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Executive Summary

In this deliverable we highlight the role of different approaches in assessment of effectiveness of Nature Based Solutions with a focus on Natural Flood Management. We review a range of approaches, indicating under what conditions the approach used is useful and the challenges to its application. We include monitoring, modelling and spatial analogue approaches. The purpose of the deliverable is to act as an indicator, across a range of NBS types and geographical settings, of the kinds of approach that are best suited to these cases. In this way the deliverable is written as a reference resource of a variety of different approaches trialed in a range of settings.

The deliverable is organised by demo, with the exception of the Thames demo, whose techniques are fully covered in D2.6. Under each demo we provide: (a) a description of the NBS and demo context, (b) a description of the approach to understanding NBS, (c) why this approach is chosen ahead of other approaches and an outline of the key challenges in applying this approach to assess the effectiveness of NBS.

We conclude by summarising the range of approaches previously applied to NBS for Natural Flood Management and how the NAIAD approach diversifies and improve on what went before. This deliverable is intended to highlight a variety of techniques available to those intending to study the effectiveness of NBS across a range of settings within and outside of those that can be examined using the Eco:Actuary or //Smart: technologies developed in D2.5 and D2.6.



Introduction to the approaches selected to understanding the role of NBS in hazard mitigation

NAIAD Demos displayed different scales, environments and hazards. Therefore several methods, models and tools were developed to assess and/or simulate the effectiveness of NBS implementation at each demonstration site. In the following sections are described the different approaches selected by each NAIAD DEMO to assess NBS effectiveness in hazard mitigation. These tools therefore in terms of replicability would be particularly well suited for gathering evidence from NBS about to be implemented *ex ante* or *ex post* assessments for different geographical settings and hazards.



GLINŠČICA DEMO

Authors: Pengal P., Cokan B.

1. Measurement

a) A description of the assessment.

Field measurements of all **barriers** on Glinščica River (dimensions).

Field measurements of all **bridges** over Glinščica River (dimensions).

Measuring **water level** changes (i.e. stage) with FreeStation stage meter (www.freestation.org) under the Brdnikovo dry retention area on Glinščica River.

b) Why the assessment approach was used in preference to other approaches

Dimensions of bridges and barriers are an important **factor** affecting the **flood risk** of the area. The measurements were necessary to obtain data for later hydrological modeling.

No hydrological station is located on Glinščica River, therefore the Freestation is needed to measure water level and discharge of Glinščica River.

c) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

Lack of past water level, discharge and other **data** needed for hydrological modeling.

2. Modelling

d) A description of the Demo NBS, it's geographical and flood risk setting.

Glinščica catchment is situated within the borders of the Municipality of Ljubljana (MOL) that spans roughly 275 km² and has a population of 284,000 inhabitants. The demo site covers 7.01% of Ljubljana's surface area, includes 5 of its districts (Dravljje, Šiška, Rožnik, Vič, Šentvid) and accounts for 8.17% (23,200) of its population, which should all be considered stakeholders in flood management. Originating at 409 m.a.s.l., the headwaters in the steep hill slopes of Toško Čelo give the Glinščica stream a torrential character which, together with climate change (less frequent, but higher intensity rainfall) and hard regulations, results in regular flooding of the Vič and Rožna dolina districts of Ljubljana.



Floods are the most common form of **natural disasters** in the Glinščica catchment, causing enormous material damages. Several unsuccessful grey measures were implemented in the past with the goal to reduce flood risk in Glinščica catchment, but not taking into account the negative impacts on the environment. With the future use of nature-based solutions (NBS) and hybrid solutions as flood prevention measures, both, **reduction** in **flood risk** and the **good state** of the **environment** can be achieved. A combination of NBS, hybrid and soft solutions (**Figure 1**) has been structured into a future risk management scenario by the stakeholders in a co-creation process and this scenario compared to the BAU (grey solutions only) through modelling. Enhancing existing retention areas effectiveness, river renaturation with re-meandering and wetlands restoration are the three NBS measures suggested to enlarge the retention capacity in the catchment. In addition, experts suggested to incorporate opening of natural floodplains, raising bridges and removing crosswise barriers as well as establishment of small multi-function wet retention areas and roof rain water tanks in the catchment to further increase capacity and lower the overall flood hazard levels.

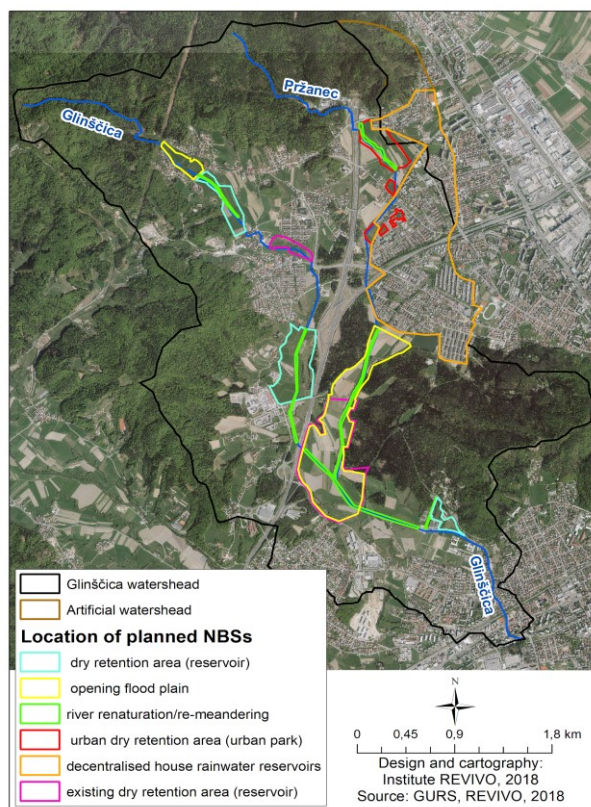


Figure 1. Potential locations for implementation of NBS measures suggested by stakeholders and experts in the Glinščica catchment (SLO demo) during the second workshop.



e) Why the assessment approach was used in preference to other approaches

The Glinščica catchment spans roughly 19 km², so the use of tools intended for larger areas is not appropriate. Since Eco:Actuary could not be applied to the Glinščica catchment due to size limitations, alternative modelling tools to estimate the effect of these measures on the retention and infiltration of surface water as well on the flood extent has been sought. Therefore, a series of models, integrated using BBN approach has been developed that fits the **size** and **specific conditions** of the **Glinščica catchment**. The hydrological model was developed using GIS tools, HEC-RAS and HEC-HMS software and different data such as LIDAR, conglomeration, land use, rainfall, discharge and other factors were analyzed and included into the model. In addition, stakeholder co-creation process was followed in which a risk perception model was developed and integrated with the bio-physical and economic data coming from individual sub-models.

Table 2. Evaluation of available models in Slovenian demo (Glinščica).

	Applicability	Accuracy	Compatibility	Practicability	Availability
Group Model Building and Social Network Analysis					
Risk perception model: Fuzzy Cognitive Map (FCM)					
Hydrological HEC-HMS and hydraulic HEC-RAS model					
Systems Dynamic Models: stock & flow					
FEV based model					
EcoActuary					
CostingNature					



f) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

Data related challenges & Scale related challenges

There are several **challenges** in using the selected modelling approaches. First, development of detailed hydrological model is **time**, **data** and **resource** demanding and requires specialist knowledge. Second, **NBS** as **specific/innovative measures** are not widely known and their functioning understood among the hydrological modelers in Slovenia and therefore, the **modelling capacities** are **very limited**. Third, the **open data policy** has not yet been integrated into Slovenian national administration and the relevant data is not fully available. Fourth, **participation** of **stakeholders** (e.g. land owners, municipality, national bodies, etc.) to achieve a consensus on the selection of NBS and their locations in Glinščica catchment has been reluctant. Finally, expert knowledge and **proposed solutions** that best suit the environment, social setting and economy are **not** usually **respected**.

3. Integrated Modelling using System Dynamics (SD) techniques

Glinščica Catchment is a short torrential stream entirely within the Municipality of Ljubljana, Slovenia's capital and as such presents a risk for the people occupying its floodplains. The stream has been deepened and channelized to acquire land for agriculture and urbanization in the early 20th century, but the practice continues today. Two main goals for the Glinščica NBS management plan have been set by the SHs: flood protection and environmental protection, so the NBS were selected to mainly target these aims.

From the 3 scenarios that were built using participatory approach, additional one was finally selected as the most suitable and has been economically valued. Three (3) physical measures were selected (Retention areas effectiveness, River renaturation with re-meandering.

And Wetlands restoration) to naturally retain water and diminish the hazard and the nine (9) soft measures were recognized as required to complement the physical measures by enabling their implementation and to diminish vulnerability. The selected physical measures will form a network of NBS across the catchment that will together lower the flood hazard and thus contribute to the overall flood risk management.

g) Description of assessment technique

Collective Fuzzy Cognitive Maps (FCMs) were built in order to define, along with the stakeholders, a shared model of the system, based on the identification of the key variables, and of their causal interconnections and influences. This is particularly useful in order to describe the main effects of NBS on the System according to their perception.

Stock and flow modelling were used to support an integrated assessment of NBS effectiveness, combining a simplified hazard modelling with a semi-quantitative analysis of benefits and co-benefits associated to NBS introduction. The synergic effect of socio-institutional measures is taken into account as well.



h) Why used in preference to other techniques

The **main advantages** of using FCMs are related to:

- The simplicity of the tool and the capability to easily visualize the multiple aspects of complex systems.
- The possibility of integrating multiple variables, dynamics and points of view in a single picture.
- The possibility of identifying key variables (such as co-benefits).
- The capability to perform a simplified scenario analysis.

All these features are highly relevant to support the preliminary analysis that is needed in the Demo, considering the local level of awareness.

The **key advantages** of stock and flow modelling can be summarized as follows:

- It provides a semi-quantitative assessment of the multi-dimensional implications of the introduction of NBS, with a focus on the production of co-benefits.
- It is a dynamic tool, and thus capable to investigate the evolution of system with time (i.e. to analyze NBS effectiveness considering a change in the external conditions and in their own level of implementation).
- It allows a full and effective involvement of stakeholders during the whole process, allowing knowledge integration, collaboration and integration of skills
- The use of system thinking supports the identification of potential policy resistance mechanisms, rebound effects and unintended consequences.
- It supports scenario analysis.

The main aspect is that SD tools allow building a comprehensive and holistic view of the system.

i) Key challenges in accurately assessing the effectiveness of NBS in hazard mitigation

The use of FCM provides a qualitative assessment, thus it cannot be considered sufficient for supporting policy- and decision-making. Rather, it is crucial to analyze and structure problem perception, and to integrate local knowledge.

Furthermore, it is directly based on the knowledge and of the subset of involved stakeholders. Potential limits of the information provided are related to the process of stakeholders' selection and on the structure of the process of participation.

It should be also considered that FCM are static, and thus not directly usable to perform a dynamic assessment, which is often needed for NBS.

The **main challenges** can be summarized as follows:



- Stock and flow models are currently not explicitly spatial, although some research is going in this direction.
- They are not suitable to describe micro-behaviors and actions, but can rather be used to model the effects of policies and decision at a global scale.
- The model can be built with different levels of complexity, i.e. it supports the integration of specific detailed sub-models (e.g. physical risk assessment, economic assessment etc.). However, the model in its current form is not directly related to external models that could improve the quality of results.

4. Expert opinion

Glinščica catchment is considered the green wedge of Ljubljana, but as such presents ideal space for further urban sprawl and continuously draws attention of developers, unaware or irrespective of the risks. **Representatives of all the key players and main stakeholders have been involved** at least in some parts of the participatory process. However, the representatives of key players did not have the mandate to express the opinion or standpoint of their institution but rather joined the activities as observers, which made it impossible to integrate their expert opinion into the overall participatory process. The **research institutions** participated openly and expressed their opinion freely, providing valuable aspects and insight into the final catchment management plan. The local residents were somewhat reluctant to participate, since they are not usually considered stakeholders during such an early planning phase. However, they attended several activities and actively participated in expressing their opinion and concerns. Finally, the **municipality** as an associated strategic partner has fully participated with representatives of several different departments and providing data and support whenever required, expressing the expert opinion of the different municipality departments, which are also sometimes in contradiction.

j) A description of the Demo NBS, its geographical and flood risk setting

Experts and local communities were involved in project activities using both individual and collective activities. More specifically:

- **Individual semi-structured interviews** were performed with local stakeholder to support eliciting individual risk perception. Fuzzy Cognitive Maps (FCMs) were built, starting from these interviews, in order to structure individual risk perception in a formal model. The key variables, and their causal interconnections and influences, were defined and analyzed (e.g. with the aim of defining their centrality). This is particularly useful in order to describe the main factors to be considered in the process of NBS co-design and modelling.
- **Workshops** were organized to perform exercises oriented to the identification and ranking of the key impacts associated to NBS, and thus to select the most effective measures to achieve the main goals identified by the stakeholders.



k) Why the assessment approach was used in preference to other approaches

The use of expert opinion and of tools oriented to support a wide stakeholders' involvement allows comprising in the modelling process a significant body of local knowledge that otherwise would be neglected. Including multiple different experts and stakeholders can support a process of knowledge and information integration, helping a multi-disciplinary approach to a complex issue such as NBS analysis and impact assessment.

Additionally, the inclusion of local stakeholders in the co-design process has the key advantage of increasing the sense of ownership of the solutions that are identified.

Lastly, the process of collective identification and selection of variables and drivers, was the basis for the building of the crowdsourcing tool that is being developed to include data provided by the local communities.

l) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

The use of tools and models based on expert opinion and on stakeholders' involvement is not straightforward, due on the one hand to the difficulties that could be faced in having a wide participation, and on the other hand to the potentially limited role of individual perception. It must be considered that the role of expert opinion structuring and, more in general, of participatory processes is fundamental in order to assess the perceived effectiveness of NBS rather than the technical effectiveness.

Potential limits are related to the process of stakeholders' identification and selection.



LEZ DEMO

Authors: Le Coent P.

1. Measurement

a) A description of the assessment

Historical claims data collected by CCR within the national insurance framework (portfolio of the 2014-event).

Land-use data collected from the official Corine Land Cover (CLC) for France and the locally-adapted land-use created by the Montpellier community (MMM).

Comparing flood water extension modeled with the real extension of the 2014-flood event on the Mosson and Verdanson, data from the SYBLE.

Hourly rainfall data has been procured from Meteo France at weather stations identified as being able to explain the karst saturation: Montpellier (34154001), Prades-le-lez (34217001) and St-Martin de Londres (34274001) stations. Hydrological data (Qtvar) at the 3 hydrological stations of the Lez River (Lavalette, Garigliano and Lattes) have been extracted from the site of the French hydro bank (<http://hydro.eaufrance.fr/>). A database at an hourly time step has been created from the Qtvar data with (i) average value if the time step of the variable Qtvar is <1 h, and (ii) linear interpolation of the raw data if necessary when the time step of the variable Qtvar is greater than 1 h.

b) Why the assessment approach was used in preference to other approaches

The utilization of the claims data allows in a first time to better understand the local damage and to define whether if the claims are due to overflow flooding or runoff effects. In the Lez case, it has been demonstrated that the claims are mostly located outside the flood-prone areas. The use of locally-adapted land-use is important to enhance the runoff modelling. The comparison between the real and modeled overflow participate in the validation of the model.

2. Modelling

c) A description of the Demo NBS, it's geographical and flood risk setting

The Lez River (29 km long) is a small coastal Mediterranean river with a watershed of 746km². Its spring is the outlet of a large karst aquifer. It then crosses natural and agricultural areas before reaching the plain of Montpellier (290 000 inhabitants) and the Mediterranean Sea. The Montpellier plain is characterized by a rapid urbanization with massive land artificialization and soil-sealing (-2920ha of agricultural and natural area from 1990 to 2012). The watershed is



exposed to a typical Mediterranean weather marked by repeated droughts and heavy rainfalls and storms in very short time scale in autumn, the so-called “Cevenol events”. These events generate flash flood of the Lez and its tributaries as well as runoff flooding in urban centers. In 2014 only, 3 major events led to 65 million euros of damages, only for private housing and businesses. Large investments have been carried out to manage overflow risk but runoff risk remains a major challenge with 78% of damages in the recent large event of 2014.

- NBS 1: Active management of the Karst System. The Karst System from which springs the Lez River is artificially pumped and provides drinking water for 340,000 inhabitants. The decrease of the water table due to pumping during the summer season increases the retention capacity of karst during flood events. This may play as a buffer against flood especially during post-summer rainfall events.
- NBS 2: Conservation of agriculture and natural land through urban planning policies. Urban planning policies allow the conservation of agricultural and natural land which in turn influences flooding risk. Three scenarios of urbanization are studied for the 2040-time horizon:
 - a. A laissez faire-scenario in which the population growth remains high and new urbanization mainly relying on individual housing that leads to the artificialisation.
 - b. A scenario calibrated on present policies with a limitation of population growth and efforts of densification that leads to the artificialisation of 1600ha.
 - c. A very virtuous scenario limitation of population growth and an objective of no additional artificialisation.
- NBS 3: Deployment of green infrastructure (GI). GI increase water retention and reduce runoff risk within urban areas. We particularly study: the deproofing of existing impervious area to restore water infiltration, permeable pavements, bioswales, green roofs, open retention basins and rain gardens.

d) Why the assessment approach was used in preference to other approaches

Similarly to the Gliscica catchment, the use of tools for larger areas is not appropriate and the Eco:Actuary tool could not be applied due to size limitations of the Lez area and to the importance of underground water. Thus, two specifically developed models are used to evaluate the effectiveness of NBS on flooding risk 1) the impact of the Karst Aquifer (BRGM Model) and 2) the impact of the conservation of agriculture and natural land and green infrastructure (CCR Model).

BRGM Model



The purpose of this model is to simulate the impact of several pumping scenarios on flood hazards and damages.

In order to forecast the flooding hazard in karst aquifers where groundwater plays a role, it is necessary to simulate the hydrodynamic response of the karst aquifer and couple several models “in a waterfall”, each model output being the input of the next downwards model:

- The hydrogeological model is a semi distributed hydrogeological lumped model (called Tempo, Pinault et al. 2001) of the Lez karst aquifer (Ladouche et al., 2014). It computes the water level into the karst aquifer and the discharge at the Lez spring according to meteorological data (rainfall and evapotranspiration) and pumping data. It provides the hydrodynamic state (saturation state of the aquifer) at any time step;
- The same numerical model Tempo (Pinault et al. 2001) is used for the hydrological modeling: computation of flow of The Lez River at several hydrometric stations on the basis of two inputs: the flow from the catchment upstream and the effective rainfall precipitated on the sub-catchment defined between the hydrometric stations considered.

CCR Model

The CCR catastrophe loss risk model is used for understanding the role of NBS 2 and 3 in runoff flood risk mitigation, in terms of avoided insured damage. This model contains 3 units (hazard units to model runoff, vulnerability unit to geolocate assets at risks, type of risks and insured value and the damage unit to calibrate damage curves and to calculate destruction rate).

The CCR national runoff model was adapted to the local Lez DEMO and for the 2014-events by using, notably, adapted-land use, and by tuning the model to calculate slopes taking into account water heights on each mesh. This method sprawls water along short watercourses, instead of being stuck in the banks. Then, the damage model was adapted to the runoff hazard of the 2014-event and validated by comparison between the estimated damage and the real costs of the damage.

In addition, for the climate change scenario, the assessment of the Lez DEMO was performed from previous CCR studies on the impact of climate change on insured damage in mainland France. The methodology relies on the Météo France climate scenarios using ARPEGE-Climat for supplying CCR hazard and damage models. The ARPEGE-Climat model generates 400 years of climatic data such as rainfall, wind speed and atmospheric pressure and soil wetness index. The calibrated runoff damage curves were applied to the climate change scenario to understand the future exposure of the DEMO.



Table 3: Evaluation of available models in Lez demo.

	Applicability	Accuracy	Compatibility	Practicability	Availability
Simurba model					
Eco-Actuary					
Combined Hydrogeological and hydraulic Tempo Model of the Karst System					
CCR catastrophe loss risk model					
Itree Eco					

The basis of the modelling approach was the modelling of the future of the Lez basin for the 2040 time horizon using an urban simulation model Simurba (Calvet et al. 2020). This model was initially developed for other purposes and therefore required specific development to be used for NBS development. The land use futures were then used as a basis for the modelling of the damages under different NBS scenarios.

Using Eco:Actuary as the assessment approach would have facilitated knowledge exchange and data integration with other NAIAD project partners. However, the grid resolution is not well suited to the scale of the water system in demo Lez. The finest resolution within Eco:Actuary (100m*100m) is too large to allow for accurate modelling of water flows in our partially urban context. In addition, Eco-actuary did not include underground water modelling.

We therefore used a combined Hydrogeological and hydraulic Tempo Model of the Karst System (Fleury et al. 2009) in order to assess the impact of various pumping strategy in the karst system to reduce Lez Overflow. This model was perfectly suited to respond to our NBS scenarios of active management of the karst. It however yielded non-significant difference between the scenarios and was therefore not pursued in the analysis.

The CCR catastrophe loss risk model was the main model we used to evaluate damages under different NBS scenarios (Moncoulon et al. 2014). Its main strength was its capacity to simulate runoff damages in urban context, based on the use of a database of private insurance claims managed by the CCR. The model allowed to test the impact of urban scenarios on flood damages and showed the limited impact of urban restrictions on the reduction of flood damages. It also allowed to make a direct link between the reduction of runoff with NBS and the reduction of damage costs. The model however lacked a module allowing to estimate precisely the reduction of runoff generated by NBS, that had to be estimated with expert judgement. The model also



allowed to estimate climate change impacts on damages. The main weak point of the model is the fact that it is an in-house model of the CCR not easily available outside the organization.

The Itree Eco (Nowak et al. 2006) was used to estimate the impact of NBS on the reduction of air-pollution and on C storage, important NBS co-benefits. The model is easily available but is mainly adapted to evaluate the impact of existing green infrastructure and not evaluate them ex-ante. It therefore required significant adaptation to be used for that purpose. A choice experiment (based on a survey) was finally preferred to evaluate the bundle of co-benefits generated by NBS scenarios.

e) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

BRGM model

The main challenge for karst aquifer modelling is the high heterogeneity of the system. Therefore, classical meshed models are not able to properly simulate the global response of the aquifer to rainfall. A lumped model should be implemented in order to properly simulate the aquifer response: in order to take into account, the specific hydrogeology of this aquifer a semi-distributed approach has been implemented.

Another challenge was related to the difference of time dynamics between groundwater and surface water flows: the latter being considered at hourly time step while the first at daily time step.

Uncertainty on water level and discharge rate during flood peak is a supplementary challenge for flood modelling.

CCR Model

In terms of data, one challenge is the inexistence of runoff damage curves calibrated for the Lez DEMO.

There are also several challenges in using the runoff modelling from hazard to damage assessment. First, adaptation of the runoff model requires locally-adapted data and time. Luckily, Montpellier city has a well-developed open access database. Second, calibrating specific runoff damage curves requires time for both development and validation processes. Third, the integration of NBS within the runoff model is quite complex and requires expert knowledge for modelling the effects on hazards. A solution to compensate this lack of knowledge has been found, by assessing the efficacy of a percentage of hazard reduction on damage costs. This method permits the evaluation of the avoided damage thanks to the implementation of NBS measures reducing a certain percent of the hazards.



3. *Expert opinion*

There were indeed some consultations with experts, but we did not use a structured expert based approach for the modelling of NBS effectiveness. The expertise mainly lied in CCR for runoff modelling and BRGM for the karst modelling.



COPENHAGEN DEMO

Authors: Van Der Keur P.

4. Measurement

a) A description of the assessment

Automated and manual measurements of groundwater potential data are used for calibrating the hydrological model used. In addition, automated measured discharge is used to calibrate the discharge of the piped urban river.

b) Why the assessment approach was used in preference to other approaches

This data is readily available from various databases. Technique is standard and long time series exist for groundwater potential some of which are reported (compulsory) to GEUS managed database, others are from various big infrastructure projects, such as metro line and road tunnels. Preference for other techniques N/A.

c) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

Focus is on shallow groundwater for which only few observations exist. So, while the hydrological model is calibrated against potential from deeper layers, the simulation of shallow groundwater is a challenge and therefore also the estimation of 'avoided damage' from groundwater flooding. In addition, the groundwater model does not exhibit a detailed sewage system description so here simplifying assumptions were necessary.

5. Modelling

d) A description of the Demo NBS, its geographical and flood risk setting

The Copenhagen NBS considers the reopening of a currently piped river to a restored urban river (RUR) in its original position and environment (**Figure 2**). That means that the urban river, contrary to its current condition, will interact with the shallow groundwater and will act as a drain for both groundwater and for cloudburst management measures connected to it.

In the analysis two different type of scenarios are considered: (1) a scenario with and without the RUR – NBS in which the 'without RUR NBS' scenario is the 'Business-as-Usual (BAU)'; and (2) the climate scenarios: the reference climate, 1981-2010 and the future climate 2071-2100 using the RCP8.5 projection.



Model area: urban and surrounding catchment

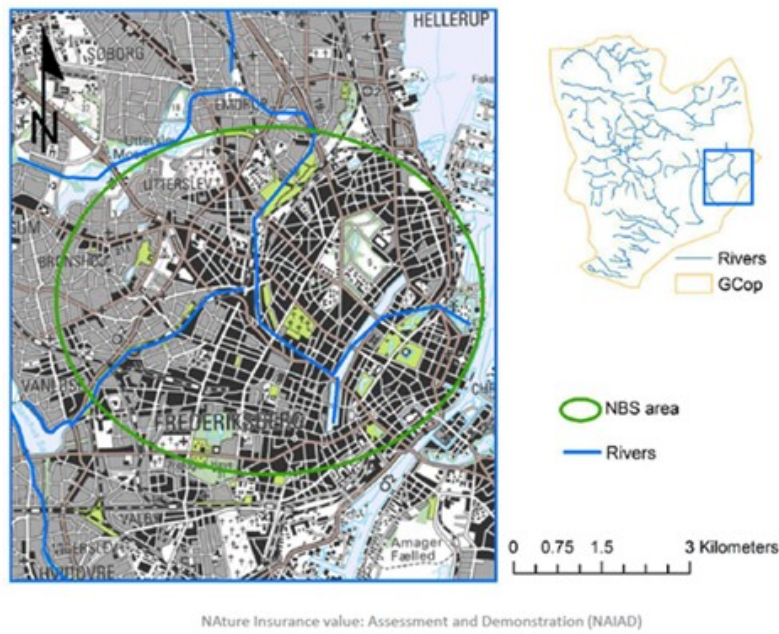


Figure 2. Copenhagen Demo catchment. The restored urban river (RUR) system is indicated with the blue line within the NBS catchment area delineated with green line.

Damage to below-surface infrastructure, residential cellars and tunnels for transportation considered:

(A) water damage due to (i) fast increased street level inundation and spilling over to lower areas, like cellars, via doorsteps or other low thresholds, as well as (ii) water pushed up from sewer system valves (in case no valve to avoid is installed). Both types are the result of fast 'catastrophic' rain events.

(B) slowly rising groundwater as a result of prolonged rainfall, changed (decreased) water abstraction patterns (water savings), and repaired sewage and drainage channels that also functioned as shallow groundwater drainage, all of which exacerbate the effects under (A) as drainage capacity to remove surface water is decreased.

The hydrologic model simulates the effect of (B) whereas mainly (A), and to an unknown extent (B) are considered in the damage functions. This means that the calculated 'avoided damage' is considered to be a minimum avoided cost.



The methodology builds on simulating shallow groundwater, which may rise above surface and become surface inundation. The avoided damage is calculated by analyzing the area in which shallow groundwater level exceeds a threshold value (2.0 m) where damage to cellars is probable and for which we have estimates depending on the type of built environment for that particular location This is illustrated in **Figure 3** below.

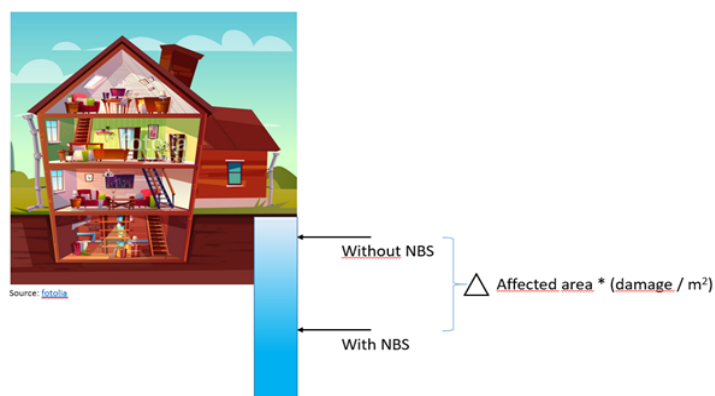


Figure 3. Avoided damage is calculated from the difference in area in which dwellings and businesses are affected by high shallow groundwater causing subsurface damage, i.e. cellars, and (in case the groundwater level rises above ground surface) inundation damage.

The avoided damage from groundwater flooding by means of a restored urban river NBS has been assessed by simulating spatial changes in shallow groundwater levels for two periods of time, current and future, and combine this with reported cellar depths. In case shallow groundwater level is higher a threshold depth value of 2.0 m below street level, a simple damage function is used to calculate damage, otherwise damage is zero. Scenarios with and without NBS are subsequently analyzed to arrive at an avoided damage by comparing scenarios on which the threshold value is exceeded or not. For both the current baseline climate and future period the avoided damage is slightly above DKK 20 million, which is a best case amount as several factors seem to underestimate the calculated avoided damage. More detailed information on the data, monitoring and modelling pls. Refer to van der Keur et al. (2018) (D6.2) and van der Keur et al. (2019) (D6.3).

e) Why the assessment approach was used in preference to other approaches

The modelling approach was used to assess the avoided damage as a result of the restored urban river NBS as focus has been on damage caused by high levels of (shallow) groundwater level. The Danish national model of water resources in Denmark already existed and is developed and



maintained by GEUS. The standard spatial resolution of 500 m x 500 m is too coarse for city scale assessments and was adjusted to 100 m x 100 m and for the NBS catchment itself at the even finer scale of 10 m x 10 m in order to realistically delineate areas of interest for the NBS avoided damage scenarios. Next step in the assessment for a refined spatially distributed damage and benefit assessment is the deployment of a GIS based Bayesian Belief Network approach in which qualitative and quantitative data can be integrated, among others from stakeholder elicitation workshops, to arrive at probabilistic results taking uncertainty explicitly into account.

Table 4: Evaluation of available models in Danish demo (Copenhagen).

	Applicability	Accuracy	Compatibility	Practicability	Availability
Group Model Building and semi-quantitative Fuzzy Cognitive Map (FCM)					
Group Model Building and Social Network Analysis					
MIKE SHE / HYDRO					
CostingNature					

f) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

Requirements for the accuracy of the model to assess the effect of NBS at the scale of a restored urban river led to downscaling the original resolution of the National Resources model (DK-model) from 500 m x 500 m to 100 m x 100 m and ultimately to 10 m x 10 m. The simulated shallow groundwater level at the finest resolution had to combine to average cellular depth at the scale of houses in affected residential areas.

6. Integrated Participative Modelling and Fuzzy Cognitive Maps techniques

g) Description of assessment technique

In order to investigate the main dynamics between NBS and its co-benefits, an FCM was developed for Copenhagen DEMO. The FCM was built from a Causal Loop Diagram that was co-



produced with key stakeholders in a participatory modelling phase. During this phase, Group Model Building techniques were used to define the main variables and relationships of the system. This was done to organize the collective knowledge of stakeholders in a graphical structure. The resulting group model was analyzed and post-processed in order to identify missing variables and relationships. During this post-analysis, the strength of the relationships between two concepts was indicated. The weights range in an interval of $\{-1, 0, 1\}$. The value 1 represents a positive causality and the strongest relationship. The closer the values approach to 0, the weaker the relationships are. This matrix defines the structure of the FCM and is needed to make possible the dynamic inferences. This is useful to analyze different management measures and strategies. For example, different NBS or risk reduction strategies can be analyzed by asking “what-if” questions to determine the state of the system under different conditions.

h) Why used in preference to other techniques?

FCM is a semi-quantitative method that is very suitable to analyze particular issues in systems where detailed quantitative information is lacking. The main advantage of FCM is that it eases the engagement of stakeholders through participatory modelling techniques. The key advantage of using participatory modelling techniques in the field of NBS analysis relies in its strong potential for integration of variables (e.g. qualitative and quantitative), knowledge (e.g. expert and derived from models) and issues (e.g. social, environmental, economic, etc.). For the Copenhagen DEMO, participatory modelling provided several advantages:

- It supports the organization of the collective knowledge of stakeholders in a graphical structure that can be used to promote learning as well as constructive and targeted discussions.
- Useful technique to conceptualize and understand the socio-environmental system where the NBS will be applied as well as the barriers and limitations of NBS implementation.
- It supports active collaboration and the rigorous integration of different expertise and interdisciplinary skills, thus building greater trust in models.
- It may contribute to show how the complex interconnections among system elements may lead to unexpected effects, thus helping to anticipate possible rebound effects or policy resistance as well as to identify suitable strategies to act on the systems.
- The whole process itself promotes awareness and motivation of those taking part in decision- or policy-making processes, thus providing a platform for the joint-ownership of results. The key advantage connected to the use of participatory modelling techniques in the field of NBS analysis (with specific focus on the decision support) relies in its strong potential for integration of



variables (e.g. qualitative and quantitative), knowledge (e.g. expert and derived from models) and issues (e.g. social, environmental, economic, etc.). This is, indeed, highly relevant for describing the multidimensionality of NBS, and their capability to produce a multitude of benefits over time.

Although FCMs are not able to make quantitative predictions, it is suitable to easily show changes in the behavior of the system due to changes in the relationships between factors. Therefore, FCMs allow the prediction of the effects of different policies taken under “what-if” scenarios.

i) Key challenges in accurately assessing the effectiveness of NBS in hazard mitigation

- It does not have no spatial dimension
- It only allows a semi-quantitative analysis of the temporal dynamics.

7. Expert opinion

j) A description of the Demo NBS, its geographical and flood risk setting

The Copenhagen Demo involved a number of stakeholders from a broad range of affiliations, including the municipalities of Copenhagen and Frederiksberg (the latter municipality is also in the restored urban river catchment, and as a whole is embedded in Copenhagen); the water utility companies; NGO Miljøpunkt Nørrebro who has been advocating the urban river NBS for many years; the Danish Regions authority and the Region of Greater Copenhagen; representatives of the climate adaptation networks; the umbrella organization for insurance and pension (F&P). The first workshop addressed the types of NBS possible, the target groups and ways to measure the effect of NBS using indicators. The second workshop tailored the outcomes of the first workshop to the by then adopted scenario of the restored urban river NBS.

k) Why the assessment approach was used in preference to other approaches

The workshop approach to involve stakeholders was preferred to other approaches because the identification of NBS, in general and later the specific restored urban river NBS required face-to-face communication and professional moderation (first workshop) to make optimal use of the stakeholder group expertise and experience. In addition, in the 1st workshop, results from other NAIAD work packages, notably WP3 and 5 were presented and further elaborated in round table discussions on the Stakeholder Network Analysis (SNA, WP3) and the System Dynamic Model for Copenhagen and the restored urban river SDM (WP5).



I) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

Key challenges acknowledged by expert opinion from the stakeholder group included ways to measure the effectiveness of the restored urban river NBS. Challenges include a reliable monitoring system for shallow groundwater (lowered as result of NBS) as this is not routinely monitored and poses technical difficulties. To be effective as urban river NBS, sufficient discharge has to be maintained from various sources (refer to D6.3) which has legislative issues on water quality to the restored urban river and subsequently to other open water recipients. In addition, the effectivity of the proposed NBS relates to avoided costs to sub-surface infrastructure for which currently a simple aggregated unit damage function is used, but which would need a higher level of sophistication to reliably estimate damage avoided by the restored urban river NBS



Lodz DEMO

Authors: Krauz K.

1. Measurement

a) A description of the assessment

The Lodz Demo has been approached twofold. The whole city has been analyzed using GIS data on distribution and quality (NDVI) of green infrastructure, frequency of flooding events according to interventions of Fire Brigades, pluvial flooding and flood risk maps, land topography, land use and surface impermeability. For 3 out of 22 rivers water chemistry has been measured before and after NBS.

Locally the focus of the study was the Jasień river catchment, with particular interest in typology of blue-green infrastructures and regulatory ecosystem services they deliver.

b) Why the assessment approach was used in preference to other approaches

The City of Lodz has been established on the dense network of rivers, currently streams, which - during the city's growth - were systematically merged into stormwater and sewage systems. In consequence the existing hydrological system of the city is complex and consists of modified rivers and underground grey infrastructure. The feasibility study clearly indicated lack of hydrological and hydraulic data, poor overview of Lodz' ecosystems and no information on risk, exposure or insurance related issues.

Additionally, the NBS interventions were limited to small scale implementation, with focus of NBS on nutrient regulation ES and water purification within single ecosystem domain - river and river-reservoirs systems, with final co-benefits like: recreation, disease prevention, habitat creation, biodiversity. The NAIAD's approach enabled pulling together existing information and identification of gaps and data needs.

c) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

In the city-scale assessment the challenge was related to data consistency, or for example no access to information about flood - related damage, cost-effectiveness of applied measures (mostly grey ones) and therefore hybrid and green alternatives. The study focused therefore on the insurance capacity of existing ecosystems. The small scale assessment has been handicapped by the high instability of flows caused by CC and urbanization that means, for example, not sufficient flows for data loggers, or peak flows being cumulation of storm water overflows.



2. Modelling

d) A description of the Demo NBS, it's geographical and flood risk setting

The City of Łódź DEMO is located in Central Poland, covers the area of 293 km² and has 683 thousand inhabitants. It is settled on 18 river catchments divided by the watershed border between the Vistula and the Oder. All the rivers except one (the Ner in the far North) have their sources located within the city borders, and all have been severely regulated. Eleven rivers have been additionally channelized and incorporated, at least partially, into underground storm water (or combined sewage-storm water) system. Particularly those impose high flood risk, when crossing the historical city center, due to limited capacity of the system confronted with growing area of impermeable surfaces. The City authorities, aware of the situation, are seeking the systemic solution to the problem and consider NBS as one of critical elements of the water management strategy for the future. At the moment however the grey approach dominates in all investments, extended with higher standards and techniques for temporal water retention (tanks), and rarely local water re-uses. The in street solutions comprise of elimination of barriers to rain water flow (e.g. path edges), new substrates with higher water infiltration capacities and planting of street trees for believed climate regulation, however do not include dedicated NBS.

The big scale NBS solutions have been applied only to rivers (not going beyond river valleys) with target to improve water quality and channel water and nutrient retention: in years 2006-2009 to the Sokołówka River and in 2010-2015 to the Bzura River, being cores of the City recreational destinations. Two other catchments – of the Łódka and the Jasień, have been chosen as DEMOS for more detailed studies concentrated on ecosystem services and NBS implementation under NAIAD and its follow up ERA-NET WaterWorks 2017 ATENAS projects. Both rivers drain together around 2/3 of the city area, what accounts for over 413 thousand inhabitants exposed to adverse effects of unsustainable urban drainage (pluvial flooding, drought and strong UHI effect).

e) Description of the Assessment technique

The Lodz DEMO worked along three lines to gather comprehensive information about the DEMO areas. The first one included expert consultations – researchers and city officers – and pulling together the information about hydrology, risks, planning, policy and existing blue- green infrastructure to identify the areas critical to sustainable water management. During the workshops Fuzzy Cognitive Maps were constructed in order to trace the perception of environment-related risks, the flow of relevant decision making and critical policies (gaps and opportunities). FCM technique was also used to construct the conceptual model of impact of NBS on regulatory services in the city. The second line involved structured and semi-structured interviews with inhabitants as well as co-design workshops. The interviews were focused on revealing the importance of different types of blue-green spaces to security and wellbeing of



citizens and identification of co-benefits they deliver in terms of ecosystem services. The co-design workshops and choice experiments were organized in order to find out the most desired elements in street, backyard and river corridor design, and, as side-effect, reluctance of society to NBS. The third line includes (still ongoing) development of indicators and models: Blue-Green Factor simplified RESI, quality indicators for blue-green infrastructure, BBN and System Dynamics, as well as the IRIP (Indicators of Intense Pluvial Runoff) model (Dehotin et al. 2015).

Independently the DAPSET approach has been applied to identify drivers of water problems in the city together with their risk profiles, power-legacy-urgency model has been applied to understand roles of stakeholders in managing /driving environmental problems, and CostingNature model has been applied to the Ner catchment in order to check its functionalities and usefulness in communication with stakeholders.

Trials to apply the CostingNature model have been carried for the biggest Lodz' river - the Ner. Although some outcomes were promising, the coarse resolution of the model applied to relatively small catchment made it not so useful as a risk management or ecosystem value communication tool.

f) Why the assessment approach was used in preference to other approaches

The approach had to consider low availability and fragmentation of data related to the role of ecosystems in securing wellbeing and city assets. On one hand it allowed completing the data and their harmonization, on the other using mixed qualitative and quantitative information. The FCM and models allowed to generate preliminary picture of the water and ecosystems in the city and to identify gaps in knowledge or new information sources. For example, the first time in the city's history, the issue of integrated environmental monitoring has become a topic for discussion.

At the same time the working formula targeted at creating the platform for broader discussion about the functionalities of the city, its structure and options to improve living conditions while simultaneously supporting biodiversity being the core of NBS. The aim was also to find out, indicate and counteract the inconsistencies in the actions taken by different agents and sectors of the city, which jeopardize achieving common sustainability targets. Experts' opinions helped to focus on priority areas, in spatial and conceptual sense. They also allowed concentrating the work with citizens on issues being on the agenda of the city authorities either in terms of available funding or urgency of actions.

Inclusion of local stakeholders and NGOs helped to understand attitudes towards the city greenscape, in terms of ecosystem services, monetary and non-monetary value, and co-benefits, and thus elements and options to be taken into account in modelling.

Table 5. Evaluation of available models in the Lodz demo (Poland).



Selection of methods in the Lodz demo was driven by data limitation, need to combine qualitative and quantitative information and complex hydrological context.

	Applicability	Accuracy	Compatibility	Practicability	Availability
EcoActuary					
CostingNature					
Bayesian Belief Network (BBN)					
Fuzzy Cognitive Map (FCM)					
Systems Dynamic Model (SDM)					
iTREE Eco					
DAPSET risk profiling					

EcoActuary and Co\$ting Nature were applied only to the catchment of one of the demo rivers – the Ner. With the catchment of 1866 km², it is the biggest river of the city, crossing mostly rural and suburban areas. The finest resolution offered by the models – 100m*100m – allows to carry some modeling and distinguish a few areas crucial from the point of view of flood risk reduction and sustaining biodiversity. However, the output is too coarse for communication with decision makers and navigate spatial planning.

Bayesian Belief Network (BBN) has been initially used to integrate knowledge about perception of blue-green infrastructure and ecosystem services derived from questionnaires and interviews with data on NBS performance and risk of flooding. The weakness of BBN is however impossibility of modelling the loop between cause, effect and the response. Also, the complexity of relationships appeared to be a limitation.

DAPSET risk profiling has been successfully applied as a tool allowing both data based and perception-based estimations (Krauze, Włodarczyk-Marciniak, 2018). The tool integrated knowledge of citizens and decision makers, who jointly chosen critical drivers of water-related problems in the city. In the next step representatives of several key City departments assessed the characteristics of the drivers according to thirteen features. Profiling enabled to precise the types of actions required to mitigate risks by applying measures that control the primary factors.

Fuzzy Cognitive Map appeared to be the most useful modelling tool both with respect to physical and societal factors. FCM has been used to elaborate SDM, and also to identify data requirements for more elaborated modelling.



Implementation of iTREE Eco as a tool for valuation and monetization of city trees has been only initiated within NAIAD project, however data collection will be continued beyond the project. Considering workload, preparation of input data for the model is rather time intense. The effort will be paid back by quantification of street trees influence on quality of urban environment, which is to be translated into fast value calculation spreadsheet. Such simplified tool will allow to better protect trees under land development.

g) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

The biggest challenge is the legacy in the field of spatial planning, people mentality, and structure of decision making system. The changes of Łódź urbanscape happened very fast in the times when there was no practice of process documentation. It resulted in building a super complex river-storm water- sewage system, additionally on the border of the first order watersheds, without any preliminary studies or systemic planning. It continued for decades so the growing system has not been parametrized until now. Water management is in fact based mostly on data gathered from several critical sewage outlets. The hydrological-hydraulic model for the whole city has been currently developed and is to be accomplished only in 2021. In such situation establishing of NBS is mostly intuitive and planning or assessment of their efficiency difficult, if not impossible, in the scale of the whole city (local efficiency is monitored). Simultaneously there is no data on soils, inventory of greenery, or economic loss caused by water-related events.

Very fragmented competencies and responsibilities make planning for NBS implementation as well as monitoring of their efficiency, difficult, e.g. implementation of small NBS in the front yard of a municipal building, aside a road requires involvement of 8 departments (Bureau of Spatial Planning, Municipal Services, City Greenery, Dpt. of Investments, Dpt. of Strategy, Lodz Infrastructural Company, Board of Roads and Transportation, Bureau for Revitalization), only for gathering all necessary data and permits. Those departments are in possession of different data series that are not pulled together, and continue with actions often of very contradictory effects.

Finally, inhabitants' mentality (both decision makers and civil society) limits the possibility for establishing participatory processes and living labs approaches. It is difficult to have wide participation in events, and then a follow up on the process. In general, civil society expects top-down management of the problems, pushing responsibility to decision makers. Simultaneously decision making system and workflow make difficult to analyze in detail community needs and respond in satisfactory way.



BRAGUE DEMO

Authors: Piton G., Tacnet JM.

1. Measurement

a) A description of the assessment

Field measurements consisted mostly in visits of all the areas that would be modelled using the 2D shallow water equation model Iber (Bladé et al., 2014). These visits enable to gather also the observations necessary to apply the Morphological Quality Index (MQI) method (Rinaldi et al., 2011) that seek to map and quantify the alterations (or lack thereof) to the geomorphology of the river. It is assessed through 28 indicators based on field qualitative observations and GIS analysis of maps and aerial pictures. The marks of each indicators are then aggregated after weighting in one unique score between 0, i.e., river totally altered, and 1, fully natural river. Additional field measurements were performed to deepen the knowledge on forest cover characteristics along the Brague and the Valmasque Rivers. The sizes, i.e., height, diameter, specie, number of stem and crown size, of about a hundred trees were measured by the forest specialists of the IGN, a sub-contractor of IRSTEA in the study of woody debris in the Brague. The same team also performed an extremely detailed digitalization work on the differences between the aerial photos of 2014 and 2017, i.e., before and after the extreme flood of Oct. 2015. They map all the eroded areas as well as nearly 3000 trees that disappear during the event. These data are available in Guitet (2018).

b) Why the assessment approach was used in preference to other approaches

The Brague River was yet covered by several detailed topographical surveys thus not requiring new ones. The MQI method is a relevant way to perform fast and rational assessments of the on-going alteration to the natural morphological functioning of the river. They were also used in a predictive way to provide a repeatable and rational assessment of the future improvement or degradation of the river quality in each protection scenarios that was proposed within NAIAD. It proved that using large dam reservoirs would degrade locally but also further downstream the river quality while the NBS strategies would enable to recovered the river quality of the 1940s., i.e., before urbanization of the lowlands when the valley was a mix of wetlands and agricultural lands. The tree measurement campaign was mostly performed because the large wood production during the Oct. 2015 extreme floods was extraordinarily high and well documented in term of deposition area. The sources of the trees were however only roughly known so far.



The inventory performed within NAIAD enable extremely detailed analysis of the behavior of a forest riparian belt during one example and extreme flash flood. It for instance highlights that (i) whatever be the vegetation management effort; large number of healthy trees can be recruited by extreme floods. In the Brague, nearly 100% of the 3000 trees that were recruited were stable, healthy trees since a vegetation management plan with regular maintenance visits was ongoing for 10 years. (ii) Mature forests along rivers naturally trap a lot of large wood, specifically if the channel width is smaller than the tree height. Conversely, young forests with smaller trees are more mobile when uprooted or scoured by the flow. Investing in vegetation management effort should thus not seek to reduce the amount of dead wood in the river (the great majority of large wood come from healthy trees) but to help the forest cover to mature in long and stable elements, prone to stops recruited logs during extreme events. These conclusions bring evidences that could shift the paradigm of riparian forest management from a dead wood removing philosophy toward a real forest quality restoration objective helped by a few large wood traps made with light structures to help the natural process of large wood deposition. This was included in the NBS strategies tailored to the Brague DEMO.

c) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

The use of the MQI method in a predictive way prove to be uncertain because we are not sure how some indicator will change. The method enables to provide an uncertain judgment and the results should be analyzed as much regarding the average score than the uncertainty range. Regarding the question of transport of large wood and shift in the way to maintain and restore the riparian belt, interviews and discussions with the stakeholders highlighted that the biggest obstacle to such a change will likely more be related to the perception of people on large wood and rivers rather than the technical and scientific rational of the approach. The trauma related to the event of Oct. 2015 when thousands of logs blocked the bridges in the city is still in all minds.

2. Modelling

d) A description of the Demo NBS, it's geographical and flood risk setting

The Brague River has a 68 km² catchment at its mouth in the Mediterranean Sea. Its headwaters are covered by suburban areas with forest and field patches on a plateau. The mid part of the catchment are steep hills covered by forests. The lowlands are former swamps, exploited by agriculture for a very long time. Suburban residential areas were built in number since the WWII



in this flat lowland valley. The Italy-Spain highway number A8 and the Nice-Marseille train line dam the valley in its middle part and near the shore. The region, as all the Mediterranean coast is subject to extreme downpour and flashflood, specifically during the autumn. Flood risks are thus actually of two kinds: surface runoff can be very intense and trigger numerous damages in all urban areas where flow is gathered by small thalwegs or road networks. This occurs throughout all the catchment. The run-off finally converges in the small valleys between hills and reach the lowlands valley where the flow is made difficult by the too narrow and shallow river bed channel and the bottleneck sections created by the numerous bridges (eventually clogged by large wood), the highway and the train line.

e) Why the assessment approach was used in preference to other approaches

Three different flood-modelling methods were implemented to assess flood risk and to appraise the NBS protection efficacy. The *Flood-Excess-Volume* method was developed with the help of colleagues from Leeds University (UK) on the Brague River and their case study (Bokhove et al., 2019). The method offers a straightforward and educational protocol targeted for flood protection effectiveness analysis and decision making involving stakeholder participation. Quantification and interpretation of effectiveness and cost of protection strategies are facilitated using a graphical display that is easy to understand and encapsulates concepts of flood magnitude and protection-measures efficacy. It enabled a fast screening of protection strategies based on multiple panels of green and grey protection measures. Based on this preliminary assessment, promising strategies involving both small water retention measures in the upper part of the catchment and giving room to the river in the lowlands were further studied with more advanced models. The runoff model used in France to quantify damages when a disaster strike was reused on the Brague DEMO (Moncoulon et al., 2014). It enabled to map at the catchment scale runoff hazards and damages with a pixel precision of 25x25 m. In a second step it was used to explore how reducing runoff, e.g. with NBS as small natural retention areas, would decrease the damages at the catchment scale. In addition, a 2D numerical model was used to compute hazards and damages only on the floodplain, i.e., where most damages and more costly ones are located, with a pixel precision of 1x1 m. Here again, in a second step it was used to map the changes in flow levels for several flood scenarios and for an NBS strategy which would give much room to the river. Without these three models we would have been unsure to explore the most relevant scenarios and we would have been unable to quantitatively assess with sufficient accuracy the protection efficacy of each type of measure.



Table 6. Evaluation of available models in La BRAGUE demo – (leader INRAE) – User profile: Technical expert.

	Applicability	Accuracy	Compatibility	Practicability	Availability
Flood Excess Volume FEV					
Stochastic hydrological model Shyreg					
Hydraulic model IBER					
Run-off modelling CCR					
Wildfire risk analysis					
Damage curves					
Effectiveness indicators					
Morphological Quality Index MQI					
Contingent cost benefit analysis					
Multicriteria decision-aiding framework		Not relevant			
Multicriteria decision analysis (example - excel spreadsheets)		Not relevant			
Multicriteria decision analysis (preference assessment - excel spreadsheets)		Not relevant			

Note that those tables are purely indicative and remain quite subjective.

Only models actually used on the Brague DEMO site are presented here for the sake of conciseness. Because only tools used are presented, they show good scores regarding applicability. Those inapplicable or hard to apply are simply not presented. The Run-off modelling of CCR is assessed to be only good, rather than very good, because it worked very well to map run-off hazards but proved complicated to use to assess the NBS efficacy to reduce run-off. An inverse method was finally used (see Deliverable 6.3), but it was less accurate than direct explicit modelling of the measures (thus also the good rather than very good score on accuracy).



Regarding accuracy, the Flood Excess Volume (FEV) approach is, by definition and construction, a simplified method that is thus only fairly accurate. Its conclusions were consolidated and verified with hydrological, hydraulic and run-off models. Damage curves and contingent analysis are based on statistical approaches that always raise the question of sample effect and applicability to our relatively small DEMO site. They were very useful but outputs remain partially uncertain.

Compatibility between tools, method and data was good except for the hydraulic model IBER: this very detailed approach lacked accurate hydrological measurements at inlets. We consequently had to fuel it with uncertain inputs that certainly affect its absolute accuracy. We analysed the results by computing relative changes with and without NBS; so we hope that bias on both results compensate each other. This uncertain hydrology affects the FEV approach in the same way.

The practicability of several approaches used is quite low in the sense that several models require a very high degree of expertise (e.g., hydraulic model IBER, run-off model of CCR), require heavy meteorological datasets unavailable to the public (e.g., wildfire risk analysis) and some modelling platforms are in addition private and cannot be shared (e.g., run-off model of CCR, source codes of Stochastic hydrological model of Shyreg), though Shyreg outputs can be acquired by subcontracting the relevant private consulting companies. Analysis as the MQI or Contingent analysis require good background in geomorphology and economy, respectively.

Regarding availability (in the sense that the tool was available to the project, not necessarily to the public out of the NAIAD project), the models and tools used were all in mature state at the beginning of the project, or were developed and fully implemented at the scale of the project (e.g., FEV).

Multicriteria decision aiding framework is both a methodology to build a decision-aiding model (e.g. a hierarchical model) and then assess the preferences and the solutions. The methodology has been equipped with specific spreadsheets allowing decision-makers to both understand the principles and then apply to their specific problem. A practical course and a tutorial, based on a real context has been tested with both decision-makers and technical staff.

f) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

Incorporating directly small water retention measures in the mode of Moncoulon et al. (2014) proved difficult. The scale at which runoff is computed, i.e., on pixels of 25x25m, is not suitable to directly fully describe the measures whose size is quite similar to a few pixels. An inverse



methods has finally been chosen: an 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. This can in the future help decision makers to target a certain ambition in term of NBS to implement in order to seek a certain damage reduction rate. Regarding flood hazards in the lowlands, we experienced great difficulties in calibrating such a detailed model in these large suburban areas where hundreds of houses, garden walls, cars and all obstacles created by the urban fabric divert or guide flows. The hydrology was known only in term of peak flows in the two main stems while flows from a dozen of small thalwegs were modelled. More than 500 flood marks enabled to check the validity of the model calibration. We are however not very confident on its relevance for much smaller events than Oct. 2015 for which a validation step with the Nov. 2011 other flood disaster proved that the model partially overestimates the flow levels. The river bed channel capacity is probably slightly underestimated while the floodplain flowing capacity is overestimated resulting in correct results for the calibration step but bias for other type of event modelled.

3. *Integrated Modelling using System Dynamics (SD) techniques*

g) Description of assessment technique

No formal system dynamics models were implemented in the Brague DEMO as it was in several other DEMOs. The integration of knowledge and techniques was performed by a comprehensive analysis of the catchment functioning in both biophysical, social and economic point of views (Yordanova et al., 2019). It was an aggregated through a new nested-DPSIR approach (Drivers-Pressures-State-Impact-Response) inspired by the widely used DPSIR approach (OECD, 1993), in order to developed comprehensive scenarios involving both NBS strategies and future changes regarding the social and economic domains. Further works were performed using decision aid methods and analytical hierarchical procedure to aggregate indicators and criteria in a way tailored to the catchment peculiarities (Tacnet et al., 2019).

h) Why used in preference to other techniques

The partners involved in the study of the Brague DEMO were not skilled in the use of System Dynamics techniques. In addition, to our knowledge, System Dynamics modelling require an in-depth knowledge of the link and coupling between processes. The processes at work in the Brague DEMO were extremely complex (flashy events involving several tributaries, extreme event magnitude, transport of large wood, cascading jamming of bridges, coupled urban runoff and fluvial flooding). The catchment was however yet studied in details by several engineering reports. Pushing further the knowledge on flood hazard and protection measures thus required to implement advanced models that are costly in term of computational power and cannot be



implemented in a System Dynamics model. The decision aid methods that we implemented had the advantage to enable the input of indicators coming from the advanced models while fully eliciting the decision context.

i) Key challenges in accurately assessing the effectiveness of NBS in hazard mitigation

As discussed in the next section, the criteria used to assess the protection strategies were selected during local stakeholder workshops but we did not manage to involve the final decision makers, i.e., the local mayors of the large cities located in the catchment. The weighing of the criteria and sub-criteria to achieve the final decision could consequently not be formally elicited and the full method, yet described, was not used as it was in other catchments (Tacnet et al., 2018).

4. Expert opinion

j) A description of the Demo NBS, its geographical and flood risk setting

The Brague River has numerous stakeholders involved in its management and use: Brague basin agency, regional water agency, regional State authority regarding risks and environment, citizen association focusing risks or environment, simple citizen curious of flood hazard management, etc. Two stakeholder workshops, a third to come beginning of 2020, and three focus groups dedicated to biophysical, social and economy were organized throughout the project in addition to several bilateral interviews to meet these people and discuss and gather their visions of the river in all its components.

k) Why the assessment approach was used in preference to other approaches

Eliciting criteria that should drive the decision making process is a key step in any implementation of decision aid method. These meetings were organized to discuss and validate the selection of the relevant criteria and indicators that NAIAD partners assessed and computed in order to fuel the decision tree.

l) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

Defining measurable indicators that could be used in a prospective way to tell people how the system might change in the various domains proved challenging. Trying to evaluate all these domains and changes with a monetary way proved impossible. It strengthened our conviction that multicriteria decision tool involving only partially economic indicator and tailored to the local visions to select the relevant indicators and criteria is the way to address decision making on river catchment management.



MEDINA DEMO

Authors: Mayor, B., Manzano, M., Calatrava, J., de la Hera, A., Llorente, M., Heredia, J., Mediavilla, R., Borruel, V., Basco, L., Tiaravanni, H., Gómez, E.

1. Measurement

a) A description of the assessment

Groundwater level (piezometric levels) monitoring in the regional aquifer.

Groundwater chemistry monitoring in the regional aquifer.

Groundwater abstraction data.

b) Why the assessment approach was used in preference to other approaches

Time series of groundwater level and groundwater chemistry are the minimum data needed for trend evolution analysis, which is the basis of aquifer assessment.

Together with groundwater levels, groundwater abstraction data (their spatial distribution and time evolution) are needed to understand the causes of water level trends and also to calibrate groundwater flow models.

c) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

Uncertainty in the representability of some data representation with respect to the aquifer depth they are informing of. This is mainly due to the fact that some data come from multi-screened wells and boreholes, where data correspond to admixtures of water tapped at different depths.

Uncertainty in the values of groundwater abstraction. This is mainly due to the absence of direct measuring (water meters) and the need to quantify abstractions through indirect methods.

2. Modelling

d) A description of the Demo NBS, it's geographical and flood risk setting

Compendium of different models and approaches to assess the different strategies and measures.

The Medina demo has considered two main NAS strategies, each one composed of one NBS measure and three soft/management measures, being the soft measures equal in the two strategies. The strategies are aimed to help offset or reduce the impacts of drought events and



current groundwater overexploitation on the socio-economic and environmental status of the region, and thus create resilience against droughts while supporting in the compliance with the European legislation in water and environment. The biophysical modelling conditions for the two NBS measures, as well as the purpose and challenges are described here below.

NBS 1: Managed Aquifer Recharge at the aquifer scale. This measure was assessed in a first stage under the following conditions:

Geographical location and scale of the assessment:

Two sites were selected according to CHD recharge project (CHD, 2016): (1) middle Trabancos basin; and (2) middle Zapardiel basin (Arroyo de las Vegas) (**Figure 4**). The applied recharge technique is a surface procedure called river bed dumping.

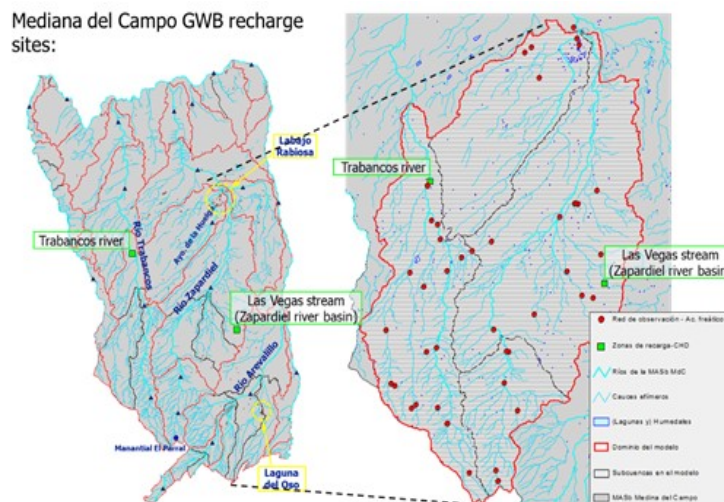


Figure 4. Location of recharge sites in Medina del Campo GWB.

Purpose and components of the assessment

Groundwater modelling assessment: The goal of this assessment was to evaluate the magnitude of the recharge impact through two different approaches:

- (a) An assessment of the recharge impact on the multilayer aquifer considering the perched aquifers, aquitards and the presence of deep unsaturated zones, using the code VS2DTI (Hsieh et al., 2000).
- (b) An assessment of the recharge impact on the unconfined aquifer and its link with the surface water bodies (river-aquifer interactions and wetlands-aquifer interactions), using the code MOFLOW-2005 (USGS. Harbaugh, 2005).



The results of the analysis showed neglectable impacts on the recharge rates in the deep aquifer and limited impact on the shallow water table. The only relevant effect with potential implications for the surface riverine ecosystems was found in both areas around the Zapardiel River and Trabancos River. The existing channel infrastructure (from the Adaja Irrigation System) could be used to carry out the recharge action without additional works and associated high costs. Therefore, the NBS was redefined as Managed Aquifer recharge in the area of the Zapardiel river with riverine ecosystem restoration purposes.

Wetland ecosystem assessment: it aimed to contribute to the description of the eco-hydrogeological features of the sites considered for the recharge and to ensure the maintenance of the ecosystem services in the wetlands' management processes. Although the most part of them provide some common ecosystem services, it is clear that different wetlands provide a range of services according to their type, size and location which has direct relevance to the achievement of the Medina del Campo GWB sustainability. The assessment included a sedimentary record of the wetlands based on long time series, which for the "Lagunas Reales" cover the last 3000 years. These long records increase the number of available scenarios and time scales allowing us to improve our knowledge about the dynamics of the system and its possible response to future changes. This is a valuable tool for the management of these sensitive environments.

NBS 2: Crop change towards drought resilient crops, including woody crops and soya bean, and application of soil water retention practices (crop rotation and mulching). This measure was assessed under the following conditions:

Geographical location and scale of the assessment:

The assessment of the crop change strategy is done at the aquifer scale, considering the measure is applied in 10% of the irrigated agricultural farms, including crop rotation practices.

Purpose of the assessment:

Drought damages were assessed using an agro-economic model calibrated to the technical, economical and hydrological characteristics of the area of study. This model simulates land and water allocation among land use alternatives and computes economic and resources use indicators.

Groundwater-related ecosystem services (GRES) assessment: In the Medina DEMO area, the regional aquifer provides several ecosystem services with paramount socio-economic impacts and whose flow has decreased due to several causes. Four GRES were initially selected to be assessed: i) freshwater abstracted from non-fossil groundwater for irrigation and ii) good-quality freshwater abstracted from non-fossil groundwater for drinking; and two regulation-maintenance services: iii) capacity of maintaining base-flow to streams, and iv) capacity of



maintaining wetlands and riverine forest. The past evolution of the flow of those services from the original, undisturbed conditions to the disturbed ones has been evaluated through the study of groundwater level and groundwater quality time data series, with the analysis of aerial images, and with the modelling of regional groundwater flow. The regional groundwater flow model builds on a preliminary iMOD based model developed by Deltares and rebuilt by UPTC, that is used to simulate the expected impact on groundwater levels of NAIAD-CHD agreed climate change and water management scenarios, and to assess the hypothetical evolution of some of the above mentioned groundwater-related ecosystem services.

Overall water balance assessment and results integration through:

- The water allocation model is a comprehensive and flexible tool developed with Deltares' RIBASIM package which links the hydrological water inputs at various locations with the specific water-users in the basin. It allows to assess the impact of groundwater extraction wells on the sustainability of the aquifers and allows a comparison between scenarios where different cropping strategies could be assessed. The results are represented spatially as maps provided at two different scales: making changes on the whole Medina del Campo basin or just taking action on sub-basin areas.
- The meta-model assists in the multi-criteria decision making and evaluation of the NBS strategies. It is as a tool to combine biophysical, economic and social indicators resulting from the groundwater and water allocation models and carry out a type of multi-criteria analysis. With this metamodel, users can access results of different models in a fast-integrated systems model. Meta modelling enables relevant stakeholders to be involved in all modelling chain using a collaborative modelling approach. This includes activities to parameterize the systems, simplify complex models, define physical state and decision support (socio-economic) indicators, formulate scenario conditions, and identify possible measures.

Meanwhile, a flood hazard assessment affecting Medina del Campo municipality was carried out using a 2D flow model in order to provide flood depth maps and flood velocity maps to be used in the risk analysis phase of the project. This hazard mapping approach has helped identifying properties within the scope of floods of different return periods. After the analysis, the only NBS that could be identified as potential alternative to address this effect was the removal of dikes along a distance of 70 km upstream of the village, which is currently being done by the River Basin Authority. However, the assessment of this solution under the NAIAD framework would require an expansion of the spatial scope of the models developed as well as additional analyses that could not be assumed by the team within the project time frame. Therefore, it was decided to limit the analysis to NBS strategies to address drought hazards and no strategy for floods was developed.



e) Why the assessment approach was used in preference to other approaches

High expertise of the team on models that could be further used by the RBA.

The groundwater modelling approach focused on the target areas for the proposed Managed Aquifer Recharge was selected because it was shown as the best tool to represent groundwater flow results. The VS2DI is a powerful code to represent unsaturated zones. In the NAIAD project an innovative application has been done of this code to represent a multilayer aquifer with perched aquifers. The MODFLOW code is a powerful tool to represent aquifer.

An assessment of wetland ecosystem services using a hydrogeological characterization approach for wetlands related to groundwater was selected based on the previous experience described in Manzano et al. (2015). This approach allowed to understand the connection and assess the implications of the measures, particularly the aquifer recharge, for the water dependent surface ecosystems.

The study of the wetlands' sedimentary record was included because the processes that are currently working in a sedimentary environment are the same to those that acted in the past (principle of actualism). The application of this principle is a key for a good interpretation of the sedimentary record. The selection of the "Laguna Reales" for their study was motivated as they show the longest and best sedimentary record of the area, and they are widely documented in historical sources.

An assessment of groundwater-related ecosystem services using statistical techniques such as the Mann-Kendall trend test, GIS analysis, and groundwater flow modelling, were selected because they are the best techniques to know the mathematical confidence of evolution trends, to quantify the spatial evolution of aquifer surface having good/bad chemical quality conditions with respect to nitrate and arsenic, and to simulate confident hypothetical conditions in aquifer levels as the result of concrete climate change and water management measures.

A water allocation model was selected because this was needed to compare the impact of selecting different cropping types and patterns on the water availability in the aquifer and droughts.

The metamodel was also developed for the assessment of NBS strategies and scenarios as a tool to combine biophysical, economic and social indicators resulting from the groundwater and water allocation models and carry out a type of multi-criteria analysis, allowing the involvement of stakeholders in all modelling chain, using a collaborative modelling approach.



Table 7. Evaluation of available models in Medina demo.

	Applicability	Accuracy	Compatibility	Practicability	Availability
Surface hydrology 2D model	Green	Light Green	Light Green	Green	Green
Coupled 1D-2D surface hydrology model	Green	Green	Light Green	Light Green	Red
MAR VS2DTI groundwater model	Green	Light Green	Yellow	Green	Green
IMOD groundwater model	Green	Red	Light Green	Green	Green
MODFLOW groundwater model	Green	Green	Light Green	Green	Green
Systems Dynamic Model	Yellow	Yellow	Light Green	Light Green	Green
Metamodel	Green	Light Green	Light Green	Green	Green
Agroeconomic GAMS model	Green	Light Green	Light Green	Green	Light Green
Water allocation RIBASIM model	Green	Yellow	Light Green	Green	Light Green
EcoActuary	Green	Orange	Yellow	Yellow	Green
Social Risk Perception model (FCM)	Green	Yellow	Light Green	Green	Light Green

The selection of models developed and applied in Medina del Campo was done regarding the different objectives of the components to be analysed: flood risk analysis, analysis of the efficacy of the measures (crop change, MAR recharge and groundwater management measures), and social analysis.

For the flood risk analysis, given the small size of the Medina del Campo city and surrounding flood plain area, the development of a tailored flood model was considered necessary. A 2D and 1D-2D coupled models were considered, being the first one chosen due to the complexity and time required to build the 1D-2D model, despite the second one providing higher accuracy and thus being more suitable.

To assess the MAR recharge, a high-resolution tailored model for the selected recharge areas was considered necessary in order to simulate the measure with enough accuracy. Therefore, the code VS2DTI (Hsieh et al., 2000) was considered the most suitable to carry out the



assessment of the recharge impact on the multilayer aquifer considering the perched aquifers, aquitards and the presence of deep unsaturated zones.

For a broader assessment of the effects of the aggregated groundwater management practices at the aquifer level, a lower resolution-higher scale model was required that could also consider water quality aspects. A first version using IMOD software was developed revealing poor accuracy, and thus a second version using MODFLOW 2005 (USGS. Harbaugh, 2005), which allowed for higher resolution and accuracy, compatibility with a water quality module, and free license was used.

For the assessment of the effects of the crop change measure, EcoActuary was considered, but due to the need to use very specific-high resolution local data, the time limitations to get the training, a specific agroeconomic model was developed using the GAMS modelling code.

A surface water allocation model using RIBASIM software was also developed in order to support the hydrologic model in getting insights on the results on surface flows of the different scenarios.

Regarding the model integration, a Systems Dynamic Model was developed in a first stage allowing some overall qualitative analysis. However, the relatively low degree of accuracy of the qualitative results motivated the development of an Excel based metamodel working as a user-friendly visualization tool that gathered the results of all the previous models for the simulation of results of different measures and strategies on selected impact indicators.

Finally, the Fuzzy Cognitive Map methodology brought by the NAIAD social assessment team was selected as the best option to develop the social risk perception model, due to the high expertise of the team and the suitability for the objectives of the analysis.

f) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

Data related:

- Lack of detailed data on actual groundwater abstractions.
- Uncertainty in the representability of some data regarding the aquifer depth. This is mainly due to the fact that some data come from multi-screened wells and boreholes, where data correspond to admixtures of water tapped at different depths.
- Uncertainty in the values of groundwater abstraction. This is mainly due to the absence of direct measuring (water meters) and the need to quantify abstractions through indirect methods.
- Lack of specific regional data on conservation agriculture practices and effects on yields driving the need to make rough assumptions or extrapolations from other regions.



- The ponds are not in a natural state and data on their natural functioning are scarce. The current system is modified by human activity and data on its operation are scarce and dispersed.
- Obtaining historical data has been laborious and, although they provide relevant information, they also convey some uncertainties.
- There was no information on the sedimentary record of the lagoons, so it was necessary to generate all the data. Different laboratories have been used to perform sediment analyses, which use to have long response periods. In some cases, the delays have been very large due to administrative management problems that have hindered the development of the work.

Scale related:

Need to work at two scales: local area targeted for the recharge, aquifer area.

Large surface covered meaning high diversity in soil conditions, farming practices, crops and even local climatic conditions.

3. Integrated Modelling using System Dynamics (SD) techniques

g) Description of assessment technique

A Systems Dynamic Model (SDM) was developed in order to represent the dynamic behavior of the Medina del Campo system over time. The factors and relationships as well as the accumulations within the systems (stocks) are described mathematically by differential equations. The SD model can be used to observe if a structural change in one part of a system (i.e. change in crop) affects or not the behavior of the system as a whole. It is also possible to set different scenarios (i.e. climate change scenarios) and to study how the system behaves under particular conditions. In the context of Medina del Campo DEMO, the SD model is focused on the aquifer and the socio-economic factors that interact with it.

h) Why used in preference to other techniques

The System Dynamic model developed for the Medina del Campo DEMO uses a participatory modelling approach which showed several key advantages for the purposes of NAIAD project (See D.5.2). It helped identifying and describing the role of key variables and relationships within the system. This method was also used to identify modelling components that needed to be integrated to effectively assess the long-term effectiveness of different NBS. The SD model developed for Medina has been used to analyze the causal connections and influences that involve the multiple dimensions that are impacted by different NBS, ranging from the economic, social and environmental. Furthermore, the adoption of a participatory approach to SDM



building helps on the one hand to collect and integrate scientific and local knowledge, and on the other hand to identify critical feedback and leverage points, in order to support the process of NBS implementation in Medina.

i) Key challenges in accurately assessing the effectiveness of NBS in hazard mitigation

The main challenge for the SDM in Medina was to find data to feed and calibrate the model in order to get realistic results. In many cases data have different temporal scales or are simply not available.

4. Expert opinion

j) A description of the Demo NBS, its geographical and flood risk setting

The participatory process in Medina del Campo demo has been carried out through a series of iterative phases of interviews and workshops, each building on results from the previous phase and aiming to advance in the further definition and validation of elements required for the modelling and assessment processes of the different work packages. The methodology for the interviews spanned both semi-structured interviews with key stakeholders during phase 1 and 2, and a structured survey for the qualitative assessment of co-benefits. Each interview round aimed to cover a complete and varied range of stakeholders relevant to the demo case, including technicians and policy makers in public administrations, farmers and farmer associations, representatives of the private sector (i.e. water supply and insurance companies), and civil society (i.e. NGOs). A similar composition representing the full range of stakeholder groups and sectors was sought for the workshop design. The workshops included several participatory methodologies spanning fuzzy cognitive mapping, agent based modelling, and social network analysis, and involved a varied range of stakeholders representing the most relevant actors. The workshops were conducted shortly after the interview round in order to provide some compounded feedback to the interviewed actors. A specific workshop applying the meta modelling approach was also carried out for the tailor-made co-designing of the meta model, involving only targeted stakeholders envisioned as potential users of the model, i.e. technicians from water and regional governmental administrations. The results from the interviews and workshops were reported to the Demo team in order to feed the model building and development and assessment of NBS strategies and scenarios.

k) Why the assessment approach was used in preference to other approaches

The semi structured interviews in different rounds were selected in order to sequentially gather and further develop specific information from selected stakeholders with high level of



knowledge and expertise. These would provide higher technical details about the solutions. The iterative workshops were selected to increase engagement and awareness among the stakeholders and create ownership of the results. The agent based modelling and social network analysis allowed to identify the importance and centrality of the different stakeholders, as well as the information flows and gaps and associated barriers.

The fuzzy cognitive maps were selected to identify the required variables and relationships to be translated into the Systems Dynamic Model.

I) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

In some cases, there was no consensus among different stakeholder types on the feasibility and potential impact of some of the solutions.

It was difficult to get representation of some stakeholder groups in the workshops, such as the water utilities or the insurance representatives.

In some cases, the measures proposed by the stakeholders were not technically feasible from a technical point of view, and needed be discarded. However, this decision had to be carefully justified in front of the stakeholders to avoid a loss of trust.



ROTTERDAM DEMO

Authors: Dartée K.W.J., Peña K., Biffin T.

The Rotterdam demo is built around the Urban Waterbuffer (UWB), an innovative solution for climate adaptation which utilises biofiltration and aquifer storage and recovery to detain, treat, store and reuse surplus rainwater. Located in a low-lying area in the west of the city, Spangen suffered from an abundance of hard impervious surfaces, leading to ongoing issues with pluvial flooding. In addition, residents in the neighbourhood expressed their desire for more green space in the neighbourhood. The potential to address these concerns simultaneously led to interest in NBS from a wide range of stakeholders, culminating in the implementation of the UWB in 2018. In the context of NAIAD, the assessment methods and measurements leading towards the implementation of the UWB represent one facet of the Rotterdam demo, the other being the ex-ante comparison of neighbourhood strategies to assess the merits of hybrid NBS such as the UWB on a larger scale. Whilst there is much overlap, where necessary separate assessment approaches have been reported below.

1. Measurement

a) A description of the assessment

The impact of the UWB as a measure to reduce the risk of pluvial flooding and to provide a sustainable source of fresh water in dry periods has been assessed through on-site measurements and locally available data. In the process leading up to and following its implementation the following measurements have been performed:

- Feasibility study (external partner):
 - Aquifer depth, groundwater quality, subsurface flows, and various other local geohydrological characteristics, obtained via drilling and geological data available via the municipality.
 - Spatial data, such as (ground)water levels, height differences, distances.
 - Water usage by Sparta Stadium.
 - Assessment of runoff water quality via sampling.
 - Current water system performance assessed by municipality and translated into specific policy objectives for the neighbourhood.
- Performance monitoring once implemented (external partner):
 - Ongoing water quality testing via EC, pressure and temperature sensors, as well as periodic sampling/lab analysis of specific pollutants.
 - Local rainfall data.



- Volume of water detained (volume and flow in retention buffer), stored (infiltration rates of the well) and supplied (exfiltration rates).
- Water levels within the buffer and biofilter, to estimate available retention capacity to deal with new rain events.
- Number of sewer overflows.

For the broader strategy comparison used to evaluate the impact of grey, green and hybrid water management approaches for the entire neighbourhood, the measurements have been much more limited, as this encompassed a conceptual comparison between the three strategies.

- GIS data gathered on:
 - Sewer length, location and capacity
 - Land use characteristics
 - Roof type and roof surface area
 - Soil type
 - Groundwater levels
 - Ownership data
- Rainfall data:
 - Climate scenarios (KNMI, 2014)
 - Standardised rain events (STOWA, 2018)
- Strategy definition:
 - The retention capacity of the various measures considered were derived from literature, expert consultation and reference projects.
- Area characteristics:
 - Number of inhabitants; employment rates; number of households via Municipality of Rotterdam (e.g. <https://onderzoek010.nl/jive> and <https://wijkprofiel.rotterdam.nl/nl/2018/rotterdam>)
 - Average house prices via Municipality of Rotterdam.
- Insurance data:

Study by Spekkers (...) on insurance claims in Rotterdam and their relation to peak rainfall events.

b) Why the assessment approach was used in preference to other approaches

The feasibility study for the implementation of the UWB was necessary to ascertain the technical and legal viability of the UWB project. The ongoing monitoring of water quality is important to understand the performance of the biofilter, and to ensure that the system continues to meet infiltration legislation. The monitoring of the volume of water detained and infiltrated is crucial



for the assessment of the capacity of the UWB to reduce the risk of pluvial flooding and to track how much water is eventually re-used.

However, in order to effectively compare grey, green and hybrid strategies and to be able to better align with the NAIAD objectives, the scope of the assessment has been focused on the definition of three neighbourhood-level strategies to deal with pluvial flooding in the area. Thanks to the open data policy of the municipality of Rotterdam, the Dutch planning culture and well documented political considerations, relevant information for developing the strategies and modelling approaches was readily available. Ongoing measurements on the actual impact of the strategies was only possible for some of the measures such as the UWB, as the broader strategies have only been defined conceptually and are not expected to be implemented.

c) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

Key challenges in this measurement approach was the level of accuracy of the available data. Data on the performance of the UWB was readily available, while some of the other measures included in the strategies had not been implemented, meaning empirical data for these measures were lacking, resulting in big differences in the level of detail of the data used. As such, it was challenging to make a fair comparison of the impact of the three strategies based on a similar level of accuracy and data resolution.

Additionally, the lack of measurements performed to monitor the impact of the measures on the majority of the social co-benefits resulted in a theoretical assessment, rather than an assessment based on empirical data. The lack of empirical data collection on social co-benefit indicators could be considered a missed opportunity, given the close involvement with the UWB implementing partners, and the need for further research in this area.

2. Modelling

d) A description of the Demo NBS, it's geographical and flood risk setting

As mentioned above, the Rotterdam DEMO is built around the implementation of the Urban Waterbuffer in Rotterdam, a hybrid NBS which is described in detail in D6.1. In order to better relate to the NAIAD objectives and the scale of other demos, the scope of the risk and economic assessment in the Rotterdam demo has been expanded to include three strategies at



neighbourhood level for the Spangen area. The three strategies that have been assessed in the Rotterdam DEMO are:

- 1) Grey strategy: Traditional and centralised
- 2) Hybrid NBS strategy: Infiltration via public squares
- 3) Green NBS strategy: Local infiltration through green infrastructure

As can be seen in Table 8 below, the UWB has been included as a measure in the hybrid strategy. A more detailed description of the three strategies can be found in D6.3.

Table 8: Details of the area and retention capacity of the measures used for three flood risk reduction strategies in Spangen, Rotterdam.

	MEASURE	UNIT	AMOUNT	RETENTION CAPACITY (m3)	NOTES
STRATEGY 1	Permeable pavement	m ²	17,500	4375	High capacity, Bufferblock or equivalent (250 mm retention)
	Separated sewer	m	16,500	1948	Static storage plus high flow rate of 60L/sec/ha
STRATEGY 2	UWB (Retention)	m ³	2800	2800	2 x 1400 m ³ underground retention tanks
	UWB (filtration)	m ²	180	N/A	2 x 90m ² biofilter, retention capacity not considered
	UWB (long term storage)	m ³	30,000	30,000	2 x deep infiltration wells, with large, long term storage and reuse capacity
	Separated sewer	m	14,000	1744	Static storage plus high flow rate of 60L/sec/ha
	Parks	m ²	10,000	2000	Renovated and expanded public parks
	Ponds	m ²	2800	1120	2 x 1400 m ² vegetated ponds located in public squares, 400 mm capacity above regular water level
STRATEGY 3	Green roofs	m ²	30,000	750	Extensive green roof (25 mm retention)
	Façade Gardens	m ²	8,000	800	100 mm estimated storage
	Green strips	m ²	22,500	2250	Simple grass planted filter strip, 100 mm storage
	Wadis	m ²	11,500	2300	Vegetated drainage channels including aggregate base (200 mm storage)
	Ponds	m ²	2800	1120	2 x 1400 m ² vegetated ponds located in public squares, 400 mm capacity above regular water level
	Parks	m ²	6650	1330	Renovated and expanded public parks (200 mm storage)



e) Why the assessment approach was used in preference to other approaches

A short list comprising a wide variety of modelling approaches and tools was developed and evaluated in preparation of the risk modelling in the Rotterdam DEMO. The short list of 9 models was defined on the basis of experience of the researchers, known applications in similar studies, and available support from NAIAD partners for the modelling. The short list of the evaluated models is shown in Table 9.

Table 9: Evaluation of available models in demo Rotterdam

	Applicability	Accuracy	Compatibility	Practicability	Availability
Water op straat (HKV)	Green	Green	Green	Orange	Yellow
Water Balance SEAWAT (KWR)	Orange	Yellow	Green	Green	Green
3Di (N&S)	Green	Green	Green	Orange	Green
CostingNature	Orange	Orange	Yellow	Yellow	Green
ECO:Actuary	Orange	Yellow	Green	Yellow	Orange
Vensim SD modelling	Orange	Yellow	Yellow	Green	Green
Simio DES	Orange	Yellow	Green	Green	Green
Insurance claim mapping (Spekkers)	Orange	Green	Yellow	Yellow	Orange
WOLK (Tauw)	Green	Yellow	Green	Yellow	Yellow

NB! This scoring of the model is area specific for the risk modelling application of the urban stormwater management context in The Netherlands.

After conducting the evaluation, 3Di was selected as the most suitable modelling tool for demo Rotterdam. 3Di supports modelling of typical urban stormwater management interventions and urban water flows at a high grid resolution, and it is compatible with standardized rain events, GIS-data and water balance principles. It had the highest score on the above criteria and facilitates stakeholder engagement of the Municipality of Rotterdam and Water board Delfland, as this will become their standard modelling tool from 2019 onwards. Additionally, a base model for Spangen was already being developed by Delfland.



Using Eco:Actuary as the assessment approach would have facilitated knowledge exchange and data integration with other NAIAD project partners. However, the grid resolution is not well suited to the scale of the water system in demo Rotterdam. The finest resolution within Eco:Actuary (100m*100m) is too large to allow for accurate modelling of water flows and interactions in a 60-ha large water system.

A more thorough description of the selected modelling approach can be found in deliverable 6.2. Towards the final assessment of the avoided damages in D6.3, the decision was made not to perform the actual risk modelling in 3Di for the following reasons:

- The application of the 3Di software in a similar study for the Spangen area had shown that the modelling the hydrological flows in the flat and small-scale neighbourhood is highly challenging and imprecise.
- The options for modelling the different interventions in the strategies at street level in 3Di were limited, and therefore little benefit would be obtained in re-doing resource intensive modelling for marginal new insights in comparison to the results from the study done by Arcadis (2019).

Instead, it was chosen to develop strategies with a similar level of service to allow for fairer comparisons in relation to costs, co-benefits and spatial impact (opportunity costs). To ensure that all three strategies could deliver the predefined core level of flood risk reduction, an iterative approach to strategy development was taken, as the final designs needed to be informed by an understanding of the hydrological performance of each measure. To achieve this, a simplified water balance model (*bakkenmodel*) was built (see D6.3), so as to ensure that the three strategies could all deliver the required risk reduction.

f) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

In order to model the different effects of the interventions within 3Di, a high level of accuracy is necessary, as many interventions are taken at street level. However, accurate data on the ground floor level of dwellings and the permeability of facades is not available within the model which can lead to a perceived high level of detail, whilst the actual accuracy of the model is compromised by the assumptions made due to insufficient data. As a result, whilst 3Di has an integrated damage assessment tool, the assessments of potential damages that result from inundated buildings is highly inaccurate. In addition, as the high level of detail also leads to long computational times, the possibilities to compare different strategies and scenarios would have been limited.



The downside of the alternative approach taken with designing three strategies with a similar level of service is that the avoided damages might not be well represented. Even though Spangen is mostly flat and the lay-out of the neighbourhood is largely symmetrical, the approach taken does not account for the spatial distribution of the retention capacity and whether that configuration is sufficient to indeed provide a similar level of service in terms of avoided damages. Additionally, seasonal variation in performance of NBS measures was not considered, leading to the potential overestimation of risk reduction capacity due to saturated soil in winter, for example.

3. Integrated Modelling using System Dynamics (SD) techniques

g) Description of assessment technique

In the Rotterdam DEMO, there was no SD model developed. However, the basis for an SD model was created by defining the causal relations between hydrological parameters in a systems diagram (see **Figure 5**).

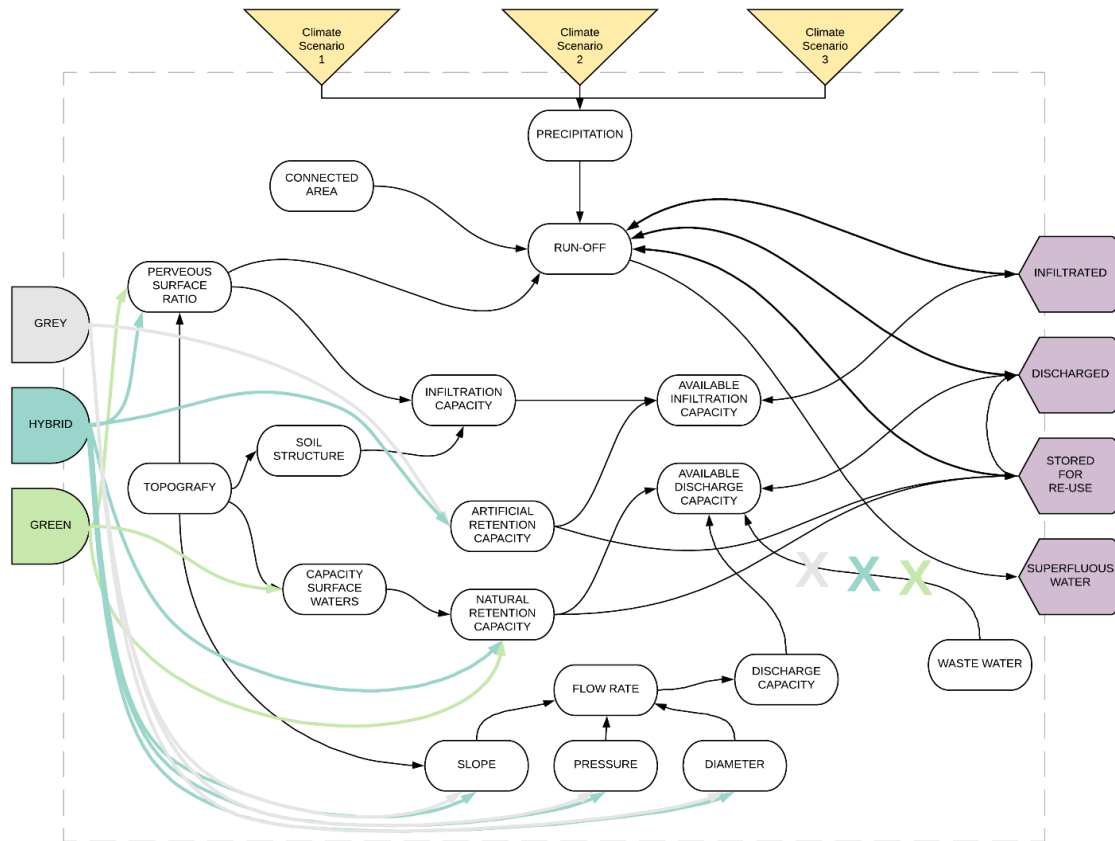


Figure 5. System diagram representing the relationships between different components of the water system in Spangen.

This system diagram as applied in this risk modelling approach shows a simplified overview of the water flows at surface level. This system diagram was developed for the hydrological modelling, with the purpose of developing it further to include LCC results, opportunity costs, avoided damages and co-benefits. Eventually, it was decided to instead integrate the economic assessment using Net Present Value and to integrate the non-monetary co-benefits qualitatively. The development of the SD model has not been pursued, since only a limited number of scenarios has been assessed and thus the efforts for its development would not justify the new insights that would be obtained from the model. Moreover, some of the causal relations between the parameters have turned out to be too complex at the urban scale to be represented accurately in a SD model.



Instead, the final integration of the DEMO results has been done in a Net Present Value (NPV) and benefit-cost ratio (BCR) assessment and through a qualitative overview of decision-making parameters that could not be monetized.

h) Why used in preference to other techniques

The integration of the final results of the insurance value assessment in an NPV assessment and qualitative description better suited the objectives of the demo to express key differences between the impact of grey, hybrid and green strategies that can facilitate future decision-making on NBS for urban water management. Comparing the impact of alternative strategies under a wider set of climatological and economic scenarios has been identified as a valuable next step in future research, that goes beyond the assessment of the Rotterdam DEMO in NAIAD. Such an assessment might benefit from the development of an SD model, but would also require a better understanding of the various causal relationship between key parameters and a more accurate estimation of avoided damages under the various configurations.

i) Key challenges in accurately assessing the effectiveness of NBS in hazard mitigation

The use of NPV and BCR proved a convenient way of integrating the various components of the assessment, though it was not without drawbacks. For example, the BCR turned out to be <1 , partially because the avoided damages had not been included in this integration. Additionally, it was challenging to assess the sensitivity of the findings to various factors, which would have been easier to overcome with a sophisticated SD model. Lastly, the approach taken resulted in a strong separation between monetary and non-monetary impacts. Other approaches may have been able to better integrate a broader range of indicators, without putting so much emphasis on the monetisation of co-benefits.

4. Expert opinion

j) A description of assessment technique

The involvement of stakeholders and expert opinion in the Rotterdam DEMO has been organised in line with the NAIAD stakeholder engagement protocol. Through the development of Fuzzy Cognitive Mapping (FCM) based on individual semi-structured interviews with key stakeholders, the risk perception and expert opinion on the effectiveness of NBS has been obtained and assessed. FCM shows interlinkages, highlights leverage points and helps to understand which issues are central to different stakeholders in urban water management practices. Additionally, stakeholder engagement has been realised through hosting two workshops in which the



stakeholder's interest in and awareness of NBS has been expanded. These workshops were also able to explore a range of alternative viewpoints on co-benefits and the effectiveness of NBS, as well as drivers and barriers for their large-scale uptake. In light of the IVE survey, various stakeholders from the insurance industry have been interviewed, and throughout the assessments performed in the DEMO, various experts and stakeholders have been consulted through one-on-one interactions.

k) Why the assessment approach was used in preference to other approaches

Involving local stakeholders and experts in the research is key for being able to fully understand what drives decision-making on NBS. The protocol applied within NAIAD, through individual interviews, stakeholder workshops and the multi-disciplinary approach have been well suited to enabling stakeholder engagement for the Rotterdam DEMO.

l) Key challenges with the approach in its accuracy for assessing the effectiveness of NBS

In addition to the general comments stated on the key challenges of the stakeholder engagement protocol, the Rotterdam DEMO specifically struggled with the underrepresentation of certain groups (inhabitants and the insurance industry in the first workshop). Additionally, the low number of respondents assessed in the FCM led to a somewhat incomplete overview of the different stakeholder perceptions and causal relationships between parameters in the SD model. Positively, the involvement of the NAIAD partners in the implementation of the UWB in Rotterdam has resulted in very strong relationships with key stakeholders that have made substantial contributions to quality of the various assessments in the Rotterdam DEMO.



Comparison of previously published and NAIAD approaches to assessment of insurance value of NBS

The majority of literature on flood-related Nature Based Solutions (NBS) focuses on benefits, type of interventions and implementation (i.e. Keesstra et al 2018, Davis and Naumann 2017, Lennon et al. 2014, Nauman et al. 2011). Very few studies have explicitly assessed the effect that NBS have on mitigating floods. The NAIAD team primarily used monitoring and modelling to assess the protective value of NBS in regards to drought and flood mitigation, which are the standard methods used to assess efficacy of both civil-engineering and NBS. A method for assessing the impact of NBS not used in NAIAD is space-for-time analogues. The use of space-for-time analogues is most suitable during the planning phase when trying to determine the most appropriate NBS for a given context. This method involves finding an analogous NBS in a similar setting to the proposed intervention and to look at the effect it has had. Such NBS can be located through databases such as the Urban Nature Atlas which contains evidence from 1000 interventions. Monitoring and modelling are preferential to space-for-time analogues where possible and appropriate because catchment peculiarities can make solutions that work in other sites, unsuitable for the studied catchment. The use of small natural water retention areas is a good example. Such NBS are widely advertise by the UK Environment Agency. When trying to transfer these solutions to our Mediterranean coast, it came up that the rainfall intensities, much higher than in UK, made such solutions barely useful if not implemented in huge numbers. Conversely, the giving room to the river approach, yet implemented on the huge river which is the Rhine delta in the Netherlands seems also of high relevance in the small catchments prone to flash floods. The definition of what is analogue is thus still not perfectly determined and defining which indicators determine whether or not two catchments are analogue and interesting and useful question to raise.

The H2020 working group on NBS recommended to use direct physical measurements to monitor NBS, such as run-off (in relation to precipitation), flood peak reduction, depth to groundwater and evapotranspiration (Raymond et al 2017). Few studies have monitored flood protection NBS, and these have largely consisted of case studies - isolated intervention(s) in a small geographic context. For example, NBS interventions have been evaluated in a small catchment in Northumberland, by monitoring river height, soil moisture, storage capacity and reduction in downstream flow (Nicholson et al. 2012, Wilkinson et al. 2010). Evidence of NBS efficacy has also been generated by the use of experiments. For example, a small-scale experiment looked at the potential of green roofs to reduce urban flooding by comparing a green to a normal roof in relation to rainfall retention and reduction in runoff (Stovin 2010). A



few studies have used hydrological modelling to assess the value of NBS. Hydrological modelling was used to assess the peak flow reduction and reduction in flooding downstream for three competing management options (NBS vs grey vs status quo) (Liquete et al 2016). Similarly, Zolch et al. (2017) used small-scale hydrological modelling to determine which green infrastructure had the highest potential to reduce river discharge volumes. Modelling has also been used to investigate the impact of variety of NBS interventions within a small catchment (Metcalf et al. 2017). A study aggregated data from 25 case studies to assess NBS efficacy but noted that differences in scale and methodology between interventions made assessing performance difficult (Iacob et al. 2014). A robust evidence base for the efficacy of NBS is lacking in scientific literature. Oxford Martin School identified important evidence gaps regarding the efficacy of NBS, including: the need for national monitoring networks to understand both flood risk and efficacy of interventions; standardized methods for monitoring interventions; and a determination to what extent individual NBS results can be extrapolated elsewhere (Dadson et al. 2017). Our results from our demonstration projects in NAIAD will make a valuable contribution to filling this assessment gap. In particular, the development of the Smart monitoring technology provides a cheap, robust and replicable way to measure the efficacy of interventions. An additional challenge of the study of NBS dedicated to protect from severe floods and droughts is that they should mostly affect extreme and rare events, which by definition, are seldom observed. Assessing their efficacy either take time to gather sufficient observations or is subject to modelling approaches with underlying assumptions and hypothesis. Compared for instance to NBS whose main function is carbon sequestration, and whose efficacy can quite rapidly be measured; quantifying flood alleviation capacity of NBS will necessarily need time and numerous studies with independent and rigorous approaches to gather all the evidences. The mainstreaming of cheap and simple to install monitoring stations, as developed by NAIAD, is a contribution to that long term aim.



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Annex 1

Figure 6: Legend - “Evaluation of available models” tables.

Ranking – suitability of the models/tools:	Definitions:										
<table border="1"> <tr> <td style="background-color: #008000;"></td><td>very good score</td></tr> <tr> <td style="background-color: #90EE90;"></td><td>good score</td></tr> <tr> <td style="background-color: #FFFF00;"></td><td>fair score</td></tr> <tr> <td style="background-color: #FFA500;"></td><td>poor score</td></tr> <tr> <td style="background-color: #FF0000;"></td><td>very poor score</td></tr> </table>		very good score		good score		fair score		poor score		very poor score	Applicability: how suitable was the tool to provide the needed results? Accuracy: how accurate was the output of the tool to assess at the end the avoided damages? Compatibility: how easy was to use the tool with available data and requirement from other tools? Practicability: expertise needed to use the tool? Availability: was a good version of the tool easily accessible?
	very good score										
	good score										
	fair score										
	poor score										
	very poor score										