# Can NBS address the challenges of an urbanized Mediterranean catchment? The Lez case study

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# Chapter 14
# Can NBS Address the Challenges of an Urbanized Mediterranean Catchment? The Lez Case Study

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## Highlights

- We carry out an integrated evaluation of the impact of two types of NBS in the Lez watershed (South of France): (i) the conservation of agricultural and natural land through the control of urbanization and (ii) the development of green infrastructure.
- Using insurance data on damages, we establish that the most ambitious green infrastructure scenarios can reduce up to 20% of the mean annual damages due to urban runoff.
- Using a stated-preference survey with 400 inhabitants of the watershed, we estimate that co-benefits generated by NBS scenarios are very significant with 180€/household/year for the most ambitious strategy.
- The cost-benefit analysis of green infrastructure strategies reveals that benefits overweight the sum of the cost of construction and maintenance and land related costs.
- Urban communities are in the driving seat for the development of NBS. To achieve this objective, urban master plan need to be updated and urban communities should tap into diverse source of financing and work across services.

P. Le Coent (✉) · C. Hérivaux · J.-C. Maréchal · B. Ladouche · G. Farina · I. Forey
G-EAU, BRGM, Université de Montpellier, Montpellier, France
e-mail: p.lecoent@brgm.fr

R. Marchal · D. Moncoulon · W. Zi-Xiang
Caisse Centrale de Réassurance, Paris, France

N. Graveline
University of Montpellier, UMR Innovation, INRAE, Montpellier, France



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## 14.1 Introduction

The Lez river, which spring is the outlet of karst aquifer, is a small coastal Mediterranean river (29 km long – 746 $km^2$) that crosses the city of Montpellier (Fig. 14.1). The urban community of Montpellier (457,000 inhabitants) is characterized by the largest population growth in France and a rapid urbanization with massive soil-sealing (−2920 ha of agricultural and natural areas from 1990 to 2012). The Lez catchment is exposed to a typical Mediterranean weather marked by repeated droughts, heavy rainfalls and storms in very short time scale in autumn. It has faced major flood events in the history and in the last years notably in 2014, with three successive large events that led to 65 million euros of damages, only for private housing and businesses.[1] Large investments have been carried out to manage overflow risk but runoff risk, accentuated by the recent urbanization, remains a major challenge with 78% of damages in the recent large events of 2014.

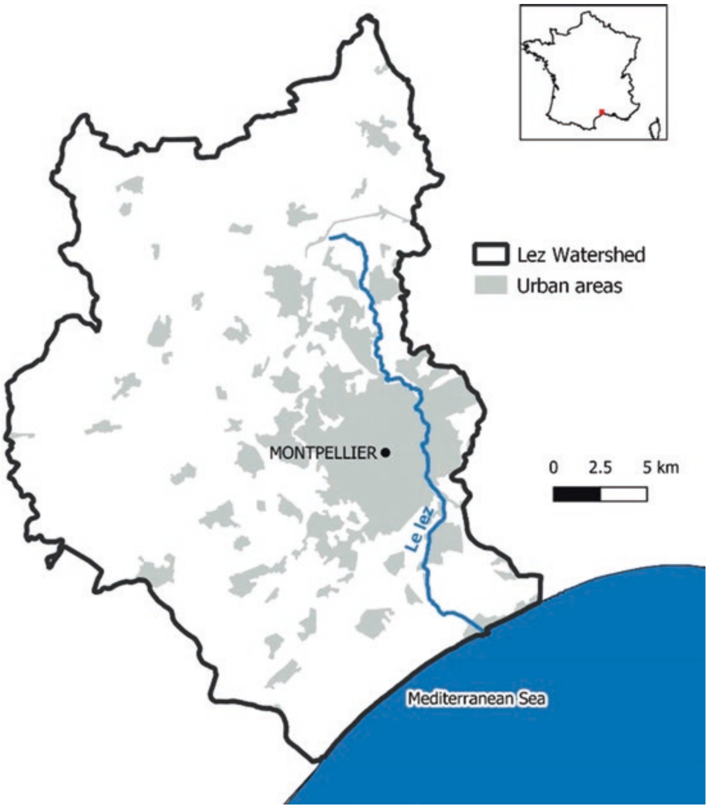


**Fig. 14.1** The Lez catchment

[1] CCR data.

Urban areas, especially the urban community of Montpellier, is facing several other challenges typical of large Mediterranean cities. Air pollution mainly due to the commuting of an increasing number of urban workers living in individual housing outside the main city centre and the vicinity of a major highway remain a large issue. Heat island effect is also a growing challenge with the increase of temperature peaks due to climate change, with a historical record of more than 45 °C reached in 2019. Finally, the Lez catchment is characterized by a very rich biodiversity due to its diversity of habitats and the inherent diversity of the Mediterranean biodiversity hotspots. This diversity is however also particularly threatened by the rapid urban sprawl observed in the last decades.

The issues and solutions studied in this case may be relevant to most urbanized catchments of the Mediterranean region, which are largely exposed to rapid urbanization, due to the attractiveness of the Mediterranean basin and the prevalence of generally dry climate with violent storms generating flash floods (Cramer et al. 2018).

NBS is considered as a potential means to address the flood risks of the territory and other urban challenges. The French Geological Survey (BRGM) and the Caisse Centrale de Réassurance (CCR, French reinsurance company), in close collaboration with local stakeholders, especially the urban community of Montpellier, decided to evaluate the interest of NBS to address these challenges. This chapter focuses on the early stages of NBS project cycle, i.e. the identification of NBS strategies and their integrated evaluation and the launching of initial pathways for their implementation.

## 14.2 Overall Methodology

The overall methodology developed in the Lez case study is presented in Fig. 14.2.

Participatory methods based on scenario planning were used to identify NBS strategies to be tested in the Lez case study (in orange). Spatial modelling was then used to translate NBS strategies into usable inputs for physical modelling (in orange).

Physical modelling (in blue) was used to evaluate the impact of NBS strategies and scenarios on flood hazard in terms runoff and river overflow hazard (Cf. Chap. 4 of this publication).

Economic methods (in green) were finally used to assess NBS strategies and scenarios (Cf. Chap. 6 of this publication)

- Damage assessment was carried out mainly based on insured damages data and flood modelling.
- The implementation costs and opportunity costs of NBS were assessed using value transfer from other reference studies.

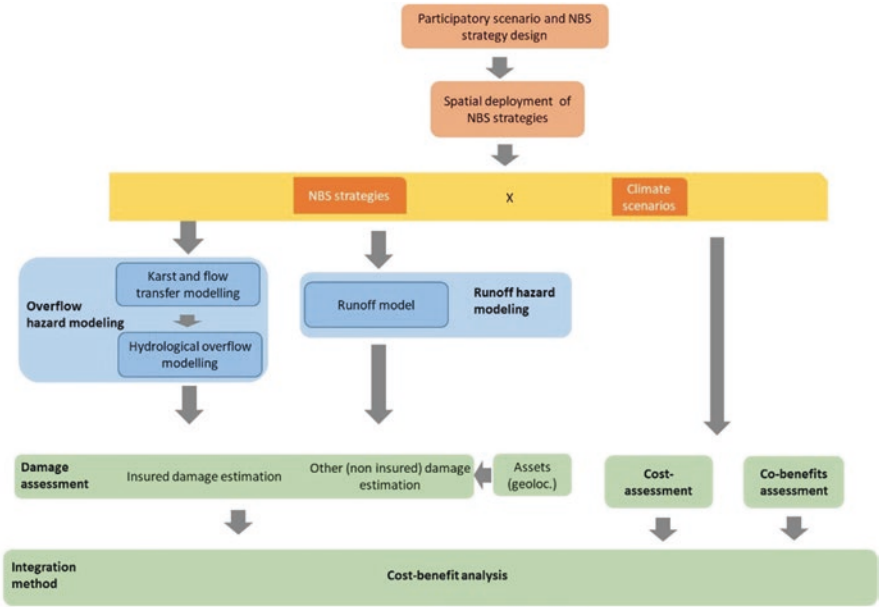


**Fig. 14.2** Modelling framework of NBS Strategies in the Lez Basin

- Co-benefits valuation was undertaken through a choice experiment[2] carried out with 400 citizens of the Lez Basin. This survey evaluates the socio-cultural and monetary value of co-benefits associated with two types of NBS strategies: (i) conservation of natural and agricultural land by limiting urban sprawl and (ii) development of green infrastructure (GI) in the city.
- A cost-benefit analysis (CBA) was finally used to compile the monetary valuation results.

Stakeholders were extensively involved throughout the process, especially for: (i) the identification of NBS strategies (ii) co-benefits valuation (iii) the evaluation of NBS assessment results and (iv) the identification of opportunities and barriers for the development of NBS including funding strategy. More details on stakeholders' involvement is provided throughout the chapter.

This chapter is structured as follows. Section 14.2 presents the identification of NBS strategies. Section 14.3 described how the impact of NBS strategies on flood risk reduction was evaluated. Section 14.4 is dedicated to the economic methods developed to assess NBS strategies and their results. Finally, Sect. 14.5 concludes with key steps towards the implementation of NBS strategies.

[2] Method described in Sect. 14.3.

### 14.2.1 Identification of NBS Strategies

The identification of NBS strategies mainly relied on a stakeholder consultation process. NBS strategies are combinations of NBS individual measures. Two workshops gathered different departments of the urban community of Montpellier "Montpellier Mediterranée Metropole", a citizen's association, public and private developers, region and State representative as well the Lez watershed Authority. The first workshop aimed to (i) identify the main challenges of the territory in terms of water risks, (ii) highlight the drivers of scenarios for the evolution of the territory at the 2040 time horizon and, (iii) identify the advantages and disadvantages of individual NBS measures for risk reduction and (iv) their respective co-benefits. The second workshop was then mainly focused on the elaboration of NBS strategies (combination of NBS) and their validation as well as a discussion of the integrated assessment methodology.

Three types of NBS strategies with the main objective to reduce flood risks and address territorial challenges were identified:

1. The active management of the Lez karst aquifer, i.e. an increased pumping of the karst aquifer during summer time, to reduce overflow risk at the peak period of storm events.
2. The conservation of agriculture and natural lands through the implementation of urbanization strategies aiming at limiting urban sprawl. These strategies will limit soil sealing and therefore avoid the increase of urban runoff and the destruction of ecosystem services linked to agricultural and natural land.
3. The development of green infrastructure in the city to improve stormwater management and to reduce runoff-flooding risk. These green infrastructures are detailed below and represent combinations of small scale measures spread throughout the territory (Sect. 14.2.4). We use the term green infrastructure to differentiate this NBS from strategy 2.

### 14.2.2 Active Management of the Karst

The karst, when not saturated, plays a buffer role and limits Lez flow and subsequent overflow. The level of saturation can be influenced by active water pumping used for drinking water. Currently, 33 $mm^3$ are abstracted each year (reference strategy). It corresponds to a pumping rate able to supply the Montpellier population with drinking water most of the time while maintaining a karst water level above the authorized threshold (35 m above sea level). An alternative strategy was identified to increase the capacity of the karst to reduce overflow risk. This strategy considers an increase in pumping (45 $Mm^3/y$) which is compatible with the pump elevation and natural recharge of the aquifer. Both strategies (reference and alternative) were compared to a theoretic situation without any pumping (0 $Mm^3/y$) in order to estimate the impact of abstraction strategies on flood hazards and damages.

### 14.2.3 Urbanization Strategies

Another type of NBS strategy relates to different urbanization strategies resulting in different levels of conservation of natural and natural land. The conservation of these areas indeed directly falls under the definition of NBS established by the IUCN (Cohen-Shacham et al. 2016). With the help of the stakeholders three different strategies characterized by different targets in terms of population growth and the level of urban densification.

The resulting effect on land artificialization, i.e. the transformation of natural or agricultural land into urban land, was estimated based on a simple model that estimates land requirement depending on additional population to accommodate, the target density of new neighbourhoods and the rate of new housing to be built in existing neighbourhoods:

- Level 1: a “laissez-faire” strategy in which the population growth remains high and new urbanization mainly relies, as at present time; on individual housing that leads to the artificialization of 4000 ha.
- Level 2: a “central” strategy with a lower rate of population growth and efforts of densification that lead to the artificialization of 1600 ha. This scenario takes on the hypotheses of the current urban strategy of the urban communities of the catchment.
- Level 3: A “green” strategy with a lower rate of population growth and an objective of almost no additional artificialization. This scenario is considered as a highly virtuous scenario. Although very ambitious, it reflects the 0 net artificialization policy ambitioned by the government.

In order to evaluate the impact of the different urbanization strategies on flood hazard, it was necessary to identify the spatial impact of these urbanization strategies on land use. This simulation was done through the application of an urban planning model (Calvet et al. 2020).

The results of the urban planning model provided land use maps for the three different urbanization strategies. We present in Fig. 14.3 a focus on one zone of the Lez Basin that shows differences of urbanization in the three strategies in the west of Montpellier. The figure especially shows the development of large patches of discontinuous urban housing (dense) around the peri-urban municipalities: Lavérune, Pignan, Saussan, Fabrègues, Saint Jean de Védas in the Laissez-faire strategy and to a lesser extent in the central strategy. In the green strategy, most new housing is rather made through the development of discontinuous collective housing.

### 14.2.4 Green Infrastructure Strategies

**Green infrastructure (GI) strategies** were developed mainly to address runoff-flooding risks, considered prevalent in the watershed. It was collectively decided during the participatory process to evaluate the effect of GI which main benefit is

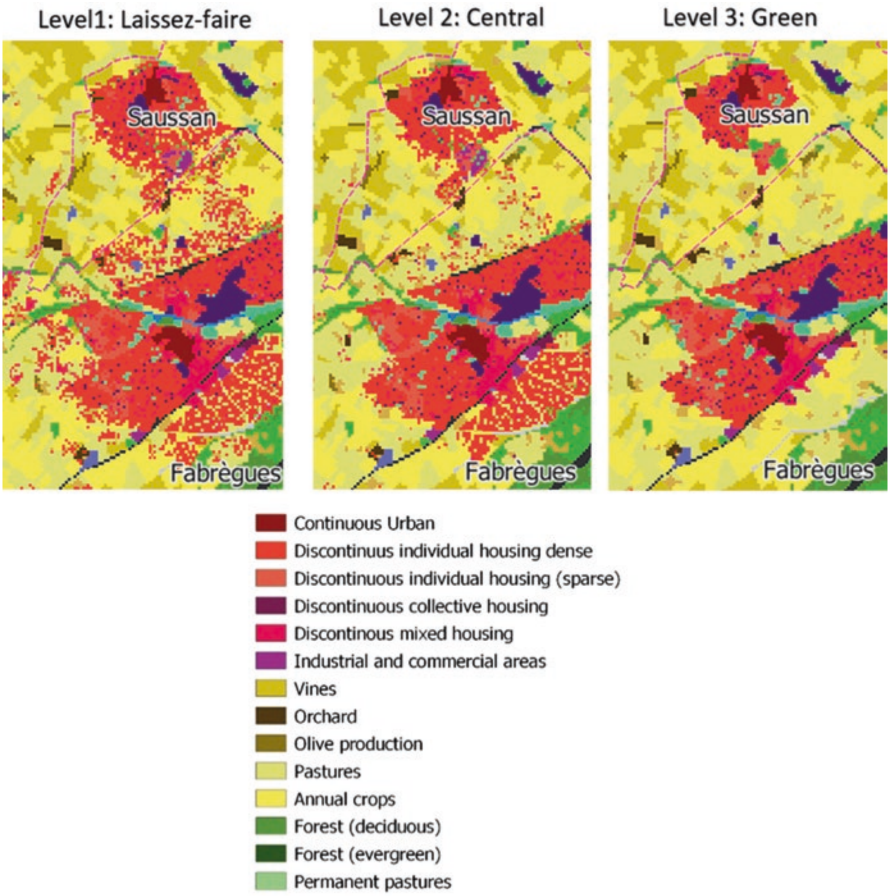


**Fig. 14.3** Detail of the Lez catchment urbanization in the laissez faire, the central and the green strategies based on the SimUrba model (Calvet et al. 2020). (Data: IGN: BD Ortho BD Topo, Corine Land Cover, Montpellier 3)

the retention of water. The combination of GI evaluated in this document are presented in Table 14.1.

The potential extent of implementation of these solutions was evaluated based on photo interpretation of four sample neighbourhoods. The available space identified in the sample neighbourhoods was subsequently extrapolated to the whole urban areas of the watershed, considering the extent of the different types of neighbourhoods throughout the urban areas of the catchment (Fig. 14.4).

For the measures that present a retention capacity, it is directly estimated based on the technical characteristics of the individual measures (Depth, porosity etc.). Table 14.2 presents the estimation of the extent (in $10^3$ $m^2$) of the measures that only reduce soil-proofing and directly the retention capacity (in $10^3$ $m^3$) for measures that generate a retention capacity.

**Table 14.1** Description of green infrastructure strategies

| NBS measure | Description | Level 1 | Level 2 |
|---|---|---|---|
| City deproofing + greening | Deproofing of large areas of urban concrete soils. | X | X |
| Green parking spaces | Waterproof concrete parking pavements are replaced by porous “green” pavements. | X | X |
| Bioswale small | 0.5 m large bioswales are to be constructed along roads. | X | |
| Bioswale large | 2 m large vegetalized bioswales are to be constructed alongside roads except in continuous habitat | | X |
| Vegetated retention basin | 25% of parking areas are transformed into vegetated multi-purpose retention basins. | | X |
| Green roofs | 50% of flat roofs are transformed in vegetated green roofs | | X |


**Fig. 14.4** NBS potential in one sample neighbourhood: example of Saint Martin neighbourhood– Montpellier

**Table 14.2** Potential extent and retention capacity of the NBS strategies

| GI Strategy | NBS measure | Unit | |
|---|---|---|---|
| Level 1 | Deproofing | $10^3$ m$^2$ | 98.5 |
| | Green parking spaces | $10^3$ m$^2$ | 352.1 |
| | Bioswale small | $10^3$ m$^3$ of retention | 24.5 |
| Level 2 | Deproofing | $10^3$ m$^2$ | 98.5 |
| | Green parking spaces | $10^3$ m$^2$ | 352.1 |
| | Bioswale large | $10^3$ m$^3$ of retention | 190.3 |
| | Vegetated retention basin | m$^3$ of retention | 44.0 |
| | Green roofs | $10^3$ m$^3$ of retention | 5.9 |

We finally estimate the retention capacity of NBS strategies in L/$m^2$ of waterproof area for the different types of habitats of the watershed. This estimation is necessary in the next step for the evaluation of the impact of NBS on the reduction of damages. On average, the GI level 2 strategy brings additional 30.3 L of water retention/$m^2$ of waterproofed area whereas the GI level 1 strategy mainly reduces water proofing and yields only 3.6 L/$m^2$.

## 14.3 Risk Modelling and the Impact of NBS Strategies

The main aim of NBS strategies identified in the Lez catchment is the reduction of flood risk. The estimation of the impact of NBS on the reduction of this risk was therefore an important focus of the research carried out in this case study. Two approaches were pursued for the assessment of NBS: the evaluation of the impact of the active management of the karst on overflow risk based on BRGM modeling and the evaluation of urban flood risk and the impact of urbanization and green infrastructure strategies based on CCR modeling. Considering the approaches developed by the CCR, we include the assessment of damage cost avoided thanks to NBS although this also belongs to the economic assessment (Sect. 14.4).

### *14.3.1 The Impact of the Active Management of the Karst on Overflow Risk*

The high infiltration capacity of karst aquifers usually contributes to increasing the retention capacity of karst catchment areas during heavy rains. This is linked to the absence of soil and the presence of surface karst phenomena that facilitate water infiltration. During heavy rains, floods are generally of lesser importance in karst basins as long as their aquifer are not fully saturated. Indeed, during flooding, the karst aquifer is recharged quickly until it is fully saturated: its infiltration capacity decreases and in some cases, rapid underground circulation within karst conduits contributes to worsening the surface flooding. Depending on the initial state of saturation of the karst aquifer, its ability to reduce flooding varies. This has been demonstrated in many karst areas of southern France in particular, where frequent heavy rains are present (Maréchal et al. 2008; Fleury et al. 2009).

It is the case of the Lez river where the karst aquifer, located upstream of the Montpellier city, is used to supply drinking water to the city. The active management practiced on this aquifer consists in pumping a flow higher than the natural flow of the spring in summer in order to reduce water levels at the spring and in the karst conduits and thus mobilize the water reserves located in the less permeable compartments of the aquifer. At the end of summer, the water level is lowered by about 30 m, creating an unsaturated zone capable of absorbing the first autumn rains.

In this study, a historical analysis of water level data from the karst aquifer, rainfall, observed flows in the river and damage caused by several flood episodes was conducted. This was complemented by a modeling approach to test the impact of the pumping strategy on floods and induced damage. A cascade of hydrogeological and hydrological models, coupled with an estimate of the damage generated, has been developed and applied to test various hydrological and aquifer management scenarios.

The results show that pumping the aquifer contributes to reducing the impact on flows and damage of the first rainfall event. However, once the karst is full, it no longer helps to reduce the flood. Therefore, from a statistical point of view, over a full hydrological year, active aquifer management has very little impact on floods and damage in the city of Montpellier (Fig. 14.5). Although differences can be observed between the three pumping strategies they remain very limited, especially to very high intensity rainfall (>50 mm/h) which are very rare.

Although the karst aquifer can play a significant role in flooding the Lez catchment, in specific cases, our results show that the alternative pumping strategy in the karst aquifer does not have a significant impact on average. In addition, the increase in water pumping, may generate side effects, such a reduction of water levels in connected aquifers which may have adverse effects on other water users or the environment. Based on the limited impact of this strategy on flood risks, we decided not to assess further the impact of intensified pumping strategies in the karst aquifer because its impact is limited to very rare specific events.

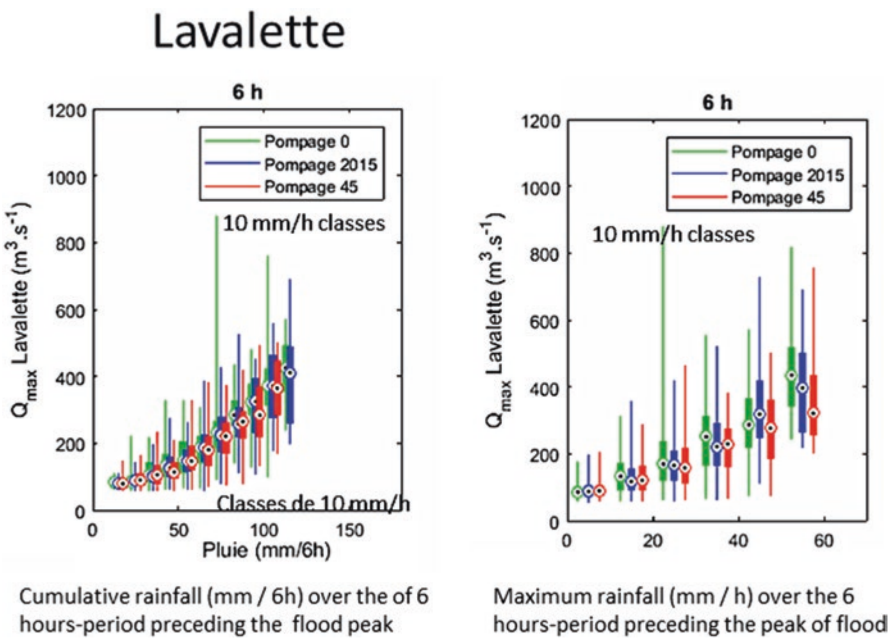


**Fig. 14.5** Maximum inflow of the Lez River (Qmax) at Lavalette station (Entry of Montpellier) according to the cumulative rainfall over a 6 hours period preceding the flow peak and the maximum rainfall over the 6-hours preceding the flow peak for the no pumping (pompage 0) the reference pumping (Pompage 2015) and the 45 mm$^3$ strategy (Pompage 45)

## *14.3.2 The CCR Risk Modelling Approach and Its Use to Evaluate the Impact of NBS Strategies*

### 14.3.2.1 General Overview

The CCR catastrophe risk model has been the basis of the evaluation of the runoff flooding risk and the evaluation of the impact of urbanization and GI strategies as described in Chap. 6 of this publication.

The catastrophe loss risk model is composed of: the hazard unit, the vulnerability and damage units (Fig. 14.6).

The hazard unit is based on a runoff model a model developed by CCR, which is a 2D rainfall/runoff spatialized production and transfer model based on hourly-spatialized rainfall data. It uses a 30 sec time step and a 25 m altitude grid, GIS data related to large watercourses, Météo-France rainfall data and Corine Land Cover data. Each land cover class is associated with a runoff coefficient that reflects the capacity of soil to infiltrate water (natural cover has the highest infiltration rate while continuous urban habitat has the lowest) (Moncoulon et al. 2014).

The vulnerability unit of the model gathers information based on the historical flood claims database (insured damage data) collected by CCR. It is called an insurance portfolio which contains address-based insured claims data such as the amount of the claims, insured value, risk location, portfolio exposure (number of policy contracts).

In the damage unit, the link between hazard and vulnerability is made to estimate damages with damage functions. There are no damage curves allowing the estimation of runoff damages in the Lez watershed. Indeed, the French national guidelines for flood damage (CGDD 2018) focus only on overflow hazards and do not consider the runoff hazard in the calibration of the curves. Specific damage curves were therefore developed for the Lez watershed. In the NAIAD project, the damage functions

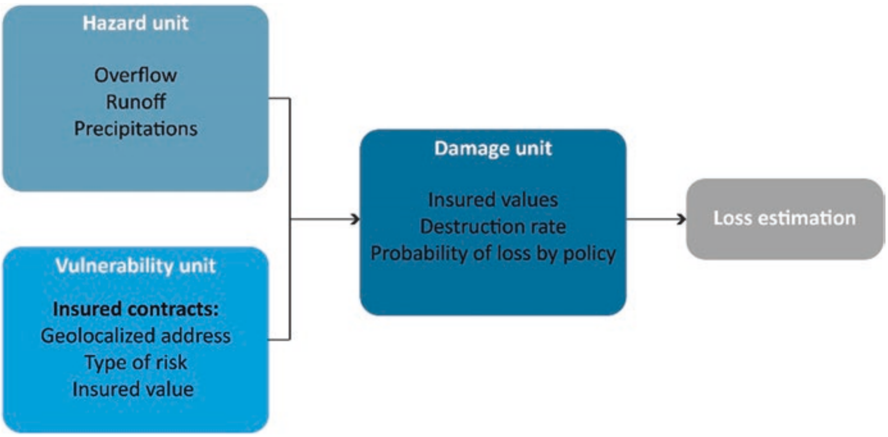


**Fig. 14.6** CCR catastrophe loss risk structure

are calibrated on the 2014-events on claims related only to residential homeowners. They are expressed in terms of damage rate (probability of damage) and destruction rate (amount of claims divided by the insured value) according to runoff flow.

Once calibrated, the catastrophe risk was used to estimate the impact of various modifications of the system (climate change, urbanization strategies, and green infrastructure strategies).

#### 14.3.2.2 Calibration of Damage Curves in the Lez Watershed

The statistical analysis of predicted urban runoff with insured loss of residential homeowners provides the correlation between the runoff (expressed in $m^3/s$) and the damage rate and between runoff and the destruction rate. These correlations are fitted in damage curves as illustrated in Fig. 14.7. Damages associated to a runoff below 0.07 $m^3/s$ are considered null.

These damage curves were used for an assessment of flood damages on the 2014-events. The validation of the damage rate curve has been done by comparing the real costs for the residential homeowners to the simulated costs (Table 14.3).

As the calibrated damage rate provides relevant and close results of the real 2014 flood losses, the damage could be used for subsequent estimations.

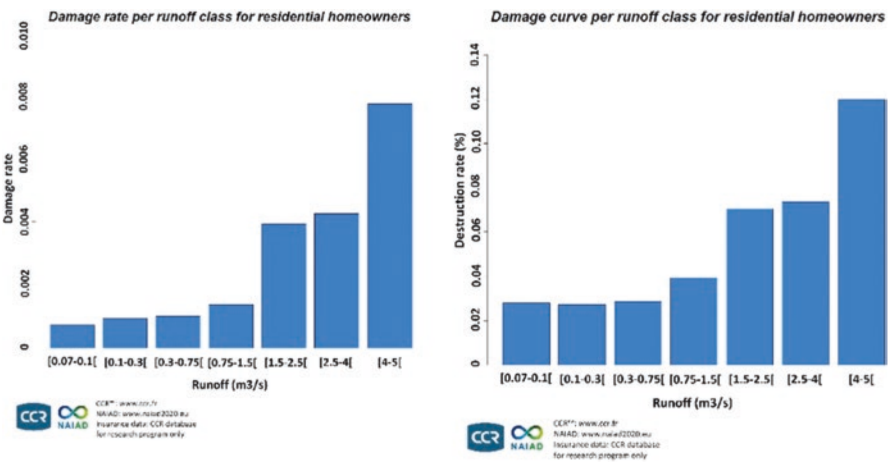


Fig. 14.7 Flow damage function for the Lez. (Source: CCR)

**Table 14.3** Validation of damage rate calibration on the Lez case study for runoff on residential home owner

| Real 2014 damage costs for residential homeowners | Simulated 2014 damage costs for residential homeowners | Simulation error |
|---|---|---|
| 3,353,146 € | 3,298,343 € | −1.63% |

Source: CCR

#### 14.3.2.3 Impact of Urbanization Strategies on Runoff Hazard

The hazard model was used to evaluate the impact of the three urbanization strategies defined in Sect. 14.2. This impact is evaluated with predicted land use maps from the GIS model and associated infiltration coefficient obtained in the three strategies and the estimation of runoff hazard on the 2014 flood events.

Figure 14.8 represents an example of hazard modeling for the laissez faire and the green strategies in the municipality of Cournonterral (periurban).

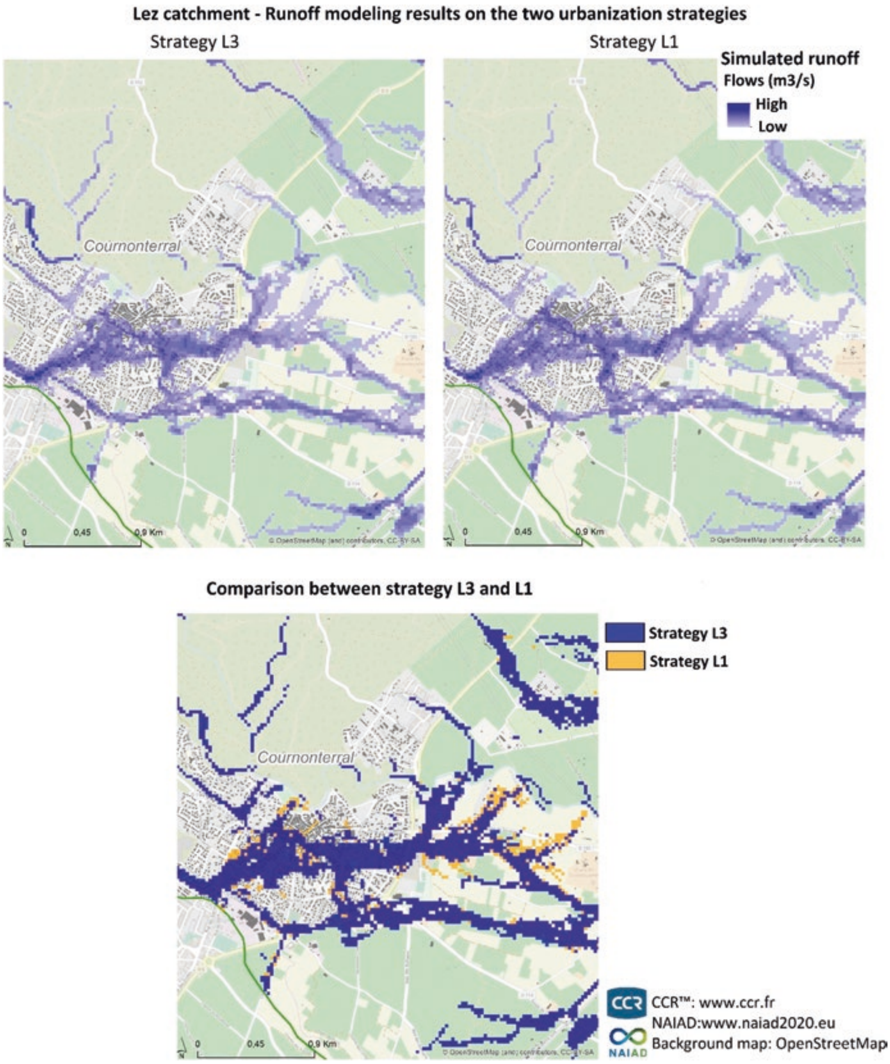


Fig. 14.8 Comparison of flood maps between two urbanization strategies in Cournonterral simulated on the 2014-flood events

The evaluation does reveal an impact in the urban areas that are expected to be built by 2040. The yellow areas reveal areas that would be impacted by urban runoff with the "laissez-faire" (L1) strategy and not in the (L3) green strategy.

However, the impact of strategies in the other highly urbanized area, which are largely dominant in the areas at stake of the catchment, did not reveal significant effects. At the catchment scale, the urbanization strategies therefore did not reveal a significant modification of runoff flood hazard. It was therefore decided not to evaluate further the impact of urbanization on the reduction of flood risks in terms of avoided damages.

#### 14.3.2.4 Impact of Climate Change on Flood Risk

The calibrated damage curves on the 2014-Lez events have been integrated within the catastrophe loss risk structure to assess the insured losses in the current and future climate for the year 2050 (RCP8.5 climate scenario) without specific flood management strategies. The annual average insured losses (AAL) in the Lez watershed was assessed based on the simulation of 400 years of climatic hourly rainfall from ARPEGE-Climat (Meteo-France) at current and 2050 conditions. Within that simulation, we detected and simulated extreme events, estimated damages and classified them in terms of return periods (see Table 14.4).

We estimated that, in the future, the number of events per year will rise from 43 to 57 and the annual average losses will increase from 7.2 to 9.2 €M (30%). We especially observed increasing damage for short-term return period (the model estimate 0 damages for 10 year return events in current climate but 53.5€M in future climate). The observed reduction of damage for long-term return period could be explained by the uncertainties related to the future events. Thus, it can be concluded that in the Lez case study the future flood events will be more frequent and costly.

This estimation of total damages are subsequently used for the estimation of the damages avoided thanks to GI strategies.

#### 14.3.2.5 Impact of GI Strategies on Urban Flood Risk

The initial aim of the study was to stimulate the impact of GI strategies on urban runoff hazard. However, the research on the integration of NBS within the CCR runoff model is complex and still on going. To avoid this difficulty and make a

**Table 14.4** Comparison of total damage costs per return period of extreme events between current and future climate damage on Lez case study without NBS strategies (source: CCR)

| | AAL | 10-year cost | 20-year cost | 50-year cost | 100-year cost | Number of simulated extreme events |
|---|---|---|---|---|---|---|
| Current climate | **7.2 €M** | 0 | 67.7 €M | 89.3 €M | 98.9 €M | **43** |
| Future climate (2050) | **9.2 €M** | 53.5 €M | 73.1 €M | 87.3 €M | 98.6 €M | **57** |

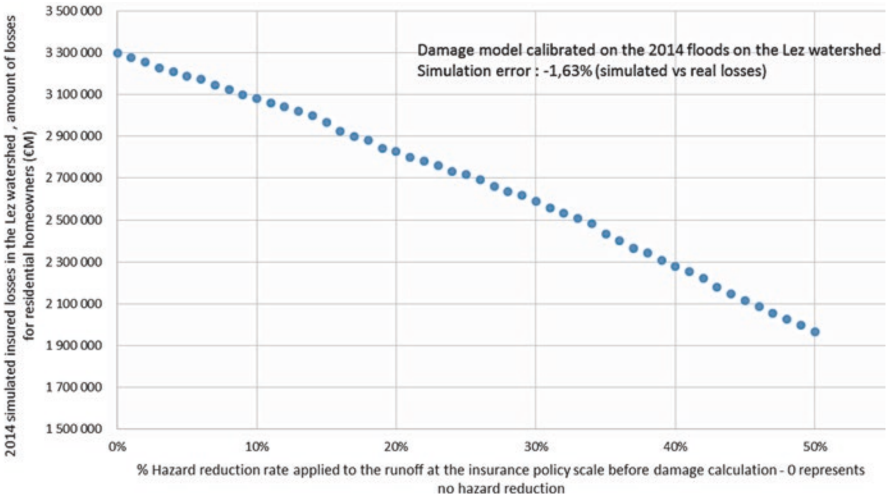


**Fig. 14.9** Effect of hazard reduction on 2014-flood insured losses for the Lez case study. (Source: CCR)

coarse estimation of damages avoided thanks to NBS strategies, the following procedure was used.

1. A relation between the percentage of reduction of runoff hazard and the related effects on avoided damage costs was estimated (Fig. 14.9)
2. A simple link between water retention resulting from GI strategies and the reduction of runoff was established by BRGM and used to estimate the impact of NBS strategies on the reduction of flood damages.

Using the results of the damage model, we estimated the effect of hazard reduction on flood damage (avoided damage) at 25 m resolution. For a reduction of 50% of hazard, the damage will be reduced by 1.9 €M (or −40.45%), a reduction of 20% of hazard reduces the damage to 2.8 €M (or −14.2%). These elements provide an overview of the necessary effect of NBS on the reduction of runoff to be effective to reduce damages.

As a simplification, we subsequently used this relationship for the estimation of damages in all events.

In order to estimate the avoided damages generated by the Green Infrastructure strategies, our assumption is that the retention they generate (30.3 L/m$^2$ for level 2 and 3.6 L/m$^2$ for level 1 (cf. Sect. 14.2.3)) stores all the rain that falls on a unit of land until its capacity is filled and that the % of rain taken out of the system is directly equivalent to the % of reduction of the resulting runoff. Concretely, considering that the average retention of water generated by the GI level 2 strategy is 30.3 L/m$^2$, we consider that if for example 100 mm of rain falls, 30.3 mm of rain is retained in the GI (for the level 2 strategy) which represents a 30.3% reduction of runoff. The argument that can justify the use of this method is that the GI strategies are spread out in a relatively homogeneous manner on the watershed.

**Table 14.5** Estimation of return period of rainfall events at the Montpellier Frejorgues weather station for the 1958–2008 period (Meteo France)

| | Montpellier Frejorgues (1958–2008) | | |
|---|---|---|---|
| Return period (years) | 1H event (mm) | 2H event (mm) | 6H event (mm) |
| 10 | 56 | 71 | 96 |
| 20 | 65 | 84 | 117 |
| 50 | 76 | 103 | 150 |
| 100 | 84 | 120 | 179 |

**Table 14.6** Estimation of the damages with and without Green Infrastructure for current climate (Infinite event is considered to be 1.5 damages of the centenal event)

| | Damages in M€ | | | | |
|---|---|---|---|---|---|
| Return period (years) | Current climate No GI | GI L1 strategy (2H) | GI L2 strategy (2H) | GI L1 strategy (6H) | GI L2 strategy (6H) |
| 10 | 0 | 0 | 0 | 0 | 0 |
| 20 | 67.7 | 65.5 | 49.4 | 66.2 | 54.6 |
| 50 | 89.3 | 87.0 | 69.6 | 87.7 | 75.7 |
| 100 | 98.9 | 96.7 | 80.2 | 97.4 | 86.3 |
| Infinite | 148.4 | 145.0 | 120.3 | 146.1 | 129.5 |

The relationship between runoff reduction and damage reduction is estimated in Fig. 14.9. The damages without NBS for different return period are also defined in Table 14.4. We identified the return-period of rainfall events based on the data of the Montpellier Frejorgues station. We obtain the following return periods in Table 14.5.

Based on these different elements, we estimate in Table 14.6 the damages with no GI, GI level 1 and GI level 2 strategy using the 2H and 6H event rainfall information.

Based on this estimation, we can infer a mean avoided damages of 1.02 to 1.45 M€/year for the GI level 2 strategy (see Chap. 6), i.e. a reduction from 14 to 20% of annual damages, and 0.12 to 0.17 M€ for the GI Level 1 strategy for insured damages. If we include an estimation of 28% of additional damages (public and agriculture) obtained from data collection on the 2014 events, we obtain a mean avoided damage of 1.30 to 1.86 M€/year for the GI level 2 strategy and 0.15 to 0.22 M€/year for the GI Level 1 strategy.

This monetary assessment of the damages avoided thanks to NBS strategies is subsequently used in the overall economic assessment of NBS strategies.

## 14.4 Economic Valuation of NBS Strategies

The economic valuation of NBS strategies is undertaken according to the methodology described in Chap. 6 of this publication. We especially present here: the assessment of implementation and opportunity costs, the economic valuation of co-benefits

**Table 14.7** Economic assessment methodologies used for the different NBS strategies

| | Avoided damage costs | Implementation and opportunity costs | Co-benefits assessment | Cost- Benefit Analysis |
|---|---|---|---|---|
| Urbanization strategies | | | X | |
| Green infrastructure strategies | X | X | X | X |

and the integration of the economic assessment through a cost-benefit analysis. As mentioned earlier, for the sake of clarity, the assessment of damage costs avoided thanks to NBS, which is the primary benefit of NBS strategies, is already described in Sect. 14.3.

We present the elements of the economic assessment that were implemented for the urbanization and the green infrastructure strategies. As mentioned earlier the active management of the karst was not evaluated in the economic assessment due to its lack of significant impact on flood hazard (Table 14.7).

Considering the lack of significant impact of urbanization strategies on hazard, the avoided damage cost can be considered negligible. Implementation and opportunity costs could not be estimated for urbanization strategy, as this would have required sophisticated research beyond the scope of this work. The complete economic assessment was therefore only carried out for GI strategies.

### *14.4.1 Assessment of Implementation and Opportunity Costs of NBS Strategies*

We present in this section the method and results of the estimation of costs for the GI strategies.

#### 14.4.1.1 Method

The estimation of implementation costs included the estimation of capital expenditures and operation maintenance (O&M) costs over a 20-years lifetime. These costs were estimated through a literature review and value transfer from other studies on GI costs, or grey literature from practitioners (Appendix A). As precise costs cannot be established based on a literature review, given the variability of land costs, the precise characteristics of GI and economies of scale, costs were set as ranges. These costs were estimated both for situations in which GI are implemented in existing urban areas, through urban requalification, and for situations in which GI are implemented in entirely new urban areas. This has a great impact on cost estimations, as requalifying already urbanized areas with GI often requires removing concrete pavement, thus implying extra investment costs. For this reason, requalification costs are often higher than new area development costs. In the case of green roofs, requalifying existing roofs requires changes in the load-bearing structure of the buildings, implying as much as 40% extra costs. Therefore, unit cost ranges are especially large for those categories.

Opportunity costs represent the costs associated with the foregone alternative, which can be measured by the net benefit foregone because the resources that provide the services cannot be used in their next beneficial use (Tietenberg and Lewis 2016). Considering that NBS generally require large amount of land for their implementation, compared to grey solutions, it is of utmost importance to consider them. We estimated the cost implied by choosing to deploy NBS instead of other land uses by using the average land market price, as a proxy of the sacrifice costs of not having this land usable for alternative profitable investments. This could be considered an upper bound estimation as it is not obvious whether these areas may have an alternative profitable use. These opportunity costs were added only to some NBS: city deproofing, bioswales and vegetated retention basins. It was indeed considered that roofs do not have alternative profitable uses.

#### 14.4.1.2 Results

The cost estimates are presented in Table 14.8. They are expressed as much as possible in terms of €/m$^3$ of water retention, which is a good proxy of the cost-effectiveness of individual NBS measures to reduce flood risks.

Costs ranges are very wide as economies of scale can greatly reduce marginal costs for surface infrastructures. A vast range of technology is available for many GI. The level of cost varies greatly depending on the type of cover included in green

**Table 14.8** Investment and annual Operation and Maintenance costs. Units depend on the type of GI

| | Unit | O&M | | Investment requalification | | Investment new areas | |
|---|---|---|---|---|---|---|---|
| NBS | | Low | High | Low | High | Low | High |
| City deproofing + greening | €/m$^2$ | 1.05 | 1.05 | 69.9 | 93.6 | 53.0 | 75.0 |
| Green parking spaces | €/m$^2$ | 0.65 | 1.00 | 66.9 | 128.6 | 50.0 | 110.0 |
| Bioswale small | €/m$^3$ | 1.20 | 1.80 | 95.5 | 103.5 | 28.0 | 36.0 |
| Bioswale large | €/m$^3$ | 8.2 | 11.9 | 102.0 | 131.4 | 63.5 | 93.0 |
| Vegetated retention basin | €/m$^3$ | 7.2 | 10.4 | 45.0 | 143.0 | 12.0 | 120.0 |
| Extensive green roofs | €/m$^3$ | 167 (2 years) | 301 (2 years) | 484 | 1322.6 | 417.5 | 1002.0 |
| Intensive green roofs | €/m$^3$ | 83 | 150 | 1282.8 | 1982.5 | 916.3 | 1416.1 |

infrastructure, from a basic herbaceous cover to systems that include trees (high level cost for large bioswales and vegetated retention basins).

We also see a large heterogeneity of cost-effectiveness among the different individual NBS evaluated in the project (Fig. 14.10). This heterogeneity raises questions especially on the opportunity of integrating green roofs in future strategies considering their limited effect on water retention and their large costs.

In order to evaluate the cost over the lifetime of the project, the net present value of costs (see Chap. 6) was calculated and aggregated for the two GI strategies and gave the following estimates for the two strategies (Table 14.9).

The figures show that the GI strategies represent very large investments for the Lez catchment reaching 73–148 €M for the level 2 of GI. When opportunity costs are included, the amounts considered are largely superior. This underlines the fact that GI have a strong spatial extent, which can represent a challenge for their generalization. This also goes in favour of implementing NBS in places that are not suitable for other uses either because of the space or of spatial characteristics. However, although it is recommended to include opportunity costs in CBAs, it is questionable whether these areas all have alternative profitable use and therefore represent an opportunity cost. In the final CBA, we will therefore present results with and without opportunity costs. These costs need to be confronted to an estimation of the benefits brought by GI strategies.

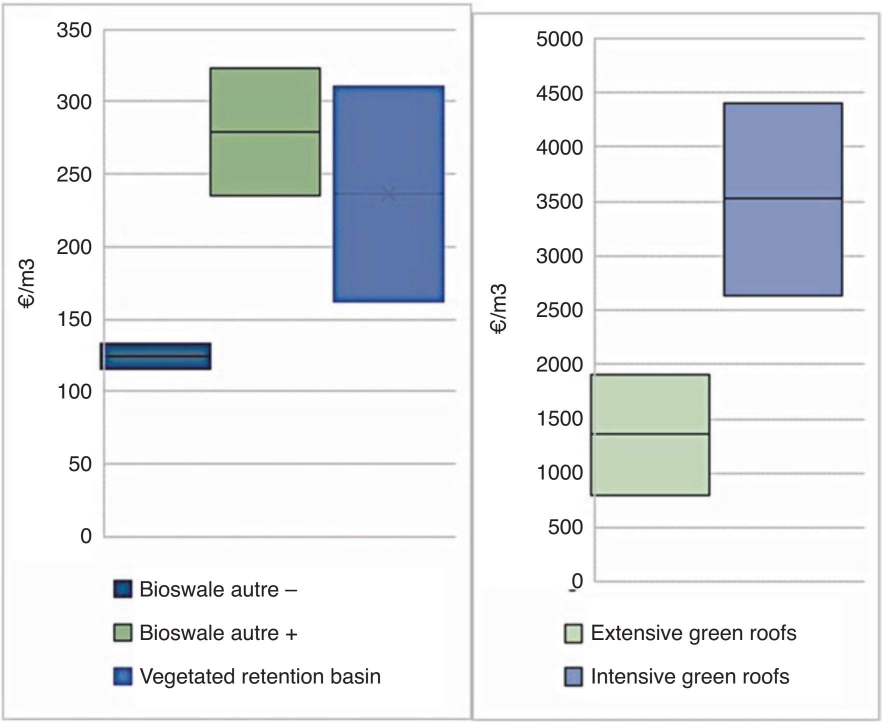


**Fig. 14.10** Cost-effectiveness of individual measures in the Lez Case study. Cost includes the investment and maintenance costs discounted for the next 20 years

**Table 14.9** Overall actualized costs of GI strategies over a 20 years lifespan (in M€)

| | | Without opportunity costs | | With opportunity costs | |
|---|---|---|---|---|---|
| Strategy | GI type | Low | High | Low | High |
| GI level 1 | Deproofing | 8.6 | 10.9 | 32.8 | 50.9 |
| | Permeable parking pavement | 27.3 | 50.1 | 113.9 | 194.0 |
| | Bioswale small | 2.8 | 3.2 | 26.9 | 105.4 |
| | **Total** | **38.6** | **65.1** | **173.6** | **350.4** |
| GI level 2 | Deproofing | 8.6 | 10.9 | 32.8 | 50.9 |
| | Permeable parking pavement | 27.2 | 50.9 | 113.8 | 194.1 |
| | Bioswale large | 44.6 | 61.3 | 151.6 | 238.3 |
| | Vegetated retention basin | 7.1 | 13.7 | 28.8 | 49.5 |
| | Green roofs | 4.8 | 11.3 | 4.8 | 11.3 |
| | **Total** | **73.4** | **148.2** | **331.9** | **544.1** |

## *14.4.2 Economic Valuation of Co-benefits*

The economic valuation of co-benefits is fundamental in the evaluation process of NBS. The multifunctionality of NBS is one of their key advantages as compared to grey solutions for flood control. The NAIAD project generally adopted an integrated valuation approach of co-benefits, that considers that co-benefits also have a physical and a socio-cultural value (Jacobs et al. 2016). Nevertheless, we will focus in this report on the research developed for the monetary valuation of co-benefits. In the Lez basin, we used a stated-preference approach through the implementation of a choice experiment (CE) to valuate co-benefits. Details of this work are presented in Hérivaux and Le Coent (2021).

### 14.4.2.1 Method

Stated-preference approaches rely on representative surveys of the population to estimate people's willingness to pay (how much they would contribute in terms of fee or tax increment) for a hypothetical modification of the environment (here the implementation of NBS strategies). The survey gives the opportunity to evaluate the preferences of the population for different NBS strategies, their flood risk perception and the importance they grant to ecosystem services. It provides socio-cultural and monetary indicators for different NBS strategies and associated bundles of ecosystem services, without seeking to evaluate ecosystem services one by one. In the Lez catchment, we used a choice experiment to evaluate two types of NBS strategies: (1) the conservation of agriculture and natural areas through urbanization strategies and (2) the development of green infrastructure.

The elaboration of the survey was first based on a participatory process, involving two preliminary workshops with local stakeholders, in order to identify expected co-benefits, NBS implementation levels and potential barriers, and to introduce the

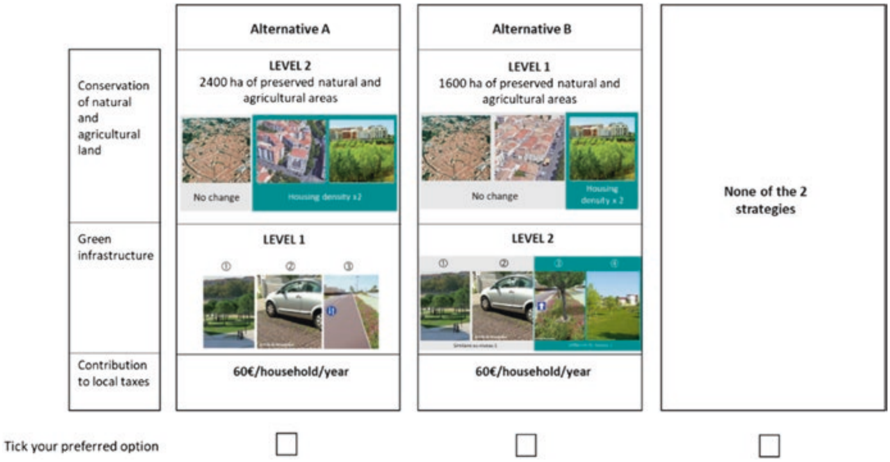


**Fig. 14.11** Example of a choice set in the Lez survey

CE method to local stakeholders (See Sect. 14.2 for a description of stakeholders' involvement). A questionnaire was then elaborated and tested with 29 respondents (face-to-face interviews with residents of the Lez catchment). The survey was subsequently administered on-line and yielded 400 valid responses from residents of the Lez case study.

In the main section of the questionnaire, the CE itself, respondent make choices between hypothetical flood management strategies for the Lez catchment presented in the form of choice cards (Fig. 14.11). In each choice card, respondents choose between two flood management strategies that achieve the same level of flood risk management but differ in the levels of implementation of NBS and in the level of contribution, in terms of tax increase. If neither of the two alternative is suitable for respondents, they can choose "Neither of the two strategies" (*status quo* situation). In this case, in which no payment is included, we emphasize that the level of flood control is not guaranteed. In the survey, respondents have to respond to six choice cards.

Each flood management strategies are characterized by three attributes. Attribute 1 is a simplification of the urbanization strategies, mentioned here as the conservation of agricultural and natural land, with a fixed population growth rate. Attribute 2 represents the GI strategies. For simplification of the questionnaire, green roofs were excluded from the strategies and therefore are slightly different from the strategies identifies in the other components. Attribute 3 is the financial contribution that respondents are willing to pay for financing the flood management strategy. The payment vehicle was identified as a 10-year yearly increase in local taxes. It is either 20, 40, 60, 80, 100 or 120€/household/year. These amounts were adjusted according to the test survey.

The questionnaire also included questions that allowed the identification of the main advantages (co-benefits) and disadvantages perceived by urban residents.

#### 14.4.2.2 Results

The main co-benefits and constraints that respondents perceive for the two NBS strategies and their level of implementation are presented in Figs. 14.12 and 14.13.

On average, three co-benefits are associated with the level 1 of conservation of natural and agricultural land (similar to our urbanization strategies), and 2.5 for level 2. The three most cited co-benefits are climate change mitigation, landscape conservation and air quality improvement. On average, 1 and 1.7 disadvantages are respectively associated with level 1 and level 2. Lower quality of life, traffic problems and landscape deterioration are quoted by more than 20% of the respondents.

Co-benefits associated with **green infrastructure** are quite similar between level 1 and level 2 (respectively 3.2 and 3.1 benefits on average). More than half of the respondents quote landscape conservation, air quality improvement, biodiversity conservation, local urban temperature regulation and climate change mitigation. The number of disadvantages is quite low (0.4 and 0.7 on average respectively for level 1 and 2). Traffic and car parking problems is the most frequently quoted disadvantage for level 2 (18% of the respondents).

The results of the econometric analysis (mixlogit model) of respondents' choice in the CE allows us to estimate the preference for the different levels of NBS strategies.

This analysis reveals that respondents prefer the level 2 of implementation of the two NBS types to the level 1 (and the level 1 over no implementation of the NBS).

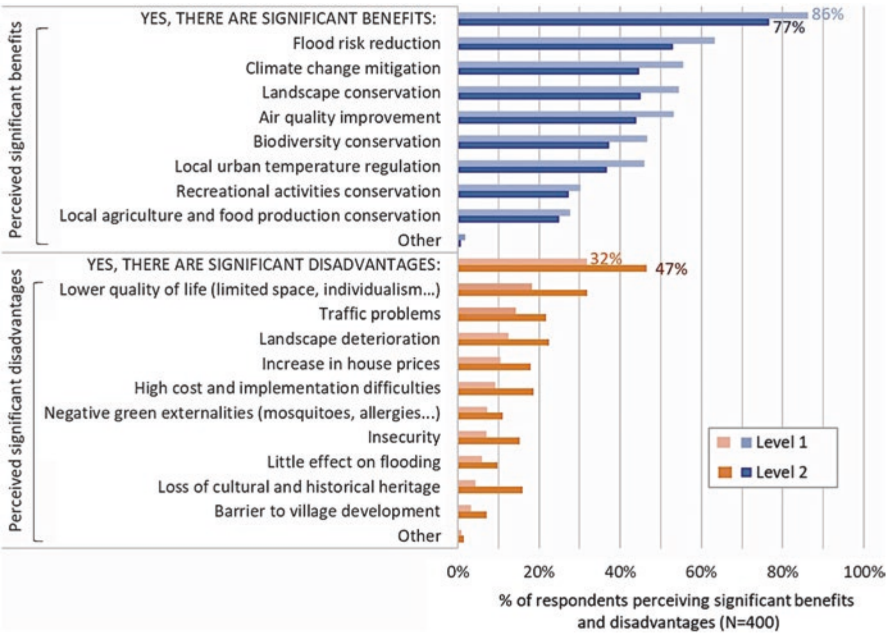


**Fig. 14.12** Perception of significant benefits and disadvantages associated to conservation of natural and agricultural land

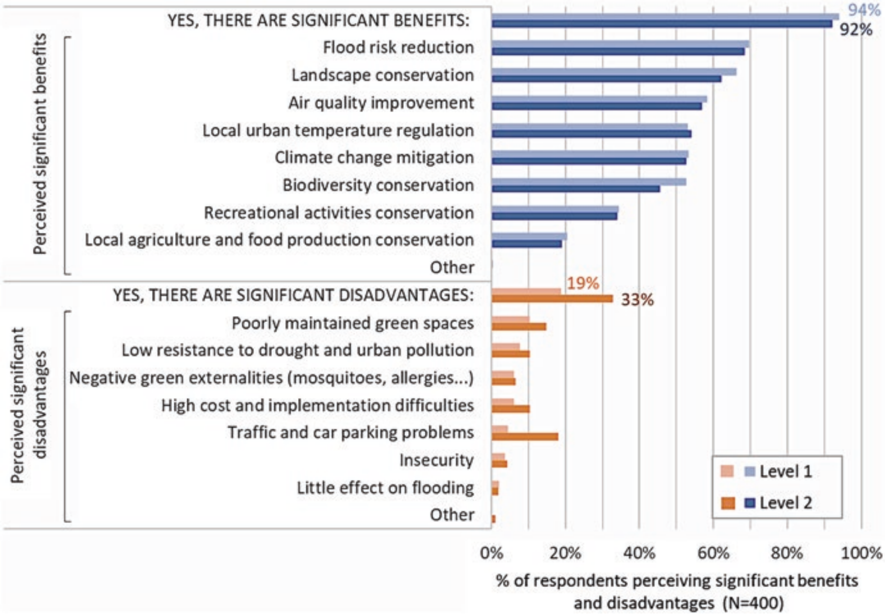


**Fig. 14.13** Perception of significant benefits and disadvantages associated to green infrastructure

- On average, respondents are willing to pay 141€ and 179€/household/year respectively if the level 1 and 2 of conservation of agricultural and natural land is implemented instead of the level 0.
- On average, respondents are willing to pay 143€ and 180€ /household/year respectively if the level 1 and 2 of green infrastructure is implemented instead of no green infrastructure.

Results also show an important heterogeneity of preferences among respondents, influenced by socio-demographic and housing environment characteristics. The analysis of this heterogeneity of preferences is beyond the scope of this chapter, but readers interested in more details can refer to Hérivaux and Le Coënt (2020).

#### 14.4.2.3 Integration of the Economic Assessment

As mentioned before, the cost benefit assessment could only be carried out for the GI strategies. The various assessment described in Sects. 14.3 and 14.4 provide the building blocks for the economic assessment of NBS strategies as per the method described in Chap. 6 of this publication. Some elements are however missing to perform this cost benefit analysis.

First, in order to carry out the assessment, we need to extrapolate the co-benefits value estimated with the choice experiment to the whole watershed. A first provisional estimation of the value granted to co-benefits associated with NBS strategies can be estimated by multiplying the average WTP by the number of households residing in the Lez Watershed (230,000 households in 2019). The annual value of the co-benefits associated with NBS can therefore be estimated at:

- 32.9 M€ for GI level 1;
- 41.5 M€ for GI level 2.

Several indicators can be calculated to carry out a CBA. In this study, we mainly report on the Benefit Cost Ratio that is estimated with the following formula, where $CB_t$ is the Co-Benefits in year t, $AD_t$ is the Avoided Damage in year t, $r$ is the discounting factor,[3] $C_t$ and $OC_t$ are implementations Costs and Opportunity Costs in year t and T is the time horizon of the assessment.

$$BCR = \frac{\sum_{t=0}^{T}\left[\frac{AD_t + CB_t}{(1+r)^t}\right]}{\sum_{t=0}^{T}\left[\frac{C_t + OC_t}{(1+r)^t}\right]} \quad (14.1)$$

We therefore obtain the following estimation of benefits and costs and economic indicators for the GI level 1 and 2 strategies (Table 14.10 and Fig. 14.14).

A first key conclusion of the Lez GI economic valuation is that the cost-benefit analysis reveals close or slightly superior to 1. Investing in GI is therefore economically efficient and should be part of the priority of investments of the urban communities of the Lez catchment. This picture is even clearer, when opportunity costs are excluded from the analysis. Finally, an overwhelmingly large share of the value granted by residents of the Lez watershed to NBS is due to their co-benefits.

**Table 14.10** Overall actualized costs of GI strategies over a 20 years lifespan (in M€)

| Strategy | GI level 1 | GI level 2 |
|---|---|---|
| Implementation costs (M€) (Sect. 14.4.1.2) | **52**<br>39–65 | **120**<br>92–148 |
| Opportunity costs (M€) (Sect. 14.4.1.2) | **210**<br>135–285 | **318**<br>239–396 |
| Avoided damages (M€) (Sect. 14.3.2.5) | **3.4** | **29** |
| Co-benefits (M€) (Sect. 14.4.1.2) | **287** | **363** |
| Avoided damages/Costs (rate) | **0.07**<br>0.05–0.09 | **0.24**<br>0.2–0.3 |
| BCR | **1.3**<br>0.8–1.7 | **1.0**<br>0.7–1.2 |
| BCR without opportunity costs | **6.0**<br>4.5–7.5 | **3.5**<br>2.7–4.3 |

[3] We use the standard rate recommended in the Quinet report of 2.5%.

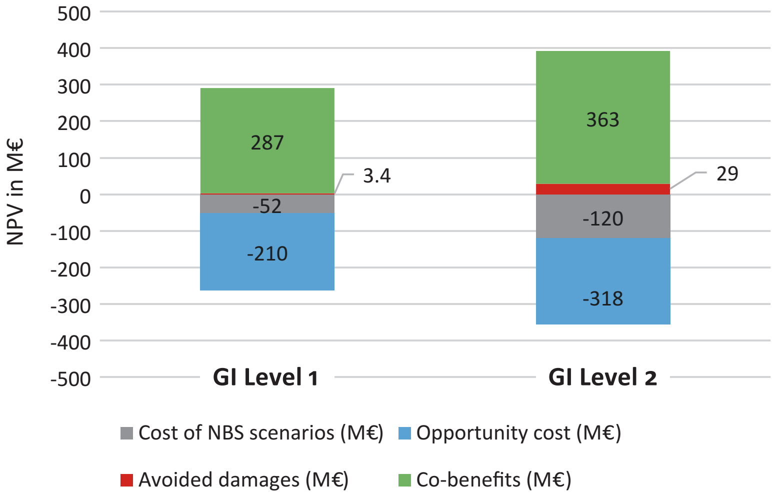


**Fig. 14.14** Cost-Benefit analysis of GI strategies in the Lez catchment

Another conclusion of our study is that ambitious GI strategies (level 2), involving the implementation of green infrastructures at a large scale could mitigate 14–20% of damages related to floods. This is quite significant and should support the interest for green infrastructure in the future. The benefits arising from the reduction of flood risks are nevertheless largely inferior to the implementation costs and even more so if opportunity cost of land are included. The inclusion of co-benefits is therefore fundamental for NBS to be perceived beneficial.

## 14.5 Towards Implementation of NBS Strategies in the Lez Catchment

In the Lez case study, the main objective was to co-design and evaluate NBS strategies aiming at mitigating flood risk and addressing other urban challenges. The strategies we have designed are hypothetical macro strategies, at the city scale. Our study has therefore desmonstrated the potential interest of these measures and call for the development of a practical implementation program that could be the framework for the implementation of neighbourhood scale projects, using the same approach developed in the Copenhagen's cloudburst programme. At present, the NBS strategies are currently not included in local development plans or investment plans for the city. The consultation process with local stakeholders has nevertheless allowed us to identify some key information on the pathway towards implementation. We especially present here some of the key opportunities and constraints for the development of NBS as well as potential policy instruments that could be mobilized for their development.

One of the constraint of NBS development is directly related to the specificity of NBS: the multiplicity of benefits they generate. Dealing with NBS therefore requires a multiplicity of skills and responsibilities that are usually fragmented in the local administration: green space management, flood management, biodiversity, climate change etc. Considering the diversity of benefits of NBS and the limited space available in cities, the development of NBS should be planned based on an optimization of the diversity of benefits and not on one single benefit such as flood protection. Our cost-benefit analysis shows that NBS may be economically efficient when all benefits are considered, but not necessarily for sectorial challenges such as flood management, which may also complicate their acceptance by an administration still characterized by silos. A transition is nevertheless currently happening with the transfer of the responsibility for the management of aquatic ecosystems and flood management (GEMAPI) to urban communities (Montpellier Méditerranée Metropole (3 M) and Communauté de Commune du Grand Pic Saint Loup (CCGPSL) in the Lez catchment) and the possibility to perceive a local tax to finance projects in line with both objectives. This transition forces urban communities to address these challenges in an integrated manner, which should favour the development of NBS. Unfortunately, stormwater management responsibility, currently being transferred to urban communities, is still treated separately from other flood risks which currently limits the opportunities for funding the NBS we have studied.

This diversity of benefits may however be an opportunity to facilitate political support for these measures. In the Lez case study, the conservation of biodiversity remains low in the agenda of local decision makers but risk management, the reduction of heat island effects and air pollution may be good entry points to ensure political buy-in for NBS development.

Several current policy instrument may be mobilized to facilitate the development of NBS. The Water Development and Management Plan (SDAGE) of the Rhone-Mediterranean and Corsica basin includes the measure 5A-04 *"Avoid, reduce and compensate the impact of new soil sealing"* that sets ambitious objective for the limitation of soil sealing in the basin. Considering that all documents developed at the territorial level should be in conformity with the SDAGE, this document provides an excellent opportunity for the development of NBS (limitation of urban sprawl and development of green infrastructure). In addition, the water basin agency can provide 50% of funding of infrastructure investment aiming at reducing soil sealing, the green infrastructure we have studied are eligible.

For the practical implementation at the territorial level, urban communities (3 M and CCGPSL) and cities are in the driving seat for the implementation of the urban NBS strategies we have evaluated. This is especially true since the recent modifications initiated by the territorial reform law of 2015, includes the transfer of water and wastewater management to urban communities. Urban communities are also in charge of the development of urban master plans (SCOT, PLUi) that could be the main instrument for the development of NBS by setting rules for the construction of new neighborhood, which should promote the limitation of soil sealing and the use of green infrastructure, in agreement with SDAGE recommendations. Finally, cities intervene directly as public developer for the creation of new neighborhoods and rehabilitation programs. Including ambitious NBS in these programs would also create an example to be followed by private developers.

## Appendix A: Sources for the Estimation of GI Costs

| NBS | Source |
|---|---|
| City deproofing | https://Construction.info/renovation/VRD_et_amenagements_exterieurs/Revetement_de_sols_exterieurs/Case studylition/ASD020_Case studylition_d_un_revetement_de_sol_e.html |
| Green Parking spaces | Guide technique Ecovegetal (2017)<br>KURAS, Maßnahmensteckbriefe der Regenwasserbewirtschaftung – Ergebnisse des Projektes KURAS, Berlin, 2017 |
| Bioswale large | Grand Lyon, fiche technique n°2, Fossés et noues, 2016<br>Daniel Johnson, Sylvie Geisendorf, Are Neighborhood-level SUDS Worth it? An Assessment of the Economic Value of Sustainable Urban Drainage System Scenarios Using Cost-Benefit Analyses, Ecological Economics, Volume 158, 2019, Pages 194–205, ISSN 0921–8009, https://doi.org/10.1016/j.ecolecon.2018.12.024<br>ARB, Etude comparative des coûts des infrsatructures grises hybrides et vertes |
| Bioswale small<br>Vegetated retention basin | Royal Haskoning DHV, Costs and Benefits of Sustainable Drainage Systems, Committee on Climate Change, July 2012, Project number 9X1055.<br>KURAS, Maßnahmensteckbriefe der Regenwasserbewirtschaftung, Ergebnisse des Projektes KURAS, Berlin, 2017<br>ARB, Etude comparative des coûts des infrsatructures grises hybrides et vertes<br>Grand Lyon: Guide pratiques de gestion des eaux pluviales Fiche 5: Bassins de rétention et/ou infiltration |
| Extensive green roofs | Mairie de Paris, Végétalisation des murs et des toits, 2016<br>IBGE, Formation Bâtiment Durable: Toitures vertes: du concept à l’entretien, 2012<br>Direction de l’Environnement et de l’Energie Nice Côte d’Azur, Etude pour la définition d’une démarche de développement des toitures végétalisées, 2009 |

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