The challenges of roadside green stormwater infrastructure: contemporary issues and solutions

Les défis des infrastructures vertes de gestion des eaux pluviales en bordure de voirie : enjeux et solutions contemporains

Bhabishya Khaniya[1 2], Christopher Szota[2], Tim D. Fletcher[2], Jennifer Drake[1 3]

1. University of Toronto b.khaniya@mail.utoronto.ca
2. University of Melbourne cszota@unimelb.edu.au, timf@unimelb.edu.au
3. Carleton University jenniferdrake@cunet.carleton.ca

RÉSUMÉ

Les infrastructures vertes de gestion des eaux pluviales (GSI) sont de plus en plus utilisées pour améliorer la qualité de l'eau, réduire les inondations et favoriser la végétalisation urbaine. Toutefois, de nombreuses installations ne fonctionnent pas comme prévu, et les causes sous-jacentes de ces défaillances restent mal comprises. Cette étude synthétise les résultats d'un sondage mondial auprès de 43 praticiens ainsi que de 14 entretiens réalisés au Canada, en Australie, au Royaume-Uni et aux États-Unis, afin d'évaluer la performance perçue, les mécanismes courants de défaillance et les facteurs contribuant à la sous-performance des GSI en bordure de voirie. La plupart des praticiens (71 %) ont qualifié les GSI de « modérément réussies », soulignant la récurrence de problèmes liés à la conception, à la construction et à l'entretien. Les défaillances surviennent fréquemment dans les 1 à 3 ans suivant l'installation, reflétant des lacunes de conception et de construction ainsi qu'un entretien insuffisant durant les premières années. Trois principaux mécanismes de défaillance ont été identifiés : le contournement des flux, la réduction de l'infiltration due au colmatage de surface et le court-circuitage hydraulique. Les problèmes de conception incluaient notamment des entrées d'eau sous-dimensionnées ou inadaptées, ainsi que des éléments difficiles, voire impossibles, à entretenir. Les défis liés à la construction provenaient principalement d'un contrôle de qualité insuffisant et d'une expérience limitée des entrepreneurs. Les enjeux d'entretien étaient dominés par l'accumulation de sédiments et les perturbations d'origine humaine. Les obstacles de gouvernance concernaient surtout le manque de financement dédié, des effectifs insuffisants et une faible coordination entre services municipaux. Les résultats mettent en évidence la nécessité de financer spécifiquement l'entretien, d'améliorer la collaboration municipale, de renforcer la formation des entrepreneurs et de mener des investigations initiales plus rigoureuses afin de réduire les risques de défaillance et de renforcer la résilience des GSI.

ABSTRACT

Green stormwater infrastructure (GSI) is increasingly used to improve water quality, reduce flooding, and promote urban greening. However, many installations do not function as intended, and the underlying causes of these failures remain poorly understood. This study synthesizes insights from a global survey of 43 practitioners and 14 interviews across Canada, Australia, the UK, and the USA to assess perceived performance, common failure mechanisms, and factors contributing to underperformance in roadside GSI. Most practitioners (71%) rated GSI as moderately successful, highlighting recurring design, construction, and maintenance issues. Failures commonly occurred within 1-3 years of installation, reflecting design and construction deficiencies and inadequate early-stage maintenance. Three primary failure mechanisms were identified: flow bypassing, reduced infiltration due to surface clogging, and short-circuiting. Key design issues included undersized or inappropriate inlets and unmaintainable features, while construction challenges stemmed largely from poor quality control and limited contractor experience. Maintenance issues were dominated by sediment accumulation and human-related disturbances. Governance barriers centred on funding shortfalls, staffing limitations, and poor interdepartmental coordination. Findings highlight the need for dedicated maintenance funding, improved municipal collaboration, enhanced contractor training, and more rigorous initial site investigations to reduce failure risks and build resilient GSI.

KEYWORDS

Stormwater control measures; green infrastructure; asset management; long-term performance; operation & maintenance

1 INTRODUCTION

Green stormwater infrastructure (GSI), including bioretention systems, bioswales, and street tree pits, has become a key component of urban water management in many regions such as North America, Europe, and Oceania. Its increasing adoption reflects both regulatory requirements and recognition of the multiple benefits GSI can provide, including improved water quality, flood mitigation, and enhanced urban green spaces (McPhillips & Matsler, 2018). Widespread implementation has revealed that many installations fail to operate as intended. Underperformance is often linked to design shortcomings, construction defects, maintenance limitations, and governance-related factors such as fragmented institutional responsibilities (Vollaers et al., 2021). However, the core factors underlying these shortcomings and their impacts on performance remain poorly understood. Municipal asset managers and engineers (hereafter practitioners), who are responsible for the design and maintenance of GSI, hold critical insights into the practical constraints shaping system performance. Yet, their perspectives remain largely underrepresented in the literature. Understanding the experiences of practitioners offers the potential to generate actionable insights to enhance the effectiveness and resilience of GSI in urban contexts worldwide. This study addresses the research gap by examining how practitioners understand roadside GSI performance, identifying common failure mechanisms and their underlying causes, and exploring strategies to reduce the risk of failure.

2 METHODS

2.1 Global survey and semi-structured interviews with the practitioners

We administered an online survey to 43 practitioners from Canada, Australia, the UK, and the USA. The survey consisted of 17 multiple-choice questions. We subsequently conducted semi-structured interviews via Zoom (N=14) with a subset of survey participants to obtain deeper insight into their survey responses. This study received ethics approval from the Research Ethics Board, University of Toronto (protocol number: 44396). Survey responses were analyzed by identifying the most frequently selected options to determine the main factors contributing to GSI underperformance. All interviews were transcribed verbatim using Zoom and analyzed in NVivo. The transcripts were reviewed in full, common themes were identified, and the data were coded into themes to understand practitioners' perspectives.

3 RESULTS AND DISCUSSION

3.1 Perspectives on performance

Most practitioners (71%) rated their GSI projects as moderately successful in delivering stormwater and ecosystem-service benefits, while 12% reported high levels of success. Complete failures were rare, suggesting that GSI installations generally meet their intended functional objectives. Performance was viewed as consistently high (>80%) for systems receiving regular maintenance. Newer installations were also seen to outperform older assets, reflecting ongoing improvements in design, construction, and maintenance practices. However, despite these gains, practitioners noted that recurring issues across the design–construction–operation and maintenance cycle limit long-term performance.

3.2 Perspectives on failures

Nearly half of the practitioners (49%) reported that roadside GSI installations often show signs of failure within 1-3 years of installation. An additional 15% observed failures immediately after construction, highlighting persistent design/construction deficiencies and inadequate early-stage maintenance. Practitioners highlighted three predominant failure mechanisms: 1) Flow bypassing (40%): runoff fails to enter the facility and instead bypasses it. This was attributed to factors like incorrect grading/elevations, poorly designed inlets, or the presence of upstream catch basins that intercept flow before it reaches the GSI. 2) Reduced infiltration (40%): water does enter the system, but infiltrates too slowly or not at all. Contributing causes include media clogging (from sediment buildup), loss of porosity, soil compaction, and vegetation die-off, all of which reduce surface permeability and subsurface hydraulic conductivity. 3) Short-circuiting (20%): runoff exits the system too quickly (via overflow or outlet pipes) without sufficient treatment, often due to improperly placed or lack of freeboard space that lets water escape prematurely. Across systems, vegetation and soil media were reported to fail more frequently than structural components. This suggests that hydraulic dysfunction (e.g. inlet blockage preventing water entry, or surface ponding persisting >24 hours) and vegetation mortality are the most common and consequential forms of GSI underperformance in practice.

3.3 Design, construction, maintenance and governance issues

Factors contributing to GSI underperformance were categorized into four primary groups: governance (28%), construction (26%), maintenance (24%) and design (21%) (Fig. 1).

Figure 1. Recurring design, construction and maintenance issues in the roadside GSI asset

Governance: The most-cited governance issues were insufficient funding and a shortage of skilled personnel (noted by 44% of practitioners). Poor coordination between the teams responsible for design, construction, and maintenance was another major challenge (24%). Other governance concerns included inadequate asset record-keeping (16%), unclear ownership of GSI assets (8%), and policy misalignment (8%), e.g., conflicts between sewer and GSI design criteria.

Construction: The primary construction-related issue was poor quality control, which accounted for approximately 70% of construction-related problems. Common errors included improper planting (e.g. wrong placement or species), flawed construction sequencing, lack of erosion and sediment control measures during installation, faulty drainage connections, and the use of untested or substandard materials. Such mistakes were often attributed to contractors' limited experience with GSI projects and a lack of knowledgeable inspectors.

Maintenance: Sediment and debris accumulation was the most frequently reported maintenance problem (33%), as it clogs inlets, outlets, and surface media. A lack of in-house maintenance expertise and the absence of standard inspection protocols were also major hurdles (24%). Human-related disturbances (24%), including trampling by pedestrians, pet waste, vandalism, and litter, emerged as a common issue, underscoring the vulnerability of roadside GSI assets to human interactions. Vegetation mortality was another notable issue (19%), often requiring replanting and increasing the overall maintenance workload.

Design: The primary design issues stemmed from hydraulic design errors (38%). Practitioners pointed to undersized or inappropriate inlet structures and inaccurate sizing of the system's area as frequent mistakes that led to the hydraulic failures noted above. Hard-to-maintain design features were another concern (28%), e.g., using river rocks in pretreatment zones or providing insufficient maintenance access. Other design shortcomings included the selection of unsuitable materials (e.g. incorrect media or plant species) and a lack of monitoring infrastructure (17%), e.g., monitoring wells which were difficult to install later. Additionally, site-related constraints (17%), like unlocated underground utilities or high groundwater tables due to inadequate site investigation, sometimes contributed to failures.

4 CONCLUSIONS AND WAY FORWARD

GSI asset management practices have advanced substantially over recent decades, yet further refinement of design, construction, and, most critically, maintenance practices remains essential for reliable performance. Practitioners emphasized that ensuring adequate funding and strengthening maintenance capacity need urgent attention. In particular, they noted that GSI should be formally recognized as a municipal asset class (on par with traditional gray stormwater infrastructure) to secure sustained budget allocations for upkeep. Improved coordination across design, construction and maintenance teams and municipal departments and the adoption of lifecycle-based maintenance plans with realistic service levels were also highlighted as key steps to support long-term GSI functionality.

On the technical side, several best practices were identified (Fig. 2). Developing simple, low-cost key performance indicators (KPIs) was seen as fundamental for efficient performance assessment of GSI assets. These KPI datasets can be integrated with existing municipal asset-management platforms to develop performance dashboards, e.g., by applying digital-twin technologies. Adhering to established design and construction standards and providing targeted training for contractors was considered critical to prevent recurring mistakes. Maintaining comprehensive asset inventories and recording inspection and maintenance data in cloud-based systems was considered important for robust condition tracking over time. Practitioners also widely recommended innovations in design (especially improved inlet and pretreatment designs that are less prone to clogging).

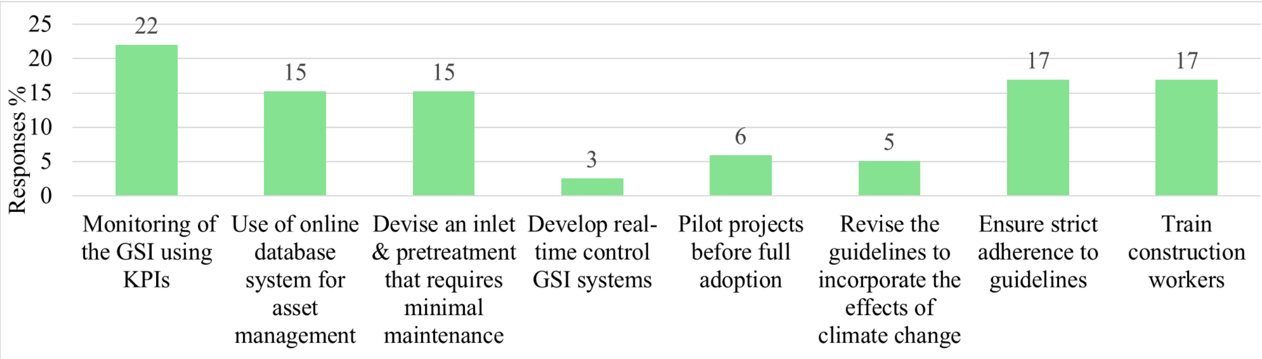

Figure 2. Technical improvements needed to establish resilient GSI asset

Given that the GSI industry is actively expanding and new approaches are continually being tested, it is important to continuously learn from both successes and failures. This study contributes to that learning process by highlighting core failure mechanisms and their root causes, and by outlining some best practices to mitigate these issues. These insights provide a foundation for establishing resilient GSI worldwide.

LIST OF REFERENCES

McPhillips, L. E., & Matsler, A. M. (2018). Temporal evolution of green stormwater infrastructure strategies in three us cities. Frontiers in Built Environment, 4. Scopus. https://doi.org/10.3389/fbuil.2018.00026

Vollaers, V., Nieuwenhuis, E., van de Ven, F., & Langeveld, J. (2021). Root causes of failures in sustainable urban drainage systems (SUDS): An exploratory study in 11 municipalities in the Netherlands. Blue-Green Systems, 3(1), 31–48. Scopus. https://doi.org/10.2166/bgs.2021.002