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]

[1] VTT Technical Research Centre Ltd, P.O. Box 1000 FI-02044 VTT, Finland
[2] CESAM – Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
[3] TECNALIA, Basque Research and Technology Alliance (BRTA), Mikeletegi Pasealekua 2, 20009 Donostia-San Sebastián, Spain

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	
References	Beven, K.J. (2012). Rainfall-Runoff Modelling: The Primer. Second Edition. Chichester, West Sussex, U.K.: Wiley-Blackwell. Clark, M.P., Bierkens, M.F.P., Samaniego, L., Woods, R.A., Uijlenhoet, R., Bennett, … Peters-Lidard, C.D. (2017). The evolution of process-based hydrologic models: historical challenges and the collective quest for physical realism. Hydrology and Earth System Sciences, 21, 3427-3440 Devia, G.K., Ganasri, B.P., & Dwarakish, G.S. (2015). A Review on Hydrological Models. Aquatic Procedia, 4, 1001-1007. Johnson, M.S., Coon, W. F., Mehta, V.K., Steenhuis, T.S., Brooks, E.S., & Boll, J. (2003). Application of two hydrologic models with different runoff mechanisms to a hillslope dominated watershed in the northeastern US: a comparison of HSPF and SMR. Journal of Hydrology, 284(1-4), 57-76. Singh, V.P. (Ed.). (1995). Computer Models of Watershed Hydrology. Highlands Ranch, CO: Water Resources Publications, LLC. Sitterson, J., Knightes, C., Parmar, R., Wolfe, K., Muche, M., & Avant, B. (2017). An Overview of Rainfall-Runoff Model Types. EPA Report Number EPA/600/R-17/482. September 2017. Athens, GA: Office of Research and Development National Exposure Research Laboratory. Woolhiser, D.A., Smith, R.E., & Goodrich, D.C. (1990). KINEROS, A kinematic runoff and erosion model: Documentation and user manual. ARS-77. Washington, D.C.: United States Department of Agriculture, Agricultural Research Service. Retrieved from https://www.tucson.ars.ag.gov/unit/Publications/PDFfiles/703.pdf