multi-Risk sciEnce for resilienT commUnities undeR a changiNgclimate

Codice progetto MUR: **PE00000005** – C93C22005160002

Deliverable title: Identification of direct impact metrics and models for all exposed assets indicated in the EU Flood Directive

Deliverable ID: 1.2.7

Due date:1/12/2024

Submission date: 1/12/2024

AUTHORS

Francesco Ballio (POLIMI); Daniela Molinari(POLIMI) Anna Rita Scorzini (Università dell'Aquila) Marta Bellocci (POLIMI), Panagiotis Asaridis (POLIMI)

1. Technical references

Project Acronym	RETURN
Project Title	multi-Risk sciEnce for resilienT commUnities undeR a changiNg climate
Project Coordinator	Domenico Calcaterra UNIVERSITA DEGLI STUDI DI NAPOLI FEDERICO II domcalca@unina.it
Project Duration	December 2022 – November 2025 (36 months)

Deliverable No.	DV#1.2.7.#
Dissemination level*	
Work Package	WP1.2 - Flood risk under environmental and climatic changes
Task	Impact Model
Lead beneficiary	POLIMI
Contributing beneficiary/ies	POLIMI, UNIVERSITA' DELL'AQUILA

* PU = Public

PP = Restricted to other programme participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

Version	Date	Lead contributor	Description
0.1	17/11/2024	Anna Rita Scorzini (Università dell'Aquila)	First draft
0.2	21/11/2024	Daniela Molinari (POLIMI)	Critical review and proofreading
0.3	26/11/2024	Marco Borga (UNIPD)	Edits for approval
1.0	28/11/2024	Francesco Ballio (POLIMI)	Final version

2. ABSTRACT

The paper outlines the ISYDE/NATFIM methodology, which was created with the aim of meeting the assessment and planning needs related to the Floods Directive, but with the potential for application to different sectors (e.g., for civil protection purposes), as well as for support to multi-hazard analyses.
The general methodological approach of ISYDE/NATFIM has been previously described in deliverable 1.2.3 (M12) , specifying nature and format of the data required for the procedure.
This deliverable provides a step-by-step detailed procedure for the implementation of the methodology into a generic informatic (territorial-based) system.

3. Table of contents

4. Identification of direct impact metrics and models

4.1 Procedure for characterization of population exposure

The procedure allows to assess the population exposed, in terms of total inhabitants, children under the age of 10 and elderly over the age of 65, using the ISTAT census section data as the main input, assuming the population to be homogeneously distributed over the entire section area and assessing the number of people exposed as proportional to the portion of the section actually flooded.

The procedure also makes it possible to calculate for each municipality the number of homeless registered in the civil registry according to the three categories described above. Homeless are placed in fictitious census sections (generally of small dimension) which, if they fell within the flooded area, would lead to an incorrect assessment of the exposed population.

4.1.1 Summary of the approach

- Input: (i) hazard scenario (raster map of water depths); (ii) vector layer with polygonal geometry representing all areas with surface water presence, such as riverbeds, lakes, artificial reservoirs, etc. (“wet areas”); (iii) polygonal vector layer representing census sections.
- Physical exposure assessment of the resident population at the meso-scale: number of residents divided by age group at the census section scale.
- Final meso-scale representation (census section).

4.1.2 Physical exposure assessment

Step 1: clipping of input data

- Extraction of the census sections superimposed on the minimum footprint area of the raster of water depths.
- Exclusion of permanently wet areas from the theme created in the previous step.
- Recalculation of the attributes present in the census sections according to the decrease in area. This operation evenly distributes the residents in the portions of the census sections without wet areas.

Step 2: identification of resident population in the flooded area

- Conversion of raster map of water depths into polygonal vector layer to determine flooded area.
- Cutout of census sections with flooded area in vector format.
- Identification of sections/parts of sections falling within the flooded area.

Step 3: calculation of resident population (total and by classes) in flooded area

- Calculation of total resident population, children under 10 years of age, and residents over 65 years of age, within each census section, according to the following formulas:

$$Residents\ tot = \alpha \cdot P1$$

$$Residents\ under\ 10 = \alpha \cdot (P14 + P15)$$

$$Residents\ over\ 65 = \alpha \cdot (P27 + P28 + P29)$$

where
α = flooded area section/total area section
P1 = Resident population - total (from Istat data)

P14 = Resident population - age < 5 years (from Istat data)
P15 = Resident population - age 5 - 9 years (from Istat data)
P27 = Resident population - age 65 - 69 years (from Istat data)
P28 = Resident population - age 70 - 74 years (from Istat data)
P29 = Resident population - age < 74 years (from Istat data)

Step 4: calculation of exposure indicators for the population

- Calculation of exposure indicators dividing the resident population in the flooded area ($Residents\ tot$, $Residents\ under\ 10$, $Residents\ over\ 65$) by the flooded area of the census section.

4.2 Procedure for exposure characterisation of strategic buildings

The procedure uses as input data the point geometry vector layer, created ad-hoc. This layer identifies strategic and sensible buildings and it returns as output both their location within the hazard map used and the aggregate data at the scale of the flooded portion of the census section, indicating the numerosity within it.

4.2.1 Summary of the approach

- Input: (i) hazard scenario (raster map of water depths); (ii) vector layer with point geometry resulting from the synthesis and homogenization activity of various institutional and non-institutional databases (regional geoportals, OSM, Open Data, etc.; the tabular structure provides their subdivision by Type (strategic buildings or sensitive buildings), by Category (administrative, sports, military, etc.) and, where possible, specifying their Name); (iii) polygonal vector layer representing census sections.
- Exposure assessment of strategic buildings, identifying those potentially impacted.
- Final meso-scale representation (census section).

4.2.2 Physical exposure assessment

Step 1: identification of strategic buildings in flooded area

- Conversion of the raster map of water depths into polygonal vector layer to determine the flooded area.
- Extraction of strategic buildings present within the flooded area, using the point theme of strategic buildings as input data.

Step 2: aggregation of information at the meso-scale

- Through spatial join tools (with geometric predicate "intersection"), association of strategic buildings to the flooded census sections in which they fall and evaluation of their total numerosity per census plot.

4.3 Procedure for exposure characterization of cultural heritage

The procedure identifies potentially exposed cultural heritage by producing an aggregate output at the scale of the census section, with associated indicator (IUBC – Indicatore Unico per i Beni Culturali) calculated as the ratio of the weighted sum of cultural property present and the flooded area of the census section.

4.3.1 Summary of the approach

- Input: (i) hazard scenario (raster map of water depths); (ii) vector layer with polygonal geometry representing all the areas with the presence of water on the surface such as riverbeds, lakes, artificial reservoirs, etc. ("wet areas"); (iii) vector layer with point geometry specifying the position of cultural assets and their relevance (local, national or world UNESCO heritage site), the category (e.g. Museum, Monument, Archaeological Area, etc.), with an impact index associated according to importance and type; (iv) polygonal vector layer representing census sections.
- Evaluation of the exposure of cultural assets, identifying those potentially impacted.
- Final meso-scale representation (census section).

4.3.2 Exposure Evaluation

Step 1: identification of cultural heritage within the flooded area

- Conversion of the raster map of water depths into polygonal vector layer to determine the flooded area.
- Exclusion of the flooded areas from the theme created in the previous point.
- Extraction of cultural assets present within the flooded area, using the point theme of cultural assets as input data.

Step 2: aggregation of information at the meso-scale

- Through spatial join tools (with geometric predicate "intersection"), association of cultural assets with the flooded census sections in which they fall and evaluation of their total number per census section.

Step 3: calculation of the unique impact indicator for cultural heritage

Assignment of the Unique Impact Indicator for Cultural Heritage (IUBC) in terms of the equivalent number of cultural heritages per unit area per km^2.

4.4 Procedure for exposure characterization of environmental heritage

The procedure allows to identify the environmental heritage impacted and to associate each flooded census section with the total number of assets in it.

4.4.1 Summary of the approach:

- Input: (i) Hazard scenario (raster map of water depths); (ii) vector layer with polygonal geometry representing all the areas with the presence of water on the surface such as riverbeds, lakes, artificial reservoirs, etc. ("wet areas"); (iii) polygonal geometry layer representing the extent of environmental assets (the attribute table describes the name and the associated ecosystem service (provisioning services, services of cultural value and regulation and conservation services); (iv) polygonal vector layer representing census sections.
- Exposure assessment of environmental assets, identifying those potentially exposed.
- Meso-scale representation (census section).

4.4.2 Exposure assessment

Step 1: identification of environmental assets within the flooded area

- Conversion of the raster map of water depths into polygonal vector layer to determine the flooded area.
- Extraction of environmental assets present within the flooded area, using the polygonal layer of environmental assets as input data.
- Exclusion of the flooded areas from the theme created in the previous point.

Step 2: aggregation of information at the meso-scale

- Through spatial join tools (with geometric predicate "intersection"), association of environmental assets with the flooded census sections in which they fall and evaluation of their total number per census section.

Step 3: calculation of the unique impact indicator for environmental heritage

- Assignment of the exposure indicator for environmental assets by dividing the number of assets within the census section by the area of the flooded portion of the census section.

4.5 Procedure for damage assessment of residential buildings – structures

The procedure allows to assess the exposure and economic damage that a building may suffer if subjected to a flood event. Subsequently, the micro-scale data is aggregated based on census sections.

4.5.1 Summary of the approach

- Input: (i) hazard scenario (raster map of water depths); vector layer with polygonal geometry representing all areas with the presence of water on the surface, such as riverbeds, lakes, artificial reservoirs, etc. ("wet areas"); (iii) vector layer with polygonal geometry of the topographic database (DBT) related to the built-up area, containing information related to the footprint on the ground of buildings (for residential use) from which information on their area (footprint area), or volumetric units from which building height values can be acquired. In addition to these, there are often associated tables showing information related to the intended use or the characteristics of the portions of the building connected to the volumetric units (whether porch, underpass, etc.); (iv) polygonal vector layer representing the census sections.
- Damage assessment at the micro-scale (i.e., at the scale of individual buildings) through models UniFi (doi: 10.1016/j.jenvman.2017.11.017), UniBo (doi: 10.5194/nhess-18-2057-2018), Simple-INSYDE (doi: 10.5194/nhess-20-2937-2020).
- Damage representation at the meso-scale (census section).

4.5.2 Assessment of the economic value of the exposure

Step 1: Identification of residential buildings within the flooded area

- Conversion of raster map of water depths to polygonal vector layer to determine flooded area.

- Spatial join (with geometric predicate "intersection") of the DBT buildings with the vector flooded area.
- Identification of residential buildings falling within the flooded area.
- Step 2: calculation of the area of residential buildings within the flooded area
- calculation of the FA (footprint area) of each building from the DBT (FA= ADBT). Where it is not possible to arrive at a detailed use category classification, the area is modified using ISTAT data according to the formula:

$$FA = A_{DBT} \cdot \frac{E_3}{E_1}$$

Where:

E1= Buildings and complexes of Buildings – Total (from ISTAT data)

E3= Residential buildings (from ISTAT data)

Step 3: water depth assignment

- Calculation of water depth h (from the raster of water depths) for each building using Zonal Statistics tools, estimating the average water height within each building.

Step 4: calculation of building height and number of floors

- Building height available in DBT
- Calculation of height for each building
- He= average building height using the information in the DBT's volumetric units; for buildings with zero height in the DBT, He=N*3.5, where N is the average number of floors from ISTAT data
- Calculation of number of floors for each building:
- N= He/3.5 rounded to higher integer; for buildings with zero height in DBT, the average number of floors from ISTAT data is considered: N = (1 ·E17 + 2 ·E18 + 3 ·E19 + 4 ·E20)/E3

Building height not available in DBT

Calculation of the average number of floors per building within the section (from ISTAT data)

N = (1 ·E17 + 2 ·E18 + 3 ·E19 + 4 ·E20)/E3

Calculation of average height for each building

He=N*3.5

Step 5: calculation of the economic value of exposed

- Calculation of the number of flooded floors per building (if h≥He n=N, if h<He n=h/3.5 rounded to higher integer); the presence of the basement is not taken into account
- Identification of structural typology (BS) based on the most frequent type from ISTAT data (fields E5, E6, E7)

Attribution of construction cost according to the following table (2020 costs)

BS	Average cost of reconstruction (RV) May 2015 (€/m²)	Annual cost of reconstruction (RV) July 2020 (€/m²)
Concrete	1513	1546
Masonry	1226	1253

- in case the most frequent typology is "wood/other materials" (E7), in the absence of specific models, the values for the most vulnerable structural type considered by the models (i.e., masonry) are adopted as a precaution.
- Calculation of the economic value of the building

$$E = n \cdot FA \cdot RV$$

4.5.3 Calculation of the damage

Step 1: application of UniBo model

- Calculation of relative damage by the formula

d=0.13h^(1/2)

- Calculation of absolute damage

D=E·d

Step 2: application of simple-INSYDE model

- Assignment of the other hazard parameters to each building/census section → default values in INSYDE (du=24 hours, q=1)
- Assignment of finish level (FL) to each building/census section → use average FL as the default value
- Attribution of maintenance level (LM) to each building/census section based on the most frequent value from ISTAT data (fields E28, E29, E30, E31), according to the following correspondence
- Residential buildings with excellent level of maintenance → high
- Residential buildings with good level of maintenance →high
- Residential buildings with mediocre level of maintenance→low
- Residential buildings with poor level of maintenance → low

Calculation of relative damage by the formula

$$d_{storey} = f(h)f(A)f(LM,du)f(BS)f(FL)f(q) \rightarrow \begin{cases} f(h) = \left(0.17h - 0.02h^2\right) \\ f(A) = \left(0.2 + \dfrac{7}{\sqrt{A}}\right) \\ f(LM,du) = \begin{cases} 1 + 0.15 \cdot \arctan(du - 36) & \text{if } LM \text{ low} \\ 0.8 + 0.2 \cdot \arctan(du - 36) & \text{if } LM \text{ high} \end{cases} \\ f(BS) = \begin{cases} 1.35, & \text{if } BS \text{ masonry} \\ 1, & \text{elsewhere} \end{cases} \\ f(FL) = \begin{cases} 1.5, & \text{if } FL \text{ high} \\ 1, & \text{elsewhere} \end{cases} \\ f(q) = \begin{cases} 1.2, & \text{if } q = 1, \text{presence of pollutants} \\ 1, & \text{elsewhere} \end{cases} \end{cases}$$

$$d_{floor} = f(h, FL) = \begin{cases} 0.04, & \text{if } h>0 \text{ and } FL \text{ high} \\ 0, & \text{elsewhere} \end{cases}$$

$$d_{boiler} = f(h) = \begin{cases} 0.015, & \text{if } h > 1.6\, m \\ 0, & \text{elsewhere} \end{cases}$$

- Calculation of absolute damage by the formula

$$D = RV \cdot A \cdot \left(\sum_{i=1}^{n} \left(d_{storey_i} + d_{floor_i}\right) + d_{boiler}\right)$$

Step 4: application of UniFi model

- Calculation of renovation cost from construction cost:

  C=RV*0.65

- Calculation of relative damage by the formula

$$d = 0, \qquad if\ h < 0.25\, m$$

$$d = 52 \cdot h - 13, \qquad if\ 0.25 \leq h \leq 1.5\, m$$

$$d = 17.5 \cdot h + 38.75, \qquad if\ 1.5 < h \leq 3.5\, m$$

- Calculation of absolute damage by the formula

$$D = d \cdot FA \cdot C$$

- Aggregation of the data at the census section level (in the case of meso-scale assessment) and calculation (sum of the values of the individual buildings in the census area) of the damage and exposure values per census section.

Calculation of damage indicator

Determination of the damage indicator as the ratio of the average of the damage values of the three methodologies with the area of the flooded portion of the census section.

4.6 Procedure for exposure characterization of economic activities (commercial and industrial)

The procedure allows to assess the exposure (of structure and content) either at the level of an individual ATECO Section present in a census section, or at the level of the census section itself as aggregate data, using the number of employees or the number of local units as proxies. The unit economic value per employee and per local unit is associated with each ATECO Section within the procedure, using appropriate tabular associations. The output at the meso-scale (census section) also returns an exposure indicator using the number of employees per flooded area unit as the reference variable.

4.6.1 Summary of the approach

- Input: (i) Hazard scenario (raster map of water depths); (ii) Table ISTAT Economic Activity: table in .txt format that defines for each census section, the ATECO Sections present and the total number of employees and associated local units; (iii) polygonal vector layer with polygonal-geometry representing all areas with the presence of water on the surface, such as riverbeds, lakes, artificial reservoirs, etc. ('wet areas'); (iv) polygonal vector layer representing the census sections.
- Monetary valuation of exposure (for structures and contents) at the meso-scale, classifying activities according to their ATECO category. The economic value of the activities is obtained by multiplying the number of local units or the number of employees in each census section by the unit net capital (per unit or per employee), by structure and content, derived from national ISTAT data.
- Final meso-scale representation (ISTAT census section).

4.6.2 Economic exposure assessment

Step 1: identification of the census sections intersected by the flooded area

- Conversion of the raster map of the water depths into a polygonal vector layer to determine the flooded area.
- Exclusion of permanently flooded areas from the theme created in the previous step.
- Extraction of ISTAT census sections superimposed on the vector flooded area.

Step 2: identification of the census sections intersected by the flooded area and association of economic activities with the corresponding census sections

- Using the ISTAT – Census of Industry and Services data base (i.e. data on the number of local units and employees by census section and by ATECO group), association by join of the economic activities to the corresponding census section (layer obtained in the previous step).
- Cutout of the theme obtained in the previous step with the vector flooded area.

Step 3: calculation of local units and employees of economic enterprises in flooded area

- Calculation of the number of local units and employees of the enterprises by ATECO section, within each census section (round up):

$$Unità_i = \alpha \cdot NUM\_UNITA_i$$

$$Addetti_i = \alpha \cdot ADDETTI_i \quad \text{con } i = B, C, D, E, F, G, H, I, J, K, L, M, N$$

where

α = flooded section area/total section area;

〚NUM_UNITA〛 _i = number of local units per census section of the enterprises belonging to the ATECO i-th section;

〖ADDETTI〗 _i = number of employees per census section of the enterprises belonging to the ATECO i-th section;

Step 4: calculation of the economic value of economic activities in the flooded area, distinguishing between structure and content, based on the following ISTAT national data: National Accounts 2018 (i.e. annual national data on net capital by ATECO type of activity) and ASIA 2018 (i.e. annual national data on the number of local units and employees by ATECO type of activity)

Calculation of the economic value of enterprises by census section, broken down by ATECO section, by multiplying the number of local units or the number of employees in each census section by the unit net capital (per unit or per employee), by structure and content, derived from national ISTAT data:

$$Capitale\ netto\_strutture\_Unità_i = Unità_i \cdot Cu_{str,unità,i}$$

$$Capitale\ netto\_contenuti\_Unità_i = Unità_i \cdot Cu_{con,unità,i}$$

$$Capitale\ netto\_strutture\_Addetti_i = Addetti_i \cdot Cu_{str,addetto,i}$$

$$Capitale\ netto\_contenuti\_Addetti_i = Addetti_i \cdot Cu_{con,addetto,i}$$

$$i = B, C, D, E, F, G, H, I, J, K, L, M, N$$

where:

〖Unità〗 _i = number of local units per census section of enterprises belonging to the ATECO Section i-th, reduced proportionally to the flooded area of the census section (step 3)

〖Addetti〗 _i = number of employees per Census Section of enterprises belonging to the ATECO i-th Section, reduced proportionally to the flooded area of the Census Section

〖Cu〗 _(str,unità,i) = net capital of structures per single local unit for enterprises belonging to ATECO Section i-th;

〖Cu〗 _(con,unità,i) = net capital of contents per single local unit for enterprises belonging to ATECO Section i-th;

〖Cu〗 _(str,addetto,i) = net capital of structures per employee for enterprises belonging to ATECO Section i-th;

〖Cu〗 _(con,addetto,i) = net capital of contents per employee for enterprises belonging to ATECO Section i-th;

The unit values of the net capital for each ATECO Section (〖Cu〗 _(str/con,unità/addetto,i)) adopted in the procedure were calculated by dividing the value of the net capital of the structures and contents at a national level (Source: ISTAT - National Accounts) by the number of local units or the number of employees present in Italy (Source: ISTAT - ASIA), grouped by type of ATECO activity (year 2018).

Sum of the results of the procedures carried out for the different ATECO Sections in order to assess the total exposed value of economic activities per census section (distinguishing as between structures and contents):

$$Unità_{TOT} = \sum_{i=B,\dots,M} Unità_i$$

$$Addetti_{TOT} = \sum_{i=B,\dots,M} Addetti_i$$

$$Capitale\ netto\_strutture\_Unità_{TOT} = \sum_{i=B,\dots,M} Capitale\ netto\_strutture\_Unità_i$$

$$Capitale\ netto\_strutture\_Addetti_{TOT} = \sum_{i=B,\dots,M} Capitale\ netto\_strutture\_Addetti_i$$

$$Capitale\ netto\_contenuti\_Unità_{TOT} = \sum_{i=B,\dots,M} Capitale\ netto\_contenuti\_Unità_i$$

$$Capitale\ netto\_contenuti\_Addetti_{TOT} = \sum_{i=B,\dots,M} Capitale\ netto\_contenuti\_Addetti_i$$

- Calculation of damage indicators by dividing the total exposure values obtained in the previous step both by the individual ATECO Sections within the census plots and by the aggregate data at the scale of the census section $Unità_{TOT}$ $Addetti_{TOT}$ $Capitale\ netto\_strutture\_Unità_{TOT}$ $Capitale\ netto\_contenuti\_Unità_{TOT}$ $Capitale\ netto\_strutture\_Addetti_{TOT}$ $Capitale\ netto\_contenuti\_Addetti_{TOT}$ for the flooded area of the census section.

4.7 Procedure for assessing expected or potential damage to agriculture – crops

The procedure is carried out in two separate sub-procedures, where the first produces part of the input data of the second; from the latter, the final outputs are obtained in terms of damage (decrease in revenue) for the crops included in the AGRIDE-c model (doi: 10.5194/nhess-19-2565-2019) and as the maximum value exposed (PLV, Gross Saleable Production) for the crops not implemented in the damage model.

4.7.1 Summary of the approach

- Input: (i) hazard scenario (raster map of water depths); (ii) Cadastral parcels: vector layer with polygonal geometry containing the cadastral parcels to which are associated the prevailing uses (type of cultivation, manufacturing, etc.) and their areas by linking them to the declarations made by farmers for CAP premiums; (iii) Crop classification table: table reclassifying the uses according to crop classes; (iv) Yield and price tables: tables showing for each crop class the yields (expressed in q/ha) and prices (in €/q); (v) Month of the event: free text field (1 (January)-12 (December); (vi) Flood duration: free text field expressed in number of days; (vii) Type of tillage (‘minimal’ or ‘traditional’); (viii) polygonal vector layer representing census sections.

- Evaluation of the exposure in monetary terms at the meso-scale (i.e. at the scale of the cadastral parcel, assuming that its surface area is entirely occupied by the prevailing crop) for crops.
- Evaluation of the damage in monetary terms at the meso-scale, using the AGRIDE-c model.
- Representation of the results at the census section scale (meso-scale).

4.7.2 Assessing the economic value of the exposure for crops

Step 1: identification of parcels in flooded area

- Conversion of the raster map of water depths into a polygonal vector layer to determine the flooded area.
- Cutout of cadastral parcels with the vector flooded area.
- Identification of the parcels/parcels falling within the flooded area.

Step 2: calculation of agricultural area in flooded area

- Calculation of the area of the prevailing crop within each cadastral parcel from the data present in the declarations made by the farmers for CAP premium purposes:
  $A = \alpha \cdot SAU$

where:

α = parcel flooded area/parcel total area

SAU = total utilised agricultural area within each parcel, assuming it is devoted entirely to the prevailing crop

Step 3: assignation of water depth

- Calculation of water depth h (from the raster of water depths) for each cadastral parcel by averaging the water depths for each polygon using Zonal Statistics tools.

Step 4: calculation of the economic value of the exposure

- Reclassification of the uses present in farmers' declarations according to crop macro-classes.
- Attribution of the crop yield to each cadastral parcel: the average values at regional level of the SIAN benchmark yields are used, calculated for the crop classes identified for each Region.
- Attribution of the sale price of the crop to each cadastral parcel: the average values at regional level of the ISMEA prices are used, calculated for the crop classes identified for each Region.
- Calculation of the economic value of crops in terms of gross saleable production (per cadastral parcel):

$$E = PLV = A \cdot yields \cdot price$$

Calculation of crop damage at the cadastral parcel scale (for maize, wheat, barley, forage, rice, sugar beet, tomato)

Application of AGRIDE-c model

- Attribution of the other hazard parameters to each cadastral parcel: flood duration and month(s) of event (from historical analysis)
- Choice of the most frequent type of tillage for each crop: traditional or minimum tillage.
- Attribution of the unit economic damage, d [€/ha], to each cadastral parcel on the basis of the absolute damage tables of the AGRIDE-c model.

- Calculation of absolute damage per cadastral parcel, D [€]: $D = d \cdot A$

Calculation of damage and exposure to crops at the scale of census sections

- Aggregation of the cadastral parcels on the census sections in which they are contained and evaluation of the minimum damage among the mitigation strategies. PLV values for those crops not implemented in the AGRIDE-c model will also be associated at this stage.
- Evaluation of the damage and exposure indicators as the ratio of total minimum damage and PLV to the area of the flooded census section, respectively.
- Representation of the results at the meso-scale (census section).

4.8 Procedure for exposure assessment of livestock farms

The procedure allows to identify the livestock farms that fall within the potentially flood-prone area, aggregating the data obtained both at the cadastral parcel scale (identifying for each farm the number of animals, subdivided by type (poultry, bovines (buffalo), pigs, sheep and goats)), and at the census section scale, calculating the total number of animals exposed.

4.8.1 Summary of the approach

- Input: (i) hazard scenario (raster map of water depths); (ii) Cadastral parcels: polygonal vector layer containing the cadastral parcels that will be used as an aggregation layer for the information; (iii) Livestock DB: vector layer with point geometry, with the location of the farms and the number of animals subdivided by type (derived from the punctual data of the National Livestock Registry Database); (iv) polygonal vector layer representing the census sections.
- Evaluation of livestock exposure, identifying those potentially exposed.
- Final meso-scale representation (census section).

4.8.2 Exposure assessment

Step 1: identification of livestock farms in flooded area

- Conversion of the raster map of water depths into a polygonal vector layer to determine the flooded area.
- Extraction of the exposed farms by intersecting the point theme of the farms with the vector flooded area.

Step 2: calculation of the physical value of the exposure on the cadastral parcels

- Intersection of the livestock obtained in step 1 with the cadastral parcels.
- Identification of the type and size (number of animals) of the livestock per cadastral parcel.

Step 3: calculation of the physical value of the exposed at the scale of the census sections

- Intersection of the livestock obtained in step 1 with the census sections.
- Aggregation of the data at the census section scale, calculating the total number of animals exposed, regardless of type.

Step 4: calculation of the exposure indicator in census sections

- Calculation of the exposure indicator as the ratio between the total number of animals and the area of the flooded portion of the census section.

4.9 Procedure for exposure characterization of installations at risk of accidental pollution

The procedure allows to assess the installations at risk of accidental pollution that fall within the flooded area, both as a point theme, by extracting the polluting sources in the hazard area, and as an aggregate meso-scale data (census sections), by determining their total number within them.

4.9.1 Summary of the approach

- Input: (i) hazard scenario (raster map of water depths); (ii) vector layer with polygonal geometry representing all areas with the presence of water on the surface, such as riverbeds, lakes, artificial reservoirs, etc. ('wet areas'); (iii) DB pollutant sources: vector layer with point geometry showing the location of installations at risk of accidental pollution subdivided by category (e.g. landfills, chemical industries, etc.); (iv) polygonal vector layer representing census sections.
- Exposure assessment of installations at risk of accidental pollution, identifying those potentially exposed.
- Meso-scale representation (census section).

4.9.2 Exposure assessment

Step 1: identification of pollutant sources in flooded area

- Conversion of the raster map of water depths into a polygonal vector layer to determine the flooded area.
- Exclusion of the wet areas from the theme created in the previous step.
- Extraction of the pollutant sources present within the flooded area, using the point layer of the installations at risk of accidental pollution as input data.

Step 2: meso-scale information aggregation

- Through spatial join tools (with geometric predicate 'intersection'), association of pollutant sources to the flooded census sections in which they fall and evaluation of their total numerosity per census **plot.**

Step 3: calculation of the exposure indicator for pollutant sources

- Assignation of the exposure indicator for installations at risk of accidental pollution by dividing their number within the census section by the area of the flooded portion of the census section.

5. Conclusions

Procedures for the calculation of direct damages / impacts to all assets required by the EU flood legislation are identified and described step by step; they can be implemented in the "Digital Twin", as a valuable component of the informatic ecosystem developed within VS1 as an interoperable tool among the different spokes of the Return project.