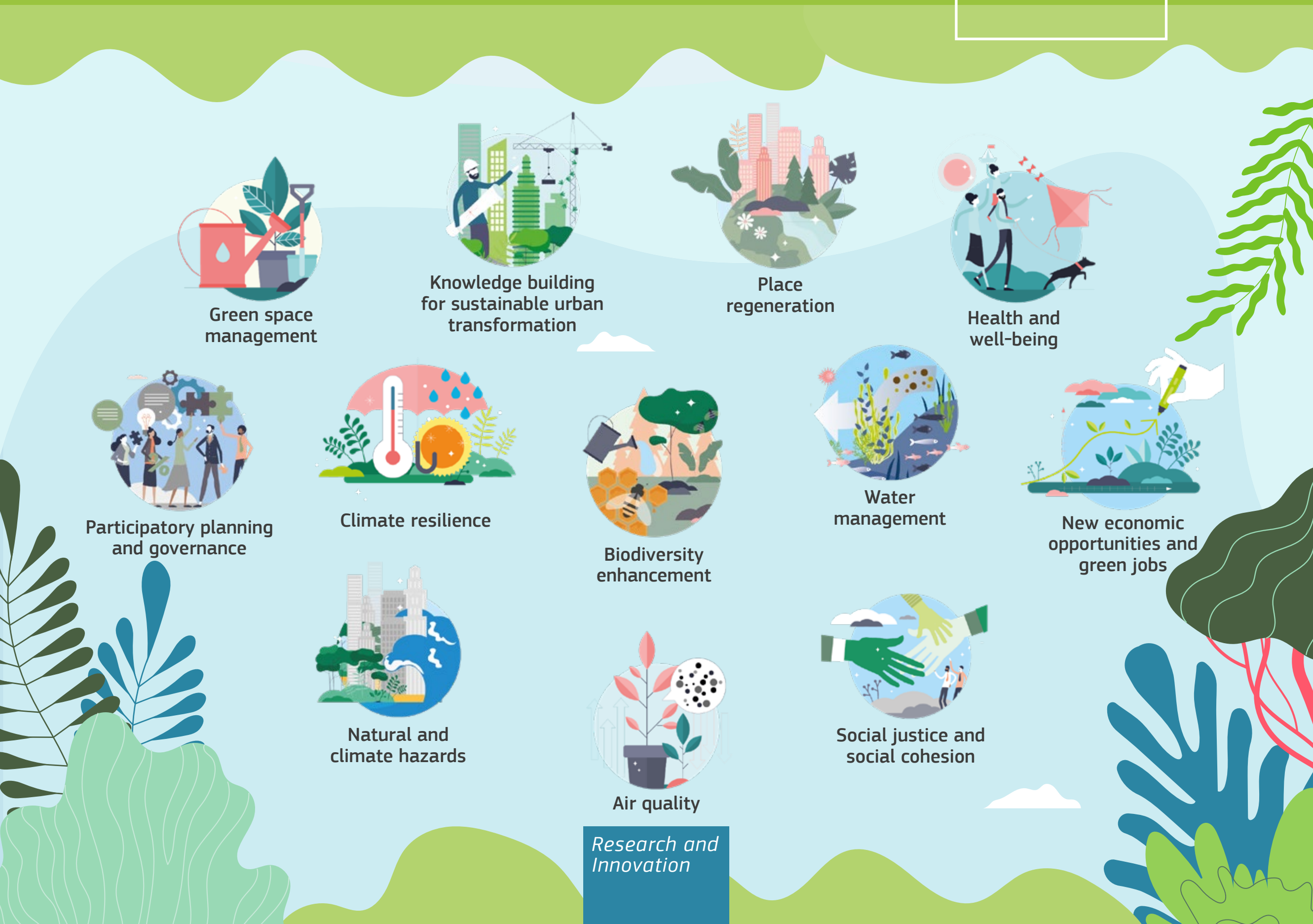
European Commission

EVALUATING THE IMPACT OF

NATURE-BASED SOLUTIONS

Appendix of Methods

Independent Expert Report



Research and Innovation

Evaluating the Impact of Nature-based Solutions: Appendix of Methods

European Commission
Directorate-General for Research and Innovation
Directorate C — Healthy Planet
Unit C3 — Climate and Planetary Boundaries

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EUROPEAN COMMISSION

EVALUATING THE IMPACT OF NATURE-BASED SOLUTIONS

Appendix of Methods

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2021

Directorate-General for Research and Innovation
Healthy Planet - Climate and Planetary Boundaries

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WATER MANAGEMENT

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3 Recommended Indicators of Water Management

3.13 Surface runoff in relation to precipitation quantity

3.13.1 Direct measurement

Project Name: UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1],Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2], Maddalen Mendizabal[3]

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Runoff coefficient – direct measurement	Water Management
Description and justification	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil

	characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).
Definition	Runoff coefficient in relation to precipitation quantities (m^3/s, L/s or depth-equivalent mm)
Strengths and weaknesses	+ Traditional, well-studied method for open channel flow measurement + Scalable for different purposes - Requires judgement in case of equipment malfunction
Measurement procedure and tool	Direct measurement of runoff (and its characteristics) using standard approaches, including weirs, pressure transducers/loggers, tipping-bucket gauges, etc. (e.g., Stovin et al., 2012). Large scale: Weirs, flumes, orifices. Weirs obstruct the flow making the head behind the weir being a function of flow velocity and flow rate though the weir. Flumes are another traditional method for open channel flow measurement in a channel with converging and diverging sections. The operation principle of the flumes is that the water level is higher in the converging section than in the diverging section, and that there is direct relationship between water depth and flow rate (Adkins, 2006). Small scale: tipping-bucket gauges, pressure transducers for discharge monitoring. Tipping-bucket gauges record runoff volumes as numbers of bucket tips per 24-h period. The depth of the daily runoff is then calculated by dividing the volume of daily runoff by the area of the test plot (Armson, Stringer, and Ennos, 2013). Pressure transducers allow for automatic continuous monitoring and data collection at certain intervals (e.g., 1-min) (Stovin, Vesuviano, and Kasmin, 2012).
Scale of measurement	Plot or building scale to district scale
Data source	
Required data	Runoff measurements
Data input type	Quantitative

Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	Moderate – ability to evaluate the accuracy of measurements is required (in case of equipment malfunction)
Synergies with other indicators	Direct relation to *Height of flood peak* and *Time to flood peak* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Adkins, G.B. (2006). Flow Measurement Devices. Utah Division of Water Rights, Utah. Armson, D., Stringer, P. & Ennos, A.R. (2013). The effect of street trees and amenity grass on -urban surface water runoff in Manchester, UK. Urban Forestry & Urban Greening, 12, 282-286. Stovin, V., Vesuviano, G. & Kasmin, H. (2012). The hydrological performance of a green roof test bed under UK climatic conditions. Journal of Hydrology, 414-415, 148-161

3.13.2 Curve Number method

Project Name: UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2], Maddalen Mendizabal[3]

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Runoff coefficient – Curve Number	**Water Management**
Description and justification	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are

	affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).
Definition	Runoff in relation to precipitation quantity (mm)
Strengths and weaknesses	+ The most widely used modelling method to estimate runoff from rainfall + Particularly useful for comparing pre- and post-development peak rates, volumes, and hydrographs - Curve number varies due to differences in rainfall intensity and duration, total rainfall, soil moisture conditions, cover density, stage of growth, and temperature
Measurement procedure and tool	USDA Curve Number – Taking into account losses (interception, infiltration and storage) as well as antecedent moisture conditions – runoff is estimated for storm events. Published Curve Numbers (CN) can be used in the equation. CN values are function of soil, hydrological conditions and landcover (can be weighted). Widely used worldwide. Soil Conservation Service (1972). Used in context of NBS (Gill et al, 2007). Steps to produce the value for the storm runoff include: 1. Determine the value of *CN* for the specific cover type, hydrologic condition, and hydrologic soil group, using Table 9-1 in the USDA National Engineering Handbook (2004). 2. Determine the value for *S* based on the *CN* value, using Table 10-1 in the USDA National Engineering Handbook (2004) or equation for the *CN*. 3. Determine the runoff (*Q*) either using the graphical solution or tables provided by the USDA National Engineering Handbook (2004). For the determination, values for rainfall and *CN* are needed. Other possibility to determine the runoff is to use the runoff equation where values for rainfall and *S* are needed. The curve number equation to estimate runoff from rainfall is:

	$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad P > I_a$ $Q = 0 \quad P \leq I_a$ Where *Q* is depth of runoff (in), *P* is depth of rainfall (in), I_a is initial abstraction (in), and *S* is maximum potential retention (in). The initial abstraction (I_a) consists mainly of interception, infiltration during early parts of a storm, and surface depression storage. The initial abstraction can be determined from rainfall-runoff events for small watersheds. However, estimation of the initial abstraction is not easy and I_a has been assumed to be a function of the maximum potential retention (*S*). An empirical relationship between I_a and *S* has been expressed as (USDA, 2004): $I_a = 0.2S$ With this relationship, the original runoff equation can be written in a more simplified form: $Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad P > I_a$ The runoff based on curve number can be determined based on graphs or tables provided by USDA (2004). The parameter *CN* is a transformation of potential maximum retention, *S* (in mm): $CN = \frac{1000}{10 + \frac{S}{25.4}}$
Scale of measurement	District scale to metropolitan area scale
Data source	
Required data	Hydrologic soil group (HSG), land use/cover, hydrologic surface condition and antecedent moisture condition
Data input type	Quantitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	High – requires ability to execute the calculations, use the graphical solutions and evaluate the results

Synergies with other indicators	Direct relation to *Height of flood peak* and *Time to flood peak* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	United States Department of Agriculture (USDA). (2004). National Engineering Handbook Part 630 Hydrology. Washington, D.C.: United States Department of Agriculture, Natural Resources Conservation Service. Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=STELPRDB1043063

3.13.3 Rational method

Project Name: UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2], Maddalen Mendizabal[3]

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[3] TECNALIA, Basque Research and Technology Alliance (BRTA), Mikeletegi Pasealekua 2, 20009 Donostia-San Sebastián, Spain

Runoff coefficient – Rational method	**Water Management**
Description and justification	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a

<table>
<tr><td></td><td>heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).</td></tr>
<tr><td>Definition</td><td>Runoff in relation to precipitation quantity (m^3/s or L/s)</td></tr>
<tr><td>Strengths and weaknesses</td><td>+ A widely used method, which gives an empirical relation between rainfall intensity and peak flow
- Requires significant judgment and understanding from the designer
- For the method, several assumptions that are seldom met under natural conditions must be made</td></tr>
<tr><td>Measurement procedure and tool</td><td>Rational Method for estimating ‘peak’ flow rates for simple urban watersheds/sewers. Often used for design discharges. Requires rainfall intensity, the runoff-coefficient (can be derived from published value) and watershed area (Kuichling, 1889).

A simplified outline of the necessary steps to determine peak runoff using the Rational Method is:
1. Determine the runoff coefficient (C). Typical values are listed in textbooks and manuals (e.g., Viessman & Lewis, 2003; VDOT, 2002). If needed, use a saturation factor (C_f) for storms with a recurrence intervals less than 10 years. These higher intensity storms require modification to estimation of runoff. Saturation factors are given by reference books and design manuals. Note that the saturation factor C_f multiplied by the runoff coefficient C should not exceed 1.0.
Saturation factors (C_f) for rational formula (VDOT, 2002).
<table>
<tr><th>Recurrence Interval (Years)</th><th>C_f</th></tr>
<tr><td>2, 5 and 10</td><td>1.0</td></tr>
<tr><td>25</td><td>1.1</td></tr>
<tr><td>50</td><td>1.2</td></tr>
<tr><td>100</td><td>1.25</td></tr>
</table>

2. Determine the time of concentration (T_c) to estimate the average rainfall intensity (i). The methods for determining the time of concentration are described by, e.g., VDOT (2002). One of them is that the time of concentration is the time required for water to flow from the hydraulically most remote point in the drainage area to the point of study.
3. Determine the rainfall intensity (i). It is assumed that the duration is equal to the time of concentration. The rainfall intensity can be selected from the IDF curve.
4. Solve the equation of the Rational Method to obtain the estimated peak runoff:</td></tr>
</table>

	$$Q = C_f CiA$$ Where Q is maximum rate of runoff (cfs), C_f is saturation factor, C is runoff coefficient representing a ratio of runoff to rainfall (dimensionless), i is average rainfall intensity for a duration equal to the time of concentration for a selected return period (in/hr), and A is drainage area contributing to the point of study (ac).
Scale of measurement	Plot or building scale to district scale. Used mostly for relatively small drainage areas, such as parking lots. The use should be limited to drainage areas <20 acres (ca. 8 ha).
Data source	
Required data	Rainfall intensity, drainage area, saturation factor, runoff coefficient
Data input type	Quantitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	High – requires significant judgement on adequacy of calculated values
Synergies with other indicators	Direct relation to *Height of flood peak* and *Time to flood peak* indicators
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Dhakal, N., Fang, X., Asquith, W.H. & Cleveland, T. (2013). Return period adjustment for runoff coefficients based on analysis in undeveloped Texas watersheds. Journal of Irrigation and Drainage Engineering, June 2013 Hayes, D.C., & Young, R.L. 2005. Comparison of Peak Discharge and Runoff Characteristic Estimates from the Rational Method to Field Observations for Small Basins in Central Virginia. Scientific Investigations Report 2005-5254. Reston, VA: United States Geological Survey. Viessman, W. & Lewis, G.L. (2003). Introduction to Hydrology. 5th edition. Upper Saddle River, NJ: Prentice Hall Virginia Department of Transportation (VDOT). (2019). Drainage Manual. Location and Design Division. Issued April 2002. Rev. March 2019. Richmond, VA: Virginia Department of Transportation. Retrieved from

	http://www.virginiadot.org/business/resources/LocDes/DrainageManual/Combined_Drainage_Manual.pdf

3.13.4 Intensity-Duration-Frequency (IDF) curve method

Project Name: UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2], Maddalen Mendizabal[3]

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Runoff coefficient – IDF curves	**Water Management**
Description and justification	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).
Definition	Runoff in relation to precipitation quantity (L/s or m^3/s)
Strengths and weaknesses	+ IDF analysis provides a convenient tool for summarizing regional rainfall information and thus it is useful in municipal stormwater management practices - Requires significant judgment and understanding from the designer - Requires fairly extensive historic rainfall data
Measurement procedure and tool	Statistical estimation of 'peak' runoff rates for return periods of 5,10,100 years based on rainfall and

	catchment characteristics (area, channel slope, length, soil permeability). E.g. IH124 or FEH methods (UK). A summary of the steps necessary to create IDF curves is given by Mirrhosseini et al. (2013): 1. Obtain annual maximum series of precipitation depth for a given duration (15 min, 30 min, 45 min, 1 h, 2 h, 3 h, 6 h, 12 h, 24 h, and 48 h) 2. Use a suitable probability distribution (e.g., generalized extreme value per Mirrhosseini et al., 2013) to find precipitation depths for different return periods (2, 5, 10, 25, 50, and 100 y). One of the most common probability distributions used in the IDF analysis is Gumbel's extreme value distribution (Wang & Huang 2004). 3. Repeat the first two steps for different durations 4. Plot rainfall intensity versus duration for different frequencies In addition, other possible probability distributions can be used. Another possibility to create IDF curves is to use the equation (MTO 1997): $i = A / (t_d + B)^c$ Where *i* is average rainfall intensity (mm/h), t_d is rainfall duration (min) and *A, B*, and *c* are coefficients. The coefficients can be solved by least squares method described in the Ontario Drainage Management Manual produced by the Ministry of Transportation of Ontario (MTO, 1997). When the coefficients are solved, the above equation can be used to produce plots of rainfall intensity vs. duration for different return periods (Wang & Huang 2004).
Scale of measurement	Different sizes of catchments, district scale to region scale
Data source	
Required data	Recorded rainfall data (historic) and catchment characteristics (area, channel length, soil permeability)
Data input type	Quantitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	High – requires ability and significant judgement to execute statistical analyses
Synergies with other indicators	Direct relation to *Height of flood peak* and *Time to flood peak* indicators

Connection with SDGs	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
References	Al Mamoon, A., Joergensen, N.E., Rahman, A., & Qasem, H. (2014). Derivation of new design rainfall in Qatar using L-moment based index frequency approach. International Journal of Sustainable Built Environment, 3(1), 111-118. Fadhel, S., Rico-Ramirez, M.A., & Han, D. (2017). Uncertainty of Intensity-Duration-Frequency (IDF) curves due to varied climate baseline periods. Journal of Hydrology, 547, 600-612. Ministry of Transportation of Ontario (MTO). (1997). Ministry of Transportation of Ontario Drainage Management Manual. Ontario, Canada: Ministry of Transportation of Ontario. Retrieved from http://www.mto.gov.on.ca/english/publications/drainage-management.shtml Mirrhosseini, G., Srivastava, P., & Stefanova, L. (2013). The impact of climate change on rainfall Intensity-Duration-Frequency (IDF) curves in Alabama. Regional Environmental Change, 13(S1), 25-33. Prodanovic, P., & Simonovic, S.P. (2007). Development of Rainfall Intensity Duration Curves for the City of London Under the Changing Climate. Water Resources Research Report No. 058. London, Ontario, Canada: Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering. Wang, X., & Huang, G. (2014). Technical Report: Developing Future Projected IDF Curves and a Public Climate Change Data Portal for the Province of Ontario. Submitted to Ontario Ministry of the Environment. Saskatchewan, Canada: Institute for Energy, Environment and Sustainable Communities (IEESC) of the University of Regina. Retrieved from http://www.ontarioccdp.ca/final_tech_report.pdf

3.13.5 Process-based hydraulic modelling

Project Name: UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2], Maddalen Mendizabal[3]

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Runoff coefficient – Process-based hydraulic modelling	**Water Management**
Description and justification	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).
Definition	Runoff in relation to precipitation quantity (mm)
Strengths and weaknesses	+ Possibility to extrapolate the measurements spatially and temporally + Allows for future predictions and forecasts given the available measurements - Modelling includes numerous simplifications and approximations (adequacy of process parametrizations, data limitations and uncertainty, and computational constraints on model analysis) - Multiple challenges arise when choosing the approach to modelling
Measurement procedure and tool	One-dimensional and two-dimensional drainage system modelling exist. There are many examples of models applied in an urban context. Existing approaches used to evaluate GI/NBS are the Stormwater Management Model (SWMM [USA]), CityCat (Newcastle), MIKE (DHI) and InfoWorks for

Sustainable Drainage Systems (SUDS [UK]). Impact of climate change on runoff can be evaluated using the design storms. The models typically require multiple parameters for accurate results.

1. The modelling process starts with a perceptual model, which is the summary of perceptions of how the catchment responds to rainfall under different conditions. In the conceptual model, mathematical descriptions are formed where hypotheses and assumptions are taken into account.
2. If the equations decided in the conceptual model cannot be solved analytically given some boundary conditions for the real system, an additional stage of approximation is necessary using the techniques of numerical analysis to define a procedural model. This is given in a form of code that will run on the computer.
3. In the next phase, the parameters used in the model needs to be calibrated. The most commonly used method in the model calibration is matching the model predictions and observations from the direct measurements if they are available.
4. After the calibration of parameters, simulations with the model could be made. Results of the simulations should then be reviewed and the model validated. The validation can be done by comparing the results to direct measurements, e.g., observed discharges, if they are available (Beven 2012).

When choosing a conceptual model, the following procedure can be used (Beven, 2012):

- Prepare a list of the models under consideration.
- Prepare a list of the variables predicted by each model. Decide if the model under consideration will give the needed output.
- Prepare a list of the assumptions made by the model. Reject models where the assumptions are estimated to be too inaccurate.
- Make a list of the inputs required by the model, for specification of the flow domain, the boundary and initial conditions and the parameter values.
- Determine whether you have any models left on your list. If not, the criteria should be reviewed again and then review the previous steps.

Comparison of the basic structure for rainfall- runoff models (adapted from Sitterson et al., 2017):

	Empirical	**Conceptual**	**Physical**

Method	Non-linear relationship between inputs and outputs, black box concept	Simplified equations that represent water storage in catchment	Physical laws and equations based on real hydrologic responses
Strengths	Small number of parameters needed, can be more accurate, fast run time	Easy to calibrate, simple model structure	Incorporates spatial and temporal variability, very fine scale
Weaknesses	No connection between physical catchment, input data distortion	Does not consider spatial variability within catchment	Large number of parameters and calibration needed, site specific
Best Use	In ungauged watersheds, runoff is the only output needed	When computational time or data are limited	Have great data availability on a small scale
Examples	Curve Number, Artificial Neural Networks[a]	HSPF[b], TOPMEDEL[a], HBV[a], Stanford[a]	MIKE-SHE[a], KINEROS[c], VIC[a], PRMS[d]

[a] Devia, Ganasri, & Dwarakish, 2015
[b] Johnson, Coon, Mehta, Steenhuis, Brooks, & Boll, 2003
[c] Woolhiser, Smith, & Goodrich, 1990
[d] Singh, 1995

Scale of measurement	All scales depending on the type of model used
Data source	
Required data	Rainfall measurements, spatial drainage area characteristics (e.g., area, slope)
Data input type	Quantitative
Data collection frequency	Annually; at minimum, before and after NBS implementation
Level of expertise required	High – requires ability to apply hydrologic models and assess the output

Synergies with other indicators	Direct relation to *Height of flood peak* and *Time to flood peak* indicators
Connection with SDGs	SDG 11 Sustainable cities and communities
Opportunities for participatory data collection	No opportunities identified
Additional information	
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3.14 Water Quality – general urban

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

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Water quality – general urban	**Water Management**
Description and justification	Run-off water in cities represents a threat to water quality by conveying high pollutant loads into receiving water bodies and ground water aquifers. NBS can help manage and improve urban water quality through settlement, filtration, bioretention and phytoremediation. Emerging techniques using remote sensing technology includes using high resolution satellite or airborne optical imagery (visible and infrared), DSM (Digital Surface Model) height information and existing building out- lines maps (footprints) to estimate the percentage of vegetated areas on building roofs and to identify potential green roof sites, providing municipalities with the opportunity to use this data for urban planning decisions in the field of climate modelling, drainage system calculation and biodiversity networks. Recent and planned launches of satellites with improved spectral and spatial resolution sensors should lead to greater use of remote sensing techniques to assess and monitor water quality parameters. Data on the water quality performance of nature-based solutions collected in these ways can be used to: • Quantify the benefits of NBS in terms of stormwater/waterway quality improvement; • Assess any negative impact on water quality of diverting rainwater through NBS; • Calculate total pollution loading being released from an NBS (when combined with flow rate calculations); • Assess compliance with Water Framework Directives; Provide easily accessible data to communities and decision-makers to change perceptions of SuDS.
Definition	Calculating/predicting the change in water quality caused by diverting rainfall or surface water flow through an NBS (e.g., green roof, tree pit, bioretention pond, rain garden, wet woodland, naturalised waterway, etc). Implementing an NBS can result in a positive or negative impact on water quality. This is dependent upon: the quality of water entering the system, the type of NBS, the age of NBS, and the water quality parameters being investigated. Both

	positive and negative impacts of NBS on water quality are of relevance for this indicator. Remote sensing and earth observation approaches are only generally used to provide background/mapping data that can be fed into water quality modelling.
Strengths and weaknesses	**Applied methods:** Robustness of evidence depends upon the precision and accuracy of the method adopted. Frequency and design of sampling is also linked to the strength of evidence. For example, regular sampling may provide long-term and seasonal patterns but may miss significant short-term events such as 'first flush' of urban areas following long dry periods. **EO/RS methods:** Methods can provide robust data, but the range of water quality parameters that EO/RS can provide is limited.
Measurement procedure and tool	*Applied/participatory methods*: Basic measurements of water quality associated with NbS have included: • NO_3, NO_2 and NH_3 (Payne et al., 2014; Batalini de Macedo et al. 2019) • Phosphorus (Bratieres et al. 2008a) • Heavy metals (Blecken et al. 2011; Batalini de Macedo et al. 2019) • Suspended/Sedimentary solids (Hatt et al 2008; Batalini de Macedo et al. 2019, Fowdar et al. 2017) • Micropollutants (such as hydrocarbons and pesticides) (Zhang et al. 2014) • Colour (Batalini de Macedo et al. 2019) • Turbidity (Batalini de Macedo et al. 2019) • Chemical Oxygen Demand (Batalini de Macedo et al. 2019; Leroy et al. 2016) • Biological Oxygen Demand (Fowdar et al. 2017; Leroy et al. 2016) • Pathogens (Bratieres et al. 2008b) • Hydrocarbons (Hong et al. 2006) • Total organic carbon (TOC) and dissolved organic carbon (DOC) (Fowdar et al. 2017) Choice of parameter to measure should be related to issues of water pollution, the type of plant species and substrates used in the bioretention process, physio-chemical processes, and the desired quality of water at the end of processing (Dagenais et al. 2018; Payne et al. 2018, Batalini de Macedo et al. 2019). Sampling can be done using in-situ stormwater sampling equipment (e.g., Teledyne ISCO 6712/7400 (Hong et al.

	2006), ISCO GLS auto-sampler (Lucke and Ncihols 2015), ISCO Model 6712 Portable Sampler (Stagge et al. 2012)). This allows continuous and simultaneous sampling. Where this is not possible, or is prohibited by cost, v-notch weirs installed to monitor flow rate can be used to create a reservoir that can be sampled using a manual sampling technique (Hong et al. 2006). Alternatively, artificial drain/reservoir features can be incorporated into the NbS design from which water samples can be collected (Leroy et al. 2016). Laboratory analysis of each parameter is then carried out based on standardised analytical methods (e.g., Standard Methods for Examination of Water and Wastewater (APHA, 2015)). An alternative, and more participatory method of monitoring water quality can be achieved through the use of biological indicators to monitor moving or still waterbodies. An example of this is the Biological Monitoring Working Party (BMWP) scoring system (Armitage et al. 1983) or adapted versions of this protocol (e.g., Romero et al. 2017). Samples are typically collected by kick sampling or surber sampling (Everall et al. 2017), providing opportunities for community engagement (including as part of school curricular activities). Wetland plants have also been used as biological indicators of water chemistry in wetland areas (US EPA 2002). Simulated storm events with artificially created water pollution can be used as a mechanism to validate performance of NbS (Lucke and Nichols 2015). This is of particular value to ensure continuity of performance as the NbS ages/matures. *Remote sensing/Earth observation methods*: Remote sensing and earth observation approaches are only generally used to provide background/mapping data that can be fed into water quality modelling. However, some remote sensing techniques are emerging. Methods for delivering this include: **a) In general:** The remote sensing technology uses high resolution satellite or airborne optical imagery (visible and infrared), DSM (Digital Surface Model) height information and existing building out- lines maps (footprints) to estimate the

	percentage of vegetated areas on building roofs and to identify potential green roof sites. The new remote sensing technology provides municipalities with the opportunity to use this data for urban planning decisions in the field of climate modelling, drainage system calculation and biodiversity networks. According to Ritchie et al. (2003), remote sensing techniques can be used to monitor water quality parameters (i.e., suspended sediments (turbidity), chlorophyll, and temperature). Optical and thermal sensors on boats, aircraft, and satellites provide both spatial and temporal information needed to monitor changes in water quality parameters for developing management practices to improve water quality. Recent and planned launches of satellites with improved spectral and spatial resolution sensors should lead to greater use of remote sensing techniques to assess and monitor water quality parameters. Integration of remotely sensed data, GPS, and GIS technologies provides a valuable tool for monitoring and assessing waterways. Remotely sensed data can be used to create a permanent geographically located database to provide a baseline for future comparisons. The integrated use of remotely sensed data, GPS, and GIS will enable consultants and natural resource managers to develop management plans for a variety of natural resource management applications. In addition, Massoudieh et al. (2017) developed a modelling framework to predict the water quality impacts of urban stormwater green infrastructure systems. Shi et al. 2017 demonstrated links between urban water quality and different landuse patterns that could be used to predict improvements in water quality. For further information, see: Connecting Nature Environmental Indicator Metrics Review Report
Scale of measurement	**Applied methods:** Implementation is typically on a component or site level. It can be scaled-up to much larger scales through replication. However, it is more typical to model the impacts of up-scaling once results have been obtained that can be fed into the model. **EO/RS methods:** Typically used on medium/large scale monitoring as resolution of satellite imagery can create a barrier to monitoring smaller scale areas.

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 Environmental Indicator Metrics Review Report
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 Environmental Indicator Metrics Review Report
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 Environmental Indicator Metrics Review Report
Level of expertise required	**Applied methods:** Some expertise required for installation of equipment and/or sampling methodology. Expertise required for sample analysis depends on the level of automation of the sampling equipment (e.g., in stream dataloggers carry out sample analysis automatically). Samples taken may require specialist analytical methods, these are typically carried out through an accredited laboratory. Data analysis/interpretation against statutory guidelines can be very basic once systems are in place. **EO/RS methods:** Data processing expertise is needed.
Synergies with other indicators	**Applied methods:** There are synergies in relation to measuring flowrates as such data is necessary for calculating total pollutant loads over time. BMWP scoring can be linked to biodiversity indicators. Improved water quality can have correlations with nature, health and social value of a waterway. **EO/RS methods:** Synergies with other water management and blue space area indicators.
Connection with SDGs	SDG3, SDG4, SDG6, SDG8-SDG12; SDG14-SDG17: Clean water supply; Links to environmental education; Clean water; Job creation; Social equality in relation to water quality; Sustainable urban development; More sustainable water management; Improved water quality (for life below water); Improved water quality (for life on land); Environmental Justice; Opportunities for collaborative working
Opportunities for participatory data collection	**Applied methods:** Opportunities are available for a participatory process, particularly in relation to carrying out visual inspection of water (e.g., in relation to combined sewage overflow occurrences and water sampling (Farnham et al. 2017; Jollymore et al. 2017). Water quality analysis can be linked to local schools/universities, especially through schemes that use BMWP methodologies to monitor

	water quality in waterways. Automated dataloggers offer less opportunity for such participation with participation limited to observing and processing the data produced. There are also opportunities for stewardship of equipment or nature-based solution, etc. **EO/RS methods:** Limited opportunities for participation
Additional information	
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3.15 Total Suspended Solids (TSS) content

Project Name: CLEVER Cities (Grant Agreement no. 776604), GrowGreen (Grant Agreement no. 730283) and UNaLab (Grant Agreement no. 730052)

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TSS content	**Water Management**
Description and justification	Total Suspended Solids (TSS) are solids in water that can be trapped by a filter. TSS can include a wide variety of material and can have adsorbed pollutants. High concentrations of suspended solids can affect the health and productivity of the aquatic life. TSS and turbidity are simple indicators of water quality. Sources of TSS include, e.g., sediment runoff from agricultural fields, logging activities, construction sites, roadways, waste discharge, or

	excessive algal growth. The TSS content often increases sharply during and immediately following a rainfall event. The EU Freshwater Fish Directive (2006/44/EC) recommends ≤25 mg/L TSS for salmonid and cyprinid fish health (European Parliament, 2006), whilst the concentration of TSS in wastewater treatment plant effluents is limited to ≤35 mg/L by Wastewater Directive 91/271/EEC (European Parliament, Council of the European Union, 1991).
Definition	Total suspended solids (TSS) or turbidity (%, mg/L and total; units dependent upon measurement technique). A measure of the suspended solids in wastewater, effluent, or water bodies, determined by tests for "total suspended non-filterable solids".
Strengths and weaknesses	+ Simple evaluation + In turbidity measurements, Secchi disk is very commonly used visual method because it is easy to use, inexpensive, and relatively accurate. The turbidity meter method is very accurate - Laboratory measurement of TSS directly quantifies the amount of fine particulate material suspended in water but is relatively time-intensive. - Time consuming TSS measurements, non-continuous compared to turbidity
Measurement procedure and tool	Total suspended solids (TSS) are typically quantified in the laboratory using a gravimetric process, yielding TSS measurement in units of mass per volume (e.g., mg/L or ppm). Measurement of TSS involves filtration of a water sample followed by drying and weighing of the particulates removed. Simply, this means anything that is captured by filtering the sample aliquot through a specific pore size filter. A measured volume (no more than 1 L) of sample is passed through a prepared, pre-weighed filter paper. The filter is dried at 104 ± 1°C. After drying, the filter is reweighed and the TSS is calculated. A semi-quantitative, rapid assessment of TSS can be accomplished by evaluating sample turbidity, a measure of the relative transparency of a water sample. Turbidity measurements rely on comparison of light scattering with standard solutions (turbidity meter) or visual assessment (Secchi disk, transparency tube). Turbidity meters use a light beam with defined characteristics to provide a semi-quantitative measure of the particulates present in the water, providing an integrated measure of light scattering and absorption. The measurement is provided in nephelometric turbidity units (NTU). Turbidity (in NTU) can

	be directly related to TSS (in mg/L) via creation of a standard curve (TSS versus turbidity) for a given location/type of fine particulate material.
	• Measuring turbidity *in-situ*:
	  o Secchi disk, which is lowered into the water and the level where the disk disappears is registered.
	  o Turbidity meter consists of a light source that illuminates a water sample and a photoelectric cell that measures the intensity of light scattered at a 90° angle by the particles in the sample.
	  o Transparency tube is a clear, narrow plastic tube marked in units with a light and dark pattern painted on the bottom. Water is poured into the tube until the pattern disappears, and the depth is recorded.

Scale of measurement	Plot scale to district scale
Data source	
Required data	TSS or turbidity measurement data
Data input type	Quantitative and semi-quantitative
Data collection frequency	Daily, weekly, monthly or annually
Level of expertise required	Low to moderate
Synergies with other indicators	Synergies with the other water quality indicators in the *Water management* indicator group
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 13 Climate action, SDG 14 Life below water
Opportunities for participatory data collection	Participatory data collection for turbidity is possible under supervision
Additional information	
References	ASTM. (2018). *ASTM D5907-18, Standard Test Methods for Filterable Matter (Total Dissolved Solids) and Nonfilterable Matter (Total Suspended Solids) in Water*. ASTM International, West Conshohocken, PA. Orhel, R.L., & Register, K.M. (2006). *Volunteer Estuary Monitoring. A Methods Manual*. 2nd edition. United States Environmental Protection Agency, Washington, D.C. International Organization for Standardization (ISO). (2016*). International Standard ISO 7027-1:2016 Water quality —*

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3.16 Nitrogen and phosphorus concentration or load

Project Name: UNaLab (Grant Agreement no. 730052)

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Water Quality: Nitrogen and phosphorus concentration or load	Water Management
Description and justification	Nutrients, including nitrogen (N) and phosphorus (P), can have significant impact on water quality, including effects on plant growth, oxygen concentration, water clarity, and sedimentation rates. Some major anthropogenic sources of nutrients are agricultural and industrial emissions, discharged wastewater and atmospheric deposition. Nitrogen and phosphorus are present in water in many different forms, or as many different chemical species. The forms of N and P that are quantified can include some or all of the following: • <u>Nitrogen</u>: total N (N_{tot}), total Kjeldahl N (TKN), dissolved organic N (DON), nitrate (NO_3^-), nitrite (NO_2^-) and ammonia/ammonium (NH_3/NH_4^+) • <u>Phosphorus</u>: total P (P_{tot}), acid-hydrolysable P (AHP), orthophosphate (PO_4^{3-})
Definition	Nitrogen and phosphorus in surface water and/or groundwater (%, expressed as total annual N or P load and/or reduction of maximum annual concentration)
Strengths and weaknesses	+ Laboratory analyses are accurate but can be quite costly. A full suite of analyses can be done for multiple chemical species of N and P. + Ion selective electrodes (ISEs) are less expensive and easier to use alternative. Whilst ISEs for various N species (NO_2^-, NO_3^-, NH_3/NH_4^+) are readily available from multiple suppliers,

	ISEs for phosphate are less common. ISEs have a potential for permanent installation at a given sampling point. - Test kits obtain a rapid result, but are in general less accurate than analyses performed in an accredited laboratory. Photometers are generally quite accurate but can be expensive to purchase and maintain. Test kits based on colour comparison, either of test strips or solutions, are relatively less costly but can have limited accuracy at low nutrient concentrations
Measurement procedure and tool	Different nitrogen and phosphorus species can be quantified in a water sample either in the field, using a test kit or ion selective electrode (ISE), or via laboratory analyses. Laboratory analyses can be done for multiple chemical species of N and P. Ion selective electrodes are analogous to a pH electrode and are used in much the same way as a pH electrode (pH electrodes are essentially ion selective electrodes that are sensitive to the H^+ ion) ISEs have a potential for permanent installation at a given sampling point. It is possible to program a data logger connected to an *in-situ* ISE to measure and record a value at a prescribed frequency. Test kits are usually used on site (in the field). Test kits typically involve the addition of chemical reagents to a water sample and yield results based on test strip colour comparison, solution colour comparison to a colour wheel or colour chart, or measurement with a photometer. The spectrophotometer measures the quantity of a chemical based on its characteristic absorption spectrum.
Scale of measurement	Plot scale to district scale, depending on location of sampling point
Data source	
Required data	Measurement data of a water sample
Data input type	Quantitative
Data collection frequency	Daily, weekly, monthly or annually
Level of expertise required	Low to moderate
Synergies with other indicators	Synergies with the other water quality indicators in the *Water management* indicator group
Connection with SDGs	SDG 13 Climate action, SDG 14 Life below water

Opportunities for participatory data collection	Participatory data collection possible with test kits and ion selective electrodes under supervision
Additional information	
References	EPA method 300.1: Determination of inorganic anions in drinking water by ion chromatography; https://www.epa.gov/sites/production/files/2015-06/documents/epa-300.1.pdf ISO 29441:2010: Water quality — Determination of total nitrogen after UV digestion — Method using flow analysis (CFA and FIA) and spectrometric detection, https://www.iso.org/standard/45480.html ISO 15681-1:2003 Water quality — Determination of orthophosphate and total phosphorus contents by flow analysis (FIA and CFA) — Part 1: Method by flow injection analysis (FIA), https://www.iso.org/obp/ui/#iso:std:iso:15681:-2:ed-2:v1:en ISO 15681-2:2018 Water quality — Determination of orthophosphate and total phosphorus contents by flow analysis (FIA and CFA) — Part 2: Method by continuous flow analysis (CFA), https://www.iso.org/standard/66474.html Orhel, R.L., & Register, K.M. (2006). Volunteer Estuary Monitoring. A Methods Manual. Second edition. Washington, D.C: United States Environmental Protection Agency. Reedyk, S., & Forsyth, A. (2006). *Using field chemistry kits for monitoring nutrients in surface water*. Publication number PRO-121-2006-1. Ottawa, Ontario, Canada: Agriculture and Agri-Food Canada PFRA. Retrieved from http://pfra.ca/doc/Water%20Quality/Water%20Quality%20Protection/using_field_chem_kits_final.pdf

3.17 Metal concentration or load

Project Name: CLEVER Cities (Grant Agreement no. 776604), GrowGreen (Grant Agreement no. 730283) and UNaLab (Grant Agreement no. 730052)

Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2], Saioa Zorita[3]

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Water Quality: Metal concentration or load	Water Management
Description and justification	Metals and metalloids (herein referred to simply as metals) are ubiquitous in the natural environment and can potentially accumulate to toxic levels for the aquatic environment and humans as metals do not degrade with time. As such, metals can have a significant impact on water quality and its fit-for-purpose use. Natural sources of metals include weathering of geologic materials (rocks and soil) and volcanic activity. The primary reservoir of metals is geological substrate. Human activity has greatly accelerated natural biogeochemical cycles, resulting in anthropogenic emissions of metals to the atmosphere one to three orders of magnitude greater than natural fluxes. Anthropogenic sources of metals include point sources such as mining and industrial activities, and non-point sources such as fossil fuel combustion and agricultural activities. Stormwater may transport heavy metals from industries, municipalities and urban areas at different quantities, which are accumulated in soil, sediments and water bodies. Removal can be achieved by appropriately designed NBS. Some of the more common metal pollutants are: aluminium (Al), arsenic (As), barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), molybdenum (Mo), nickel (Ni), lead (Pb) and mercury (Hg), selenium (Se), vanadium (V) and zinc (Zn).
Definition	Metal pollutants in surface water and/or groundwater (%, expressed as total annual metal pollutant load and/or reduction of maximum annual concentration). (Concentration of heavy metals before NBS treatment - Concentration of heavy metals after NBS treatment)/ Concentration of heavy metals before NBS treatment)*100
Strengths and weaknesses	+ ICP analyses are highly precise and accurate to very low concentrations

	- ICP analyses can be quite costly and with the high number of metals (Cd, Cr, Pb, Hg, Ni, Zn, Cu…) some of which could be at very low concentration levels, this can add to the expense. - There is usually a significant delay between the time of sample collection and receipt of water quality data from the laboratory + Test kits and ion selective electrodes (ISEs) can provide rapid results + ISEs can be installed in-situ to take measurements at regular intervals - A separate kit or ISE is required for each element of interest, and the limit of detection for a given element of interest may be substantially higher than the respective accredited laboratory analysis technique - Analysis of individual metals using field test kits can be time-intensive and/or require trained personnel to conduct the tests
Measurement procedure and tool	Metals in water samples are typically quantified in an accredited laboratory using a suite of standardised analyses. Ion-coupled plasma spectrophotometry (ICP) coupled with atomic emission spectrometry (MS), with or without pre-treatment/pre-concentration, is a well-recognised analytical method for the quantification of trace metals in waters. Multiple elements can be analysed from a single sample. Methods may vary depending on the water matrix and metals to be analysed, but generally the method compromised the following steps: • Sample preparation which may include weighing of the sample, solubilisation of the solids with acids with/without heat (for total recovery analysis), separation of undissolved material • Calibration of the equipment • Sample analysis The nature of ICP analyses means that the analysed samples represent a single point in time (the time at which the sample was collected), and metal concentrations may vary substantially in urban waters due to the contribution of run-off from urban surfaces. Field test kits are available for on-site testing of some metals (e.g., As, Cd, Cu, Pb, Mo, etc.) whilst other metals can be detected using an ion-selected electrode (ISE; e.g., Cd, Pb, Zn, etc.). Field test kits vary greatly and range from semi-quantitative paper test strips for multiple metals, to quantitative colourimetric-type analyses. Some field test kits may involve the use of portable laboratory

	equipment such as a photometer, fluorometer or similar. With ISEs there is a potential to install a testing unit in-situ to take measurements at regular intervals and save results to a data logger or upload to a central data repository.
Scale of measurement	Plot scale to district scale, depending on location of sampling point for concentrations ranging from ng/L to mg/L
Data source	
Required data	Water samples. Relatively small sample volume is required (typically 100 mL or less)
Data input type	Quantitative and semi-quantitative
Data collection frequency	Daily, weekly, monthly or annually
Level of expertise required	Low to Moderate for sampling High for analysis
Synergies with other indicators	Synergies with the other water quality indicators in the *Water management* indicator group
Connection with SDGs	SDG 6 Clean water and sanitation, SDG 13 Climate action, SDG 14 Life below water
Opportunities for participatory data collection	Participatory data collection possible with test kits and ion selective electrodes under supervision
Additional information	
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3.18 Total faecal coliform bacteria

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Total faecal coliform bacteria in NBS effluents	Water Management
Description and justification	Faecal coliform bacteria are a subgroup of a larger total coliform group referring to the Gram-negative, rod-shaped bacteria. Faecal coliform bacteria denote a group of thermotolerant coliform organisms, optional aerobic or anaerobic, which grow at 44 ± 0.5 °C and ferment lactose to produce acid and gas (Bartram & Pedley, 1996; Doyle & Erickson, 2006). Although coliform bacteria are easy to detect, their presence does not imply the faecal contamination due to the natural occurrence of some faecal coliform organisms of non-faecal origin. Thus, the pathogenic strains of *Escherichia coli (E. coli)* are usually analysed to determine the sanitary contamination of water

	(ISO, 2014). Presence of faecal coliform bacteria in the natural waters may indicate the faecal contamination and degradation of the water bodies originating from diffuse sources such as urban runoff and transport from sewer overflows (Davies et al., 1995; Davies & Bavor, 2000).
Definition	Observed number of faecal coliform colony units determined by direct counting (Colony Forming Unit (CFU)/100 mL or CFU/100 g) or most probable number (MPN) methods (MPN/100 mL or MPN/g)
Strengths and weaknesses	+ Almost always implies the faecal contamination of water + Standardized methodology for analyses - Analyses require expert knowledge and judgement
Measurement procedure and tool	a. Membrane filtration and direct counting The traditional way of evaluating the water samples for bacteria is the membrane filtration method. First, the water sample is filtered through a membrane, then the bacteria are cultured on an agar medium in a Petri dish and incubated at a specified temperature for a specified period of time depending on the type of bacteria analysed. Later, the number of the target organisms in the sample is calculated. The background bacterial growth may inhibit the enumeration of coliform bacteria, so this method is not deemed suitable for shallow and surface waters. b. Most probable number (MPN) method MPN is a statistical method used for enumeration of the viable target organisms by sequential inoculation and incubation in a liquid medium in ten-fold dilutions. Several assumptions must be made when using the MPN method, such as assuming the random distribution of the organisms in the sample (implying that no bacterial clustering and repelling is present), and assuming that the tubes will produce detectable growth. The advantages of the MPN method include the possibility for adjustment of the accuracy of the results when increasing the number of tubes per dilution, and larger sample size than in the plate count method. The MNP method is suitable for all types of water.
Scale of measurement	Plot scale
Data source	
Required data	Microbiological analyses of water
Data input type	Quantitative

Data collection frequency	At minimum before and after NBS implementation
Level of expertise required	High – requires familiarity with the laboratory practices and expertise for conducting the microbiological analyses and evaluating the outcomes
Synergies with other indicators	Together with other *Water Management* indicators determines the overall status of water quality in an area
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 14 Life below water
Opportunities for participatory data collection	Participatory data collection is possible under direct qualified staff supervision
Additional information	
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This *Evaluating the Impact of Nature-based Solutions: Appendix of Methods accompanies the Handbook* for Practitioners for evaluating the impact of nature-based solutions (NBS). The overarching objective of the *Handbook* and this accompanying *Appendix of Methods* is to provide standardised guidance and methods to aid the selection and implementation of indicators to assess impacts of NBS, and, over time, establish a robust European evidence base on NBS performance and impact. In order to compare impacts of different types of NBS, implemented in different contexts, and to draw valid, evidence-based conclusions regarding NBS impact, similar indicators, methods, and types of measurement are needed. The *Evaluating the Impact of Nature-based Solutions: Handbook for Practitioners* and accompanying *Appendix of Methods* identifies indicators and briefly details methodologies to assess impacts of nature-based solutions across 12 societal challenge areas: Climate Resilience; Water Management; Natural and Climate Hazards; Green Space Management; Biodiversity; Air Quality; Place Regeneration; Knowledge and Social Capacity Building for Sustainable Urban Transformation; Participatory Planning and Governance; Social Justice and Social Cohesion; Health and Well-being; and, New Economic Opportunities and Green Jobs.

Evaluating the Impact of Nature-based Solutions: Appendix of Methods provides a brief description of each indicator and recommends appropriate methods to measure specific impacts, along with guidance for end-users about the appropriateness, advantages and drawbacks of each method in different local contexts. As such, it is intended to guide the implementation of selected indicators to assess NBS performance and impact.

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