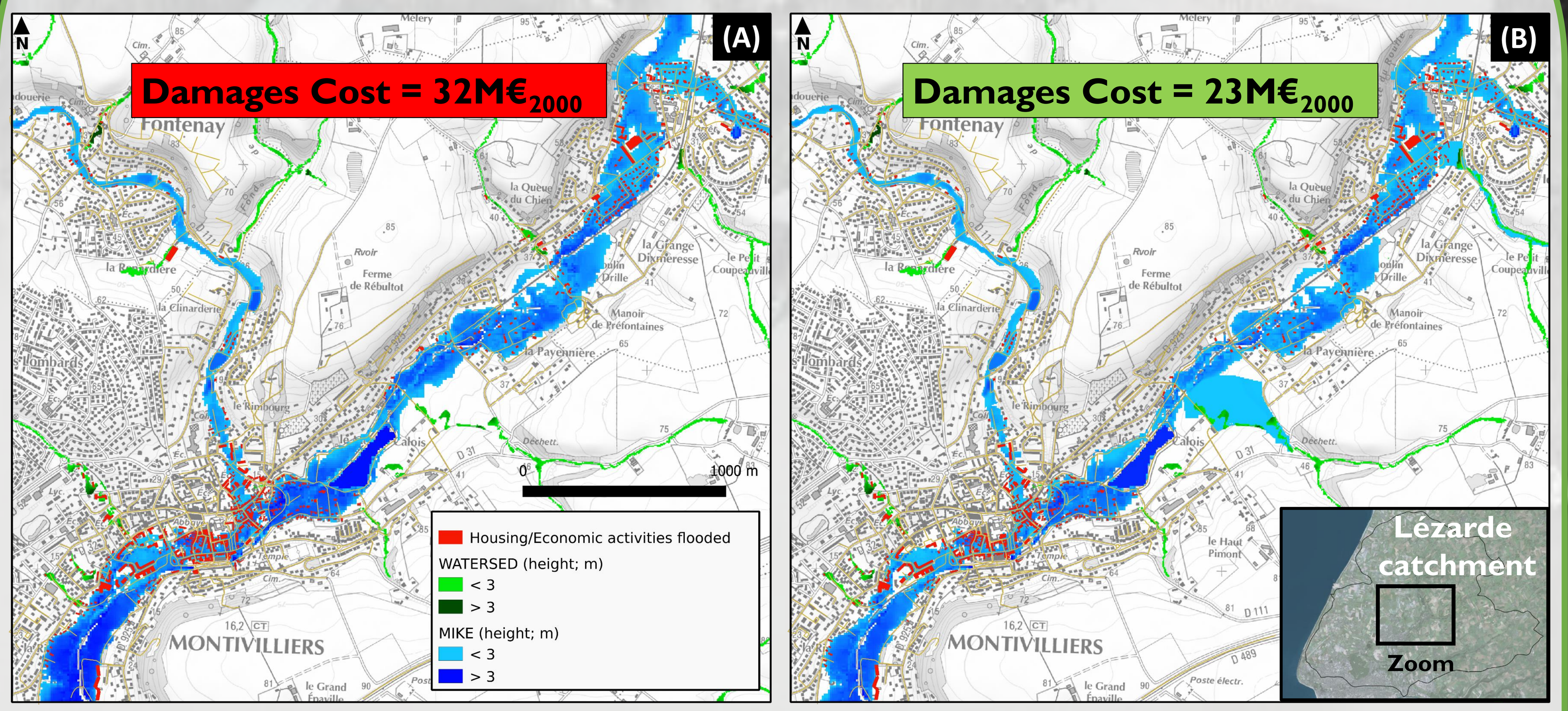
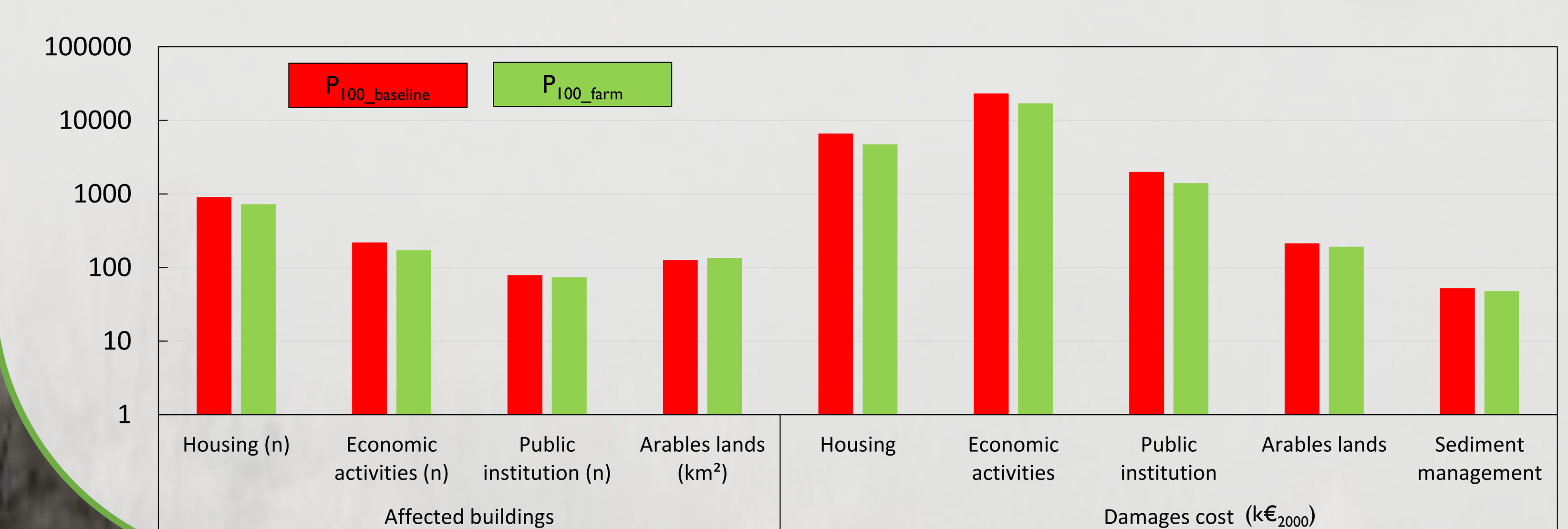
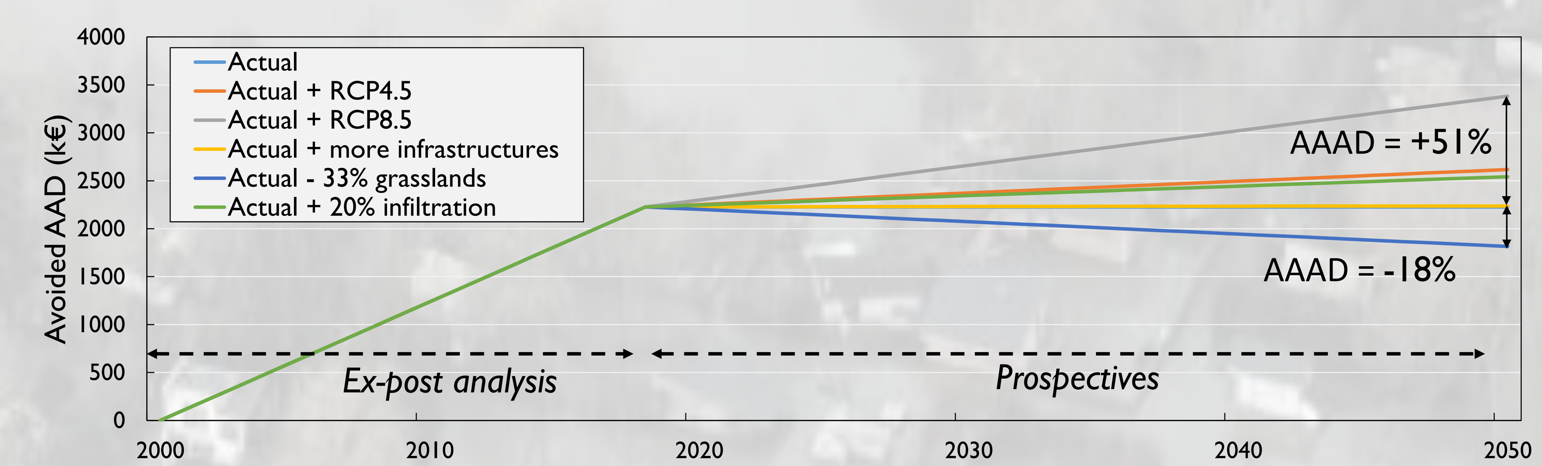


Fig.: Flood and runoff hazard modeling for the P_{100} (87 mm d^{-1}) on (A) the baseline scenario, and (B) the scenario including best farming practices by 2050. Total Damages Cost accounts for the entire catchment.



Economic Analysis of Scenarios

- Temporal analysis of Avoided Average Annual Damages (AAAD) Evolution
- NPV calculation → Economic flows discounted at 2.5%
- All costs adjusted for inflation → $€_{2000}$



	B/A	B/(A+RCP4.5)	B/(A+RCP8.5)	B/(A+G)	B/(A+F)	B/(A+I)
ΔAAD ($M€_{2000}$)	44.2	46.2	50.1	42.1	45.8	44.3
NPV ($M€_{2000}$)	15.7	17.7	21.7	13.6	17.4	11.4
BCR	1.554	1.624	1.763	1.479	1.611	1.347

*B=baseline; A=actual; G=ploughing up grasslands; F=best farming practices, I = More infrastructures

Conclusions & Perspectives

1. Hydraulic asset's BCR significantly positive → High contribution of dam/retention pond
2. Cost valuation less sensitive to sediment load reduction
3. Climate Change tends to increase the relevance of 'past' investments (RCP8.5 = +51% AAAD in 2050)
4. High sensitivity to farming practices (+20% infiltration = +14%AAAD ; -33% grasslands = -18%AAAD)
5. Farming practices improvement highly encourage by upcoming Climate Change

a. Improving the assessment of sediment load in each asset
b. Refining the cost function of sediment management
c. Integrating and Modeling sediment discharge to water treatment plant with Deep Learning algorithm (*Patault et al., 2020, In prep*)