Assessing the environmental and social co-benefits and disbenefits of natural risk management measures

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Appendix A – Literature analysis

A1- Articles dealing with the assessment of multifunctionality, co-benefits in the risk management domain

A literature analysis was carried out of the Web of Science (https://www.webofknowledge.com) and the SCOPUS databases (https://www.elsevier.com/solutions/scopus) in October 2022. The requests were:

- Search in the title, abstract and keywords: (multifunctionality OR multi-functionality OR co-benefit) AND "risk management";
- Search in the title: sustain* AND "risk management" (we limited the search to the title as search in the title, abstract and keywords led to 8 240 articles);
- (TI =("nature-based solution" OR "sustainable urban drainage system" OR NBS OR SUDS) AND ALL= "assess*").

Journal articles in English were considered. Duplicates were removed after which finer analyses were performed on abstracts and full reviews. Articles related to other domains such as ecology, agriculture, medicine, supply chain were removed. Finally, we analyzed 116 articles. Among, them, 19 propose a method for assessing co-benefits or dis-benefits. We also added the recent EU report dealing with the assessment of the social, environmental and economic impacts of NBS.

A2- Inventory of GS, HS and NBS

We used several sources for this research: the institutional literature, the scientific literature (search in SCOPUS and Web of Science), and technical reports. Keywords used were: Flood, Wildfire, Coastal Flood, Risk Management, NBS, Infrastructure (French terms were also used – search on the Internet). Documents selected were:

Institutional literature: (Global Water Partnership, 2000; Joint Steering Committee for Water Sensitive Cities, 2009; UNESCO, 2009; World Meteorological Organization, 2006; World Meteorological Organization, 2009; World Meteorological Organization, 2012; World

Meteorological Organization, 2013; World Meteorological Organization, 2017; World Wildlife Fund (WWF), 2016; WWAP/ONU-Eau, 2018; European et al., 2015).

Scientific literature in English: (Estrella and Saalismaa, 2013; Cohen-Shacham et al., 2016; Alves et al., 2019; Alves et al., 2018a; Alves et al., 2018b; Aly et al., 2022; Andersson-Sköld and Nyberg, 2016; Bana e Costa et al., 2004; Banihabib et al., 2019; Beceiro et al., 2022; Bezak et al., 2021; Biswal et al., 2022; Borsje et al., 2011; Brouwer and van Ek, 2004; Carsel et al., 1988; Chan et al., 2022; Curt and Gervais, 2014; Curt and Talon, 2013; Curt and Frejaville, 2018; Curt et al., 2016; Davis et al., 2009; Day Jr et al., 1997; Dittrich et al., 2019; Edjossan-Sossou et al., 2014; Edjossan-Sossou et al., 2020; Eggermont et al., 2015; Faivre et al., 2017; Faivre et al., 2018; Ferrans et al., 2022; Folk, 1966; Ganteaume et al., 2013; Giordano et al., 2020; Gourlay, 1992; Haque et al., 2022; Hoang et al., 2018; Johnson and Geisendorf, 2019; Kumar et al., 2021; Lähde et al., 2019; McVittie et al., 2018; Möller, 2006; Nikolaidis et al., 2017; O'Donnell et al., 2020; Ossa-Moreno et al., 2017; Qi et al., 2020; Stephan et al., 2017; Teal and Weishar, 2005; Titko and Ristvej, 2020; Turkelboom et al., 2021; van Veelen et al., 2015; Vercruysse et al., 2019; Vincent et al., 2017; Viti et al., 2022; Wendling et al., 2018; Wójcik-Madej and Sowińska-Świerkosz, 2022; Yang and Zhang, 2021; Sayers et al., 2013).

Scientific literature in French: (Beer et al., 2003; Benard and Peruisset, 2010; Dupraz et al., 2014; Binggeli, 1997; Bouisset, 2011; Bourgogne, 2009; Chevillot-Miot and Mercier, 2014; Darly, 2014; Ernwein and Salomon-Cavin, 2014; Etienne, 1996; Étienne, 2001; Fernandes, 2010; Hellequin et al., 2013; Henine et al., 2012; Jorda and Lippmann-Provansal, 1990; Labadie and Chastel, 1994; Letortu et al., 2012; Morandini, 1979; NODIN et al., 2009; Poulard et al., 2008; Roose, 1996; Valette et al., 1993; Vanroye and Auffret, 2010; Vélez, 1990; Vidal and Fleury, 2009a; Vidal and Fleury, 2009b; Vinet et al., 2012; Mangiavillano, 2008; Peuziat, 2005; Samat, 2007).

Technical reports (French and English): (Bridges et al., 2021; Castelli, 2003; CIRIA, 2013; Cousin, 2011; European Commission, 2021; Global Water Partnership, 2000; Joint Steering Committee for Water Sensitive Cities, 2009; UNESCO, 2009; Vanroye and Auffret, 2010; World Meteorological Organization, 2006; World Meteorological Organization, 2009; World Meteorological Organization, 2012; World Meteorological Organization, 2013; World Meteorological Organization, 2017; World Wildlife Fund (WWF), 2016; WWAP/ONU-Eau, 2018; CETE Méditerranée, 2010; 2008).

Thesis and Books (French and English): (Nédélec, 1999; Poletti, 2014; Valdieu and Outrequin, 2009; Mangiavillano, 2008; Peuziat, 2005; Samat, 2007).

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Appendix B – Indicator grids

Criterion	Indicator (Code)	Definition – Assessment scale
Multi-functionality	Multifunctional property (M1)	Ability of the RMM to fulfil other useful roles for the territory than protection against a hazard: +1: the RMM has a recreational role, protects the environment, maintains the landscape, and promotes the social fabric... (positive externalities) 0: the RMM has no other role than protection against a hazard
Resilience	Anticipation – Hazard performance (RE1)	Ability of the RMM to contribute to the reduction of risk in the territory it protects, through the implementation of forecasting or prevention means: +1: The RMM makes a strong contribution to risk reduction, it can contribute significantly to risk reduction on its own 0: The RMM contributes little to risk reduction and must be associated with other RMMs to contribute significantly to risk reduction
	Recovery from shocks and events (RE2)	Ability of the RMM to be restored following the hazards: +1: the RMM ensures its function after the event, within a defined timeframe - for example, the RMM can be restored or rebuilt quickly and easily after the event (human, technical and financial resources), particularly in the case of repeated events 0: the RMM ensures its function after the event, within a defined timeframe - for example, the RMM can be restored or rebuilt quickly and easily after the event (human, technical and financial resources), excluding repeated events -1: the RMM does not perform its function after the event, within a defined timeframe - for example, the RMM cannot be quickly and easily restored or rebuilt after the event (human, technical and financial resources), especially in the case of repeated event

Criterion	Indicator (Code)	Definition – Assessment scale
Resilience	Preparing for change to increase risk awareness (RE3)	Ability of the RMM to affect risk awareness: +1: the RMM allows people to have a better awareness of risk - for example, the RMM is visible, the RMM is identified as a risk management solution 0: the RMM does not allow people to have or improve their risk awareness - for example, the RMM is not visible, is too integrated in the landscape or is not considered a risk management solution
	Preparing for change towards more sustainable practices (RE4)	Ability of the RMM to influence people to move toward more sustainable practices: +1: the RMM influences people to move toward more sustainable practices - for example, the RMM promotes people's adoption of sustainability principles (biodiversity protection, saving water, energy...) 0: the RMM has no effect on people's sustainability practices -1: the RMM encourages people to move towards less sustainable practices - for example, the RMM encourages people to adopt principles that run counter to sustainability (excessive use of water for irrigation, energy...)

Criterion	Indicator (Code)	Definition – Assessment scale
Attractiveness of place	Sense of place – Sense of identity (A1)	Ability of the RMM to influence the sense of place or identity +1: the RMM strengthens the sense of place or identity. For instance, the use of particular architecture, materials (e.g., local), old or traditional know-how to build the RMM, or the presence of a RMM considered as a man-made or natural heritage can contribute to the increase and preservation of the sense of identity or to the place 0 : the RMM have no effects on the sense of place or identity -1: the RMM degrades the sense of place or identity. If the RMM replaces another infrastructure or natural environment that was a marker of the place or identity
	Interest of citizens and other stakeholders – Use of the place (A2)	Ability of the RMM to be used by a wide range of people and to foster citizen participation: +1: the RMM can be used by a wide range of people: different audiences can come to the site, take ownership of the site, and share different activities depending on the time of day - e.g., cultural activities, sports. Or the RMM promotes citizen participation - e.g., the public participates in the life cycle of the RMM (RMM cultivated and/or maintained voluntarily by residents) 0: the RMM cannot be used by a wide range of people: access is restricted or forbidden and the RMM does not promote citizen participation -1: the RMM generates maintenance or introduction of public spaces that degrades the quality of life - for example, noise or odour nuisance, attracts pests (rats, mosquitoes...)

Criterion	Indicator (Code)	Definition – Assessment scale
Social cohesion	Accessibility (S1)	Ability of the RMM to make the site accessible to all: +1: The RMM is accessible to all - e.g., access for people with disabilities, presence of public transportation to the site, free access -1: the RMM is not accessible to all - e.g., no disability access, paid access, not accessible by public transportation, not equitable access. OR the RMM is not accessible to anyone for safety reasons
	Social permeability (S2)	Capacity of the RMM to act on shared experiences, inter-generational, intercultural and social mixing and exchanges, citizen participation: +1: the RMM favours co-habitations, co-uses, co-sharing of spaces, integrative practices, citizen participation - for example, appropriation by associations, sports sessions on the site 0: the RMM does not affect co-habitation, co-use, co-sharing of spaces, integrative practices, citizen participation -1: the RMM degrades co-habitation, co-use, co-sharing of spaces, integrative practices, citizen participation - for example, associations can no longer practice on the site
	Equity - Reduction of inequalities (S3)	Ability of the RMM to provide the same level of service to everyone: +1: the RMM allows populations to benefit from new facilities and helps reduce inequalities - e.g., buffer zone in which vegetable gardens are installed, green roofs 0: The RMM does not affect the level of service -1: the RMM increases gaps between different strata of the population, widening the gap between disadvantaged populations and others

Criterion	Indicator (Code)	Definition – Assessment scale
Social cohesion	Integration (S4)	Ability of the RMM to affect social integration: +1: the RMM promotes social integration - for example, development of jobs related to the implementation or maintenance of this type of development (services in communities) 0: the RMM neither promotes nor hinders social integration -1: the RMM penalizes social integration
	Social Mobility (S5)	Ability of the RMM to have an effect on social mobility +1: the RMM has a beneficial effect on social mobility - for example, the RMM improves the image of the neighbourhood 0: the RMM has no effect on social mobility -1: the RMM has a negative effect on social mobility - for example, the RMM degrades the image of the neighbourhood
Well-being and Quality of life	Creativity – Recreation (W1)	Ability of the RMM to enable creativity and recreation and to inspire culture within the territory: +1: the RMM enables regeneration or generates opportunities for multiple expressions - e.g., artistic, creative and recreational practice; local practices, traditional practices 0: the RMM does not regenerate or generate opportunities for multiple expressions - e.g., artistic, creative and recreational practice; local practices, traditional practices

Criterion	Indicator (Code)	Definition – Assessment scale
Well-being and Quality of life	Education – Training (W2)	Ability of the RMM to create educational and training opportunities (other than those related to risk) +1: the RMM generates educational, skill-building, and training opportunities (various activities including with children) outside of risk information activities - e.g., gardening, beekeeping, agricultural production, painting, photography 0: the RMM does not generate education, skill development and training opportunities (various activities including with children) outside of risk information activities
	Landscaping (W3)	Ability of the RMM to affect how the place is developed and how it can be disposed of +1: the RMM improves the way the place is designed and disposed of - for example, installing an RMM in a wasteland with litter 0: the RMM does not affect the way the place is designed and disposed of -1: the RMM degrades the way the site is landscaped and the way it can be disposed of - for example, the RMM replaces landscaping or the RMM is visibly installed in a landscaped area, degrading its aesthetics
	Liveable city (W4)	Ability of the RMM to participate in creating a liveable city: +1: the RMM generates maintenance and/or introduces spaces that improve quality of life - 0: the RMM generates maintenance and/or introduces spaces that do not impact the quality of life - or the RMM does not introduce public spaces -1: the RMM generates maintenance and/or introduces public spaces that degrade the quality of life
	Sense of security (W5)	Level of safety, excluding the natural or technological risk concerned, offered by the RMM and the place in which it is located: +1: the RMM and its location is a safe place to walk, a welcoming space, the surroundings are safe from accidents... -1: the RMM and the place where it is located is not a safe place to walk, is not a welcoming space, the surroundings are not safe from accidents...

Criterion	Indicator (Code)	Definition – Assessment scale
Responsible use of resources	Improvement of land use (RU1)	Ability of the RMM to affect land use: +1: the RMM improves land use - e.g., the RMM has dual use if little space available 0: the RMM does not affect the land use (no or reduced right-of-way) - for example, buried structure - The RMM is located on low quality soils or on a wasteland -1: the RMM degrades the land use (large footprint) or is located on soils with a high quality index
	Reduction, reuse and recycling of materials - Sustainable production (RU2)	Ability of the RMM to be part of a sustainable production framework throughout its life cycle, including the transportation of the materials necessary for its construction: +1: during the construction of the RMM, the use of materials is reduced, or the use of recycled materials is encouraged, or its implementation allows for the reuse or recycling of its constituent materials, or the RMM is based on a policy of efficient use of energy, or the RMM is part of a sustainable management of natural resources (e.g., use of water to fight fires) -1: the life cycle of the RMM is not part of a sustainable production framework

Criterion	Indicator (Code)	Definition – Assessment scale
Preservation and improvement of the environment	Improving environmental performance (P1)	Ability of the RMM to improve the environmental performance of the territory, which may aim at adaptation or mitigation of the effects of climate change: +1: the RMM improves environmental performance - for example, the RMM creates a cool island, or limits CO2 and greenhouse gas emissions... 0: the RMM has no effect on environmental performance -1: the RMM degrades environmental performance - for example, the RMM creates a heat island or generates CO2 or greenhouse gas emissions
	Protection, restoration and enhancement of biological diversity and ecosystem services (P2)	Ability of the RMM to act on environmental protection, restoration: +1: the RMM increases biodiversity - e.g., the RMM renatures the site, welcoming native wild plants 0 : the RMM preserves biodiversity - for example, the RMM maintenance plan includes treatment of invasive species -1: the RMM degrades biodiversity - for example, RMM destroys natural areas or native plants
	Restoration and enhancement of connectivity (P3)	Ability of the RMM to act on the restoration or improvement of the ecological connection +1: the RMM strengthens the restoration and improvement of the ecological connection. For instance, the RMM creates a green or blue belt 0 : the RMM have no effects on the restoration and improvement of the ecological connection -1: the RMM degrades the restoration and improvement of the ecological connection. For instance, the RMM cut an existing green or blue belt

Criterion	Indicator (Code)	Definition – Assessment scale
Preservation and improvement of the environment	Health risks (P4)	Ability of the RMM to have effects on the environment; the effects are expressed in the quality of water, air, soil and health +1: the RMM lowers health risks. For instance, the RMM performs an effective depollution of rainwater by decantation of particles; the RMM creates a cool island 0: the RMM has no effects on health risks -1: the RMM strengthens health risks. For example, the RMM traps undesirable components (heavy metal, toxic residues) in playgrounds leading to possible concentration of pollutants; the RMM allows the development of undesirable fauna (mosquitoes, rats…)
Technical specifications	Ease of monitoring (technical means) (T1)	Technical means necessary for the design and realization of the RMM : +1: the design and implementation of the RMM require minor technical means - for example, light mechanized means -1: the design or realization of the RMM requires important technical means - for example, heavy mechanized means
	Ease of maintenance (technical means) (T2)	Technical means required for the maintenance of the RMM: +1: the maintenance of the RMM requires little or no technical means - for example, light mechanized means -1: the maintenance of the RMM requires important technical means - for example, heavy mechanized means
	Ease of monitoring (know-how) (T3)	Expertise required for the design and implementation of the RMM: +1: the design and realization of the RMM requires only one trade - for example, landscaper -1: the design or realization of the RMM requires several trades

Criterion	Indicator (Code)	Definition – Assessment scale
Technical specifications	Ease of maintenance (know-how) (T4)	Expertise required for the RMM maintenance: +1: the design and realization of the RMM requires only one trade - for example, landscaper -1: the design or realization of the RMM requires several trades
	Lifespan (T5)	Estimate of how long the RMM can operate or be active: +1: the RMM has a "medium or long" life (10 years or more) -1: the RMM has a short lifetime (0 to 9 years)
	Health and safety (T6)	Potentiality of the RMM to pose a health and safety (H & S) risk to the personnel in charge of its maintenance: +1: the RMM is not likely to pose an H & S risk to the personnel in charge of its maintenance -1: the RMM is likely to present an H & S risk to the personnel in charge of maintenance and upkeep - for example, risk of falling, injuries, zoonosis
	Vandalism – Theft (T7)	Potential of the RMM to be subject to vandalism or theft: +1: the RMM is not very or not at all susceptible to vandalism or theft - for example, elements that cannot be dismantled or reused, protected elements or RMMs cannot be vandalized -1: the RMM is very sensitive to vandalism or theft - for example, elements that can be easily dismantled and reused, unprotected elements or RMMs can be vandalized
	Legal constraint (T8)	Need for the RMM to meet legal or regulatory constraints or possibility of actions in the public interest for the implementation of the RMM: +1: the RMM does not need to meet legal or regulatory constraints -1: the RMM needs to meet legal or regulatory constraints - e.g., compliance with PLU, environmental protection regulations, expropriations

Appendix C – Global scores (flood and coastal flooding hazards)

Global Score	Classical pond	Multifunctional retention structure	Green roof - Green wall	Bioretention (rain garden)
Without weighting	-0,03	0,65	0,42	0,69
With weighting (wAMRis=10 - wETU=5 - wCoDiBe-Env=2 - wCoDiBe-Soc=2)	0,41	0,69	0,32	0,55
With weighting (wAMRis=10 - wETU=2 - wCoDiBe-Env=5 - wCoDiBe-Soc=5)	0,20	0,82	0,46	0,60

Table B1. Global scores (without and with criteria weighting) for flood RMMs

Global Score	Breakwater	Artificial reef	Gabion	"Ganivelle"
Without weighting	0,04	0,18	-0,20	0,02
With weighting (wAMRis=10 - wETU=5 - wCoDiBe-Env=2 - wCoDiBe-Soc=2)	0,36	0,04	0,22	0,05
With weighting (wAMRis=10 - wETU=2 - wCoDiBe-Env=5 - wCoDiBe-Soc=5)	0,33	0,20	0,14	-0,02

Table B2. Global scores (without and with criteria weighting) for coastal flooding RMMs