# Maintenance Scenarios and Risks of Insufficient Performance in Blue–Green Infrastructure

## Scénarios de maintenance et risques de performance insuffisante dans les infrastructures Bleu-Vertes

Utsav Adhikari, Ico Broekhuizen, Godecke-Tobias Blecken, Maria Viklander

Department of Civil, Environmental and Natural Resources Engineering, Architecture and Water, Luleå University of Technology

utsav.adhikari@ltu.se

## RÉSUMÉ

Les infrastructures vertes-bleues (BGI) contribuent au contrôle du ruissellement urbain mais restent vulnérables à des défaillances structurelles, aggravées lorsque la maintenance est insuffisante. Cette étude évalue le risque de sous-performance de quatre BGI — bassins de rétention à sec, étangs pluviaux, systèmes de biorétention et EcoVaults — à l'aide d'une matrice combinant le risque de défaillance structurelle (RSF) et le risque d'absence de maintenance (RNM). Les scores de probabilité et de conséquence ont été attribués selon des critères informés par des experts. Les résultats montrent que les obstructions d'exutoires dans les étangs et les dysfonctionnements cachés des drains dans les biorétentions génèrent les risques les plus élevés. Les processus cumulatifs comme l'accumulation de sédiments augmentent également le risque dans les systèmes fondés sur l'infiltration, alors que des défaillances similaires sont plus maîtrisables dans les systèmes de stockage. Certaines tâches centralisées, comme l'enlèvement des sédiments dans les étangs, restent plus faciles à réaliser que les mêmes interventions sur des unités décentralisées. Les travaux futurs étendront l'analyse à d'autres BGI et aux performances de qualité de l'eau.

## ABSTRACT

Blue–Green Infrastructure (BGI) supports urban runoff control but is vulnerable to structural failures. Insufficient maintenance is a main driver amplifying these failures and reducing design performance. This study assesses risk of insufficient performance in BGI under relevant maintenance scenarios using a structured risk-interpretation matrix that combines the risk of structural failure ($R_{SF}$) and the risk of no maintenance ($R_{NM}$) for four BGIs - dry detention basins, stormwater ponds, bioretention systems, and stormwater vaults (EcoVault®). Likelihood and consequence scores for both $R_{SF}$ and $R_{NM}$ were assigned using expert-informed criteria to evaluate how each failure condition affects overall risk. Results showed that outlet blockages in stormwater ponds and hidden underdrain malfunctions in bioretention systems, produced the highest risk classes. Cumulative processes such as sediment accumulation also generated elevated risks in infiltration-based BGIs like bioretention systems, whereas similar failures were more manageable in storage-based systems like dry detention basins. The assessment further highlights practical differences in maintenance motivation, with (especially very frequent and/or labour-intensive) tasks concentrated at single end-of-pipe assets (e.g., sediment removal in ponds) being more feasible than equivalent tasks across multiple decentralised units. Ongoing work will extend the assessment to additional BGIs and water-quality performance.

## KEYWORDS

BGI failure, BGI maintenance, risk assessment, asset management, runoff control

# 1 INDRODUCTION

Blue–Green Infrastructure (BGI) such as dry detention basins, swales, and bioretention systems, provides distributed capacity for runoff control in urban catchments during storm events. However, the performance of these facilities is vulnerable to structural failure conditions arising either instantaneously (e.g., inlet blockage, overflow damage, erosion during high-flow events) or cumulatively (e.g., sediment buildup, surface clogging, vegetation decline) (Bahrami et al., 2024; Funke & Kleidorfer, 2024). To mitigating these failures, BGI operators have diverse maintenance responsibilities varying in frequency, scale, complexity and cost. However, in practice maintenance regimes are often insufficient or neglected causing BGI to lose their intended performance over time (Blecken et al., 2017, Beryani et al., 2021), like uncontrolled discharge or leakage from ponds (Birkinshaw et al., 2021), decline in infiltration capacity in bioretention systems (Haile et al., 2016) and so on. This study addresses this problem by evaluating the risk of insufficient performance in BGI for runoff control under defined structural failure scenarios and maintenance regimes using expert-derived criteria scores and a structured risk interpretation matrix approach.

# 2 METHOD

## 2.1 BGI structural failures and maintenance

Four BGI facility types were selected to represent both naturalness and spatial scale developed by Adhikari et al. (2024). These include dry detention (natural, decentralized), stormwater pond (natural, end-of-pipe), bioretention systems (engineered, decentralized) and stormwater vaults (engineered, end-of-pipe). A list of potential and relevant structural failure mechanisms occurring in these BGIs were created based on relevant literature (Bahrami et al., 2024; Funke & Kleidorfer, 2024), and their commonly applied maintenance guidelines (CIRIA, 2015).

## 2.2 Risk assessment

Risk assessment was carried out based on a structured risk interpretation matrix approach, which combines the risk for structural failure condition ($R_{SF}$) with the risk of no maintenance ($R_{NM}$). Risk was defined as the product of likelihood (the possibility of occurrence of the event) and its consequence (the severity of the impact if it occurred) (Crouch & Wilson, 1982).

For $R_{SF}$, likelihoods and consequences for each structural failure condition were quantified using a five-level scoring system (Table 1). Structural failure likelihood ranges from *rare* to *very likely* depending on their frequency of occurrence, while consequences range from *negligible* to *severe*, covering effects such as local ponding, service loss, property damage, or widespread flooding. For $R_{NM}$, the likelihood of missed or insufficient maintenance was graded based on expert judgement and practical considerations such as whether a task aligns with existing municipal routines. Tasks that fit routine operations (e.g., mowing or sediment removal) generally have a lower likelihood of being missed thus low likelihood score (Table 1), whereas tasks requiring specialist skills or contracted services or issues which are difficult to detect (e.g. clogging of underground structures) are more prone to deferral. Finally, $R_{SF}$ and $R_{NM}$ scores were combined using the structured risk-interpretation matrix that classifies overall risk into eight categories (Table 2).

*Table 1 : Scoring criteria for likelihood and consequence to quantify $R_{SF}$ and $R_{NM}$.*

| **Likelihood of structural failure ($L_{SF}$)** | | **Likelihood of no maintenance ($L_{NM}$)** | | **Consequence (C)** | |
|---|---|---|---|---|---|
| 1 | Rare (<1/10yr) | 1 | Low | 1 | Negligible |
| 2 | Unlikely (5–10yr), | 2 | Low-Medium | 2 | Minor (e.g., local ponding), |
| 3 | Possible (1–5yr or seasonal) | 3 | Medium | 3 | Moderate (e.g., insufficient service /complaints) |
| 4 | Likely (several times/yr) | 4 | Medium-High | 4 | Major (e.g., property/asset damage, flooding) |
| 5 | Very likely (after most storms/ongoing) | 5 | High | 5 | Severe (e.g., widespread flooding, safety or critical asset damage) |

*Table 2 : Risk-interpretation matrix combining $R_{SF}$ and $R_{NM}$ scores to classify BGI performance risk.*

| | | $R_{NM}$ | | |
|---|---|---|---|---|
| | | 10-25 | 5-9 | 1-4 |
| $R_{SF}$ | 10-25 | Critical | High | Vulnerable but control |
| | 5-9 | High | Moderate risk | Important but controlled |
| | 1-4 | Program-risk high | Fixable but at risk | No risk |

| | Description |
|---|---|
| Critical | High probability of service loss/flooding or asset damage. Needs immediate action. |
| High | Near critical: one dimension is severe, the other not quite Green. Maintain soon. |
| Moderate risk | Moderate inherent risk and moderate program risk. Prevent to tip Red. |
| Vulnerable but control | Asset is vulnerable, but operation and maintenance should manage it. |
| Fixable but at risk | The asset is inherently fine; the weak link is program reliability. |
| Program-risk high | Asset itself is fine; Lack of maintenance makes the system vulnerable. |
| Important but controlled | Asset is vulnerable, but operation and maintenance is strong enough to control it. |
| No risk | A missed cycle has little effect but also it is unlikely to be missed. |

## 3 RESULTS AND DISCUSSION

The assessment revealed substantial variation in risk for structural failure condition ($R_{SF}$) and the risk of no maintenance ($R_{NM}$) across BGI types (Table 3). From an $R_{SF}$ perspective, failures such as lack of mowing in dry detention ($R_{SF}$ =8) or tree growth nearby storm water ponds ($R_{SF}$ =6) received lower $R_{SF}$ even though these might occur seasonally. Whereas issues like outlet blockage in stormwater pond ($R_{SF}$ =12), hidden underdrain malfunction in bioretention ($R_{SF}$ =12), or severe sediment accumulation across different BGI consistently produced high $R_{SF}$ scores due to their potential to disrupt hydraulic function during storms. In terms of $R_{NM}$, tasks that fit routine operations e.g., mowing in dry detention ($R_{NM}$ =4) or replacing filters every year in stormwater vaults ($R_{NM}$ =4) generally have a lower likelihood of being missed, whereas tasks requiring specialist skills or contracted services like conducting infiltration tests in bioretention ($R_{NM}$ =16) or replacing parts of weir/control structures in stormwater pond ($R_{NM}$ =16) are more prone to deferral or usually not budgeted. As a result, when $R_{SF}$ and $R_{NM}$ were combined, routine maintenance issues generally fell into *controllable* risk categories whereas failures involving hydraulic structures or subsurface components frequently fell into *high or critical* risk classes.

Differences were also evident between more engineered and less engineered/more natural BGIs when exposed to similar failure conditions. For example, sediment accumulation in more engineered bioretention systems produced overall risk as *High* ($R_{SF}$ = 8, $R_{NM}$=12) because even relatively small amounts of sediment can rapidly reduce infiltration capacity and trigger surface clogging. In contrast, sediment deposition in less engineered dry detention facilities generally resulted in overall risk of *Moderate risk* ($R_{SF}$ = 6, $R_{NM}$=6), as these systems rely on temporary storage rather than infiltration; modest sediment buildup does not immediately disrupt the storage function but might not be equally effective in the subsequent storm events.

An additional aspect shown in this assessment is the difference in maintenance motivation between decentralised and end-of-pipe systems. Decentralized systems often comprise numerous small, dispersed assets, which may reduce the likelihood of consistent upkeep compared with a few larger, centralised facilities. For example, sediment removal in a stormwater pond can be scheduled and carried out efficiently at *one* single site ($L_{NM}$ =1), whereas performing the same task across a large number of decentralised bioretention systems in an urban catchment is far less practical, needs more organisation, might be done by several operators, and therefore more likely not to be performed ($L_{NM}$ =3).

Preliminary results show performance risk in runoff control under structural failure and maintenance conditions for selected few BGIs. In the next step, additional BGIs will be included, and the risk for insufficient performance in water quality will be evaluated. This will provide a more comprehensive understanding of how different structural failure conditions and maintenance conditions influence stormwater runoff control and pollutant management under real-world scenarios.

*Table 3 : Risk classification of BGI under structural failure and maintenance conditions*

| BGI | Structural failure condition | Consequences | Required maintenance | $L_{SF}$ | C | $L_{NM}$ | $R_{SF}$ | $R_{NM}$ | Risk category |
|---|---|---|---|---|---|---|---|---|---|
| dry detention | surface clogging by sediment deposition | reduced infiltration, surface ponding, surface flooding | routine inspection and remove sediment every 5–10 years | 3 | 2 | 3 | 6 | 6 | Moderate risk |
| | high-energy inflows erode sides/outfalls | instability - seepage pathways | reinstate eroded areas, recompact and seed slopes | 2 | 4 | 2 | 8 | 8 | Moderate risk |
| | lack of mowing | flattening during runoff events | routine mowing to maintain grass cover, prevent rutting | 4 | 2 | 2 | 8 | 4 | Important but controlled |
| stormwater pond | sediment accumulation | reducing volume and residence time | dredge every 5–10 yrs; maintain forebay traps; remove litter monthly | 3 | 2 | 1 | 6 | 2 | Important but controlled |
| | tree growth on embankment | root penetration, piping along roots | Remove trees; reseed with grass. | 2 | 3 | 2 | 6 | 6 | Moderate risk |
| | liner or outlet blockage | uncontrolled discharge or leakage | annual inspection: repair or replace liner and outflow devices | 3 | 4 | 3 | 12 | 12 | Critical |
| | weir or control structure corrosion | leakage, flow bypass | Inspect metalwork; sandblast/coat or replace parts | 1 | 4 | 4 | 4 | 16 | Program-risk high |
| bioretention | surface clogging by sediment deposition | reduced infiltration, surface ponding, surface flooding | surface scarification or mulch/media replacement (1–5 yrs) | 2 | 4 | 3 | 8 | 12 | High |
| | hidden underdrain malfunction | hidden hydraulic failure | conduct infiltration test | 3 | 4 | 4 | 12 | 16 | Critical |
| | reduction in porosity (fine particles and organic buildup) | cumulative decline in infiltration rate | partial media replacement (10–15 yrs) | 1 | 3 | 5 | 3 | 15 | Program-risk high |
| | poor compaction at perimeter | Preferential flow | edge re-compaction and reseeding | 3 | 2 | 3 | 6 | 6 | Moderate risk |
| stormwater vaults | sediment intrusion in chambers | clogging of filters; risk of bypass during storms | vacuum clean filters (6–12 months); replace filters (1–2 yrs) | 2 | 4 | 1 | 8 | 4 | Important but controlled |
| | clogging of outlet pipe or orifice. | reduced flow capacity | lush outlet annually; remove sediment | 3 | 3 | 3 | 9 | 9 | Moderate risk |

## LIST OF REFERENCES


Blecken, G.-T., Hunt, W.F., Al-Rubaei, A.M., Viklander, M., Lord, W.G., 2017. Stormwater control measure (SCM) maintenance considerations to ensure designed functionality. Urban Water J. 14, 278–290. https://doi.org/10.1080/1573062X.2015.1111913

Adhikari, U., Broekhuizen, I., Pons, V., Sun, Z., Sjöman, J. D., Randrup, T. B., Viklander, M., & Blecken, G. T. (2024). Comparing the hydrological performance of blue green infrastructure design strategies in urban/semi-urban catchments for stormwater management. Water Science and Technology, 90(9), 2696–2712. https://doi.org/10.2166/wst.2024.346

Bahrami, M., Roghani, B., Tscheikner-Gratl, F., & Rokstad, M. M. (2024). A deep dive into green infrastructure failures using fault tree analysis. Water Research, 257. https://doi.org/10.1016/j.watres.2024.121676

Beryani, A., Goldstein, A., Al-Rubaei, A. M., Viklander, M., Hunt, W. F., & Blecken, G. T. (2021). Survey of the operational status of twenty-six urban stormwater biofilter facilities in Sweden. Journal of Environmental Management, 297. https://doi.org/10.1016/j.jenvman.2021.113375

Birkinshaw, S. J., Kilsby, C., O'donnell, G., Quinn, P., Adams, R., & Wilkinson, M. E. (2021). Stormwater detention ponds in urban catchments—analysis and validation of performance of ponds in the ouseburn catchment, Newcastle Upon Tyne, UK. Water (Switzerland), 13(18). https://doi.org/10.3390/w13182521

CIRIA. (2015). The SuDS manual. https://www.ciria.org/CIRIA/Books/Free_publications/C753F.aspx

Crouch, E. A. C., & Wilson, R. (1982). Risk-Benefit analysis (Vol. 1, pp. 51–75). Ballinger Publishing Company.

Funke, F., & Kleidorfer, M. (2024). Sensitivity of sustainable urban drainage systems to precipitation events and malfunctions. Blue-Green Systems, 6(1), 33–52. https://doi.org/10.2166/bgs.2024.046

Haile, T. M., Hobiger, G., Kammerer, G., Allabashi, R., Schaerfinger, B., & Fuerhacker, M. (2016). Hydraulic Performance and Pollutant Concentration Profile in a Stormwater Runoff Filtration Systems. Water, Air, and Soil Pollution, 227(1). https://doi.org/10.1007/s11270-015-2736-4