Deliverable 6.3 DEMO Insurance Value Assessment - PART 7: FRANCE - Brague

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Deliverable 6.3

DEMO Insurance Value Assessment

PART 7

FRANCE - Brague

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Executive Summary

The Brague River basin is a 68 km² catchment located along the French Mediterranean coast between the cities of Cannes and Nice. On 3rd Oct. 2015, the basin was severely hit by an extreme flash flood (time return was over 100 years). The basin very flat lowlands experienced numerous damages and casualties related to this flooding event. The several campsites located in these areas were closed by State decision because of the flood risk but dozens of houses remain at risk. The closing of the campsite opened a window of opportunity to redefine the economic activities of the valley and the river corridor in order to improve its life, landscape and environmental quality and to decrease the flood risk.

Within the NAIAD project, several teams of researchers and experts in forest and river management, natural hazards (flood, erosion, wildfire), vulnerability and damage assessment, economy and decision aid gathered to perform an in-depth study of the Brague River catchment. More precisely, we studied its peculiarities, the potential efficacy and efficiency of flood protections measures based on green or grey measures, as well as their co-benefit.

NBS flood alleviation strategies studied for the Brague catchment are a combination of both retention measures by small natural retention areas in the upper catchment, along with a widening of the river corridor in the lowlands enhanced by floodplain reconnection. Floodplain works consist in several measures as bed and bridge widening, forest corridor and wetlands restoration, and large woods debris management. They are integrated in a so-called “giving-room-to-the-river” strategy. Two levels of ambition, namely high and very high, are considered as well as a more classical grey scenario based on huge retention dams.

This report presents the assessment of the Basin state in term of flood risk and river quality. Total costs of the three protection strategies were evaluated. Damage related to historical events and to theoretical floods with known return period were computed in the current and projects’ situation, thus enabling to compute mean annual avoided damage. The co-benefit related to NBS strategies were also evaluated using two different methods: transfer of values based on a meta-regression-analysis of values provided in other catchments and a contingent valuation performed locally through the interview of more than 400 peoples in the basin. The cost-benefit analysis demonstrates that costs are higher than the main benefit, i.e., avoided damage, but when including co-benefit the balance may reach higher benefits than costs for NBS strategies, though not for the grey solution. It worth being stressed that several intangible criteria, e.g., the improvement of the natural status of the river, are poorly captured by the monetary methods and a complementary multicriteria decision framework was developed to handle both tangible and intangible criteria.

Keywords : flash floods, large woody debris, giving room to the river, protection measure efficacy, willingness to pay.

Chapter 1. Preliminary elements of the economic assessment

1.1 Framing the analysis

The aim of this report is to perform the economic assessment of Nature Based Solutions (NBS) in the Brague Demo. The Brague is a short river, 21-km long, of the Mediterranean coast with a flash flood regime. As the Mediterranean climate promote heavy rains in autumn, the floods of the Brague are often devastating and sometimes deadly. Over the period 1970-2015, the Brague caused fourteen natural disaster floods and eight deaths. For example, the insured damages of the October, 2015 flood mount to €50 million (Pengal et al., 2017). In this context, there is a need for additional measures to reduce flooding risks of the Brague.

NBS are alternative measures or complementary to tradional grey ones to water related risks management (Graveline et al., 2017). It is worth noting that NBS is a 'catch-all' concept with multiple definitions (Albert et al., 2019; Nesshöver et al., 2017; Cohen-Shacham et al., 2016; Eggermont et al., 2015). The concept indeed encompases several ecosystem-based concepts (Nesshöver et al., 2017; Eggermont et al., 2015) of which Catchment Systems Engineering (CSE), Ecological Engeeneering (EE) or Natural Flood Management (NFM) (**Table 1**).

CONCEPTS	DEFINITION	EXEMPLE OF MEASURES
ECOLOGICAL ENGINEERING (EE)	EE is defined as the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both (Mitsch, 2012, p. 5)	¬ Restoration of river systems, etc. ¬ Wetlands creation, ¬ Agro-ecological engineering, ¬ Wastewater wetlands, ¬ Bio-manipulation, ¬ Soil bioremediation
CATCHMENT SYSTEMS ENGINEERING (CSE)	CSE is an interventionist approach to altering the catchment scale runoff regime through the manipulation of hydrological flow pathways throughout the catchment (Wilkinson et al., 2014, p.1245)	¬ Drain barriers ¬ Runoff storage features, ¬ Large woody debris dams, ¬ Buffer strip management, ¬ Willow barriers.
NATURAL FLOOD MANAGEMENT (NFM)	Natural flood management involves techniques that aim to work with natural hydrological and	¬ Woodland creation ¬ Land and soil management practices ¬ Overland sediment traps

	morphological processes, features and characteristics to manage the sources and pathways of flood waters. (SEPA, 2015, p. 6)	¬ River morphology and floodplain restoration ¬ Instream structures (e.g. large woody debris)

Table 1: Definitions of concepts related to NBS

Nesshöver et al. (2017) consider CSE a version of NBS because "CSE specifically focuses on catchment-scale working and manipulating hydrological processes in order to benefit humans (p.1218). NBS measures in the Brague Demo are aimed to river flooding mitigation. For this reason, they are essentially river features restoration and mangement measures. They include floodplain and wetlands restoration, stream bed re-naturalization, natural bank stabilization and coarse woody debris management (**Table 2**). The economic assessment is an ex-ante valuation of these NBS measures. It consists in the valuation, over fifty years, of costs, avoided damages and co-benefits due to their implementation on the particular context of the Brague DEMO.

NBS MEASURES	DEFINITION FROM HTTP://NWRM.EU/MEASURES-CATALOGUE
FLOODPLAIN RESTORATION AND MANAGEMENT	The objective is to restore retention capacity and ecosystem functions of floodplains by reconnecting them to the river. A floodplain is the area bordering a river that naturally provides space for the retention of flood and rainwater Restoring floodplains requires measures such as: modification of the channel; removing of the legacy sediment; creation of lakes or ponds in the floodplain; new/modification of agricultural practices; afforestation; plantation of native grasses, shrubs and trees; creation of grassy basins and swales; wetland creation, invasive species removal; riparian buffer installation and development.
WETLANDS RESTORATION AND MANAGEMENT	According to the Convention on Wetlands (1971), a wetland is an area of marsh, fen, peatland, or whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters. It provides water retention, biodiversity enhancement or water quality improvement. Wetland restoration and management can involve: technical, spatially large-scale measures (including the installation of ditches for rewetting or the cutback of dykes to enable flooding); technical small-scale measures such as clearing tree; changes in land-use and agricultural measures, such as adapting cultivation practices in wetland areas. Creating artificial or constructed wetlands in urban areas can also contribute to flood attenuation, water quality improvement and habitat and landscape enhancement.
STREAMBED RE-NATURALIZATION	Streambed re-naturalization consists in removing some concrete or inert constructions in the riverbed and on riverbanks, then replacing them with vegetation structures. Stabilization techniques are among the main measures to be implemented including bank re-naturalization and plant engineering. Bank re-naturalization is a stabilization technique used to correct mild erosion problems and that does not require a high degree of expertise to be implemented.

	Plant engineering is defined as the techniques combining the principles of ecology and engineering to design and implement slope, bank and bank stabilization works, using plants as raw materials for making vegetable frames.
NATURAL RIVER BANK STABILIZATION	River bank renaturalization consists in recovering its ecological components allowing bank to be stabilize, as well as rivers to move more freely. It preferentially refers to bioengineering but civil engineering can be sollicited in complement in case of strong hydrological constraints.
COARSE WOODY DEBRIS	Coarse woody debris consists of large sections or deadfall: tree stems or stumps that either fall into or are deliberately placed in streams. Coarse woody debris can be deployed with varying degrees of naturalness. At one extreme, coarse woody debris can be uses to form coffer or placer dams which effectively limit water flow. At the other extreme, natural deadfall coarse woody debris is found when riparian trees are allowed to fall naturally into streams. Coarse woody debris generally slow water velocity and can reduce the peak of flood hydrographs.

Table 2: Definition of NBS measures in the Brague Demo

The assessment of avoided damages and co-benefits are performed at the Brague catchment scale but focuses on damage related to river flooding. Urban runoff also triggered damages in the catchment though more concentrated on uplands (Piton, et al., 2018). River floods are natural and highly complex phenomena. The increasing of the water stage, its overflow and velocity are non-linear physical processes that depend on several factors related to rains (e.g. intensity of rains, duration of continuous rains), topography (e.g. river morphology, slope between highlands and lowlands, size of floodplains), land uses (e.g. artificialized lands, agricultural lands, forests) and flood control measures (e.g. retention ponds, dikes). Usually, most impact of floods are located in the floodplain and the assessment of damages can be performed at micro-scale for single elements at risk (e.g. buildings, infrastructures), meso-scale for spatial aggregation units (e.g. residential areas, industrial areas, administrative units) or macro-scale for large spatial units (municipalities, departments, regions) (Calatrava et al., 2018). However, it can be misleading to solely focus on cities or municipalities impacted when studying the flood risk and particulary in the context of NBS. Basin level is the most relevant scale insofar as it allows considering the linkages between different features of river systems. This scale suits the physical process that results in risk for socioeconomic systems.

1.2 Define and describe scenarios and strategies

This section focus on the definition of scenarios including the past and future scenarios. Scenario represents a combination of strategies to risk mitigation and socio-economic trends that influence the flood risk (land use, rain, urban planning and of the assets) (Graveline et al., 2017). We refer to past scenario as the reference situation and there is a need to characterize the demo context before performing the economic assement of the NBS (Graveline et al., 2017).

1.2.1 Past scenario: historicity and ecological status of the Brague ecosystem

At the catchment scale, the impact of river flooding is context dependent; likewise the impact of NBS will. We used an ecosystem based approach to identify and value some general aspect of the socioecological system of the Brague catchment (Landers & Nahlik, 2013). Based on desk review and stakeholders interviews, this section gives some contextual elements of the Brague catchment in order to characterize the baseline scenario. It describes the Brague catchment ecosystem, its major changes in the past and ecological status in October, 2015.

1.2.1.1 Ecological status of the Brague catchment

The Brague catchment is shaped by several natural aquatic and terrestrial ecosystems namely the River Brague and its streams, the Mediterranean Sea, ground water tables, wet meadows, natural forests “the Brague” and “the Valmasque”, urban forests, agricultural lands and other natural areas[1]. The interaction between these ecosystems allows the population to benefit a number of ecosystem services. General characteristics of the catchment are presented in **Table 3**. It includes about ten municipalities of which seven concerned by more than 15% of its territory[2]. However, five municipalities are at the heart of the Brague catchment, namely Antibes, Biot, Valbonne, Opio and Châteauneuf-Grasse, on which we focus on. The Brague River can be seen as the spine of the catchment around which the others natural ecosystems are articulated.

Type of climate	**Mediterranean**
Municipalities in the catchment (number)	11
Population in 2015 (inhabitants)*	227,000
Surface area of the catchment (ha)	6948
Headwater altitude (m)	350
Slope in the lowland (%)	0.4
River length: The Brague (km)	21
The Valmasque stream (km)	8
The Bouillide stream (km)	7

[1] Natura park and ZNIEFF (Zones Naturelles d’Intérêt Ecologique Faunistique et Floristique)
[2] Biot (95%), Valbonne (92%), Châteauneuf-Grasse (78%), Opio (32%), Mougins (39%), Vallauris (26%), Antibes (25%), Mouans-Sartoux (15%), Villeneuve-Loubet (7%), Rouret (3%) and Grasse (2%).

Surface area of Valmasque forest (ha)	561
Surface area of Brague forest (ha)	430
Surface area of Golf courses (ha)	486
Surface area of ZNIEFF « Massif de Biot » and « Prairies et cours intérieur de la Brague (ha)	803
Surface area of Natura 2000 Sites « Dôme de Biot » (ha)	176
Length of coast of Mediterranean Sea close to the catchment (km)	5

*** population in all the 11 municipalities includes in the Brague catchment**

Table 3 : General characteristic of the Brague catchment

Since the late 1960s, the catchment has experienced major changes in the population. From the year 1968 to the year 2014, the population density and housing density was respectively multiplied on average by 2.61 and 2.65 in the upstream area (Châteauneuf-Grasse and Opio), by 5.11 and 5.58 in the central-stream area (Valbonne and Biot) and by a 1.59 and 2.56 in the downstream area (Antibes) (**Figure *1***). In 2014, the population density was 293 hab. /km² in the upstream area, 662 hab./km² in the central-stream area and 2,860 hab./km² in the downstream area.

Population growth and urbanization have had several consequences that disturb the ecological functioning of the catchment. The Brague water body agency (SIAQUEBA) evaluates the ecological status of the catchment and shows the gap between the optimal and actual ecological functioning of the catchment. The evaluation is based on on-site observations in 2012 to score different aspects of the River and its interactions with others natural ecosystems (**Table 4**).

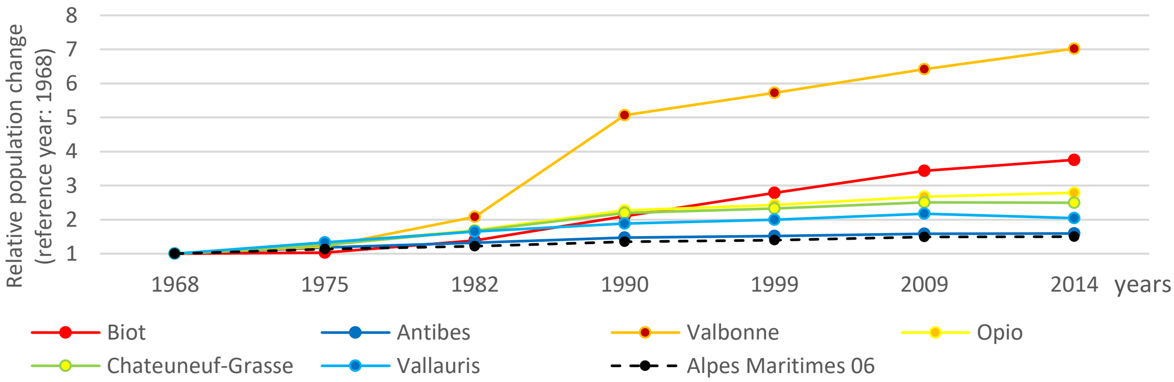

Figure 1: Changes in population density over the period 1968-2014 (Source: INSEE)

Considering the whole catchment (the last column of the **Table 4**), the ecological status is medium according to the comprehensive study by GAIADOMO (2012). It seems that this medium status of the whole catchment is correlated with two aspects of the Brague system including riparian vegetation and water quality (**Table 4**).

ECOLOGICAL STATUS / DENSITY	HEADWATERS (7 KM OF STREAMS)	CENTRAL PART (16,6 KM OF STREAMS)	LOWLANDS (12,7 KM OF STREAMS)	CATCHMENT (36,3 KM OF STREAMS)
WILDLIFE DIVERSITY	8/22	10/22	8/22	25/66
NURSERY HABITAT	1/4	3/4	1/4	5/12
SURFACE WATER ENVIRONMENT	6/12	10/12	7/12	23/36
RIPARIAN VEGETATION	6/16	11/16	7/16	24/48
CORRIDOR	3/8	5/8	2/8	10/24
SURFACE WATER QUALITY	1/7	5/7	3/7	9/21
MORPHOLOGICAL QUALITY	6/8	7/8	7/8	19/24
HYDROLOGICAL QUALITY	2/3	2/3	2/3	6/9
TOTAL SCORE	32/80	53/80	36/80	120/240
POPULATION DENSITY (2014)*	293 hab./km²	662 hab./km²	2,860 hab./km²	1,306 hab./km²
HOUSING DENSITY (2014)*	159 houses/km²	335 houses/km²	2,319 houses/km²	952 houses/km²

*includes antibes, biot, valbonne, opio and châteauneuf-grasse

Table 4 : Ecological status of the Brague catchment and urbanisation (Sources: INSEE, GAIADOMO, 2012)

These aspects indeed reveal a medium ecological status. Riparian vegetation represents aquatic and river bank vegetation including forest, grass and herbaceous. It has multiple ecological and dynamic functions that determine the equilibrium of a river ecosystem. On the surface, riparian trees' shade regulates temperature of water and maintains optimal oxygenation for aquatic fauna. On the underground, riparian tree roots form a net that fixes river bank soil and limits erosion during floods. Aquatic vegetation regulates the water velocity, contributes to water filtration and provides habitat for juvenile population. The status of riparian vegetation in the catchment by the end of 2015 results from anthropogenic activities due to urbanization. ***Figure 2*** shows the conservation status of the riparian vegetation. In the upstream and in the downstream, the riparian vegetation is missing or poor along the Brague stream and its main streams: the Valmasque and the Bouillide. The bank vegetation is partially replaced by concrete banks or are only been made of herbaceous vegetation and some shrubs or hedgerows in urban area. This may be the result of general thinking of water body management in France until 2000s that consisted in the facilitation of water flow in vulnerable areas.

The indicators used in the 2000s are relevant to provide an instantaneous picture of the catchment but according to the experience of the NAIAD partners they are complicated to assess in a prospective way: estimating how qualitatively these indicators may change is uncertain; estimating quantitatively how much they would change is extremely doubtful. Using complementary indicators – coarser but usable in a prospective study – has thus been decided as presented in the next pages.

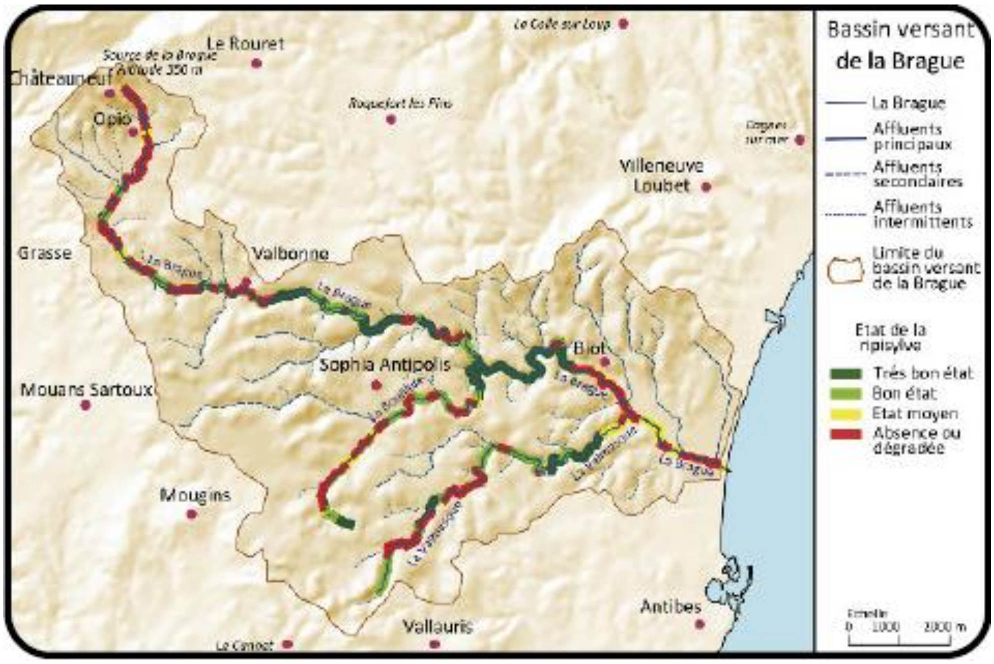

Figure 2 : Ecological status of the riparian vegetation in the Brague Catchment (Source: SIAQUEBA)

In addition to these existing data, IRSTEA performed within the NAIAD project an evaluation of the overall hydrogeomorphological quality of the Brague and its tributaries using the Morphological Quality Index method (Rinaldi, Surian, Comiti, & Bussettini, 2013). The MQI is a morphological assessment procedure based on a geomorphological approach. Initially developed on numerous water courses of Italy, it has been tested and validated on rivers of all Europe during the European project REFORM (https://reformrivers.eu) and it potentially applicable everywhere in the world. The method aggregates 28 indicators assessed by expert judgment to compute a single mark ranging between 0 (river extremely altered) to 1 (river fully natural). A good understanding of the study site is required to provide the parameters and indicators for this assessment but very clear and standard guidelines for the assessment of each indicator is provided in Rinaldi et al. (2015). This method fully complies with the Water Framework Directive (WFD) requirements. Morphological conditions are evaluated exclusively in terms of physical forms and processes without any reasoning on their consequences or implications in terms of ecological state.

The basic idea of this method is to assess the quality of a river system as compared to a reference state, i.e., without alteration. The reference state here does not mean its initial state but a state of dynamic equilibrium (Rinaldi et al. 2011). The river network is divided into a number of homogenous reaches based on geographic, confinement, catchment size and other elements (slope break, key structure). The 28 indicators of each of these reaches are then assessed considering them as separate units.

There are 28 indicators to be assessed in MQI. These indicators are based on different parameters and field conditions. So a detailed set of data is required as described in Table 5.

INDICATOR	NAME	ESTIMATION	OPERATIONAL LAYERS GIS
	GEOMORPHOLOGICAL FUNCTIONALITY		
F1	Longitudinal continuity in sediment and wood flux	Existing Studies	
F2	Presence of a modern floodplain	Remote Sensing (GIS)	AZI - Present River Bed
F3	Hillslope – river corridor connectivity	Remote Sensing (GIS)	
F4	Processes of bank retreat	Remote Sensing (GIS) + Field Visit	Zone Arrachment
F5	Presence of a potentially erodible corridor	Remote Sensing (GIS)	Digitalizing Map for Brague
F6	Bed configuration – valley slope	Remote Sensing (GIS) + Field Visit	Exceptional = Profile Excel
F7	Planform pattern	Field Visit	
F8	Presence of typical fluvial landforms in the floodplain	Just applied in Low Energy - Ana Branching rivers	
F9	Variability of the cross-section	Existing Studies + Field Visit	
F10	Structure of the channel bed	Field Visit	
F11	Presence of in-channel large wood	Field Visit	
F12	Width of functional vegetation	Remote Sensing (GIS)	Functional Vegetation Polygons
F13	Linear extension of functional vegetation and presence of emergent aquatic macrophytes	Remote Sensing (GIS)	Linear Extension
	ARTIFICIALITY		
A1	Upstream alteration of flows	Existing Studies	
A2	Upstream alteration of sediment discharges	Existing Studies	
A3	Alteration of flows in the reach	Existing Studies	
A4	Alteration of sediment discharge in the reach	Existing Studies	
A5	Crossing structures	Remote Sensing (GIS)	Crossing Structure
A6	Bank protections	Remote Sensing (GIS) + Field Visit	Bank Protection
A7	Artificial levees	Remote Sensing (GIS) + Field Visit	Artificial Levees
A8	Artificial changes of river course	Existing studies +Remote Sensing (GIS)	Artificial change in river course
A9	Other bed stabilization structures	Field Visit	
A10	Sediment removal	Existing Studies + Field Visit	
A11	Wood removal	Field Visit	
A12	Vegetation management	Field Visit	
	CHANNEL ADJUSTMENTS		
CA1	Adjustments in channel pattern	Existing Studies + Remote Sensing (GIS)	1946 Reference
CA2	Adjustments in channel width	Existing Studies + Remote Sensing (GIS)	Past River Bed
CA3	Bed-level adjustments	Existing Studies + Remote Sensing (GIS)	Past River Bed

Table 5: Indicators assessed in the Morphological Quality Index (MQI)

Based on the physiographic setting, confinement degree and channel morphology the reaches were defined. The overall studied river system was divided into 7 reaches (**Figure *3***). For each of these 7 reaches we defined the physiographic setting and channel morphologies and following is a table which shows different index values.

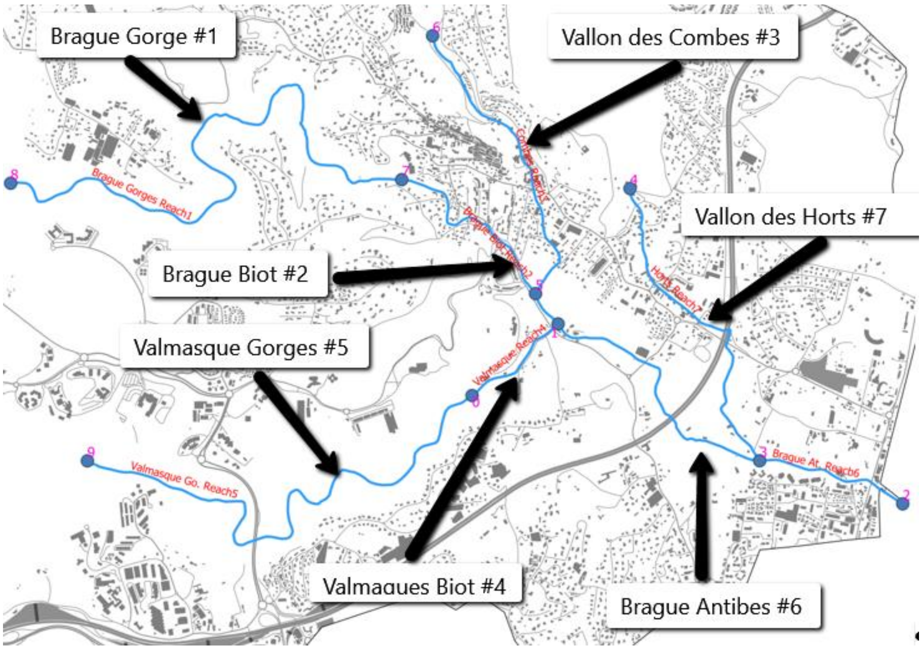

Figure 3 Reach Delineation

REACHES	REACH LENGTH (M)	SINOUSITY INDEX	BRAIDING INDEX	ANABRANCHING INDEX
BRAGUE GORGES (#1)	3 729	1,00	1	1
BRAGUE BIOT (#2)	1 371	1,10	1	1
VALLON DES COMBES (#3)	1 764	1,08	1	1
VALMASQUE BIOT (#4)	656	1,04	1	1
VALMASQUE GORGE (#5)	3 220	1,00	1	1
BRAGUE ANTIBS (#6)	2 424	1,15	1	1
VALLON DES HORTS (#7)	1 935	1,14	1	1

Table 6: Indices for reach delineation

For the confinement index it was quite clear that “Brague Gorges” and “Valmasque Gorges” reaches are completely confined while all others are completely unconfined. Reach quality is defined by a given value of MQI which is obtained after careful identification and assignation of the indicators to each reach and their assessment. In general following are the MQI defined classes based on quality (**Table 7**)

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GEOMORPHOLOGICAL QUALITY CLASS	MQI RANGE
VERY GOOD	0.85 – 1
GOOD	0.7 – 0.85
MODERATE	0.5 – 0.7
POOR	0.3 – 0.5
EXTREMELY POOR	0 – 0.3

Table 7: Quality class and range of MQI variation

An MQI assessment for the current state (data of 2017) was conducted, is detailed in **Table 8** and synthetized in **Table 9** and as well as in **Figure *4***.

	Reaches	Brague Gorges #1	Brague Biot #2	Brague Antibes #6	Valmasque Gorges #5	Valmasque Biot #4	Vallon Combes #3	Vallon Horts #7
Indicator	**Name**	#1	#2	#6	#5	#4	#3	#7
	GEOMORPHOLOGICAL FUNCTIONALITY							
F1	Longitudinal continuity in sediment and wood flux	-	B	C+	-	B	C	C
F2	Presence of a modern floodplain	-	C	A	-	B	C	B
F3	Hillslope – river corridor connectivity	A	-	-	A	-	-	-
F4	Processes of bank retreat	A	A	A	A	A	C	C
F5	Presence of a potentially erodible corridor	-	-	-	-	-	-	-
F6	Bed configuration – valley slope	A	A	A	A	A	C	C
F7	Planform pattern	A	A	A	A	A	C2	C2
F8	Presence of typical fluvial landforms in the floodplain	C	C	C	C	C	C	C
F9	Variability of the cross-section	A	B-	B	A	C	C	B+

F10	Structure of the channel bed	A	C	B-	A	C	C	C
F11	Presence of in-channel large wood	-	B	C+	-	B	C	C
F12	Width of functional vegetation	-	C	A	-	B	C	B
F13	Linear extension of functional vegetation	A	-	-	A	-	-	-
	ARTIFICIALITY							
A1	Upstream alteration of flows	A	A	A	A	A	B	A
A2	Upstream alteration of sediment discharges	A	A	A	A	A	C2	A
A3	Alteration of flows in the reach	A	A	A	A	A	A	A
A4	Alteration of sediment discharge in the reach	A	A	A	A	A	A	A
A5	Crossing structures	A	C	C	A	C	C	C
A6	Bank protections	A	B	A	A	A	D	C
A7	Artificial levees	A	A	B	A	A	C	B
A8	Artificial changes of river course	-	A	B	-	A	C	C
A9	Other bed stabilization structures	A	A	A	A	A	A	A
A10	Sediment removal	A	B1	B1	A	A	A	A
A11	Wood removal	C	C	C	C	C	C	C
A12	Vegetation management	B	C	C	B	C	C	C
	CHANNEL ADJUSTMENTS							
CA1	Adjustments in channel pattern	A	A	A	A	A	A	A
CA2	Adjustments in channel width	A	A	B	A	A	C+	A
CA3	Bed-level adjustments	A	A	A	A	A	A	A

Table 8: Indicator marks for the Morphological Quality Index

Reaches	Brague Gorges	Brague Biot	Brague Antibes	Valmasque Gorges	Valmasque Biot	Vallon Combes	Vallon Horts
Geomorphological functionality	**0.93**	**0.65**	**0.67**	**0.93**	**0.65**	**0.12**	**0.23**
Artificiality	**0.94**	**0.84**	**0.83**	**0.94**	**0.89**	**0.64**	**0.65**
Channel adjustments	**1.00**	**1.00**	**0.88**	**1.00**	**1.00**	**0.75**	**1.00**
Mean Value	**0.94**	**0.82**	**0.80**	**0.94**	**0.85**	**0.52**	**0.58**
Uncertainty range	**[0.94;0.94]**	**[0.81;0.82]**	**[0.79;0.82]**	**[0.94;0.94]**	**[0.85;0.85]**	**[0.52;0.54]**	**[0.58;0.6]**

Table 9: Morphological Quality Index values for the different reaches (state 2017) and values of intermediate aggregation

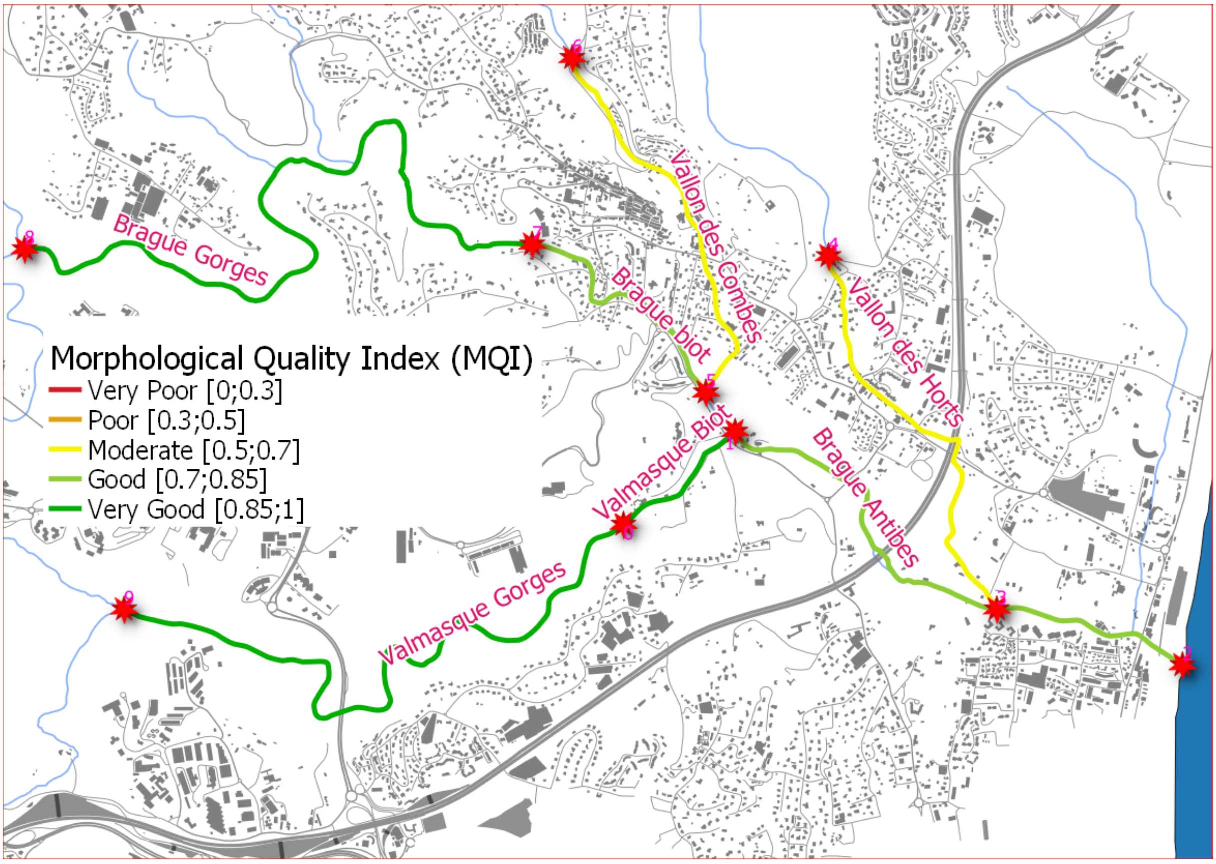

Figure 4: Map of Morphological Quality Index values – state based on data and maps in 2017

The morphological quality of the Brague and its tributaries is very good in the gorges, natural areas, only good in the floodplain and moderate to poor on the secondary tributaries (Vallons des Combes and des Horts). One must stress that the difference of alteration between a good and a very good MQI is quite high. Consistently, a moderate MQI as the one of the Vallon des Horts is the footprint of a strongly degraded reach. The Vallon des Combes, a dry, rectangular concrete channel has a poor MQI. MQI values of the Brague and tributaries would have been worse if hydrological alteration would have been higher.

The main use of water in the Brague is for the irrigation of about 486 ha of golf courses and private gardens. The Brague and its streams play a key role in the sewage network. Three water treatment plants collect and purify wastewater from 2/3 of houses before discharging it into the River. The treatment plant of “Opio-Chateauneuf” and the treatment plant of “Plascassier” respectively serve 3,900 and 1,140 people in the upstream area; the treatment plant of

"Bouillides" serves 39,000 people in the central-stream area[3]. Although the purified wastewater discharged in the River meets standards, the ecological function of waste disposal do not eliminate the residual pollutants (organic matter, bacteria, phosphate and nitrate) because of the lower level of water available in the summer.

The hydro-morphological and surface water environment quality are a good status with a score greater than the mean (**Table 4**). They measure the status of different characteristic of the aquatic environment such as the sustainability of the surface water availability; the capacity of the riparian vegetation to ensure their role; banks stability and erosion. In contrast, aspect related to biodiversity measured by wildlife diversity, nursery habitat and the quality of corridor have a poor status. However, the October, 2015 flood sheds light on several consequences of passed strategies of the water body and flood risk management that weaken the ecological functioning of the Brague catchment. The morphological analysis of the catchment, after the October, 2015 flood, shows that concrete measures such as river channeling, rectification, rock embankment and damming have led to the degradation of the physical environment and ecosystem services; and resulting in the extension of flooded area (**Table 10**). These measures have locally straight-armed the river bed, increase its slope and width, and homogenize its cross profile. These changes were aiming at flood prevention or supporting urbanization process by clearing forests for urbanization, by standardizing flows in the rivers and by reducing the travel time of water flows to the Mediterranean Sea. But, they also have disturbed the hydrological cycle, the water flow regulation, the control of sediment deposits, the erosion and pest control, the aquatic habitat for populations. For example, the catchment suffers from the spreading of alien vegetation in the expense of native one. The main alien vegetation identified are the Acacia Robinia and the Ludwigia from North America, the Buddleia from Asia, the Ailanthus from South of China and the Arundo donax from Far East. The measures also disconnected the channel and floodplain, and other hydrological annexes of the Brague and have introduced incisions in the channel bed.

One can note that, when considering the different areas of the catchment, the ecological status is not correlated to the population density or the housing density (**Table 4**). On explanation of this may be the spatial distribution of the natural ecosystems and land use. On the **Figure *5***, one can note that urbanized areas in the upstream and the downstream are close to the River streams whilst the natural forest ecosystems are concentrated in the central-stream area, although the forest are clearing. Indeed, in 1970s, the Brague catchment experienced human activities that irreversibly changes the ecological functioning of it global ecosystem. To gain land for urbanization, about 2 400 ha of forest in the upland of Valbonne have been cleared in the central-stream area of the catchment. Nowadays, 1,041 ha of land are dedicated to protect

[3] From educational booklet of SIAQUEBA "La Brague à la loupe"

forests namely the Brague forest (480 ha) and the Valmasque forest (561 ha)[4]. They are typical Mediterranean forests dominated by Provencal-Ligurian, Aleppo Pines, Holm oaks and Cork oaks species. They locally border the Brague River and the Valmasque stream (**Figure *2***) and contribute to the relative general good ecological status in this area (**Table 4**). The interaction between the aquatic ecosystem (The Brague River and its streams) and the forest ecosystems (the Brague and the Valmasque) promotes a diversified biodiversity and supportive habitat juvenile populations. The central-stream area of the catchment shelters a number of protected species, such as Cordulia (*Oxygastra curtisii*), European ell (*Anguilla Anguilla*), Dipper (*Cinclus cinclus*) and Coluber viperinus (*Natrix maura*), and birds such as Common Moorhen (*Gallinula chloropus*), heron (*Ardeidae*), Waterfowl (*Anseriformes*) and woodcocks (*Scolopax*). In this area, the riparian vegetation also presents good ecological status. The forests are maintained as natural parks with about 10 km of bike path allowing residents and tourists to enjoy recreational ecosystem services such as hiking, horse riding, bird watching and picnic. According to tourist office of Biot, about 500 tourists expressed a demand for family hiking around the Brague in 2017.

	HEADWATERS	MIDDLE BASIN	LOWLANDS
LINEAR OF MISSING OR DEGRADED RIPARIAN FORESTS	6,629 m	1,910 m	5,180 m
LINEAR OF ERODED BANK	242 m	146 m	2,025 m
LINEAR OF SITES WITH ALIEN SPECIES	115 m	90 m	561 m
NUMBER OF UNSUITABLE BRIDGES	-	-	4
NUMBER OF UN-USEFUL DAMS AND OTHER TRANSVERSAL BARRIERS	1	9	3
FLOODED AREA			3.9 km²

Table 10 : Consequences of passed strategies of Brague water body and flood risk management (Source: Master plan of the management of the Brague 2018-2028)

Moreover, in the floodplain in the municipality of Antibes and Biot, there are no public arrangements allowing the population to access and to interact with the River because land is privately owned in this area. Land use in the floodplain at the north and the south of the highway A8 includes individual houses, mineralized parking, amusement parks and camping sites, golf courses, meadows, hedges and poplar and natural afforestation. According to the local urbanism

[4] Land uses in the municipalities of Biot and Antibes also include Natura Park and ZNIEFF area (Zones Naturelles d'Intérêt Ecologique, Faunistique et Floristique) that are not represented on the **Figure *5***.

plan, this offers an unstructured overview with a low-level of amenities of the landscape in the floodplain. This situation deprives the population from enjoying a number of recreational ecosystem services in both Biot and Antibes. In short, one can conclude that there is a room for enhancing the ecological functioning of the Brague catchment and the ecosystem services that residents can derive from.

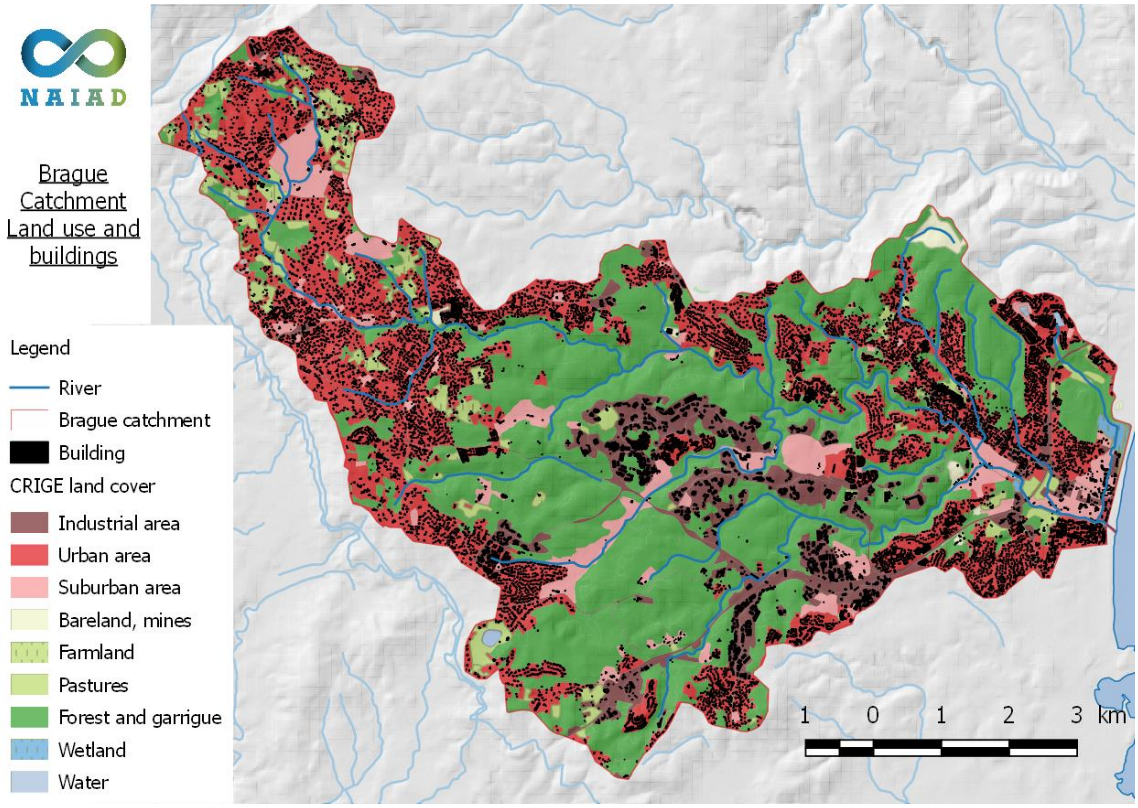

Figure 5 : Land use in the Brague Catchment (Source: NAIAD deliverable D6.1)

1.2.1.2 *Brague Flooding risk: the hazard and exposure*

The downstream area of the Brague catchment mainly extends over a part of the territory of Antibes; and in the lesser extent a part of the territory of Biot. The floodplain of the Brague is located in this area. The "Atlas des zones inondables des Alpes Maritimes[5]" developed in 2003, defines three types of the riverbed: the channel bed that includes the low-water bed, the flood

[5] It is a document elaborated by the French state that to characterizes each river basin and recalls the existence and consequences of the historical events. It is not a regulatory document, but constitutes a reference point for the application of Article R.111-2 of the Urban Planning Code, the development of prevention plans of natural risks and the preventive information of citizens on major risks.

corridor that is the first natural expansion zone for frequent floods, and the floodplain that is the second natural expansion zone from centennial floods. A part of the flood corridor and floodplain of the River had undergone unregulated urbanization until 1998 when the “Plan de Prévention des Risques d’Inondations” (PPRI) has limited and has regulated the urbanization in these areas. The flood corridor and the floodplain roughly correspond to the “red” area and the “blue” area of the PPRI, which are defined by crossing the height and speed of floods. The red is the high risk area while the blue is the moderate risk area. Basically, in the red zone, the height of floods is greater than 1 m or the height and water velocity are greater than 0.5 m and 0.5m/s respectively or the velocity is greater than 1m/s whatever its height (DDTM-06, 2017). Otherwise, the area is considered a blue one. The total estimated area of floodplain is 386 ha including 318 ha for the red area (DDTM-06, 2017).

In the Antibes site, two important transport infrastructures cross the River that is the highway A8 at the north and the railway at the south creating a kind of bottleneck for floods evaluation toward the Mediterranean Sea (**Figure *6***). These transport infrastructures play an important role at regional and transnational level. They have been shaped the floodplain since 1860s for the railway and since 1960s for the highway. The highway A8 connects France and Italy and its average traffic in 2004, on the geographic portion “Mandelieu-La Napoule” (city at western of Antibes) - “Cagnes-sur-Mer” city (city at East of Antibes), is about 86,000 – 110,000 vehicles a day. Over the period 2005-2015, the annual traffic, between France and Italy, was 24,000 vehicles including 5,000 trucks[6]. The railway connects the two biggest city of the region Provence-Alpes-Côte d’Azur (Marseille and Nice). The number of rail passengers between Cannes (city at western of Antibes) and Nice (city at East of Antibes) in 2015 was 8,085,000 people[7].

[6] Direction départementale des équipements des Alpes Maritimes (2005)
[7] Conseil régional de Provence-Alpes-Côte d’Azur – Direction des transports

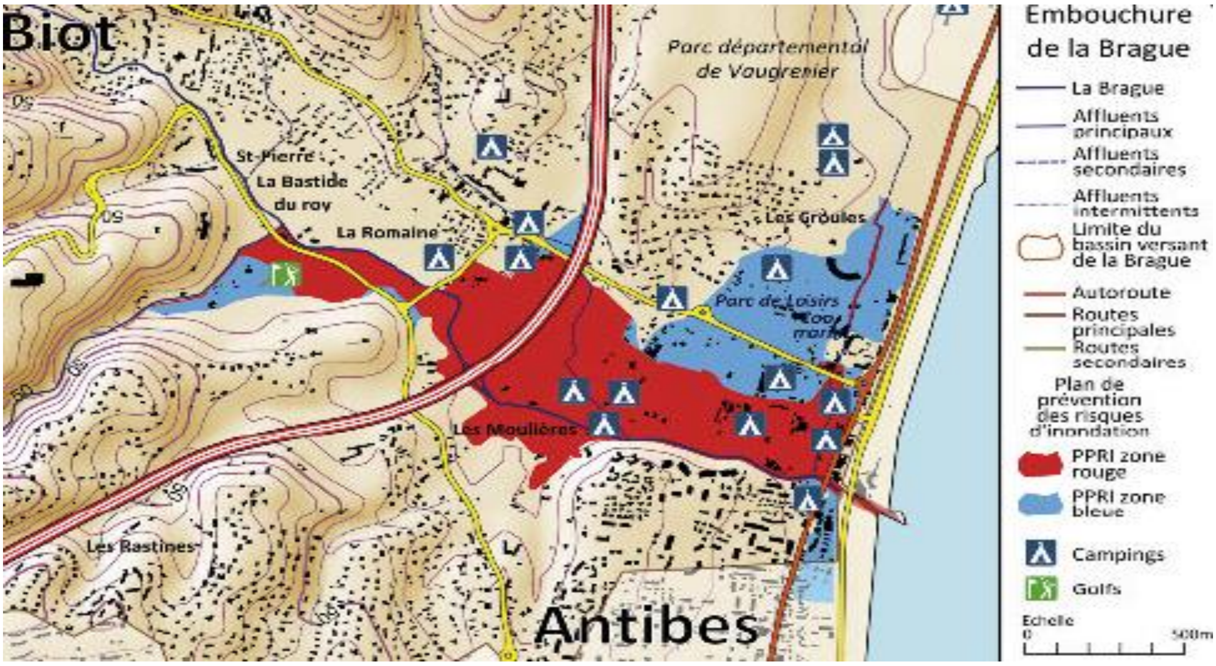

Figure 6 : Flood map in the Brague before the October, 2015 flood (Source: SIAQUEBA)

Since 1998, new buildings are prohibited in the red area whilst in blue area they are allowed under prescriptions. However, in the Biot side about 400 people have already lived in the flood corridor and about 100 jobs are located in the flood corridor (**Table 11**). In addition, about the half of campsites are located in the red and blue. Indeed, the temperate and sunny Mediterranean climate has lead, over the years, to the development of touristic activities in the floodplain, especially amusement parks (Marineland and Antibesland) and campsites with an accommodation capacity of 30,000 people. A part of the riverbed hosting the campsites was wet meadows. They are supposed to host tourists during the touristic season in the spring and the summer. But, in facts they host tourists all year along including in autumn when the occurrence probability of a flood is high[8].

[8] Note that after the October, 2015 flood, the prefecture of Alpes Maritimes closed camping sites located in the red area of the PPRI.

	RED ZONES	BLUE ZONES
RESIDENTS (NUMBER OF INHABITANTS) IN BIOT AND ANTIBES	600	254
TOURISTS (ACCOMMODATION CAPACITY OF CAMPSITES) IN ANTIBES AND BIOT	8,200	4,100
ECONOMIC ACTIVITIES (NUMBER OF JOBS) IN BIOT	69-129	109-201

Table 11 : Population and economic activities in the PPRI blue and red zones (Source: PLU-Biot, PLU-Antibes, PAPI-1, SIAQUEBA)

The Mediterranean climate indeed promotes torrential rain events, especially in autumn, and that results in relatively frequent floods since the early 70s (**Table 11**). Rain events from 50 mm can already generate a flood and the average recorded rainfall over the period 1961-1990 oscillated between 70-80 mm in winter (January-March), 35-60 mm in spring (April-June), 15-60 mm in summer and 80-110 in autumn (October-December). Over the period 1970-2015, the catchment has experienced fourteen natural disaster floods of which four 10-year return period, four 30-year return period and one 100-year return period (table 7).

Flood episodes	Date of CATNAT ministerial decree	Spate peak discharge (m3/s)	Return period at the Biot Station (41km²)
October, 1973	-	n.a	30-years
October, 1987	02/12/1987	173	30-years
October, 1993	19/10/1993	83- 160	10-years
January 11-12, 1996	02/02/1996	n.a.	5-years
December 24-25, 1996	24/03/1997	173	30-years
November 23-24, 1999	03/03/2000	n.a.	5-years
October 11, 2000	29/05/2001	n.a.	5-years
November 4-6, 2000	19/12/2000	102	10-years
December 25, 2000	03/04/2001	n.a.	10-years
September 8-9, 2005	16/12/2005	93	10-years
November 4-6, 2011	18/11/2011	173	30-years
November 4-11, 2014	17/02/2015 and 03/03/2015	n.a.	5-years
June 12-14, 2015	02/10/2015	n.a.	5-years
October 3-4, 2015	7/10/2015 and 23/12/2015	300	100-years and more

Table 12: Natural disaster floods in the Brague (Source: SIAQUEBA, PLU-Biot, data.gov, PAPI-2)

The frequency and the magnitude of floods can be explained by two phenomena. The first is natural and it is related to the topography in the catchment that promote torrential and flash floods. According to the local urbanism plan of Biot, the topography in Biot and Antibes is characterized by narrow valleys, hills, uplands, lowlands and steep slopes between uplands and lowlands. At the south of Biot, the slope is between 0-5 percent whilst in the rest part of Biot composed of the valley of the Brague, a part of the upland of Valbonne and hilly massifs, the slope is between 20-40 percent. This form of topography accelerates the speed of runoff leading to floods in the floodplain in 2 hours. One must stress that the French Mediterranean coast is regularly submitted to intense and severe rainfall events, specifically during Autumn: the so-called "pluies cévennoles". The second phenomenon is the soil mineralization resulting from the urbanization. Due to population growth, the Brague catchment has experienced an important urbanization and specifically in Biot and Antibes. The figure 6 shows that agricultural lands and meadows significantly decrease between 1950 and 2012 for the benefit for built-up lands for houses, business buildings and transport infrastructures. In 2012, 70 percent of the territory of Biot and Antibes are built and that can results in the increase of the runoff coefficient. Indeed, the runoff coefficient mechanically increases with built-up lands, from 0.08 for forests to 0.80 for port areas (Annex 1).

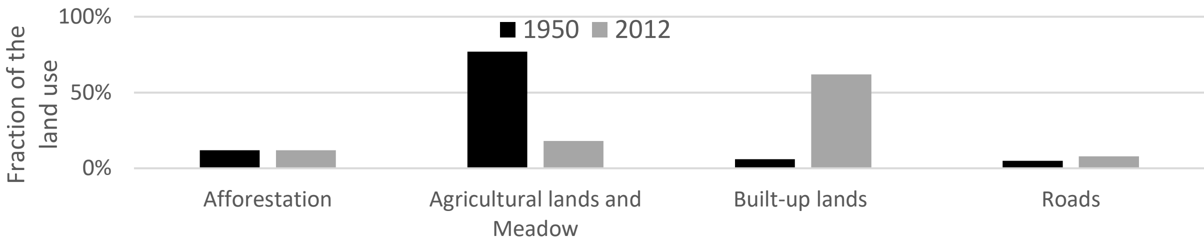

Figure 7 : Land use change in Biot and Antibes over 1950-2012 (Source: DDTM, 2017)

1.2.1.3 Baseline strategies to flood risk mitigation

Risk is commonly defined as the probability of a certain event and associated impacts occurring. It results from a combining of hazard, exposure and vulnerability (including fragility) (Mechler, 2005). Measures to risk reduction may target, separately or simultaneously, each of the three components of risk. They are classified in three distinct strategies namely prevention, preparedness and risk transfer (Mechler, 2016). Prevention reduces risk before the event by modifying the hazard, exposure and physical vulnerability. Preparedness reduces risk during the event by modifying socio-economic vulnerability in terms of the response to disaster. Risk financing also modifies socio-economic vulnerability, but modifies risk only in terms of cutting out the variability of losses (i.e., the variance statistically speaking), not reducing risk overall (i.e., the mean statistically speaking). **Table 13** presents the effect of each strategy and some example of keys measures.

	PREVENTION	PREPAREDNESS	RISK TRANSFER
EFFECT	Reduce risk	Reduce risk	Transfer risk
KEY MEASURES	¬ Physical works, irrigation systems ¬ Land-use planning ¬ Economic incentive for pro-active risk management	¬ Early warning systems ¬ Building codes ¬ Contingency planning ¬ Shelter facilities ¬ Networks for response ¬ Information and education	¬ (Re-) insurance of public infrastructure and private goods ¬ National and local reserve funds

Table 13: Disaster Risk Reduction strategies (Source: Hugenbusch & Neumann (2016))

Regarding measures to flood risk reduction, Mechler (2016) identifies six strategies. The hard strategy refers to the strengthening of structures and physical components of systems in order to brace against shocks imposed by floods. In contrast, the soft strategy refers to less tangible and process-oriented measures as well as policy in order to robustly cope with events as they occur and minimize impacts. The structural strategy groups the measures such as levees, dams, diversions and channel improvements, flood gates, restoration of floodplain, retention basins. The non-structural strategy groups early-warning measures and are applicable for protecting against a wide range of threats (Hugenbusch & Neumann, 2016). The exposure and property modification strategy groups measures such as zoning and land-use planning, voluntary purchase, building codes and regulation, house elevation, other flood proofing. Behavioural strategy groups the measures such as information and education, preparedness, forecasts and warning systems, emergency response.

We identify four types of flood risk reduction measures in the Brague catchment (**Figure *8***). In addition to the active riparian forests management in order to prevent from logjams formation during flooding, public investments over the period 1998-2015 are related to behavioural measures, restoration of the river ecosystem measures, land use change measures and grey infrastructures. About €16 million were invested in these measures over the period 1998-2015.

Figure 8: Public investments in flood risk reduction over the period 1998-2015 (Sources: PAPI-1, PAPI-2, municipalities of Biot, Antibes and Valbonne)

Most of the investments have been planned and supported by the "Programme d'Action de Prévention des Inondations" (the PAPI-1 (2007-2013) and the PAPI-2 (2014-2019)) of the urban community of Sophia-Antipolis (CASA).[9] **Figure *8*** shows that the hard and grey strategy accounts for 62% of total investments. This strategy includes hydro-morphological studies, three concrete retention basins of a total volume of 31,300 cubic meters and civil engineering work for the re-calibration of the River in the floodplain. Indeed, the general idea that has supported the flood risk prevention is the construction of concrete retention basins to temporarily store the runoff and to break the water velocity.

The exposure and property modification strategy represents the second strategy encompassing 25% of the total investments. This strategy includes hydrological study allowing the establishment of the flood map and building regulation in the floodplain (PPRI/98) and the vulnerability of assets and people studies conducted before the October, 2015 flood. Measures also aim at the reduction of exposure by purchasing and demolishing highly exposed houses and setting building regulation in other part of the catchment. The third strategy is related to bio-engineering works aim to restore some ecological functions of the River namely natural bank stabilization, streambed re-naturalization. Lastly, the behavioural strategy encompasses measures for early warning systems, contingency planning and risk awareness.

1.2.1.4 Empirical impact of flood

In this section, we adopted backward looking approach over the period 1970-2015 and used historical data from insurance, official post-disaster publications and stakeholder interviews in order to estimate an accurate damages. The analysis aims complete the description of the context of flood risk in the Brague catchment by shedding light on hidden costs of flooding impact.

[9] The PAPIs are agreements between municipalities, the urban community of Sophia-Antipolis, the Department of Alpes Maritime, the Regional council, the Rhône Méditerranée Corse water body agency and the French government to conjunctly finance planned investments.

Framing of the estimates

The flood risk occurs when the natural process of river flood meets socioeconomic systems and causes damages. Note that a flood in an urbanized area like the Brague catchment is expected to bring about a whole gamut of consequences for the socioeconomic system. We then analyse the flood risk in the Brague via its impacts on socioeconomic systems or damages. Damages are classified according to the type of impacts including tangible and intangible damages (Calatrava et al., 2018). Tangible damages refer to impacts on market goods enabling quantification in monetary metrics while intangible damages refer to impacts on non-market goods. These damages are difficult or even impossible to measure. Damages can be direct or indirect when considering the spatial and temporal extend of the impacts (first impacts in very short terms vs impacts in the medium and long term)[10]. Damages can also be classified according to the socioeconomic sector impacted: individuals, businesses, public infrastructures and agriculture.

The available historical data on damages determine the type of damages considered in this analysis. We consider tangible, intangible direct and indirect damages by calculating the expected annual damage (DMA)[11] for insured assets, uninsurable assets, deaths and psychological damages. Insured assets refer to private and public assets insured by the insurance market which compensates its clients when floods occur. Uninsurable assets refer to public infrastructures (e.g. roads networks, drinking and waste-water systems, public buildings) that are not insured by the market. Impacts on these assets stand for tangible and direct damages. The number of deaths and the number of people suffering a Post-Traumatic Stress Disorder (PTSD) respectively stand for intangible/direct and intangible/indirect damages.

Safety issue

Our analysis shows the vulnerability of the population. Based on empirical data, the two highest flood events (return period of 30-year and 100-year return period) resulted in the loss of human lives (Annex 2). Each year during the period 1970-2015, there was 17% of chance that flooding costs people's live. People may die at their home, at camping sites or on roads. The October, 2015 flood seems to be the last straw for residents that have initiated complaint proceeding to the court against local authorities for endangerment of people's live.

Post Traumatic Stress Disorder

The analysis also emphasizes indirect impact on people mental health due to assets losses and the death of relatives. Each year since 1970, flooding in the Brague has negatively affected the mental health of about 20-140 people (Annex 3). Impacted people by flooding may suffer from long-term physiological problems and disabilities that deeply affect their well-being. This long-

[10] Indirect impacts may occur within 5 years after the flooding.
[11] Dommage Annuel Moyen: Mean annual damage

term physiological impacts named PTSD are different from short lived reaction to the flooding. They are characterized by repeated episodes where the flooding is re-lived in the form of dreams, flashbacks or intrusive memories often accompanied by emotional numbness and dissociation (Lamond et al., 2015; Fontalba-Navas, et al., 2017). PSTD includes anxiety, depression and generic mental health problems (Lamond et al., 2015) and symptoms are sleeping disorder, focusing disorder, phobia of water or rain and over-alertness. The likelihood of suffering symptoms of PTSD is nine times greater in the population affected by the floods compared to the rest of the population. An average, one third of flooded people develop symptoms of PTSD (Lamond et al., 2015). Note that the rate of impacted population that can exhibit symptoms of PTSD depends on a range of factors including the initial mental health of the population and its socio-economic characteristics, the intensity of the flood and the efficiency of flooding crisis management (Lamond et al., 2015). Typically, women, low income population, single-parent family, minorities have more chances to develop symptoms of PTSD.

According to the head of the medical and psychological emergency cell,[12] flood disaster in the Brague silently breaks people live. PTSD multiplies suicide risk by fifteen. There is a high probability that the flood has consequences on the mental health of the population in the Brague. The intensity of the flooding in the Brague catchment fulfil characteristics favouring PTSD especially the formation of floods in 2 hours, the level of economic losses and the exposure of people's live to the risk. Moreover, the fact that residents in the flood corridor and floodplain of the riverbed successively experienced flood events may increase the impact on their mental health. The situation is more critical insofar some economically and socially fragile people live in camping sites. Before the October, 2015 flood, there was no routine to identify and treat PTSD. In addition to the suicide risk, this can encourage the development of risk behaviour.

Mean annual damages

The DMA integrates the relative importance of each flood damage according to the return period. It expresses the average annual cost of all possible level of floods occurred over the period 1970-2015; and therefore corresponds to the annual provision to tackle any damages (Auffret, et al., 2010).

$$DMA_i = \int_f^1 D_i(f)df$$

[12]The Cellule d'Urgence Médico-psychologique du département des Alpes Maritimes (CUMP-06) provides assistance to the population impacted by a natural or man-made disaster.

with DMA_i the expected annual damage for the impact of type i, D_i the damage and f the inverse of the flood return period.

For the purpose of estimating the DMSs, data are gathered from different sources. Regarding insured assets, data on insurance payouts are provided by the "Caisse Centrale de Réassurance" (CCR)[13]. In order to provide an accurate damage estimation, we adjusted this data to consider the fact that there are terms of insurance contract defining a ceiling for compensation. Indeed, insurance payouts represent on average 20-25% of insured damages (Perriez et al., 2003). Data on uninsured damages are provided by the prefecture of the Department of Alpes-Maritimes that manage the Natural Disaster Solidarity Fund on behalf of the French State[14]. All damages expressed in monetary value are adjusted for inflation and converted into euro, 2015. In addition, we reviewed official post-disaster publications to identify a broader range of damages. We also draw on results from individual interviews and the first workshop[15] with stakeholders conducted in respect to the participatory approach adopted in the NAIAD-H2020 project (Graveline, et al., 2017). Fifteen stakeholders, including water body agencies (Rhône, Méditerranée et Corse "RMC", and Brague), local governments (municipalities, the urban community of Sophia Antipolis, and the Department of "Alpes Maritimes"), disaster management authorities, environmental associations, risk awareness associations and a citizen association have been involved[16]. Individual interviews were conducted between June and September, 2017 and the workshop was held in March 2018. The individual interview protocol allowed stakeholders to describe the impacts flood risk in the Brague.

Furthermore, we also make some hypothesis when estimating the DMAs. It seems that river flooding and urban runoff flooding are linked, both can occur simultaneously or one can cause the other. In this case, we are not able to separate damages caused by river flooding from damages caused by urban flooding[17]. Moreover, official reports usually report aggregated damages at administrative jurisdictions level (department, region). Therefore, we only consider damages explicitly localized in the Brague catchment. In addition, the analysis only considers floods recognized as a natural disaster by ministerial decree (**Table 12**). We make a conservative hypothesis that damages caused by other floods are not significant. In other words less than 5-year floods are assumed not damageable. These hypothesis can under estimate the impacts.

[13] The CCR is the French reinsurance company, belonging to the French State, providing an unlimited state-guaranteed coverage to its clients for natural disasters covered within the Natural Catastrophe compensation scheme.
[14] The Natural Disaster Solidarity Fund helps impacted municipalities, Departments or regions in case of natural disaster recognized by ministerial decree, up to 30-80% of damage to uninsurable public assets.
[15] Three workshops are planned within the NAIAD-H2020 project.
[16] See Rica, et al., 2017 for the role of stakeholders in flood risk management in France.
[17] The CCR reports that 60% of claims of the October, 2015 flood are located outside the flood-prone area.

Moreover, we consider that compensations from insurance companies cover the average rate of 25% of insured assets (Perriez et al., 2003). This allow us to consider loses from insured assets that are not covered by a natural disaster clause[18]. Based on the available data, it is not possible to account for all damages. Our results do not include insurable but uninsured private assets. Potential impacts on the environment (e.g. biodiversity, water quality) from breaking of waste-water pipes and leaking of gasoline are not assessed in this analysis. Regarding the estimates of intangible and indirect (physiological) damages, we only consider permanent residents in the flood corridor and floodplain of the Brague. This is a conservative hypothesis insofar as floods may impact tourists and road users. For the October, 2015 flood, the majority of people in emergency were tourists, road users and train passengers.

Lastly, we assume that floods with same return period trigger comparable damages. This is a conservative and reducing hypothesis of the complexity of interactions between the physical process of river flooding and the socioeconomic system. The return period of river flooding are determined according to the observation of the water flow at specific location (Table 14). However, damages also depend on the fragility of elements at risk (Mechler, 2005); especially the population. Due to transport networks, the vulnerability of the population may be affected by both the time of day and the day of the week. Impacts of a 10-year return flood for example, may depend on both the time of the day and the day when the flooding occurs. Stakeholders stated that the October, 2015 flood that occurred in the night on Saturday, will be more damageable if it has been occurred during the week at rush time.

LOCATIONS	DRAINED AREA (KM²)	PEAK DISCHARGE (M3/S)		
		10-year	30-year	100-year
OLD BRIDGE OF BIOT	41	120	175	230
HIGH WAY A8	63,5	170	230	300

Table 14: Peak discharges of the Brague and return periods.

Source: Brague water agency (SIAQUEBA)

The estimated damages of the Brague flooding over the period 1970-2015 are presented in the **Table 15**. The impacts of the fourteen flooding occurred during this period cost about € 260 million of which 82% of insurable private damages, 8 human lives and about 2,094 people

[18] For example, a significant part of insurance contract does not cover vehicle damages in case of natural disaster. We provide sensitive analysis in relation to this hypothesis.

suffering a Post-Traumatic Stress Disorder (PTSD). On average, each flooding in the Brague costed € 18.5 million, 0.6 people live and 150 PTSD. The total tangible damages over the period represents 16.5 times the total investment in the flood risk reduction in the Brague insofar as the average cost of a flood event already outweigh the total investment in flood risk reduction. There is one in two chances that a natural disaster flood in the Brague costs people's live.

As floods are probabilistic events, expected annual damages (DMA) over the period is calculated (**Table 15**) and figures 8, 9 and 10 present the loss frequency curves for each impacts considered in this analysis based on empirical losses observed on the period 1970-2015. Chapter 3 provides a more comprehensive analysis based on simulations. The three figures together help mapping the compound picture of the Brague flood consequences. Each year, flooding cost € 6.07 million in the Brague catchment, 0.17 human live and 74 people suffering a PTSD.

TYPE OF EVENTS	INSURED ASSETS DAMAGES (M€ YEAR 2015)	UNINSURED PUBLIC INFRASTRUCTURE DAMAGES (M€, YEAR 2015)	TOTAL TANGIBLE DAMAGES (M€, YEAR 2015)	DEATHS (NUMBER OF PEOPLE)	AVERAGE PTSD (NUMBER OF PEOPLE)
Q-5	0	0	0	0	0
Q5	3.76	0.89	4.65	0	168
Q10	12.92	3.04	15.96	0	168
Q30	39.01	10.81	49.82	4	240
Q100	158.11	30.58	188.69	4	1,517
MEAN ANNUAL DAMAGE	-	-	6.07	0.17	74

Table 15: Tangible and intangible damages of the Brague flooding over 1970-2015 (Source: Authors' calculations based on empirical data reported, not based on simulation and statistical analysis)

Looking at the tangible damages (Annex 4), the interviews with stakeholders reveal that main impacted sectors are residential and tourism. Most of impacted assets are houses, vehicles, camping sites, commercial and small business buildings, transports infrastructures, wastewater and drinking water networks. The tourism sector is one of important economic activity in the Brague. The floodplain hosts almost all the camping sites, a golf course and the two big amusement parks (MarineLand and AntibeLand) in the catchment. The floodplain also hosts transport networks playing important role at regional and transnational level. The railway and the highway A8 shape the floodplain since 1860s and 1960s, respectively. The October, 2015 flood shed light on the potential impact on the socioeconomic system disruption. It has resulted in 12 hours highway transport interruption, 24 hours power cut, one week rail transport and school interruption, two weeks landline phone interruption and 6-12 months business interruption in the floodplain. Note that the economic costs of these disruptions that may increase the overall tangible impacts are not assessed here. The sensitive analysis in regard to compensation rate (from 100% to 20%) show that tangible damages range from 2.38 to 7.31 million each year (Annex 5).

Synthesis on current flood risk and status of the Brague socio-ecosystem

In synthesis, the reference situation is characterized by:

- An average ecological status of the Brague ecosystem with a general bad status riparian vegetation in the headwater and lowland areas;
- An empirical probability of 1/3 of experiencing a natural disaster flood risk with significant tangible and intangible damages;
- 5-year return period floods already have disastrous impact;
- A social anger due to frequent floods that complicates the dialogue between local authorities and the population;
- Low level of risk awareness and risky behaviour among the population;
- A philosophy in risk management dominated by grey solutions and strong believe on the effectiveness of those infrastructures in the population;
- A legal action against the mayor of the municipality of Biot;
- About 2/3 of past investments in the construction of grey infrastructure;
- Important urbanization in the lowland with two key regional transport infrastructures
- Rapid increase in the population in particular in the municipalities of Biot and Valbonne since the construction of Sophia Antipolis in 70's.

Having describe the socio-economic context in which NAIAD partners assess economic costs and benefits of NBS in the Brague demo, the next session presents future scenarios and flood mitigation strategies.

1.2.2 Future scenarios and strategies

1.2.2.1 *Surface runoff analysis with the CCR Method*

1.2.2.1.1 Climate change

The climate change scenario used in the Brague DEMO has been drawn from (CCR Departement Analyse et Modélisation Cat, 2018). The study estimates the future exposure and number of assets through horizon 2050 in mainland France and is based on the results of the Météo-France Arpege-Climat model. The Météo-France results are the hydro-meteo inputs of the CCR model. The CCR modelling rely on a catalogue of one thousand fictive events simulated from the 400 years of precipitations, outputs of the Météo-France climate model for both the current climate and the scenario RCP 8.5 for future climate. The fictive events catalogue are simulated from the runoff and overflow CCR models. The probability of occurrence of runoff and overflow is mapped by return periods of hazard.

Concerning the vulnerability unit, the projected insured assets has been done for mainland France taking into account: (i) the assessment of the increased assets number at horizon 2050; (ii) the evolution of the spatial distribution and (iii) the estimation of the insured value. These projections are based on INSEE demographic projections scenarios by 2050 for individual risks at community scale. For the Brague area, the evolution of the number of risks between 2015 and 2050 is stable for the entire catchment.

The calibrated damage curve on the 2015-Brague events have been integrated within the catastrophe loss risk structure to assess the cost on probabilistic hazard at current climate and at future climate (see Chapter 3).

In terms of hazard evolution by 2050, the flood modelling results highlight the extension of flooded areas notably due to the expected increase of extreme rainfall events. For the Brague area, this evolution is relatively stable between -5 to 5%, excepted for the Biot community which is susceptible to have an increase from 5 to 15% (**Figure *9***).

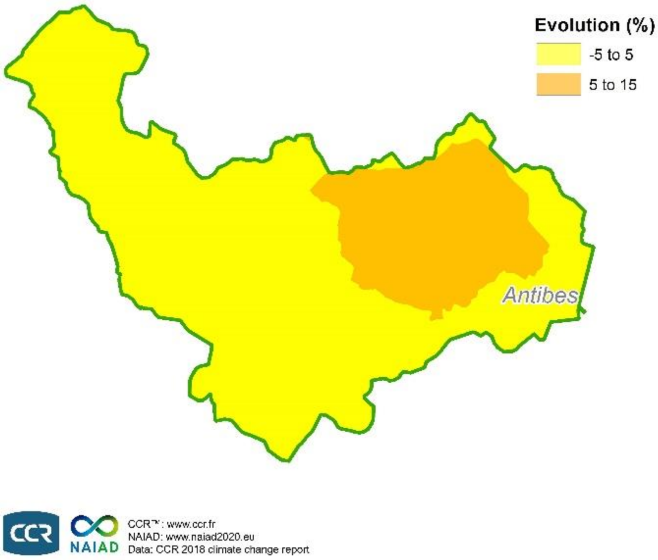

Figure 9 : Increase of flooded areas by 2050 according to the CCR model chain

Figure 10, highlights the extension of areas impacted by runoff on Biot/Antibes area and for Châteauneug-Grasse/Opio. This runoff hazard of 20-years return period allows the distinction of increased impacted areas in 2050. We noted an extension of flooded area by runoff in the city centre of these communities, in deep slope and in the lowest altitude. This modelling do not consider the evolution of waterproof surface due to higher built areas in 2050.

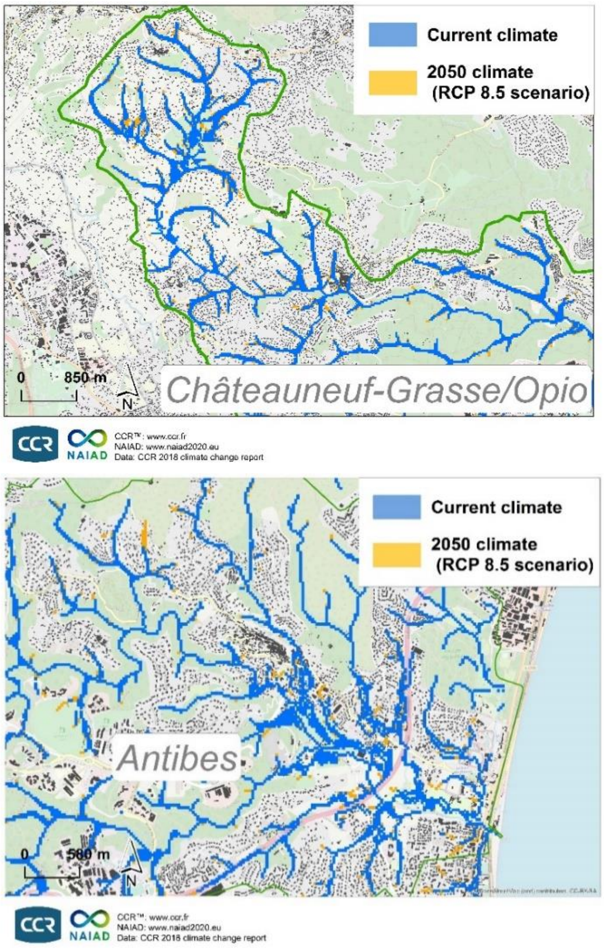

Figure 10 : Comparison of flooded areas by runoff for a return period of 20-years in Antibes (left) and Châteauneuf-Grasse/Opio (right)

It is possible to assess the annual average insured losses (AAL) in the Brague watershed based on the stochastic simulation of 400 years of climatic hourly rainfall from ARPEGE-Climat at current and 2050 conditions (**Table 16**). Within that stochastic simulation, we detect and simulate the related events. Then the damage (see below) are classified in terms of return periods. We do not calculate return periods for rainfall events.

We observed that in the future according to the model hypothesis and way of modelling climate change effect on rainfall regime, **the number of events per year will increase with an annual average losses about 61 €M**. In comparison, the number of simulated events at current climate was 43 against 57 for future climate. This result highlights that the climate change at horizon 2050 according to the RCP8.5 scenario description encapsulated in the model will increase losses by 25.5%. We also calculated the losses in terms of return periods based on the losses related to the 400-years of climatic hourly rainfall from ARPEGE-Climat at current and future conditions. Then, in terms of return periods' damage, we observed increasing damage for short-term return period (10 yr, 20 yr). The observing reduction of damage for long-term return period could be explained by the uncertainties related to the future events. Thus, it can be conclude that in the Brague DEMO the future flood events will be more frequent and costly (**Table 16**). It is a similar conclusion of the French Mediterranean coastline (CCR Departement Analyse et Modélisation Cat, 2018).

	ANNUAL AVERAGE INSURED LOSSES	DECENNIAL COST	TWENTY-YEAR COST	FIFTY-YEAR COST	CENTENNIAL COST	NUMBER OF SIMULATED EVENTS
CURRENT CLIMATE	**48.7 €M**	-	470.8 €M	534. 7€M	588.9 €M	**43**
FUTURE CLIMATE (2050)	**61 €M**	388.5 €M	470.8 €M	540.8 €M	576.7 €M	**57**

Table 16 : Comparison between current and future climate damage on Brague DEMO (source: CCR)

The results obtained depicted that total damage will increase with the impacts of climate change in comparison to the current climate probabilistic situation on the Brague DEMO

1.2.2.1.2 Land use change

The land-use urbanization projects on Sophia-Antipolis area is based on a public website proposing interactive mapping of urbanization projects[19]. Each project has been validated through peer research and local knowledge on the on-going projects (***Figure 11***). The importance of natural areas in Sophia-Antipolis has been also highlighted (**Figure *12***).

[19] https://mysophiaantipolis.jimdofree.com/urbanisation-de-sophia/

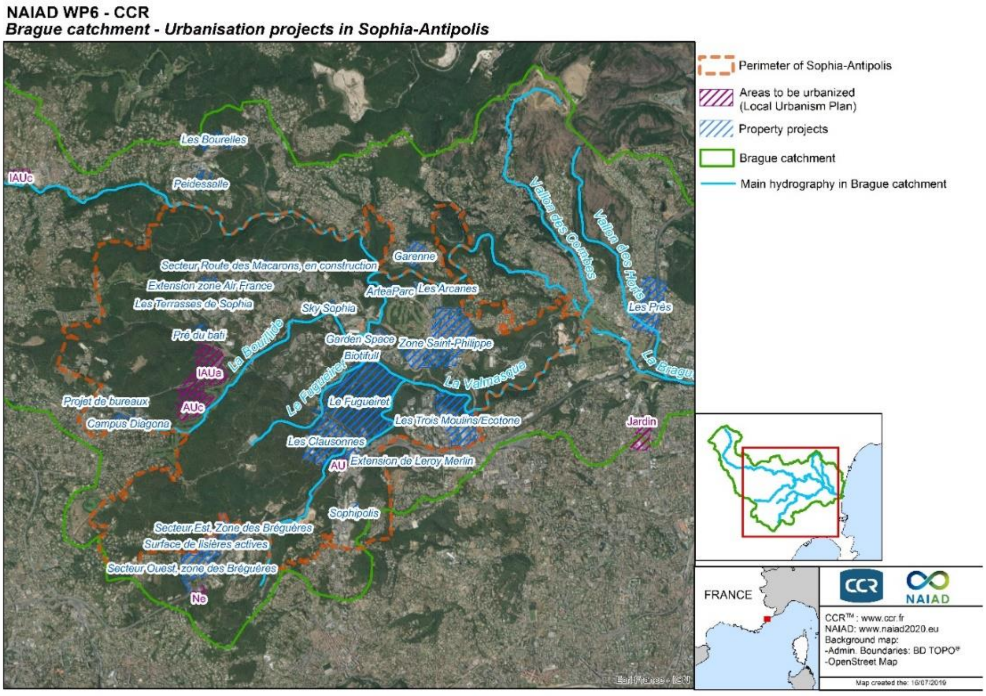

Figure 11: Urbanisation projects in Sophia-Antipolis

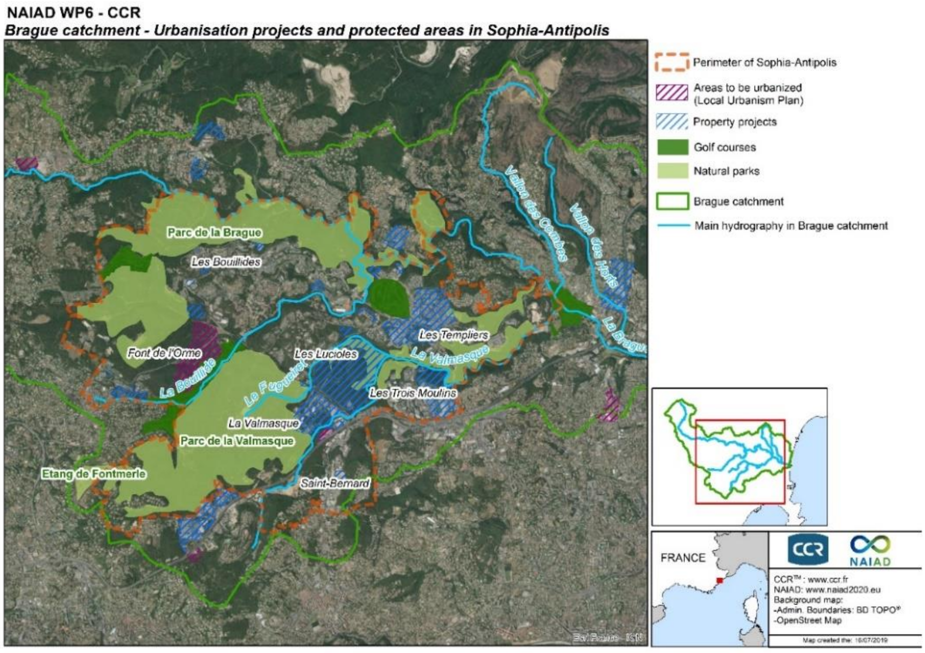

Figure 12 : Urbanisation projects and protected areas in Sophia Antipolis

Over 375ha of urbanization projects are projected on Sophia-Antipolis, as demonstrated in the **Figure 13** comparing the nowadays land-use and the projected land-use. We observed changes in terms of runoff coefficient from low to moderate or high level depending on the type of the project. Most of the projects generated change from low to moderate runoff coefficient.

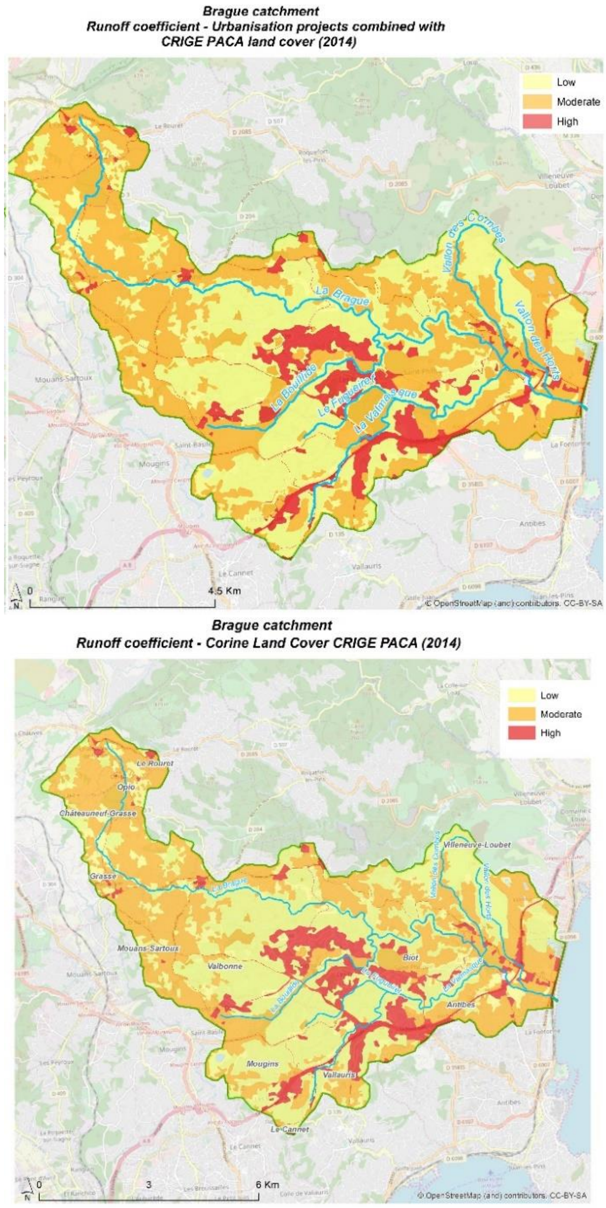

Figure 13 : *Comparison of runoff coefficient with urbanization projects in Sophia-Antipolis*

We observed that the impact of land-use change is not significant on runoff hazard increase or decrease according to the different land use scenarios (from less to large urbanization). The land-use change does not significantly impact the surface runoff (**Figure *14***). The more likely explanation explanation is that the land-use change have been simulated on the 2015 flood event (G_201510_Sud-Est) of very high intensity of runoff flows and a return period of 500-years for this event. Another explanation is that the Sophia-Antipolis area is currently urbanized which has already an impact on flows and infiltration. It could be also finally be an artefact of the resolution of the model at 25*25m and the urbanized areas which are at a finest scale.

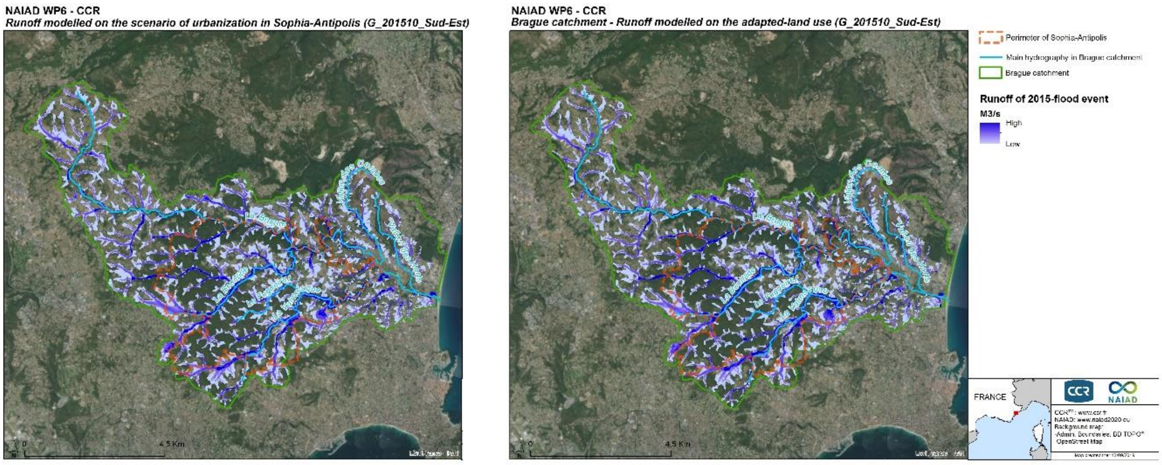

Figure 14 : Comparison between runoff modelling on scenario of urbanization in Sophia-Antipolis (left) and on the adapted-land use CRIGE PACA

In terms of scenarios' impacts on runoff values, the scenario of urbanization in Sophia-Antipolis largely increases areas in ha for low runoff values from 0.02 to 0.25 m3/s. For medium to high flows, the BAU and urbanization scenarios have more or less the same effects, **Figure *15***.

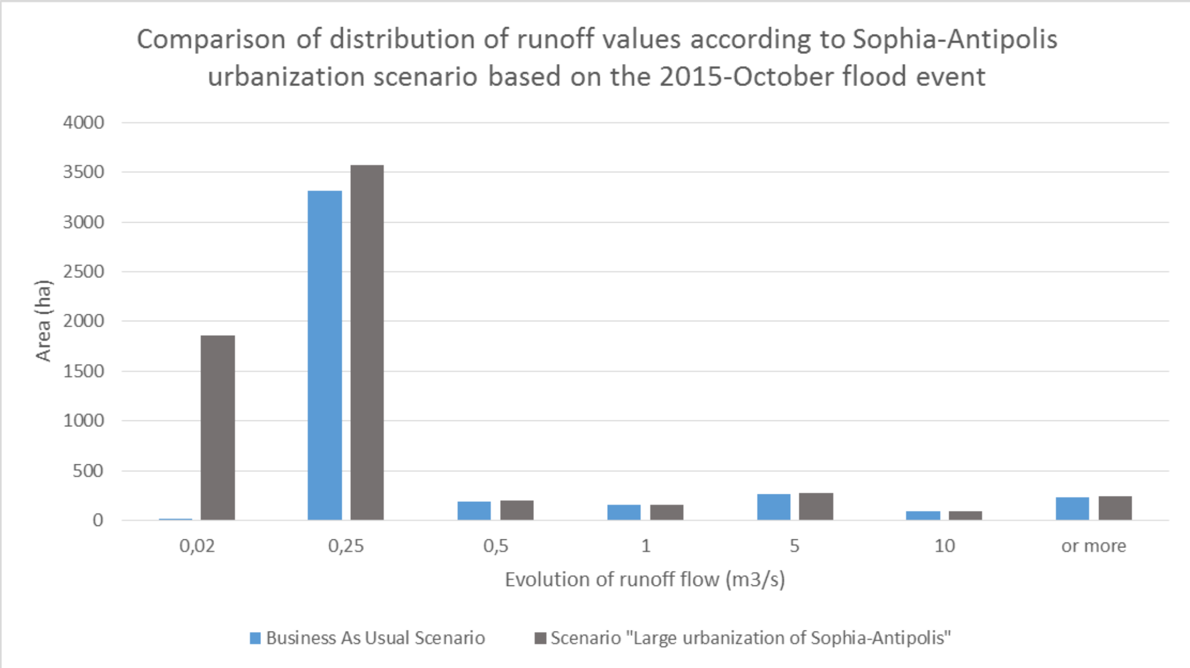

Figure 15 : Comparison of distribution of runoff values from BAU to urbanization of Sophia-Antipolis (based on the 2015-flood event)

An in-depth analysis of the runoff evolution on the "Le Fugueiret" project (Cote 121 projected urbanization for Sophia 2030 program) located in Valbonne community can be exemplified[20] (**Figure *32***). The objective of the project is to reinforce network and to improve soft mobility between this area and Saint-Philippe, les Clausonnes and Trois Moulins. This project is located within a woody area and willing to be an international city of knowledge with 60 000m² for universities, 40 000m² for tertiaries activities. In that case, runoff flows and extension increase, due to a change in runoff coefficient from "low" to "medium" (**Figure 13**). The project has been designed to reduce its impacts on biodiversity and to avoid negative effects on flood hazard. People opposed to the project do not want the destruction of the forest area and raised also the issue of cultural heritage, an ancient roman bridge may be destroy.

[20] For more information : https://casa-infos.agglo-casa.fr/amenagement/amenagement-du-secteur-du-fugueiret-valbonne-sophia-antipolis

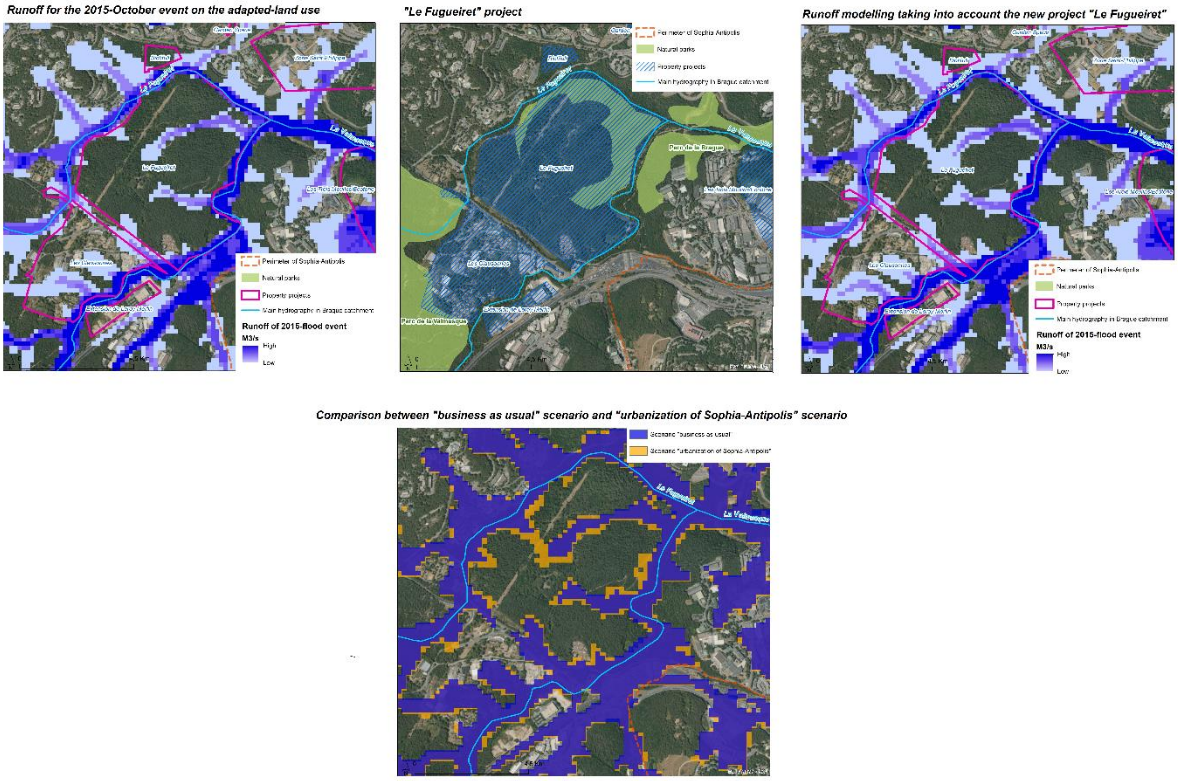

Figure 16 : Evolution of runoff modelling from today's land-use to future urbanisation project, the case of « Le Fugueiret » project

In terms of hazard extension, the "urbanization of Sophia-Antipolis" scenario increases the low runoff flows extension (**Figure *17***). Concerning the medium to high flows the comparison between the scenarios do not highlights significant differences.

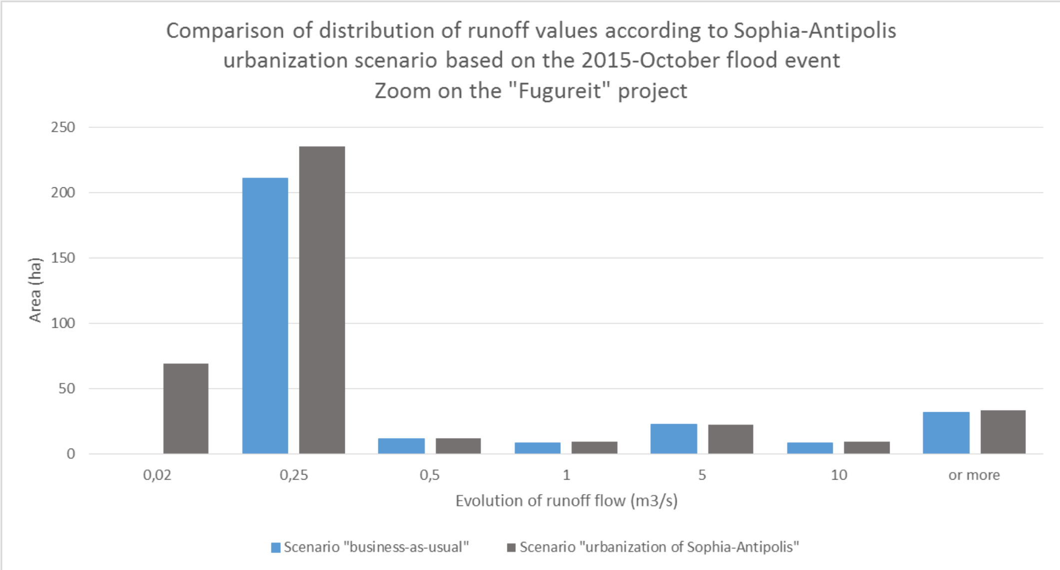

Figure 17 : Comparison of distribution of runoff values for the two scenarios (based on the 2015-flood event) for Fugureit project

1.2.2.2 *River discharge analysis with the Shyreg Method*

In order to cross control the results of the runoff modelling, the Shyreg method, yet thoroughly described in D6.2 (Piton, et al., 2018) has been reused in a prospective way.

1.2.2.2.1 Climate change

Climate change have diverse effect on floods with regions where peak discharges are increasing as north and western Europe while other dryer regions experience more decrease in peak discharges (Blöschl et al. 2019). The Mediterranean region in particular might rather experience decreases because, even though rainfall intensity seems to increase, antecedent soil moisture, a key driver of the catchment response, seems to decrease with the warmer temperatures (Tramblay et al. 2019).

The Shyreg hydrologic model (Arnaud, Cantet, & Aubert, 2015) has been used throughout all the NAIAD project on the Brague DEMO site and is presented in NAIAD D6.2 Part 3 (Piton, et al., 2018). To check how might change peak discharges with climate change in the Brague catchment, the classical method of using several Global Circulation Models (GCM) for two time windows (2046-2065 & 2081-2100) with downscaling on the region with several Regional Circulation Models (RCM) was performed. For further elements on the method see Folton, Cantet, Arnaud, & Fouchier (2012), Cantet & Arnaud (2016) or Organde, Arnaud, Cantet, & Fine

(2017). Two IPCC scenarios were tested, namely RCP 4.5 and RCP 8.5 thus providing five estimates of peak discharges per time window and IPCC scenario (**Table 17**).

RCP 4.5				**RCP 8.5**			
N°	Time window	GCM	RCM	**N°**	Time window	GCM	RCM
1	2046-2065	HIRHAM5	ICHEC	**11**	2046-2065	HIRHAM5	ICHEC
2	-	RACMO22	ICHEC	**12**	-	RACMO22	ICHEC
3	-	RCA4	CNRM	**13**	-	RCA4	CNRM
4	-	RCA4	ICHEC	**14**	-	RCA4	ICHEC
5	-	REMO2009	MPI-M	**15**	-	REMO2009	MPI-M
6	2081-2100	HIRHAM5	ICHEC	**16**	2081-2100	HIRHAM5	ICHEC
7	-	RACMO22	ICHEC	**17**	-	RACMO22	ICHEC
8	-	RCA4	CNRM	**18**	-	RCA4	CNRM
9	-	RCA4	ICHEC	**19**	-	RCA4	ICHEC
10	-	REMO2009	MPI-M	**20**	-	REMO2009	MPI-M

Table 17: Climate change RCP, time window, GCM and RCM tested with Shyreg on the Brague DEMO

Peak discharges of the whole Brague catchments for three different time return, namely 20 years, 100 years and 500 years, for each time window and IPCC scenarios are compared to current peak discharges in **Figure *18***.

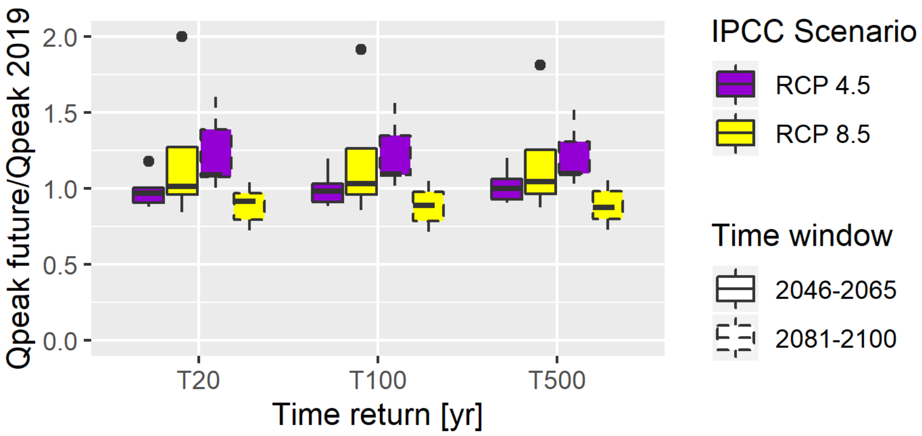

Figure 18: Ratio of future peak discharge over current peak discharge at the sea outlet of the Brague for two IPCC scenarios and tow time windows

Over the short term, i.e., time window 2046-2065, no clear consistent trend toward higher or lower peak discharges are detected although the uncertainty is higher for the warmer IPCC scenario RCP 8.5 than for the IPCC scenario RCP 4.5 represented by the larger boxplots. The median values of the subsamples related to each time return are within a range 1-1.05.

On the long term, the peak discharges seems to decrease consistently in warmer IPCC scenario RCP 8.5, while the trend is rather toward an increase for the less warm IPCC scenario RCP 4.5. The scattering remains high with some GCM-RCM coupled models giving an absence of change, i.e., a ratio equal to one, while other GCM-RCM coupled models reaches changes of ± 40% or even more for some couples. Overall the median values of the subsamples related to each time return are in a range of ± 12%.

The opposite trends identified for the long term time windows of the IPCC scenarios RCP 4.5 and RCP 8.5 are likely related to the aforesaid contradicting effect of increase in rainfall intensities and decreasing soil moisture. The first effect seems to overcome the second in IPCC scenario RCP 4.5, while the second seems to overcome the first in IPCC scenario RCP 8.5.

1.2.2.2.2 Land use change

Future changes not only concern changes in the river management and geometry related to protection measures: the lifetime and time of implementation of the protection strategies are of several decades, not only the river will change but land use, climate and other environmental aspects too. Yordanova et al. (2019) provided in NAIAD Deliverable 5.4 Part 2 a full analysis of the Brague catchment components regarding not only bio-physical but also social and economic aspects. They demonstrate that land use, forest status and climate are key component also changing in time.

The hydrological study on daily discharges performed in NAIAD D6.2 (Piton, et al., 2018) has consequently been extended regarding possible effect on hourly discharges. The details are provided in Annex 6. In essence the SHYREG method to estimate flood hydrograph was reused considering several land use changes:

- Wildfire hazards were studied in detail to check how cascading effecting regarding the main threat to ecosystem service may affect flood hazards. Three wildfire scenarios of burnt surfaces 5.5, 100, and 700 ha with return period of 2, 60 and ~700 years were assessed, computed and mapped after careful analysis of wildfire activity on more than 40 years. The potential effect of the extreme wildfire scenario on the hydrology of the catchment is presented hereafter. Changes in hydrology of other burnt French catchments was studied too within NAIAD D6.2. Great variability of hydrological responses to fire was observed: from marginal and negligible changes up to short lasting but significant increase of runoff during a few years. In order to perform the analysis with a conservative approach, we decided to assign a hydrological behavior of burnt area similar to the hydrological behavior of urbanized area (low infiltration).

- Urbanization and increase of impervious areas is regularly pointed too as responsible for increase in flood hazards in the catchment. An analysis was performed by NAIAD to inventory and map urban projects in the catchment. Overall, more than about 310 ha of urban project were inventoried. The current land use was then modified to assign a dense urban land use to the location of all of these projects, assuming them to be completed. The hydrological models were then re-run with these new land uses.

The peak discharge of the main branches of the Brague River were extracted and are provided in **Table 18**. Current peak discharges are provided in m^3/s and relative change related to a more urbanized future land use (noted "F") or a 700 ha wildfire occurrence (noted "W") are also given in percentage of increase of the latter value.

RETURN PERIOD	A [KM²]	2 YEARS			20 YEARS			100 YEARS			1000 YEARS		
SCENARIO		-	F	W	-	F	W	-	F	W	-	F	W
BRAGUE AT BIOT	43.3	48.3	*0%*	*17%*	148	*0%*	*14%*	268	*0%*	*10%*	492	*0%*	*6%*
VALLON DES COMBES	3.1	5.03	*0%*	*0%*	17.9	*0%*	*0%*	34.5	*0%*	*0%*	66.4	*0%*	*0%*
VALMASQUE	13.6	20	*2%*	*0%*	64.9	*3%*	*0%*	120	*3%*	*1%*	225	*1%*	*0%*
BRAGUE AT SEA	68.2	66.8	*0%*	*10%*	201	*1%*	*8%*	364	*1%*	*6%*	664	*0%*	*4%*

Table 18: Peak discharge of several main branches of the Brague catchment in the current landuse and without upstream water retention measures [m^3/s] and relative change for Future Land Use (F) or for wildfire of large extension (W)

The effect of wildfire are concentrated on the Brague upper branch, i.e., upstream of Biot, because we localised the wildfire scenario in one of the remaining consistent large forest unit. The increase in peak discharge is more than 15% for frequent floods, i.e., with return period of less than 20 years. For less frequent events, it decreases, down to 6% for the 1000 years event. From this analysis, we conclude that the water peak discharge might increase by 10% at Biot and by 6% at the sea for a 100 years return period flood event triggered at the catchment scale after a 700 years return period wildfire. It is worth stressing that this increase, which is not extremely high, concerns water discharge only. We expect that torrential hazard would increase in the catchment but according to this Shyreg method analysis, more because of large increase in soil erosion and woody debris availability than due to increase in runoff. It is worth stressing that the burnt area is only 7 km² in this scenario, i.e., 10-16% of the catchment area. In case of decrease of fire fighter efficacy or if they are overwhelmed, the burnt area could increase and the related effect would increase too.

The effect of urbanization is considered even lower: the cumulated change in surface modelled is 3.13 km², concerning thus only about 5% of the catchment. Under the rainfall intensity usually experienced in this region, runoff coefficients are yet quite high; the footprint of increased impervious surface of such a small portion of a catchment that is yet nearly saturated has consequently a low effect on the downstream water peak discharge.

The hydrological effect of both wildfire and urbanization being relatively low, we did not performed specific flood mapping for future scenarios of urban or burnt land use for this deliverable due to lack of time to rather focus on estimating NBS effectiveness in current hydrological scenario. However, comprehensive simulations with future river status and hydrology might be done later in the framework of a journal publication.

1.2.2.3 Definition of NBS strategies

A Grey strategy was proposed in D6.2 (Piton, et al., 2018) with two large retention dams located in the gorges directly upstream of the lowlands (**Erreur ! Source du renvoi introuvable.**, right panel). Large wood trapping facilities were added to these measures that merely seek to reduce the peak discharges of events similar to Oct. 2015 to the 10 years peak discharges that can pass through the lowlands without damages.

Flood alleviation NBS strategies studied for the Brague catchment are on the contrary a combination of both retention measures by small natural retention areas in the upper catchment, along with a widening of the river corridor enhanced by floodplain reconnection (**Erreur ! Source du renvoi introuvable.** and **Table 19**).

Since the submission of D6.2, new elements were brought to our knowledge and further analysis were performed regarding:

- The potential effect of small natural retention measures in the upstream part of the catchment. In essence, an inventory of eventually suitable areas for the implementation of small natural water retention measures was performed and a potential for about 100 000 m^3 of retention seems a first approximation. Modelling of the effect of these measures are on-going at CCR and these potential water retention basins have been digitalized from existing inventory of areas prone to natural water retention measures (Lindénia, 2012), see **Figure *19***.

- The Brague passes through highway A8 by culverts that forms a bottleneck section. It was until recently considered too technically complicated to replace them by a bridge due to the poor quality of the geology requiring deep, technical foundations. The French State recently decided to push further the study of potential techniques usable on the site to eventually, on the long term, increase the discharge capacity of the Brague where passing the highway. An additional scenario was consequently designed with an even greater ambition than the high ambition scenario to include this option.

The NBS strategies were developed and inspired by the MQI approach: they were tailored to the site to improve the geomorphological quality which is assessed by a new estimation of both the MQI and flood risk in the next chapters. Floodplain works gather several measures as bed and bridge widening, restoration of forest corridor and wetlands, and large woody debris management. They are integrated in a strategy called “giving-room-to-the-river”. Several levels of ambition (low, high and very high) related to this strategy are considered. The works planned in the lowlands within the low and high ambition strategies were yet mostly presented in D6.2 (Piton, et al., 2018).

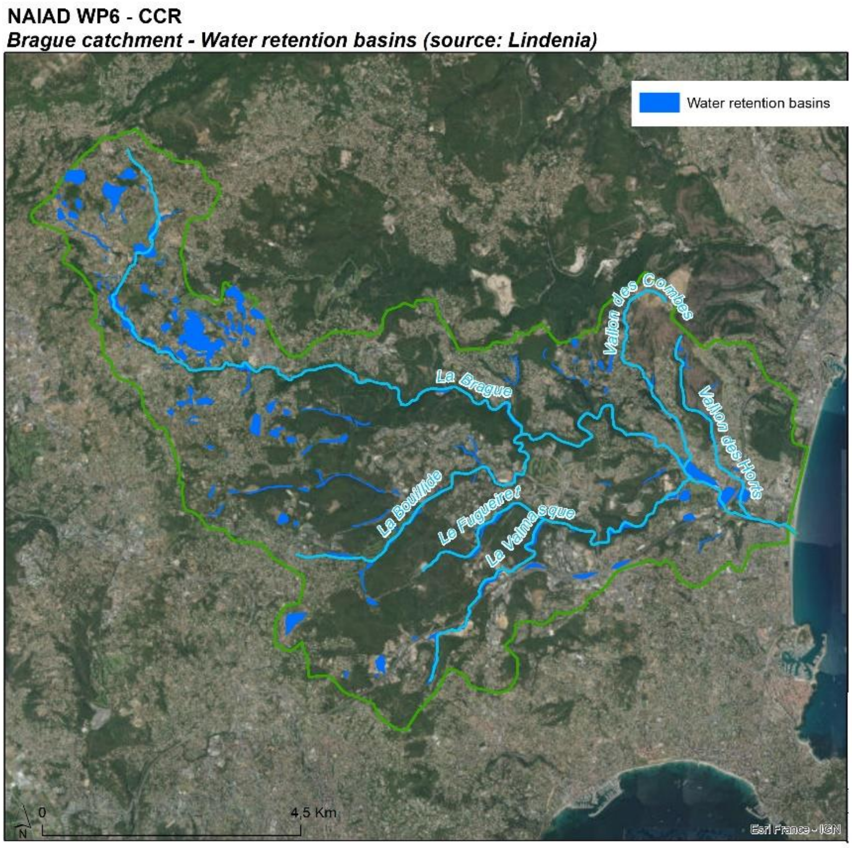

Figure 19 : Areas prone to implement natural water retention measures based on Lindénia invent

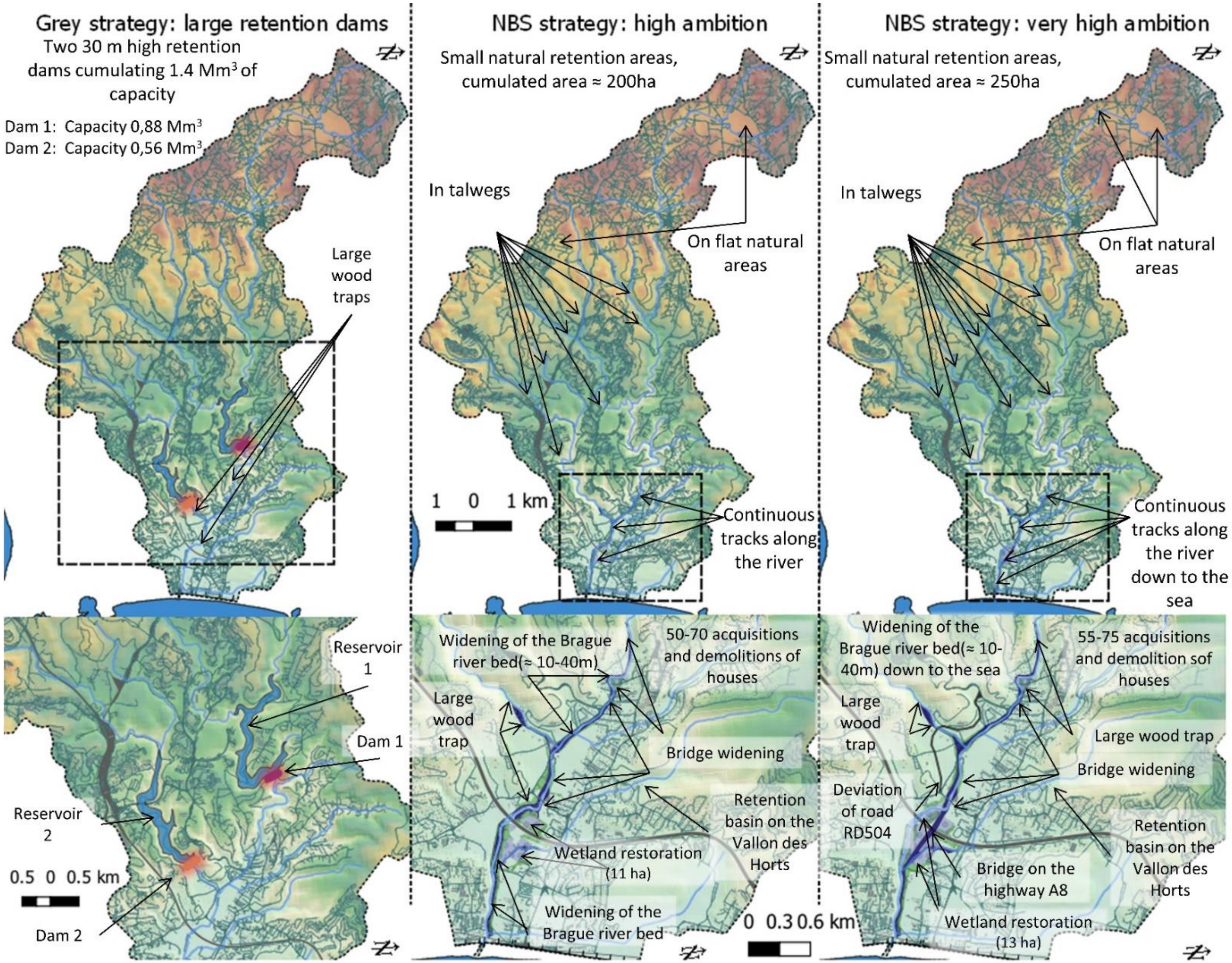

Figure 20: Synthesis maps of the three protection strategies studied in NAIAD

Grey strategy : ***large retention dams***	**NBS strategy high ambition :** ***reopening a river corridor***	**NBS strategy very high ambition:** ***restoring an integrated floodplain to the river***
	Principle	
Building of two large flood control dams on the Brague River and Valmasque River. The dams are design to store the Oct. 2015 flood hydrograph with outlet discharge equivalent to the 10 years return period discharge of each river	Implementing small natural water retention measures in the upper part of the catchment and giving-room-to-the-river in the lowlands by widening the bed, restoring the riparian forests and wetlands	Same than NBS strategy : high ambition + removing more lateral and longitudinal constraints (road, highway culverts), recreating a wide natural bed in the central natural area
	Key measures	
- Flood control dam on the Brague River: retention capacity 880 000 m^3 Outlet open to let normal flows pass up to the 10 years return peak discharge ; - Flood control dam on the Brague River: retention capacity 560 000 m^3 Outlet open to let normal flows pass up to the 10 years return peak discharge ; - 200 m of dikes to build on the Brague River right bank, close from the train line. - No building expropriation required.	¬ Small natural retention areas, cumulated area ≈ 200ha ¬ 10 à 40 m of Widening of the Brague river bed ; ¬ Restoring riparian forests (13 ha); ¬ 3 bridges to demolish and rebuild wider and without central pile (bridge Brejnev, bridge Murator and golf course first pedestrian bridge) ; ¬ 5 Large wood trapping structures on the Brague River (3) and Valmasque River (2), height: 3 m; ¬ 11 ha of wetland restoration ; ¬ 50-70 acquisitions and demolitions of houses; ¬ Continuous pedestrian and bicycle tracks along all banks.	¬ Small natural retention areas, cumulated area ≈ 200+ha ¬ 10 à 40 m of Widening of the Brague river bed ; ¬ Restoring riparian forests (13 ha); ¬ 3 bridges to demolish and rebuild wider and without central pile (bridge Brejnev, bridge Murator and golf course first pedestrian bridge) ; ¬ 5 Large wood trapping structures on the Brague River (3) and Valmasque River (2), height: 3 m; ¬ 20 ha of wetland restoration ; ¬ 55-75 acquisitions and demolitions of houses; ¬ Continuous pedestrian and bicycle tracks along all banks. ¬ Building a new high bridge for the highway #A8 and create a second channel in the natural central part of the floodplain with better connectivity with wetlands; ¬ Removing and rebuilding further from the river 1.4 km of the departemental road RD504 between roundabouts of route des Colles (accès Sophia-Antipolis) and of chemin de la Romaine (Pont Brejnev) : rebuilding behind the golf course at the hillslope toe and through or close to the quarry.

Table 19: Summary of measures implemented in each strategy

The NBS scenario of intermediate ambition presented in D6.2 is not described and studied in this report because expected not to have sufficient efficacy based on the FEV analysis performed by (Bokhove, Kelmanson, Kent, Piton, & Tacnet, 2019). Conversely, a scenario of very high ambition has been added with the aforesaid bridge on the highway (**Erreur ! Source du renvoi introuvable.** and **Table 19**).

Combine strategies and future/past scenarios to form NBS visions

The main stem of the Brague and the main tributary of the Valmasque were only marginally modified in the last decade and only within small restoration projects: removing of several weir to allow fish continuity, bank protection bioengineering at Biot close to the gorges and at Antibes upstream of the sea mouth. Along these two stems, assets and pressures are less dense than along the smaller ephemeral tributaries and implementation of NBS seems more possible. We consequently decided to try to improve the status of reaches in good geomorphological quality to very good on these bigger and more promising water courses.

Conversely the morphological quality assessment demonstrated that the two small tributaries (vallons des Combes and des Horts) are the most degraded ones, it was decided not to try to restore and focus most of the attention on these small ephemeral streams. Passing through heavily urbanized terrains, they are too constrained to imagine a NBS scenario in short to medium term. In addition, numerous works were performed on them in the last decade: channel lining and retention basin building.

Finally in the following, hydrology changes due to climate change or land use change are not considered because of lack of time and because their effect was assessed to be of secondary importance (see §1.2.2), e.g., compared to the main works that could change the river geometry and use.

1.2.3 Impact assessment

1.2.3.1 Perception of the river by citizens and tourists

The Brague River in its current state of its lowlands is not easily accessible. A few pedestrian paths exist but are usually dead ends and several sections cannot be accessed because being located on private terrains surrounded by fences. The basin agency has difficulties to perform the most essential maintenance and launched a public acquisition procedure[21] to own the bank terrains and maintain them more easily. A masterplan for the Brague management on the long

[21] DUP procedure (Déclaration d'Utililté Publique) to acquire about 20 ha along the Brague main stem and tributaries.

term is under study and proposes to profoundly change the land use in the high flood risk zone around the highway (compare **Figure *20*** and **Figure *21***).

A coherent network of pedestrian and cycle paths was part of the strategies we defined to reconnect people with the river and change their perception of this key component of their territory.

The questionnaire defined in Chapter 4 for a survey to perform on fall 2019 will help to gather data on the public perception of the Brague and of NBSs and help to refine the scenario in the next stages of the Brague valley management after the NAIAD project.

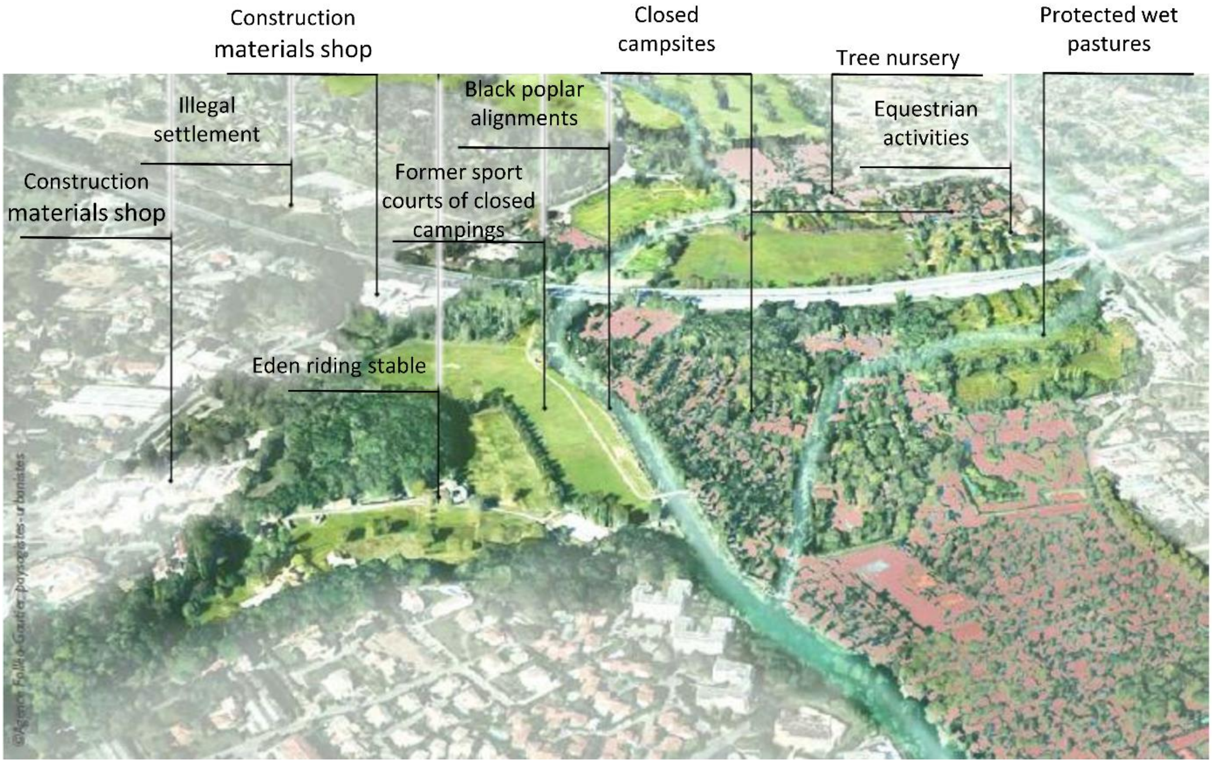

Figure 20: Current land use and activites in the Brague lowlands (©Agence Foléa-Gautier, downloaded from http://www.cotita.fr/IMG/pdf/2_2-Plaine_de_la_Brague.pdf)

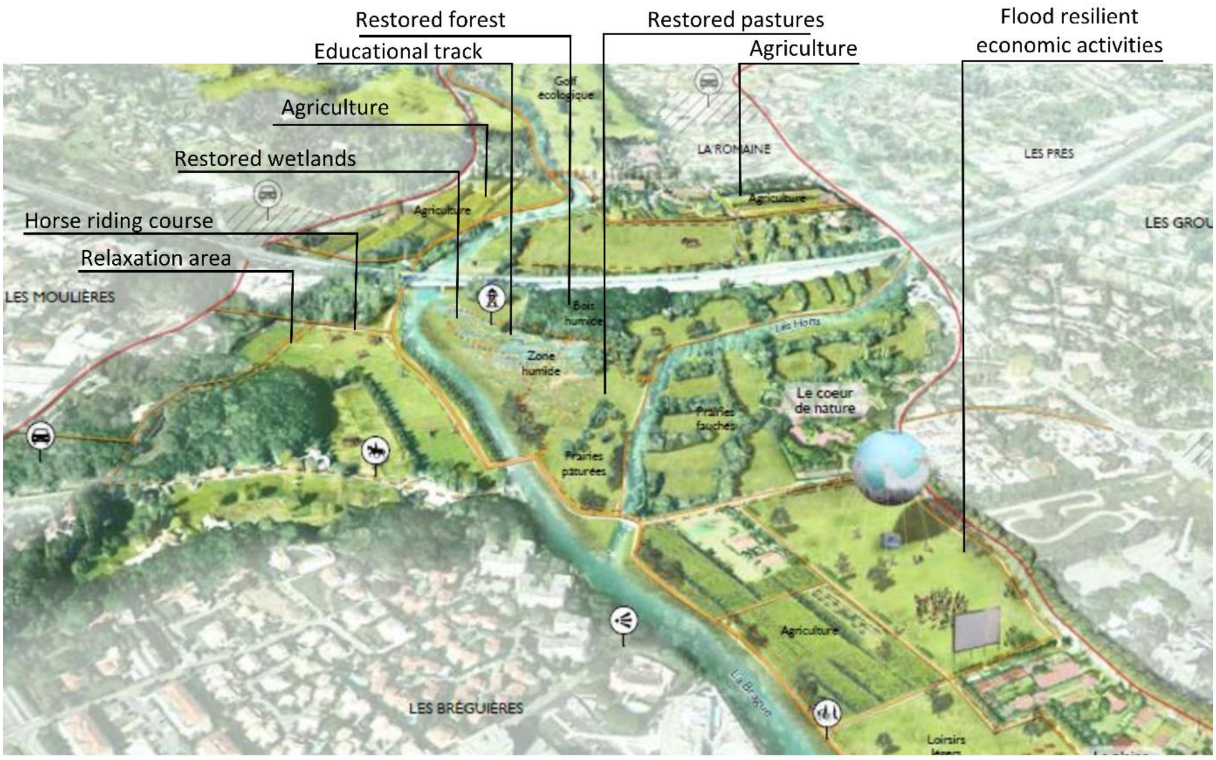

Figure 21: One vision of future land use and activities in the Brague lowlands (©Agence Foléa-Gautier, downloaded from http://www.cotita.fr/IMG/pdf/2_2-Plaine_de_la_Brague.pdf)

1.2.3.2 *Morphological quality changes*

The assessment of the Morphological Quality Index was repeated in a prospective way to check how this proxy of the environmental quality would change in the several scenarios studied. Assessing environmental indicator in a prospective way is usually extremely uncertain but the scale of work of the MQI, i.e., reaches hundreds to thousands of meter long, is suitable to prospective analysis, as yet performed by Piton, Philippe et al. (2018).

The maps of surface and linear works as well as the 3D changes in the geometry of the river and floodplains were used to re-assess each indicator in a prospective way. When we were uncertain on the mark to assign to a given indicator, the best estimate was assigned, e.g., “B” and it was added a sign to signal this uncertainty and the direction, i.e., an assessment ‘we consider “B” to be the best estimate but it could be “C”, the mark is thus “B^-“.’ While the assessment ‘we consider “B” to be the best estimate but it could be “A”, the mark is thus “B^+“.’ The MQI index in this case is still compute with the mark “B” for the said indicator but the range of uncertainty [MQI_{min};MQI_{max}] is computed by cumulating all the uncertainties. MQI_{min} is thus computed taking into all the "-", e.g., a mark "C" in our example, while MQI_{max} is computed taking into account all the "+", i.e., a mark "A" in our example. **Table 20** compare the assessment for each reaches and for all scenarios. The details of the prospective MQI assessment are provided in Annex 7.

Scenario	Reaches	Brague Gorges #1	Brague Biot #2	Brague Antibes #6	Valmasque Gorges #5	Valmasque Biot #4	Vallon Combes #3	Vallon Horts #7
Current	MQI	0.94	0.82	0.80	0.94	0.85	0.52	0.58
[MQImin;	MQImax]	[0.94;0.94]	[0.81;0.82]	[0.79;0.82]	[0.94;0.94]	[0.85;0.85]	[0.52;0.54]	[0.58;0.6]
Grey	MQI	0.87	0.79	0.76	0.87	0.82	0.52	0.58
[MQImin;	MQImax]	[0.87;0.88]	[0.76;0.79]	[0.74;0.79]	[0.87;0.88]	[0.8;0.82]	[0.52;0.54]	[0.58;0.6]
	ΔMQI	-0.07	-0.03	-0.04	-0.07	-0.03	-	-
NBS High Ambition	MQI	0.97	0.86	0.90	0.97	0.88	0.52	0.58
[MQImin;	MQImax]	[0.96;0.97]	[0.83;0.87]	[0.86;0.91]	[0.96;0.97]	[0.84;0.92]	[0.52;0.54]	[0.56;0.61]
	ΔMQI	0.03	0.04	0.1	0.03	0.03	-	-
NBS Very High Ambition	MQI	0.97	0.87	0.95	0.97	0.88	0.52	0.58
[MQImin;	MQImax]	[0.96;0.97]	[0.83;0.88]	[0.89;0.95]	[0.96;0.97]	[0.84;0.92]	[0.52;0.56]	[0.56;0.62]
	ΔMQI	0.03	0.05	0.15	0.03	0.03	-	-

Table 20: Prospective indicator marks for the Morphological Quality Index and change in value $\Delta MQI = MQI_{Strategy\#} - MQI_{Current}$. The darker the green, the better the morphological quality, the darker the blue, the better the morphological improvement, the darker the red, the worse the morphological degradation

From this analysis, it is concluded on the morphological quality[22], assessed by the proxy of the MQI applied to the Brague River and its tributaries in the lower part of the catchment:

- The morphological quality of the Brague and Valmasque in their forested part is very good and only good in the lowlands in the current state. The morphological quality of the Vallon des Combes and Vallon des Horts tributaries is moderate or poor and would not change within the scenarios proposed since all works are related to the Valmasque and Brague reaches.
- Within the Grey scenario, the reaches' morphological quality would be degraded because of the additional alteration to the hydrological regime of the rivers and because of side effect of sediment trapping in the retention dams. The highest loss of quality (dark red) would take place directly in reaches where the dam would be located: their Very Good MQI would decrease to an only Good MQI. Further downstream, the MQIs

[22] It is worth reminding from **Table 7** that the class of MQI are Very Good (MQI=0.85 – 1); Good (0.7 – 0.85); Moderate (0.5 – 0.7); Poor (0.3 – 0.5) and Extremely Poor (0 – 0.3).

still decrease (light red) but by about 0.05, the reaches remain nonetheless in Good MQI range as in current condition.

- Within the High Ambition scenario, the reaches' morphological quality would generally increase. All reaches along the Brague and Valmasque stems would achieve a Very Good MQI. Significant improvement (dark blue) would be possible in the Brague in Antibes while only general improvement (light blue) are possible in the reaches yet showing a Very Good status.
- Within the Very High Ambition scenario, the reaches' morphological quality would improve consistently with the NBS High Ambition except for the Brague lowlands: removing the road in Biot enables an increase of the length without bank protection even more; but the improvement is much more significant in the Brague in Antibes reach where the removing of the highway culvert increase the longitudinal continuity, allow more erosion process to occur in the new channels and decrease the necessity to remove large wood from the stream bed.

Chapter 2. Assessment of Life Cycle Cost and Opportunity Costs of NBS visions

2.1 Introduction

In the Brague Demo, NBS represent river restoration measures that are related to the concept of “Ecological Engineering” and “Catchment Systems Engineering” (Nesshöver et al., 2017). For both the population and authorities, the Octobrer, 2015 flood acts as the straw that broke the camel’s back; and leading to drastic and regulation measures of closing campsites and house demolition in the red area of the PPRI. About twenty houses have been already bought for demolition with the Barnier fund[23]. However, the implementation of NBS scenarios will require additional land use change in the low land of the Brague catchment and other operation costs. Most of the NBS measures have been implemented in recent year in France under the Water Framework 2000/60/CE. In the Brague, measures such as natural bank stabilization, streambed restoration and dam removal was locally implemented in order to restore the aquatic environment.

We thus resort to data on implementation costs of various restoration measures in the Brague catchment and through the country. In addition to the key report of the RMC water agency on the costs of river hydro-morphological restoration (AERMC, 2011), we gather data on the market price of real estate in the Brague. The RMC water agency report propose a methodology and data for estimating the implementation costs of a set of restoration measure.

2.2 Methodology and data

Our approach to assess the costs associated with the NBS strategies is grounded by the Life Cycle Cost describe in the NAIAD deliverable D4.2 (Altamirano & Rijke, 2017). The costs of NBS strategies involve investment costs and maintenance costs. Maintenance costs include both “operating and minor maintenance expenditure”, i.e., normal regular maintenance, and “capital maintenance expenditure”, more exceptional but still required maintenance operation as reparations after extreme flood events. In the context of urbanized area as the Brague catchment, restoration measures require a range of technical and administrative procedures. In addition to preliminary studies, NBS strategies require expropriation procedures because of the

[23] The French Barnier Fund was established by law n°95-101, of the 2 February 1995. It is dedicated to finance the national policy on disaster risk reduction. This fund is dedicated to reducing vulnerability of the assets exposed to natural hazards relocation, evacuation, implementation of protection works and hazard assessment and risk mapping. It is funded by a 12% levy on the additional premium related to natural disasters - this is linked to the compulsory extended “NatCat” coverage on all property damage insurance contracts. This State fund was designed to finance compensation for expropriation of property in high risk areas (Rica, et al., 2018, pp. 71-74).

strategies impact private proprieties in lowlands of the Brague catchment. Expropriation allow securing the longevity of NBS (AERMC, 2011). Practically, this requires times and administrative costs that are included in the estimated costs.

Table 21 summarizes the methodology for estimating the costs of measures. Investment and maintenance costs include operationalization of restoration or grey infrastructure works and land costs. Indeed, there is a need to first expropriate private proprieties impacted by the flood mitigation strategy (grey and NBS). In the literature of ecosystem restoration and conservation, one of the indicator of opportunity costs is the property values (Renaud, 2016). In the context of ecosystem-based disaster risk reduction, this indicator is relevant when there is a change in land use. Scholars consider that if the land is unused, ecological restoration does not entail opportunity cost. In the contrast, opportunity costs result from not using the area for other revenue-producing activities (Renaud, 2016). The French expropriation procedure provides that urban land to be compensate in accordance to market values. Moreover, it provides for compensations to the owner and notary fees to change the deed of property.

The total costs of land may be up to three times the estimated market values (AERMC,2011, p. 125):

- a factor two being applied to uncertainty on the real value of the land, and
- a factor of one time the value of the land being dedicated to pay :
  - the notary fee (20% of the land value) and
  - a compensation to the owner for losses on the use of the asset (80% of the land value).

Furthermore, investment costs also entail basic expenditures such as ecological and civil engineering, procurement, installation, planting, pedestrian path creation, etc. Maintenance costs represent annual expenditures to ensure the performance of grey infrastructures. One of the advantage of NBS measures is that they need fewer maintenance works in comparison to grey infrastructures. However, in the Brague Demo, NBS strategies to flood risk mitigation necessitate some civil engineering works at the margin. For this reason, we also consider the maintenance costs of civil engineering infrastructures to sustain NBS functioning.

To compute the Net Present Value of the costs of NBS strategies, we assume that all investments are made at the period 0. Hence, investments costs are not discounted. The discounting rate for maintenance costs is *r*=2.5% until 2070 and *r*=1.5% after (CGDD, 2018). The total costs is thus computed by:

$$Cost_{Total} = Cost_{land\ Acq.} + Cost_{invest.} + Cost_{opport.}(Cost_{maint} + Cost_{excep}) \sum_{i=1}^{Time\ window} \frac{1}{(1+r_i)^i}$$

The variables are defined in **Table 21**. Assuming a year of implementation of 2023 and a time window of 50 years, the annual maintenance costs are to be multiplied by a factor of 28.4 to compute 50 years of maintenance including discounting.

#	Costs	Type	Indicators (€, 2018)	NPV
$\textbf{Cost}_{\text{land Acq.}}$	Land acquisition	investment	Market price of real estate	Not discounted
$\textbf{Cost}_{\text{invest}}$	Operationalisation costs	investment	Operationalisation costs of measures	Not discounted
$\textbf{Cost}_{\text{opport.}}$	Opportunity costs	investment	Compensation and notary fee	Not discounted
$\textbf{Cost}_{\text{maint.}}$	Operating and minor maintenance expenditure	maintenance	Maintenance costs of civil engineering infrastructure and of vegetation management	2.5% until 2070; 1.5% after
$\textbf{Cost}_{\text{excep.}}$	Capital maintenance expenditure	exceptional maintenance	Estimation of typical reparation costs after severe flood event triggering damages	Not discounted

Table 21: Definition and indicators of the costs of measures

We gathered data from diverse reports of water agencies in France, academic literature and the national database of market price of real estate. In complement, we survey practitioners including river agencies, protecting infrastructure managers and forest managers in France. The costs were defined using unit costs, e.g., €/m² of planting, €/house demolition. Whenever several values of unit costs were available, the mean value is used for the estimation but we also used the minimum and maximum values to provide a range of uncertainties. When no information was available on the range of uncertainties, an expert guess of ±15% was used. The quantities were computed based on counting and measurements of lengths and surface of works in GIS maps. The main sources of unit costs are SETRA (1995), CEREMA (2014), CEREMA (2017) and ONF-RTM06 (2018). The latter was specifically executed for the NAIAD project and is provided in the Annex 8.

Real estate acquisitions were evaluated based on local market price (Annex 9). Minimum and maximum estimates were set to [-15%; +15%] of the available costs.

2.3 Results

Strategies represent a set of grey or restoration measures. **Table 22** presents estimated costs of the strategies that range from €57 million to €271 million (€, 2018). The ratio between the minimum and maximum costs is slightly more than two for both NBS strategies and about 3 for the grey strategy. This can be explained by the large ranges of costs of different measures. The costs of both grey infrastructures and restoration measures vary according to a number of characteristics such as environmental context, the size of the infrastructure and the level of the complexity of the ecological or civil engineering. The investment costs of the grey strategy mainly consist in infrastructures construction (99%) while land and opportunity costs represent about 80-90% in the context of NBS strategies. This is due to the market price of real estate in the Brague catchment (Annex 9). Because of the NBS strategies give more room for nature, it impacts more change in land use. Maintenance costs also depend on the type of infrastructure. It encompasses the annual maintenance cost of grey infrastructures and annual management cost of the floodplain.

The total cost of the **Grey strategy** on a 50 years time windows is estimated to 170 M€ (range of uncertainty 88 M€ ; 270M€) with roughly the following balance:

- Land acquisition costs 1%
- Construction costs 60%
- Maintenance costs (operating and exceptional) 37%
- Opportunity costs <1%

The total cost of the **high ambition NBS strategy** on a 50 years time windows is estimated to 77 M€ (range of uncertainty 57 M€ ; 128M€) with roughly the following balance:

- Land acquisition costs 43%
- Construction costs 28%
- Maintenance costs (operating and exceptional) 5%
- Opportunity costs 25%

The total cost of the **Very high ambition NBS strategy** on a 50 years time windows is estimated to 83 M€ (range of uncertainty 60M€ ; 134M€) with roughly the following balance:

- Land acquisition costs 41%
- Construction costs 31%
- Maintenance costs (operating and exceptional) 3%
- Opportunity costs 25%

COSTS	MIN	MEAN	MAX
1. GREY STRATEGY	**88**	**170**	**271**
1.0. LAND ACQUISITION COSTS	1.1	1.4	1.6
1.1. INVESTMENT COSTS	60.6	102.6	145.2
1.2. MAINTENANCE COSTS OVER 50 YEARS	26.1	65.7	123.0
1.3. OPPORTUNITY COSTES	0.5	0.6	0.7
2. NBS HIGH AMBITION STRATEGY	**59**	**80**	**132**
2.0. LAND ACQUISITION COSTS	25.0	32.9	58.0
2.1. INVESTMENT COSTS	17.3	24.2	34.6
2.2. MAINTENANCE COSTS OVER 50 YEARS	2.8	3.7	4.8
3.3. OPPORTUNITY COSTES	13.8	19.2	34.8
3. NBS VERY HIGH AMBITION STRATEGY	**93**	**122**	**211**
3.0. LAND ACQUISITION COSTS	38.2	49.1	89.3
3.1. INVESTMENT COSTS	29.5	39.9	61.7
3.2. MAINTENANCE COSTS OVER 50 YEARS	2.8	3.8	4.8
3.3. OPPORTUNITY COSTES	22.4	29.8	55.4

Source: Authors' calculations

Table 22: Strategies costs over fifty years (M€, 2018)

The Grey strategy cost was computed roughly assuming that building large retention dams cost 71 €/m^3, range of uncertainty [42€; 100€] for the 1 440 000 m^3 of retention needed as computed in D6.2 (Piton, et al., 2018). Such structures have annual maintenance cost of 1.5% of their building cost [1%; 3%] and provision for major works is also 1% of the building cost. One hectare of bare land should be acquired for each dam. Large wood traps must be built similarly than in the NBS strategies.

The details of the estimations of the NBS ambitious and very ambitious strategies are provided in Annex 10. It should be stressed that the lack of definition of the natural water retention measures located in the upper part of the basin made difficult to estimate their cost. The costs estimated in **Table 22** do not include them, consistently, the avoided damage estimated in the next chapter and the cost-benefit analysis do not include their effect.

2.4 Discussion

The Grey solution has the known interest to have limited land acquisition and opportunity costs but have the highest investment and maintenance costs. It is worth stressing that the dams are supposed to be built in natural parks and that compensation measures should be implemented as a consequences but their cost has not been estimated here. Overall, the high costs of this strategy, its absence of co-benefit and its lack of alignment with the current philosophy of natural stream management does not deserve more effort of study. NBS strategies on the contrary require much more land and houses to acquire, thus increasing also the opportunity costs, but result in much lower construction and maintenance costs.

Chapter 3. Assessment of the impact of NBS visions on avoided damages

3.1 Introduction

The computation of avoided damage enables to compute the benefit of flood protection measures in flood protection strategies. In France, cost-benefit analysis (CBA) as recommended by the EU Flood directive since 2011 are performed on all large flood protection projects, i.e., costing more than 2M€. For river flooding, the French national guidance on how to perform them were updated during the NAIAD project (CGDD, 2018) and we simply applied these standards on the numerical simulation of flood extends with and without NBSs. At a broader scale and regarding runoff-related risks, the CCR model is planned to be used at a later stage once a proper way to introduce NBS will be found in their large scale runoff risk model suite.

3.2 Methodology

3.2.1 Runoff risk at catchment scale

3.2.1.1 Hazard estimation

The catchment-scale runoff hazards and risks were studied in the current situation by the CCR partners in NAIAD (Piton, et al., 2018). The CCR model is a full risk analysis model first computing runoff at the pixel size of 25x25 m and secondly computing damages with a damage curve and maps of the asset locations. The integration of numerous small scale NBSs as natural water retention areas in such large-scale models is complicated and still in progress. Within this report we simply perform a preliminary GIS mapping and straightforward analysis of the retention potential at the catchment scale, i.e., the total volume that might be stored. The actual effect of NBS on discharges, i.e., on the fluxes, is to be modelled later once relevant way to model the NBSs will be found.

The Brague basin agency had an existing inventory of potential suitable sites for the implementation of NBSs (Lindénia, 2012). The inventory was reused to map the various potential sites where retention could be performed (**Figure *22***). Then hypothesis regarding the average water depth that could be stored in each measure were performed to provide a quick and coarse estimate of the cumulated retention volume of all NBSs and existing retention dams (**Table 23**).

Type	High potential areas (HPA) [ha]	Complementary areas (CA) [ha]	Average water retention depth [cm]	Retention volume on HPA [10^3 m3]	Retention volume on CA [10^3 m3]
Terraces	69	67	2.5 - 5	17.2 – 34.5	16.8 – 33.5
Flat zone	-	53	25 - 50	0	132.5 – 265
Floodplain	24	11	10 - 20	24 – 48	11 – 22
Dry talweg	-	106	10 - 20	0	106 – 212
Retention dam	1	-	350	35	0
Total	94	237		76.3 – 117.5	266.3 – 532.5
Cumulated	331			**342 – 650**	

Table 23: Total surface areas, potential retention depth and total volume of retention measures in the Brague catchment

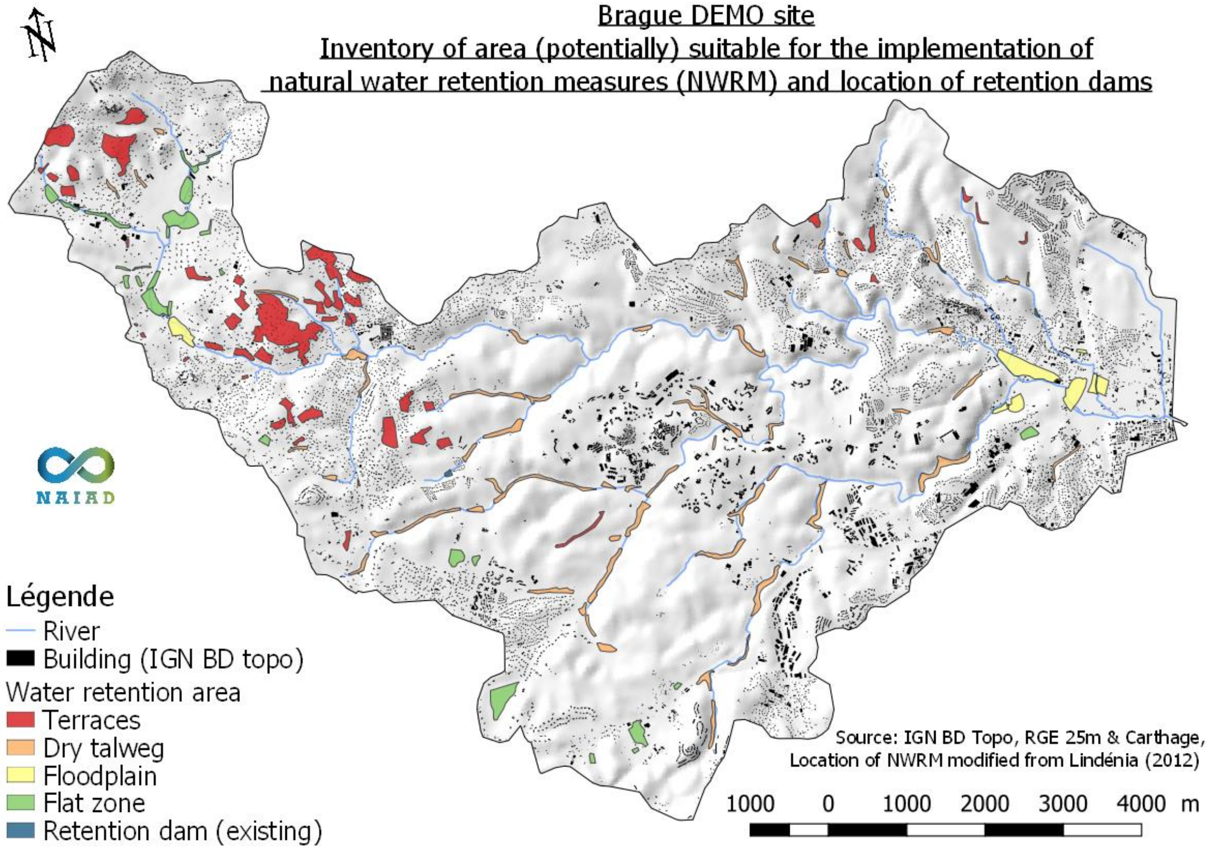

Figure 22: Map of areas suitable to implement retention measures (grey or NBSs)

A retention potential of about 0.1 Mm^3 seems to be available in the high potential area, i.e., in the areas that were considered promising to implement NBSs. A complementary potential volume of 0.2-0.5 Mm^3 may exist but will be slightly more complicated to implement because of issues regarding the existing land use, longer structures to build to store an equivalent volume of water and more complicated access to the area. Overall, we conclude that the retention potential according to this very simple GIS inventory is of about 0.3 to 0.6 Mm^3. This volume is to be compared to the total rainfall and runoff volume involved in the extreme events hitting the Brague catchment. According to the comprehensive feedback analysis of the extreme events of Oct. 2015 (Préfécture des Alpes Maritimes, 2016), the total rainfall volume on the Brague catchment was about 8.6 Mm^3, half of it flowed to the sea within the event. Thus overall, the total retention potential at the scale of the catchment for an event as Oct. 2015 is about 5%-20% of the total volume involved. It is thus non negligible but certainly not sufficient to manage the flood and runoff risk.

NAIAD partners thus recommend to push further the analysis of the retention potential at the catchment scale but also to be ambitious on facilitating the downstream flows down to the sea because one can never store enough water in the headwaters and middle part of the basin to protect the lowlands.

3.2.1.2 Damage curves

The methodology is the same than the one applied in the Lez DEMO. Hereby some specificities for the Brague DEMO. The developed methodology is easily replicable from one DEMO to another.

The calibration of insured damage functions relies on the hazard and vulnerability unit's outputs (**Figure *23***). There were no curves specifically representing the runoff damages in the studied area, synthetic absolute flow damage curves were developed in the frame of NAIAD. Indeed, the French damage curves developed by the Ministry of Ecology focus only on overflow hazards, i.e., river flooding, and do not consider the runoff hazard in the calibration of the curves.
Such curves are used to obtain costs and probability of losses for a certain water flow relative to the extent of hazard. In the NAIAD project, the functions are specific, obtained and established from the CCR historical geolocalised 2015-flood data at Brague DEMO scale. The calculation are carried out on a 25*25m mesh (CCR overflow and runoff model) and also for river flooding on a 1*1m mesh (IRSTEA Iber-flood model). The insured value is estimated by CCR. Flow duration is not taken into account. The validation of the damage functions is not based on extrapolation of the losses for residential homeowners to the all types of risks. The extrapolation coefficient will be the same for real and simulated losses

The methodological choice has been done concerning runoff classes, on Brague DEMO a threshold of 0.02 m3/s has been defined as the threshold of the moment of probability of losses is higher in hazard area than outside hazard area. It avoids to consider runoff in streets where there is no assets and the flow are concentrated between the sidewalks. This threshold is minor than in the Lez DEMO (0.07 m3/s), it is explained by the extreme characteristics of the 2015 flood.

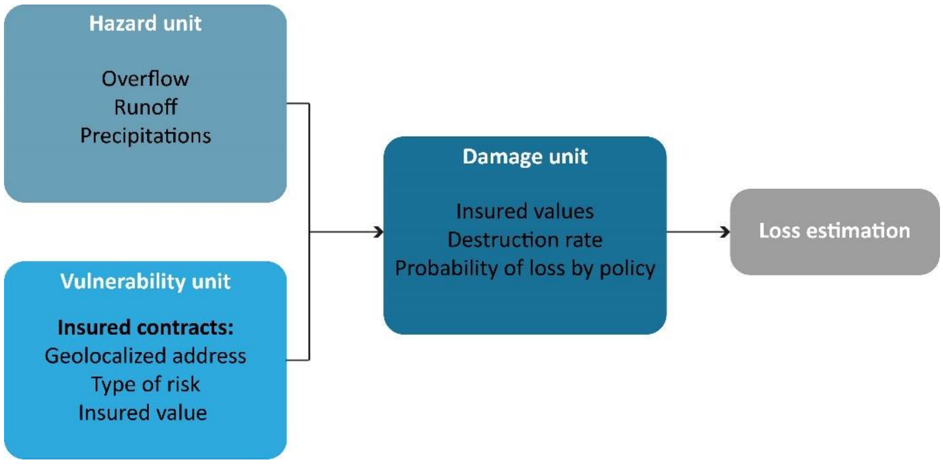

Figure 23: Catastrophe loss risk structure

The damage model is based on the damage function relating hazard intensity (discharge per pixel or water depth at pixel) and observed damages. The observed damages are defined by the destruction rate (DR). The destruction rate is obtained by dividing the amount of claims by the insured value.

$$DR = \frac{Amount\ of\ claims}{Insured\ value}$$

Hazard such as overflow is a function of water height (h) in meters and runoff hazard is a function of runoff flow rates (m^3/s) in cubic meters per second. The damage function is then: $DR = f(h)$ or $DR = f(\mathrm{m}^3/\mathrm{s})$

The damage functions could be divided into different groups such as residential building homeowners, commercial, industrial or agricultural businesses. As the main objective is to assess the flood damage at the local scale, the functions are elaborated for one homogenous class: residential homeowners (excluding high buildings). The type and material of buildings are not included in the analysis, as well as indirect damages are not modelled (indirect costs, public assets, damage to networks).

Then, damage rate histogram is calibrated. It is the average destruction rate per runoff/water height class, integrating probability of losses (with NULL values = 0, policy contract). The damage curve histogram is the average destruction rate per runoff/water height class, without NULL values (claims only).

The catastrophe loss risk model is applied to the Brague DEMO, using runoff and overflow damage functions to evaluate the potential direct tangible damage. Damage functions calibrated on 2015 flooding events are then used to estimate protection effectiveness in terms of avoided damage. The applied damage curves results for DEMOs are back-tested by comparing the simulated losses with the real losses of the 2015 events.

The statistical analysis provides a histogram of losses: the correlation between the m3/s and the damage rate and between the m3/s and the destruction rate. The calibrated curve for runoff losses strictly exclude the claims related to overflow.

The findings indicated that damage will be more serious with an increasing m3/s level. At more than 2.5 m3/s, the damage will be approximatively 15%. Both damage rate and damage curve are very high and higher than in the Lez DEMO for example. It can be explained by the intensity of the 2015-flood event with extreme rainfall and flows.

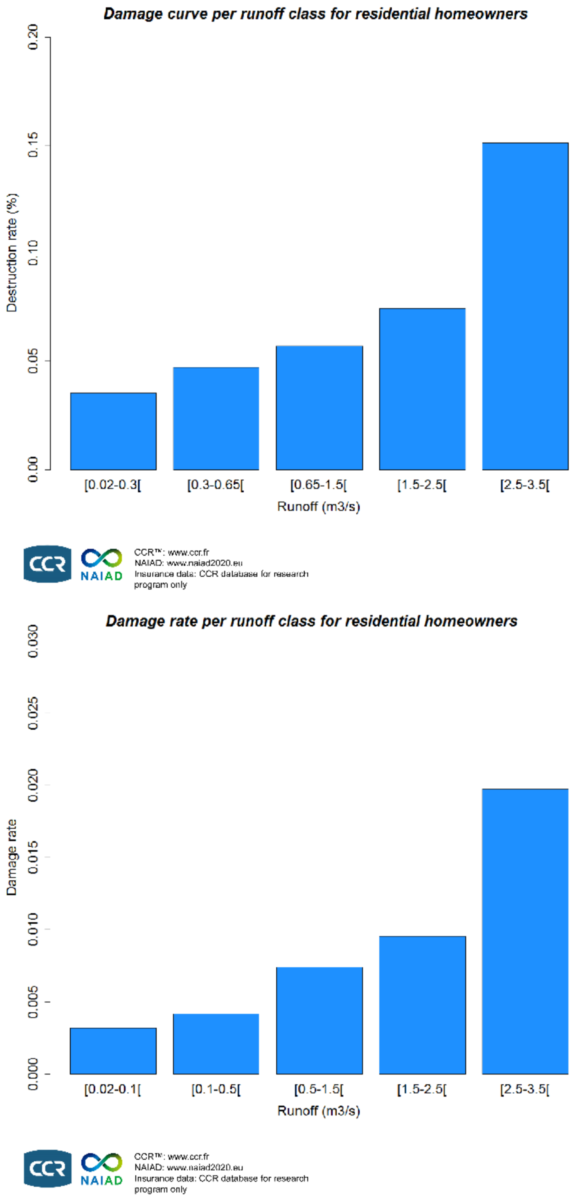

Figure 24 : Flow damage functions for Brague DEMO

These functions provide the damage rates which were used for a total flood damage assessment. The validation of the damage rate curve has been done by comparing the real costs of the residential homeowners' damage to the simulated costs and prove to be accurate (**Table 24**).

Real 2015 costs For residential homeowners	Simulated 2015 costs For residential homeowners	Simulation error
4 172 079 €M	4 077 596 €M	-2%

Table 24 : Validation of damage rate calibration on the Brague DEMO for runoff (source: CCR)

As the calibrated damage rate provides relevant and close results of the real 2015 flood losses, the calibration matrix can be used to simulate the effect of hazard reduction on damage.

An in-depth analysis of the runoff damage at IRIS scale has been performed in the Brague DEMO. The objective was to understand if there are correlation between the water flow and damage rate.

Figure *25*, reveals that in the case of Haut-Sartoux the damages are not significantly related with the level of flow. In fact, in this rural IRIS, the average runoff flow is higher but the total damage is still low. The result can be explained by the low degree of urbanization and low number of claims. Localization nearby the river also explain the high flow level but in steep slope there is no houses. In Valmasque-Notre-Dame-de-Vie, Les Groules-Les Breguières and Bois-Fleuri-Chevre d'Or-Saint-Philippe IRISes largely urbanized we observed large runoff and higher costs. These IRISes are located in low-lying areas largely damaged and overflowed during the 2015-event. For the IRISes with high runoff flow (Les Trois Moulins, Les Cougoulins-Rastines, Azurville-Val Claret) but with lower damage costs, are IRISes located along the highway A8 highly urbanized and with steep slopes recording high flow levels.

These elements are coherent with the local observations of 2015-events, with a strong runoff in Antibes (namely Azurville-Val Claret, Les Courgoulins-Rastines, Les Groules-Les Breguières). The runoff flow have passed through the highway via the road of the Avenue Jean Michard Pellissier. The small "vallons" have been areas of large runoff. The flows are very high due to a pluvial episode of 48h (82mm) before the 3rd October which has saturated soil and reinforcing runoff (Préfécture des Alpes Maritimes, 2016).

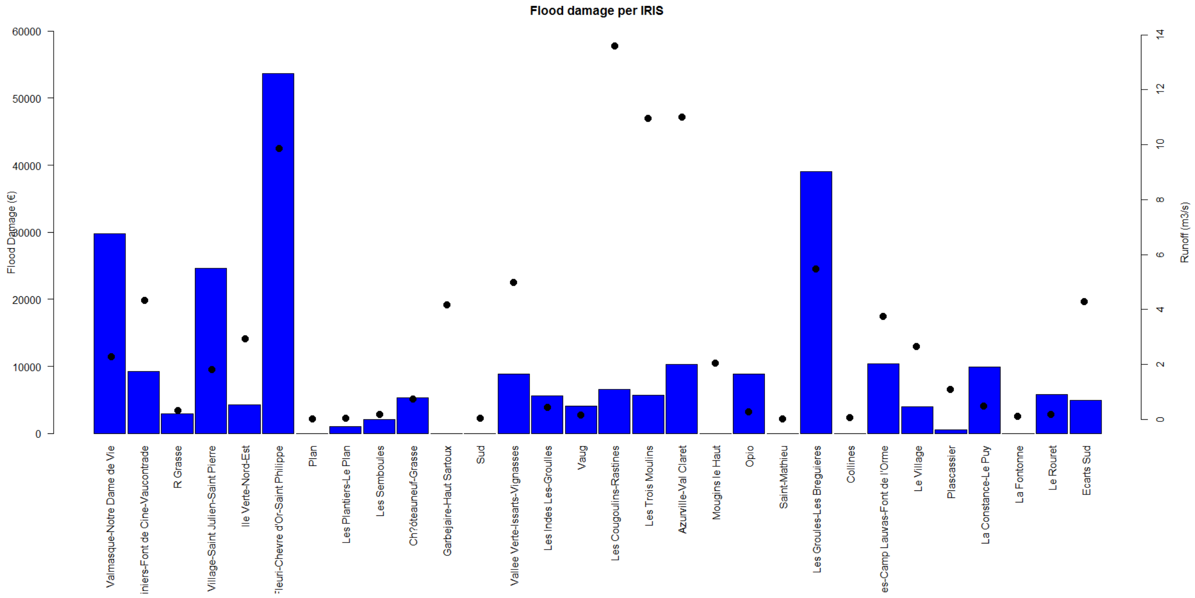

Figure 25 : Flood damage (€) and mean runoff (m3/s) per IRIS

3.2.2 Flood risk in the lowlands

3.2.2.1 Hazard estimation

Flood levels were extracted from the Iber simulations for several events, i.e., flood hydrograph with return period of 20, 100 and 500 years. The hydrographs were initially computed using the previously mentioned Shyreg method and were corrected using the method presented in NAIAD D6.2 to be representative of flood events of the said return periods at the scale of lowlands, i.e., the computation domain. Namely, a 100 years return period of the Brague at the sea (catchment 68 km²), i.e., of the computation domain, does not imply a 100 years return period of the Brague at Biot (catchment 42 km²) but a lower one. It is the simultaneous occurrence of flood events in all branches that trigger the said 100 years return period at the outlet. As a consequence, one could detect by careful study of the results flood extend, level or damage lower than previously computed at the scale of one branch.

The grey solution has not been modeled so far in Iber. It may be provided later.

The NBS high ambition strategy has been modelled and the NBS very high ambition strategy modelling is ongoing.

Flow level were exported in raster with pixel size of 1 m. The flow depth was computed by the difference between the flow level at each pixel and the ground level extracted from the lidar data.

Buildings being included in the model as holes in the mesh, i.e., no water can flow through the building extension. No flow depth is available precisely within the building extend. We thus defined 1-m wide buffer strips around all building and sampled flow depth in all pixels located within these strips. For each building, flow depth all around the building was extracted. The mean, minimum and maximum values were recorded.

3.2.2.2 Damage curves

The French standard method for damage estimation actually provide damage curves of different types and for various building component and type (CGDD, 2018). The two main categories are the damage curves at asset scale and the damage curves at scale of square meter of asset. For these two categories, damage curves are then provided for different asset type (single story house, multi-storey house, residential building) and for different component (building, furniture, basement).

Within the work performed on the Brague for the NAIAD project, we used the following assumptions:

- Flooding duration are assumed lower than 48h;
- All buildings are assumed not to have basements;
- Building extensions are used according to the database of the French geographical survey (IGN BD Carto);
- Buildings with surfaces, i.e., surface of the polygon in BD Carto, higher than 200 m^2 are assumed to be residential building, i.e., connected multiple houses;
- Buildings higher than six meters (metadata HAUTEUR in BD Carto) are assumed to be multiple-storey houses,
- In all building, the damage curves are computed by summing damages to the building and damages to furniture (**Figure *26***).

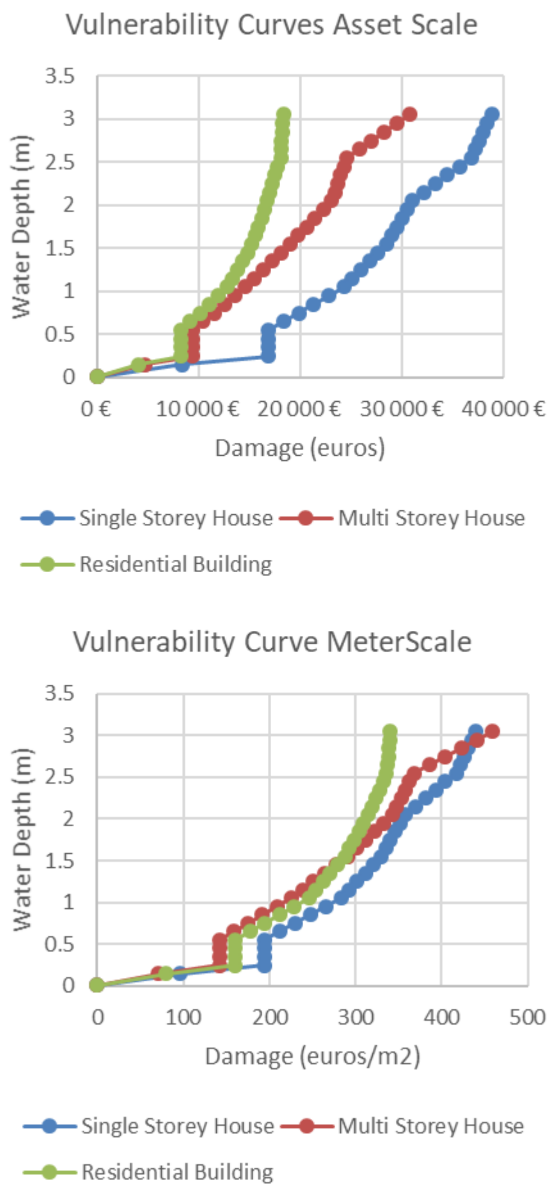

Figure 26: Damage curves used for residential assets at asset scale (left panel) and at square meter scale of asset (right panel) according to (CGDD, 2018).

The asset scale curves were tested and proved to underestimate the damages because in the Brague lowlands, many houses are built adjacently, i.e., with shared walls and are thus mapped as one single polygon in the database. We consequently decided to correct this proportionally to each building surface area and divided by 150 m² which is the median surface area of the local houses.

In addition to the French standard curves. The CCR partners performed a back analysis of the damages to residential houses of the Oct. 2015 event from their database crossed to the flood level computed by the Iber model (**Figure *27***). The results are expressed in damage rate [-], i.e., in damage value divided by the asset value. It encapsulates the false positives, i.e., the assets that were mapped as flooded by the model but which did not report damages. The actual damage rates for the studied water depth are actually slightly higher but applied only to a fraction of the assets. The values provided in **Figure *27*** can and should be used only on large enough samples of assets.

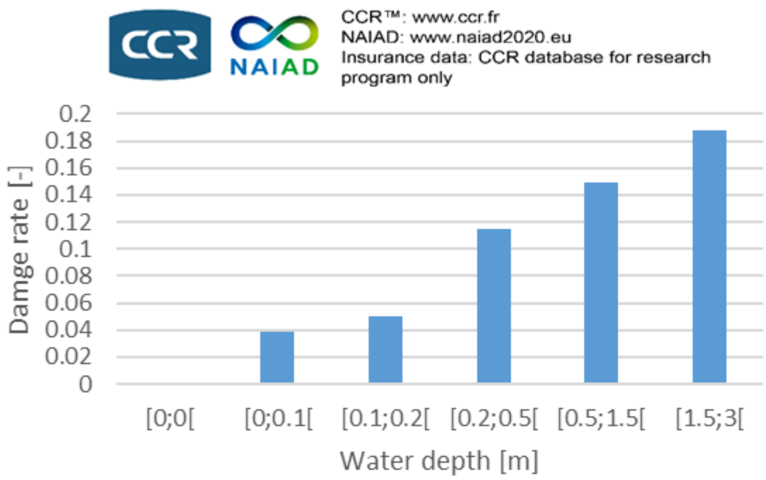

Figure 27: Damage rate against flow depth in the Iber model in the Brague Oct. 2015 flood disaster

A damage rate curve was deduced from this back analysis considering the application of the damage rate to the mean value of water depth of the range studied. Using then an average cost of houses of 365,000 € and a median house surface of 150 m², we applied a value of 2400 €/m² to be multiplied by the damage rate to compute the damages.

In order to test the possible effect of hazard model on such curves, the same procedure was performed by the CCR partner with their flood model, also called overflow model. Concerning the water height (m) correlated with damage rate, we observed similarities between the two overflow models at pixel sizes of 25m or 1m resolution (Figure 28 and **Figure 29**), the class are relatively similar even if the CCR 25m model has a tendency to estimate higher destruction rates compared to the IRSTEA 1m model for the highest class:

- CCR overflow model 25m Damage rate: 0.15 Destruction rate: 0.38
- IRSTEA overflow model 1m Damage rate: 0.18 Destruction rate: 0.28

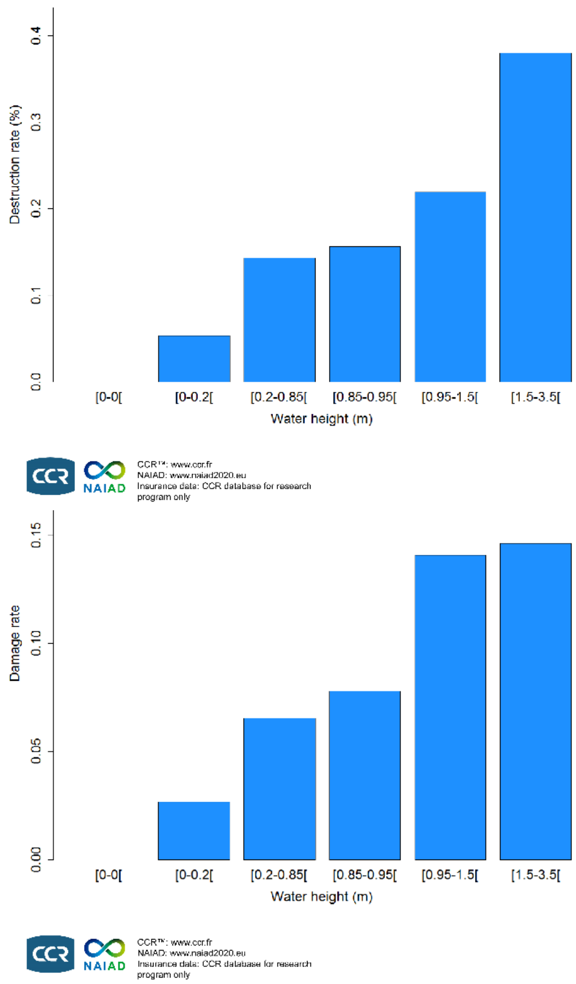

Figure 28: Destruction and damage functions for Brague DEMO – Calibration on CCR 25m resolution

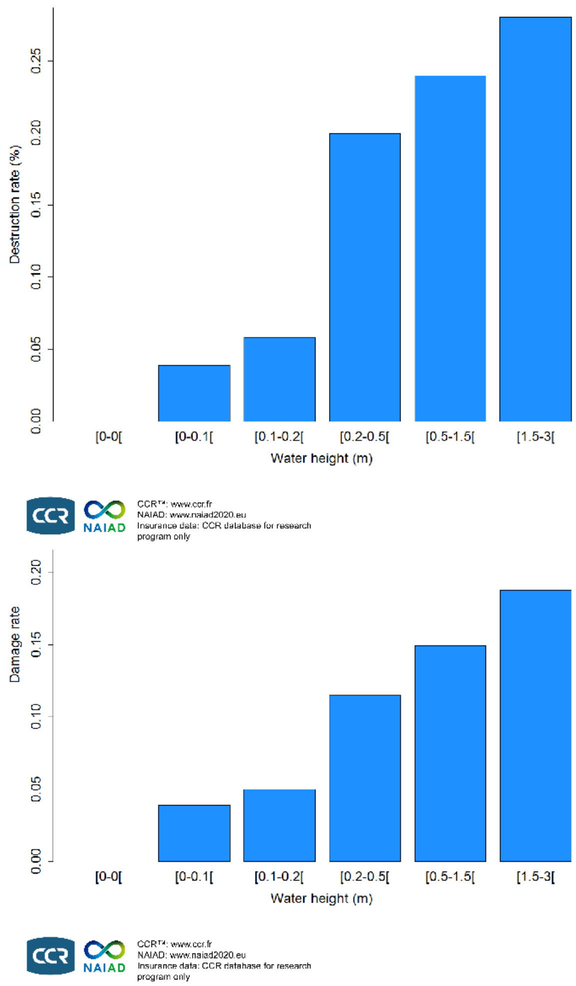

Figure 29: Depth damage functions for Brague DEMO - Calibration on IRSTEA 1m resolution

On the both calibration results, the 20cm threshold appears. This threshold is considered as the threshold from the moment when the damage largely increases. Indeed, above 20cm the electricity network started to be damaged which generates higher costs notably in terms of rehabilitation works.

This function provided a damage rate which was used for a total flood damage assessment on the 2015-event. The validation of the damage rate curve has been done by comparing the costs reported in the insurance data base for the residential homeowners to the simulated costs (**Table 25**):

MODEL	SIMULATED 2015 COSTS [M€]	REPORTED 2015 COSTS IN INSURANCE DATA BASE [M€]	SIMULATION ERROR
CCR 25M	10.4	10.6	-3%

Table 25 : Validation of damage rate calibration on the Brague DEMO for overflow (source: CCR)

As the calibrated damage rate provides relevant and close results of the real 2015 flood costs, the calibration matrix can be used to simulate the effect of hazard reduction on damage.

3.3 Results

Table 26 gathers the results of the damage estimations per events and per scenarios.

Scenario	Current situation			Grey			NBS high ambition			NBS very high ambition		
Flood event	❶*	❷*	❸*	❶*	❷*	❸*	❶*	❷*	❸*	❶*	❷*	❸*
Oct. 2015	16.4	39.6	55.3				12.1	29.3	43.0			
Nov. 2011	13.0	31.8	45.0				8.4	20.6	30.2			
Q20	6.0	15.0	23.2	4.9	12.1	19.0	4.1	10.2	16.1			
Q100	11.4	27.5	42.5	7.0	17.2	26.8	7.2	17.5	27.8		****	
Q500	15.4	37.2	52.4	9.8	23.8	37.4	12.1	29.3	43.0			
MAD**	0.6	1.6	2.4	0.5	1.1	1.7	0.4	1.1	1.7			
MAAD***				0.2	0.5	0.7	0.2	0.5	0.7			
MAAD/MAD				30%	29%	28%	32%	32%	31%			

*Curves ❶ = CGDD curves for asset scale (modified);Curves ❷ = CGDD curves for m² scale; Curves ❸ = CCR damage rates, ** MAD : Mean Annual Damage ; ***MAAD : Mean Annual Avoided Damage, **** The numerical modelling of the NBS very high ambition strategy is still on-going and its results will be published later.

Table 26: Damage per events and mean annual damage and mean annual avoided damage in M€

3.3.1 Historical events back analysis and model performance

The historical events of Oct. 2015 and Nov. 2011 in the current land use and river situation are estimated to have trigger high damages.

When aggregating the 2015-flood claims for residential homeowners the most costly areas are well correlated with the overflow area in Biot, Antibes, Mougins and Vallauris (**Figure *30***). The level of damage in euros are very high (from 10k€ to 53k€ for the higher classes).

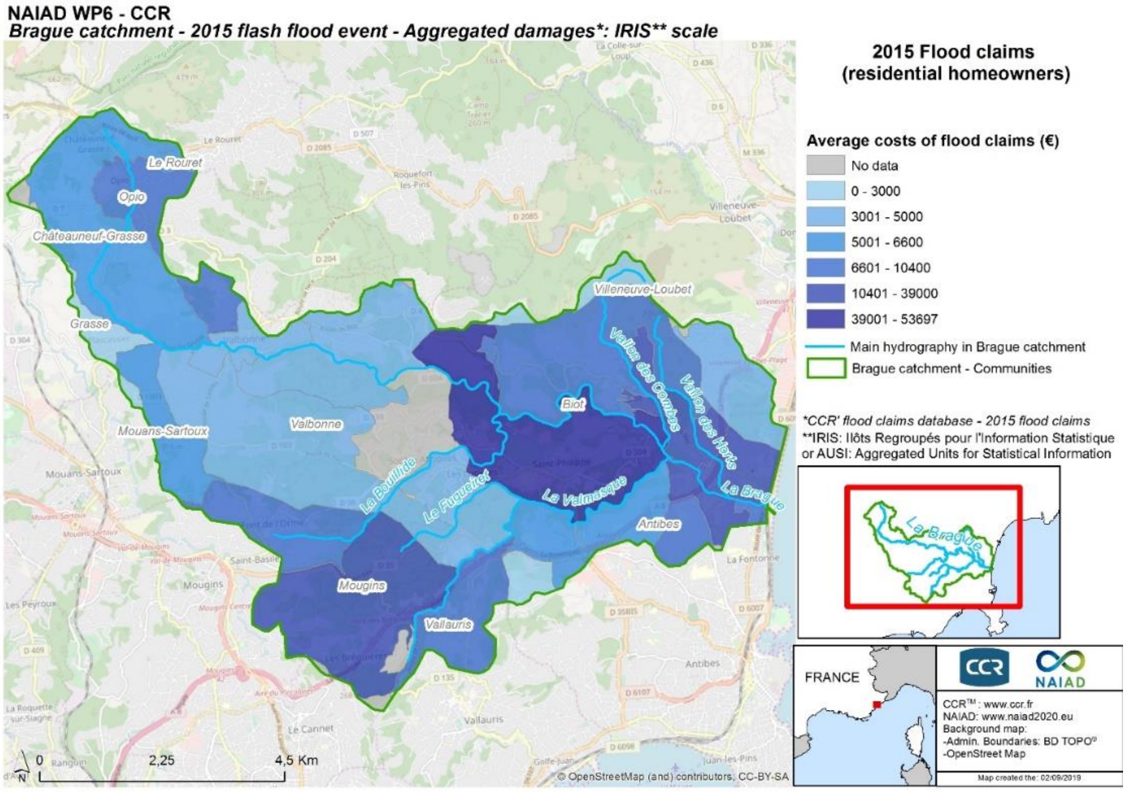

Figure 30 : Aggregated 2015-damages at IRIS scale for residential homeowners

According to the CCR database, damages located in and close to the computation domain, i.e., the Brague lowlands were estimated to about 27 M€ for the event of Oct. 2015 and about 2 M€ for the event of Nov. 2011. The two first lines of **Table 26** shows that the CGDD asset scale method underestimates the damage for Oct. 2015 while the other methods overestimate it. In addition, although lower than Oct. 2015, the damages estimated by all methods overestimate the damage actually observed after the event of Nov. 2011. Two reasons one related to the hazard mapping and the other related to the damage estimation explain this general trend to overestimation:

- The hydraulic model was calibrated for the Oct. 2015 event and the blind validation test performed on the event of Nov. 2011 proved that the model tends to overestimate flow level for events of magnitude lower than Oct. 2015 (Munir, 2019). Based on the available flood marks, we know that the flow levels for the Nov. 2011 event are partially overestimated.

- The damage evaluation considers that all assets located in the flooded area experience damages, i.e., that the exposure is 100% and that the first floor level is at the surrounding soil level. In reality, stairs and super-elevated first floor level protect some houses and building of which the garden might be flooded but the interior is not. Building scale protection measures (sand bags, waterproof barriers on doors) can also protect buildings during events.

Consequently, the numbers provided in **Table 26** should be considered as roughly correct for extreme event as Oct. 2015 (return period of about 1:500 years at the catchment scale according to our computations) and overestimated for less extreme events. Since the damages computed for the 1:100 years return period event are quite close to the damages computed for Nov. 2011 event, we conclude that the Brague catchment experienced a 1:100 years return period and a 1:500 years return period event in less than 5 years.

3.3.2 Efficacy of protection measures

3.3.2.1 Runoff reduction efficacy

An in depth integration of natural water retention measures in the CCR runoff model has not be possible to implement so far and will be done later. As CCR is not expert on modelling the effect of NBS on hazard and in the objective to avoid the multiplication of uncertainties for decision-makers, we decided to develop an approach based on an assessment of a percentage of hazard reduction to assess the related avoided damages. This straightforward analysis was performed to check how much should be reduced the runoff (whatever be the measures to do so) to reduce the runoff-related damage by a certain amount.

Using the results of the damage model enable to estimate the effect of **runoff hazard reduction** in terms of m3/s, on flood damage (avoided damage) at 25m resolution (**Figure *31***).

- Without any effect on hazard reduction (0%) the amount of damage is the simulated 2015 losses for residential homeowners (4.241 €M) which is extremely close from the measured value in the CCR database, namely 4.172 €M Simulated damages are 102% of measured damages.
- A reduction of 20% of hazards reduced insured damages by ≈ 7%, i.e., ≈0.26 M€,
- A reduction of 50% of hazards reduced insured damages by 45%, i.e., ≈1.6 €M.

A bootstrapping analysis was performed to check how the uncertainties on hazards would affect these results. Using a random uncertainty of ±30% on hazards' intensity (m^3/s) at each assets triggered an uncertainty of less than 1% on damages. The results seems thus quite stable regarding local uncertainties in the hazard mapping.

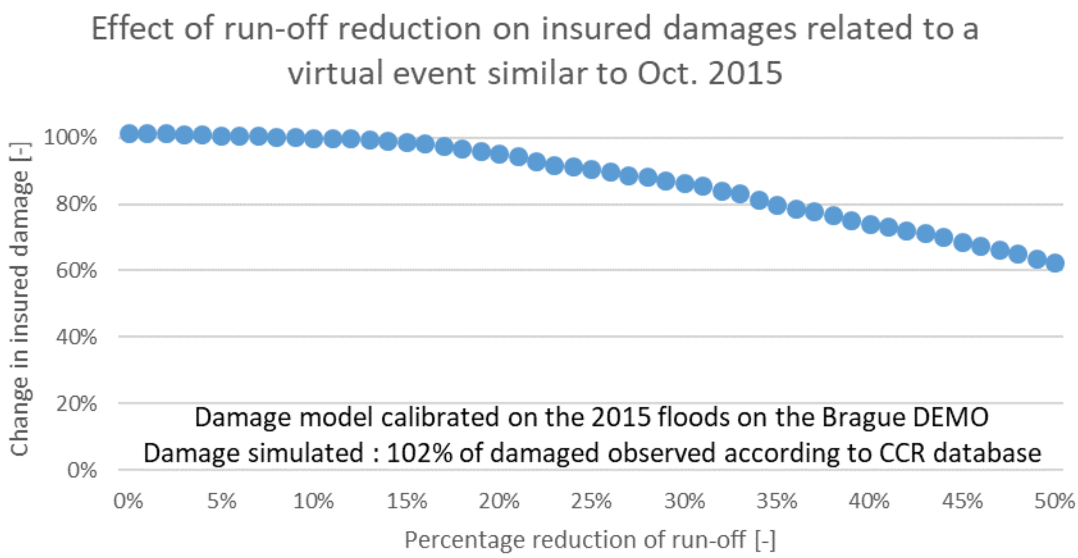

Figure 31 : Effect of hazard reduction on 2015-runoff insured losses for Brague DEMO (source: CCR)

These elements provide an overview of the necessary ambition of NBS on the reduction of runoff to effectively reduce damages.

3.3.2.2 River flooding reduction efficacy

Using the Iber model on the lowlands, one can analyze the protection efficacy of the scenarios. **Table 26** shows that both the grey scenario with large flood retention dams and the NBS ambitious strategy enables to reduce the damage by about one third, i.e., decrease the mean annual damage by 0.2 M€ to 0.7 M€ according to our estimations.

3.4 Discussion

3.4.1.1 CCR modelling of runoff at catchment scale

Calibrating damage functions on runoff and overflow hazards and based on insurance data for residential homeowners is a nascent field in scientific research. The damage functions for the Brague DEMO are specifics, even if the methodology could be applied in other areas (i.e, see Lez Part). The previous development do not underestimate the importance of the 2015-flood damage on Brague area causing terrible human losses and large number of claims.

Taking into account flood risk in land-use management is necessary in territory highly urbanized and exposed. The local authorities have to manage risks with urbanization legacy when dealing with it. The assessment of different scenarios of land-use on the October flood event do not have significant changes on the runoff extension.

In contrast, the results also reveal that the impact of climate change will increase the annual average insured losses from floods by 25%, from a current annual average insured losses of 48.6 €M towards 61 €M in 2050 in the Brague DEMO.

However, to mitigate the effect of climate change appropriate flood mitigation measures such as a hazard reduction of 10% or 30% will be helpful in reducing the impacts of losses from floods by approximatively -3.9% and -13.25%, respectively. Moreover, for the 2015-flood event, a hazard reduction of 10%, 30% or 50% will reducing the impacts of losses from flood by approximatively -6.1%; -24.9%; and -45.3%, respectively.

We analyse the needed percentage of hazard reduction and we can conclude that preventive measures implementation policies have to be largely ambitious to be effective enough. These results may help decision-makers to prioritize their response measures, by taking into account uncertainties and unpredictability of flood events. The increase of vulnerability exposure into at-risk areas can be considered as the key metric of rising damage costs. The present report captures order of magnitude to orientate decision-making processes.

A lot of research and discussions have been and are still performed within the Brague catchment in order to reduce the flood risks while still developing the economic attractiveness of the area. It is important to notice that Mongins, Roquefort-les-pins and Valbonne have not implemented Risk Prevention Plans in 2015. The existing Risk Prevention Plans have been revised after the 2015 flood with new mapping and regulations (Nice Matin, 2019). Locally there are many discussions about the effect of continuous urbanization of the catchment especially in Sophia-Antipolis, after 2015, people have been increasingly aware and implicated in the understanding of flood hazard.

With the previous results, we observe more the role of vulnerability than the land-use change role on increasing damage costs. Hence, appropriate land-use plan is required to avoid continuous urbanization, to care about the vulnerability of people and buildings in current and future high risk areas.

Concerning the (re)insurance industry interest on that kind of research, it is linked to the on-going research on the hazard and preventive measures modelling to be able to assess damage of future events and to orientate prevention policies (Expertise Center IARD, 2019). One of the main key messages is also that preventive measures to do totally avoid damages, the residual risk is still here, but mitigation measures participate to reduce it.

3.4.1.2 *IRSTEA flood modeling of the lowlands*

One could be surprised that both ambitious strategies studied here, either civil engineering- or NBS-based, only reduce the damages by roughly one third. Damage calculations using different recurrence interval discharges show that there is around 30% decrease in mean annual damage. **Figure *32*** shows in green the area where we have significant influence of the proposed works in the NBS high ambition strategy.

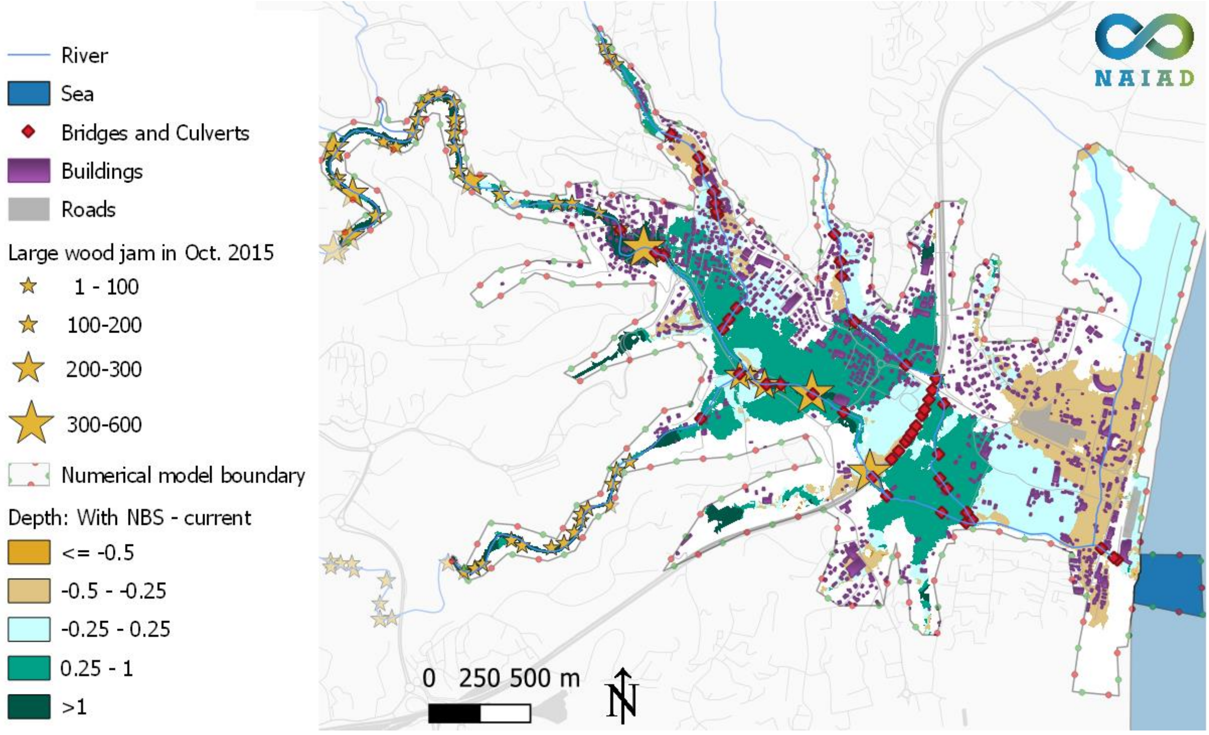

Figure 32 Damage locations and influence zone (decrease in water depth of more than 0.5 m: dark green, decrease of 0.25 to 0.5: clear green, decrease of less than 0.25: blue zone)

As the works to be carried out are extensive, we were expecting quite significant reduction in damages. A reduction of 30% is not so great, but can be explained by the influence zone of works carried out. It is quite clear that most of the assets are still outside of the high influence zone (the green zone); several reasons to this:

- Heavy flood protection works were performed on the tributaries of the Vallon des Combes and Vallon des Horts in the last decade: lining of the channel with concrete, flood walls and a concrete retention basin on the Vallon des Combes. The urban fabric is very dense around these tributaries and we consequently did not recommend particular works to be added to the existing one within NAIAD. Because of too extreme discharges, large wood jams or cars transported in the lined channels and jamming bridges, tributaries overflowed in Oct. 2015 and will likely overflow again for extreme events. The damage estimation consequently does not change around them in our computation between the current and the future situations.

- The culverts at the highway A8 and at the sea mouth where bridges constrains the river width to enable the crossing of a railway track and two roads are key bottleneck sections on the Brague main stem. They constrain the flow and do not let the flood pass through easily thus even though the upstream and eventual downstream sections of the river are widened, the reduction of water level around upstream of these sections is not significant.

To decrease the flood level further and to increase the effectiveness of the proposed solution, it is advised to consider a redesign of the bottleneck sections or to build additional discharge works to cross the highway and downstream embankment.

The same reasons also bring reduce the protection efficacy of the grey scenario. The cumulated flows coming from the numerous small thalwegs surrounding the lowlands were actually significant in Oct. 2015. Investing in 30-m high flood retention dams in the two main stems would significantly reduce the flooding related to these stems but the surface runoff still play a key role in the total damages, thus the low protection efficacy of the two large retention structures.

Chapter 4. Economic valuation of co-benefits of NBS visions

4.1 Introduction

Estimating the economic values of NBS in the context of the Brague Demo is not straightforward due to the importance of economic costs of NBS strategies (Chapter 2) and the particular social context related to the flood risk (0). This stresses the need of public support, a more inclusive approach and an individual valuation method to go beyond the miscommunication between stakeholder groups. Indeed, interviews and focus groups with stakeholders revealed both a demand for additional risk management measures; in particular concrete infrastructures and NBS but also for more communication on what is going on regarding flood risk management in general. However, the social context and the misperception of the social, economic and ecological impacts of the different measures create barriers to dialogue and a consensus among stakeholders about level of the ambition of measures. Moreover, most stakeholder' concerns are focused on the impacts in the lowland while the scale of the valuation in the NAIAD project is at the catchment scale. Finally, valuating co-benefits is a complex task rising scientific, technical and social and ethical issues. Our mission being to evaluate the total cost and benefits of NBS strategies, we nonetheless did our best to provide an as-rigorous-as-possible assessment.

We were not sure to fully perform a survey directly with the population until late in the project because of the social context with several miscommunication issues and the trauma of the Oct. 2015 event still fresh. This context has motived a coupled approach for the estimation of co-benefits:

1. An estimation of co-benefits (and only of co-benefits, not of the main benefit i.e., avoided damages) based on the **transfer of co-benefit valuations** assessed in other catchments,
2. A **contingent valuation** of all benefits (reduced flood risk and co-benefits) of flood strategies to implement in the catchment, valuation based on a survey performed in the Brague DEMO.

The method of co-benefit valuation transfer is thoroughly described in the paper written by Arfaoui and Gnonlonfin (2019). It is consequently only summarized in the present report. Conversely the contingent valuation method is only described in the report by Gnolonfin & Douai (2019) in French. After discussions with the BRGM partners and their quite similar concern on the estimation of co-benefit in the NAIAD Lez DEMO, it was decided to perform this survey to gain the acceptance of the population and to support decision making while providing the Total Economic Value. The contingent valuation consisted in a socio-cultural survey to (i) evaluate individual perception and experiences of the flood risk in the Brague catchment, (ii) value individual preferences to measures and their potential impacts and (iii) value individual contribution to the measures. Contingent valuations are widely used to value public and environmental goods because they provide a methodological sound way to analysis individual preferences (Kahneman et al., 1993; Kotchen & Reiling, 2000; Lankia et al., 2014; Pondorfer & Rehdanz, 2018). It uses a questionnaire or interview to create a realistic but still hypothetical market or policy. In our context, we used the survey to convey the description of measures and their potential impacts and allow respondents to indicate their preferences and Willingness To Contribute (WTC). The WTC represent a psychological perspective interpreting the Willingness To Pay (WTP) for public or environmental goods as *"cause that needs supporting"* according to Kahneman et al. (1993, p. 311). We adopted this interpretation to demonstrate public support to NBS measures in the Brague catchment.

Both approaches, namely the co-benefit valuation by transfer and the local contingent analysis, are complementary: the co-benefit valuation by transfer should be summed with the estimation of avoided damages (Chapter 3) to provide an estimation of the total costs with rational methods. The contingent valuation provide a similar estimation of total costs but in the perspective of the Brague DEMO citizens, not based on methods developed elsewhere.

4.2 Methodology and Data

4.2.1 Value transfer function for co-benefits of NBS

Value transfer represents one of the estimating method of the impact of projects or policies on the public well-being at the lower cost. The Meta Regression Analysis (MRA) is considered the most promising method among the three value transfer methods identified by Richardson et al. (2015). The MRA method is less sensitive to the problems related to individual studies (Rosenberger & Stanley, 2006; Chaikumbung et al., 2016).

Arfaoui and Gnonlonfin (2019) performed such a meta regression analysis. A database was constructed with 187 monetary estimates from 52 studies since the 1990s, conducted in 20 countries in America, Europe and Asia-Oceania, which evaluate the impacts of restoration projects (real or hypothetical) on provision of ES. It more specifically assessed how individuals value the NBS restoration measures and their primary benefit (water regulation) and co-benefits (food and material provision, local environmental regulation, global climate regulation, habitat quality and species diversity protection, recreational services, aesthetic appreciation). Each of the 52 studies was thoroughly studied to (i) extract the willingness to pay per household and per year for some or each of these services, and (ii) extract explanatory parameters: socioeconomic variables, methodological attributes and project characteristics. In a second step several statistical models were developed to estimate the willingness to pay based on local values of the explanatory parameters.

Model #6 was reused on the Brague to compute several possible estimates of the WTP the Brague DEMO households could have to promote restoration strategies enabling to decrease flood risk and to improve the aspects related to the co-benefits. Minimum and maximum were computed by accounting for the variability not statistically related to the parameters. The correlation coefficient R^2 of Arfaoui and Gnonlonfin (2019)'s model #6 being of 0.38, this results in a quite large range of uncertainty.

4.2.2 Contingent valuation of main and co-benefit of NBS

4.2.2.1 Identification of co-benefits

A first work was performed to determine the relevant co-benefits of NBS strategies in the context of the Brague Demo. Co-benefits result from the two main characteristics of NBS: use of nature and stakeholders' involvement (Eggermontet al., 2015). In the context of NAIAD project, they represent additional benefits to flood risk mitigation including the provision of other ecosystem services (ES) (Eggermontet al., 2015), "substantive benefits", "instrumental benefits" and "normative benefits" (Nesshöver et al., 2017, p. 1221). However, the co-benefits of NBS are context-dependent and require the identification of relevant ones.

The process of identification of co-benefits consisted in three focus groups organized in June, 2018 in which potential benefits of NBS were discussed with stakeholders (**Table 27**). On the Basis of the Common International Classification of Ecosystem Services (CICES) and EKLIPSE frameworks, stakeholders identified and validated co-benefits relevant for the Brague DEMO context. Indeed, because of the social context in the Brague Demo (0) and disagreement between stakeholders, we avoided direct discussions and design exercises of flood risk mitigation strategies. Rather, discussions focused on what was expected by stakeholders in term of co-benefits and how to assess them. In essence, one objective was to identify the most relevant criteria stakeholders would use when choosing a strategy, be it grey or NBS. In addition, since the NBS strategies were not fully defined, the questionnaire and survey is not exactly describing the strategies described in 0. These strategies are in addition excessively detailed and technical for non-technical audiences, see Piton, et al. (2018) for more details and maps. Rather, the survey compare conventional civil engineering measures with conceptual NBS strategies.

STAKEHOLDERS GROUPS	MISSION	AGENCIES
PUBLIC SECTOR	Representative of the French State, departements in charge of risk management and environmental protection	Préfecture des Alpes Maritime : Direction Départementale des Territoires et de la Mer (DDTM) – services risques et police de l'eau
	Water agency	Agence de l'Eau Rhône Méditerranée Corse

	Urban community of the Brague Catchment	Communauté d'Agglomération Sophia-Antipolis (CASA)
	Brague catchment basin agency	Syndicat Mixte Inondations, Aménagement et Gestion de l'Eau (SMIAGE)
	Coastal area conservation agency	Conservatoire du Littoral
	French agency for biodiversity	Agence Française pour la Biodiversité (AFB)
CIVIL SOCIETY	Societies for nature conservation and environmental protection, Biot and Alpes Maritime	Association De Sauvegarde De L'environnement De Biot Et Des Alpes-Maritimes (ASEB-AM)
	Societies for nature conservation and environmental protection, Côte d'Azur	Groupement des Associations de Défense des Sites et de l'Environnement de la Cote d'Azur (GADSECA)
	Non-affiliated citizens	Citoyens non affiliés

Table 27: Represented stakeholders groups and agencies.

Stakeholders' involvement in designing strategies

The feedback provided by stakeholders was however not dismissed. Three main strategies were identified at mid-NAIAD project and described in NAIAD Deliverable 6.2 - Part 3 (Piton, et al., 2018). Following several meetings with various stakeholders, the NBS low ambition strategy was abandoned because yet on-going while another strategy, more ambitious, was adopted. Stakeholders' knowledge and vision were thus really integrated in the design of strategies.

4.2.2.2 The survey

The decision of implementing an individual survey was made in accordance with stakeholders. During the second workshop attended in December, 2018, NAIAD partners presented methods to access the different criteria to be used in the strategy comprehensive appraisal to be done by the end of the NAIAD project. Among other methods, the opportunity and necessity of the individual survey project was debated. Except the urban community of Sophia-Antipolis (CASA) who expressed reservations because of political concerns due to consequentiality[24], others stakeholders agreed about the relevance of such a survey. They stressed the importance of a survey to go beyond strategic behaviors of the representatives of stakeholder groups. Hence, the protocol of designing the survey was flexible to take into account particular concerns of the CASA. It was carefully designed over an eight-month period based on the guides for stated

[24] "Consequentiality" is one of desired characteristic of stated preferences survey referring to the fact that respondents perceive their responses as influencing the provision of the item being valued. This (termed "the letter to Santa Claus" by stakeholders) can result in political consequences in the context of the Brague if the valued strategies are not finally implemented (Johnston et al., 2017).

preferences studies to ensure validity and reliability of the resulting value estimates (Johnston et al., 2017).

4.2.2.3 The questionnaire

The design of the questionnaire followed a protocol that allowed for stakeholder comments and peer review. The process started in November 2018 with an outline of the objectives and modules of the questionnaire based on an extensive review of the literature. This outline was presented to stakeholders during the second workshop to comment. After that, comments on successive revisions were received from different NAIAD partners and colleagues. The first draft of the questionnaire was presented to stakeholders on March, 2019 before a one-on-one pre-test interviews with sixty undergraduate students to check bias and revise the questionnaire. We also conduct additional meetings with the CASA officers in order to take in consideration their concerns about the presentation of scenarios. The design process also included a review by the representing office of the protection of individual data who must approve all questionnaires for individual survey.

In addition to the particular social context in the Brague Demo, the challenge in designing the questionnaire was related to the uncertainty, complexity and multidimensionality on outputs of NBS strategies. For this reason, rather than accessing the contribution to flood risk mitigation and co-benefits, our strategy was to access the contribution to strategies. Hence, the scenario development describe grey and NBS measures as substitute and with different level of potential impact on flood risk mitigation and co-benefits. Consistent with the general structure of the questionnaire, the final draft included six modules.

1. It begun with a module aiming to evaluate the respondent's socio-economic characteristics, values and believes.
2. The second module evaluated the respondent's perception of the flood risk perception and other environmental, economic and social challenges. These challenges represented the impact domains of NBS measures discussed in the focus groups in Jun, 2018.
3. The third module evaluated the respondent's experiences of flood risk in the Brague.
4. The fourth module evaluated the respondent's preferences for either grey and/or NBS measures and their potential impact.
5. The fifth module evaluated the respondent's WTC.
6. Finally, the sixth module collected respondent's other comments.

Annex 11 presents the final questionnaire. Consistent with the goal of measuring the WTC from the general public and considering the CASA's concerns, NAIAD partners devoted a particular attention to the design of the fourth module. This module focused on the measures and the potential benefits (flood risk mitigation and co-benefits) that might accrue from their implementation. For the purpose to demonstrate the relative preference of purely NBS, purely grey or hybrid strategy, the module presented three level of ambition of civil engineering and ecological restoration works. Three "fixed attributes" were used to describe the level of ambition including a description of specific works, an estimate costs of investments required and a description of impact on land use change (**Figure *33*** & **Figure *34***). The objective of these attributes was to remind the respondent the main side effects of measures that it was supposed to consider in addition to the impact on the flood risk mitigation and co-benefits. It provided respondents the opportunity to consider all the possible alternative strategies and income effects of strategies. Beside, this presentation of strategies had the advantage to avoid the selection bias identified during the pre-test of the initial non-attribute-based description of scenario presenting directly the strategies and their impact. Indeed, the initial presentation had a high potential of embedded effect.

The attribute-based description of scenario also offered the opportunity to analyse the relative demand for ecological restoration works in the catchment. The respondent had the possibility to design its "preferred strategy" by choosing only grey measures of three ambition level, only NBS measures of three ambition level or a mixed of measures of varied ambition. There are fifteen potential "preferred strategies" including three purely grey, three purely NBS and nine hybrid. We classified respondents into nine categories according to their "preferred strategy" in order to analyse the determinants of the demand for a range of flood risk mitigation strategies in the Brague (**Table 28**). Moreover, the presentation satisfy the CASA's concerns.

Respondent profile	Preferred strategy (equivalent regarding strategies designed by NAIAD partners)
Pure Grey +	Grey measures low and medium level
Pure Grey ++	Grey measures high level (NAIAD grey strategy)
Pure NBS+	NBS measures low and medium level
Pure NBS++	NBS measures high level
Hybrid NBS-Grey	NBS and Grey measures low-low level; medium-medium level; high-high level.
Hybrid NBS-dominated	NBS and Grey measures medium-low level; high-medium level (NAIAD NBS high ambition strategy); high-low level
Hybrid Grey-dominated	NBS and Grey measures low-medium level; medium-high level; low-high level

Table 28: Possible flood risk mitigation strategies chosen by interviewees

Furthermore, we paid a particular attention to the design of the fifth module eliciting the value of the contribution. Because of the potential uncertainty related to this kind of exercise, we preferred the range-WTP method (Pondorfer & Rehdanz, 2018). We also carrefuly chose the payment method to account for the particular general context of "fiscal fed up" in France. The

Water Agencies, organism in charge to coordinate and fund the Water Framework Directive are for instance yet funded by taxes on the water bill. We reused the same reference of acceptable increase in the water bill. Lastly, a professional was hired to administer the questionnaire to 405 respondents forming a representative sample in the Brague in September and October, 2019.

Travaux/Contraintes	Niveau d'ambition		
	Faible	Moyen	Fort
Travaux de restauration écologique et d'accessibilité	⊕ ¬ Création de pistes d'accessibilité discontinues	⊕⊕ ¬ Création de pistes d'accessibilité discontinues ⊕ Restauration du lit moyen de la Brague (élargissements) ⊕ Restauration de zones humides	⊕⊕⊕ ¬ Restauration du lit moyen de la Brague (élargissements) ¬ Restauration de zones humides ⊕ Création de pistes d'accessibilité continues ⊕ Restauration de zones de rétention de crues ⊕ Restauration de la ripisylve
Dépenses en investissements (foncier, constructions et en entretien)	⊕ ¬ Entre 2,5 millions et 3 millions €	⊕⊕ ¬ Entre 40 millions et 95 millions €	⊕⊕⊕ ¬ Terrains nus ¬ Entre 232 millions et 459 millions €
Expropriation de terrains nus et de bâtis	⊕ ¬ Terrains nus ¬ Entre 0 et 5 bâtis	⊕ ¬ Terrains nus ¬ Entre 0 et 5 bâtis	⊕⊕⊕ ¬ Entre 50 et 100 bâtis
Votre choix	○	○	○
⊕ : Travaux en supplément par rapport à un niveau d'ambition plus faible ¬ Travaux en commun avec à les niveaux d'ambition			

Figure 33: Description of NBS measures

Travaux/Contraintes	Niveau d'ambition		
	Faible	Moyen	Fort
Travaux de génie civil	¬ Pièges à flottants	¬ Pièges à flottants ⊕ Reprise de ponts et ou déviation de route	¬ Grands barrages de rétention ¬ Endiguements et recalibrage de la Brague
Dépenses en investissements (foncier, constructions et en entretien)	¬ Entre 0,4 et 1,5 millions €	¬ Entre 32 et 47 millions €	¬ Entre 65 et 150 millions €
Expropriation de terrains nus et de bâtis	¬ Terrains nus ¬ Entre 0 et 5 bâtis	¬ Terrains nus ¬ Entre 0 et 5 bâtis	¬ Terrains nus ¬ Entre 5 et 10 bâtis
Votre choix	○	○	○
⊕ : Travaux en supplément par rapport à un niveau d'ambition plus faible ¬ : Travaux en commun avec à les niveaux d'ambition			

Figure 34: Description of grey measures

4.2.2.4 Sampling

The survey was conducted as a face to face questionnaire to ensure that complex concepts could be conveyed as much as possible. The population of interest consisted of the Brague catchment residents and users (tourists and surrounding population). Indeed, a large part of the economic activity in the valley is related to tourists. Flood risk is also key for surrounding population because a strategic road to access the activity area of Sophia Antipolis, where many people work, is located in the Brague flood zone. People not living in the floodplain are thus nonetheless passing by the high flood risk area twice a day during the working days. We estimated the population in the Brague based on that of the eleven included municipalities (Annex 12). Table 15 summarizes the socio-demographic characteristics of the population in the Brague. The size of the sample represents 0.66% of the estimated population. We select three representative criteria of the sample. The first is the geographic localization of the respondent in the catchment that is divided into tree geographic strata including upstream, central and downstream areas. The second and the third represent the sex and the age criteria.

Criteria	Statistical modality	Municipalities in the Brague	Sample characteristics
Population	Estimated	60,500	405
Household	Number of people per	2.3	2.61
Sex	Men	49%	48%
	Women	51%	52%
Localisation in the catchment	Upstream area	27%	27%
	central-stream	28%	18%
	Downstream area	55%	55%
Professional categories	Workers	66%	17%
	Job seekers	9%	6%
	Training	11%	47%
	Retirees	6%	29%
	Other	8%	1%
Socio-professional categories	Farmers	0.3%	1%
	Artisans/Businesses	11%	15%
	Executives	28%	22%
	Liberal professions	26%	19%
	Employees	23%	35%
	Workers	11%	5%
Age structure	15-24 years	14%	14%
	25-34 years	12%	12%
	35-44 years	16%	15%
	45-54 years	18%	18%
	55-54 years	16%	16%
	65 years and more	25%	26%

Table 29: General socio-demographic characteristics of the population in the Brague

4.2.2.5 Outputs

The results of the WTP survey are available in full detail in the report by Gnolonfin & Douai (2019). The two main features of NBS according to (Eggermont & co-authors, 2015) are the biodiversity and stakeholders' involvement. Here we tried to include the population that represents a principal stakeholder because the population is the first impacted by the benefits of NBS. Moreover, we observed that their support is essential for decision making in the context of the Brague. The objective of the survey was then to analyse the population preferences for NBS measures and for their impacts while accessing the public contribution to the provision for additional flood risk mitigation measures in the Brague. In addition, the survey provided an evaluation of (i) environmental values in the context of the Brague (ii) the population's perception of the flood risk, (iii) the population's perception of other environmental, economic and social challenges and (iv) the tangible and intangible damages of passed flood risk. Collected data permitted to estimate Total Economic Value to the cost-benefit analysis. In complement it was possible to analysis how environmental values and experiences of flood risk influence the preferences for NBS measures.

4.3 Results

4.3.1 Relevance of co-benefits in the Brague DEMO context

Stakeholders identified the important benefits to consider when valuing the impact of risk mitigation strategies. In addition to the impact on flood risk, stakeholders also highligthed four domains including (i) biodiversity and natural habitats quality, (ii) economic development, (iii) quality of life and (iv) social cohesion and territorial coherence. In the perspective of stakeholders, it is important to enchance the quality of biodiversity and natural environment. They acknowledged the negative impacts on the Brague ecosystem of urbanization and limitations of former strategies for flood risk protection. They expessed their desire to protect and improve biodiversity, water resource availability and hydro-morthological equilibrium. Hence, it is important that future strategies to flood risk mitigation do not have (at least) negative impacts on the Brague ecosystem. As well, stakeholders stressed the importance of economic impact for tourism sector. They valued strategies integrating the development of ecotourism based on the development of soft mobility and natural amenities. Impact on the quality of life is also important in order to reconnect residents to the Brague. In particular, stakeholders valued impact on recreational activities, air quality, hot temperature mitigation and soft mobility. Lastly, it is important that strategies support the transition to the resilience of the Brague catchment via impact on social cohesion and territorial coherence.

4.3.2 Value transfer of co-benefits

The transfer value function proposed by Arfaoui and Gnonlonfin (2019) was apllied considering the characteristics of NBS measures and the co-benefits that stakeholders consider relevant in the context of the Brague; since the authors demonstrate that this leads to lowest transfer error.

Table 30 presents the estimated mean values for the two NBS strategies in the Brague. The estimates include the annual WTP of residents and the annual economic activities generated by ecotourism[25]. The latter represents about 4% of economic values of NBS strategies. The former is computed at the scale of the catchment. Results show that the mean total economic value for NBS strategies varies according to the level of ambition in restoring nature. Individuals gain more well-being from the strategy that gives more room to the nature. In order to represent the uncertainty associated with these estimated values, we compute the lower and upper 95% prediction interval values following the method proposed by Osborne (2000).

STRATEGIES	ESTIMATED VALUES (M€, 2017/YEAR)
NBS HIGH AMBITION	4.3 [0.7;47.3]
NBS VERY HIGH AMBITION	7.3 [1.0;84.2]

Table 30: NBS measures and co-benefits in the Brague: mean values [5% quantile; 95% quantile]

Theses co-benefits are subsequently considered in the Cost Benefit analysis for the 50 years time window using a similar discount rate than for the costs.

4.3.3 Contingent analysis of Total Economic Value of strategies

The contingent analysis main results are (Gnolonfin & Douai, 2019):

- People prefers hybrid strategies mixing grey and NBS measures rather than purely NBS or purely grey measures.
- Two estimates of the willingness to pay were asked to interviewees:
  - A lower bound below which they are certain to contribute,
  - An upper bound above which they are certain not to contribute.

[25] We have used unit transfer method for ecotourism on the basis of the length of pedestrian and bicycle pathway to be created.

On average the willingness to pay lower bound is close from 30 €/household/year and the upper bound is close from 91 €/household/year.

We computed an acceptable estimate by a linear interpolation between lower bound and upper bound to 60 €/household/year.

RESULT	VALUE
POPULATION [NUMBER OF INHABITANTS]	226 523
NUMBER OF HOUSEHOLDS	98 488
YEARLY TOTAL ECONOMIC VALUE	
LOWER BOUND	0.788 M€
ACCEPTABLE ESTIMATE	1.58 M€
UPPER BOUND	2.39 M€
50 YEARS TOTAL ECONOMIC VALUE	
LOWER BOUND	21.5 M€
ACCEPTABLE ESTIMATE	**43.1 M€**
UPPER BOUND	65.3 M€

Table 31: Willingness to pay estimatitons according to the suervey

Source : authors calculations

For more details, the reader is invited to read the report by Gnolonfin & Douai (2019).

4.4 Discussion

In less than a decade, NBS have become a part of policy agenda stressing on the need to demonstrate their economic values to inform decision-making. Here, we access the monetary values that individuals attach to NBS restoration measures to flood risk mitigation in the context of the Brague Demo. We resort to the transfer methods and find the impact NBS strategies on the well-being amount several million a year, 4.3 M€ on average with a large range of uncertainaties of 0.7 M€ to 47 M€. The contingent analysis also demonstrated a the total economic value of 0.8-2.4 M€ yearly of protection against flood and co-benefit of hybrid strategies made of well balanced civil engineering measures and NBS.

Results also show that the ambitious strategy giving more room to the nature results in more economic impact. However, the prediction intervals of the estimates are large and emphasise the need to treat transferred values with caution, particularly the high values. Overall, the contingent valuation method provide an independent validation of the transfer value in their lower range of estimates.

Chapter 5. Integration of the economic assessment

5.1 Cost-Benefit analysis

The avoided damage are not available so far for the Grey and NBS very ambitious strategies. Hereafter we only analyse one strategy: the NBS ambitious strategy.

5.1.1 Main results

It is worth reminding that the cost of the natural water retention measures to implement in the upper basin is not considered and that indirect damages are not considered either.

Table 32 compares costs to benefits. The benefits, namely the avoided damage (**Table 26**) and the co-benefits (**Table 30**), have been computed by multiplying the mean annual damage or co-benefits by 28.4 to account for the discount on a 50 years time window as yet present in Chapter 2.

Strategy	Total cost (M€)	Main benefit (avoided damage) (M€)	Co-benefits by transfer method (M€)	Main benefit/ total cost (-)	All benefit/ total cost (-)	Contingent analysis of total economic value (M€)	Total economic value / total costs (-)
GREY	**170**	**13**	**0**	**0.1**	**0.1**	**?**	**?**
	[88; 271]	[5; 19]	[0; 0]	[0.1; 0.1]	[0.1; 0.1]		
NBS AMBITIOUS	**80**	**14**	**122**	**0.2**	**1.7**	**43.1**	**0.5**
	[59; 132]	[6; 21]	[20; 1343]	[0.1; 0.2]	[0.3; 11.3]	[21.5; 65.3]	[0.3; 0.8]
NBS VERY AMBITIOUS	**122**	**?**	**207**	**?**	**>0.5**	**?**	**?**
	[93; 211]		[28; 2391]		[>0.3; 0.8]		

Table 32: Cost benefit analysis on a 50 years time window: mean estimate [min; max]

As can be seen, the main benefit of the strategy on a 50 years time windows is only about 0.2 times the costs of the measures of for the NBS high ambition strategy. However, when considering the co-benefit, even though the uncertainty range is very high, the ratio benefit over cost became very likely more than one, i.e., there is an overall gain to invest in such solution.

The contingent analysis of the willingness-to-pay-survey provides a complementary estimation of the value local people assign to the cumulated benefit of lower flood damages and improved quality of the environment. The strategy that was best described by the choices of people is considered to be close to the NBS ambitious strategy. When comparing its total economic value with its total over a 50 years' time windows, the ratio is below one, i.e., one cannot expect to finance all the strategy with only the people contribution, except if the lower range of costs and the upper range of contribution are finally reach. In such a case the financial equilibrium can be reached.

The estimation of the co-benefit is clearly more critical in the economic assessment of NBS solutions: while the co-benefit are negligible in grey solution, they can be significantly higher than the main benefit of flood protection in NBS solutions. The survey performed with the questionnaire described in Chapter 4 will enable to refine the estimate of the co-benefit through a willingness to pay approach but it should be also acknowledges that numerous benefit or damages of strategies are intangible and that multicriteria analysis are required.

5.1.2 Sensitivity analysis

Costs and benefits were all estimated using averaged but also max and min estimates. Costs and damages both vary in a range of roughly [/2; *2] depending on the method or reference used. Conversely de co-benefits, estimated by transfer of values from other catchments, varies in a range of roughly [/10; *10].

Ratio main benefit / cost and all / benefit / cost provided in **Table 32** were computed using averaged values of costs and benefits and the values given between square brackets were computed using all minimum estimates (first number) or all maximum estimates (second number). An extremely wide range of variability would be obtained if mixing min, averaged and maximum values of all parameters.

5.2 Toward multicriteria analysis

5.2.1 Moving from economic assessment to co-benefits analysis

The analysis and choice of the best solution for flood protection are key issues for national and local authorities. Many different strategies may exist with different relative advantages.

The French standard guideline described in (CGDD, 2018) has been designed in order to choose the most effective flood protection project considering mostly economic issues. It is essentially based on a cost-benefit analysis. It therefore provides guidance regarding cost and damage estimation but also lists additional indicators that aim at completing the estimation of damages that is only dedicated to easily assess tangible damages (**Table 33**). In a second step, several aggregated indicators are computed as the mean annual damage, mean annual number of people flooded, the ratio benefit over cost, etc.

No aggregation, weighting or ranking of these indicators are however proposed or performed according to the national guidelines (CGDD, 2018). These long lists of indicators merely seek to capture a more complete image of the flood protection performance. Some challenges were identified to implement those methods especially when dealing with environmental issues even if additional criteria have been added to extend the initial economic-based analysis, e.g., indicators P8, P9, P10 and M8 in **Table 33**.

A recent law called GEMAPI (French acronym for flood protection and aquatic environment preservation) now requires demonstrating that measures are compliant with both objectives of better flood protection and improved environmental quality. Two kinds of problems are currently to address in order to comply with the new paradigm introduced by this law: first describing the new administrative process linked to management responsibilities assignment and secondly proposing a framework to handle in an integrated way both flood protection efficacy and environmental restoration ambition (Tacnet et al. 2018).

<table>
<tr><th>Objective</th><th>Topic</th><th>N°</th><th>Indicator</th></tr>
<tr><td rowspan="5">Safety for people</td><td rowspan="5">Health</td><td>P1</td><td>Number of inhabitant in the flood zone</td></tr>
<tr><td>P2</td><td>Ratio of people living in apartments and houses at terrain level in the flood zone</td></tr>
<tr><td>P3</td><td>Number of people potential present in offices and shops in flood zone</td></tr>
<tr><td>P4</td><td>Ratio of building in charge of flood crisis management in flood zone</td></tr>
<tr><td colspan="2">Other side indicators : S1, S2</td></tr>
<tr><td rowspan="5">Reducing damage to asset and business</td><td rowspan="8">Economy</td><td>M1</td><td>Damages to residences</td></tr>
<tr><td>M2</td><td>Damages to companies</td></tr>
<tr><td>M3</td><td>Damages to agriculture</td></tr>
<tr><td>M4</td><td>Damages to public offices</td></tr>
<tr><td colspan="2">Other side indicators : indirect damages to networks M5*</td></tr>
<tr><td rowspan="3">Improving resilience</td><td>P5</td><td>Daily traffic on transportation network in flood zone</td></tr>
<tr><td>P6</td><td>Ratio of companies involved in recovery in the area</td></tr>
<tr><td>P7</td><td>Number of jobs in flood zone</td></tr>
</table>

		Other side indicator : S3	
		P8	Average daily load in wastewater treatment plant located in the flood zone
		P9	Treatment and storage capacity of garbages in the flood zone
		P10	Number of dangerous sites (chemical, energy production) in the flood zone
		Other side indicator S4	
Protecting culture	Patrimonial	P11	Number of cultural buildings in the flood zone
		Other side indicator : S5	
Reducing costs	Finance	M6	Investment costs
		M7	Maintenance costs
		M8	Environnemental costs

Table 33: List of indicators to assess damages and risks according to the French standard guideline

5.2.2 Identifying decision needs and contexts

Dealing with Nature-Based solutions requires to consider a multifactorial context mixing both technical, physical, economic, environmental, human and social points of views. A global framework was proposed to both take benefits from physical assessment[26] but also new multicriteria decision-making frameworks able to handle the different qualitative and quantitative criteria linked to Nature-Based solutions. The main result was that, when dealing with risk management issues and NBS dedicated to first reduce their adverse consequences, physical assessment of NBS is the first necessary aspect to check before addressing the others co-benefits (**Figure *35***).

[26] see above in this report and also in NAIAD Deliverable 5.4 (Tacnet et al., 2019)

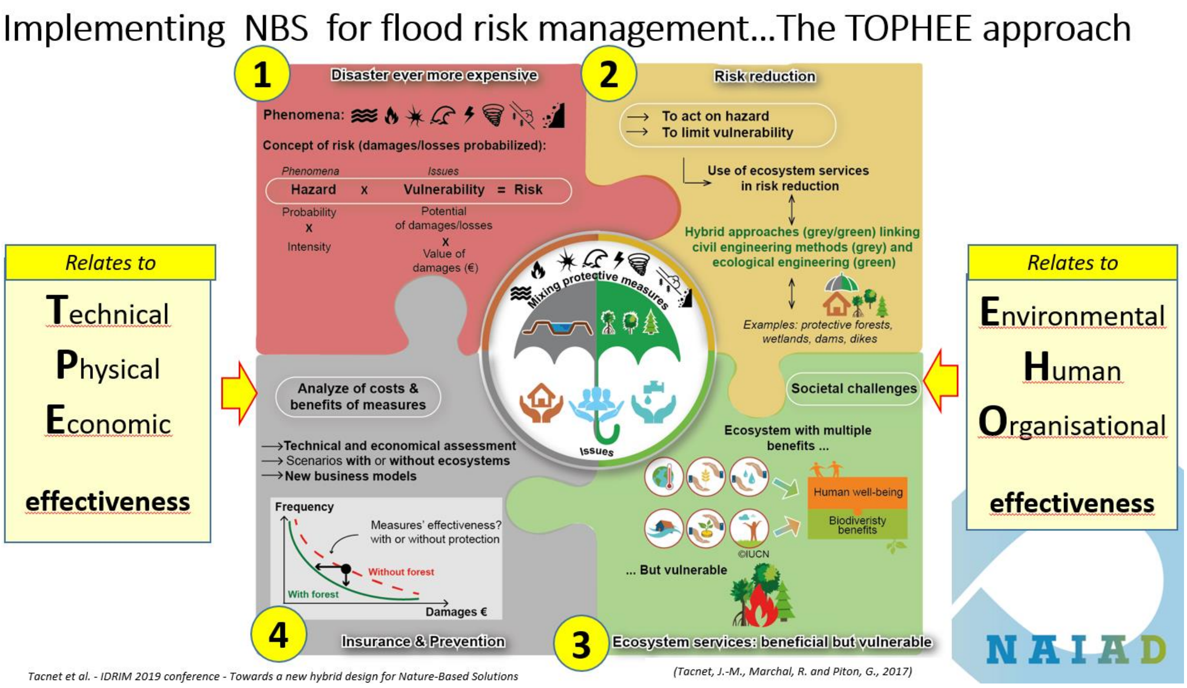

Figure 35: Assessing and implementing NBS for flood risk management is a multifactorial process (source Tacnet et al., 2019 , IDRIM conference, Nice, France, 16-18/10/2019)

If peculiarities in the catchment would eventually justify to integrate other indicators and to remove some from the typical list as provided by **Table 33**, there is no clear framework or guidance to do so as was for instance done by Tacnet et al. (2018) to help decision making with a tailored criteria, hierarchical ranking and weighting of them for flood protection strategies involving also environmental restoration on the Büech alpine River (French Alps). This topic is extensively addressed in NAIAD Deliverable 5.4 (Tacnet et al., 2019).

On The Brague catchment basin, the decision contexts and the management process involve, as usual, several actors belonging to different institutions. Focus group workshops and stakeholder workshops were organized in the Brague DEMO to start identifying an equivalent work which is the basis to build proper decision-aiding (see results in Annex 13). A first structured analysis is proposed according to some main topics dealing with flood protection (Annex 13 - **Figure 41**), economic re-development (Annex 13 - **Figure 42**), some social objectives related to quality of life (Annex 13 - **Figure 43**), some social objectives linked to increase of social cohesion (Annex 13 - **Figure 44**) and, finally, some environmental issues (Annex 13 - **Figure 45**).

Finally, those elements have to be organized in order to help decision-making regarding the question “*which NBS solutions would be the best given stakeholders requirements?*” As an example, five main points have been identified (in grey on **Figure *36***): The proposed structure for a global multicriteria decision-making framework is described on the right hand side with for main criteria: flood protection, environmental impacts, economy and social/cultural impacts.

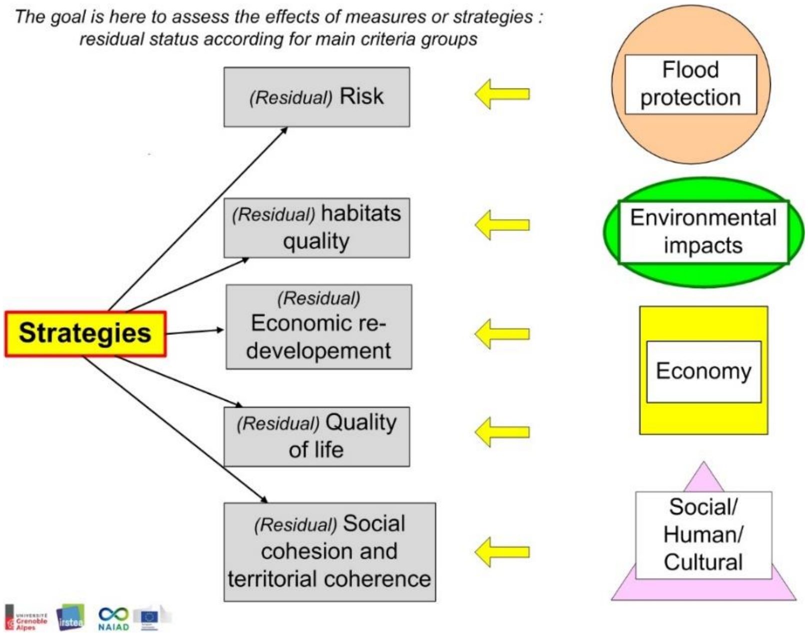

Figure 36: Different topics for decision-making addressed during workshop

This structure can then be used in a multi-criteria decision-aiding model which links physical-based, deterministic and others co-benefits' assessments (**Figure *37***).

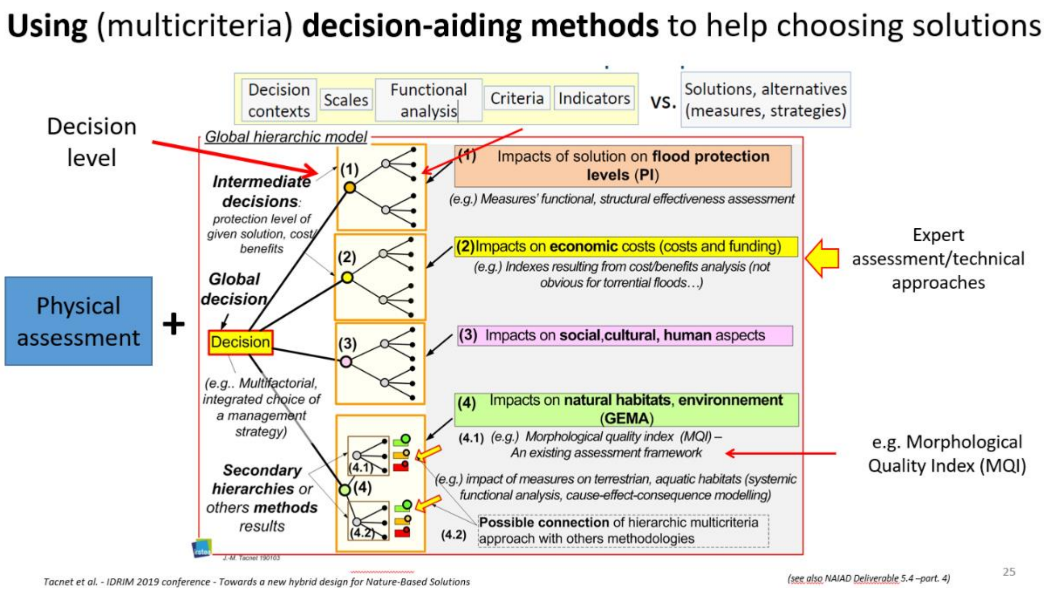

Figure 37: The main identified criteria are used (e.g.) in a hierarchic multicriteria model

A framework was developed to propose assessment of NBS solutions but the real implementation with stakeholders and their involvement for instance to determine their preferences on given criteria would still have to be done. However, the proposed framework (supported by tools described in NAIAD Deliverable 5.4) constitutes a full generic and versatile environment to assess multifactorial roles of NBS and to help choosing the most adequate strategy for NBS implementation.

The strong advantage of such a method compared to the simple cost-benefit analysis is that it enables to account for the intangible criteria: the great improvement of the morphological quality highlighted by the MQI analysis (see §1.2.3.2) or the expectation related to pedestrian and cycle paths in the currently fragmented valley are high. We have not been able to evaluate with monetary methods the co-benefits related to these aspects of our strategies but it is possible to account for these qualitative or quantitative but not economic criteria and indicators using the multicriteria decision aid framework presented above.

To the experience of the authors, implementing such a multicriteria decision aid is useful and appreciated by the decision makers but it requires their full commitment. The commitment of their technical staff is also required. Several workshop and training sessions are required to assimilate the rational of the framework. Setting the decision context and organizing a decision in a hierarchical tree to finally weigh each stem with preferences also impose an extremely high degree of transparency that sometime disturbs people and that can be rejected.

Chapter 6. Conclusion

Within the present report we demonstrated that:

- The Brague catchment has a river network partially altered by human impact, though natural reaches located in the mid part of the catchment are still in good state.
- The runoff and flood hazards and risks are high on assets located in the catchment and specifically high in the lowlands close to the sea.
- The flood- and runoff-related risks are likely to increase in the future mostly because of increase in vulnerability and also marginally because of climate change, land use change and wildfire hazard increase.
- Three flood protections scenarios were studied within NAIAD:
    - A grey strategy based on two huge retention dams, 30-m high and capable of storing a cumulated volume of 1.4 Mm^3. This solution is however very expensive, does not provide co-benefit, has finally a disappointing protection efficacy since it reduce the mean annual damage only by about 30% and would be complicated to implement because relevant building sites are located in natural parks.
    - A NBS ambitious strategy based on the implementation of numerous small natural water retention measures in the catchment complemented by huge works to widen and give room to the river in the lowlands. Multiple expropriations and demolition of houses would be required but co-benefits are numerous and the costs are half of the grey strategy for a similar protection efficacy.
    - A NBS very ambitious strategy where the bottleneck section of the highway crossing the Brague in the lowlands would be removed thank to a new bridge and a road located along the river would be moved to get a more continuous river and riparian corridor. The cost are likely lower and at most similar to the grey strategy, the protection efficacy is still under study. It can only be better than the other NBS strategy thus better than the grey strategy but would probably suffer from another bottleneck section related to other transportation networks and bridges near the sea mouth.
- The estimation of the co-benefit is complicated. An estimation by transfer of co-benefit evaluations coming from other sites was performed and provide an uncertain but still useful estimation of co-benefits worth several millions of euros per years.
- For the NBS high ambition strategy, the cost-benefit balance is not sufficient to justify the project if only avoided damages are accounted as benefits. Including the co-benefit can on the contrary result in a positive balance of total benefits higher than total costs of such strategies. This stress the key importance of including co-benefit with a (as rigorous as possible) assessment protocol. Although it is worth stressing that the cost of natural water retention measures were not considered but are expected to be rather

small compared to the measures involving inhabited land acquisitions and that indirect damages are not considered either which would increase the avoided damages.

- A contingent valuation of total benefits was performed through a willingness to pay survey. This demonstrated that people were willing to contribute by on average 60€/household/years to strategies seeking to mitigate flood hazards and to improve environmental and life quality in the river basin. This contribution is significant but remains too low to finance totally the NBS ambitious strategy.
- Physical assessment of any measure's (including NBS) effectiveness is a key and essential factor to check when dealing with flood protection objectives. However, multicriteria analysis should complement pure economic analysis, several effects of the river management are intangible but weight in the perception and quality of Nature and life in the catchment.

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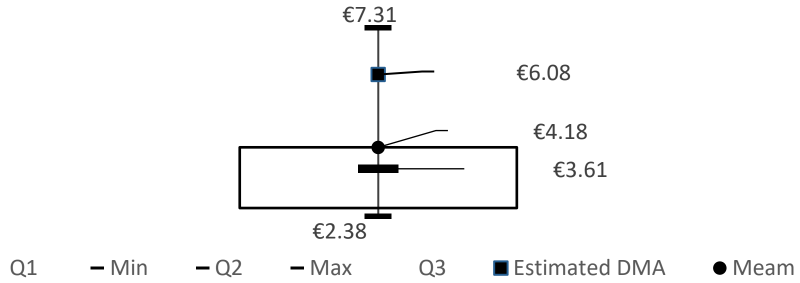
Annexes

Annex 1. Land uses and runoff coefficient

LAND USES	UNIT RUNOFF COEFFICIENT
FORESTS	0.08 – 0.12
BEACHES. SAND DUNE	0.15
AGRICULTURAL LANDS (INCLUDING GREENHOUSES AND RICE FIELDS)	0.18
LAWN AND NATURAL GAZING LANDS	0.20
SCRUBLANDS	0.25
URBAN GREEN SPACES/ URBAN FORESTS	0.28
DISCONTINUOUS BUILT-UP LANDS	0.40
DISCONTINUOUS URBAN FABRIC	0.50
BARE ROCKS	0.50
HIGH DENSITY AREAS OF GREENHOUSES	0.75
INDUSTRIAL AND COMMERCIAL AREAS	0.75
CONTINUOUS URBAN FABRIC	0.75
PORT AREAS	0.80

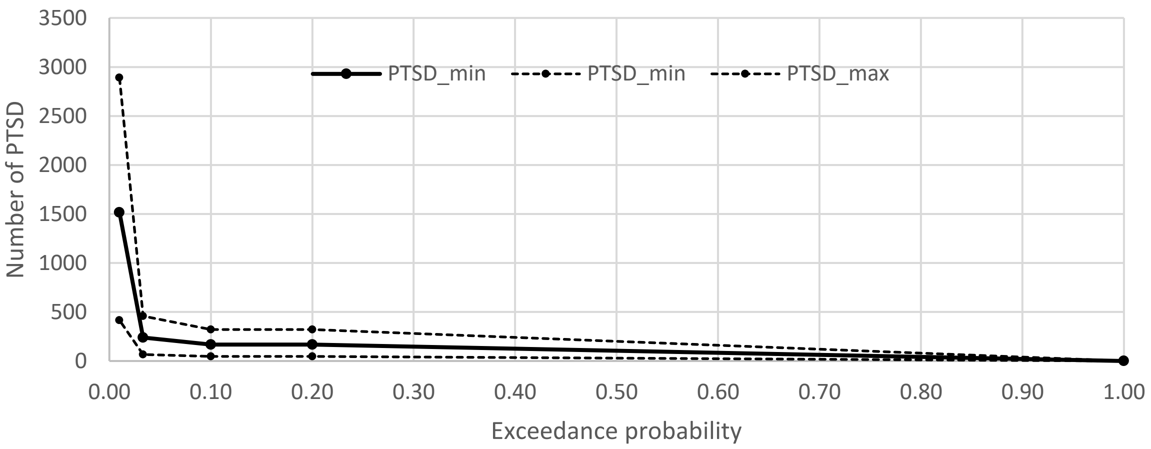
Source: DDTM, 2017

Annex 2. Sensitive analysis of the DMA for tangible damages in relation to compensation rates (20-100%)



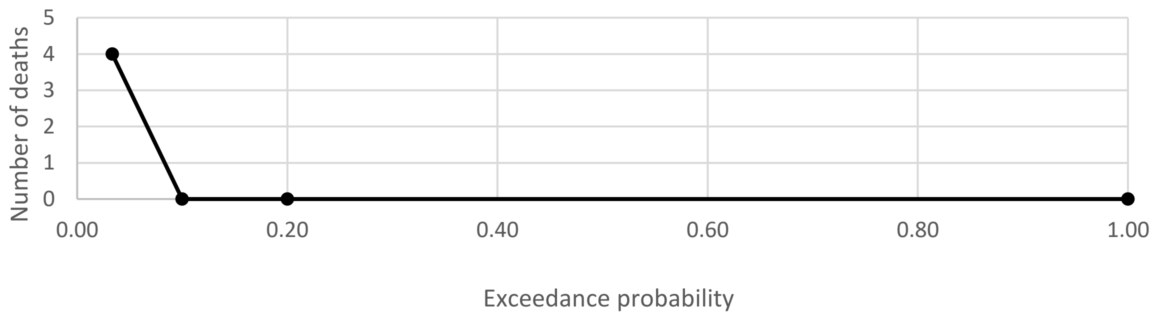
Source: Authors' calculations

Annex 3. Loss frequency curve of intangible and indirect damages in the Brague catchment over the period 1970-2015



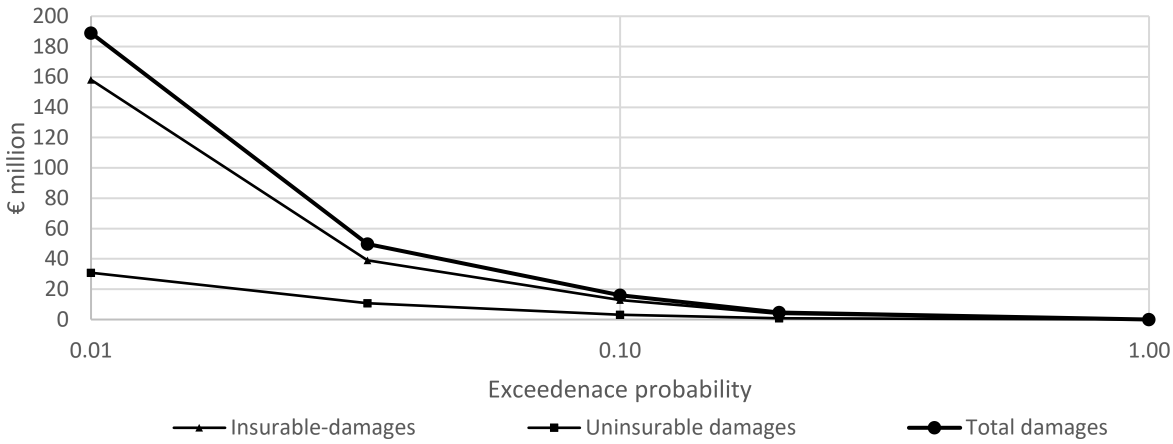
Source: Authors' calculations

Annex 4. Loss frequency curve of intangible and direct damages in the Brague catchment over the period 1970-2015



Source: Authors' calculations

Annex 5. Loss frequency curve of tangible damages in the Brague catchment over the period 1970-2015



Source: Authors' calculations

Annex 6. Hydrological analysis of land use change in French Mediterranean catchements

A. Methodologic uncertainties in the search for step change approach: application to forest fire

Preliminary works on the search for modification of the hydrological behavior of a sample of French Mediterranean burned catchment at the daily time scale yielded variable results which did not support any systematic conclusions regarding the existence of changes in flow regimes.

As results seemed to be sensitive to modelling uncertainties and methodological choices, a framework was built to assess the extent to which our conclusions could be considered significant. The framework was implemented on a set of 31 fire events which occurred on 27 catchments with areas ranging from 5 to 590 km² and burned surface ratio from 5 to 60 %.

For each watershed, 30 simulated discharge series yielding equivalent performance were used for further analysis. These series were obtained through a Bayesian calibration approach on the pre-fire period. Modelling uncertainties were assessed by retrieving the number of cases for which tests results varied across the 30 series. Depending on the threshold used, 5 to 10 % of the total number of tests was deemed dubious.

Studies were conducted with three monthly hydrological descriptors representative of low, central and high flows analyzed on four seasons. Investigations of methodologic uncertainties focused on three main items usually found in the search for step change approach, namely statistical test, modality of hydrological descriptor and type of control series. The uncertainty related to each item was assessed in terms of number of dubious results using user-defined aggregation rules. We found out that uncertainties attributed to statistical test and hydrological descriptor choice each causes a mean 10% increase of the number of dubious tests, while the type of control series is responsible for a mean 30% increase. In the end, following our aggregation rules, **there are reliable evidence of a change for 7 out of 372 combination of [fire event x flow regime part x season] and evidence of no change for 144** (Figure 38).

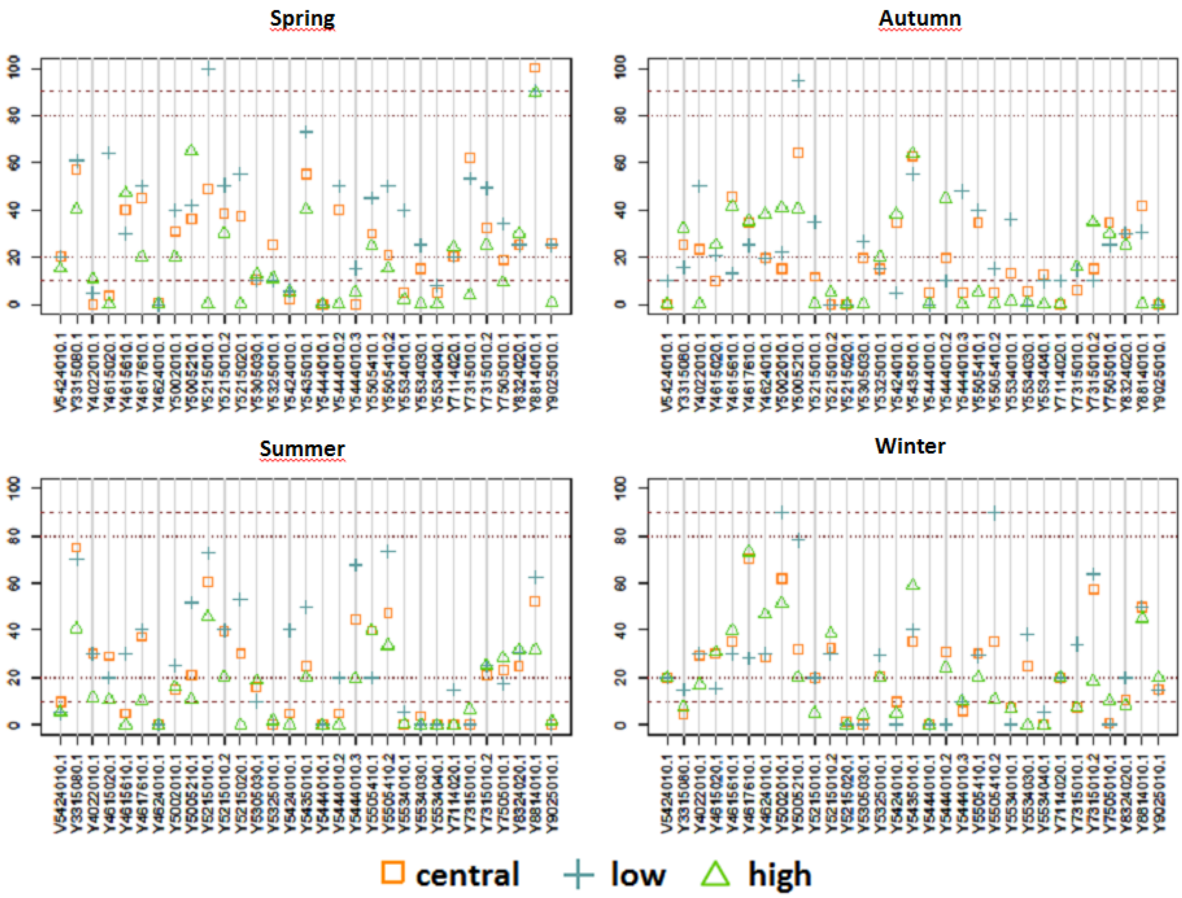


***Figure 38**: results of the uncertainties study following one of the aggregation approaches. Vertical axis represents the number of significant tests as a percentage of the total number of tests. Markers below the lower dashed lines are considered unsignificant of a change, and markers above the upper dashed line are significant of a change. Markers in between are dubious.*

These results will be refined by working on the aggregation scheme and investigating correlations effects between uncertainties sources. However, it is already a reliable basis to point out the extent to which such studies might be affected by modeling uncertainties as well as methodological choices.

B – Use of finer time scale to tackle peculiar hydrological concerns

a) Forest fire

Hourly data and models can be used to have an in depth look at flood events. Due to the scarcity of reliable hydrometeorological data, the initial study sample for burned catchments was reduced to 9 fire events. For each event, an hourly hydrological model was calibrated on the pre-fire period and adjusted parameters were used to simulate theoretical discharge on the post-fire period. The comparison of modeling errors of several flood indicators between pre and post fire period did not exhibit systematic patterns, but behavior changes were observed on some catchments. There is more or less solid evidence of (**Figure 39**):

- an increase in observed peak flow for catchments Y5424010 and Y5444010
- earlier flood peak on catchments Y4115020, Y4225610 and Y5444010

However, these changes appear to last longer than those expected from forest fire impact, which may indicate the presence of another, more perennial disturbance. In addition, calibration performances are quite limited on several catchments thus questioning the ability of the model to provide reliable simulations on the post fire period.

This initial study provided the opportunity to establish and validate a methodological framework on a small number of events. Efforts will be made toward the improvement of our approach (through testing of different calibration procedure and analysis of additional hydrologic descriptors) and the collection of new data to enrich our study sample.

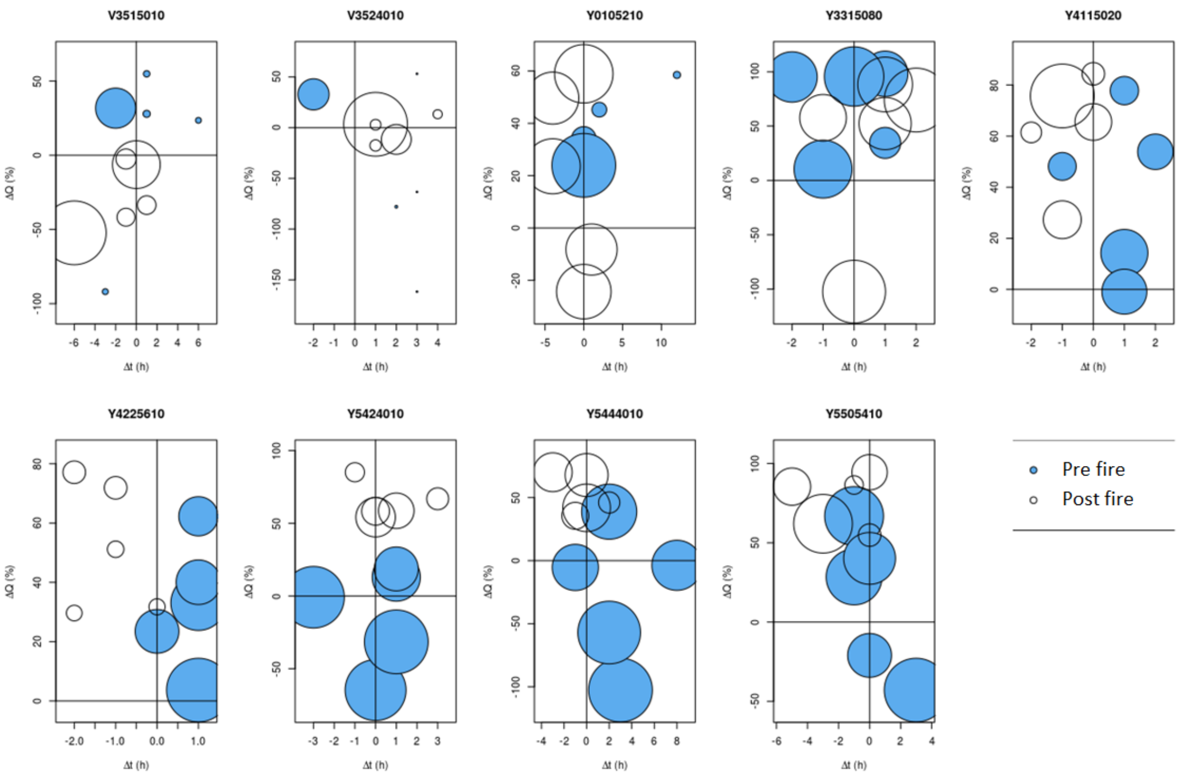


***Figure 39**: modeling errors on peak flow magnitude and timing for the five biggest flood events on each period. Circles radius are proportional to observed flow.*

b) Urbanization

The impact of urbanized area increase on flood regimes has been studied on 15 French watersheds whose main characteristics are presented in **Table 34**. Catchments have been selected based on an analysis of their increase in urbanized area between 2000 and 2018. Increase above 5% of total watershed area was considered significant and only catchments meeting this requirement were considered for analysis.

As urbanization is a progressive phenomenon, it is possible to calibrate the hydrological model on successive periods properly chosen to represent stable states of the watershed regarding its urbanized extent. In order to limit computation time, we chose to only calibrate the model on two periods representative of pre urbanization and post urbanization state. As reliable hourly hydrometeorological data are available for our catchment sample from 1998 to 2016, calibration was done from 1998 to 2004 for the pre-urbanization period and from 2010 to 2016 for the post-urbanization period. These timeframes have been chosen as a tradeoff between sufficient length for efficient calibration and limited duration to ensure stable urbanization state. Once adjusted parameters set are obtained, they are used to simulate discharge on the whole record period. Flood events simulated with the pre and post urbanization parameters sets are then compared using several metrics. In addition, pre-urbanization simulations are compared to observed floods.

Among the 15 studied catchments, 5 exhibit poor calibration performance on one of the periods thus making any further analysis inadequate. Those five catchments were discarded from the sample. On the remaining catchments, changes in flood regimes between the two periods vary in direction and amplitude. Three catchments exhibit evidence of a change toward higher peak flow, and three catchments exhibit evidence of a change toward lower peak flow. Estimated change in flood peak with respect to pre-urbanization period values were computed with simulations to simulations and simulation to observation comparison. Results are indicated in the summary table.

There does not appear to be any systematic relationship between change in catchment hydrology and catchment characteristics. Affected catchments are of varying size and urban area extent. They are representative of different hydro-region and local climate conditions. Detailed investigations will be conducted to have an in depth look at urban area structure and existence of potential additional disturbance. Efforts will also be made toward improvement of calibration approach and accounting for modeling uncertainties.

Catchment ID	Area [km²]	Urban area increase [%]	Runoff coefficient increase	Estimated change in flood peak	
				Obs/sim	Sim/Sim
N0204210	36,7	5,2	0,49	-51 %	-11 %
Q8345910	17,6	5,3	0,32		
A0220200	15,3	5,4	0,11		
Y4122040	642,4	5,8	0,32		
L0614020	86,6	6	0,22	35 %	31 %
U2356610	43	6,2	0,47	40 %	13 %
Y4225610	71,9	6,2	1,65	-46 %	-17 %
Y3315080	51,8	6,3	0,21		
Y4414030	164,9	6,6	0,35		
O9685310	49,3	8	0,39	-43 %	-66 %
Y4115020	52,5	8,8	0,59		
O2034010	191,2	9	0,43	39 %	50 %
Y5535410	43,8	10	0,34		
Y5605210	41,4	18	0,82		
H5833010	19,9	19	0,76		

Table 34 : Characteristics of the studied catchments and estimation of urbanization impact

These studies of the hydrological effects of forest fires and urban sprawling were granted both the H2020 NAIAD project and by the French Ministry of Environment, in addition to the present results and to the ones present in NAIAD Deliverable 6.2, some more elements can be found in the reports written for the French Ministry by Mas (2018) and Mas & Arnaud (2019).

Annex 7. Prospective MQI assesssement for the protection strategies

Table 35: Prospective indicator marks for the Morphological Quality Index: Scenario #1 Grey

	Reaches	**Brague Gorges #1**	**Brague Biot #2**	**Brague Antibes #6**	**Valmasque Gorges #5**	**Valmasque Biot #4**	**Vallon Combes #3**	**Vallon Horts #7**
Indicator	**Name**	#1	#2	#6	#5	#4	#3	#7
F1	Longitudinal continuity in sediment and wood flux	C+	A	B+	C+	A	B	A
F2	Presence of a modern floodplain	-	A	A	-	A	B1	B1
F3	Hillslope – river corridor connectivity	A	-	-	A	-	-	-
F4	Processes of bank retreat	-	B	C+	-	B	C	C
F5	Presence of a potentially erodible corridor	-	C	A	-	B	C	B
F6	Bed configuration – valley slope	A	-	-	A	-	-	-
F7	Planform pattern	A	A	A	A	A	C	C
F8	Presence of typical fluvial landforms in the floodplain	-	-	-	-	-	-	-
F9	Variability of the cross-section	A	A-	A-	A	A-	C	C
F10	Structure of the channel bed	A	A	A	A	A	C2	C2
F11	Presence of in-channel large wood	C	C	C	C	C	C	C
F12	Width of functional vegetation	A	B-	B	A	C	C	B+
F13	Linear extension of functional vegetation	A	C	B-	A	C	C	C
	GEOMORPHOLOGICAL FUNCTIONALITY	0.81	0.65	0.67	0.81	0.65	0.12	0.23
A1	Upstream alteration of flows	A	B	B	A	B	B	A
A2	Upstream alteration of sediment discharges	A	B1	B1	A	B1	C2	A
A3	Alteration of flows in the reach	B	A	A	B	A	A	A
A4	Alteration of sediment discharge in the reach	B	A	A	B	A	A	A
A5	Crossing structures	A	C	C	A	C	C	C
A6	Bank protections	A	B	A	A	A	D	C
A7	Artificial levees	A	A	B	A	A	C	B
A8	Artificial changes of river course	-	A	B	-	A	C	C
A9	Other bed stabilization structures	A	A	A	A	A	A	A
A10	Sediment removal	A	B1	B1	A	A	A	A
A11	Wood removal	C	C	C	C	C	C	C
A12	Vegetation management	B	C	C	B	C	C	C
	ARTIFICIALITY	0.88	0.79	0.78	0.88	0.84	0.64	0.65
CA1	Adjustments in channel pattern	A	A	A	A	A	A	A
CA2	Adjustments in channel width	A	A	B	A	A	C+	A
CA3	Bed-level adjustments	A	A	A	A	A	A	A
	CHANNEL ADJUSTMENTS	1.00	1.00	0.88	1.00	1.00	0.75	1.00
	Morphological Quality Index MQI	0.87	0.79	0.76	0.87	0.82	0.52	0.58
	MQImin	0.87	0.76	0.74	0.87	0.8	0.52	0.58
	MQImax	0.88	0.79	0.79	0.88	0.82	0.54	0.6

Table 36: Prospective indicator marks for the Morphological Quality Index: Scenario #2 High ambition

	Reaches	Brague Gorges #1	Brague Biot #2	Brague Antibes #6	Valmasque Gorges #5	Valmasque Biot #4	Vallon Combes #3	Vallon Horts #7
Indicator	**Name**	#1	#2	#6	#5	#4	#3	#7
	GEOMORPHOLOGICAL FUNCTIONALITY	A	A	B+	A	A	B	A
F1	Longitudinal continuity in sediment and wood flux	-	A	A	-	A	B1	B1
F2	Presence of a modern floodplain	A	-	-	A	-	-	-
F3	Hillslope – river corridor connectivity	-	B+	B	-	B+	C	C
F4	Processes of bank retreat	-	C	A	-	B+	C	B+
F5	Presence of a potentially erodible corridor	A	-	-	A	-	-	-
F6	Bed configuration – valley slope	A	A	A	A	A	C	C
F7	Planform pattern	-	-	-	-	-	-	-
F8	Presence of typical fluvial landforms in the floodplain	A	A	A	A	A	C	C
F9	Variability of the cross-section	A	A	A	A	A	C2	C2
F10	Structure of the channel bed	C	A-	A-	C	B-	C	C
F11	Presence of in-channel large wood	A	B	A	A	B-	C	B+
F12	Width of functional vegetation	A	C	A-	A	B-	C	C
F13	Linear extension of functional vegetation	0.93	0.72	0.88	0.93	0.74	0.12	0.23
	ARTIFICIALITY	A	A	A	A	A	B	A
A1	Upstream alteration of flows	A	A	A	A	A	C2	A
A2	Upstream alteration of sediment discharges	A	A	A	A	A	A	A
A3	Alteration of flows in the reach	A	A	A	A	A	A	A
A4	Alteration of sediment discharge in the reach	A	C	C	A	C	C	C
A5	Crossing structures	A	C	C	A	C+	D	C
A6	Bank protections	A	A	A	A	A	C	B
A7	Artificial levees	-	A	A	-	A	C	C
A8	Artificial changes of river course	A	A	A	A	A	A	A
A9	Other bed stabilization structures	A	B1	B1	A	A	A	A
A10	Sediment removal	B	B	B	B	B	C	C

A11	Wood removal	A	A	A	A	A	C	C
A12	Vegetation management							
	CHANNEL ADJUSTMENTS	A	A	A	A	A	A	A
CA1	Adjustments in channel pattern	A-	A-	A-	A-	A-	C+	A-
CA2	Adjustments in channel width	A	A	A	A	A	A	A
CA3	Bed-level adjustments							
	Morphological Quality Index MQI	0.97	0.86	0.90	0.97	0.88	0.52	0.58
	[MQImin; MQImax]	[0.96; 0.97]	[0.83; 0.87]	[0.86; 0.91]	[0.96; 0.97]	[0.84; 0.92]	[0.52; 0.54]	[0.56; 0.61]

Table 37: Prospective indicator marks for the MQI Index: Scenario #3 Very high ambition

	Reaches	**Brague Gorges #1**	**Brague Biot #2**	**Brague Antibes #6**	**Valmasque Gorges #5**	**Valmasque Biot #4**	**Vallon Combes #3**	**Vallon Horts #7**
Indicator	**Name**	#1	#2	#6	#5	#4	#3	#7
	GEOMORPHOLOGICAL FUNCTIONALITY	A	A	A	A	A	B	A
F1	Longitudinal continuity in sediment and wood flux	-	A	A	-	A	B1	B1
F2	Presence of a modern floodplain	A	-	-	A	-	-	-
F3	Hillslope – river corridor connectivity	-	A-	A-	-	B+	C	C
F4	Processes of bank retreat	-	C	A	-	B+	C	B+
F5	Presence of a potentially erodible corridor	A	-	-	A	-	-	-
F6	Bed configuration – valley slope	A	A	A	A	A	C	C
F7	Planform pattern	-	-	-	-	-	-	-
F8	Presence of typical fluvial landforms in the floodplain	A	A	A	A	A	C	C
F9	Variability of the cross-section	A	A	A	A	A	C2	C2
F10	Structure of the channel bed	C	A-	A-	C	B-	C	C+
F11	Presence of in-channel large wood	A	B	A-	A	B-	C	B+
F12	Width of functional vegetation	A	C+	A-	A	B-	C	C
F13	Linear extension of functional vegetation	0.93	0.77	1.00	0.93	0.74	0.12	0.23
	ARTIFICIALITY	A	A	A	A	A	B	A
A1	Upstream alteration of flows	A	A	A	A	A	C2	A

A2	Upstream alteration of sediment discharges	A	A	A	A	A	A	A
A3	Alteration of flows in the reach	A	A	A	A	A	A	A
A4	Alteration of sediment discharge in the reach	A	C	C	A	C	C	C
A5	Crossing structures	A	C	B	A	C+	D	C
A6	Bank protections	A	A	A	A	A	C+	B
A7	Artificial levees	-	A	A	-	A	C	C
A8	Artificial changes of river course	A	A	A	A	A	A	A
A9	Other bed stabilization structures	A	B1	B1	A	A	A	A
A10	Sediment removal	B	B	A	B	B	C	C
A11	Wood removal	A	A	A	A	A	C	C
A12	Vegetation management							
	CHANNEL ADJUSTMENTS	A	A	A	A	A	A	A
CA1	Adjustments in channel pattern	A-	A-	A-	A-	A-	C+	A-
CA2	Adjustments in channel width	A	A	A	A	A	A	A
CA3	Bed-level adjustments							
	Morphological Quality Index MQI	0.97	0.87	0.95	0.97	0.88	0.52	0.58
	[MQImin; MQImax]	[0.96; 0.97]	[0.83; 0.88]	[0.89; 0.95]	[0.96; 0.97]	[0.84; 0.92]	[0.52; 0.56]	[0.56; 0.62]

Annex 8. Report ONf-RTM (2018) 27

[27] ONF-RTM (2018) Inventaire Détaillé Des Zones De Production D’embâcles Sur La Brague Et Estimations Des Coûts De Gestion Du Cours D’eau Des Boisements De Berge Et De Versant - Partie Rtm De L’appel D’offre Irstea 18_gren_35, report prepared for IRSTEA within the H2020 project NAIAD

Rapport

Octobre 2018

IRSTEA

INVENTAIRE DETAILLE DES ZONES DE PRODUCTION D'EMBACLES SUR LA BRAGUE ET ESTIMATIONS DES COUTS DE GESTION DU COURS D'EAU DES BOISEMENTS DE BERGE ET DE VERSANT

PARTIE RTM DE L'APPEL D'OFFRE IRSTEA 18_GREN_35

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Date	
Signature	

Sommaire

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1. REANALYSE DES VOLUMES D'EMBACLE

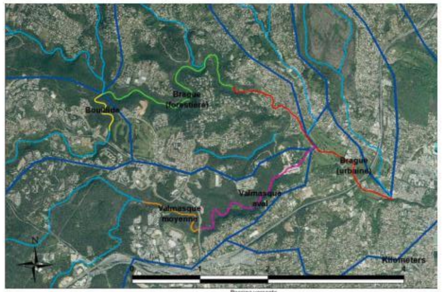
Les embâcles de la crue du 03 octobre 2015 sur la Brague et ses affluents la Valmasque et la Bouillide ont fait l'objet d'une cartographie par le service RTM des Alpes Maritimes dans les semaines qui ont suivis l'événement. Les embâcles ont été localisés pendant les travaux de désembâclement d'urgence et leur volume avait été estimé, parfois par mesure au décamètre lorsque les amoncellements de bois étaient accessibles, parfois par une simple estimation visuelle des 3 dimensions, parfois sur photo pour les embâcles qui étaient déjà démantelés lors de l'inspection. Lors de ces visites, les cours d'eau présentaient une hydrologie encore forte et la dangerosité des amoncellements d'arbre ne permettaient pas toujours de s'approcher des embâcles.

Les résultats de cette cartographie ont été compilés sous SIG et ont permis d'établir des cartes de situation des embâcles. Les limites amont de cette cartographie sont :

- Brague : confluence Bouillide
- Bouillide : viaduc de la RD 98
- Valmasque : Ponceau de la piste DFCI des Croutons
- Vallon des Combes : bassin écrêteur des Combes
- Vallon des Horts : ponceau du chemin des Cabots

Sur la Bouillide et la Valmasque des embâcles se sont créés en amont de cette cartographie et n'ont pas été répertoriés. Des embâcles se sont aussi produits sur d'autres affluents secondaires qui n'ont pas été inspectés (vallon du Fugeiret, vallon de la Rine...)

	Volumes d'embâcle estimés en 2015 (m^3)
Brague urbaine	1670
Brague moyenne	3470
Bouillide	890
Valmasque aval	390
Valmasque moyenne	850
Total	7270



Carte des tronçons étudiés

L'objectif de l'analyse de 2018 est d'affiner si possible les estimations de volumes d'embâcle et les dimensions des arbres principaux.
Pour se faire, nous avons mesuré sur site l'emprise des embâcles en retrouvant des points de repère fixe présent sur les photos (ouvrages de génie civil, arbre encore en place, rocher...). Cette analyse a pu être réalisé sur les gros embâcles dont l'emplacement a pu être retrouvé à postériori. A l'aide d'impression des photos d'embâcle, leur emprise a pu être reconstitué en 2018. Le diamètre des tronçons des embâcles a été estimé en fonction du diamètre des arbres en place retrouvés sur les photos.

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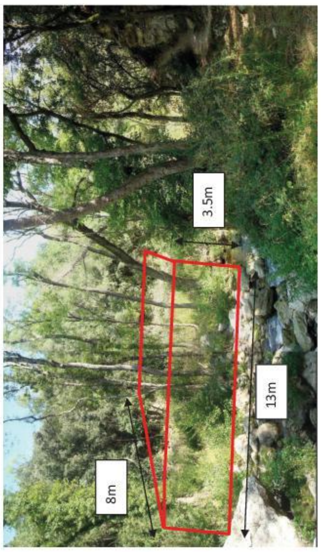
1.1. Confluence Bouillide Brague :

Photos octobre 2015

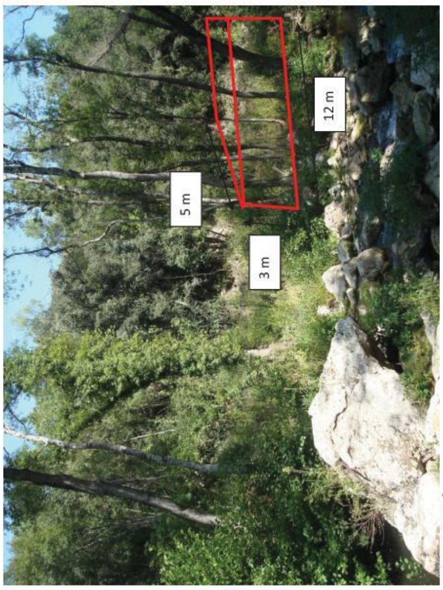
Photo août 2018



Volume 364 m³.
Circonférence des bois principaux 100 cm à 130cm sur une longueur de 10 à 13m

Photo octobre 2015

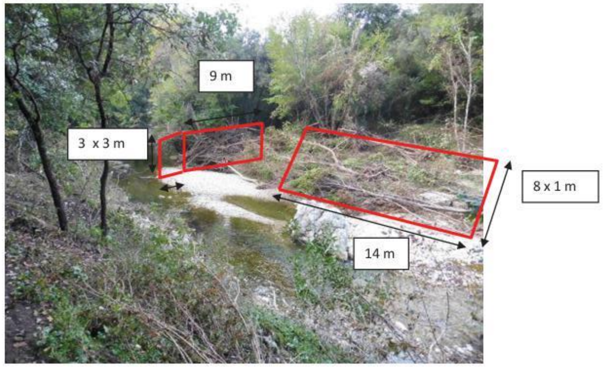
Photo août 2018



Volume 180 m³.
Circonférence des bois principaux 80 cm à 110 cm pour une longueur de 10 à 12m.

1.2. Les Soullieres

Photo octobre 2015



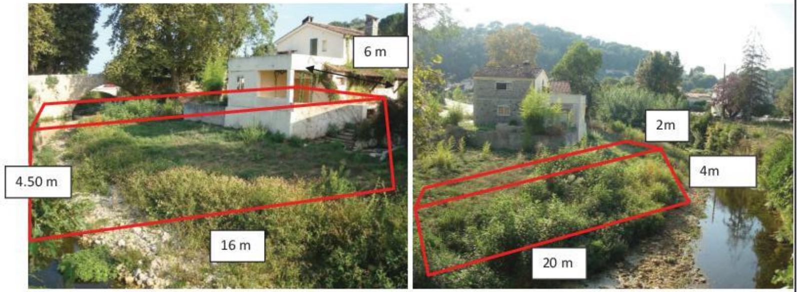
Volume : 81 + 112 = 201 m^3

Circonférence des bois principaux 70 cm à 120 cm pour une longueur de 9 à 14m.

1.3. Pont Murator

Photo octobre 2015

Photo août 2018



Volume : 160 + 432 = 592 m^3

Circonférence des bois principaux 100 cm à 140 cm pour une longueur de 14 à 18 m.

1.4. Confluence Valmasque Brague

Photo octobre 2015

Photo août 2018

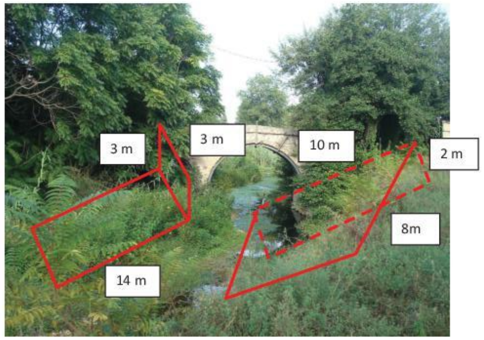
Volume : 103 + 126 = 229 m³

Circonférence des bois principaux 120 cm à 150 cm pour une longueur de 15 à 20 m.

1.5. Pont du golf de Biot

Photo octobre 2015

Photo août 2018

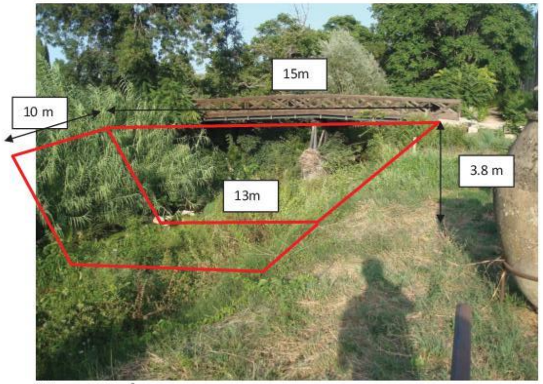


Volume : 126 + 160 = 286 m³
Circonférence des bois principaux 80 cm à 110 cm pour une longueur de 10 à 14 m.

1.6. Passerelle golf de Biot

Photo octobre 2015

Photo août 2018



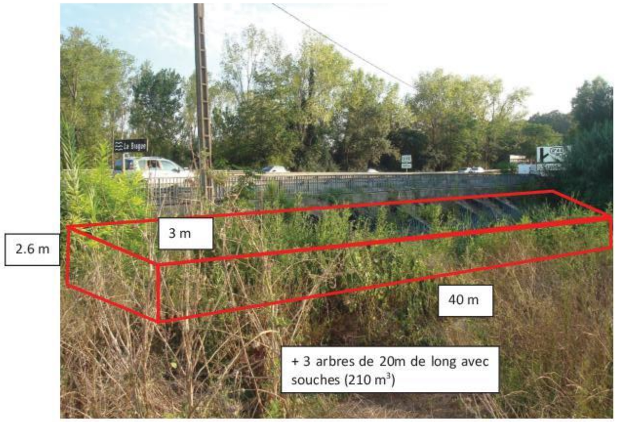
Volume : 532 m³

Circonférence des bois principaux 100 cm à 120 cm pour une longueur de 10 à 17 m.

1.7. Autoroute A8 passage buse

Photo octobre 2015

Photo août 2018



Volume 522 m³

Circonférence des bois principaux 100 cm à 130 cm pour une longueur de 15 à 20 m.

1.8. Bilan volumetrique

Site	Volume estimé visuellement 2016	Volume recalculé 2018
Confluence Brague Bouillide	200	364
Confluence Brague Bouillide	200	180
Les Soullieres	200	201
Pont Murator	400	592
Confluence Brague Valmasque	80	229
Pont du golf de Biot	200	286
Passerelle golf de Biot	200	532
Autoroute A8 Buse	350	522
Total	**1830**	**2906**

En analysant les volumes des principaux embâcles de plus de 200 m^3, il semble que l'analyse visuelle de 2016 soit sous-estimée, notamment pour les gros embâcles du pont Murator, de la passerelle du golf de Biot et de l'autoroute A8 qui étaient peu accessibles avant les travaux de désembâclement. En 2015, ces embâcles avaient fait l'objet d'une appréciation de volume visuelle approximative. Pour les embâcles déposés à la confluence Brague Valmasque, l'estimation de 2015 ne tenait compte que des arbres obstruant le lit de la Valmasque. Les photos conservées par la CASA ont permis de revoir le volume à la hausse en ajoutant les arbres déposés en lit majeur dans les terrains de golf.

En août 2018, l'accessibilité totale des sites désencombrés en période d'étiage a permis de faire des mesures directement sur les ouvrages ou en travers du lit.

Pour les petits embâcles de moins de 200 m^3 il semble que les volumes mesurés en 2015 soient plus proches de ceux recalculés en 2018, du fait de leur accessibilité directement après la crue.

2. COUT D'INVESTISSEMENT ET DE GESTION DE RIVIERE ET DES PEUPLEMENTS FORESTIERS

L'estimations des coûts des différents items de gestion des peuplements rivulaires a été réalisés sur la base de l'analyse du coût réel d'opérations effectuées par les collectivités en charge des cours d'eau.

Les opérations comptabilisées sont situées principalement sur les bassins versants réputés à crue rapide de l'arc méditerranéen, des Alpes du Sud et des Cévennes, car il s'agit des collectivités les plus actives en matière d'action sur la végétation rivulaire vis-à-vis des risques d'inondation et en matière de prévention contre les incendies.

Pour chaque poste d'intervention, des sous-catégories ont été définies pour caractériser les principales modalités de travaux qui font varier les prix d'une opération, comme les matériaux mis en œuvre ou l'accessibilité du site.

Les prix sont rapportés à une unité de mesure commune à tous les ouvrages analysés pour un même poste, tel que le mètre linéaire de cours d'eau ou le m^3 de bassin de rétention. La comparaison d'opérations d'échelle différente permet d'établir une fourchette de coût unitaire. Le montant total de l'opération, les techniques employées et la conjoncture locale du marché du TP, font varier les prix unitaires dans cette fourchette.

Les prix sont tous actualisés à 2018 sur la base de l'évolution de l'indice INSEE du BTP. Il s'agit de prix TTC des travaux, hors étude de maitrise d'œuvre.

Poste	Sous catégorie	Unité	coût		
Aménagement de cours d'eau			min	moyen	max
Investissement					
Démantèlement pont	portée de moins de 10 m	m2 de tablier	150 €	195 €	240 €
	portée plus de 10 m	m2 de tablier	450 €	540 €	673 €
Construction pont	portée de moins de 10 m	m2 de tablier	2 062 €	2 062 €	2 062 €
	portée de plus de 10 m	m2 de tablier	2 432 €	3 070 €	3 645 €
Construction passerelle	portée de moins de 10 m	m2 de tablier	491 €	583 €	675 €
	portée de 10 à 20 m	m2 de tablier	870 €	1 028 €	1 187 €
Barrage de rétention	petit ouvrage - H < 5m -	m3 de rétention	21 €	80 €	113 €
	ouvrage moyen - H de 5 à 10m	m3 de rétention	35 €	66 €	99 €
	grand ouvrage de plus de 10m -	m3 de rétention	7 €	15 €	28 €
Zone d'expansion de crue - ralentissement dynamique	remobilisation par recul de digue de faible hauteur et reconstruction en retrait	m linéaire	2 320 €	2 568 €	2 817 €
	aménagement de risberme, reméandrage	m linéaire	728 €	1 495 €	2 147 €
Piège à flottants	filet métallique ancré au rocher latéralement	m linéaire	1 214 €	1 214 €	1 214 €
	râtelier ou herse de pieux - avec ou sans radier	m linéaire	4 389 €	6 597 €	9 825 €
Seuil en rivière	petit ouvrage - H < 2m -	m linéaire	934 €	1 272 €	1 609 €
	ouvrage moyen - H de 2 à 5m	m linéaire	4 097 €	6 233 €	8 096 €
Radier	enrochement bétonné une couche 1,5m d'épaisseur	m2	466 €	567 €	669 €
Digue	petit ouvrage en remblais avec simple clef d'étancheité - H<2m	m linéaire	563 €	570 €	578 €
	ouvrage moyen avec protection à la surverse - H de 2 à 5m	m linéaire	1 589 €	1 723 €	1 834 €
Protection de berge	génie végétale en pied - boudin d'hélophytes	m linéaire	25 €	34 €	42 €
	végétalisation par fascinage - tressage	m linéaire	86 €	122 €	144 €

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	caisson bois en pied de berge	m linéaire	360 €	379 €	398 €
	parafouille enrochement libre et végétalisation berge	m linéaire	404 €	498 €	662 €
	parafouille enrochement libre et enrochement libre berge une couche H= 3m	m linéaire	433 €	1 300 €	2 088 €
	parafouille enrochement bétonné et enrochement libre berge une couche H= 3m	m linéaire	1 544 €	2 297 €	3 049 €
	semelle parafouille et mur en béton armé H=3m	m linéaire	2 575 €	4 540 €	6 506 €
Aménagement de berge	ensemencement et géotextile coco pour H=3m	m linéaire	21 €	44 €	88 €
	plantation arbre et arbuste pour H=3m	m linéaire	41 €	48 €	55 €
	retalutage pour H=3m	m linéaire	100 €	126 €	152 €
	renaturation talutage géotextile plantation pour H=3m	m linéaire	298 €	301 €	303 €
Coût de fonctionnement et de maintenance opérationnelle mineure					
Entretien ripisylve	zone naturelle peu d'enjeu - passage tous les 10 ans	m linéaire de cours d'eau	6.43 €	7.14 €	8.27 €
	zone naturelle enjeu moyen - passage tous les 5 ans	m linéaire de cours d'eau	4.97 €	5.87 €	7.28 €
	zone urbaine - risque d'embâcle fort - passage tous les 1 à 2 ans	m linéaire de cours d'eau	1.55 €	3.36 €	5.34 €
	protection flores protégées - surcoût de l'entretien	m linéaire de cours d'eau	2.14 €	2.14 €	2.14 €
	élimination espèces envahissantes	m linéaire de cours d'eau	1.15 €	2.30 €	3.44 €
Maintenance exceptionnelle					
Nettoyage d'embâcle	accès mécanique	m3 d'embâcle	121 €	167 €	218 €
	accès pédestre	m3 d'embâcle	168 €	191 €	214 €
Curage d'urgence	accès mécanique stockage en berge	m3	3 €	9 €	16 €
	accès mécanique avec transport réinjection aval	m3	5 €	16 €	28 €
	par dragage sur barge - dragage par succeuse, décantation, chargement	m3	77 €	77 €	77 €
Confortement d'urgence	enrochement libre de la berge H= 3m et parafouille	m linéaire	1 740 €	2 661 €	3 426 €

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	déversement de bloc d'enrochement en vrac dans brèche 10 m3/m	m linéaire	1 400 €	1 400 €	1 400 €
Défense contre l'incendie					
Investissement					
Signalisation	barrière	unité	1 228 €	1 559 €	2 148 €
	signalisation limitation de circulation	unité pour 3 panneaux	150 €	228 €	376 €
Accessibilité	création de piste DFCI, non revêtue, terrain doux	m linéaire	5 €	7 €	10 €
	création de piste DFCI, non revêtue, terrain escarpé	m linéaire	7 €	18 €	32 €
Equipement	citerne DFCI	unité	22 220 €	30 249 €	40 047 €
	aménagement de bande parre feu	ha de forêt	1 622 €	1 895 €	2 398 €
Coût de fonctionnement et de maintenance opérationnelle mineure					
Surveillance incendie	vigie - par an	ha de forêt	0.73 €	0.92 €	1.12 €
	patrouille - par an	ha de forêt	5.69 €	6.29 €	6.89 €
	moyen aérien de détection du feu - par an	ha de forêt	0.26 €	0.35 €	0.44 €
Maintenance parre feu	débroussaillement mécanisé terrain doux, par an	ha de forêt	103 €	152 €	180 €
	débroussaillement mixte terrain escarpé, par an	ha de forêt	322 €	329 €	336 €
Entretien des pistes	terrassement, soutènement, curage ouvrage hydraulique - par an	m linéaire de piste	0.65 €	1.01 €	1.38 €
Maintenance exceptionnelle					
Abattage post incendie	abattage et débardage des bois calcinés, hors transport et valorisation potentielle du bois	ha de forêt incendiée	1 776 €	2 085 €	2 394 €
Lutte contre l'érosion	mise en fascine des bois brulés - pente moyenne à prononcée	ha de forêt incendiée	1 053 €	1 852 €	2 651 €
Reboisement	plantation avec protection contre prédation	ha de forêt	14 196 €	16 737 €	19 277 €

Annex 9. Estimated property values in the Brague over the period 2017-2018 (€, 2018)

Type	Unit	€/unit
Non -constructible land	m²	7
Private garden	m²	15
Constructible land	m²	152
Serviced land	m²	412
Office-shops	m²	910 -2,990
Garages	garage	45,000
Houses*	house	365,000
Apartments	Apartment	188,000

*assumed to be 150 m² polygon on the IGN BD Carto database

Source: PERVAL database

Annex 10. Cost estimations for the NBS ambitious and very ambitious projects

Table 38: Costs estimations for the High Ambition NBS scenario (Land acquisition & Investment)

#	Name	Unit	Quantity	Unit price (mean)	Unit price (min)	Unit price (max)	Cost (mean estimate)	Cost (min - max range)
100	**Land acquisition**							
110	Houses	m2	7 000	2 400 €	2 040 €	4 800 €	16 800 000 €	14280000€ - 33600000€
120	Offices - shops	m2	3 300	1 950 €	910 €	2 990 €	6 435 000 €	3003000€ - 9867000€
130	Gardens	m2	153 500	15 €	13 €	17 €	2 302 500 €	1957125€ - 2647875€
140	Bare lands (not constructible)	m2	272 500	7 €	6 €	8 €	1 907 500 €	1621375€ - 2193625€
150	Notary fees (20% of costs)	F	1	5 489 000 €	4 172 300 €	9 661 700 €	5 489 000 €	4172300€ - 9661700€
	Sub-total Land acquisition						**32 934 000 €**	**25033800€ - 57970200€**
200	**Prepartion studies and works**							
210	Engineering studies and building supervision	F	1	1 210 000 €	910 000 €	1 510 000 €	1 210 000 €	910000€ - 1510000€
220	Environemtal impact studies	F	1	520 000 €	390 000 €	650 000 €	520 000 €	390000€ - 650000€
230	Side works for building site preparation (network deviation, etc.)	F	1	2 580 000 €	1 940 000 €	3 230 000 €	2 580 000 €	1940000€ - 3230000€
	Sub-total Prepartion studies and works						**4 310 000 €**	**3240000€ - 5390000€**
300	**Building site preparation**							
310	Removing vegetation	m2	58 000	1.0 €	0.1 €	2.0 €	58 000 €	5800€ - 116000€
320	Existing building demolition	m2	17 200	130 €	100 €	160 €	2 236 000 €	1720000€ - 2752000€
	Sub-total Building site preparation						**2 294 000 €**	**1725800€ - 2868000€**
400	**Earth moving works**							
410	Removing surface soil layer (50cm), kept on-site	m2	48 000	0.61 €	0.45 €	1.85 €	29 280 €	21600€ - 88800€
420	Removing deep soil + evacuation	m3	701 000	9.55 €	6.51 €	15.81 €	6 694 550 €	4563510€ - 11082810€
430	Prepartation of surface soil layer (50cm)	m2	48 000	0.50 €	0.20 €	1.50 €	24 000 €	9600€ - 72000€
440	Dyke construction	m	190	570 €	563 €	578 €	108 385 €	107028€ - 109743€
	Sub-total Earth moving works						**6 856 215 €**	**4701738€ - 11353353€**
500	**Civil engineering works**							
510	Bridge demolition	m2	170	540 €	450 €	673 €	91 785 €	76505€ - 114344€
520	Bridge reconstruction (span length>10 m)	m2	1 640	3 070 €	2 432 €	3 645 €	5 034 115 €	3988247€ - 5978377€

530	Pedestrian bridge construction (span length>10 m)	m2	240	1 028 €	870 €	1 187 €	246 735 €	208682€ - 284789€
540	Large wood rack	m	140	6 597 €	4 389 €	9 825 €	923 562 €	614415€ - 1375465€
	Sub-total Civil engineering works						**6 296 197 €**	**4887849€ - 7752975€**

Table 38 (Continued)

#	Name	Unit	Quantity	Unit price (mean)	Unit price (min)	Unit price (max)	Cost (mean estimate)	Cost (min - max range)
600	**Planting works**							
610	Wetland vegetation planting	m²	227 000	2.00 €	1.00 €	4.00 €	454 000 €	227000€ - 908000€
620	Grass seeding on bio-geotextile (banks)	m	3 700	44 €	21 €	88 €	164 044 €	78574€ - 327212€
630	Tree planting (banks)	m	6 600	48 €	41 €	55 €	317 301 €	270314€ - 364288€
640	Bank reshaping and planting	m	-	301 €	298 €	303 €	- €	0€ - 0€
650	Light bioengineering bank protection (fascine)	m	4 400	122 €	86 €	144 €	536 780 €	378207€ - 631433€
660	Heavy bioengineering bank protection (fascine + submerged riprap)	m	800	498 €	404 €	662 €	398 752 €	323038€ - 529287€
		Sub-total Planting works					**1 870 877 €**	**1277133€ - 2760220€**
700	**Urban works**							
710	Pedestrian path	m	3 200	10 €	8 €	13 €	32 000 €	24000€ - 40000€
720	Cycle path	m	8 300	200 €	100 €	400 €	1 660 000 €	830000€ - 3320000€
730	Road construction	m	100	4 000 €	2 000 €	5 000 €	400 000 €	200000€ - 500000€
		Sub-total Urban works					**2 092 000 €**	**1054000€ - 3860000€**
		Total investment costs					**24 249 289 €**	**17285520€ - 34644548€**

Table 39: Costs estimations for the High Ambition NBS scenario (Maintenance and Opportunity costs)

#	Name	Unit	Quantity	Unit price (mean)	Unit price (min)	Unit price (max)	Frequency	Cost (mean estimate)	Cost (min - max range)
800	**Operating and minor maintenance expenditure**								
810	Light vegetation maintenance (1 every 10 yr)	m	48 550	7.78 €	6.43 €	8.65 €	0.1	37 772 €	31218€ - 41996€
820	Moderate vegetation maintenance (1 every 5 yr)	m	2 000	6.26 €	5.35 €	7.28 €	0.2	2 504 €	2140€ - 2912€
830	High vegetation maintenance (1 every yr)	m	4 450	3.87 €	3.09 €	5.34 €	1	17 222 €	13751€ - 23763€
840	Dyke maintenance	m	190	19.97 €	11.41 €	28.52 €	1	3 793 €	2168€ - 5419€
850	Large wood rack cleaning	Unit	5	600 €	300 €	1 200 €	2	6 000 €	3000€ - 12000€
860	Pedestrian and cycle path maintenance	m	3 200	1.01 €	0.65 €	1.38 €	1	3 247 €	2084€ - 4409€
870	Wildfire survey and fighting	km²	25	1 513 €	1 135 €	1 891 €	1	37 825 €	28369€ - 47281€
		Sub-total Operating and minor maintenance expenditure						**108 363 €**	**82730€ - 137780€**
		Cumulated on 50 years, accounting for discounting,						**3 077 500 €**	**2349532€ - 3912952€**
900	**Capital maintenance expenditure**								
910	Large wood rack cleaning	m3	1 000	167 €	121 €	218 €	0.10	16 693 €	12135€ - 21822€
920	Sediment and trashes dredging	m3	1 000	9 €	3 €	16 €	0.05	457 €	125€ - 789€
930	Bioengineering work reparation	m	520	122 €	86 €	144 €	0.05	3 172 €	2235€ - 3731€
940	Emergency riprap reparation	m	100	2 661 €	1 740 €	3 426 €	0.01	2 661 €	1740€ - 3426€
		Sub-total Capital maintenance expenditure						**22 983 €**	**16235€ - 29768€**
		Cumulated on 50 years, accounting for discounting,						**652 705 €**	**461074€ - 845411€**
1000	**Opportunity costs**								
1010	Compensation on houses acquisitions	m2	7 000	1 920 €	1 632 €	3 840 €	1	13 440 000 €	11424000€ - 26880000€
1020	Compensation on offices and shops acquisitions	m2	3 300	1 560 €	728 €	2 392 €	1	5 148 000 €	2402400€ - 7893600€
		Sub-total Opportunity costs						**19 240 705 €**	**13826400€ - 34773600€**
		Total costs on 50 years time window						**80 154 199 €**	**58956326€ - 132146711€**

Table 40: Costs estimations for the Very High Ambition NBS scenario (Land acquisition & Investment)

#	Name	Unit	Quantity	Unit price (mean)	Unit price (min)	Unit price (max)	Cost (mean estimate)	Cost (min - max range)
100	**Land acquisition**							
110	Houses	m2	12 000	2 400 €	2 040 €	4 800 €	28 800 000 €	24480000€ - 57600000€
120	Offices - shops	m2	3 900	1 950 €	910 €	2 990 €	7 605 000 €	3549000€ - 11661000€
130	Gardens	m2	172 800	15 €	13 €	17 €	2 592 000 €	2203200€ - 2980800€
140	Bare lands (not constructible)	m2	269 100	7 €	6 €	8 €	1 883 700 €	1601145€ - 2166255€
150	Notary fees (20% of costs)	F	1	8 176 140 €	6 366 669 €	14 881 611 €	8 176 140 €	6366669€ - 14881611€
			Sub-total Land acquisition				**49 056 840 €**	**38200014€ - 89289666€**
200	**Prepartion studies and works**							
210	Engineering studies and building supervision	F	1	2 050 000 €	1 540 000 €	2 560 000 €	2 050 000 €	1540000€ - 2560000€
220	Environemtal impact studies	F	1	880 000 €	660 000 €	1 100 000 €	880 000 €	660000€ - 1100000€
230	Side works for building site preparation (network deviation, etc.)	F	1	4 390 000 €	3 290 000 €	5 490 000 €	4 390 000 €	3290000€ - 5490000€
			Sub-total Prepartion studies and works				**7 320 000 €**	**5490000€ - 9150000€**
300	**Building site preparation**							
310	Removing vegetation	m2	58 000	1.0 €	0.1 €	2.0 €	58 000 €	5800€ - 116000€
320	Existing building demolition	m2	22 300	130 €	100 €	160 €	2 899 000 €	2230000€ - 3568000€
			Sub-total Building site preparation				**2 957 000 €**	**2235800€ - 3684000€**
400	**Earth moving works**							
410	Removing surface soil layer (50cm), kept on-site	m2	54 000	0.61 €	0.45 €	1.85 €	32 940 €	24300€ - 99900€
420	Removing deep soil + evacuation	m3	747 000	9.55 €	6.51 €	15.81 €	7 133 850 €	4862970€ - 11810070€
430	Prepartation of surface soil layer (50cm)	m2	54 000	0.50 €	0.20 €	1.50 €	27 000 €	10800€ - 81000€
440	Dyke construction	m	190	570 €	563 €	578 €	108 385 €	107028€ - 109743€
			Sub-total Earth moving works				**7 302 175 €**	**5005098€ - 12100713€**

Table 40 (Continued)

#	Name	Unit	Quantity	Unit price (mean)	Unit price (min)	Unit price (max)	Cost (mean estimate)	Cost (min - max range)
500	**Civil engineering works**							
510	Bridge demolition	m2	250	540 €	450 €	673 €	134 978 €	112508€ - 168152€
520	Bridge reconstruction (span length>10 m)	m2	1 160	3 070 €	2 432 €	3 645 €	3 560 716 €	2820955€ - 4228608€
530	Pedestrian bridge construction (span length>10 m)	m2	560	1 028 €	870 €	1 187 €	575 716 €	486924€ - 664508€
540	Large wood rack	m	110	6 597 €	4 389 €	9 825 €	725 655 €	482755€ - 1080722€
550	Highway brigde creation	m²	2 000	6 100 €	4 900 €	10 900 €	12 200 000 €	9800000€ - 21800000€
			Sub-total Civil engineering works				**17 197 065 €**	**13703142€ - 27941990€**
600	**Planting works**							
610	Wetland vegetation planting	m²	259 000	4.00 €	2.00 €	10.00 €	1 036 000 €	518000€ - 2590000€
620	Grass seeding on bio-geotextile (banks)	m	2 800	44 €	21 €	88 €	124 141 €	59461€ - 247620€
630	Tree planting (banks)	m	6 700	48 €	41 €	55 €	322 109 €	274410€ - 369808€
640	Bank reshaping and planting	m	-	301 €	298 €	303 €	- €	0€ - 0€
650	Light bioengineering bank protection (fascine)	m	5 400	122 €	86 €	144 €	658 775 €	464163€ - 774941€
660	Heavy bioengineering bank protection (fascine + submerged riprap)	m	700	498 €	404 €	662 €	348 908 €	282658€ - 463126€
			Sub-total Planting works				**2 489 933 €**	**1598692€ - 4445495€**
700	**Urban works**							
710	Pedestrian path	m	3 900	10 €	8 €	13 €	39 000 €	29250€ - 48750€
720	Cycle path	m	7 500	200 €	100 €	400 €	1 500 000 €	750000€ - 3000000€
730	Road construction	m	100	4 000 €	2 000 €	5 000 €	400 000 €	200000€ - 500000€
			Sub-total Urban works				**1 939 000 €**	**979250€ - 3548750€**
			Total investment costs				**39 851 173 €**	**29501582€ - 61682948€**

Table 41: Costs for Very High Ambition NBS scenario (Maintenance and Opportunity costs)

#	Name	Unit	Quantity	Unit price (mean)	Unit price (min)	Unit price (max)	Frequency	Cost (mean estimate)	Cost (min - max range)
800	**Operating and minor maintenance expenditure**								
810	Light vegetation maintenance (1 every 10 yr)	m	48 550	7.78 €	6.43 €	8.65 €	0.1	37 772 €	31218€ - 41996€
820	Moderate vegetation maintenance (1 every 5 yr)	m	2 000	6.26 €	5.35 €	7.28 €	0.2	2 504 €	2140€ - 2912€
830	High vegetation maintenance (1 every yr)	m	4 450	3.87 €	3.09 €	5.34 €	1	17 222 €	13751€ - 23763€
840	Dyke maintenance	m	190	19.97 €	11.41 €	28.52 €	1	3 793 €	2168€ - 5419€
850	Large wood rack cleaning	Unit	5	600 €	300 €	1 200 €	2	6 000 €	3000€ - 12000€
860	Pedestrian and cycle path maintenance	m	3 900	1.01 €	0.65 €	1.38 €	1	3 957 €	2540€ - 5374€
870	Wildfire survey and fighting	km²	25	1 513 €	1 135 €	1 891 €	1	37 825 €	28369€ - 47281€
				Sub-total Operating and minor maintenance expenditure				**109 073 €**	**83186€ - 138745€**
				Cumulated on 50 years, accounting for discounting,				**3 097 670 €**	**2362482€ - 3940358€**
900	**Capital maintenance expenditure**								
910	Large wood rack cleaning	m3	1 000	167 €	121 €	218 €	0.10	16 693 €	12135€ - 21822€
920	Sediment and trashes dredging	m3	1 000	9 €	3 €	16 €	0.05	457 €	125€ - 789€
930	Bioengineering work reparation	m	610	122 €	86 €	144 €	0.05	3 721 €	2622€ - 4377€
940	Emergency riprap reparation	m	100	2 661 €	1 740 €	3 426 €	0.01	2 661 €	1740€ - 3426€
				Sub-total Capital maintenance expenditure				**23 532 €**	**16622€ - 30414€**
				Cumulated on 50 years, accounting for discounting,				**668 296 €**	**472065€ - 863758€**
1000	**Opportunity costs**								
1010	Compensation on houses acquisitions	m2	12 000	1 920 €	1 632 €	3 840 €	1	23 040 000 €	19584000€ - 46080000€
1020	Compensation on offices and shops acquisitions	m2	3 900	1 560 €	728 €	2 392 €	1	6 084 000 €	2839200€ - 9328800€
				Sub-total Opportunity costs				**29 792 296 €**	**22423200€ - 55408800€**
				Total costs on 50 years time window				**122 466 276 €**	**92959343€ - 211185530€**

Annex 11. The questionnaire

Enquête : Quel avenir pour le territoire de la Brague face au risque d'inondations ?

Introduction à l'enquête

Le débordement des cours d'eau de leur lit mineur est l'une des principales causes des inondations. Ces dernières peuvent avoir des conséquences catastrophiques lorsque des personnes et des biens sont implantés dans la plaine inondable. Les dommages se alors chiffrent à des millions d'euros, des impacts psychologiques et des décès. **Dans un contexte de changement climatique, trouver des solutions efficaces pour réduire les dommages est devenue une question essentielle pour les autorités publiques, mais aussi pour les populations qui sont les premières concernées.**

La présente enquête s'inscrit dans un cadre de **travail universitaire et dans le cadre du projet NAIAD**[28] **financé par l'Union Européenne**. Son objectif est de collecter votre perception du risque d'inondations et vos préférences par rapport aux solutions de gestion du risque d'inondations.

Cette enquête est **un sondage d'opinion** qui ne vous prendra **qu'une vingtaine de minutes**. Elle représente donc pour vous une opportunité de participer à la définition de nouvelles solutions adaptées à votre territoire.

[28] NAIAD est un projet européen H2020 et interdisciplinaire financé par l'Europe sous le contrat nº 730497. Rendez sur http://naiad2020.eu/ pour plus d'information.

0.Parlez-nous de vous et de vos valeurs

0.1 Vous êtes

Une femme	Un homme	Autre
○	○	○

0.2 Votre code postal de résidence est :

Code postal : ……………………

0.3 Vous travaillez dans la commune de :

…………………………………………………

0.4 Vous êtes propriétaire, locataire ou hébergé :

Propriétaire	Locataire	Hébergé par un tiers/parents
○	○	○

0.5 Vous êtes âgés de :

18-24 ans	25-34 ans	35-44 ans	45-54 ans	55-64 ans	65 ans et +
○	○	○	○	○	○

0.6 Vous êtes au nombre de … personnes dans votre ménage

1 personne	2 personnes	3 personnes	4 personnes	5 personnes	+ 5 personnes
○	○	○	○	○	○

0.7 Vous êtes diplômé d'un (e) :

Brevet	CAP	BAC	BAC +2	Licence	Master et plus
○	○	○	○	○	○

0.8 Vous êtes … sur le plan professionnel

En formation (élèves, étudiants, stagiaires)	Au chômage	En emploi	A la retraite	Autres
○	○	○	○	○

Si vous êtes en formation passez à la question 0.10

Votre catégorie socio-professionnelle est :

Agriculteurs	Artisans, commerçants, chefs d'entreprises	Cadres et professions intellectuelles supérieures	Professions intermédiaires	Employés	Ouvriers
○	○	○	○	○	○

0.9 Vous avez un <u>revenu mensuel</u> de :

0-1 000€	1 000 – 1 500€	1 500 – 2 000€	2 000 – 2 500€	2 500 – 3 000€	Plus de 3 000€
○	○	○	○	○	○

0.10 Quels sont <u>les principes</u> qui <u>motivent vos actions au quotidien</u> ? <u>Servez-vous de l'échelle</u> ci-après pour <u>donner l'importance</u> que vous accordez à <u>chacun des principes dans la liste</u>.

Contraire à mes principes	Pas du tout important	●○○○○○	●●○○○○	●●●○○○	●●●●○○	●●●●●○	Très important	Importance ultime
-1	0	1	2	3	4	5	6	7

Principes	-1	0	1	2	3	4	5	6	7
Richesse (Les avoirs matériels et monétaires).	○	○	○	○	○	○	○	○	○
Influence (La capacité à influencer les autres et les évènements).	○	○	○	○	○	○	○	○	○
Justice sociale (Lutter contre l'injustice, protéger les plus faibles).	○	○	○	○	○	○	○	○	○
Serviabilité/Obligeance (Travailler pour le bien-être des autres).	○	○	○	○	○	○	○	○	○
Prévenir la pollution (Eviter toutes sortes de pollution).	○	○	○	○	○	○	○	○	○
Respecter la nature (Vivre en harmonie avec la biodiversité).	○	○	○	○	○	○	○	○	○

0.11 Quelle est votre <u>opinion par rapport aux affirmations ci-après ?</u> Servez-vous de l'échelle suivante **:**

Pas du tout d'accord	Pas d'accord	Ni en désaccord ni d'accord	D'accord	Tout à fait d'accord
-2	-1	0	1	2

Affirmations	-2	-1	0	1	2
Je suis préoccupé par les problèmes environnementaux car cela affecte ma santé.	○	○	○	○	○
Je suis préoccupé par les problèmes environnementaux car cela affecte ma prospérité.	○	○	○	○	○
Je suis préoccupé par les problèmes environnementaux car cela affecte les résidents de ma commune.	○	○	○	○	○
Je suis préoccupé par les problèmes environnementaux car cela affecte les générations futures.	○	○	○	○	○
Je suis préoccupé par les problèmes environnementaux car cela affecte les animaux.	○	○	○	○	○
Je suis préoccupé par les problèmes environnementaux car cela affecte les plantes.	○	○	○	○	○

0.13 Quelle est votre opinion par rapport aux affirmations ci-après ? Servez-vous de l'échelle suivante **:**

Pas du tout d'accord	Pas d'accord	Ni en désaccord ni d'accord	D'accord	Tout à fait d'accord
-2	-1	0	1	2

Affirmations	-2	-1	0	1	2
Les rivières sont des écosystèmes naturels qu'il faut protéger/restaurer.	○	○	○	○	○
Il est important de développer une agriculture locale dans les plaines inondables.	○	○	○	○	○
Il est important de développer des activités récréatives dans les plaines inondables.	○	○	○	○	○
Je me sens en partie responsable de la réduction de biodiversité.	○	○	○	○	○
Je me sens en partie responsable du changement climatique.	○	○	○	○	○

Je me sens responsable de l'urbanisation massive et la minéralisation des sols.	○	○	○	○	○
Je me sens personnellement obligé de préserver/restaurer la nature autant que possible.	○	○	○	○	○
Je me sens moralement obligé de préserver/restaurer la nature, indépendamment de ce que font les autres personnes.	○	○	○	○	○
Je devrais être une meilleure personne si j'accorde plus d'importance à la nature qu'à l'argent.	○	○	○	○	○
Nous devrions protéger la nature.	○	○	○	○	○
Nous devrions accorder de l'importance d'abord aux activités économiques, et seulement après aux questions environnementales.	○	○	○	○	○

1. Votre territoire et le risque d'inondations

1.1. Vous sentez-vous concerné par le risque d'inondations dans votre commune de résidence ?

Oui	Non
○	○

1.2. Vous qualifieriez la fréquence des inondations dans votre commune de résidence au cours des 20 dernières années de :

Plus fréquente	Stable	Moins fréquente
○	○	○

1.3. Vous qualifieriez les dommages/dégâts causés par les inondations dans votre commune de résidence au cours des 20 dernières années de :

Plus dommageables	Stable	Moins dommageables
○	○	○

1.4. Vous pensez que les inondations dans votre commune de résidence sont aggravées par : (plusieurs choix possibles)

L'imperméabilisation du sol	L'urbanisation des zones à risque	Des pluies d'automnes de plus en plus intenses et fréquentes	Les mesures de protection ne sont pas adaptées	Les mesures de protection ne sont pas suffisantes
○	○	○	○	○

Autres, précisez :	Je ne sais pas
……	○

1.5. Le Plan de Prévention du Risque d'Inondations (PPRI) délimite les zones d'exposition aux risques. Vous <u>résidez</u> en :

Zone rouge	Zone bleu	Zone blanche	Je ne sais pas
○	○	○	○

1.6. A propos des <u>informations sur le risque</u> et sur les <u>bons réflexes/comportements</u> à avoir en <u>cas d'inondations, vous estimez être :</u>

Bien informés	Plutôt informés	Pas assez informés	Pas du tout informés
○	○	○	○

1.7. Pour vous, <u>l'enjeu économique le plus important</u> pour <u>l'avenir</u> de <u>votre commune de résidence</u> est : (un choix possible).

Une économie de proximité (produits locaux)	L'éco-tourisme	La croissance économique et la création d'emploi
○	○	○

1.8. Pour vous <u>l'enjeu social le plus important</u> pour <u>l'avenir</u> de votre <u>commune de résidence est :</u> (un choix possible).

La qualité de vie et le bien-être de la population	La cohésion et la justice sociale	La croissance démographique (le vieillissement de la population et les flux migratoires)	L'insécurité
○	○	○	○

1.9. Pour vous, <u>l'enjeu environnemental le plus important</u> pour <u>l'avenir</u> de votre <u>commune de résidence est :</u> (un choix possible)

Le réchauffement climatique (réduction des gaz à effet de serre)	L'eau (sa qualité et sa disponibilité)	La gestion des déchets	La qualité de l'air	La biodiversité et la qualité des milieux
○	○	○	○	○

1.10. Pour vous, l'enjeu d'aménagement urbain le plus important pour l'avenir de votre commune de résidence est : (un choix possible).

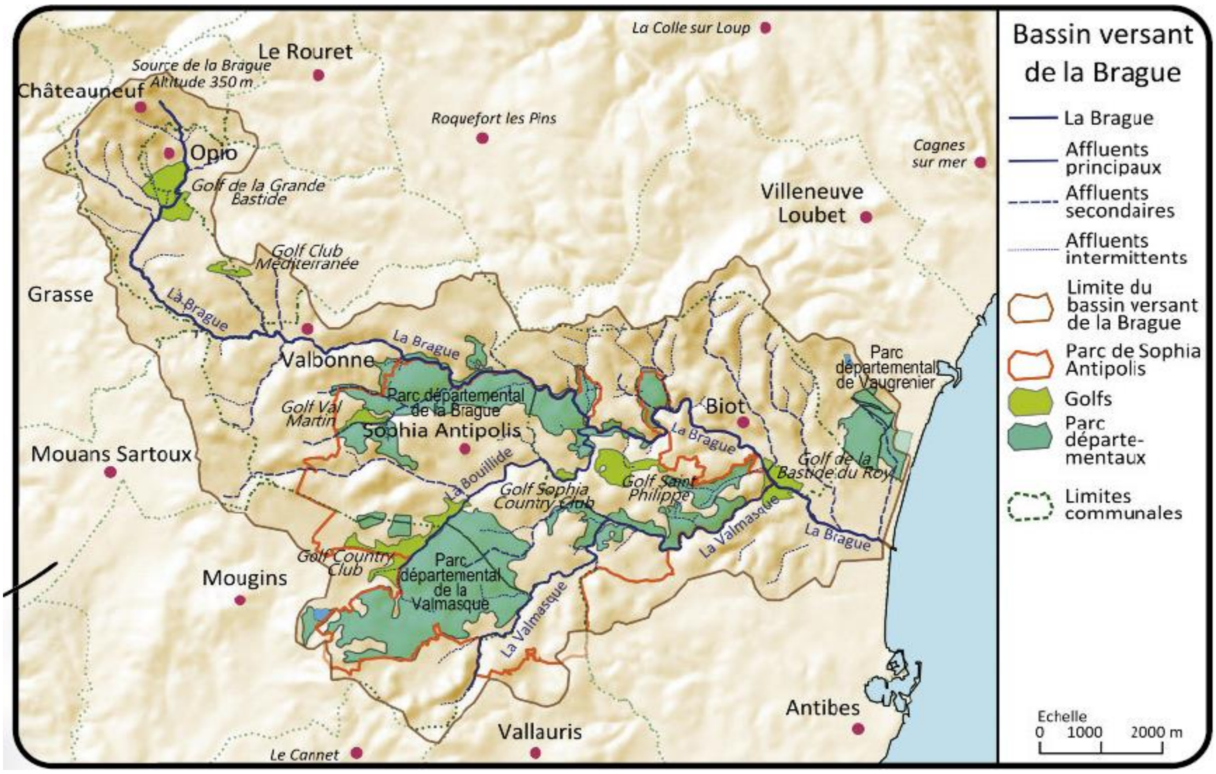
La cohérence et la continuité territoriale (Continuité entre les espaces, littoral, ville, parcs naturels, forêts)	Les transports / modes de déplacement / la congestion	Le logement et l'habitat
○	○	○

2. La Brague et vous

Qu'est-ce qu'un bassin versant ?

Un bassin versant est la surface dont un cours d'eau collecte l'eau drainée. La Brague est un des cours d'eau des Alpes Maritimes qui prend sa source dans la commune de Châteauneuf de Grasse et se jette dans la Méditerranée au niveau de la commune d'Antibes. Le bassin versant de la Brague a une superficie de 70 km² répartie sur 11 communes dont principalement les communes Châteauneuf de Grasse, Opio, Valbonne, Biot et Antibes.

Figure 40: Bassin versant de la Brague



Source (SIAQUEBA)

2.1. Avez-vous déjà entendu parler des inondations de la Brague ?

Oui	Non
○	○

2.2. Cochez <u>les épisodes d'inondations de la Brague</u> que vous avez <u>personnellement vécus</u> (plusieurs choix possibles).

Octobre 1973	Octobre 1987	Octobre 1993	Janvier 1996	Décembre 1996	Novembre 1999	Octobre 2000
○	○	○	○	○	○	○
Novembre 2000	Décembre 2000	Septembre 2005	Novembre 2011	Novembre 2014	Juin 2015	Octobre 2015
○	○	○	○	○	○	○

Autres précisez : ……………………………………………………………………….

Aucun ○

2.3. Combien de <u>fois avez-vous été inondé</u> dans votre <u>commune de résidence</u> ou <u>dans la Brague</u> ?

………..… ……fois

Si 0 fois, passez au module 3

2.4. Pour toutes <u>les inondations que vous avez vécues</u>, quels sont les <u>types de dommages</u> que vous avez <u>personnellement subis</u> ?

Dommages matériels et tangibles (maisons, voitures, entreprises, blessures corporelles, etc.)	Dommages immatériels et non tangibles (blessures psychologiques, décès, etc.)	Pas de dommages
○	○	○
	Si vous cochez uniquement cette réponse, passez à la question 2.8	*Si vous cochez uniquement cette réponse, passez au module 3*

2.5. Pour toutes <u>les inondations que vous avez vécues</u>, pouvez-vous donner <u>une estimation du montant des dommages</u> que vous avez subis ?

Moins de 5 000€	5 000€ - 10 000€	10 000€ - 20 000€	20 000€ - 30 000€	30 000€ - 50 000€	Plus de 50 000€	Je ne sais pas
○	○	○	○	○	○	○

2.6. Est-ce que <u>les biens endommagés</u> étaient <u>couverts par une assurance</u> ?

Oui	Non
○	○

Si non, passez à la question 2.8

Quel est le <u>pourcentage des dommages remboursés</u> par votre assurance ?

Moins de 10%	10-30%	30-50%	50%-70%	70%-90%	90%-100%	Je ne sais pas
○	○	○	○	○	○	○

2.7. Quelles sont <u>les affirmations qui décrivent le mieux les dommages immatériels</u> que vous avez <u>personnellement subis</u> (Plusieurs choix possibles).

Le décès de proches ou des blessures corporelles	Les troubles du sommeil, de concentration, un sentiment de culpabilité, ou des conduites d'évitement que je pense liées aux inondations	La phobie de la pluie que je pense liée aux inondations	Les comportements d'hyper vigilance que je pense liés aux inondations	La perte confiance dans les autorités locales
○	○	○	○	○

3. Vos préférences de solutions de réduction du risque d'inondation

Pour réduire le risque d'inondations causées par le débordement de rivières, plusieurs travaux d'aménagement sont possibles. Les partenaires de NAIAD ont fait une revue de ces travaux et ont identifié deux familles de travaux.

- **Travaux de génie civil** correspondent à la création ou à la reprise d'ouvrages lourds. Ces ouvrages massifs peuvent viser la rétention temporaire de l'eau (bassins de rétention, grand barrages de rétention), la prévention des débordements (digues, chenaux), la traversée des réseaux (ponts, buses) ou le piégeage des flottants (pièges à flottants, barrages flexibles en filets).

Exemple de barrage de rétention	Exemple de digues	Exemple de pièges à flottants
		
Un barrage est un ouvrage artificiel ou naturel (par accumulation de matériaux) établi en travers du lit d'un cours d'eau, retenant ou pouvant retenir de l'eau. Le plus souvent, la construction d'un tel ouvrage nécessite des opérations de recalibrage et d'endiguement.	**Une digue** (en terre ou en béton) est un ouvrage bâti afin d'empêcher un écoulement d'atteindre une zone.	Les pièges à flottants sont des obstacles aux embâcles. Ils peuvent être en pieux ou en filets. **Un embâcle** est une accumulation de matériaux apportés par les flots (végétation, rochers, véhicules, etc.). Ces matériaux sont déposé en amont des ouvrages (pont) ou dans une zone naturelles (gorges étroites, arbre stable) et entraînant une aggravation des inondations.

Source : http://www.georisques.gouv.fr

- **Travaux de restauration écologique et d'accessibilité** correspondent à la restauration des caractéristiques naturelles de la rivière qui jouent un rôle dans la régulation des crues. Les caractéristiques à restaurer peuvent concerner directement le lit de la rivière afin d'augmenter sa capacité de rétention et de ralentir la vitesse de l'écoulement des crues (méandres, lit moyen/majeur) ; les zones humides (marais, tourbières) et zones de rétention des crues (pairies, champs) afin de servir de zone d'expansion de crues ; la ripisylve afin de réduire l'érosion et stopper les flottants dans l'eau. Par exemple, les travaux de restauration d'une rivière peuvent se traduire par un élargissement du lit, une reconnexion avec les zones humides, une amélioration du potentiel des zones naturelles d'écrêtement des crues en amont, des plantations ciblées et du génie végétal pour la stabilisation des berges. Ces travaux sont souvent accompagnés d'infrastructures permettant à la population d'interagir avec la rivière dans le respect de la biodiversité.

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Exemple de caractéristiques naturelles de la rivière jouant un rôle dans la régulation des crues

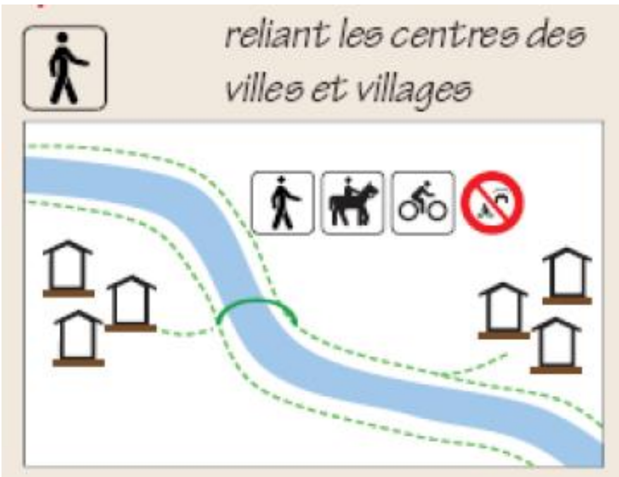
Source : AERMC[29]

¬ **La ripisylve** est l'ensemble des arbres et des plantes du bord de la rivière.
¬ **Les champs ou zones d'expansion des crues** sont des zones subissant des inondations naturelles. Par définition, elles font partie du lit majeur d'un cours d'eau délimité dans l'atlas des zones inondables.
¬ **Le lit moyen/majeur** est l'espace occupé temporairement par les rivières lors du débordement des eaux en période de crues.
¬ **Le méandre** est la sinuosité d'une rivière.
¬ **Une zone humide** est tout élément du continuum reliant l'environnement aquatique et terrestre.

Sources : http://www.georisques.gouv.fr, Siaqueba[30]

Illustration d'accessibilité discontinue | **Illustration d'accessibilité continue**

[29] Rapport « Sauvons l'eau »
[30] Livret pédagogique et d'informations pour les enseignants et les animateurs - La Brague à la loupe

Source : AERMC[31]

Parmi les deux familles de travaux de réduction du risque d'inondations, les partenaires de NAIAD ont identifié certains qui peuvent s'adapter au contexte de Brague. Cependant, ces travaux peuvent être contraints notamment par leurs impacts en coût financier et en foncier. Dans des environnements construits comme celui de la Brague, ces contraintes se traduiront concrètement par des expropriations de terrains, de bâtis et d'importantes dépenses en investissements.

Les partenaires de NAIAD ont alors imaginé trois niveaux ambition des travaux allant de niveau faible à fort. Plus le niveau d'ambition est élevé, plus l'impact potentiel sur la réduction du risque sera important et plus il sera nécessaire d'exproprier et d'investir.

Il vous est **demandé de faire un choix entre les trois niveaux d'ambition afin de construire votre scénario d'aménagement préféré**. A cet effet, vous pouvez **choisir une seule famille de travaux (génie civil ou restauration écologique) ou combiner les deux familles de travaux (génie civil et restauration écologique)**.

3.1. Avant d'opérer vos choix, pouvez-vous **nous confirmer** si vous avez **déjà eu l'occasion**, dans cadre **d'une politique publique**, **d'exprimer votre opinion** sur **les solutions de gestion du risque d'inondations** dans **votre commune de résidence** ?

Oui	Non
○	○

[31] Rapport final d'étude de restauration pour l'AERMC

3.2. Choisissez le **<u>niveau d'ambition de la ou les familles de travaux</u>** que vous **<u>préférez afin de construire le scénario d'aménagement que vous pensez le plus adapté à la Brague.</u>**
<u>NB : Vous pouvez choisir une seule famille de travaux ou combiner les deux familles de travaux.</u>

Travaux/Contraintes	Niveau d'ambition		
	Faible	Moyen	Fort
Travaux de génie civil	⊕ ¬ Pièges à flottants	⊕⊕ ¬ Pièges à flottants ⊕ Reprise de ponts et ou déviation de route	⊕⊕⊕ ¬ Grands barrages de rétention ¬ Endiguements et recalibrage de la Brague
Dépenses en investissements (foncier, constructions et en entretien)	⊕ ¬ Entre 0,4 et 1,5 millions €	⊕⊕ ¬ Entre 32 et 47 millions €	⊕⊕⊕ ¬ Entre 65 et 150 millions €
Expropriation de terrains nus et de bâtis	⊕ ¬ Terrains nus ¬ Entre 0 et 5 bâtis	⊕ ¬ Terrains nus ¬ Entre 0 et 5 bâtis	⊕⊕ ¬ Terrains nus ¬ Entre 5 et 10 bâtis
Votre choix	○	○	○

⊕ : Travaux en supplément par rapport à un niveau d'ambition plus faible
¬ : Travaux en commun avec à les niveaux d'ambition

Travaux/Contraintes	Niveau d'ambition		
	Faible	Moyen	Fort
Travaux de restauration écologique et d'accessibilité	¬ Création de pistes d'accessibilité discontinues	¬ Création de pistes d'accessibilité discontinues ⊕ Restauration du lit moyen de la Brague (élargissements) ⊕ Restauration de zones humides	¬ Restauration du lit moyen de la Brague (élargissements) ¬ Restauration de zones humides ⊕ Création de pistes d'accessibilité continues ⊕ Restauration de zones de rétention de crues ⊕ Restauration de la ripisylve
Dépenses en investissements (foncier, constructions et en entretien)	¬ Entre 2,5 millions et 3 millions €	¬ Entre 40 millions et 95 millions €	¬ Terrains nus ¬ Entre 232 millions et 459 millions €
Expropriation de terrains nus et de bâtis	¬ Terrains nus ¬ Entre 0 et 5 bâtis	¬ Terrains nus ¬ Entre 0 et 5 bâtis	¬ Entre 50 et 100 bâtis
Votre choix	○	○	○
⊕ : Travaux en supplément par rapport à un niveau d'ambition plus faible ¬ Travaux en commun avec à les niveaux d'ambition			

3.3. Parmi les propositions suivantes, quelles sont **les deux principales raisons** qui ont **motivé vos choix** ?

Le risque d'inondations	La biodiversité et amélioration des habitats naturels	Les dépenses en investissement et en entretien	La préservation du bâti
○	○	○	○

3.4. **L'ensemble des deux familles de travaux** pourraient avoir des **impacts potentiels** ci-après. **Sélectionnés les 5 impacts les plus importants** pour vous.

Impacts	Les 5 plus important
Réduction du risqué d'inondations	○
La production agricole dans les plaines inondables (produits agricoles locaux)	○
La récréation/le tourisme/ appréciations paysagères (promenades, pêche, randonnées, éducation et observation à la nature et à la biodiversité.)	○
La biodiversité et l'amélioration des habitats naturels (richesse écologique aquatique et terrestre)	○
La régulation de l'environnement local (îlots de fraîcheur, contrôle des érosions)	○
La régulation du climat (séquestration de carbone)	○
La régulation de l'eau (recharge des nappes phréatiques)	○
Purification et filtration de l'eau par la végétation (élimination des polluants résiduels dans l'eau).	○
Purification et filtration de l'air par la végétation (diminution de la concentration des particules fines)	○
Cohérence et la continuité territoriale (Continuité entre les espaces, littoral, ville, parcs naturels, forêts)	○

3.5. **Distribuer 100 points entre les 5 cinq impacts** ci-dessus sélectionnés afin de montrer l'importance que vous accordez à chacun d'eux. Par exemple, vous pouvez **accorder les 100 points à un seul impact, ou les partager entre les 5 impacts**. **Le total des points ne doit pas excéder 100** et vous devez **utiliser nécessairement les 100 points**.

Impacts	Points pour 5 impacts les plus importants
Réduction du risqué d'inondations	

La production agricole dans les plaines inondables (produits agricoles locaux)

La récréation/le tourisme/ appréciations paysagères (promenades, pêche, randonnées, éducation et observation à la nature et à la biodiversité.)

La biodiversité et l'amélioration des habitats naturels (richesse écologique aquatique et terrestre)

La régulation de l'environnement local (îlots de fraîcheur, contrôle des érosions)

La régulation du climat (séquestration de carbone)

La régulation de l'eau (recharge des nappes phréatiques)

Purification et filtration de l'eau par la végétation (élimination des polluants résiduels dans l'eau).

Purification et filtration de l'air par la végétation (diminution de la concentration des particules fines)

Cohérence et la continuité territoriale (Continuité entre les espaces, littoral, ville, parcs naturels, forêts)

4. Votre contribution financière à votre scénario préféré

Ce module vise à évaluer votre contribution financière aux coûts que peuvent entrainer la mise en œuvre de votre scénario de réduction du risque préféré dans la Brague. Les travaux ne peuvent être mise en œuvre que si les autorités publiques obtiennent le financement nécessaire. Votre contribution financière permet de quantifier :

- L'importance que vous accordez à la gestion du risque d'inondation dans le bassin versant de la Brague
- L'importance que vous accordez à la concrétisation des travaux sélectionnés dans à la question 3.

4.1. Etes-vous prêt à contribuer financièrement, par une augmentation de votre facture d'eau, à la mise en œuvre des travaux sélectionnés? Nous vous rappelons que toute contribution est une ressource en moins pour d'autres postes de consommation dans votre ménage.

Oui	Non
○	○

Si non passez à la question 4.3

4.2. Si oui, donnez (i) le **montant à partir** duquel vous **êtes certains de contribuer** et **(ii)** le **montant à partir** duquel vous êtes **certains de ne pas contribuer**

NB : Pour être cohérent, le montant reporté sur la ligne (i) doit être inférieur au montant reporté sur la ligne (ii).

	Contribution annuelle (€/an/ménage)
(i) Le montant à partir duquel vous êtes certains de contribuer	………………
(ii) Le montant à partir duquel vous êtes certains de ne pas contribuer	………………..

4.3. Si non, quelle est l'affirmation qui justifie le mieux votre réponse ?

La description des travaux n'est pas claire pour moi	Je ne crois pas que les travaux auront un impact significatif sur le risque inondation	Je ne crois pas que les travaux vont changer grande chose à la situation actuelle	Je ne suis pas concerné par les impacts et je ne pense pas devoir contribuer financièrement
○	○	○	○

Je paie déjà suffisamment de taxes locales	Ma situation financière ne me permet pas de contribuer à ma stratégie préférée	Autres, précisez

5. Cette enquête et vous

5.1. Avez-vous des commentaires sur ce questionnaire ?

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Annex 12. Estimated population in the Brague (2015)

ID	Municipalities	Part of the area includes in the catchment	Population (2015)	Estimated population in the Brague*
1	Biot	95%	9,876	9,353
2	Valbonne	92%	13,183	12,142
3	Châteuneuf	78%	3,219	2,504
4	Mougins	39%	18,476	7,150
5	Opio	32%	2,212	699
6	Vallauris	26%	25,966	6,803
7	Antibes	25%	74,875	18,344
8	Mouans-Sartoux	15%	9,510	1,407
9	Villeneuuve-loubet	7%	14,266	927
10	Le Rouret	3%	4,003	112
11	Grasse	2%	50,937	968
Total population			226,523	60,410

*: We assume uniform distribution of the population on the territory.

Annex 13. Criteria elicitated during Focus Group Workshops

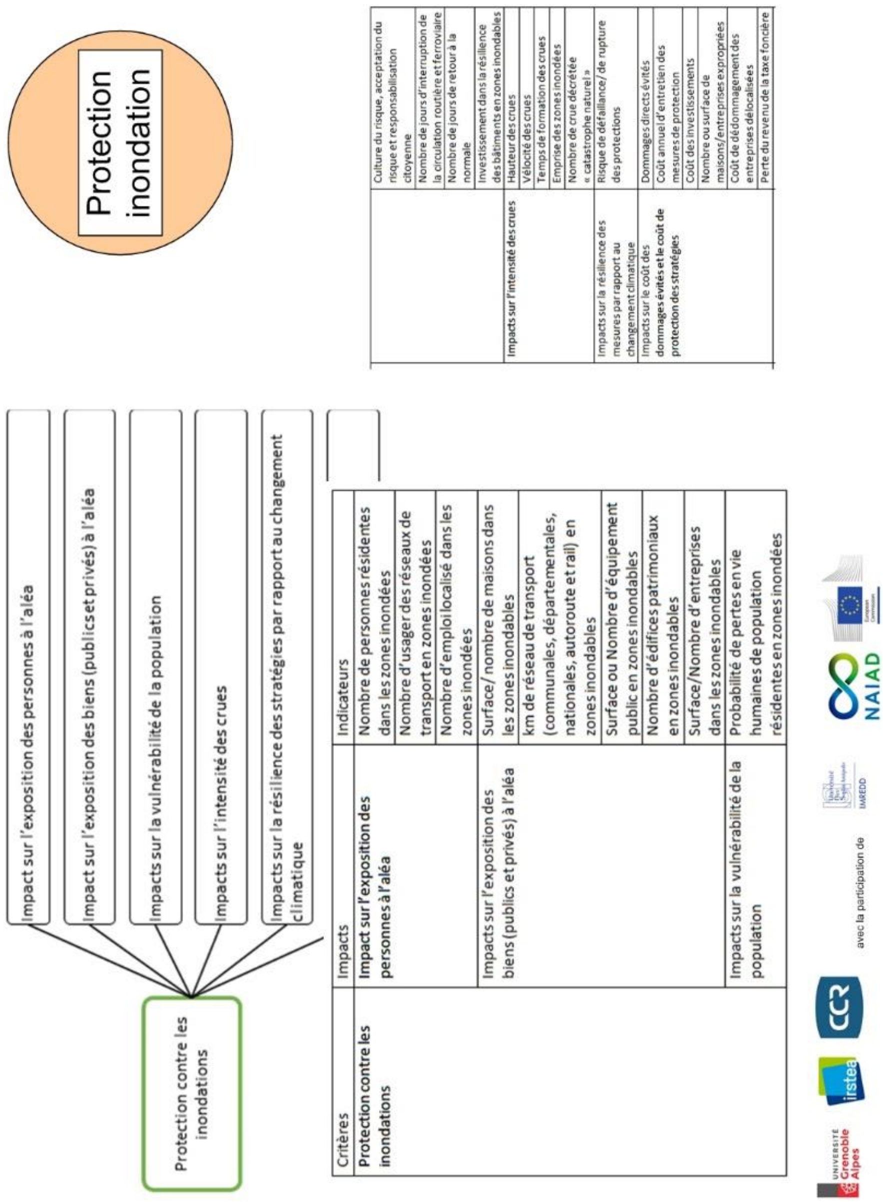

__Figure 41__: Some Flood protection issues resulting from workshop with stakeholders (Irstea,CCR, Univ. Nice)

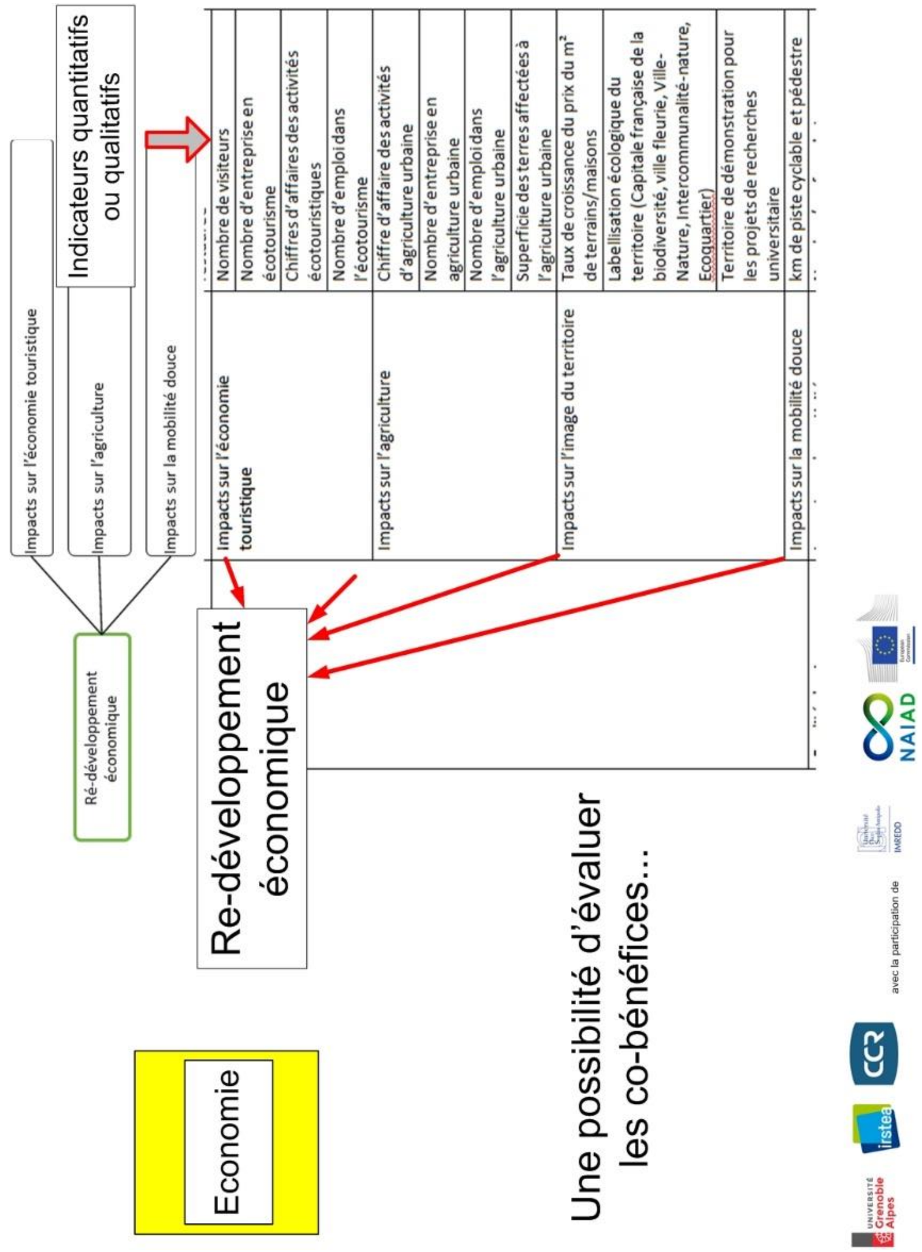

***Figure 42**: Some economic redevelopment objectives resulting from workshop with stakeholders (Irstea,CCR, Univ. Nice)*

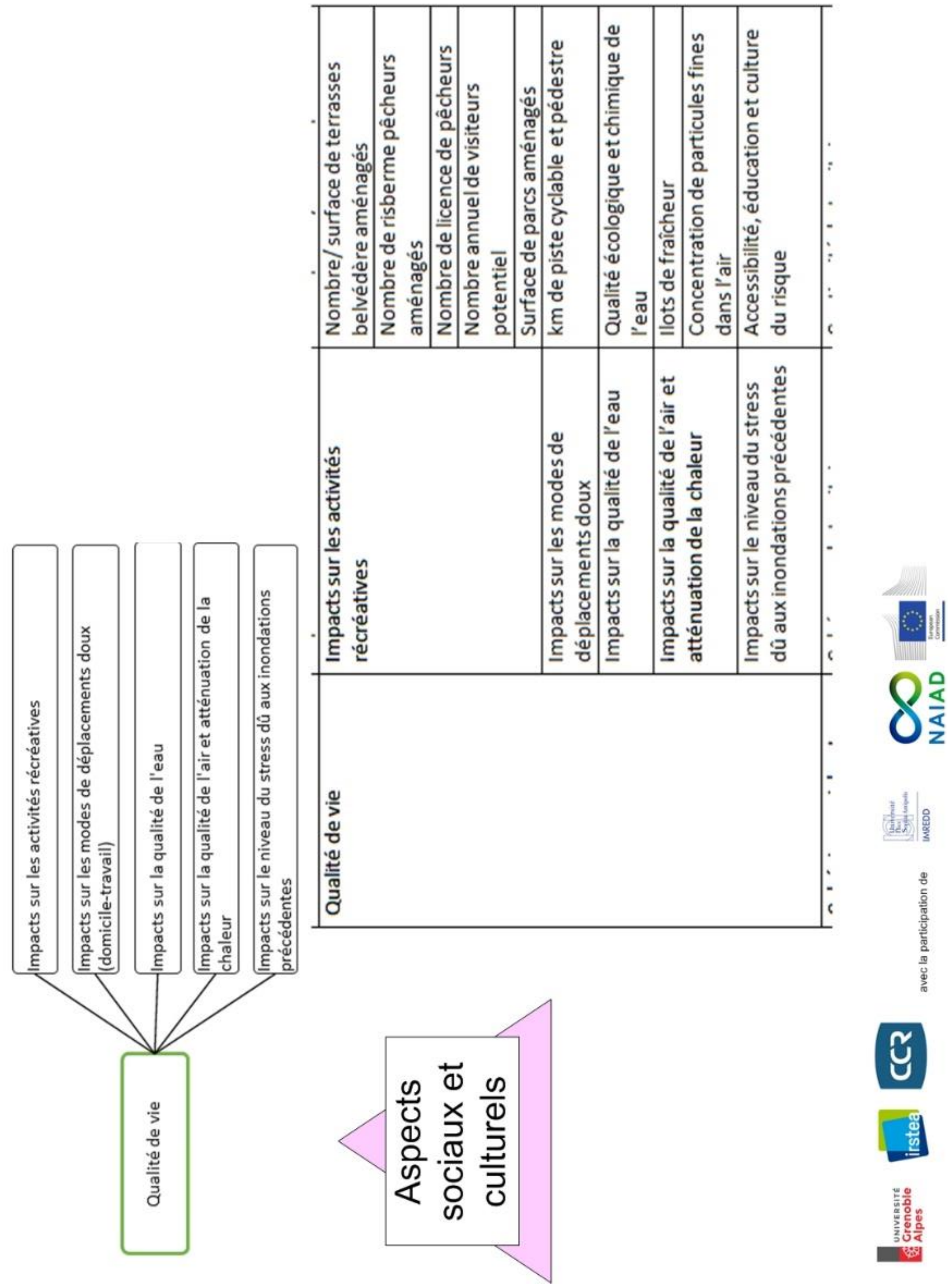

Figure 43: *Some quality of life objectives resulting from workshop with stakeholders (Irstea,CCR, Univ. Nice)*

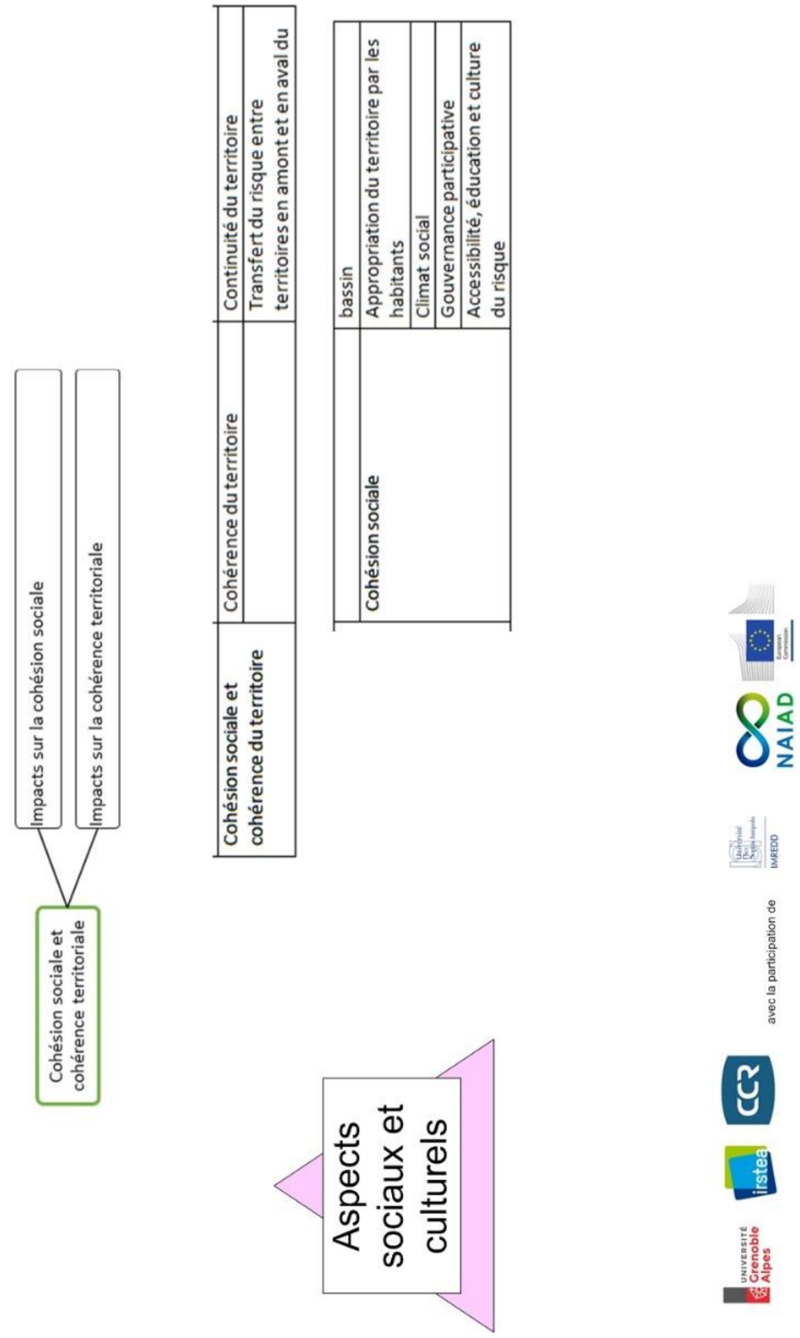

Figure 44*: Some social objectives resulting from workshop with stakeholders (Irstea,CCR, Univ. Nice)*

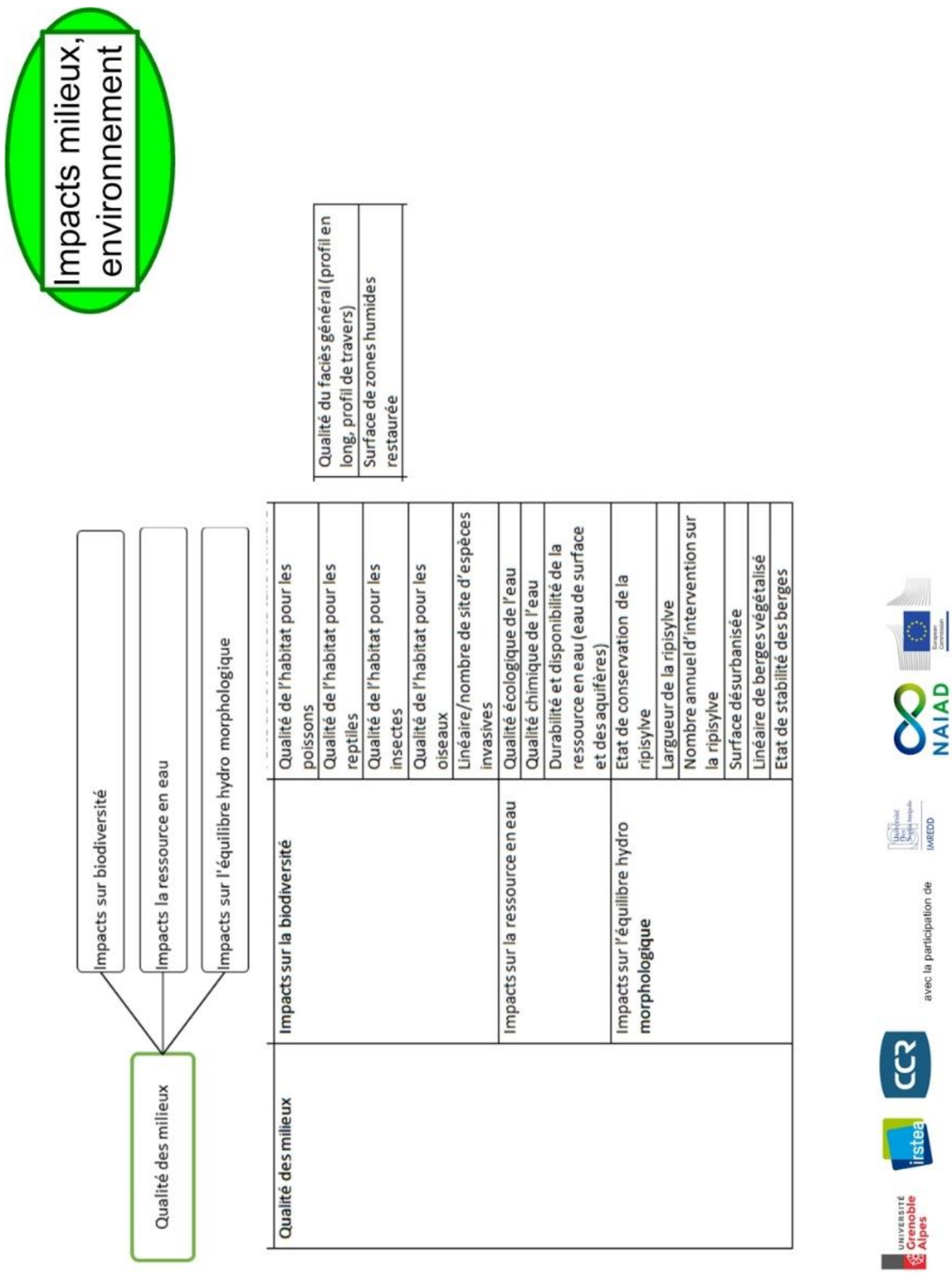

Figure 45: Some environmental objectives resulting from workshop with stakeholders (Irstea,CCR, Univ. Nice)