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Cost-effectiveness analysis for identifying flood risk mitigation measures in Sardinia

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The Flood Risk Management Plan (FRMP) of Sardinia Region

The **FRMP** has been developed by Sardinian Region Water District Authority (ADIS) in according with the EU and Italian National legislation. The European Flood Directive 2007/60/CE has stated that the flood-risk evaluation should be include a **cost-benefit analysis** and an **integrated decision-making** process should help the Authority to optimize in planning new flood control works and in defining operating rules for risk management.

DICAAR, of the University Cagliari, is supporting ADIS for the methodological, technical and scientific aspects of the **FRMP**

The **FRMP** is also currently assessing the interaction of reservoirs operating rules and new works planned for flood damage mitigation. Based on a calibrated **benefit-cost analysis**, the proposed modelling approach suggested the best scenario of reservoir operating rules and flood control works with a significant saving of money compared to the actual scenario evaluated in the **FRMP**.

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Preliminary information and knowledge background preparing the FRMP for Sardinia region

Mediterranean regions have experienced severe flood damage caused by flash floods, which are characterised by a short duration and concentrated rainfall intensity in small river basins and steep slope areas. **Recent flood events in Sardinia (Capoterra 2008, Cleopatra 2013)** have been in such way characterized.

Flood damage and loss estimation forms an integral part of flood risk assessment and it is useful for planning flood mitigation structural works. Specifically, the Article 7 of Chapter IV states that the "Flood Risk Management Plans shall take into account relevant aspects such as costs and benefits", and the Chapter III requires the preliminary preparation of flood hazard and risk maps.

Frequently, in Sardinia region, upstream reservoir management policies for flood wave lamination interact with downstream flood mitigation works.

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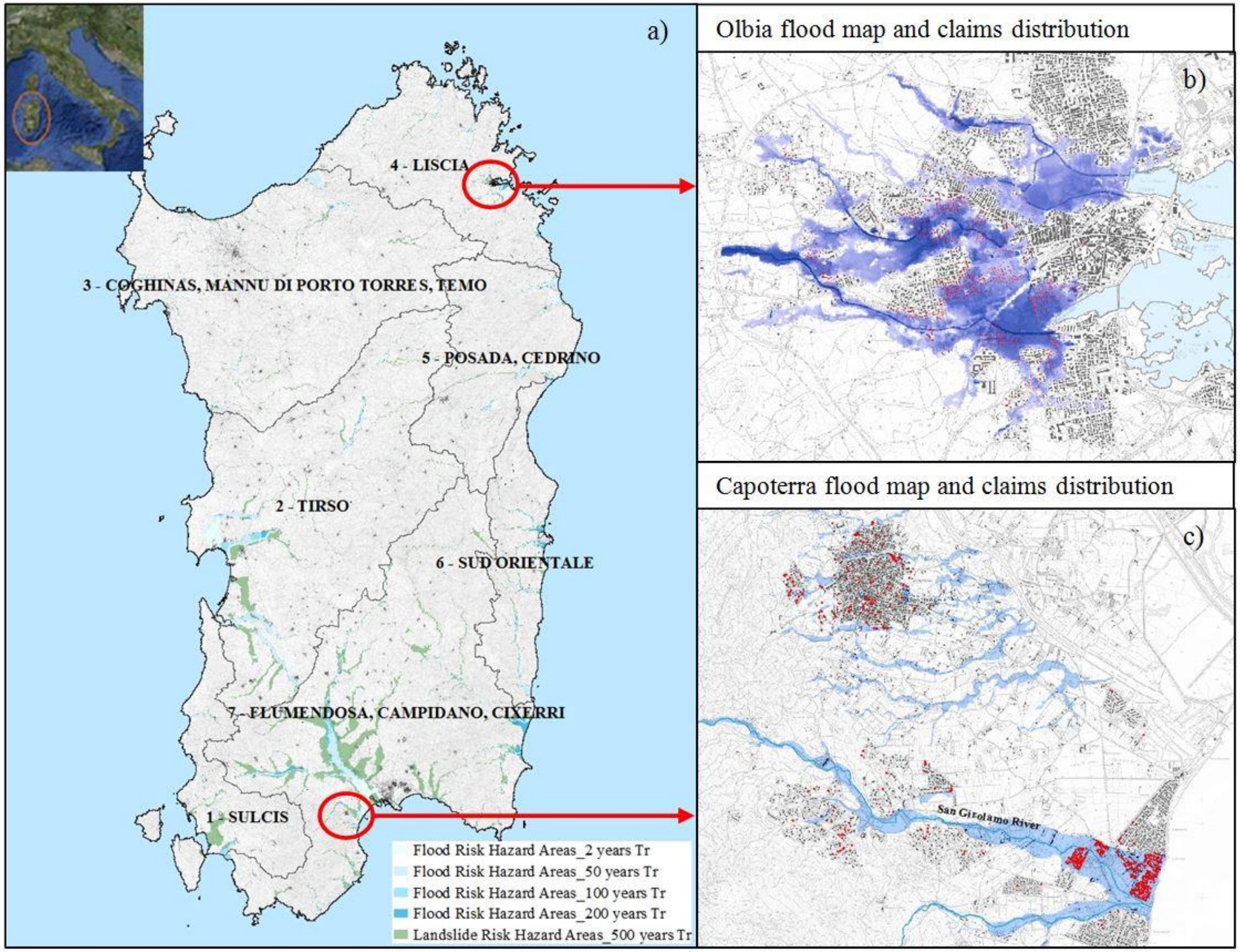

Figures: a) Olbia and Capoterra territory in Sardinia; b)Flood map of the 19th November 2013 event in Olbia and damage claims distribution; c)Flood map of the 22nd October 2008 event in Capoterra and damage claims distribution (Frongia et al., 2017)

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Water Depth-Damage curve evaluation

Studies of flood impact on the territory have been conducted to determine regional water depth-damage curves using the **database of claimed refunds** after floods registered in October 2008 and November 2013. This aiming to obtain regional representative water depth-damage functions and allowing a comparison with the **European JRC water depth-damage function** (Huizinga, 2007; Huizinga et al., 2017) for residential land-use territories.

The work is focused on the evaluation of the **direct component of the tangible flood damage** by applying the water-depth damage functions. The need of **deeper local analysis** arose planning mitigation measures for specific zones.

Obtained water depth-damage functions for flooded zones in Sardinia have been compared with the JRC curve and differences mainly due to the structural dwelling typologies have been highlighted.

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Water Depth-Damage curve evaluation

FLOOD DAMAGES
(Smith, 1994; Jongman et al. 2012)

Tangible
(Direct and Indirect)

- Buildings
- Roads
- Infrastructures
- …

- Losses of commercial income
- Losses of industrial production
- …

Intangible
(Direct and Indirect)

- Losses of life
- Environmental historical and archaeological heritage areas
- …

- Psicologic trauma
- Loss of touristic income
- …

FLOOD DIRECTIVE 2007/60/EC

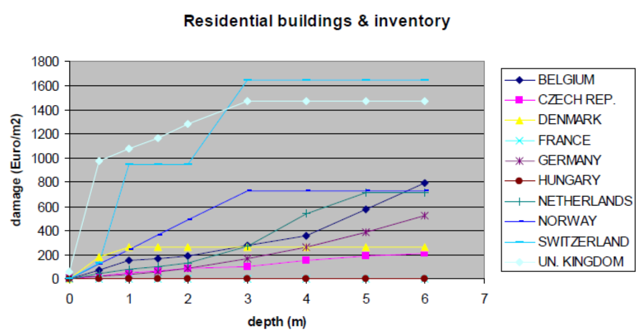
Point 3, Article 7, Chapter IV

“Flood risk management plans shall take into account relevant aspects such costs and benefits…”

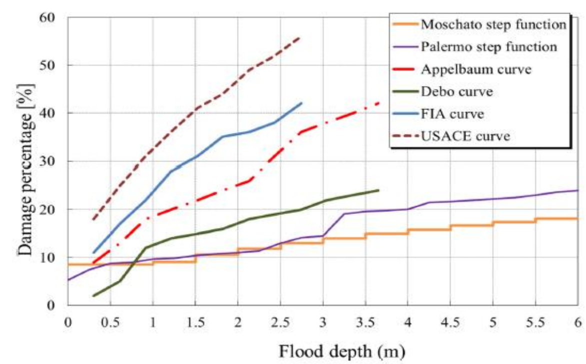
Tangible

- **Direct**
- **Indirect**

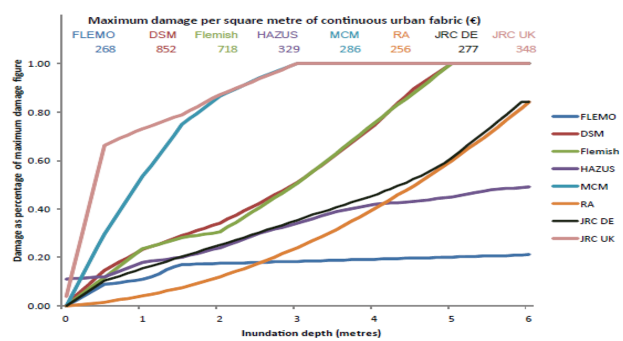
JRC Model



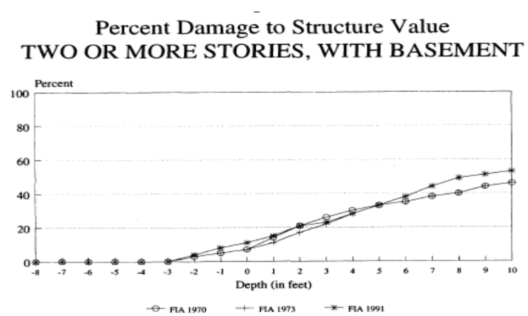
Pistrika et al. (2014)



Jongman et al. (2012)



USACE – FIA (1992)



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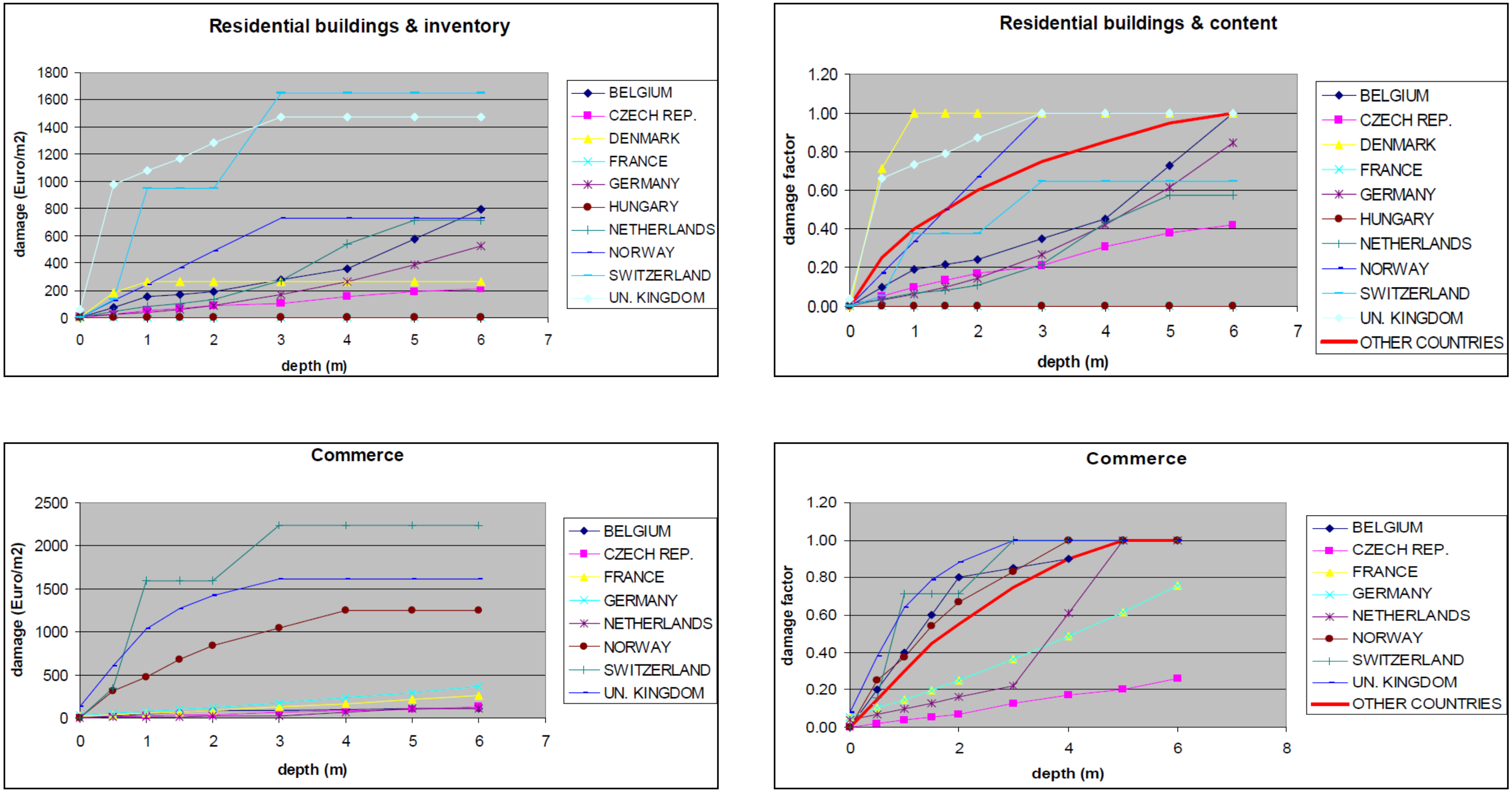

European JRC water depth-damage curves (Huizinga, 2007; Huizinga et al., 2017) for Residential and Commerce land-use territories

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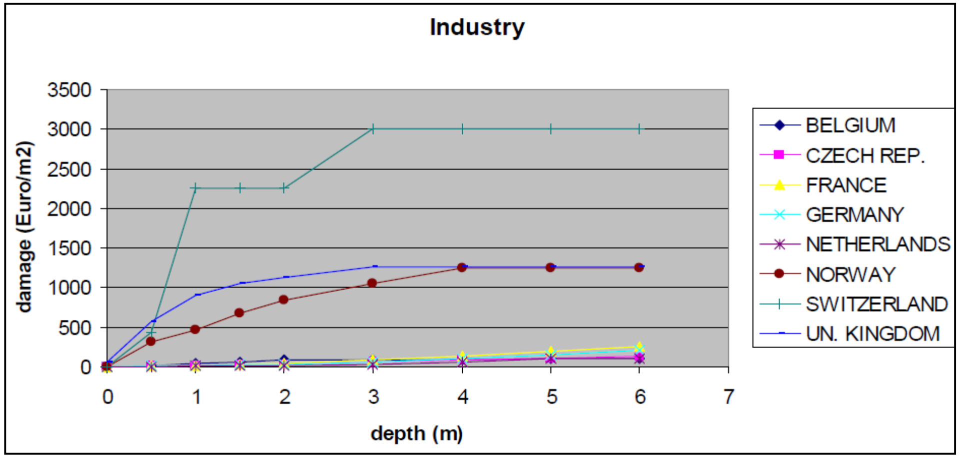
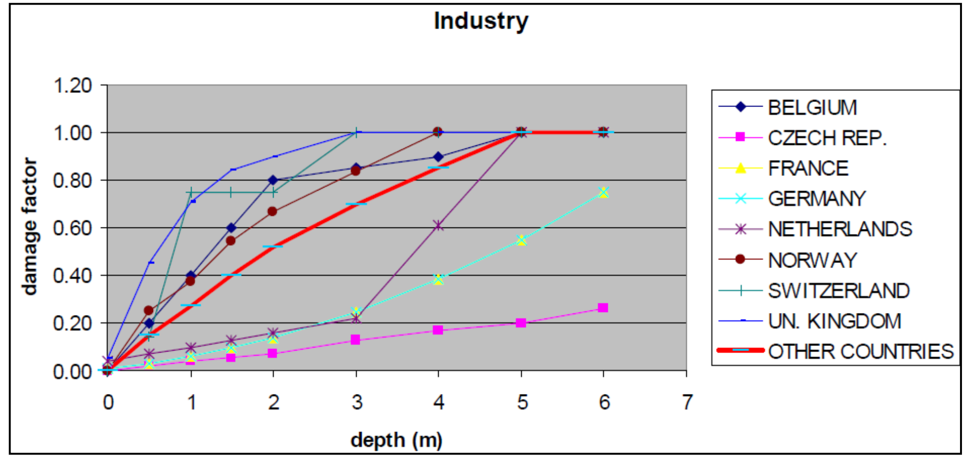
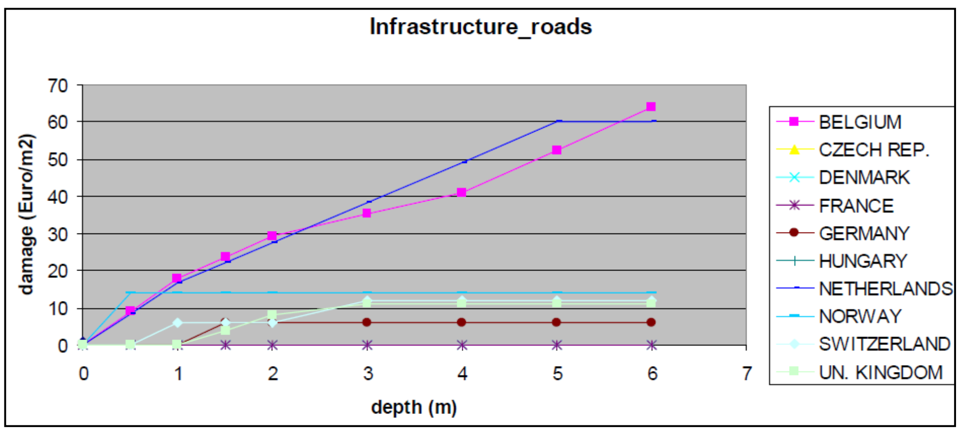
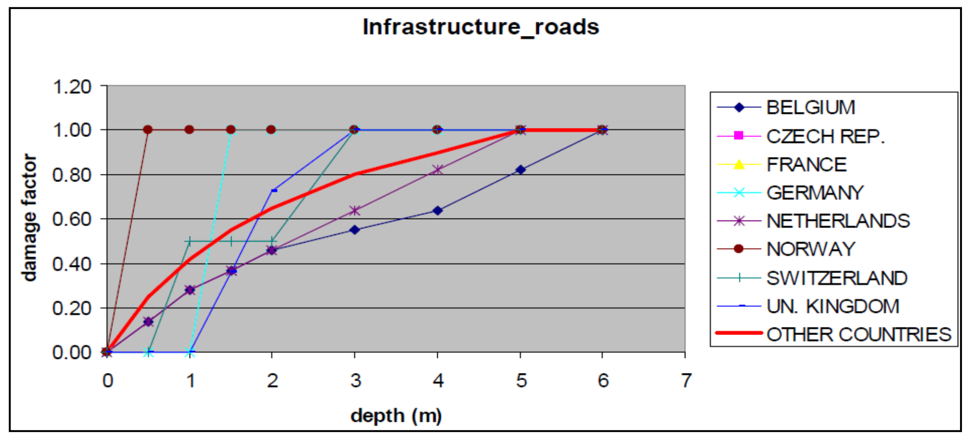
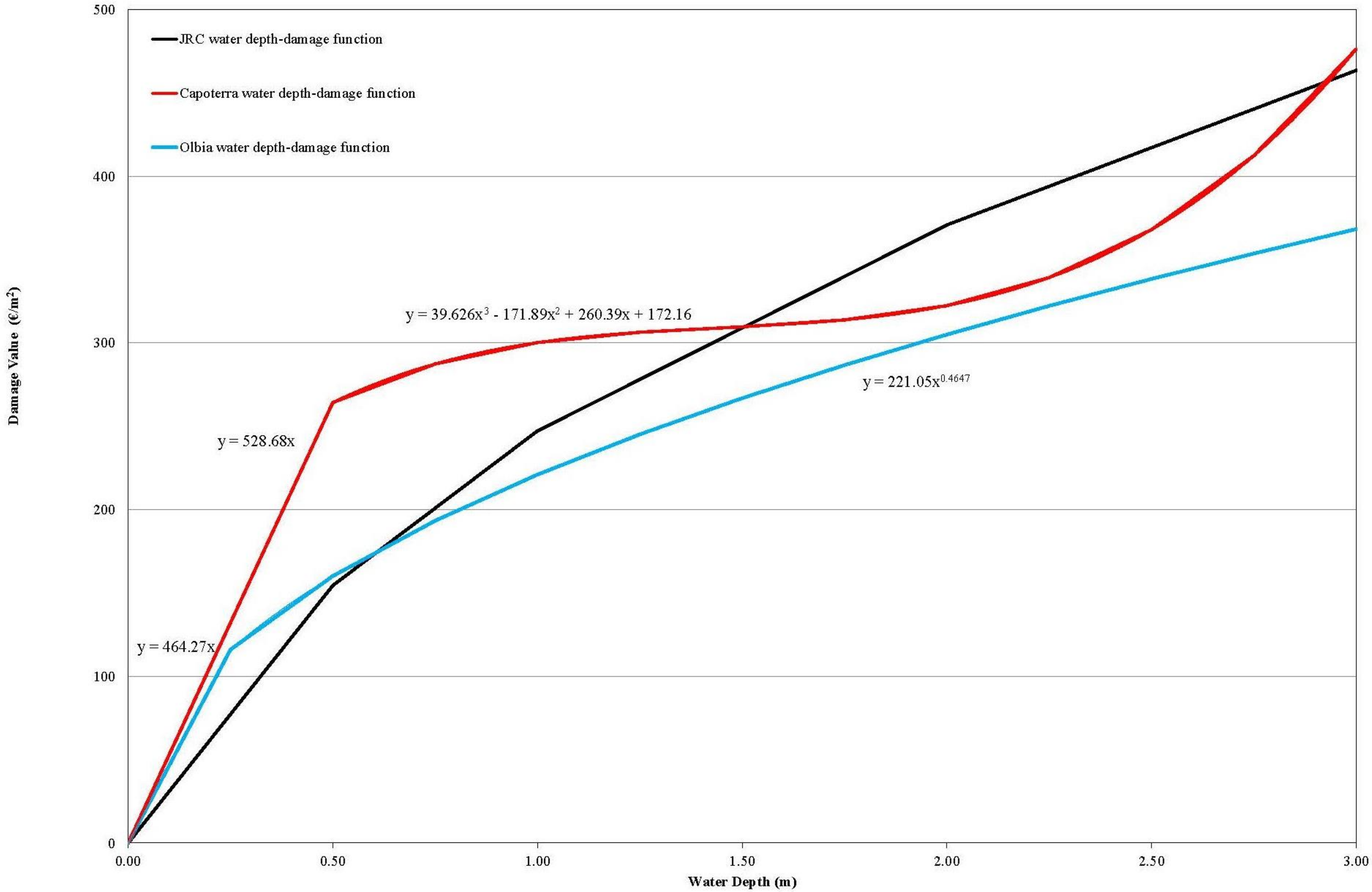








European JRC water depth-damage curves (Huizinga, 2007; Huizinga et al., 2017) for industry and Infrastructures land-use territories



500
400
300
200
100
0
JRC water depth-damage function
Capoterra water depth-damage function
Olbia water depth-damage function
y = 39.626x3 - 171.89x2 + 260.39x + 172.16
y = 221.05x0.4647
y = 528.68x
y = 464.27x
Damage Value (€/m2)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Water Depth (m)

Considered Regional flood damages Data-base and Statistical Validation

Capoterra and Olbia flood damage data-base are organized by records reporting the claims with economic evaluation of the damage (*€/m²*) and the related water depth (*m)* for each residential unit. Samples are categorised in classes, each one of 0.25 m depth-range; mean values and standard deviation are evaluated for each class.

Depth-damage relations can be described by a linear trend starting from zero and reaching 0.25 m for Olbia and 0.50 m for Capoterra. In the Figure, JRC function obtained for residential areas in Italy has been compared with the obtained curves. The mathematical expressions of the two water depth-damage curves are:

Olbia water depth-damage function

$$\text{Damage }[€/m^2] = \begin{cases} 464.27 \cdot h & h<0.25\text{ m} \\ 221.05 \cdot h^{0.4647} & h\geq 0.25\text{ m} \end{cases}$$

Capoterra water depth-damage function

$$\text{Damage }[€/m^2] = \begin{cases} 528.68 \cdot h & h<0.5\text{ m} \\ 39.626 \cdot h^3-171.89 \cdot h^2+260.39 \cdot h+172.16 & h\geq 0.5\text{ m} \end{cases}$$

Differences between curves need some comments: 1) Evaluated curves for considered flooded areas do not exceeded 3 metres. 2) Different type of urbanization in considered areas: in Capoterra mainly family houses of one or two floor. In Olbia losses are mainly related to multi-storey buildings and damages become more significant, as the water depth is growing.

Evaluation of Flood Potential damages for Hystoric (2013) scenario

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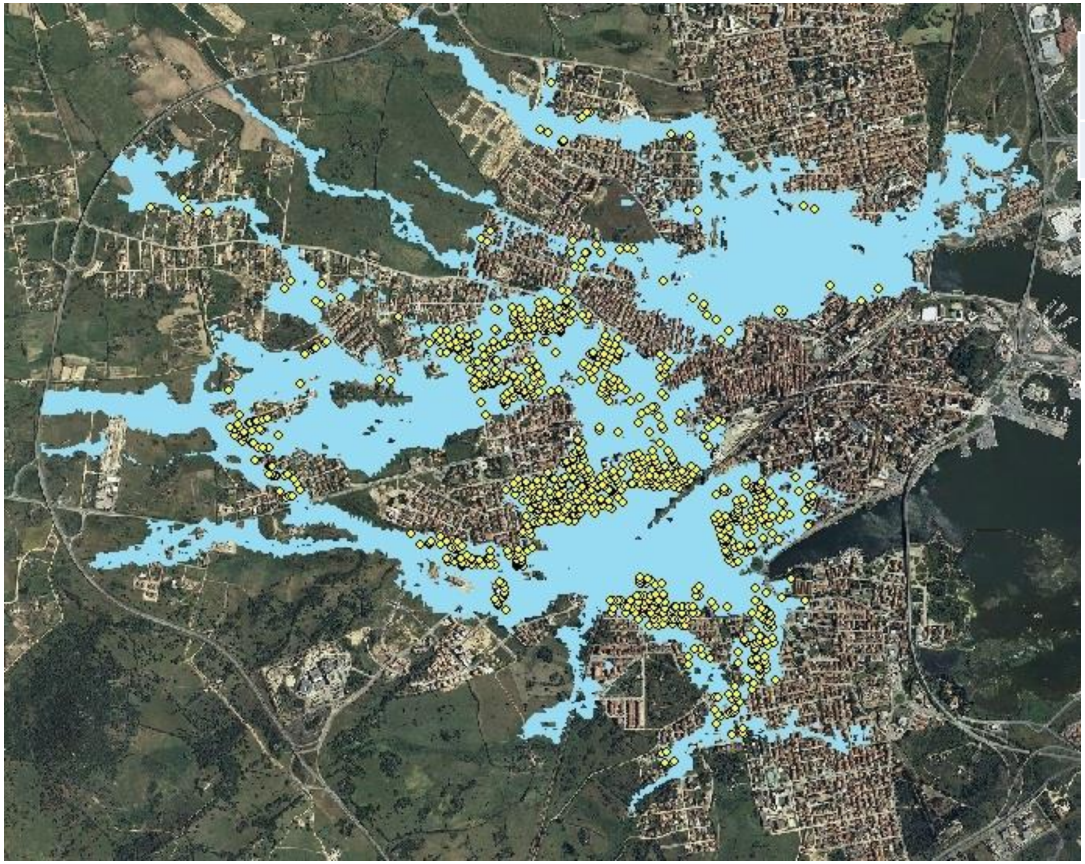

Olbia flood map and claims distribution due to Cleopatra Cyclone event

2013 Event:	Total Claimed Refund [€]	Olbia μ curve Total damage [€]	Olbia μ+σ curve Total damage [€]	JRC Total Damage [€]
Cleopatra Cyclone	15,010,789	16,896,238	28,626,809	30,803,661

Total damage evaluated applying Olbia water depth-damage function considering the mean damage values is highly comparable to the total claim required for the 989 refunds records in the data-base.

Uncertainties embodied evaluating all the economic damages that have to be included could be considered as the results of the sum of mean and standard deviation values in each claim sample.

Despite the apparent incongruity with claimed refunds, this global economic evaluation could be considered reasonable according with recent studies developed by Huizinga et al., 2017. In fact, as asserted in the "Flood Damage Functions for EU member states" and in the "Global flood depth-damage functions", the study should take into account both damages caused directly and indirectly by the flood and, moreover, tangible damages to inventories that usually represents at least the 30% of the damage to the dwelling structures (Huizinga et al., 2017).

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Evaluation of Flood Potential damages for Synthetic scenarios

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In a later stage of the study, hydrologic and hydraulic models of synthetic flood events are generated with estimated occurrence of 50, 100, 200 and 500 years. For Olbia floodplain the synthetic data are provided by the result of the HR Wallingford 1D-2D hydraulic model InfoWorks ICM implementation (Mancini, 2014).

For other FRMP basins, hydrologic data are available by the PSFF study (RAS 2007) and flood extension and water depth are obtained using the HEC-RAS 1D-2D models.

The damage sample, inside each class of water depth, has been fitted considering a Pearson III probability distribution:

$$p(x \mid a,b) = \frac{1}{b^{a}\,\Gamma(a)} x^{a-1} e^{-\frac{x}{b}} \qquad \Gamma(a) = \int_0^{\infty} e^{-t} t^{a-1} dt$$

b is the scale parameter and *a* the shape parameter of the distribution, Γ(a) is the Gamma function.

A procedure of synthetically generation of damages due to flood events has been then implemented.

Flood Event Occurrence [years]	Olbia Total Damage [€]	JRC Total Damage [€]	Percentage JRC-Olbia [%]	Difference Percentage JRC-Olbia [%]
Tr 50	22,559,709	22,905,109	98.5	1.51
Tr 100	26,819,595	28,439,989	94.3	5.70
Tr 200	30,238,492	33,253,553	90.9	9.10
Tr 500	32,500,244	36,694,710	88.6	11.4

Evaluation of Flood Potential damages for Synthetic scenarios

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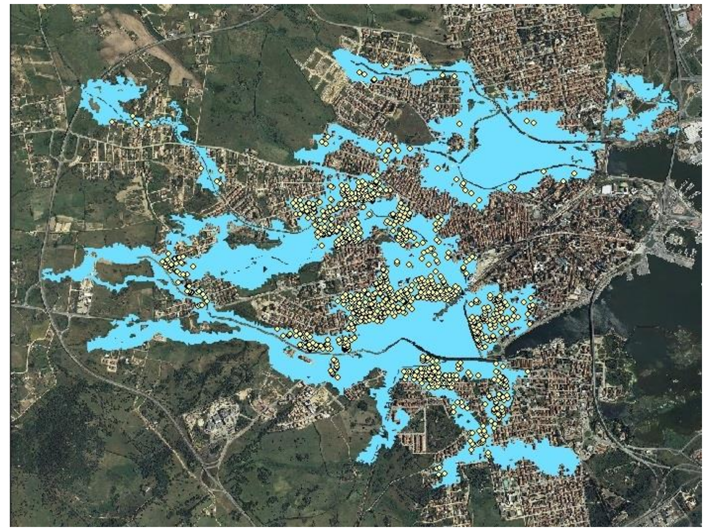
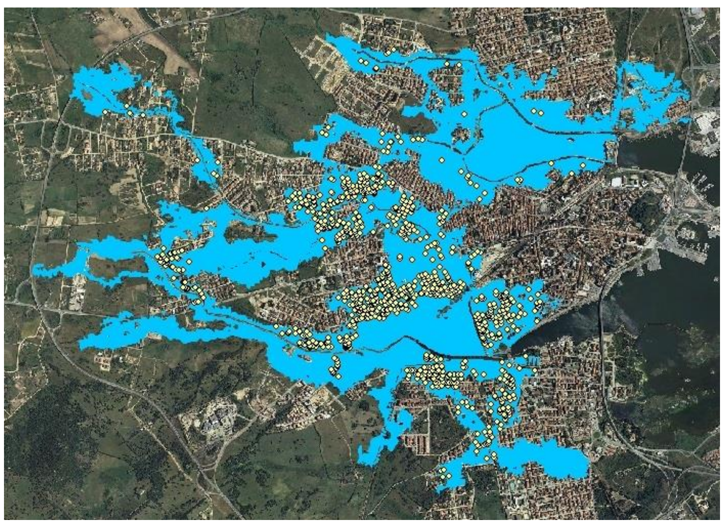
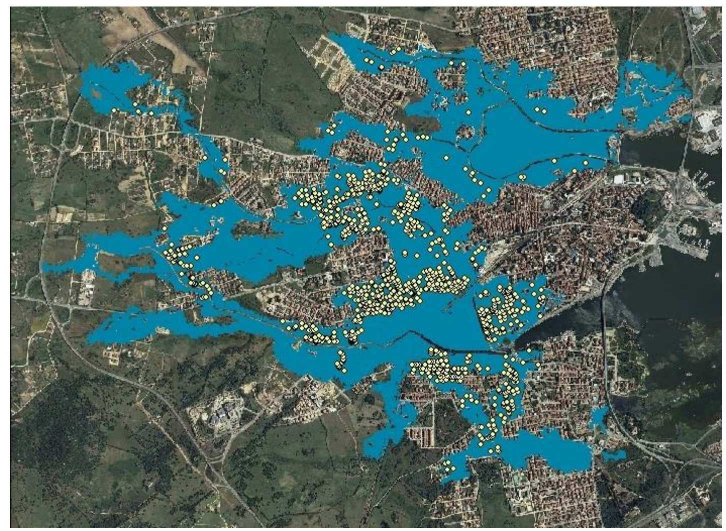
Flood map Tr 50 years and associated claims



Flood map Tr 100 years and associated claims



Flood map Tr 200 years and associated claims



Flood map Tr 500 years and associated claims

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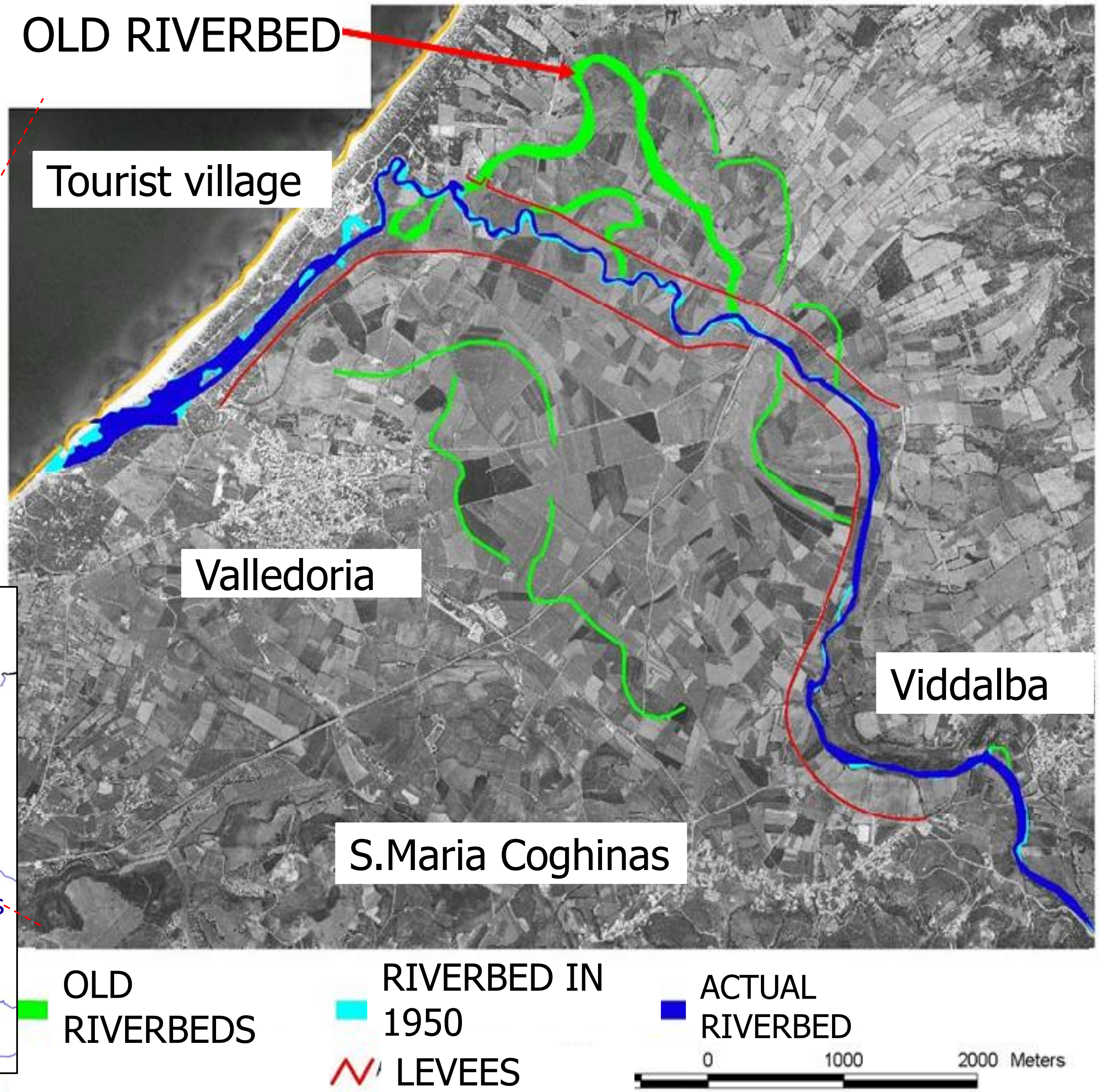
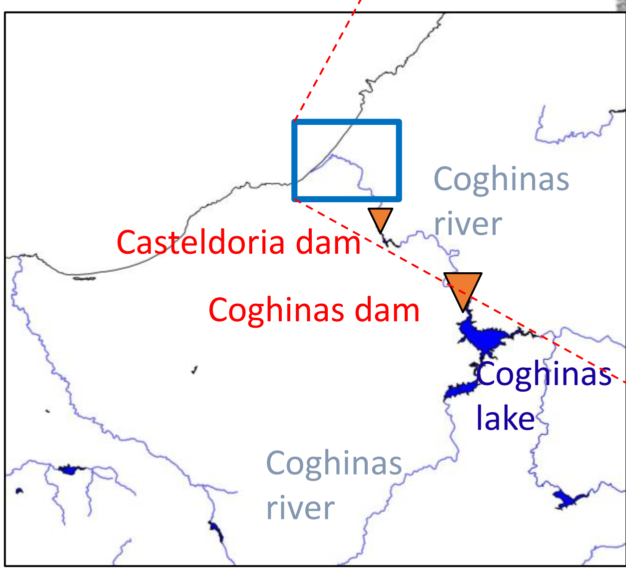
Pilot Basin in Sardinia FRMP:
Lowland valley of the Coghinas river





Corine Map Land cover evaluation

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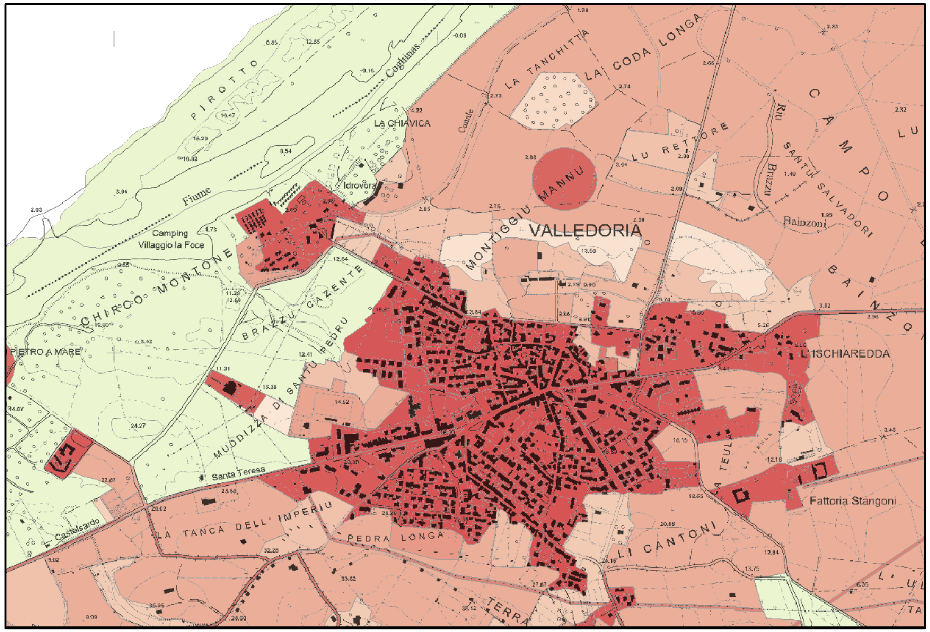
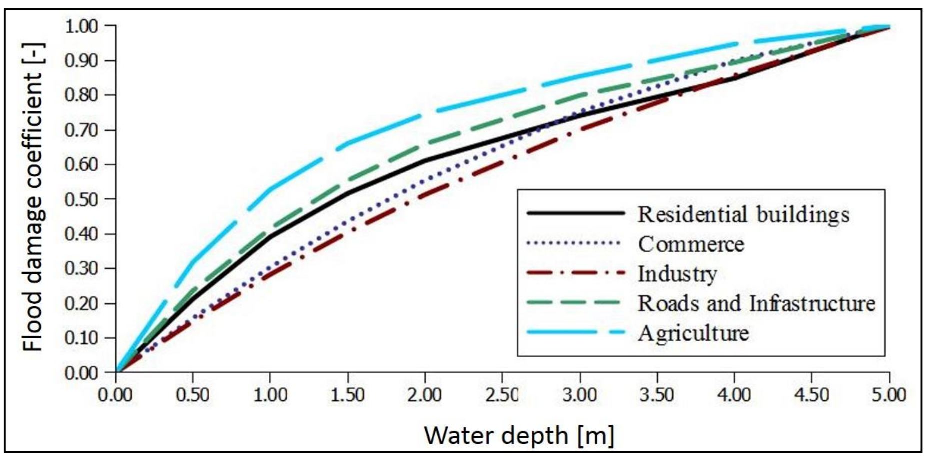
Legenda

Uso del Suolo

- 11110, Tessuto residenziale compatto e denso
- 11120, Tessuto residenziale rado
- 11210, Tessuto residenziale rado e nucleiforme
- 11220, Fabbricati rurali
- 11230, Edificio di culto
- 11240, Aree funerarie
- 11300, Architetture religiose
- 12211, Strade comunali
- 12212, Strade provinciali
- 12241, Rete di approvvigionamento di acqua potabile
- 12244, Tratto di linea della rete elettrica
- 12610, Istituto Comprensivo
- 12620, Scuola dell'infanzia
- 13100, Aree estrattive
- 14200, Aree ricreative e sportive
- 14300, Cimiteri
- 21210, Seminativi semplici e colture orticole a pieno campo
- 21240, Coltura in serra
- 22100, Vigneti
- 22300, Oliveti
- 23200, Prati stabili (altri usi)
- 24200, Sistemi colturali e particellari complessi
- 24300, Aree prevalentemente occupate da colture agrarie con presenza di spazi naturali importanti
- 24400, Aree agroforestali
- 31200, Boschi di conifere
- 32310, Macchia mediterranea
- 32320, Macchia bassa e garighe
- 32410, Aree a ricolonizzazione naturale





LAND USE CATEGORY	MAX DAMAGE VALUE [h ≥ 5m] (€/m²)
Residential buildings	618
Commerce	511
Industry	440
Roads	20
Agriculture	0.63

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Coghinas flood damage evaluation

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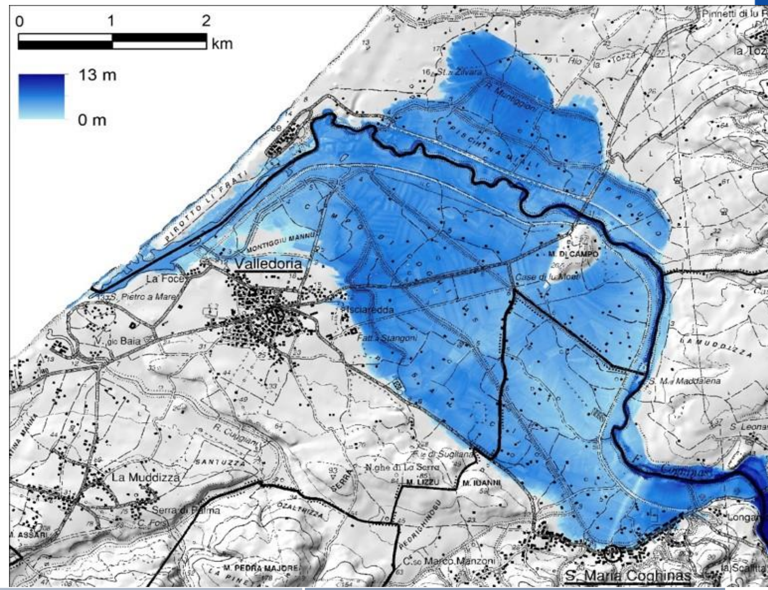
GIS-based process

Cellular grid [3 x 3] meters
- land use category to each cell;
- expected water depth for each expected Tr;
- depth-damage function (JRC);
- maximum damage value (JRC).



Total potential flood damage

Land-Use Category (max damage value €/m²)	Tr 50 years		Tr 100 years		Tr 200 years	
	Area (10^3 m²)	Damage (10^3 €)	Area (10^3 m²)	Damage (10^3 €)	Area (10^3 m²)	Damage (10^3 €)
Agric. (0.63)	13'055	5'222	13'219	5'689	13'319	6'019
Comm. (511)	41	7'581	42	9'108	42	10'305
Ind. (440)	53	7'194	70	9'150	73	10'951
Council roads (10)	43	169	45	205	46	232
rov. Roads (20)	99	802	104	980	111	1'138
Resid. Build. (618)	115	23'916	135	31'182	148	37'856
Infrastr. (40)	213	3'498	217	4'055	220	4'505
Total	**16'352**	**48'382**	**16'616**	**60'369**	**16'793**	**71'006**

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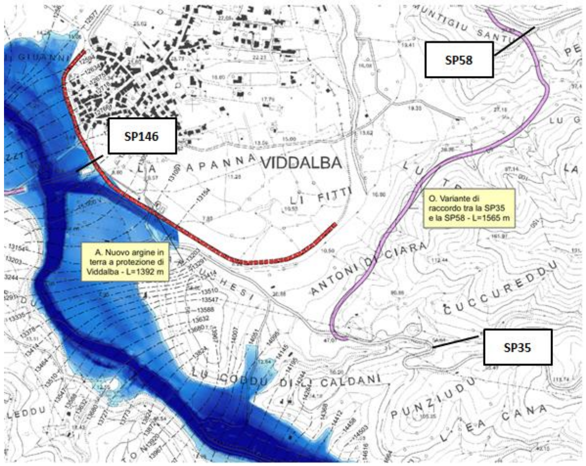
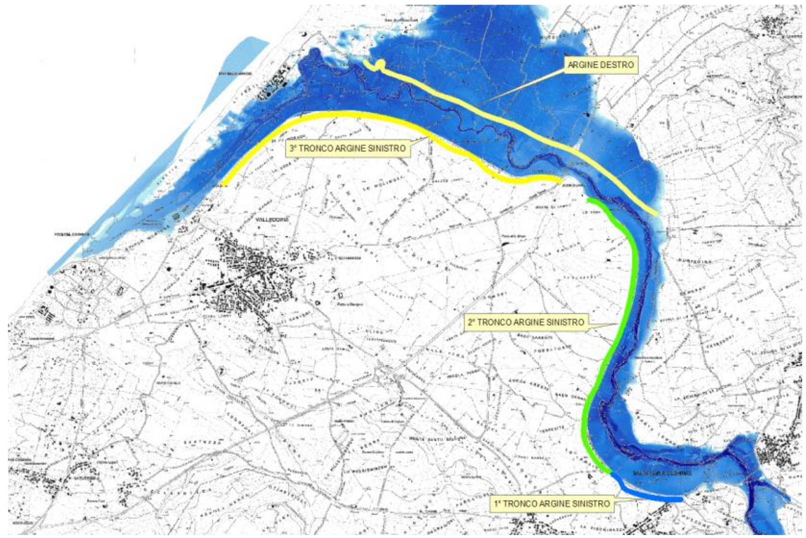
Structural mitigation measures

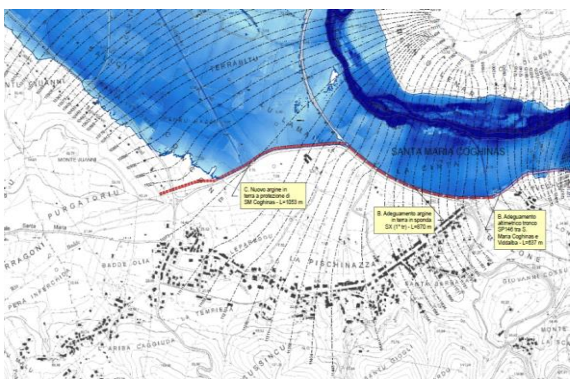
Bacino pilota della bassa valle Coghinas



Scenario 1



Scenario 4



Scenario 2

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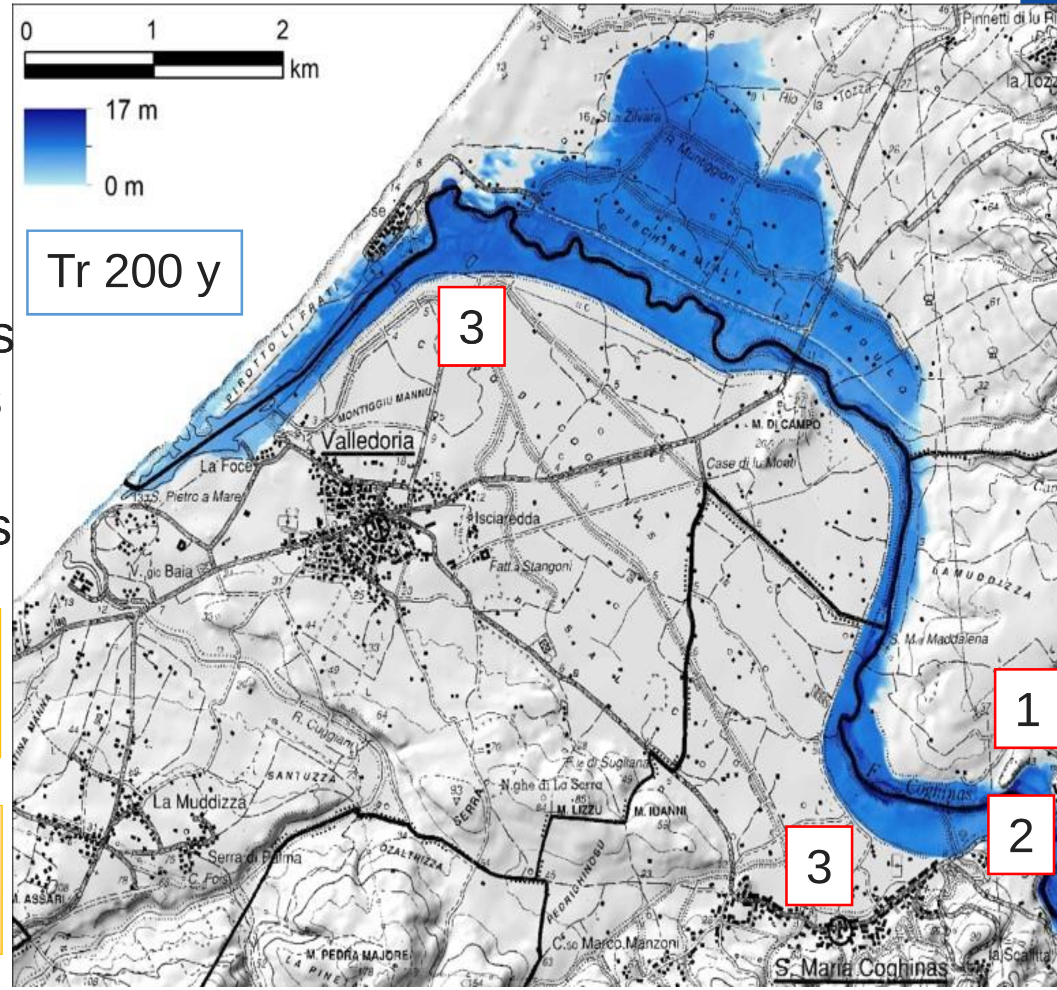
Flood damage mitigation

1. A new levee (2 km) on the right river bank
2. Demolition of the two old bridges
3. Improvements of existing levees on the left river bank (8.5 km)
4. Improvements in drainage works



TOTAL INVESTMENT COST
21.6 M€

ANNUAL MAINTENANCE COST
137.000 €/year

	Tr 50 years		**Tr 100 years**		**Tr 200 years**	
	Area (10^3 m²)	**Damage (10^3 €)**	**Area (10^3 m²)**	**Damage (10^3 €)**	**Area (10^3 m²)**	**Damage (10^3 €)**
Current situation	16'352	48'382	16'616	60'369	16'793	71'006
After mitigation	**7'604**	**28'426**	**7'781**	**33'258**	**7'921**	**37'563**

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Structural and non-structural mitigation

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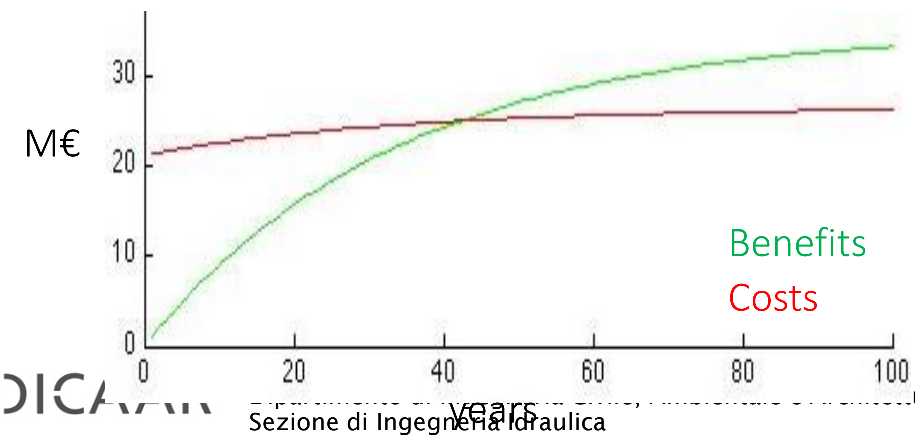
Only Structural works

- New embankment works
- Demolition of the two old bridges
- Improvements in drainage works

TOTAL INVESTMENT COST
21.6 M€
ANNUAL MAINTENANCE COST
137.000 /year

Only structural

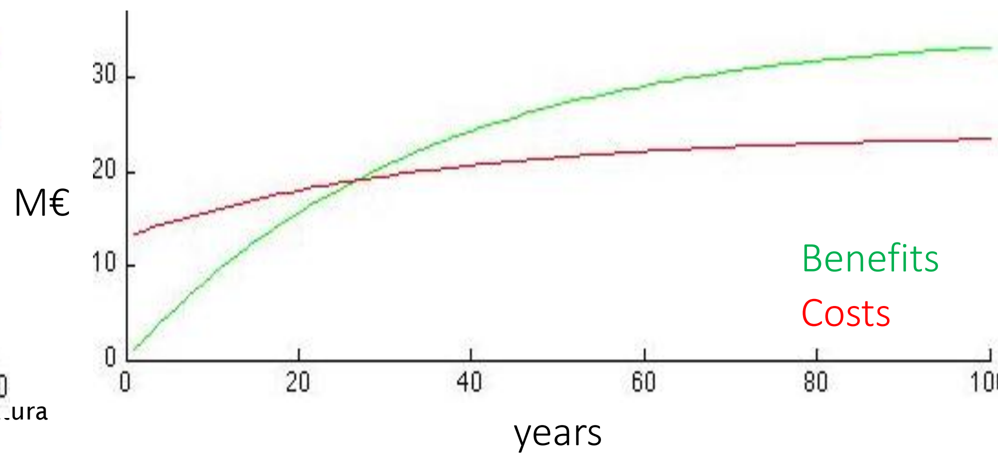


Structural and non structural

- New reservoir management rules
- Reduced embankment works
- Improvements in drainage works

TOTAL INVESTMENT COST
13.2 M€
MAINTENANCE AND ECONOMIC COMPENSATION
300.000 €/year

Structural and non-structural



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