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)

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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

	heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).
Definition	Runoff in relation to precipitation quantity (m^3/s or L/s)
Strengths and weaknesses	+ 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
Measurement procedure and tool	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).

Recurrence Interval (Years)	C_f
2, 5 and 10	1.0
25	1.1
50	1.2
100	1.25

	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:

	$$Q = C_f C i A$$ 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