Reponses to second referee's comments on "Nature-Based Solutions for hydro-meteorological risk reduction: A state-of-the-art review of the research area" by Laddaporn Ruangpan et al.

<u>Comments from Referee</u>: Summary of the manuscript This manuscript (ms) reviews scientific publication on Nature-based solutions (NBS) for hydro-meteorological risk reduction and related terms. The authors proceeded in a systematic way by using search terms in various scientific literature databases and analyzed over 1000 references. The ms concludes by summarizing the main findings and suggesting further research in some of the reviewed areas. Evaluation I think the topic of this manuscript is highly relevant and important in order to review NBS to tackle the ecological crisis the world is facing. Accordingly, I do think that this ms should be considered for publication. However, I have major doubts if the presented ms really helps to summarize the vast amount of literature on NBS and if it really identifies the knowledge gap in order to be able to recommend the area of focus for future research. My main concerns are the following:

<u>Authors' response:</u> Thank you for your encouragement and comments. Your concerns are addressed in this response letter. Please find our point-by point response below.

i) Methodology

<u>Comments from Referee</u>: a simple search for "Nature-based solutions" in the WoS shows that three of the four most relevant and most cited papers have not been considered in this ms (Keesstra et al. 2018, Nesshover et al. 2017, and Eggermont et al. 2015). Accordingly, I would recommend revising the method of selecting research articles that are being taken into account in the review.

<u>Authors' response</u>: Thank you for your suggestion to make this review more complete. Yes indeed, a simple search for "Nature-based solutions" in the WoS shows that these three papers that the review is referring to did come up in the search and they are indeed among the most cited ones and -without doubt- of relevance for the general subject of NBS. However,we would like to clarify that the goal of our study is to not review the state of the art on all NBS terms (i.e. SuDs, WSUD, BMP, GI etc.) in general, rather to specifically investigate how Nature-based solutions have been used or studied to reduce hydro-meteorological risk. Therefore, the search terms had to simultaneously include on terms for "Nature-based solutions" and one term for hydro-meteorological risk as risk was one of the critieria used to filter the total number of articles (over 6,300). For that reason, Nesshöver et al., (2017) and Eggermont et al., (2015) are not shown in this case and were not taken forward for a more detailed analysis in the 'Finding' section. On the other hand, having recognized the relevance of those articles with respect to the general topic of NBS, they will be included in "Overview of definitions and theoretical backgrounds" in the revised version. This section is not part of the Findings section. On the contrary, Keesstra et al., (2018) has now been included as it fulfils the search criteria mentioned above. Note that following Reviewer 1's suggestion, we have expanded the literature search beyond Scopus, by including Web of Science database. This has made more articles, including Keesstra et al., (2018)", discoverable.

ii) Structure

Comments from Referee: I recommend limiting the structure to three levels of subsection: especially section 4 could be better structured, avoiding sections with titles that do not clearly adhere to a three-level subsection structure.

Authors' response: Thank you very much for pointing out the structural issues. The authors have limited the structure to three levels of the subsection. The different sub-sections in Section 4 are meant to reflect the 4 key objectives defined for the review with the intention that the results could be both quantitative and qualitative.

iii) Content

Comments from Referee: Content is more valuable than academic metrics: while I do see a value in using academic metrics and search engines to select relevant literature, it would be helpful to review the actual characteristics, benefits, and scales of various NBS. Specifically, it would be helpful to have a table that summarizes area, volume of water retention, costs, and effectiveness (and other characteristics) of different NBS. The number of articles does not indicate anything about the effectiveness of a NBS, accordingly, I would encourage the authors to focus more on the characteristics of NBS rather than the number of articles found. In short, more quantitative assessments of the benefits of NBS rather than generic statements would be highly appreciated.

Authors' response: In the revised version, we have investigated further those aspects and carried out a a more quantitative assessment of NBS for hydro-meteorological risk reduction. A new table has been included, which summarizes effectiveness, benefits and costs of different NBS based on the case studies found in the reviewed literature. The table is given below.
We agree that such quantitative information are indeed very valuable and thank the Reviewer for this input. Neverthless, we also see value in using academic metrics: although the number of articles does not indicate anything about the effectiveness of NBS, it provides indications on the direction and the degree of advancement of the research done on this specific topic, which is one of the review objectives.

Authors' change in the revised manuscript: A summary of effectiveness, co-benefits and cost of NBS measures at small scale is shown in Table 4 and at large scale is shown in Table 5

Table 4: Summary of effectiveness, co-benefits and costs of small scale NBS measures

Measures	References	Case studies	Area/ volume covered by NBS	Effectiveness		Co-benefits	Cost/ m^2*	Remark
				Runoff volume reduction	Peak flow reduction			
Porous pavement	Shafique et al., (2018)	Seoul, Korea	1050 m^2	~30–65%	-	• Removing diffuse pollution • Enhancing recharge to groundwater	~$252	• More effective in heavier and shorter rainfall events.
	Damodaram et al., 2010	Texas, USA	2.99 km^2	-	~10% - 30%			
Green roofs	(Burszta-Adamiak and Mrowiec, 2013)	Wroclaw, Poland	2.88 m^2	-	54%-96%	• Reducing nutrient loadings. • Saving energy • Reducing air pollution • Increasing amenity value	~$564	• More efficient in smaller storm events than larger storm events
	(Ercolani et al., 2018)	Milan, Italy	0.39 km^2	~15%-70%	~10-80%			
	(Carpenter and	Michigan, USA	325. 2 m^2	~68.25%	~88.86%			

Measures	References	Case studies	Area/ volume covered by NBS	Effectiveness		Co-benefits	Cost/ m²*	Remark
				Runoff volume reduction	Peak flow reduction			
	Kaluvakolanu, 2011)							
Rain gardens	(Ishimatsu et al., 2017)	Japan	1.862 m^2	~36-100%	-	• Providing a scenic amenity. • Increasing the median property value • Increasing biodiversity	~$501	• More effective in dealing with small discharges or rainwater
	(Goncalves et al., 2018)	Joinville, Brazil	34,139 m^2	50%	48.5%			
Vegetated swales	(Luan et al., 2017)	Beijing, China	157 m^3	~0.3–3.0%.	2.2%	• Reducing concentrations of pollutants • Increasing biodiversity	~$371	• More effective in heavier and shorter rainfall events. • Not suitable in mountains areas
	(Huang et al., 2014)	Haihe River basin, China	1,500 m^3	9.60%	23.56%			
Rainwater harvesting	(Khastagir and Jayasuriya, 2010)	Melbourne, Australia	1 m^3 -5 m^3	~57.8%-78.7%	-	• Improving water quality (TN was reduced around 72%-80%)	~$865 /$m^3$	
	(Damodaram et al., 2010)	Texas, USA	1.5 km^2	-	~8%-10%			
Dry detention pond	(Liew et al., 2012)	Selangor, Malaysia	65,000 m^2	-	33-46%	• Providing recreational benefits.		• Delaying the time to peak by 40-45 min
Detention pond	(Damodaram et al., 2010)	Texas, USA	73,372 m^3	-	~20%	• Providing biodiversity benefits • Providing recreational benefits.	~$60	
	(Goncalves et al., 2018)	Joinville, Brazil	9,700 m^3	55.7%	43.3%			
Bio-retention	(Luan et al., 2017)	Beijing, China	945.93 m^3	~10.2–12.1%.	-	• Reducing TSS pollution • Reducing TP pollution	~$534	• Measure has a better reduction effectiveness in various rainfall intensities.
	(Huang et al., 2014)	Haihe River basin, China	1,708.6 m^3	9.10%	41.65%			
	Khan et al., 2013;	Calgary	48 m^3	~90%	-			
Infiltration trench	(Huang et al., 2014)	Haihe River, China	3,576 m^3	30.80%	19.44%	• Reducing water pollutant • Improving surface water quality.	~$74	
	(Goncalves et al., 2018)	Joinville, Brazil	34,139 m^2	55.9%	53.4%			
Street trees	(Soares et al., 2011)	Lisbon, Portugal	41,247 street trees			• Net benefit €6.55 million per annual of benefits	€45.6 per annual	
Green roof and Porous pavement	(Damodaram et al., 2010)	Texas, USA	4.49 km^2	-	~10%-35%	• Saving energy • Increasing amenity value		• More effective in smaller events
Swale and Porous pavement	(Behroozi et al., 2018)	Tehran, Iran	-	5%-32%	~10%-21%	• Decreasing TSS pollution 50-60%		More effective in smaller events
Rainwater harvesting and Porous pavement	(Damodaram et al., 2010)	Texas, USA	4.49 km^2	-	20%-40%	• Removing diffuse pollution		• More effective in smaller events
Detention pond and Raingarden	(Goncalves et al., 2018)	Joinville, Brazil	18,327 m^2	70.8%	60.0%	• Providing a scenic amenity.		

Measures	References	Case studies	Area/ volume covered by NBS	Effectiveness		Co-benefits	Cost/ m^2*	Remark
				Runoff volume reduction	Peak flow reduction			
Detention pond and Infiltration trench	(Goncalves et al., 2018)	Joinville, Brazil	18,327 m^2	75.1%	67.8%	Improving surface water quality.		

***Remark** Cost of each measure is based on (CNT, 2009; Nordman et al., 2018; De Risi et al., 2018)

Table 5: Summary of effectiveness, co-benefits and costs of large scale NBS measures

Measures	References	Case studies	Area/ volume covered by NBS	Effectiveness	Co-benefits	Cost
De-culverting (river restoration)	(Chou, 2016)	Laojie River, Taiwan	3 km	• It can reduce flood risk up to 100 year return period	• Increasing landscape value • Increasing recreational value	~$18.6 million
Floodplain lowering	(Klijn et al., 2013).	Deventer Netherlands	5.01 km^2	• It can reduce water level 19 cm	• Increasing nature area • Increasing agriculture value	~€136.7 million e
Dike relocation/ floodplain lowering	(Klijn et al., 2013).	Nijmegen/ Lent, Netherlands	2.42 km^2	• It can reduce water level 34 cm	• Increasing floodplain area • Increasing recreational value	~€342.60 million
Floodwater storage	(Klijn et al., 2013).	Volkenrak-Zoommeer	200 million m^3	• It can reduce water level 50 cm	• Increasing habitat and biodiversity in the area • Increasing recreational value	~€386.20 million
Green floodway	(Klijn et al., 2013).	Veessen-Wapenveld	14.10 km^2	• It can reduce water level 71 cm	• Increasing floodplain area • Increasing recreational value	
Wetlands (Mangroves and salt Marshes)	(Coppenolle , 2018; Gedan et al., 2011)			• It can mitigate storm surge 80% • It can protect against tsunami impacts	• Providing shoreline protection services	
Forest rapirian buffer, basins and ponds and coarse woody debris	(McVittie et al., 2018)	Pickering, North Yorkshire, UK	68,6 km^2	• Increased water storage 90,000-138,000 m^3 • Peak flow rate reduction 6.7–14.7% • Flood peak delay by 20 min	• Increase habitat creation value • Education and knowledge • Community development • A benefit/cost ratio of 4.98	~€1.58 million
Renaturation	(McVittie et al., 2018; NWRM, 2019)	Seymaz river, Switzerland	0.4 km^2	• Water storage 800,000 m^3	•	~€61 million (€76.3/m^3)

iv) Definitions

<u>Comments from Referee</u>: in my opinion, it would be helpful to provide a table with definitions and examples of the various academic terms used in the review: The study provides generic definitions for GI, EbA, and NBS, but it is left upon the reader to interpret the definitions. I would recommend to complement Table 2 with some quantitative figures on water retention, area, costs, advantages, disadvantages etc.... (see also the previous comment).

<u>Authors' response:</u> Thank you for the comment and suggestion. Referee 1 also raised similar comments on the definitions. We have included more explanation on the definition in section 3 (now section 2) "Overview of definitions and theoretical backgrounds on the terminology of NBS" Here we also recommend the reader to refer to Nesshöver et al., (2017). and others works for a more exhaustive analysis on terminology, which is beyond the goal of our study. We feel that this additions, together with the newly provided Tables 4 and 5, should provide the reader enough guidance in the interpretation of our results.

Authors' change in the revised manuscript (revised and added texts have yellow highlights)**:**

There are several terms and concepts which have been used interchangeably in the literature to date. In terms of NBS, the two most prominent definitions are from International Union for Conservation of Nature (IUCN) and the European Commission. The European Commission defines Nature-Based Solutions as "*Solutions that aim to help societies address a variety of environmental, social and economic challenges in sustainable ways. They are actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions. Nature-based solutions use the features and complex system processes of nature, such as its ability to store carbon and regulate water flows, in order to achieve desired outcomes, such as reduced disaster risk and an environment that improves human well-being and socially inclusive green growth"* (European Commission, 2015). The IUCN has proposed a definition of NBS as "*actions to protect, sustainably manage and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*" (Cohen-Shacham et al., 2016). Eggermont et al., (2015) proposed a typology characterising NBS into three types: i) NBS that address a better use of natural/protected ecosystems (no or minimal intervention), which fully fits on how IUCN frames NBS; ii) NBS for sustainability and multi-functionality of managed ecosystems and iii) NBSs for the design and the management of new ecosystems, which are more representative of the definition given by the European Commission.

NBS is a collective term for innovative solutions that are based on natural processes and ecosystems to solve different types of societal and environmental challenges. Therefore it considered as an "umbrella concept" covering a range of different ecosystem-related approaches and linked concepts (Cohen-Shacham et al., 2016; Nesshöver et al., 2017), which provide an integrated way to look at different issues simultaneously.

Due to the diverse policy origins, NBS terminology has evolved in the literature to emphasize the different aspects of natural processes or functions. In this regard, nine different terminologies are commonly used in the scientific literature in the context of hydro-meteorological risk reduction: Low Impact Developments (LIDs), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SuDS), Green Infrastructure (GI), Blue-Green Infrastructure (BGI), Ecosystem-based Adaptation (EbA) and Ecosystem-based Disaster Risk Reduction (Eco-DRR). The timeline of each terminology based on their appearances on literature shown in Fig. 1 and their definitions are given in Table 1.

The analysis of publications sourced from Scopus from 2007 to 2018 shows that only 62 out of 1387 articles (i.e., 5%) explicitly used the term "Nature-Based Solution" for hydro-meteorological risk reduction (Figure xx). This can be explained due to difference in terms used in different countries while the term NBS has been used only from 2008 (MacKinnon et al.,

2011) (Fig. 2). However, the significant increase of published articles in recent years testifies how NBS is a rapidly growing research area (Fig.2).

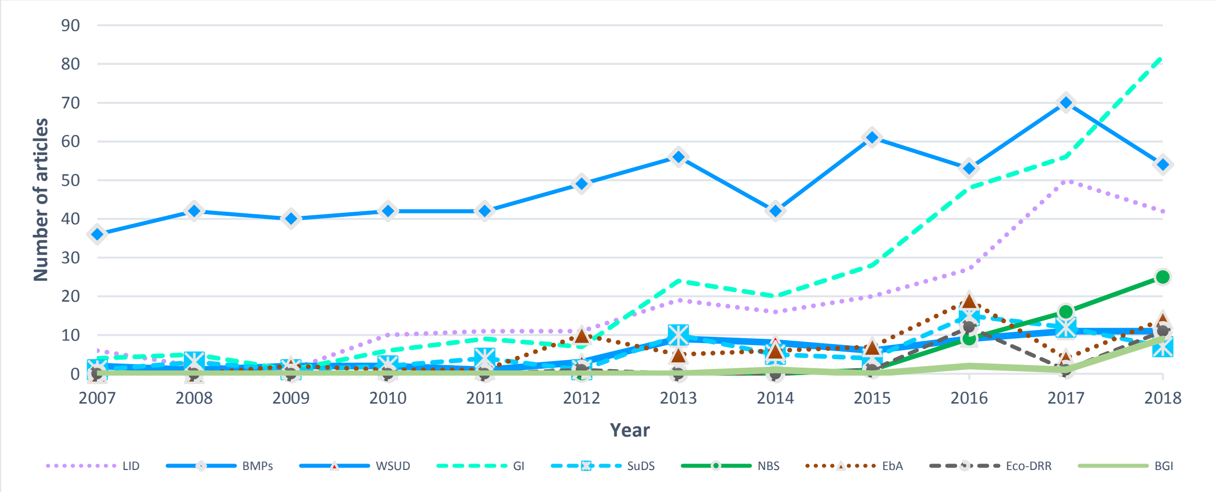

Figure 2: Number/trend of published articles on Nature-Based Solutions (NBS) for hydro-meteorological risk reduction and its sister terms: Low Impact Developments (LIDs), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Green Infrastructure (GI), Sustainable Urban Drainage Systems (SuDS), Nature-Based Solitions (NBS), Ecosystem-based Adaptation (EbA), Ecosystem-based Disaster Risk Reduction (Eco-DRR) and Blue-Green Infrastructure (BGI)

The commonalities between NBS and its sister concepts (i.e., GI, BGI, EbA, Eco-DRR) is that they take a participatory, holistic, integrated approach using nature to enhance adaptive capacity, reduce disaster risk, reduce the vulnerability, increase the resilience, enhance biodiversity, and improve human well-being. More information on the history, scope, application and underlying principle of terms of SuDs, LIDs, BMPs, WSUD and GI can be found in Fletcher et al., (2015) while the relationship between NBS, GI/BGI, and EbA is described in more detail by Nesshöver et al., (2017).

Although all terms are all based on a common idea, differences in definitions reflect their historical perspectives and knowledge base pertinent for that point in time (Fletcher et al., 2015). The distinguishing characteristic between NBS and its sister concepts is how they address social, economic and environmental challenges (Faivre et al., 2018). Some terms such as SuDs, LIDs, and WSUD refer to NBS that specifically address stormwater management. They use landscape for transforming the linear character of conventional stormwater management into a more cyclic approach where drainage, water supply, and ecosystems are treated as part of the same system, mimicking more natural water flows (Liu and Jensen, 2018). GI/BGI focuses more on technology-based infrastructures by applying natural alternatives (Nesshöver et al., 2017) for solving specific activity (i.e., urban planning or stormwater). EbA focuses more on a long-term change within the conservation of biodiversity, ecosystem services, and climate change, while Eco-DRR focuses more on immediate and medium-term impacts from the risk of weather, climate and no climate-related hazards. EbA is often perceived as a subset of NBS that is explicitly concerned with climate change adaptation through the use of nature (Kabisch et al., 2016; Nesshöver et al., 2017). From the above discussion, it can be concluded that EbA, Eco-DRR and GI/BGI provide more specific solutions to more specific issues. One key distinction is that unlike the sister concepts, the NBS concept is more open to different interpretations. It can be useful as they may be easier to encourage stakeholders to take part in the discussion.

Moreover, features of NBS provide an alternative to work with existing measures or grey infrastructures. Therefore, it is important to note that very often a combination between natural and traditional engineering solutions (a.k.a. "hybrid" solutions) is likely to produce more effective results than any of these measures alone, especially when their co-benefits are taken into consideration (Alves et al., 2019).

Important advances in the science and practice of NBS is provided by the EKLIPSE Expert Working Group, who developed the first version of a multiple-dimension impact evaluation framework to support planning and evaluation of NBS projects. The document includes a list of impacts, indicators and methods for assessing the performance of NBS specifically at the urban scale (EKLIPSE, 2017). Lafortezza et al., (2018) has also reviewed different case studies around the world where NBS have been applied from micro-scale to macro-scale. Furthermore, an overview on how different types of nature based solutions can regulate to ecosystem services (i.e., soil protection, water quality, flood regulation, and water provision) has been carried out by Keesstra et al., (2018).

v) Drought

Comments from Referee it is well know that land reclamation and restoration reduces evaporation and mitigates the drought risk. However, the authors found only one single study referring to the drought risk. This might be due to a methodology based on "key words" rather than content.

Authors' response:

Thank you very much for your suggestion. While the methodology helps limit the scope of the paper, the authors understand that it may also cause some gaps in the study. However, the authors have attempted to review papers as comprehensively as possible to mitigate this issue.

Since the aim of the study is to review Nature Based Solutions and those terms used in conjunction with NBS, additional terminology like reclamation and restoration were not specifically used. This search term could introduce a bias, as the authors then assume the solutions before the review. To be transparent, we have included a sentence to acknowledge that the selection of key search words can limit the hydro-meterological risk measures that appear in returned papers.

Nevertheless, the authors believe that the method still provides useful direction for a state of the art review and defining research gaps on Nature-Based Solutions for Hydro-meteorological risk reduction.

vi) Scale and examples

Comments from Referee one example that struck me is the NBS "Room for the River Programme" in the Netherlands at the Rhine and Meuse. It is general knowledge that flood protection has to start upstream in the headwaters, where most of the precipitation occurs, to be efficient. Nevertheless, the ms only mentions NBS in the Netherlands (a third of the Netherlands are below sea level and sea levels are rising), ignoring the far more relevant NBS in upstream countries. This might be linked to the somewhat limited methodology of the literature review (see comment i).

<u>Authors' response</u>: Thank you very much for your comment. The requirements of this articles that is to focus on peer-reviewed articles in English and we agree with the reviewer that upstream cases exist, which the authors had conducted additional research based on the comment of the reviewer.

It can be summarized that the EU Flood directive specifies that countries upstream or downstream should avoid taking measures that will increase the flood risk to other countries in the same river catchment. In case this is not feasible, the countries should consult with the other member states to agree to the proposed measures (EU, 2019). As far as the authors are aware, there is a project in the Rhine basin called Adaptive Land use for Flood Alleviation (ALFA). "Room for the River Programme" by the Ducth is also part of this project. However, all of the project's documents from upstream in Germany that the authors have found are only in the grey literatures and in the German language, which are out of the scope of this article.

On the other hand, there are many documents and publications on the "Room for the River Programme" that are available in English. Moreover, "Room for the river programme" is one of the big projects on a large scale NBS which has been successfully studied and implemented it can be used as an example to other countries.

vii) Tools

<u>Comments from Referee</u>: in my opinion, the review of tools could be shortened, as it is slightly off the topic. Instead, more attention could be given to the quantification of the various benefits of NBS could be provided (see comment iii).

<u>Authors' response:</u> Authors have shortened the review of tools. However, the leading message should still be included since the tools are important for selection, evaluation and operation of NBS. One of the purposes of this review is to review the use of techniques, methods and tools for planning, selecting, evaluating and implementing NBS. The benefit of this section is to provide information to the reader as to what the available tools are that can be used for a specific purpose.

The authors have also included some quantification of NBS measures as suggested by the reviewer in Table 4 and 5 as shown in comment iii and benefits of NBS also discuss in section 4.5 in manuscripts. However, discussing the quantitative co-benefits of NBS is still very challenging as there is a lack of information on assessment quantitative value of the ecosystem. Such challenges and limitations will be explictely commented on in the revised version.

viii) Conclusion

<u>Comments from Referee</u>: the current conclusion provides general and generic statements and any reader somewhat familiar with the topic does not really learn anything new. It would be helpful to generate more conclusive and quantitative statement based on the review: which NBS are most effective, which provide most multi-benefits, which require least areas, which are most accepted?

<u>Authors' response:</u> Thank you for the suggestion. The authors have revised the conclusion to summarize the quantitative statement of NBS on; "which NBS are most effective, which provide most multi-benefits, which require the least area, which are the most accepted” as the authors suggested.

However, this has proven to be very difficult because the effectiveness, benefits and acceptance of NBS are dependent on the implementation purposeslocal context and cultural setting. For example, small NBS are more suitable for urban flooding while large scale NBS are more suitable for river floods, coastal floods, droughts and landslides. Large scale NBS can provide more benefits compared to small scale NBS because it has a bigger space, thus more function can be included in the design process. For example, Laojie river project in Taoyuan City in Taiwan changed the channel into an accessible green corridor. This project helps in reducing flood risk, improving riverside landscapes, increasing recreation area, increasing the aesthetic value in the area, and improving river water quality. On the other hand, small scale NBS need less area because most of the measures can be implemented in the free space. For example, green roofs can be implemented on the roofs of buildings, and permeable pavements can be implemented in car parks. Investments in NBS will benefit society by providing cost-effective measures and adaptive strategies that protect their communities and achieve a range of co-benefits. Therefore, bridging the gaps between researchers, engineers and stakeholders will help to improve the capacity of NBS in reducing hydro-meteorological risk as well as increasing thier benefits. Strengthening these aspects may be beneficial for improving acceptance of NBS at the local level.

In the revised version, all of the above information has been included in the conclusion section, and a summary of quantitative information on effectiveness, co-benefits and cost for different NBS measures can be found in Table 4 and 5 in the revision.