

## Treatment Function in the Spotlight: How Bioretention Design Guidelines Address Water Treatment?

La fonction de traitement sous les projecteurs : comment les guides de conception des solutions de biorétention abordent le traitement de l'eau?

Bardia Roghani<sup>1</sup>, Sylvie Spraakman<sup>2</sup>, Timothy F. M. Rodgers<sup>3</sup>, Frédéric Cherqui<sup>4</sup>

<sup>1</sup> Norwegian University of Life Sciences (NMBU) [bardia.roghani@nmbu.no](mailto:bardia.roghani@nmbu.no)

<sup>2</sup> City of Vancouver [sylvie.spraakman@vancouver.ca](mailto:sylvie.spraakman@vancouver.ca)

<sup>3</sup> Department of Civil Engineering, University of British Columbia [tim.rodgers@ubc.ca](mailto:tim.rodgers@ubc.ca)

<sup>4</sup> INSA Lyon, DEEP, France / WERG, SAFES, The University of Melbourne [frederic.cherqui@insa-lyon.fr](mailto:frederic.cherqui@insa-lyon.fr)

### RÉSUMÉ

Les solutions fondées sur la nature (SFN) sont des solutions conçues pour gérer les eaux pluviales tout en répondant à des objectifs de service tels que l'amélioration des services écosystémiques et de la qualité de l'eau. Les guides de conception spécifiques à chaque SFN doivent inclure des informations complètes sur les stratégies et les méthodes nécessaires pour atteindre les objectifs de service désignés, garantissant ainsi leur mise en œuvre réussie. Dans le présent document, nous avons évalué les guides de conception de biorétention provenant de différentes régions du monde afin d'examiner comment les praticiens recommandent d'atteindre les objectifs d'amélioration de la qualité des eaux pluviales, notamment en analysant les conseils relatifs à la qualité de l'eau concernant les matériaux filtrants. Parmi les sept guides examinés, un seul ne fournit aucune indication explicite concernant les polluants à éliminer. En outre, seuls trois guides sur sept proposent des recommandations pour la sélection des médias filtrants en fonction des considérations relatives à l'élimination des polluants, et un seul guide lie le calcul de la profondeur du média à la qualité de l'eau. Des examens plus approfondis de ces guides permettront d'évaluer le choix des plantations, la profondeur des bassins, l'estimation du volume d'eau et leur effet sur la qualité de l'eau.

### ABSTRACT

Nature-based solutions (NBS) are infrastructure systems designed to manage stormwater while also meeting service goals such as improving ecosystems services and water quality. Design guidelines for each specific NBS should include comprehensive information on the strategies and methodologies necessary to achieve the designated service objectives, thereby ensuring their successful realization. Herein, we evaluated bioretention design guidelines from different parts of the world to examine how various practitioners recommend achieving stormwater quality improvement objectives, in particular by reviewing the water quality advice recommended regarding filter media. Among the seven guidelines reviewed, one did not provide any explicit statements regarding the targeted pollutants for removal. Furthermore, only 3/7 guidelines offered recommendations for selecting filter media materials based on pollutant removal considerations, and only 1/7 guidelines tied the calculation of media depth to water quality. Further reviews of these guidelines will evaluate the planting selection, ponding depth, water quantity volume estimation, and their effect on water quality.

### KEYWORDS

Nature-based Solutions, performance, pollutants, recommendations, water quality, Solutions fondées sur la nature, performance, polluants, recommandations, qualité de l'eau

---

## 1 INTRODUCTION

Infrastructure design is a crucial phase in the life-cycle of infrastructure systems. Any deficiency in this phase can lead to significant challenges in subsequent life-cycle phases, including construction, operation and maintenance, and renewal. Design guidelines provide essential guidance to designers and practitioners, thereby playing a crucial role in ensuring the success of the infrastructure design process. According to design practitioners, a high-quality design guideline should be grounded in a body of evidence-based and universally applicable knowledge. Design guidelines should also be service-oriented since defined levels of service are essential for evaluating key performance indicators (or metrics) and making informed decisions at later stages of infrastructure asset management, such as operation and maintenance. Accordingly, design guidelines for nature-based solutions (NBSs) should be developed based on scientific evidence and aimed at ensuring the effective delivery of the key services expected from these infrastructures.

Although NBSs are designed to provide multiple ecosystem services, many existing design guidelines focus primarily on stormwater quantity control. For instance, Ekka et al. (2021) highlighted that current swale design guidance is largely centered on hydraulic conveyance, often overlooking the role of swales in water quality improvement.

Bioretention (BR) systems are among the most widely implemented stormwater control measures worldwide (Chaves et al., 2024). Over the past decades, many different design guidelines have been developed by various regional authorities to support the planning, construction, and operation of BR practices. Although these guidelines are intended to serve the same purpose (i.e. designing a BR system that delivers multiple benefits), their quality and level of detail vary significantly. The focus of this study is on the comparison of selected design guidelines developed globally for BR practices, specifically targeting the design of components that play a key role in improving stormwater quality.

## 2 METHODOLOGY

To identify BR design guidelines, the authors conducted a comprehensive search of online documents using search engines, employing keywords such as 'bioretention system', 'bioretention basin,' and others, in conjunction with terms like 'design guideline' and 'design standard.' Additionally, to ensure the inclusion of non-English documents, the authors contacted their connections in various non-English-speaking countries, requesting information about the presence of such guidelines locally. Our search identified more than thirty BR design guidelines, particularly from the USA and Australia. From these, we selected the 7 most comprehensive design guidelines for review across our target regions (Table 1), excluding many local or municipal documents that were either derived from the guidelines that we selected or that provided substantially less detail. The selected guidelines are applied to governments ranging from the state to the country level.

Table 1: List of bioretention design guidelines included in this study

Region	Country	State or City	(Original) Title of publication	Code
Asia	Hong Kong	-	Guidelines on Bioretention System (Practice Note No. 3/2022)	HK-2022
Australia	-	Queensland	Bioretention technical design guidelines	QLD-AUS-2014
	UK	-	The SuDS manual	UK-2015
Europe	Netherlands	-	Wadi's: aanbevelingen voor ontwerp, aanleg en beheer	NL-2006
	USA	Minnesota	Minnesota Stormwater Manual (Online)- <a href="https://stormwater.pca.state.mn.us/design_criteria_for_bioretention">https://stormwater.pca.state.mn.us/design_criteria_for_bioretention</a>	MN-USA-2021
North America	Canada	Toronto	LID SWM Planning and Design Guide (Online)- <a href="https://wiki.sustainabletechnologies.ca/wiki/Bioretention">https://wiki.sustainabletechnologies.ca/wiki/Bioretention</a>	TOR-CA-2023
South America	Colombia	-	Crterios para diseo y construccin de sistemas urbanos de drenaje sostenible (suds)	COL-2018

As this study focuses on the stormwater quality improvement functions of BR systems, the screening process of the seven guidelines was conducted in three steps (Fig. 1). First, the examined guidelines were assessed to determine whether they explicitly acknowledge the water quality treatment function of these systems. Guidelines that did not satisfy this criterion were to be excluded; however, in our study, all guidelines satisfied this criterion. Second, we assessed which pollutant groups were identified as targets for removal, highlighting differences in the intended application and purpose of BR in different regions. Third, we conducted a more detailed examination of how each guideline structures the design procedures for components influencing stormwater quality improvement. The findings from each screening step are summarized in tabular form. The detailed result of the screening process is presented in Table 2 in the next section.

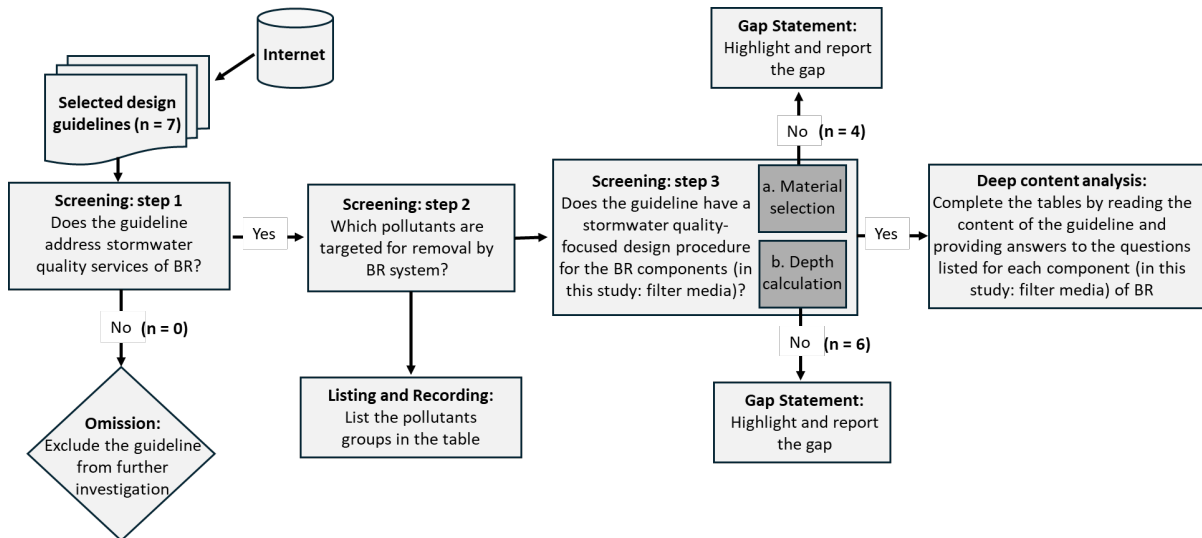


Figure 1: Flowsheet of the applied approach in this study. In this figure,  $n$  refers to the number of guidelines.

### 3 GENERAL RESULTS AND KEY FINDINGS

Our results indicate that all seven of the studied design guidelines acknowledge the treatment function of BR systems (Table 2), however the depth of this consideration varied. While all of the guidelines either implicitly or explicitly mentioned specific pollutants, the number and variety of groups of pollutants targeted differed between guidelines. While certain pollutants—such as nutrients, heavy metals and TSS—are commonly addressed across most guidelines, bacteria are mentioned only in the North American documents (MN-USA-2021, TOR-CA-2023). Moreover, the level of detail provided in relation to pollutant removal varies considerably among the guidelines. For instance, UK-2015 provides detailed information on common runoff contaminants, specifying elements within each pollutant family (e.g., nickel, copper, cadmium for heavy metals) along with their minimum, average, and maximum concentrations based on land use. Further, the North American and UK-2015 guidelines explicitly specify expected pollutant removal efficiencies that designers should consider, whereas the COL-2018 guideline does not explicitly list the pollutants intended for removal by BR systems. It should be noted that recent scientific studies have demonstrated that BR systems are also capable of removing pollutants beyond those mentioned in these guidelines, such as microplastics (Smyth et al. 2024) and some emerging organic contaminants (Rodgers et al., 2022).

The findings from Step 3 also revealed varying levels of comprehensiveness among the studied guidelines. While the guidelines from Europe, Asia, and Australia do not specify filter media material selection in relation to pollutant removal, the MN-USA-2021 guideline provides six different soil mixtures, outlining their advantages and limitations, including their suitability for removing specific pollutants. In contrast, COL-2018 guideline only recommends appropriate media materials for nutrient removal.

Although all the reviewed guidelines recommended a range for filter media depth (not necessarily with treatment functions in mind), none provide a well-established design procedure for determining the required

depth based on stormwater quality improvement objectives. Some guidelines, such as the UK-2015, attempt to relate pollutant removal to adequate contact time by considering factors such as permeability limits and storage volume. While these parameters are relevant, they are likely too general to serve as reliable design criteria for the removal of different pollutant types—particularly since pollutants are retained at different media depths and may migrate through the media over time (DiBlasi, 2009)

Table 2: status of each studied guideline regarding the acknowledgment and inclusion of the stormwater treatment functions of bioretention systems in their design procedures and the specific pollutants they listed (Y=Yes; N=No)

	Asia	Australia	Europe		North America		South America
	HK-2022	QLD-AUS-2014	UK-2015	NL-2006	MN-USA-2021	TOR-CA-2023	COL-2018
Step 1: Is the "Stormwater Quality Improvement" service from bioretention system acknowledged and mentioned in the guideline? (Y/N)	Y	Y	Y	Y	Y	Y	Y
Step 2: Which pollutants are targeted for removal? (or named as the pollutants that can be removed by bioretention systems)	Nutrients, HM & sediment	Anthropogenic & organic litter, P, N, HC, HM & sediment	TSS & HM	PAHs, HM & P	TSS, TP, TN, Metals, Bacteria & HC	TSS, TP, TN, metals, HC & bacteria	Nutrients
Step 3: Does the guideline provide a filter media layer material selection procedure considering pollution removal? (Y/N)	N	N	N	N	Y	Y	Y
Step 3: Does the guideline provide a well-established design procedure for calculating the required depth of the filter media, considering the improvement of stormwater quality? (Y/N)	N	N	Y	N	N	N	N

HM = heavy metals, HC = hydrocarbons TSS = total suspended solids, PAHs = polycyclic aromatic hydrocarbons, (T)P = (total) phosphorous, (T)N = (total) nitrogen.

## 4 CONCLUSION

We reviewed BR design guidelines to determine how important water quality is in the design of this type of infrastructure. We found that the filter media design of BR systems is more focused on water quantity and drainage than on water quality, with only 3/7 guidelines providing guidance on how filter media can be designed to enhance pollution removal. We plan to continue this work to evaluate other BR design components: vegetation, ponding layer, water quantity estimation, and drainage layers.

**Acknowledgments:** Thank you to Floris Boogaard of Deltares for providing the design guidance on bioretention in the Netherlands. Thank you to Juan Pablo Rodriguez Sanchez, University of the Andes, for providing bioretention design guidance from Colombia.

## LIST OF REFERENCES

- Chaves, M. T. R., Farias, T. R. L., & Eloi, W. M. (2024). Comparative analysis of bioretention design strategies for urban runoff infiltration: a critical overview. *Ecological Engineering*, 207, 107352.
- DiBlasi, C. J., Li, H., Davis, A. P., & Ghosh, U. (2009). *Removal and fate of polycyclic aromatic hydrocarbon pollutants in an urban stormwater*

*bioretention facility*. Environmental science & technology, 43(2), 494-502.

Ekka, S. A., Rujner, H., Leonhardt, G., Blecken, G. T., Viklander, M., & Hunt, W. F. (2021). *Next generation swale design for stormwater runoff treatment: A comprehensive approach*. Journal of Environmental Management, 279, 111756.

Rodgers, T. F., Wu, L., Gu, X., Spraakman, S., Passeport, E., & Diamond, M. L. (2022). *Stormwater bioretention cells are not an effective treatment for persistent and mobile organic compounds (PMOCs)*. Environmental Science & Technology, 56(10), 6349-6359.

Smyth, K., Tan, S., Van Seters, T., Gasperi, J., Dris, R., Drake, J., & Passeport, E. (2024). *Small-size microplastics in urban stormwater runoff are efficiently trapped in a bioretention cell*. ACS ES&T Water, 4(6), 2522-2531.