Élaboration d'un protocole d'inspection visuelle pour l'évaluation de l'état des rigoles de drainage biologiques

Development of Visual-Based Inspection Protocol for Bioswales Condition Assessment

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RÉSUMÉ

Les exigences à long terme en matière de performance et de gestion des bassins de rétention biologiques restent mal comprises. Les gestionnaires d'actifs s'appuient souvent sur leur jugement personnel ou adoptent une approche « run-to-failure » (fonctionnement jusqu'à la défaillance), guidés par des rapports d'inspection souvent peu fiables, incomplets, subjectifs et manquant de normalisation. Cette pratique contribue à la dégradation progressive et, à terme, à la défaillance fonctionnelle des systèmes de bassins de rétention biologiques. En conséquence, cette recherche vise à développer un protocole d'inspection structuré et normalisé qui permette une procédure uniforme et une évaluation objective de l'état des bassins de rétention biologiques. Le protocole proposé est élaboré à partir de l'analyse de 507 rapports d'inspection, complétée par une revue exhaustive de la littérature. Il présente un catalogue détaillé des composants du système, des types de défauts associés et des modes de défaillance potentiels. Chaque défaut est accompagné de notes numériques, de descriptions formelles et d'une échelle visuelle de qualité afin de garantir la clarté et la cohérence de l'interprétation. En outre, le protocole précise les paramètres à évaluer, ainsi que la séquence et les outils nécessaires à une inspection efficace. Les résultats contribuent à l'avancement de la gestion des actifs fondée sur des données probantes, permettant une planification efficace et une allocation optimisée des ressources.

ABSTRACT

The long-term performance and management requirements of bioswales remain inadequately understood. Asset managers often rely on personal judgment or adopt a run-to-failure approach, guided by inspection reports that are frequently unreliable, incomplete, subjective, and lacking in standardization. This practice contributes to the progressive degradation and, ultimately, the functional failure of bioswale systems. Accordingly, this research aims to develop a structured and standardized inspection protocol that enables a uniform procedure and objective condition assessment of bioswales. The proposed protocol is developed through the analysis of 507 inspection records, supplemented by a comprehensive literature review. It introduces a detailed catalogue of system components, associated defect typologies, and potential failure modes. Each defect is accompanied by numerical scores, formal descriptions and a visual quality ruler to ensure clarity and consistency in interpretation. Furthermore, the protocol specifies the parameters to be evaluated, and the sequence and tools required for effective inspection. The outcomes contribute to the advancement of evidence-based asset management, enabling effective planning and optimized allocation of resources.

Keywords:

Asset management, Blue green infrastructure, Natural based solution, Standardization, Wadi.

1 INTRODUCTION

Bioswales, among other types of Blue Green Infrastructure, have been introduced to the Netherlands since 1998 as a response to climate change and urbanization challenges. Despite the high groundwater level and low permeable soil in the country, bioswales are widely applied and preferred due to their extensive list of benefits (Boogaard, 2015).

In recent years, growing attention has been directed toward understanding the long-term performance of bioswales systems in order to improve the asset management practices. For instance, Boogaard et al. (2023) evaluated the hydraulic performance of 6 bioswales and 15 raingardens installed between 2011 and 2022. Boogaard et al. (2024) further investigated the long-term treatment performance of 20 bioswales aged 10-20 years. In addition, Bahrami et al. (2024) and Almasalmeh et al. (2025) systematically analysed the potential failure mechanisms and degradation pathways, providing valuable insight into how bioswales deteriorate throughout their lifecycle.

Despite this progress, a substantial gap remains between available scientific knowledge and current practice of bioswale asset management, contributing to frequent underperformance or premature failure. At present, no comprehensive and well-structured inspection protocol exists that organizes the inspection process, reduces subjectivity and human error, and ensures consistent coverage of all relevant defects. For instance, the Maintenance Guidance of Stormwater Management Practices (New York State Department of Environmental Conserv, 2017) provides guidance for three levels of visual inspection. However, the associated damage inventory is narrow in scope and lacks anchored ordinary scale.

The Quality Catalogue of Public Space (CROW, 2023) provides a strong foundation for objective visual condition assessment but does not explicitly address all bioswale components, nor does it include instructions on essential aspects such as component inventories, inspection sequences, or standardized inspection templates. Likewise, the Vancouver Bioretention Condition Assessment Inspector Guidebook (Humes, et al., 2024) explicitly targets bioretention components yet remains constrained by a narrow damage inventory, limited inspection instructions, and insufficient accommodation of component and design variability. Other existing protocols tend to focus on specific municipal concerns, often emphasizing parameters related to clogging or hydraulic decline while overlooking broader system dynamics. As a result, many inspections omit critical design components or overlook key indicators of system inadequacy.

Consequently, asset managers lack reliable and comparable condition data and are often forced to rely on personal experience or adopt a run-to-failure approach when planning maintenance and allocating resources. This situation underscores the need for a standardized, comprehensive, and evidence-based inspection protocol tailored specifically to bioswale systems.

2 METHODOLOGY

The development of the inspection protocol is the outcome of a structured and iterative process that incorporates theoretical knowledge with field-based learning, Figure 1.

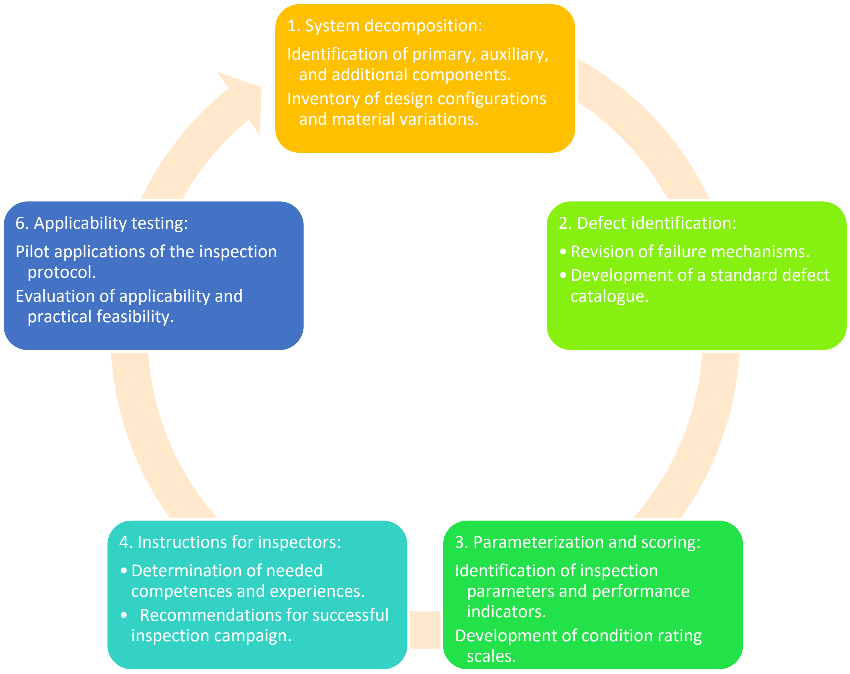

Figure 1: Development cycle of the inspection protocol

3 RESULTS AND DISCUSSION

The bioswale system was decomposed into its functional components, categorized as primary components (e.g. inlet and infiltration basin), auxiliary components (e.g. flow spreader and sediment forebay), and additional components (e.g. bench and decorative element). Furthermore, an inventory of the prevalent design configurations and material variations for each component within the Dutch urban contexts was compiled to ensure the protocol applicability across diverse typologies. For example, bioswale inlet configurations—designed to capture, convey, and regulate stormwater inflow while maintaining an effective hydraulic connection with the surrounding drainage system— include side-flow inlets, curb cuts, curb drops, depressed curbsides, roof drains, drainage pipes, headwalls, depressed drains, and sumps. This approach mitigates the variability inherent in customized designs, establishes a structured inspection hierarchy, and provides a robust foundation for component-level condition assessment, asset management, and clearly defined institutional responsibilities.
Since each component is susceptible to specific failure mechanisms and requires distinct management practices, a component-based defect catalogue was developed, as presented in Table 1.

Table 1: Standard list of defects for bioswale inlets

Defect category	Defect
Misalignment	Position of neighbour gully pot relative to inlet, inlet–overflow separation
	Elevation difference results from vegetation lip, sediment lip, pavement, wrong installation
	Directing inflow slope, soil subsidence
Surface cleanliness	Posters and graffiti
Contamination	Oil, fuel, greywater, airborne pollutants, de-icing salts
Blockage	External obstruction resulted by sediments, vegetation, leaves, grass clippings, litter, debris, trash, physical object
Clogging	Internal obstruction resulted by sediments, vegetation, leaves, grass clippings, litter, debris, trash, physical object
Structural damage	Gaps, cracking, spalling, rotting / corrosion, loose components, deformation, collapsing, erosion / scour, settlement, displacement

The quality scale developed for each defect, such as the presented in Table 2, integrates qualitative, quantitative, and visual descriptions for service quality levels to support robust and reproducible condition assessments. Qualitative descriptors ensure clarity in interpretation, quantitative thresholds introduce measurable criteria, and visual examples support objectivity by illustrating representative conditions for each quality level.

Tableau 2: Example of a quality scale for inlet blockage

Inlet: Misalignment – Elevation difference (*Vegetation lip, Sediment lip, Pavement*)				
A+	**A**	**B**	**C**	**D**
				
				
Optimal elevation	Slight deviation	Moderate deviation	Major deviation	Critical difference
Inlet elevation is ≤ 50 mm to adjacent street/pavement	≤ 30 mm	≤ 15 mm	≤ 0 mm	> 0 mm
Measurement instructions: Elevation difference relative to adjacent street/pavement (mm) – Ruler.				

The overall condition score of a bioswale component is determined based on the assessment of its individual defects, whereby the lowest defect rating governs the final condition of the component.

Although inspectors are primarily required to identify defects and assign the corresponding quality levels, adequate training and preparation remain essential to ensure that inspections are conducted consistently, safely, and in accordance with the objectives of the protocol. A successful inspection campaign consists of three main stages. First, prior to the site visit, the inspector reviews all available asset documentation to establish context, define baseline expectations, identify potential vulnerabilities, and prepare an efficient field inspection strategy. Second, during the field inspection, the inspector validates assumptions derived from the desk study and systematically observes and records visible defects in a structured and repeatable manner. Third, following the field visit, the inspector consolidates and interprets the collected information to ensure that field observations are accurately translated into meaningful condition assessments, thereby supporting reliable reporting and informed decision-making.

Repeated pilot applications were conducted under different field conditions to evaluate the usability of the protocol and its capacity to capture the full range of system behaviours and relevant defects. In total, five comprehensive visual inspection campaigns were carried out between 2024 and 2026, encompassing 507 bioswale systems across five Dutch municipalities. The evolution of the inspection protocol from Version 1 to Version 5 reflects a progressive transition from basic observational tools toward an advanced methodological framework that formalizes the assessment process through detailed catalogue of system components, associated list of potential defects, standardized scoring systems, and integrated evaluation criteria.

The proposed protocol Version 5 demonstrated sensitivity in distinguishing early-stage from advanced degradation, produced consistent results independent of the inspector, and enabled the identification of maintenance priorities, generating actionable information for asset managers. However, these benefits are accompanied by increased complexity and field effort, requiring higher levels of inspector training and potentially digital support to ensure practical usability.

4 CONCLUSIONS

This study addresses the persistent limitations in the long-term management of bioswale systems due to inconsistent, subjective, and incomplete inspection data. By analyzing 507 inspection records and conducting an extensive literature review, this research develops a structured and standardized inspection protocol that responds directly to these shortcomings. The resulting protocol offers a comprehensive catalogue of bioswale components, associated defect typologies, and potential failure modes. Each defect is supported by numerical scoring, formal descriptions, and a visual quality ruler to ensure clarity, consistency, and repeatability in condition assessment. In addition, the protocol defines the parameters to be evaluated, the recommended inspection sequence, and the tools required to carry out effective field inspections. The outcomes significantly enhance the understanding of bioswale performance over their life cycle and provide a foundation for more reliable, objective, and comparable condition data.

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