Details on the valuation functions per module

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**Urban (M1)**

*From Sogreah (2011)*

- **Impacts of PF and RF**
  
  o **Denial**
  
  \[
  URBAN_{PF+RF} = \sum_{ij} S_i \cdot d_i \cdot \gamma_{ij} \cdot P_{Hj} + \sum_i N_{ij} \cdot P_{Bj}
  \]
  
  o **Laissez-faire**
  
  \[
  URBAN_{PF+RF} = \left(1 - \Delta\right) \cdot \sum_{ij} S_i \cdot d_i \cdot \gamma_{ij} \cdot P_{Hj} + \left(1 - \Delta\right) \cdot \sum_i N_{ij} \cdot P_{Bj}
  \]

**URBAN$_{PF+RF}$** economic impacts of PF and RF on urban assets (housing and business premises)

- **Impacts of EF**
  
  \[
  URBAN_{EF} = \sum_{ij} S_i \cdot d_{ij} \cdot \gamma_{ij} \cdot P_{Hj} \cdot \left(\alpha \cdot (H - h_j) + \beta\right) + \sum_{ij} N_{ij} \cdot (d_{Ej} + d_{Sj} + d_{Pj} + OL_j)
  \]

\[
\begin{align*}
  d_{Ej} &= \delta_j \cdot V_{Ej} \\
  d_{Sj} &= \sigma_j \cdot V_{Sj} \\
  OL_j &= \frac{T_j}{12} \cdot \tau \cdot \theta
\end{align*}
\]

**URBAN$_{EF}$** economic impacts of EF on urban assets (housing and business premises)

- **S$_i$** EF urban area per type of housing area $i$ (continuous, discontinuous and dispersed) [2006 SIG-LR database; Lecacheux et al. 2010]

- **$d_i$** property density per type of housing area $i$ (continuous, discontinuous and dispersed) [estimated with INSEE 2008]

- **$\gamma_{ij}$** percentage of type of housing $j$ (individual, collective) per type of housing area $i$ (continuous, discontinuous and dispersed) [estimated by the authors]

- **$P_{Hj}$** mean property value per type of housing (individual, collective) [immobilier.com and terrain-construction.com consulted in March 2011]

- **$N_{ij}$** number of business premises in (PF+RF) urban areas per type of housing area (continuous, discontinuous, industrial and commercial zones, leisure facilities, mining) and per class of size (< 10 employees and ≥ 10 employees) [estimated with INSEE 2008]

- **$P_{Bj}$** mean value of business premise per class of size (< 10 employees and ≥ 10 employees) [business premise market survey in 2011]

- **$\Delta$** 10-years accounting depreciation of the capital asset located in a future flooded area [estimated by the authors]
database; Lecacheux et al. 2010]

\[ d_i \]  density of ground-floor housing per type of housing area \( i \) (continuous, discontinuous and dispersed) [estimated with INSEE 2008]

\[ y_{ij} \]  percentage of type of ground-floor housing \( j \) (individual, collective) per type of housing area \( i \) (continuous, discontinuous and dispersed) [estimated by the authors]

\( H \)  water level during EF [Lecacheux et al. 2010]

\( h_j \)  ground-floor level per type of housing \( j \) (individual, collective) [estimated by the authors]

\( \alpha \)  damage coefficient [estimated with Torterotot (1993) damage function]

\( \beta \)  damage coefficient [estimated with Torterotot (1993) damage function]

\( N_{ij} \)  number of business premises in EF urban areas per type of housing area \( i \) (continuous, discontinuous, industrial and commercial zones, leisure facilities, mining) and per type of activity \( j \) (16 types of the NA17 classification INSEE Alisse database) [estimated with INSEE 2008]

\( d_{Ej} \)  damage to equipment per type of activity \( j \) (16 types of the NA17 classification INSEE Alisse database)

\( d_{Sj} \)  damage to stocks per type of activity \( j \) (16 types of the NA17 classification INSEE Alisse database)

\( d_{Pj} \)  damage to premises per type of activity \( j \) (16 types of the NA17 classification INSEE Alisse database)

\( OL_{ij} \)  operating loss per type of activity \( j \) (16 types of the NA17 classification INSEE Alisse database)

\( \delta_j \)  damage coefficient for equipment per type of activity \( j \) [estimated with IIBRBS (1998)]

\( V_{Ej} \)  mean value of equipment per type of activity \( j \) [INSEE Alisse database 2008]

\( \sigma_j \)  damage coefficient for stocks per type of activity \( j \) [estimated with IIBRBS (1998)]

\( V_{Sj} \)  mean value of stocks per type of activity \( j \) [INSEE Alisse database 2008]

\( \epsilon_j \)  damage coefficient for construction per type of activity \( j \) [estimated with IIBRBS (1998)]

\( T_j \)  turnover per type of activity \( j \) [INSEE Alisse database 2008]

\( \tau \)  time required to restart the activity in months per type of activity \( j \) [estimated with IIBRBS (1998)]

\( \theta \)  gross margin rate per type of activity \( j \) [estimated with IIBRBS (1998)]

**Agriculture (M2)**

*From Agenais (2010)*

- **PF and RF**

Denial, “Laissez-faire” and Retreat

\[
AGRI_{PF+RF} = \sum_{it} S_{it} \cdot V_i \cdot \pi
\]

\( AGRI_{PF+RF} \)  economic impacts of PF and RF on agricultural land

\( S_{it} \)  total area of agricultural land loss per municipality \( i \) year \( t \) [2006 SIG-LR database; Lecacheux et al. 2010]

\( V_i \)  mean agricultural land values per municipality [2010 AGRESTE and SAFER databases]

\( \pi \)  investment return rate (10%)
\( AGRI_{EF} = \sum_{i} S_i \cdot (d_{Yi} + d_{Ri} + d_{Ei}) \)

**AGRI\(_{EF}\)** economic impacts of EF on crops

- **\( S_i \)** EF agricultural areas over time per crop type \( i \) (34 types of crops considered) [2006 SIG-LR database, SAA Agreste 2008, Lecacheux et al. 2010]
- **\( d_{Yi} \)** yield losses per crop type \( i \) (34 types of crops considered)
- **\( d_{Ri} \)** costs of rehabilitation tasks per crop type \( i \) (34 types of crops considered)
- **\( d_{Ei} \)** damage to equipment per crop type \( i \) (34 types of crops considered)

- For annual crop:
  \[
  d_{Yi} = \sum_{t=N}^{N+2} (\alpha_{it} \cdot y_i \cdot p_i) - \alpha_{IN} \cdot c_{pi} + l_w \cdot (1 - \alpha_{IN}) \cdot (y_i p_i - c_{pi}) - l_R \cdot (\alpha_{RN} \cdot y_R \cdot p_R - c_R)
  \]

- For perennial crop
  \[
  d_{Yi} = \sum_{t=N}^{N+T_{prod}} (\alpha_{it} \cdot y_i \cdot p_i) - \alpha_{IN} \cdot c_{pi} - \sum_{t=N+1}^{T_{prod}} (\delta_t \cdot c_t) + (c_{inv} + c_m \cdot T_{prod})
  \]
  with \( \alpha_{it} = \alpha_{it} (1 - \delta_t) + \delta_t \)

- For pastures
  \[
  d_{Y} = \sum_{t=N}^{N+2} (\alpha_{t} \cdot y \cdot p) - \alpha_{N} \cdot c_p
  \]

- **\( y \)** yield per crop type \( i \) [2008 AGRESTE database]
- **\( p \)** market price (2010 agricultural compensation grid in the case of the natural disasters dataset, CER France 2009)
- **\( N \)** the year of the EF event
- **\( c_i \)** operating costs per crop type \( i \) [Chamber of Agriculture database, CER France 2009, interviews with local agricultural experts]
- **\( c_{pi} \)** operating costs after the flood event per crop type [Chamber of Agriculture database, CER France 2009, interviews with local agricultural experts]
- **\( y_R \)** yield of the resowed crop [2008 AGRESTE database]
- **\( p_R \)** market price of the resowed crop [2010 agricultural compensation grid, in the case of the natural disasters dataset and CER France, 2009]
- **\( c_R \)** operating costs of the replanted crop [Chamber of Agriculture database, CER France 2009, interviews with local agricultural experts]
- **\( T_{prod} \)** time period before the first year of production
- **\( c_{inv} \)** investment costs for replanting [Chamber of Agriculture database, CER France 2009, interviews with local agricultural experts]
- **\( c_m \)** maintenance costs before the first year of production [Chamber of Agriculture database, CER France 2009, interviews with local agricultural experts]
\( \alpha_{it} \) damage coefficient for the year \( t \) per crop type \( i \), function of soil type and the intensity of EF [Devaux-Ros 2000, SYMADREM 2010, Deleuze et al. 1991, adapted by Agenais 2010 to integrate the additional impacts of salt on crops and soil]

\( \alpha_{NR} \) damage coefficient for the year \( N \) of the replanted crop [Devaux-Ros 2000, SYMADREM 2010, Deleuze et al. 1991, adapted by Agenais 2010 to integrate the additional impacts of salt on crops and soil]

\( \delta_{def} \) destruction coefficient of the perennial crop [Devaux-Ros 2000, SYMADREM 2010, Deleuze et al. 1991, adapted by Agenais 2010 to integrate the additional impacts of salt on crops and soil]

\( I_w \) weeding index \( (I_w = 0 \text{ if } \alpha_{IN} < 0.6 \text{ and } I_w = 1 \text{ if } \alpha_{IN} \geq 0.6) \) [estimated by the authors according to Deleuze, 1991]

\( I_R \) resowing index \( (I_R = 1 \text{ if clay soils and } \alpha_{IN} \geq 0.6, I_R = 0 \text{ otherwise}) \) [estimated by the authors according to Deleuze, 1991]

\[
 d_{E_i} = q_{wi} \cdot c_w + q_{Ai} \cdot c_A + I_G \cdot c_G
\]

\( c_w \) hourly cost of labour [interviews with agricultural experts post Xynthia storm]

\( c_A \) cost of amendment (gypsum, organic matter) [interviews with agricultural experts post Xynthia storm]

\( c_G \) cost for green manure sowing [interviews with agricultural experts post Xynthia storm]

\( q_{wi} \) number of working hours for rehabilitation function of crops (annual, perennial or pastures) [interviews with agricultural experts post Xynthia storm]

\( q_{Ai} \) quantity of amendment (gypsum, organic matter) necessary to rehabilitate the agricultural land, function of crops (annual, perennial or pastures) and soil types (clay, sand) [interviews with agricultural experts post Xynthia storm]

\( I_G \) index indicating green manure sowing \( (I_G = 1 \text{ if sandy soils and } \alpha_{IN} \geq 0.6, I_G = 0 \text{ otherwise}) \) [estimated by the authors according to Deleuze, 1991]

\[
 d_{E_i} = \beta \cdot E_i
\]

\( E_i \) equipment values per type of crop \( i \) [Chamber of Agriculture database, CER France 2009], interviews with local agricultural experts post Xynthia storm

\( \beta \) damage coefficient, function of the intensity of EF [Devaux-Ros 2000, SYMADREM 2010, Deleuze et al. 1991, adapted by Agenais 2010 to integrate the additional impacts of salt on crops and soil]

**Beaches and dunes (M3)**

For the assessment of the storm protection service, see Rulleau et al. (2015)

For the assessment of the recreation service, see Rulleau and Rey-Valette (2013)

**Lagoons (M4)**

- **PF and RF**
  Denial, “Laissez-faire” and Retreat

\[
 LAGOON_{PF+RF} = \sum_{i} C_N Q_{N,i} + C_P Q_{P,i}
\]

\( LAGOON_{PF+RF} \): Economic impacts of sea level rise on lagoons water purification service due to PF and RF

\( C_N \): Cost (euros / population equivalent (p.e.) of N) for nitrates purification service replacement with a treatment station

\( C_P \): Cost (euros / p.e. of P) for phosphates purification service replacement with a treatment station
\[ Q_{N,l} = \begin{cases} 0 & \text{if } N_{l,2010} < \bar{N} \\ \frac{\bar{N}}{V_{l,2100} - V_{l,2010}} & \end{cases} \]

- \( N_{l,2010} \): Lagoon \( l \) initial concentration in nitrogen (in 2010) (expressed in p.e. of N / litre)
- \( \bar{N} \): Threshold concentration in N for eutrophication (expressed in p.e. of N / litre)
- \( V_{l,2100} \): Estimated water volume of lagoon \( l \) in 2100 after sea level rise
- \( V_{l,2010} \): Initial water volume of lagoon \( l \) in 2010

\[ Q_{P,l} = \begin{cases} 0 & \text{if } P_{l,2010} < \bar{P} \\ \frac{\bar{P}}{P_{l,2100} - P_{l,2010}} & \end{cases} \]

- \( P_{l,2010} \): Lagoon \( l \) initial concentration in phosphorus (in 2010) (expressed in p.e. of P / litre)
- \( \bar{P} \): Threshold concentration in P for eutrophication (expressed in p.e. of P / litre)

\[ \text{EF} \]

No impact.

**Wetlands (M5)**

For the assessment of the two provisioning services (grazing and materials), and the two regulating services (flood protection and water purification), see Kuhfuss et al. (2016)

**Coastal aquifers (M6)**

- PF and RF

\[ AQUI_{PF+RF} = \sum_{i,t} V_{PF+RF,i,t} \cdot C_i \]

- \( AQUI_{PF+RF} \): economic impacts of saltwater intrusion in coastal aquifers sur to PF and RF
- \( V_{it} \): annual volume abstracted for drinking water supply in the coastal aquifer \( i \) affected by saltwater intrusion over time \( t \)
- \( C_i \): mean annual costs for the installation of a small desalination plant to offset the decrease in fresh groundwater availability in the coastal aquifer \( i \) including investment, operating costs and environmental cost of CO2 emissions [estimated as a function of the required capacity and based on the analysis of the Worldwide Desalting Plants Inventory database provided by Zhou and Tol (2005)]

Denial, “Laissez-faire”

- For five coastal unconfined aquifers:
  \[ V_{PF+RF,i,t} = (v_{1it} + v_{2it}) \]
- For two other coastal aquifers:
  \[ V_{PF+RF,i,t} = v_{2it} \]
Retreat, Protection

- For five coastal unconfined aquifers:
  \[ V_{PF+RF_{it}} = V_{1it} \]

- For two other coastal aquifers:
  \[ V_{PF+RF_{it}} = 0 \]

\( v_{1it} \) Sum of the annual water volume abstracted for drinking water supply in the coastal aquifer \( i \) in wells potentially affected by a shift in the saltwater wedge (wells with a depth close to the saltwater wedge and located in one of the five unconfined aquifers) due to PF and RF over time \( t \) [estimated with Ghyben and Drabbe (1889) and Herzberg (1901), Lecacheux (2010), ADES, BRGM and AERMC databases]

\( v_{2it} \) Sum of the annual water volume abstracted for drinking water supply in the coastal aquifer \( i \) in wells potentially flooded by PF and RF over time \( t \) [estimated with Lecacheux (2010), ADES, BRGM and AERMC databases]

- EF

  \[ AQUI_{EF} = \sum_i v_{3i} \cdot C_i \]

\( v_{3i} \) Sum of the annual water volume abstracted for drinking water supply in the coastal aquifer \( i \) in wells potentially flooded by EF [estimated with Lecacheux (2010), ADES, BRGM and AERMC databases]