	article "assessment of economic flood damage." Nat. Hazards Earth Syst. Sci. 10, 1697–1724. https://doi.org/10.5194/nhess-10-1697-2010 Sørup, H.J.D., Fryd, O., Liu, L., Arnbjerg-Nielsen, K., and Jensen, M.B. 2019. An SDG-based framework for assessing urban stormwater management systems. Blue-Green Systems, Blue-Green Systems, 1, 1, 102-118. DOI: 10.2166/bgs.2019.922. Zhou, Q., Mikkelsen, P.S., Halsnæs, K., Arnbjerg-Nielsen, K., 2012. Framework for economic pluvial flood risk assessment considering climate change effects and adaptation benefits. J. Hydrol. 414–415. https://doi.org/10.1016/j.jhydrol.2011.11.031

5.16 Risk to critical urban infrastructure

Project Name: CONNECTING Nature (Grant Agreement no. 730222)

Author/s and affiliations: Connop, S.[1], Dushkova, D.[2], Haase, D.[2] and Nash, C.[1]

[1] Sustainability Research Institute, University of East London, UK

[2] Geography Department, Humboldt University of Berlin, Berlin, Germany

Reduction of inundation risk for critical urban infrastructures (probability-economic) (Applied and EO/RS combined)	**Natural and Climate Hazards**
Description and justification	Metrics are based on the quantification of infrastructure that has a reduced risk of flooding due to NBS implementation. Ultimately, this relates to a reduced economic cost of flooding, or increased health & wellbeing of communities due to reduced stress levels associated with flooding or risk of flooding. It should be noted that, if NBS is poorly designed or well-designed but poorly constructed, it has the potential to lead to increased local flooding risk for some areas. Advances in remote sensing technology and new satellite platforms such as ALOS sensors have widened the application of satellite data, for instance to validate flood inundation models. Flood modelling based on remote sensing rainfall data will be useful for developing regional flood early-warning and flood mitigation systems in flood hazardous areas. Reduction in flood-risk by nature-based solutions simulation can be used to: • Support the development of strategic plans for NBS implementation to reduce flood risk and comply with Flood Risk Management; • Predict the impact of individual NBS projects;

	- Quantify the predicted impact of implemented NBS; - Promote stakeholder engagement in NBS planning; - Support the leveraging of finances necessary for delivering NBS projects.
Definition	Probability of a reduction of inundation risk for critical urban infrastructures based on more applied and participatory hydraulic modelling and GIS assessment.
Strengths and weaknesses	**Applied methods:** Robustness of evidence depends upon the level of precision of the simulation software and the data analysed. Typically, simulations requiring the most basic data input are associated with the least precise results. This is not always the case, however, and model validation (either through real-world testing or validation against other models) is recommended. **EO/RS methods:** There are some limitations/barriers to the reliability of the evidence generated. This includes the expense associated with the most high-resolution satellite images when financial resources are scarce, or when images are not available on the study area. In addition, some areas can be covered with clouds causing a partial loss of information. The presence of dense urban areas and forests also affect both SAR and multispectral based flood mapping and requires a more-complex data processing which is not straightforward to accomplish with a user-friendly approach. High spatial resolution is a key factor when mapping floods in dense urban areas, and it is one of the limitations of the free of charge satellite data approach. These services provide rapid mapping products that can be affected by uncertainty and are not always validated. Maps of flooded areas produced by official authorities and based on bespoke aerial photos and field surveys are more accurate, although they are time-consuming and require higher costs to be generated. Based on experience, however, on-demand high costs, high resolution data and field surveys are often necessary to ensure reliability of evidence.
Measurement procedure and tool	A variety of methods exist from applied/public participation techniques through to earth observation/remote sensing approaches. For further details on measurement tools and metrics, including those adopted by past and current EU research and innovation projects, refer to Connecting Nature Indicator Metrics Reviews Env19_Applied and Env19_RS.
Scale of measurement	**Applied methods:** Simulations are typically carried out on catchment scales identifying flood risk areas under different climate scenarios. Local impacts can also be modelled to

	assess impacts on storm sewer systems and local flood risk areas. **EO/RS methods:** Can be applied at various geographical scales, but is most commonly applied at a catchment scale.
Data source	
Required data	Required data will depend on selected methods, for further details on applied and earth observation/remote sensing metrics refer to Connecting Nature Indicator Metrics Reviews Env19_Applied and Env19_RS.
Data input type	Data input types will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to Connecting Nature Indicator Metrics Reviews Env19_Applied and Env19_RS.
Data collection frequency	Data collection frequency will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to Connecting Nature Indicator Metrics Reviews Env19_Applied and Env19_RS.
Level of expertise required	**Applied methods:** Expertise required is very much based on the complexity of the data requirements of the model. Very basic models exist that require very low levels of expertise and are ideal for use as community engagement tools. To maximise the value of participatory approaches, experience of managing such projects is beneficial. **EO/RS methods:** There a semi-automatic method for flood mapping, based only on free satellite images and open-source software. The proposed method is suitable to be applied by the community involved in flood hazard management, not necessarily experts in remote sensing processing. Much of the freely available data is available with the first level of atmospheric or radiometric calibration, allowing their use by different types of users and not only experts in remote sensing processing. In addition, free GIS plugins allow the downloading and processing of free multispectral satellite images. The availability of these resources is useful for the management of natural hazard effects. However, expertise will be needed in order to improve and manually refine the automatic mapping using free ancillary data such as the digital elevation model-based water depth model and available ground truth data.
Synergies with other indicators	**Applied methods:** Simulation software often characterises multiple benefits of NBS implementation, often including impacts on water quality. Flood risk prediction also has synergies with the economic cost of such flooding, particularly in relation to insurance values. Flood risk

	reduction can also be related to health & wellbeing indicators associated with the stress caused by flood risk to properties, business and other infrastructure. **EO/RS methods:** Synergies exist between floods, climate change adaptation and disaster risk reduction. Synergies between managing flood risk, reaching or maintaining a good ecological status, promoting of ecosystem services and safeguarding the nature or ecosystem services in floodplains can be very complex.
Connection with SDGs	All except SDG2, SDG5 and SDG12: Decreasing costs associated with insurance risk; Decreased stress, health risk and physical risk; Links to environmental education; Possible cleaner water co-benefit; Decrease risk to energy infrastructure; Job creation; Reduced infrastructure risk; Green infrastructure development; Social equality in relation to flood risk; Sustainable urban development; Climate change adaptation; More sustainable water management; Habitat enhancement/creation; Environmental Justice; Opportunities for collaborative working.
Opportunities for participatory data collection	**Applied methods** Opportunities are available for a participatory process, particularly in relation to stakeholder decision-making (Voinov and Gaddis 2008; Voinov et al. 2016; Gray et al. 2018) and or data-gathering through ICT-enabled citizen observatories (When et al. 2015). Involving stakeholders through active participation can increase the legitimacy of risk processes, public acceptance, commitment, and support with respect to decision-making processes (Inam et al. 2017). **EO/RS methods:** To assess flood risk at a neighbourhood level, accurate data on flood extent, exposure and vulnerability is required. One of the possible and useful ways to obtain these data is a combination of remote sensing data and local knowledge through participatory processes. Further detail can be found on participatory processes in Env19_Applied.
Additional information	
References	**Applied methods:** Bhaduri, B, Minner, M, Tatalovich, S and Harbor, J (2001) Long-term Hydrologic Impact of Urbanization: A Tale of Two Models. Journal of Water Resources Planning and Management 127, 13-19. Damodaram, C, Giacomoni, MH, Prakash Khedun, C, Holmes, H, Ryan, A, Saour, W and Zechman, EM (2010) Simulation of combined best management practices and low impact development for sustainable stormwater management.

Journal of the American Water Resources Association 46(5), 907-918.

Darabi, H, Choubin, B, Rahmati, O, Haghighi, AT, Pradhan, B and Kløve, B (2019) Urban flood risk mapping using the GARP and QUEST models: A comparative study of machine learning techniques. Journal of Hydrology 569, 142-154.

Freni, G, Mannina, G and Viviani, G (2010) Urban storm-water quality management: centralized versus source control. Journal of Water Resources Planning and Management 136(2), 268-278.

Johannessen, BG, Hamouz, V, Gragne, AS and Muthanna, TM (2019) The transferability of SWMM model parameters between green roofs with similar build-up. Journal of Hydrology 569, 816-828.

Gray, S, Voinov, A, Paolisso, M, Jordan, R, BenDor, T, Bommel, P, Glynn, P, Hedelin, B, Hubacek, K, Introne, J, Kolagani, N, Laursen, B, Prell, C, Schmitt-Olabisi, L, Singer, A, Sterling, E and Zellner, M (2018) Purpose, Processes, Partnerships, and Products: 4Ps to advance Participatory Socio-Environmental Modeling. Ecological Applications 28(1), 46-61.

Abhijith, KV and Kumar, P (2019) Field investigations for evaluating green infrastructure effects on air quality in open-road conditions. Atmospheric Environment 201, 132-147.

Inam A, Adamowski PO, Halbe J, Malard J, Albano R. (2017) Coupling of a distributed stakeholder-built system dynamics socio-economic model with SAHYSMOD for sustainable soil salinity management. Part 1: model Development. Journal of Hydrology 6, 596–618.

Lim, KJ, Engel, BA, Kim, Y and Harbor, J (2001) Development of the Long-Term Hydrologic Impact Assessment (L-THIA) WWW Systems. In: D.E. Stott, R.H. Mohtar, and G.C. Steinhardt, (eds), Sustaining the Global Farm - Selected papers from the 10th International Soil Conservation Organization Meeting, May 24-29, 1999, West Lafayette, Indiana, International Soil Conservation Organization in cooperation with the USDA and Purdue University, West Lafayette, Indiana. pp. 1018-1023.

Loperfido, JV, Noe, GB, Jarnagin, ST and Hogan, DM (2014) Effects of distributed and centralized stormwater best management practices and land cover on urban stream hydrology at the catchment scale. Journal of Hydrology 519, 2584-2595.

Lucas, WC and Sample, DJ (2015) Reducing combined sewer overflows by using outlet controls for Green Stormwater Infrastructure: case study in Richmond, Virginia. Journal of Hydrology 520, 473-488.

Macro, K, Matott, LS, Rabideau, A, Ghodsi, SH and Zhu, Z (2019) OSTRICH-SWMM: A new multi-objective optimization tool for green infrastructure planning with SWMM. Environmental Modelling & Software 113, 42-47.

Palla, A, Gnecco, I and La Barbera, P (2017) The impact of domestic rainwater harvesting systems in storm water runoff mitigation at the urban block scale. Journal of Environmental Management 191, 297-305.

Pregnolato, M, Ford, A, Robson, C, Glenis, V, Barr, S and Dawson, R (2016) Assessing urban strategies for reducing the impacts of extreme weather on infrastructure networks. Royal Society open science, 3(5), p.160023.

Rossman, LA (2015) StormWater Management Model User's Manual Version 5.1. EPA- 600/R-14/413b.

Voinov, A, and Gaddis, EJB (2008) Lessons for successful participatory watershed modeling: a perspective from modeling practitioners. Ecological modelling 216(2), 197-207.

Voinov, A, Kolgani, N, McCall, MK, Glynn, PD, Osterman, F, Palaniappan, R, Pierce, S, and Kragt, ME, (2016) Modelling with stakeholders – Next generation. Environmental Modelling & Software 77, 196-220.

Wehn, U, Rusca, M, Evers, J and Lanfranchi, V (2015) Participation in flood risk management and the potential of citizen observatories: A governance analysis. Environmental Science & Policy 48, 225-236.

Zellner, M, Massey, D, Minor, E and Gonzalez-Meler, M (2016) Exploring the Effects of Green Infrastructure Placement on Neighborhood-Level Flooding via Spatially Explicit Simulations. Computers, Environment and Urban Systems 59, 116-128.

EO/RS methods:

Awadallah, A., and N. Awadallah, (2013) A novel approach for the joint use of rainfall monthly and daily ground station data with TRMM data to generate IDF estimates in a poorly gauged arid region. Open Journal of Modern Hydrology, 3, 1–7, doi:10.4236/ ojmh.2013.31001.

Berger, M.; Moreno, J.; Johannessen, J.A.; Levelt, P.F.; Hanssen, R.F. (2012) ESA's sentinel missions in support of Earth system science. Remote Sens. Environ., 120, 84–90. [CrossRef]

EEA (2016) Flood risks and environmental vulnerability. Exploring the synergies between floodplain restoration, water policies and thematic policies. Report 1 / 2016. Luxembourg: Publications Office of the European Union, 2016.

EOSDIS Worldview (2019). Available online: https://worldview.earthdata.nasa.gov/ (accessed on 27 March 2019).

Khan, S. I. et al. (2011) Hydroclimatology of Lake Victoria region using hydrologic model and satellite remote sensing data.

	Hydrology & Earth System Sciiences, (15) 1, 107–117, doi:10.5194/ hess-15-107-2011. Klein, T.; Nilsson, M.; Persson, A.; Håkansson, B. (2017). From Open Data to Open Analyses—New Opportunities for Environmental Applications? Environments, 4, 32. [CrossRef] Li, S.; Dragicevic, S.; Castro, F.A.; Sester, M.; Winter, S.; Coltekin, A.; Pettit, C.; Jiang, B.; Haworth, J.; Stein, A. (2016). Geospatial big data handling theory and methods: A review and research challenges. ISPRS J. Photogramm. Remote Sens., 115, 119–133. [CrossRef] Li, X.-H., Zhang, Q. and Xu, C.Y (2012) Suitability of the TRMM satellite rainfalls in driving a distributed hydrological model for water balance computations in Xinjiang catchment, Poyang lake basin. Journal of Hydrology,(426–427) 28–38, doi:10.1016/ j.jhydrol.2012.01.013. Moel, H.D.; Alphen, J.V.; Aerts, J. (2009). Flood maps in Europe–methods, availability and use. Nat. Hazards Earth Syst. Sci., 9, 289–301. [CrossRef] Notti D., Giordan D., Calo F. et al. (2018). Potential and Limitations of Open Satellite Data for Flood Mapping. Remote Sens. 2018, 10, 1673; doi:10.3390/rs10111673 Pregnolato, M, Ford, A, Robson, C, Glenis, V, Barr, S and Dawson, R (2016) Assessing urban strategies for reducing the impacts of extreme weather on infrastructure networks. Royal Society open science, 3(5), p.160023. Wulder, M.A.; Masek, J.G.; Cohen, W.B.; Loveland, T.R.; Woodcock, C.E. (2012) Opening the archive: How free data has enabled the science and monitoring promise of Landsat. Remote Sens. Environ., 122, 2–10.

5.17 Mean number of people adversely affected by natural disasters each year

Project Name: RECONECT (Grant Agreement no. 776866)

Author/s and affiliations: Karsten Arnbjerg-Nielsen[1]

[1]*Department of Environmental Engineering, Technical University of Denmark, Denmark*

Mean number of people adversely affected by natural disasters each year	Natural and Climate Hazards
Description and justification	This indicator is closely related to the previous indicator on the costing of natural hazards / disasters, but specifically addresses the problem that while intangible costs are important in relation to assessing impacts of natural disasters they may be difficult to assign an