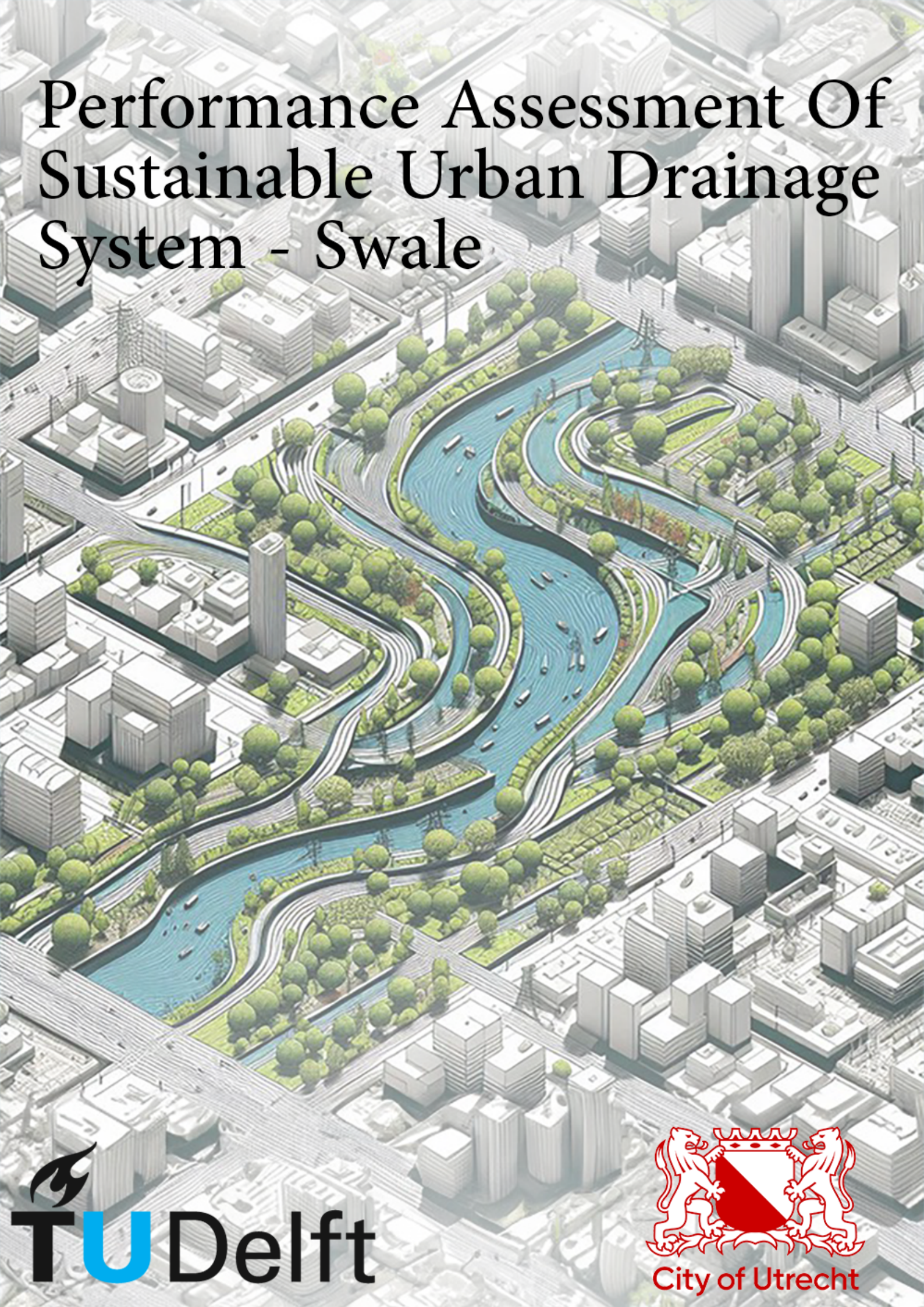
Performance Assessment Of Sustainable Urban Drainage System - Swale



TU Delft

City of Utrecht

Performance Assessment of Sustainable Urban Drainage System - Swale

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Master of Science Thesis

For the degree of Master of Science in Civil Engineering at Delft University of Technology

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Abstract

In recent years, Sustainable Urban Drainage Systems (SUDS) have gained popularity for managing stormwater in urban areas. However, effective asset management of these systems remains challenging due to the widespread reliance on reactive maintenance. This thesis examines the condition of dry swales in Utrecht, Netherlands, and their role in managing stormwater under the municipality's current maintenance framework.

A comprehensive visual inspection of 210 dry swales was conducted, alongside an evaluation of the area characteristics influencing component failures. The results indicate that only 67% of the swales function properly, with overflow failures being the most common issue, particularly due to clogging; 5% of swales were found to be in a failure state. Conversely, the vegetation layer emerged as the component requiring the most continuous maintenance, with only half of the swales sustaining a well-functioning vegetation layer. Notably, complete clogging issues in swale overflows were linked to a high percentage of impermeable areas within the catchment and a smaller length-to-width scale.

The analysis further revealed that filter basins exhibited the highest percentage of functioning components, emphasising the critical role of the infiltration process. However, even minor deterioration in these basins could significantly impact overall swale performance. The study also identified that a larger impervious area within a swale's catchment correlates with increased failure likelihood in various components. Factors such as tree density in a catchment area, impervious area, and the age of the swales were shown to contribute to issues like standing water and sediment accumulation in filter basins.

The investigation into sediment accumulation at overflows indicated that sediment tends to build up more in catchment areas with higher percentages of impermeable surfaces, although this phenomenon is influenced by multiple factors that warrant further research.

The findings underscore the necessity of improving the current reactive asset management of swales. By establishing a comprehensive database of inspection data, future research can better inform predictive asset management applications, incorporating parameters such as impervious area percentage, tree density, and swale age into machine learning models to predict swale failures.

Ultimately, the research emphasizes the importance of effective asset management for SUDS, not only to enhance swale efficiency but also to mitigate urban flooding risks. Regular inspection and monitoring are essential to understanding swales' functionality and degradation over time, informing design improvements and promoting the adoption of sustainable urban drainage systems. This study contributes to the broader goal of creating more resilient and sustainable urban environments through robust asset management of SUDS.

Contents

Contents **1**

List of Figures **5**

1 Introduction **1**

1.1 Background 1

1.2 Purpose of the study 3

2 Literature Review **4**

2.1 Swales maintenance necessity 4

2.2 Swales assessment & failures 5

2.3 Urban catchment area estimation 7

3 Research Objective and Questions **8**

3.1 Research objective 8

3.2 Research questions 8

3.3 Study structure 9

4 Methodology **10**

4.1 Area characteristic 10

4.2 Visual inspection 11

4.3 Swale visual inspection design 13

4.4 Visual inspection process 26

5 Study Area Characteristic **27**

5.1 Study area 27

5.2 Digital elevation model 29

5.3 Catchment area. 30

5.4 Land use . . . 34
5.5 Trees distribution . . . 35
5.6 Underground soil type . . . 36
5.7 Soil subsidence . . . 37

6 Swales Data 38

6.1 Swales documentation . . . 38
6.2 Construction details . . . 39
6.3 Maintenance data . . . 41
6.4 Failure data . . . 44

7 Visual Inspection Implementation 47

7.1 Inspection applicability . . . 47
7.2 Inlet & outlet inspections . . . 48
7.3 Water flow alignment . . . 48
7.4 Vegetation inspection . . . 51
7.5 Filter basin inspection . . . 54
7.6 Overflows inspection . . . 56
7.7 Overall swales condition . . . 59
7.8 Inspection repetition & maintenance indicators . . . 60

8 Data analysis & Results 64

8.1 Catchment area analysis . . . 64
8.2 Swale length/width scale analysis . . . 66
8.3 Vegetation failure analysis . . . 67
8.4 Filter basin failure analysis . . . 71
8.5 Overflows failure analysis . . . 76

9 Discussion 87

10 Conclusion & Recommendation 89

10.1 Conclusion . . . 89

10.2 Recommendation 90

Bibliography **96**

A Appendix **97**

A.1 Municipality registered swales data 97

A.2 Inspection form 103

List of Figures

1.1 Urban flooding frequency (Li et al., 2022) . . . 1

1.2 Dry swale without overflow cross-section (Polypipe, 2024) . . . 2

1.3 Dry swale with an overflow cross-section during a rainfall event (Urban Green Blue Grids, n.d.) . . . 2

4.1 The swales inspection details . . . 14

4.2 Swales perfectly aligned with surrounding area . . . 15

4.3 Swales vegetation layer in good condition . . . 16

4.4 Vegetation mowing practice . . . 18

4.5 The swale discharge optimized hierarchy (Green, 2019) . . . 19

4.6 A filter basin in good condition . . . 20

4.7 Types of inlet flow in swales . . . 22

4.8 Overflows in a dry swale . . . 23

4.9 Outlet types . . . 24

4.10 Additional swale components at swales . . . 25

4.11 Inspection implementation using QField . . . 26

5.1 Study area . . . 27

5.2 Sampled swales for inspection . . . 28

5.3 Digital Elevation Model . . . 29

5.4 Sub-areas of the study area . . . 30

5.5 DEM of the sub-areas . . . 31

5.6 Flow direction in each pixel in the sub-areas . . . 31

5.7 Strahler order for stream network tributaries (Pradhan et al., 2024) . . . 32

5.8 Water flow paths and channel network in the sub-areas . . . 33

5.9 Catchments area in sub-areas within the channel network . . . 33
5.10 Land use within the study area . . . 34
5.11 Trees distribution within the study area . . . 35
5.12 Underground soil type distribution in the study area . . . 36
5.13 Subsidence soil rate in the study area . . . 37

6.1 The Histogram distribution of swales by age . . . 39
6.2 Construction details one of the built swales in the study area . . . 40
6.3 The construction details of the swale as outlined in the Utrecht manual . . . 40
6.4 The SUDS practice operation and maintenance (Erickson et al., 2013) . . . 41
6.5 The type of maintenance work carried out by the municipality of Utrecht in the study area for the sampled swales. . . . 43
6.6 The volume of cleaned sediments in all swales within the study area. . . . 43
6.7 The P-F curve (Zofka, 2020) . . . 44
6.8 The distribution of failure points in the study area. . . . 45
6.9 The types of failures and their number of occurrences recorded in the municipality data. 46

7.1 Swales can not be inspected . . . 47
7.2 Outlets are not inspected . . . 48
7.3 Swale misalignment issues and needed maintenance . . . 49
7.4 Examples of misalignment . . . 50
7.5 Misalignment cause a complete block of water runoff flow . . . 50
7.6 Vegetation issues . . . 51
7.7 Inspected swales vegetation condition and required maintenance . . . 52
7.8 Vegetation protection measures . . . 53
7.9 Filter basin issues . . . 54
7.10 Overall condition of swales' filter basins and the required maintenance . . . 55
7.11 Overflows data documentation . . . 56
7.12 The number of occurrences of overflow failures . . . 56
7.13 Examples of various overflow issues . . . 57

7.14 Overflow systems condition 58

7.15 Overall swales condition in the study area 59

7.16 Map of the overall swales condition distribution in the study area 59

8.1 Histogram of swales catchment area distribution 64

8.2 Histogram of the distribution of impermeable area percentages in swale catchments . . 65

8.3 Histogram of swale impermeable area-to-surface ratio distribution 66

8.4 Histogram of swale length-to-width ratio distribution 66

8.5 Vegetation failures in four types of analysis 68

8.6 The percentage of vegetation failures in four types of analyses 70

8.7 Filter basins failures in four types of analyses 72

8.8 The percentage of filter basins failures in four types analyses 74

8.9 The swale filter basin condition concerning the age and the tree density 75

8.10 The distribution of dry swales with overflow catchments and the occurrences of clogging failures 77

8.11 The distribution of dry swales with overflow based on the impermeable area/surface scale and the occurrences of clogging failures 78

8.12 The distribution of dry swales with overflow based on the impermeable percentage in catchments and the occurrences of clogging failures 79

8.13 The distribution of dry swales with overflow based on the length-to-width scale and the occurrence of clogging failures 80

8.14 The percentage of overflow clogging failures in four types of analyses 82

8.15 The Clogging cases regarding the tree density and impermeable percentage 83

8.16 The sediment accumulation and the distance of overflow from the closest inlet 84

8.17 Analysis of swale catchment area and impermeable percentage in relation to sediment volume in overflows 85

8.18 The worsening situation of overflows and increases in high numbers of overflow failures since the last maintenance 86

List of Tables

2.1 Examples of deviations from design plans (Hirschman & Woodworth, 2010). 6

7.1 The number of blockages issues in swales 49

7.2 Vegetation issues in swales study area and their frequency 52

7.3 Filter basin issues in swales study area and their frequency 55

7.4 Clogging reasons 58

7.5 Inspection framework 61

8.1 Swales vegetation condition used in vegetation failure analysis 67

8.2 Swales filter basin condition used in filter basin failure analysis 71

8.3 The number of occurrences of swale overflow system partial and complete clogging failures 76

1 Introduction

1.1. Background

In recent times, the combination of rapid urbanisation and climate change has intensified rainfall and stormwater runoff, especially in urban areas, leading to a significant rise in the frequency of floods (Jha et al., 2012). Urban flooding has become the most recurrent among all-natural disasters, highlighting the urgent need to address and mitigate its far-reaching consequences on communities and infrastructure (Li et al., 2022).

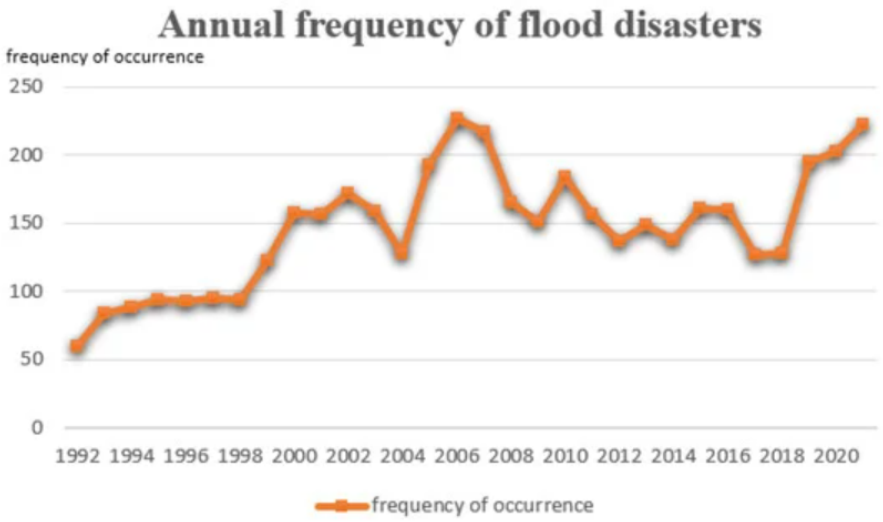


Figure 1.1: Urban flooding frequency (Li et al., 2022)

Protecting and preserving community health and safety is the major goal of urban drainage systems by swiftly managing floodwaters during storms, preventing structural damage, and ensuring seamless municipal traffic and activities. Simultaneously, they play a crucial role in maintaining a clean environment by efficiently eliminating human waste, mitigating waterborne disease risks, and promoting public well-being (Butler & Parkinson, 1997). As a result, enhancing the capacity of urban infrastructure becomes imperative, particularly in the case of drainage systems, when these systems reach their limits, a solution involves augmenting their capacity. Despite the challenges of implementation in a particular area, the development of conventional sanitation systems requires long-term planning and money allocation. Still, these solutions are also associated with time-consuming, high cost, and hardly meet the challenges (Öberg et al., 2020).

One of the strategies to reduce the reliance on conventional sewerage is to promote more sustainable urban drainage systems and separate stormwater runoff from wastewater (Butler & Parkinson, 1997). Therefore, introducing Sustainable Urban Drainage Systems (SUDS) can be an effective solution for urban flooding caused by stormwater. Conventional systems typically rely on engineered pipes to transport stormwater either to water bodies in separate drainage systems or to treatment plants in combined systems. In contrast, SUDS reduce runoff flow and enhance water storage capacity by employing a ”Management Train” technique, which includes source control, pre-treatment, retention, and infiltration (Srishantha & Rathnayake, 2017).

A swale is widely used as a sustainable drainage system in urban areas. It manages rainwater by retaining and slowly conveying runoff to surface water or stormwater sewers. Additionally, it recharges groundwater through infiltration. The main function of swales is to buffer the sewer system and prevent flooding during heavy rainfall events (Mondria, 2020). Some types of swales include various designs, with a focus on one main type of swale with two different designs:

1. Dry swale without overflow:

A dry swale is a vegetated conveyance channel equipped with a filter bed of enhanced soil that overlays an under-drain system. This system increases the swale’s infiltration capacity by preventing water saturation. Additionally, if the water level rises, a drain pipe could be added to discharge excess water to nearby waterbodies or sewer systems (Woods Ballard et al., 2015).

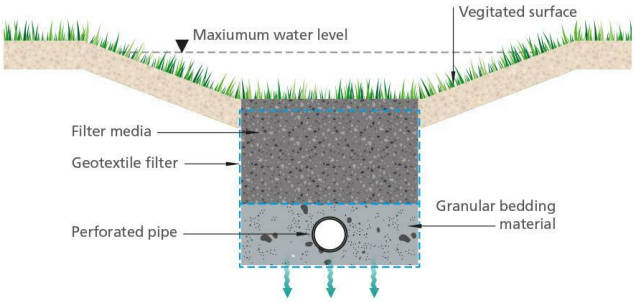


Figure 1.2: Dry swale without overflow cross-section (Polypipe, 2024)

2. Dry swale with overflow:

Another design of dry swales includes the integration of overflow screens, which help manage excess stormwater by directing it to drainage systems, ensuring continuous flow management (Allard, 2016). These overflows are connected to drain pipes, allowing rainfall to infiltrate the ground while also discharging water to nearby waterbodies when it rises above the overflow level (Lee, 2019)

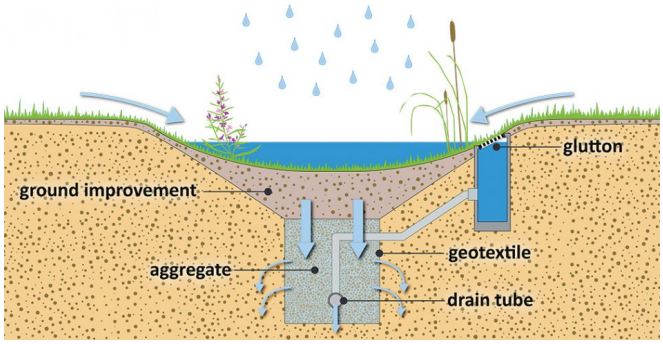


Figure 1.3: Dry swale with an overflow cross-section during a rainfall event (Urban Green Blue Grids, n.d.)

1.2. Purpose of the study

Enhancing sustainability through improved infrastructure asset management, as outlined in the ISO 55000 standards ”coordinated activity of an organisation to realise value from assets” (Hastings et al., 2010), involves optimising the utilisation of infrastructure throughout its service lifetime. This suggests the need for robust systems for monitoring, maintenance, and performance assessment to extend the lifespan and efficiency of critical assets, which includes allocating costs to ensure a specific level of service (Malano et al., 1999). Therefore, implementing these concrete and sustainable asset management approaches empowers cities to proactively tackle the challenges posed by urban flooding, creating more resilient and environmentally conscious urban spaces.

In traditional sewer asset management strategies, one of the approaches is reactive, where infrastructure is operated until it fails, and only then is it rehabilitated or replaced to restore service. This means that maintenance and repair actions are triggered in response to breakdowns or failures, often resulting in service disruptions, increased repair costs, and environmental risks (Ugarelli et al., 2010). This method relies on fixing problems after they occur, which can lead to inefficiencies, prolonged downtime, and higher overall life cycle costs for sewer systems. In contrast, a proactive approach to sewer asset management involves the utility taking preventive measures by rehabilitating an asset before it reaches a state of failure. Instead of waiting for visible deterioration or critical issues, the utility employs a systematic and predictive maintenance strategy. This could include regular inspections, condition assessments, and rehabilitation techniques such as relining or structural reinforcement based on the asset’s condition (Ugarelli et al., 2010). While predictive maintenance is known as an advanced approach, it may employ predictive modeling algorithms and machine learning methods that analyze historical data, performance trends, and environmental factors to forecast the future condition of sewer assets (Hernandez et al., 2021). This enables timely intervention, such as targeted maintenance or rehabilitation efforts, to mitigate risks and optimise the overall performance of the sewer system.

SUDS has been widely adopted, but their design and construction often lack proper maintenance protocols and overlook the need for monitoring and rehabilitation access. This assumption that they will operate flawlessly throughout their lifespan is a common oversight (Blecken et al., 2017). The SUDS asset management process is still underdeveloped due to a lack of regular maintenance and limited options for repairing and improving infrastructure, and the inspection procedures that should address key factors leading to failures are not well-established (Langeveld et al., 2022). There is a notable absence of models that define these processes. Additionally, monitoring approaches that should encompass the broad range of benefits and performance indicators associated with Blue Green Infrastructure (BGI) is still in the early stages of development (Langeveld et al., 2022). Furthermore, the current strategy for managing SUDS is predominantly reactive, relying on a run-to-failure approach. To enhance the overall maintenance approach and transition from reactive to proactive practices, there is a clear need for improvements in monitoring procedures. This shift is crucial for anticipating issues before they escalate and ensuring a more effective and sustainable management of SUDS (Cherqui et al., 2020).

The lack of a framework for assessment, such as visual inspection, hinders the development of SUDS asset management. This type of assessment is crucial for collecting data and understanding how SUDS systems fail, the types of failures they are prone to, and which components are most susceptible to degradation over time (Dinyake et al., 2022). Despite the limited experience, exploring inspection techniques for SUDS is essential. This highlights a gap in current practices and knowledge regarding the effective monitoring of these systems (F. Boogaard et al., 2024). Further, integrating asset management principles into infrastructure practices enhances resilience, reduces resource consumption, and aligns with global efforts to create more sustainable and resilient built environments.

2

Literature Review

The chapter concerns the literature review and focuses on common swale failures and the quantitative assessment of swales, as well as estimating the urban catchment area. The first part of the review consists of papers about the various swale maintenance necessities and expected obstacles. The second part will deal with the assessment of swales. Lastly, different approaches to estimating the urban catchment area will be reviewed.

2.1. Swales maintenance necessity

American Society of Civil Engineers (2019) pointed out that there is a strong correlation between drainage area characteristics and sediment accumulation. In addition, the vegetation's desired performance was consistently a common problem due to degradation caused by extreme rainfall events, erosion, uneven flows, weeds, and invasive plants, resulting in some plants failing to adapt to the site characteristics. Therefore, it was identified that invasive plants required a lot of maintenance. However, sediment accumulation, litter, and debris were found to be the most frequent factors that reduce swale performance. As a consequence, the most common maintenance activity is sediment removal.

Erickson et al. (2013) demonstrated that practices of SUDS based on infiltration functionality are more susceptible to failure due to clogging. Therefore, clogging can lead to long periods of standing water, flooding of surrounding areas, and untreated stormwater as a result of clogging. While, Sauer & Auken (2022) emphasizes that the most frequent reason for stormwater control measures (SCMs) failure is inadequate and improper management, maintenance, and operation. Moreover, implementing routine maintenance activities is crucial for removing debris and cleaning sediments. These activities also include vegetation management; for instance, unhealthy or dead plants need to be replanted or replaced, as well as connections such as valves, joints, and other parts that may need to be reconstructed, replaced, or adjusted.

Blecken et al. (2017) described the maintenance needs for SCMs face many barriers, such as the lack of communication among different stakeholders and unclear ownership or responsibility. Additionally, SCMs are intended to be built and maintained correctly. However, stormwater managers frequently either neglect SCMs once they are constructed or assume they will function during the designed lifespan without ongoing maintenance. Hence, the financial investment made during the initial phase of design and implementation is wasted if maintenance is neglected. As a result, failed systems do not contribute to a more sustainable environment, as they are not fulfilling their intended function.

de Macedo et al. (2017) conducted a study on the bio-retention basin during five rainfall events in July and August, representing the dry seasons when the sediment accumulation is highest. During the study, it was found that after each rainfall event, maintenance was needed due to a lower infiltration rate at the topsoil layer, unstructured soil, erosion at the outlet, and difficulties in maintaining the vegetation layer. Undoubtedly, the average hydraulic retention efficiency rose from 66% to 86% after maintenance, underscoring the need for both preventative and remedial maintenance.

Woods Ballard et al. (2015) suggested that inspection should be conducted monthly in the first year of operation and after heavy rainfall events to ensure appropriate system functioning. While, Erickson et al. (2013) highlighted that the watershed's land use, construction works, and rainfall intensity determine the frequency of inspection and maintenance needs. Therefore, visual inspection should be carried out at least once a year.

DelGrosso et al. (2019) emphasised that the long-term performance and lifespan of Green Stormwater Infrastructure (GSI) rely on adequate maintenance activities and proper construction, which depend on various factors such as site conditions, design criteria, and authority support. Due to these factors, GSI is more prone to poor construction and maintenance compared to traditional stormwater management systems. Moreover, vegetated swales require an enhanced soil layer and specific area characteristics to be effective, as they are susceptible to high-velocity flow.

2.2. Swales assessment & failures

DelGrosso et al. (2019) used GSI inspection data consisting of 3,141 inspection records covering the period between 2011 and 2017, collected by the County's Maintenance and Stormwater Management Division in Fairfax County, Virginia, USA. For vegetated swales, 94 inspections were conducted, revealing various issues. The most common issue was blockages, affecting 20.2% of the swales, followed by bare spots at 18.1%. Debris and structural issues were noted in 19.2% and 11.7% of the swales, respectively. Vegetation problems and erosion both affected 9.6% of the swales, while access issues were the least common, contributing to 5.3% of the swales.

Another study conducted by American Society of Civil Engineers (2019) reported the most common performance issues of SCMs based on 21 survey responses from 11 states in the USA. Erosion and sedimentation were the highest, reported by 56% of respondents, while vegetation management was the second most common issue, by 39%. Poor drainage and storm impacts were each reported by 17% of respondents. Seasonal performance and installation issues were noted by 11% and 6% of respondents, respectively. Issues during small intense storms were also reported by 6%.

Erickson et al. (2013) indicated that respondents identified several factors causing deterioration in the performance based on the study of 19 swales across the USA. Litter and debris were highlighted by 26% of the respondents as a significant issue, the same percentage for invasive vegetation. Sediment accumulation was mentioned by 21% of the participants, while bank erosion was reported by only 11%. Pipe clogging and structural problems were each mentioned by 5% of respondents.

Vollaers et al. (2021) reviewed the causes of technical failures in SUDS in their study, analysing 70 cases across 11 Dutch municipalities. The study categorised failures into three main groups: technical failures, failing functions, and failure locations. Among technical failures, interference with obstacles was the most common, occurring in 11 cases, followed by clogging in 10 cases and incomplete design in 8 cases. In terms of failing functions, infiltration failures were the most frequent, with 36 cases, followed by conveyance with 25 cases, and storage with 9 cases. For failure locations, internal failures were most prevalent in public open spaces with 21 cases, followed by streets with 19 cases. Failures at the interface locations were most common between private plots and streets, with nearly 11 cases, almost double the number of failures at the next most frequent location, between streets and public open spaces.

On the other hand, deviation from the design plan can also be one of the main reasons that cause swales' poor performance and failures. Hirschman & Woodworth (2010) referred to the field assessment of around 200 stormwater best management practices (BMPs) within Virginia's James River watershed. It was found that about 47% of 72 BMPs had one or two deviations from the main design in comparison with their approved design. These deviations can result in malfunctioning or a decrease in stormwater treatment. The table 2.1 below shows the list of types of deviations.

Table 2.1: Examples of deviations from design plans (Hirschman & Woodworth, 2010).

Category	% of Subset (n=72)	Examples of Deviations
Vegetation composition	18%	• Fewer plants, less diversity of plants • Wetland plants missing – no aquatic bench
Dimensions and/or volume	13%	• No retention volume • No detention of runoff • Under sized dimensions / volume
Soil type	10%	• Excessive clay in soil • Soil compacted – reduced permeability • Clogged gravel • Missing filter materials (e.g., sand and gravel)
Pretreatment type and/or size	8%	• Pretreatment feature missing, changed, filled in or blown out
Inlet type, number, and sizing	8%	• Curb cuts too small • Missing inlets • Extra inlets
Outlet type, number, and sizing	6%	• Missing gravel diaphragm • Missing underdrains
Low-flow channel	3%	• Channel created by erosion

2.3. Urban catchment area estimation

Rodriguez et al. (2000) evaluated the SURF model for urban catchments using 7 years of GIS-based land use data. The model validation shows superior accuracy and effectiveness in describing temporal runoff variations by comparing observed data and a conventional model. Nevertheless, this model faces issues like minimal previous area contribution and overestimation of runoff in small rain events. Therefore, a more physically-based approach is needed to address these concerns.

Shen et al. (2024) developed a model that integrates hydraulic and topological features of interdependent networks to analyse sewer system failure and inundation during rainfall. Moreover, the interdependence of sewer and road networks forms a complex system with diverse micro-structures.

Choosing a good model to estimate catchments in an urban area involves a lot of consideration. Ertl et al. (2024) review various methods for assessing stormwater management systems under exceptional events and conditions. However, each model has its advantages and disadvantages; thus, the choice depends on specific goals and practical considerations like cost and data availability. For instance, topological flow path analysis is quick and cost-effective. Additionally, the simulation of precipitation events is known within a specific return period. In contrast, hydrodynamic 1D and 1D-2D flood models can simulate both system behaviour and surface runoff, but they require more data with high spatio-temporal resolution and high computational effort. A fully coupled 1D-2D approach accounts for drainage infrastructure and surface processes; therefore, it is recommended for the accurate assessment of urban drainage systems during extraordinary events.

There are currently no studies that integrate the sewage system with SUDS to determine the catchment area of swales on an urban scale. Additionally, the topological flow pathways, surface processes, and sewerage system structure are not taken into account in these studies. Due to this gap, it is challenging to determine the overall flow load at the swale inlet, leaving the swale failure mechanism unknown.

3

Research Objective and Questions

3.1. Research objective

This study aims to evaluate the performance and condition of swales. Through inspections, it will determine whether swales meet their functionality requirements for stormwater management, including the conveyance, retention, and infiltration of runoff water. The study will consider current failures and the overall condition. Additionally, designing a proper inspection checklist will focus on specific components of swales, such as inlets, outlets, filter basins, vegetation, and overflows. These components are susceptible to deterioration over time, which can impact the swale's functionality.

The investigation seeks to determine whether a correlation exists between a swale's deterioration and its location, with careful consideration of the swale catchment area and area characteristics, including land use, tree density in the catchment, subsidence, and underground soil type. This will help analyze the potential parameters of swale failures. While the research primarily addresses the quantitative aspects of swales' state, specifically focusing on quantity, broader considerations of quality and biodiversity within the context of swales are beyond the scope of this study.

3.2. Research questions

Based on the objective, the main research question can be formulated as follows:

How do the catchment area and area characteristics of a swale influence the susceptibility of its components to failure and, consequently, its overall functionality?

To achieve the research objective, some questions should be answered:

1. Which specific components of a swale are most susceptible to failure over time?

2. What types of failures are swale components such as inlets, outlets, vegetation cover, infiltration basins, and overflows prone to?

3. What are the primary reasons contributing to the failure of swales, including the degradation of their components?

4. How can the catchment area of each swale, as well as the inlet of the upstream and the outlet of the downstream be determined using GIS (Geographic Information System)?

5. Is there a spatial correlation between failures, catchment area, and the swale's area characteristics?

By answering these questions, the study seeks to offer a comprehensive picture of swale performance, advancing both academic research and practical urban water management applications. The quantitative assessment will also focus on several crucial points:

- **Improved swale maintenance**
  This research can inform better maintenance practices by identifying swale components that are more susceptible to failure. This will ensure that swales remain functioning in good condition throughout their lifespan.
- **Enhanced the urban water management**
  Analysis of the correlation between swale location, catchment, area characteristics, and failure will provide a better understanding of how urban planning and landscape design can mitigate swale failures.
- **Sustainable and resilient built environments**
  Swales play a significant role in reducing runoff. Improving the asset management of swales and their longevity will contribute to a more environmentally sustainable approach and build resilience against climate change impacts.
- **Development of predictive models**
  The data collected during this research could be used to establish predictive models for swale failure and help in switching to a more advanced asset management approach.
- **Regulation recommendations**
  The outcomes of this study can provide advice on practices, proper maintenance, and the efficiency of current regulations.

3.3. Study structure

The general approach in this thesis will be structured as follows:
Chapter 1 introduces the background of this research and the purpose of the study. Chapter 2 will discuss the articles and papers related to this research that have followed a similar approach or have potentially common results. Then Chapter 3 introduces the research objective and the research question that this study aims to answer. Chapter 4 will delve into the methodology of the study, and what has been selected to analyse and represent the findings, and also look at the criteria for setting up the visual inspection form and how it is conducted, while Chapter 5 will explore the area characteristics that have been chosen and how they could influence swale performance and condition. The swales data, such as maintenance, failure, and construction details, are outlined in Chapter 6. Chapter 7 will look at the visual inspection implementation and the results of assessing swales. The data of inspection and area characteristics will be analysed in Chapter 8, and the findings will also be discussed in Chapter 9. Followed by a conclusion and recommendation for future research in Chapter 10.

4

Methodology

In this chapter, the methodology for selecting data on area characteristics is outlined. Additionally, the design of swale inspections is discussed, focusing on identifying which parts of the swale should be inspected, along with their functional criteria and operational standards. The chapter will also examine the types of failures to which swales may be prone and recommend appropriate maintenance actions when necessary. Furthermore, the process of collecting inspection data in the study area will be introduced. Each component of the methodology contributes to building the final dataset.

4.1. Area characteristic

In this study, the Geographic Information System (GIS) will play a role in identifying the area characteristics of swales. Additionally, QGIS software will be employed to process topographical and raster data, facilitating the creation of a visualisation. This data will include five main area characteristics:

1. **Trees distribution:** The location of trees within the study area will be analyzed to determine the number of trees in a swale's catchment, assessing the potential correlation between the trees and clogging failures in filter basins and overflows.
2. **Subsidence rate:** A subsidence rate map of the study area will be created to ensure that more swales are sampled in areas with a high subsidence rate, allowing for the exploration of potential misalignment issues that may be associated with subsidence.
3. **Underground soil:** An underground soil map will be created to visualize the different types of underground soil and to examine a possible correlation between the standing water issue in a swale's filter basin and the underground soil.
4. **Land use:** The distribution of green areas and impervious surfaces such as buildings, roads, and pavements can be analyzed using a land use map. This map will also be used to assess the size and percentage of permeable and impermeable surfaces within a swale's catchment area.
5. **Catchment area:** It seems to be the most important feature that presents the size of the swale drain area. The catchment analysis will be fundamental to explore the possible patterns of failures with area characteristics.

4.1.1. Catchment area estimation

The maps generated by QGIS are highly dependent on the data quality and resolution, particularly concerning the catchment area. For instance, QGIS may overlook factors such as runoff loss or the presence of physical obstacles within the swale's environment. While the actual size of the catchment area is challenging to quantify precisely, it can still be estimated, and the water flow direction can be determined. QGIS will be used in developing a swales catchment area and visualise the remaining provided data as follows:

- **Determine swale location:** Identify the locations of swale in the study area by using an open street map and swale data.
- **Data acquisition:** The next step is to acquire the necessary data for the study. This includes the Digital Elevation Model (DEM) and other relevant geospatial data provided such as swale outlets and drain pipes.
- **Data preprocessing :** Removing outlier data and preparing data for further analysis and visualising. Further, The DEM data needs to be pre-processed to make it suitable for analysis. This includes removing any data gaps, correcting for biases and inconsistencies, and converting the data to the appropriate format for analysis by using the Fill Sinks algorithm (Wang & Liu).
- **Data analysis:** Use QGIS to analyse the DEM data and identify the flow direction for each pixel. Further, based on flow direction a channelization network can be obtained to determine the inlet and outlet parts within the swale.
- **Determine the catchment area:** To establish catchment areas for each swale, Open Street Map (OSM) data and a DEM map will be integrated. The utilization of OSM to identify key features and land use around each swale, forming an initial drainage area estimate. Simultaneously, the channel networks and drainage basin map, crafted through GIS analysis, reveal natural water flow patterns. Overlaying this map with OSM data to refine and validate the catchment area and determine the upstream and downstream parts.

Maps created through QGIS serve as valuable tools for estimating water flow in the catchment area of each swale, both upstream and downstream. The use of QGIS enables a deep analysis of spatial characteristics influencing water drainage. This investigation assesses whether swales fulfil their intended drainage functionality, considering factors such as the equal distribution of runoff water in the case of lateral inlets. Additionally, it examines whether specific parts of the swales, including inlets or outlets, are overloaded with runoff water, potentially making them more susceptible to failures than other sections. This detailed spatial analysis provides insights into the performance of swales, aiding in their effective maintenance.

4.2. Visual inspection

The assessment of a system's functional and physical states is fundamental in planning operation, and maintenance, and it depends on the quality of collected data. Given that the investment in data gathering is relatively low for infrastructure, this process should effectively provide valuable information that aids in decision-making (Memarzadeh & Pozzi, 2016).

Visual inspection is a routine method for assessing the reliability of infrastructure conditions. However, inspections can sometimes cause service interruptions, be time-consuming, and result in high costs. Consequently, the frequency of inspections is often reduced (Agnisarman et al., 2019). When it comes to inspecting swales, visual inspection offers the advantages of rapid assessment and low cost by visually examining the top layer and visible parts without using any complex tools. Nevertheless, its downside is the limited knowledge gained, as only the visible parts can be assessed, leaving hidden components unexamined (Erickson et al., 2013). These inspections aim to identify evidence of malfunctioning and provide insight into the overall condition of swales and whether a higher level of assessment is needed while requiring less effort, time, and cost.

The visual inspection assessment process can be broadly divided into three key parts. The first part focuses on historical data, which is essential for a comprehensive understanding of the system. This involves data registration, including system data, maintenance records, and detailed swale information. Without this historical data, inspectors would likely encounter significant obstacles during both the inspection process and subsequent analysis.

The second part involves thorough documentation of the inspection data. This step is crucial to ensure that all observations and findings are accurately recorded and organized for future reference. Proper documentation facilitates continuity between inspections and supports subsequent assessments.

Lastly, data collection during the inspection is substantial and forms the backbone of the assessment. Inspections are conducted to evaluate the performance and condition of sampled swales. The process involves classifying the swales based on types, such as dry swale with overflow or dry swale without overflow and their intended functions. The inspection will assess individual components of each swale, considering factors like the condition and operational criteria, which indicate deterioration and poor performance. This involves gathering all critical information, such as identifying the occurrence of failures, providing detailed descriptions of maintenance activities, and conducting an overall condition assessment of the swale's components. Many concerns should be considered in the swale visual inspection assessment to ensure the efficient collection of useful information and to make the inspection process as straightforward as possible.

The visual inspection will also examine oversights in design considerations, such as the absence of sediment traps, inadequate provisions for energy dissipation, and insufficient erosion protection. Additionally, the research will investigate instances where rehabilitation works have not been conducted, which could lead to the deterioration of specific components and structural damage over time.

The main aspects of assessment mentioned in (Erickson et al., 2013), (Woods Ballard et al., 2015), and (Sauer & Auken, 2022), that should be covered by the visual inspection assessment are as follows:

- **History of previous visual inspection:** Part of the assessment involves reviewing previous inspections and assessment actions. This historical data provides context and helps in understanding the current condition of the swale relative to past performance.
- **Accessibility:** The condition to reach the site should be also evaluated. If there is no access, the assessment is more likely not to be completed. This includes assessing the physical access routes to the swale and any obstacles or barriers that might impede inspection activities.
- **Geographic information:** The location of swales and the surrounding environment should be clearly documented, along with the swale's dimensions on a map, ensuring the right address and coordinates are provided. This includes capturing details about the type of land use in the surrounding area and any environmental factors that might influence its condition and performance.
- **System components:** All the elements of the swale should be included in the inspection with comprehensive data such as the number of parts, Code ID, dimensions, and location. For instance, components like the inlets, outlets, vegetation, filter basins, and overflows must be inspected.
- **System description** A summary of the intended design and its essential information, such as the year of construction and the materials used in some components, should be provided. This description provides insight into the original design parameters and intended performance of the swale.
- **Weather data:** The weather conditions should be noted. This information is critical because weather events affect the condition of the swale and the presence of standing water.
- **Maintenance activity record:** Last maintenance activity should be clearly documented and reviewed, detailing which components were addressed and what type of repairs were made. Keeping a thorough maintenance log helps in tracking the frequency and effectiveness of maintenance.
- **Expected failures:** The inspection should detect all types of failures, causes, and severity. For instance, clogging, whether it is complete or partial and by sediments, vegetation, or litter and debris, should be identified. Understanding the types of failures that occur can help in developing targeted maintenance strategies and in preventing future occurrences.
- **Proposed maintenance:** All triggers that require maintenance should be included, along with an explanation of the objectives for the proposed maintenance.

- **Components condition:** To distinguish between different states—failure, approaching failure, routine maintenance needs, and proper functioning—each condition must be clearly defined. These states are classified based on whether operational standards are met. When a system meets these standards, it is considered to be functioning properly. If the standards are not met, the system is classified as a failure. Routine maintenance needs depend on ongoing activities such as cleaning and mowing. Approaching failure refers to situations where components require non-routine maintenance, with a high risk of failure if not addressed. This involves setting clear standards for acceptable performance and identifying indicators of potential issues.
- **Documentation:** The date of inspection, the inspector's name, and photos should all be taken as part of the assessment to document the swale condition. Comprehensive documentation provides a reliable record of the swale's condition at the time of inspection, which is essential for tracking changes over time.

All findings, inspection data, and failures are documented, summarizing the status of the swales and the effectiveness of implemented measures. This methodology will be used in this study to provide insights into the degradation of swales over time and to assess whether there is a spatial correlation between the common failures and their intended functionality. The correlation analysis aims to discern patterns that could reveal the factors influencing swale performance and resilience within their hydrological function. Additionally, understanding the common types of failures will contribute valuable information for enhancing the asset management of swales. This knowledge aims to shift the management of swale assets from a reactive to a proactive approach, ensuring the implementation of an effective monitoring system aligned with the identified failure patterns. This concrete approach ensures a systematic and actionable plan to detect and monitor swale performance and enhance the drainage capabilities of swales.

4.3. Swale visual inspection design

The visual inspection designed for this research is comprehensive, covering all critical aspects necessary for effective asset management of swales. The evaluation is divided into several key parts: swale data & geographic information, weather, maintenance, water flow alignment, vegetation layer, filter basin, inlet, overflows, outlet, and other components. For each of the swales' elements, the functionality, operation standards, potential failures, and maintenance requirements will be addressed. This aims to create a thorough inspection form that ensures all relevant factors and concerns are considered.

4.3.1. Swale data & Geographic information

The initial part of the inspection focuses on essential information about the swales and their locations. This begins with recording the inspection date, providing the swale code ID for registration purposes, and distinguishing between the two types of swales: dry swale with and without overflow. This section also involves identifying all components within a swale, such as the outlet, overflows, and drain pipe. Additionally, it notes the type of surrounding environment, which could be a street, highway, pavement, cycle path, parking area, green space, or roof drain. Figure 4.1 below shows an example of the sampled swales and their components for inspection.

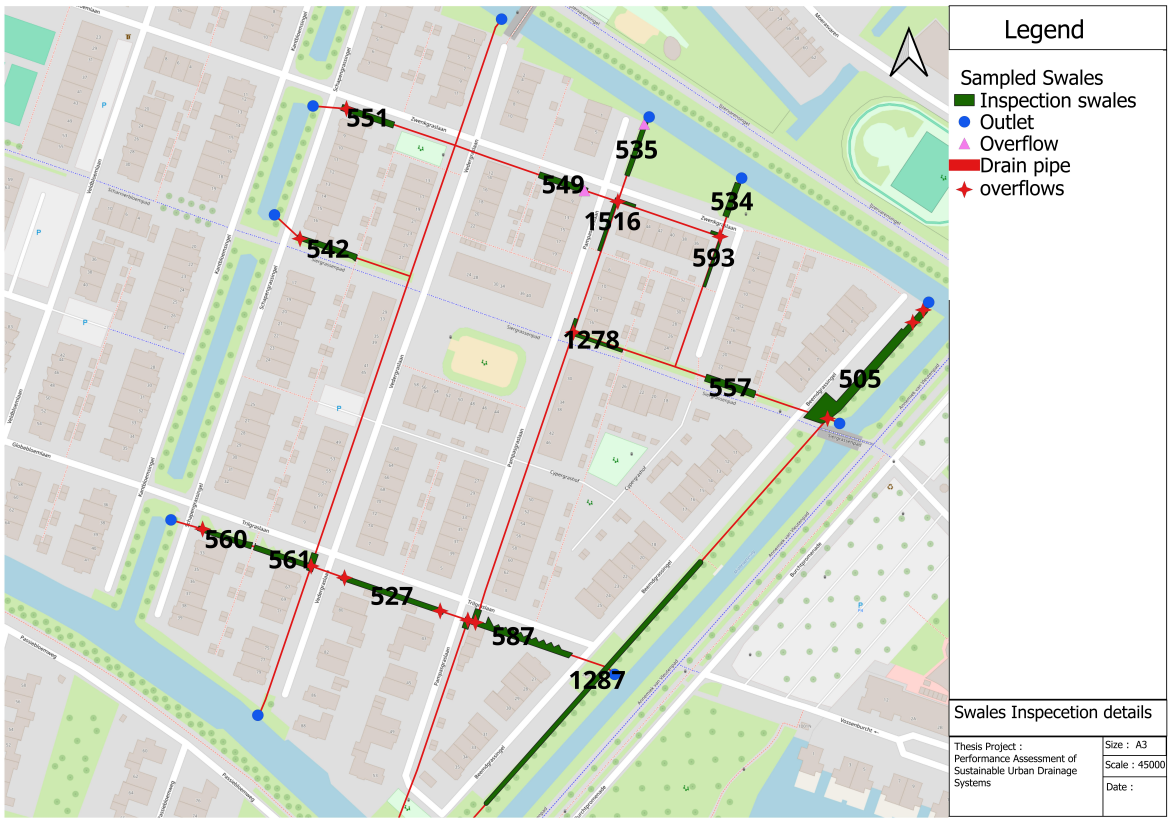


Figure 4.1: The swales inspection details

4.3.2. Weather

Referring to the weather conditions on the inspection day is crucial, as the primary functions of swales are influenced by rainfall runoff. It is important to note the date and the intensity of the last rainfall, and whether it has rained in the last 48 hours. Conducting inspections during or immediately after rainy weather allows for the observation of standing water, the water level, the discharge of the overflow, and the visibility of the water flow path to the swale. Therefore, noting the weather conditions, including any rainfall in the preceding two days, is essential. However, inspections are not limited to rainy conditions; inspecting during dry weather can still reveal potential malfunctions or maintenance needs.

4.3.3. Maintenance

All the maintenance activities that occurred at the swales' location should be documented. To simplify the inspection list, only the specific swale components that have been maintained are noted initially. Detailed information about the maintenance work will be added later for data analysis. However, tracking the maintenance activities helps reveal not only the frequency of these activities but also the most vulnerable components.

4.3.4. Water flow alignment

Swale alignment with the surrounding environment is a critical functional criterion, even though it is not considered one of the system components. The water flow should enter the swale smoothly without any barriers. The presence of obstacles in the water path to a swale can disrupt its function and is a common cause of functional failure (Vollaers et al., 2021). For example, obstacles can change the water flow direction from lateral to channel flow or redirect the flow to gully pits, preventing infiltration. Blockages in water flow can be partial or complete: partial blockages divert some runoff to a swale, while blocking the rest, whereas complete blockages entirely prevent runoff from accessing the swale and redirect it elsewhere.

Various factors can cause disruptions in the water flow path to swales. These obstacles can be due to elevation differences, such as high elevation on a swale side, or subsidence, which lowers the swale side over time and alters the flow type. Physical obstacles or pavements can also redirect the water flow. Ensuring the swale is aligned with other urban plans is essential to avoid water flow issues.

When inspecting water flow alignment, it is important to identify the type of obstacle - whether partial or complete- and the type of blockage under the described conditions. The recommended maintenance activities will depend on these findings. Maintenance could involve rearranging the elevation of the swale, pavement, or street due to subsidence or removing physical obstacles to ensure smooth water flow. Immediate removal of any obstacles is crucial to maintaining the proper operation of the swale (Erickson et al., 2013). Figure 4.2 below illustrates examples of optimal swale alignment with the surrounding area.



(a) Swale alignment next to a street



(b) Swale alignment next to a cycle path

Figure 4.2: Swales perfectly aligned with surrounding area

4.3.5. Vegetation layer

The common element in the SUDS is the grassed vegetation layer, which is planted in various soils, dimensions, and with different plants. A variety of plants can be used in the swale, such as grass, sedge, tufted grass, and wildflower grass seed mixes, which promote biodiversity. Generally speaking, native plant species are recommended to ensure a proper vegetation layer that also creates a habitat for native species (Woods Ballard et al., 2015). A well-vegetated swale is crucial for bioretention systems as it enhances treatment processes and provides significant infiltration and bio-filtration capacity. Vegetation offers numerous benefits, such as preventing erosion, stabilizing side slopes, and enhancing filtration into constructed soil in the filter basin by creating channels through plant roots (Apt et al., 2019). The infiltration rate rose linearly with plant age as a result of the plants growing and developing dense, longer, and thicker roots. Therefore, underestimating the age of the plant during the establishment process cannot be neglected (Leung et al., 2018). Additionally, the presence of a vegetation layer boosts processes like evapotranspiration and soil aeration, reduces soil compaction, replenishes organic matter in the soil, and provides an environmental habitat for beneficial bacteria that help reduce stormwater pollutants (Apt et al., 2019). Therefore, the effectiveness of pollution removal and flow dynamics in stormwater management may be greatly impacted by natural vegetation (Ahmari et al., 2023). Grassed swales are useful in residential areas but require regular mowing and maintenance. The grass species selected for swale lining must be sturdy, drought-resistant, easy to establish, and able to spread and develop a strong turf layer. Effective grass lining requires proper planting equipment and methods. The chosen grass species must be adaptable to the site conditions to tolerate flooding and continue growing after inundation. Grass height should be maintained between 50 mm and 150 mm, with a maximum height not exceeding 150 mm (Woods Ballard et al., 2015). All the vegetation characteristics, including height, type, and condition have an influence on the flow and the swale's roughness coefficient. This coefficient tends either to stay constant or increase when the swale begins to inundate (Mustaffa et al., 2016). Figures 4.3 show an example of a healthy vegetation layer in swales.



(a) Vegetation layer in perfect condition next to highways



(b) Healthy vegetation layer with two lines of trees

Figure 4.3: Swales vegetation layer in good condition

The primary function of the vegetation layer in a swale is to filter and absorb water runoff, slowing its flow and naturally filtering out pollutants before the water infiltrates the ground (Chen et al., 2023). Additionally, the vegetation helps stabilize the soil, preventing erosion, and promotes groundwater recharge by enhancing water infiltration (Hu et al., 2023). When the vegetation layer fails to perform these functions, it can compromise the effectiveness of the swale. Signs of such failure include browning plants, patchy growth, bare spots, and increased soil erosion. Based on the significant function of the vegetation layer and its role in swale performance, it is clear that vegetation management activities need to be conducted more frequently than other types of maintenance (Sauer & Auken, 2022). Inspectors should ensure that the maintenance is performed regularly and look for indicators that vegetation needs attention. These practices should be evaluated according to (Woods Ballard et al., 2015), (Apt et al., 2019), and (Sauer & Auken, 2022) as follows:

- **Mowing and clipping:** Maintain the grass length between 50 mm and 150 mm by appropriate mowing and clipping and by removing dead plants.
- **Weed control:** Prevent weeds and noxious species from competing with desirable plants and fauna.
- **Mono culture vegetation:** Avoid the growth of invasive and weedy plants where they should not be present.
- **Health and density check:** Assess the health and density of the vegetation regularly.
- **Vegetation coverage:** Ensure there is no poor vegetation layer, spotty grass growth, or completely bare spots exceeding more than 10% of the total covered area.
- **Variety in vegetation:** Monitor for different types, colours, and heights of vegetation, which could indicate seepage or groundwater issues.
- **Tree and woody vegetation:** Remove any emergent trees or woody vegetation.
- **Overgrowth control:** Remove any overgrowth that might block water flow or reduce the bioretention system's capacity.
- **Replacement unhealthy plant:** Replace any missing, infected, dead, or dying plants. If this issue occurs on a large scale, consultation with a horticulture specialist is needed to address the issue before replanting.

It can be said that vegetation maintenance is defined by vegetation management, planting, and mowing which includes all the standards necessary to keep the vegetation properly maintained. Figure 4.4 illustrates some of the maintenance practices to sustain the vegetation layer.



Figure 4.4: Vegetation mowing practice

4.3.6. Filter basin

The infiltration process occurs within the swale area and the filter basin. To promote this process, swales are designed with a subsurface improved soil layer and a drain buried in a layer of gravel to aid in infiltration (Woods Ballard et al., 2015). A common misconception about infiltration in conventional designs is that infiltration does not continue when the swale is filled with water. As a result, the design of the swale during construction might deviate because of variations in infiltration capacities (Chin, 2024). Moreover, the design of a swale is not the only factor influencing the infiltration process; the soil structure can play a significant role. This structure can be changed naturally or by human activities, such as changes in land use and soil amendments. It has been found that tillage affects the infiltration process negatively (Basset et al., 2023).

The main function of the filter basin is to convey, retain, or infiltrate the stormwater runoff. Filtering swales have been shown to manage inflow volumes effectively, capturing runoff during significant storm events (Monrabal-Martinez et al., 2018). The risk of not being able to handle the next rainfall event should be minimized; the infiltration components should be half-empty within a reasonable time, often defined as 24 hours (Woods Ballard et al., 2015). Some guidelines recommend a maximum emptying time of one day for the swale to effectively infiltrate stormwater, whereas others allow up to 48 hours (F. C. Boogaard, 2015).

Moreover, swale design—including factors such as length, longitudinal slope, cross-section, and other components—plays a crucial role in sediment reduction. Sediments are pollutant particles carried by stormwater runoff, generally from impermeable areas, with sizes of 6-15 µm. Trapping sediment depends on the hydraulic retention time (HRT) of the swale. Swales are typically designed with an HRT between 40 and 400 seconds. Increasing HRT can improve sediment removal if the swale length is sufficient, or adding check dams can enhance this process (Ekka et al., 2021). Therefore, sediment accumulation in the filter basin can impede the infiltration process and clog the soil pores, ultimately leading to swale failure (Mobron, 2019).

Managing stormwater in swales involves prioritizing the discharge method and controlling the volume of discharged water. This includes maximizing the beneficial use of infiltration and evaporation to control volume. Increasing the retention time of stormwater and decreasing the discharge flow are effective ways to manage peak flows. Discharging water to the sewerage system should not be an option SUDS or be a part of the components (Green, 2019). The figure 4.5 below illustrates the swale discharge optimized hierarchy.

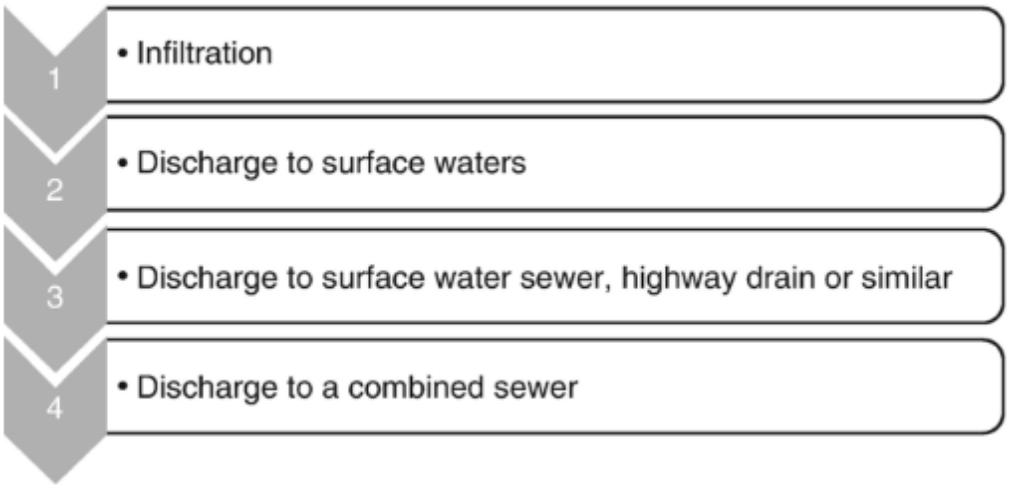


Figure 4.5: The swale discharge optimized hierarchy (Green, 2019)

Similarly, filter basins also require frequent inspection. These inspections are fundamental for scheduling maintenance activity and evaluating the condition and performance of the filtering practices according to (Erickson et al., 2013), (Woods Ballard et al., 2015), (Apt et al., 2019), and(Sauer & Auken, 2022) as follows:

1. **Clean filter bed:** Removing accumulated trash, litter, and debris to ensure the filter bed remains clean and unobstructed.
2. **Filter basin alignment:** Checking the sides slope and filter basin level to ensure they are properly aligned within the swale.
3. **Standing water:** Inspect for indicators of standing water on the filter bed for more than 24 hours. If standing water is found, the type of water should be determined because it could be evidence of an illicit connection.
4. **Sediment accumulation:** Monitor this process because swales usually accumulate a low volume of sediments. In case of accumulation, remove and clean the filter basin to maintain infiltration capacity.
5. **Vegetation health:** The absence of vegetation can indicate clogging and improper drying of the swale, leading to extended retention time that damages the plants.
6. **Channelization:** Addressing channelization, as it can increase the build-up of suspended solid concentration due to the high velocity of the stormwater runoff.

Maintaining a filter basin involves several key activities to ensure its proper functionality. First, if the filter bed is damaged, it may need to be reconstructed. Additionally, the filter bed should be regularly cleaned to remove any accumulated litter, debris, or sediments. Furthermore, it is essential to reshape the filter bed and side slopes to correct any issues with elevation and alignment, ensuring that water flows smoothly and effectively through the basin. Figure 4.6 shows an example of a filter basin maintained in good condition.



Figure 4.6: A filter basin in good condition

4.3.7. Inlet

The method by which water flow is transferred to the swale varies according to the type of component, the surrounding area, land use, and the water flow paths. Ideally, the runoff water should enter the swale gradually as a lateral flow along the sides of the swale to ensure water flow distribution across the entire swale area. Nevertheless, the water can flow to the swale in a channelized form from a pipe source, which is not recommended because of high velocity and the possibility of resulting issues like erosion and channelization but still may be applied if appropriate measures are considered (Woods Ballard et al., 2015). However, the inlet design and location should be taken into design consideration for better utilization of the storage (Shevade & Montalto, 2021). The majority of swales receive stormwater laterally, often with flow from roof drain pipes.

The effectiveness of a swale in removing pollutants depends on higher retention time, and facilitating pollutant settling is closely related to flow velocity. For a design based on a 2-year storm event, the maximum recommended flow velocity is 1.2 m/s. For more extreme conditions, such as a 10-year design flow event, the maximum recommended flow velocity can reach up to 2.1 m/s. (Ahmari et al., 2023). Therefore, high inflow velocity causes channelization and increases the sediment build-up in the swale, thus, the flow velocity must be reduced to mitigate these issues (Erickson et al., 2013).

The structure elements where the runoff is designed to enter SUDS, such as inlets require also inspection. The inlets should be visually inspected to explore the structural integrity and alignment. According to (Woods Ballard et al., 2015), (Erickson et al., 2013), and (Sauer & Auken, 2022) the following points should be considered in the inspection:

- **Misalignment:** Dynamic loads, differential loads, and freeze-thaw cycles can all contribute to inlet misalignment, particularly after construction.
- **Clogging:** Removing any sediments, roots, vegetation, and litter to prevent clogging and flooding of upstream areas.
- **Structural integrity:** Checking the structural elements, such as pipes, joints, and the inlet structure for any signs of corrosion, damage or degradation.

The condition and maintenance of the inlet significantly influence swale performance, as it is the primary element for delivering runoff water from the catchment area. Consequently, any disturbance in the inlet flow can reduce the efficiency of the swale in managing stormwater, making regular inspection and maintenance of the inlets essential for optimal swale operation. Figure 4.7 below demonstrates the type of swale inlets.



(a) Drain roof pipe inlet with flow spreader



(b) Lateral flow from the sides of a swale

Figure 4.7: Types of inlet flow in swales

4.3.8. Overflows

The volumes of stormwater runoff generated by impermeable areas in an urban area can exceed the capacity of the existing drainage system network (Ramos et al., 2017). Similarly, the hydraulic capacity of swales can be surpassed during a rainfall event. To prevent the risk of flooding, some dry swales are equipped with overflows that help control the maximum water level by discharging excess water to a surface water body (Mobron, 2019). Some dry swales discharge excess water directly into a water body.

The overflows are positioned slightly higher than the filter basin to encourage water accumulation and the infiltration process in the filter bed (Irvine & Kim, 2018). However, during stormwater events, trash and debris can accumulate and be discharged into the underground drainpipe systems. This might lead to issues such as clogging (Allard, 2016). Therefore, the efficiency of overflows highly relies on the frequency of maintenance, as they act like sediment traps. Additionally, there are concerns about the low water quality stored in overflows being washed downstream (Woods Ballard et al., 2015).

Regarding the functionality of overflow, maintaining this component as one of the structural elements of the swale is fundamental in assessing the state of the swale. Therefore, regular visual inspections are required to be conducted frequently according to (Erickson et al., 2013), (Woods Ballard et al., 2015), and (Sauer & Auken, 2022), as follows:

- **Clogging:** Check the overflow is not blocked either partially or completely by vegetation, sediments or litter.
- **Structure damage:** Inspection the condition of the overflow structure to ensure it is functioning without structure damage or leaking.
- **Elevation:** Verify the proper elevation of the overflow to prevent the risk of over-immersion or untreated water from discharging to water bodies.

- **Design alignment:** Ensure the overflow is constructed and properly aligned with other swale components.
- **Sediments volume:** Monitor the volume of sediment in the overflows to ensure it does not exceed their capacity.

Overflows are significant components in swales, responsible for controlling the maximum water level and preventing flooding. Therefore, regular inspection and maintenance are highly important to ensure their proper function and overall swale efficiency. The figure 4.8 below shows an example of an overflow in a dry swale.



(a) Overflow alignment in a dry swale



(b) Overflow in a perfect condition

Figure 4.8: Overflows in a dry swale

4.3.9. Outlet

The capacity of the system to handle low or high flow is largely based on the outlet structure. This component is responsible for transporting and controlling the flow out of the SUDS. Outlets can be designed in various ways, including a visible open channel at the end of SUDS, a piped system for water transport, or a porous medium for slow water infiltration (Woods Ballard et al., 2015). SUDS are designed to handle low-velocity flow near the source, by interception small components and managing surface runoff. This makes outlets more visible and less cost-effective (Woods Ballard et al., 2015).

Like other structural components such as inlets and overflows, outlets also need frequent maintenance. Any defect in this feature can disrupt the swale's function and increase the risk of downstream flooding. Thus, scheduled inspection activities should be carried out according to (Erickson et al., 2013), (Woods Ballard et al., 2015), and (Sauer & Auken, 2022) as follows:

- **Misalignment:** Subsidence and erosion can cause misalignment of the outlet.
- **Clogging:** Removing any sediments, roots, vegetation, and litter to prevent clogging and flooding of downstream areas.
- **Structural integrity:** Ensure that structural elements such as pipes, joints and the outlet structure are checked for any signs of corrosion, damage or degradation.
- **Elevation alignment:** Check the outlet elevation is properly aligned with the swale and the discharging location at the water body.

Assessing the condition of structural elements like outlets can provide a better understanding of the issues that affect their function. Outlet inspections remain one of the crucial features in swale maintenance. Figure 4.9 demonstrates different types of outlets in swales.



(a) Concrete outlet discharges in a water body



(b) Piped system outlet

Figure 4.9: Outlet types

4.3.10. Other components

Adding extra components to the swale can help sustain its functions and protect it from failures such as erosion or channelization. These additional components include:

- **Check dams:** These small structures, typically around 0.6 meters in height, are used to increase the retention time of the flow and regulate its velocity. This enhancement aids in sediment settling and improves the infiltration process (Ahmari et al., 2023).
- **Leaves screen:** A screen layer is employed to prevent litter and leaves from entering under drain pipes, thus mitigating clogging issues (Woods Ballard et al., 2015).
- **Flow spreader:** Installed at the inlet or point of inflow, a flow spreader reduces flow velocity and ensures even distribution. This promotes effective treatment and helps control erosion (Woods Ballard et al., 2015).

These additional components are also prone to failure and require regular maintenance. Just like other swale components, they need frequent inspections. The same protocol applies for structural elements, such as inlet, overflow, and outlet should be followed for check dams, leaf screens and flow spreaders. Figure 4.10 shows additional components added to a swale.



(a) Flow spreader at the drain pipe inlet



(b) Leaf screen at the overflow

Figure 4.10: Additional swale components at swales

4.4. Visual inspection process

After addressing the functionality and inspection aspects for each swale component, along with common issues swales typically encounter. An inspection form has been created.

In more detail, the inspection form begins with swale data, which includes the date of inspection, code ID, the type of land use around a swale and the type of swale. It also covers weather conditions, the date of the last rainfall and its intensity. Maintenance activities are detailed by the features involved and the type of work performed. Swale components addressed in the inspection form include vegetation, filter basin, inlet, overflow, outlet, and additional components. For each component, the form notes the number of issues, types of failures, possible reasons for failure, and required maintenance. For the overflows, the water level is measured to compare with other overflows within the same swale. This helps determine if there is clogging in the overflow's outlet. To better understand how sediment accumulates in the overflow, the distance between the overflow and the main inflow is measured. For example, the inflow from a roof drain pipe or lateral flow from the side is evaluated based on which side of the swale receives more water. The complete inspection form can be found in the appendix A.2.

To simplify the inspection form, the inspection list was created in QGIS, focusing solely on data collection. Supplementary information, such as catchment size and the percentage of permeable versus impermeable areas, will be integrated later during data analysis. For the visual inspection process, the QField app is used. After uploading the necessary data such as swale locations, overflows, outlets, and drain pipes to the QField cloud along with the inspection list, another device can download this data and conduct the inspection. Once the inspections are completed, the data is uploaded back to the QField cloud and can then be downloaded into QGIS for further analysis. Figure 4.11 illustrates the steps in this process. The swale condition is assessed by categorizing each component as functioning, needing routine maintenance, approaching failure or in failure. This categorization is based on the component's functionality under the current condition and the severity of any present damage. Additionally, the form includes sections for general notes and a summary of observations. All inspected components' conditions are documented with photos as part of the inspection.

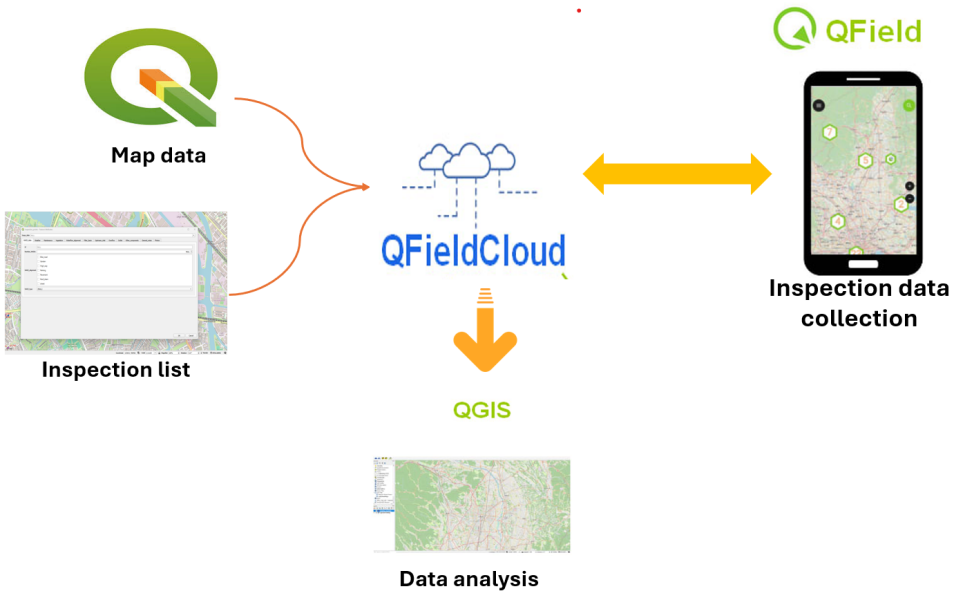


Figure 4.11: Inspection implementation using QField

5

Study Area Characteristic

This chapter highlights the fundamental area characteristics in the selected study area. Specifying the source and type of data analysed to obtain these characteristics and explains their subsequent use in various data analysis contexts.

5.1. Study area

For this research, the city of Utrecht in the Netherlands has been selected as the study area, given its extensive implementation of swales especially in two regions: Leidsche Rijn and Vleuten De Meern. Figure 5.1 shows the swale distribution within the study area.

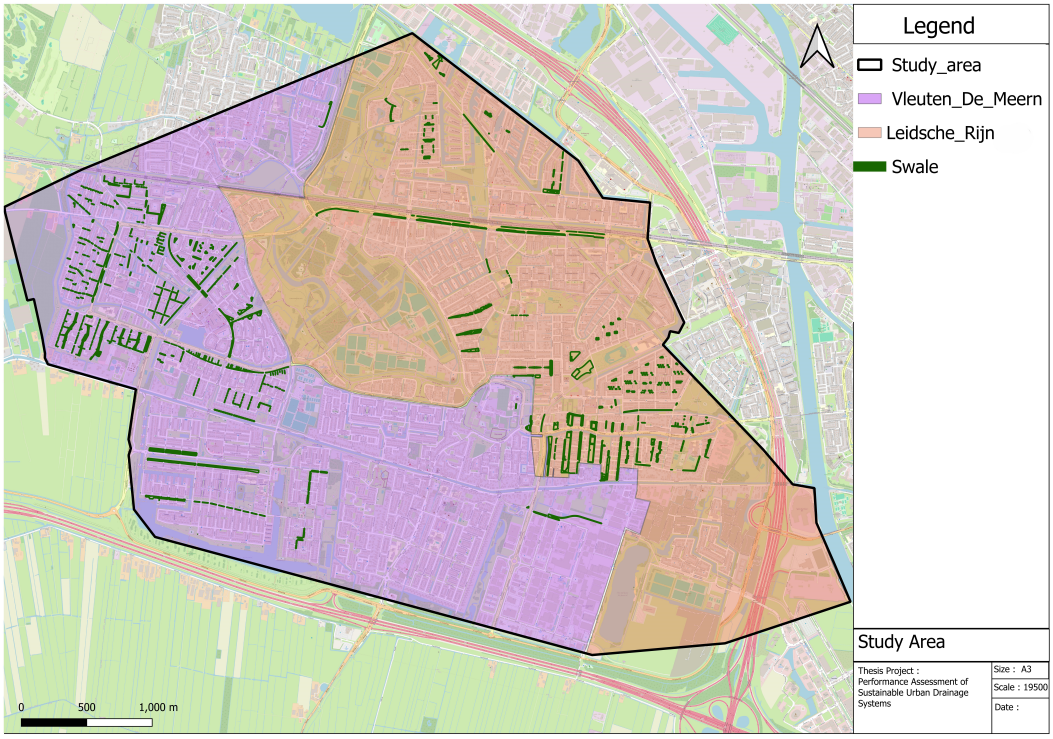


Figure 5.1: Study area

Given the vast number of swales in Utrecht, spanning approximately 202000 m², a sampling method has been adopted because it is not feasible to inspect all of them within the research period. The process of sampling considers several criteria. Firstly, the location of the swales will be considered, including whether they are situated in a neighbourhood, adjacent to a street, or aligned with a highway. Secondly, the size of the swales will be considered, focusing on different segments for larger swales, specifically at the inlet (upstream), in the middle of the swale, and at the outlet (downstream).

Finally, the research will also consider one type of swales, dry swales with and without overflows. Moreover, the latest records of swale maintenance and subsidence rates were also considered in the sampling. For instance, the measured volume of sediments in the overflows and the high subsidence rates, enable a fair distribution of samples within the study area, taking into account both the swale and location characteristics.

The selected samples in the study area can be seen in figure 5.2, resulting in an inspection area of approximately 55300 m², which represents 27% of the total swales in the study area. This includes 64 swales in Leidsche Rijn and 146 in Vleuten De Meern.

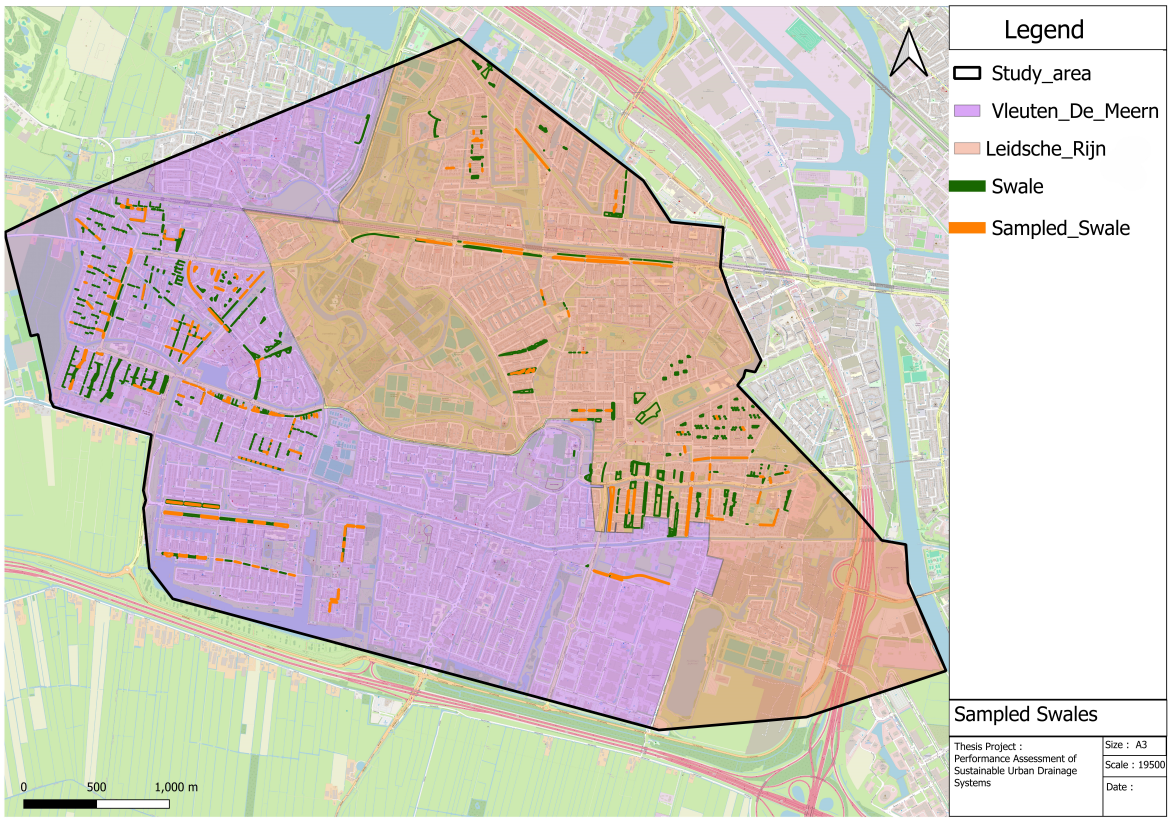


Figure 5.2: Sampled swales for inspection

This sampling method aims to provide a detailed overview of the different types and functions of swales in various locations across Utrecht. By inspecting sampled swales to assess their condition, the research will offer valuable insights into their performance and the reasons for their failures of swales in managing stormwater in urban environments. However, the municipality of Utrecht is responsible for swale management and employs a reactive approach, operating swales until they fail. While this approach might be cost-effective in the short term, it incurs significant expenses and poses risks of urban flooding and infrastructure damage. Furthermore, the municipality lacks a comprehensive, systematic asset management program for swales and relies primarily on notifications from citizens regarding swales that are no longer functional.

5.2. Digital elevation model

One of the primary characteristics to be analyzed is the Digital Elevation Model (DEM). The DEM is crucial for understanding elevation differences and analyzing flow direction and flow paths, which are essential for accurately estimating the catchment area.

The analysis of the DEM begins with the collection of satellite imagery data. The Actueel Hoogtebestand Nederland (AHN) provides satellite imagery with high-resolution of $0.25\,\mathrm{m}^2$ per pixel for the entire Netherlands. By selecting and merging the appropriate satellite images and clipping the excess areas beyond the study area, a precise DEM is created. The DEM reveals that the elevation in the study area varies from around -1.0 m below sea level to 58.9 meters. Notably, the map indicates that the majority of the study area elevation is approximately above 0 meters sea level. Figure 5.3 illustrates the DEM of the study area.

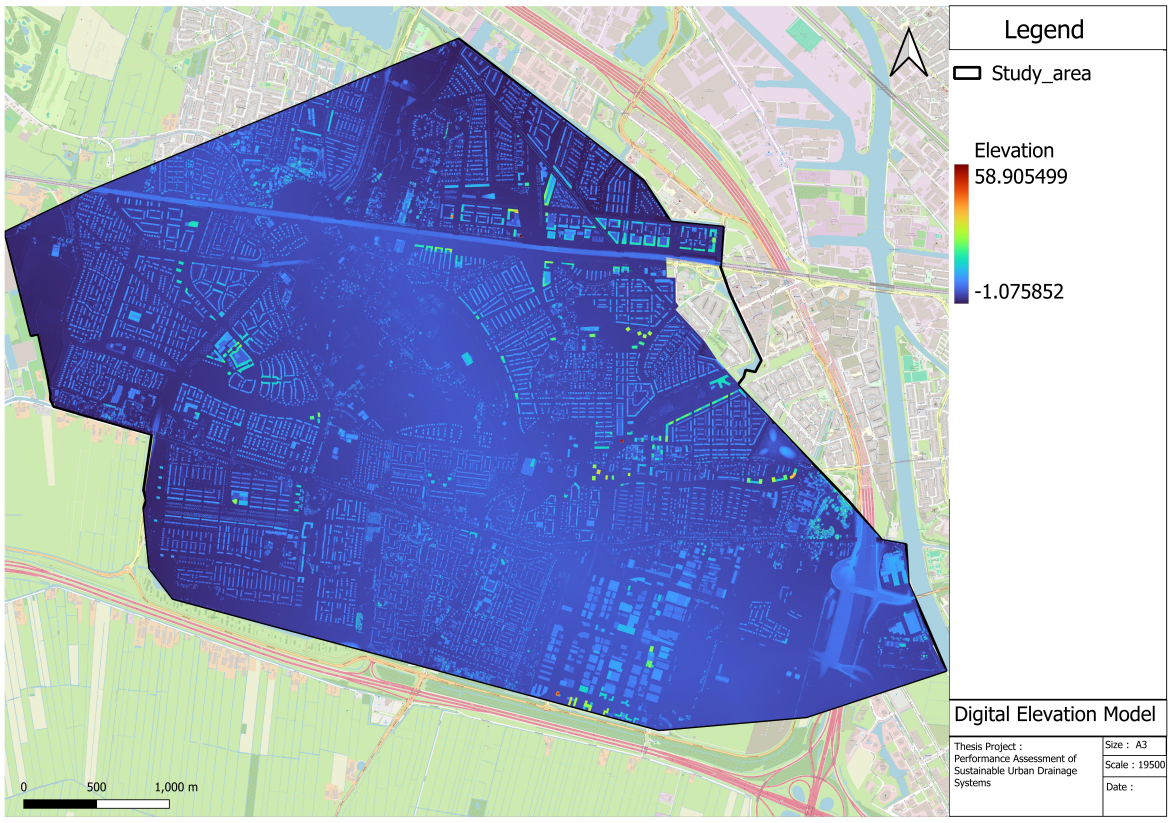


Figure 5.3: Digital Elevation Model

5.3. Catchment area

Drainage basins or catchments are defined as the geographical areas where all precipitation accumulates and then is eventually discharged at the downstream outlet. The boundaries of each catchment are outlined by natural obstacles such as ridges or elevated terrain, which divide and direct water flow (Oliveira et al., 2019). Similarly, in urban areas, the catchments are modified by the land use and the infrastructure. Hence, the runoff created by rainfall and the volume of water retained by a catchment area depend on different land uses (Farina et al., 2024).

After creating the DEM of the study area, it was found that using the DEM for the entire area would significantly increase time consumption in data analysis and also produce unrealistic results. Therefore, the study area was divided into sub-areas based on the locations of the sampled swales. The boundaries of these sub-areas were determined by residential blocks and waterbodies as shown in the figure 5.4.

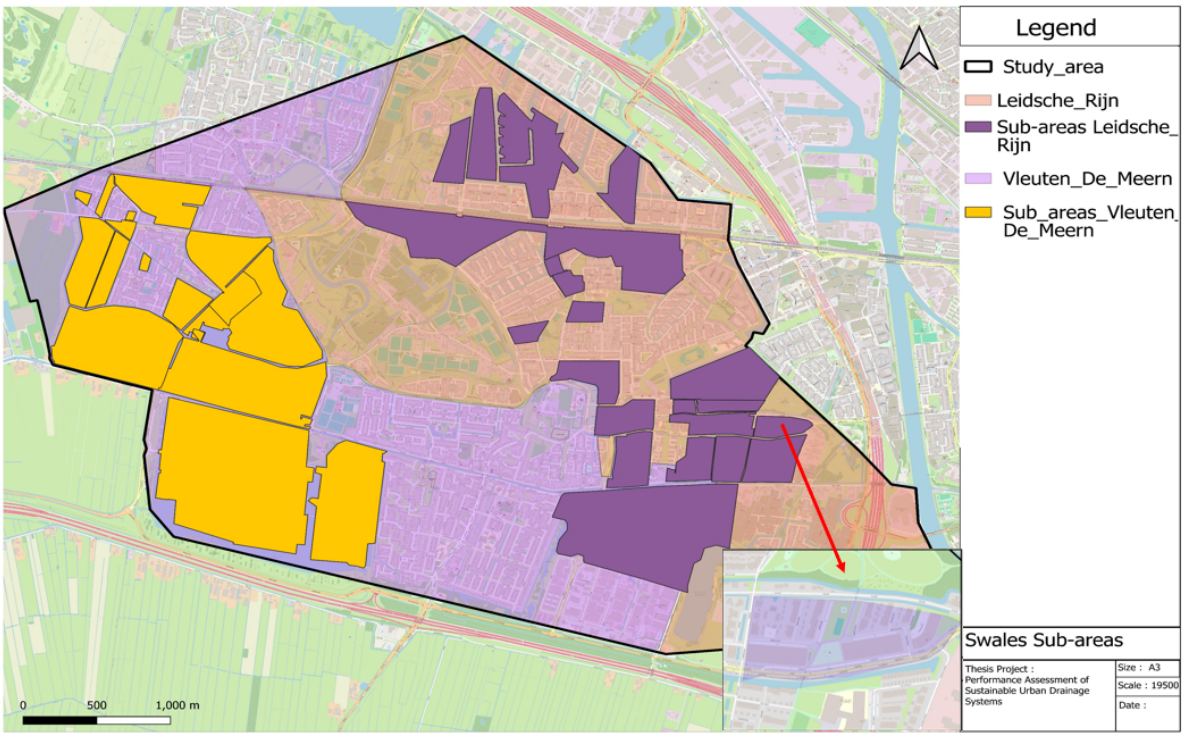


Figure 5.4: Sub-areas of the study area

For each sub-area, a DEM was generated using the satellite images provided by AHN with a high resolution. Figure 5.5 displays the DEM of the sub-areas.

The DEM layer of the sub-areas will be processed using the QGIS tool Fill Sink (Wang & Liu). The algorithm generates three main outputs; a Filled DEM, flow direction, and watershed. The filled DEM will be used for later catchment area analysis. The flow direction can be visualized by converting pixels into points, where each point is assigned a directional value based on the slope between adjacent pixels. Also, the flow direction has the same resolution as the DEM used in this analysis. Figure 5.6 shows the water flow direction in each sub-area.

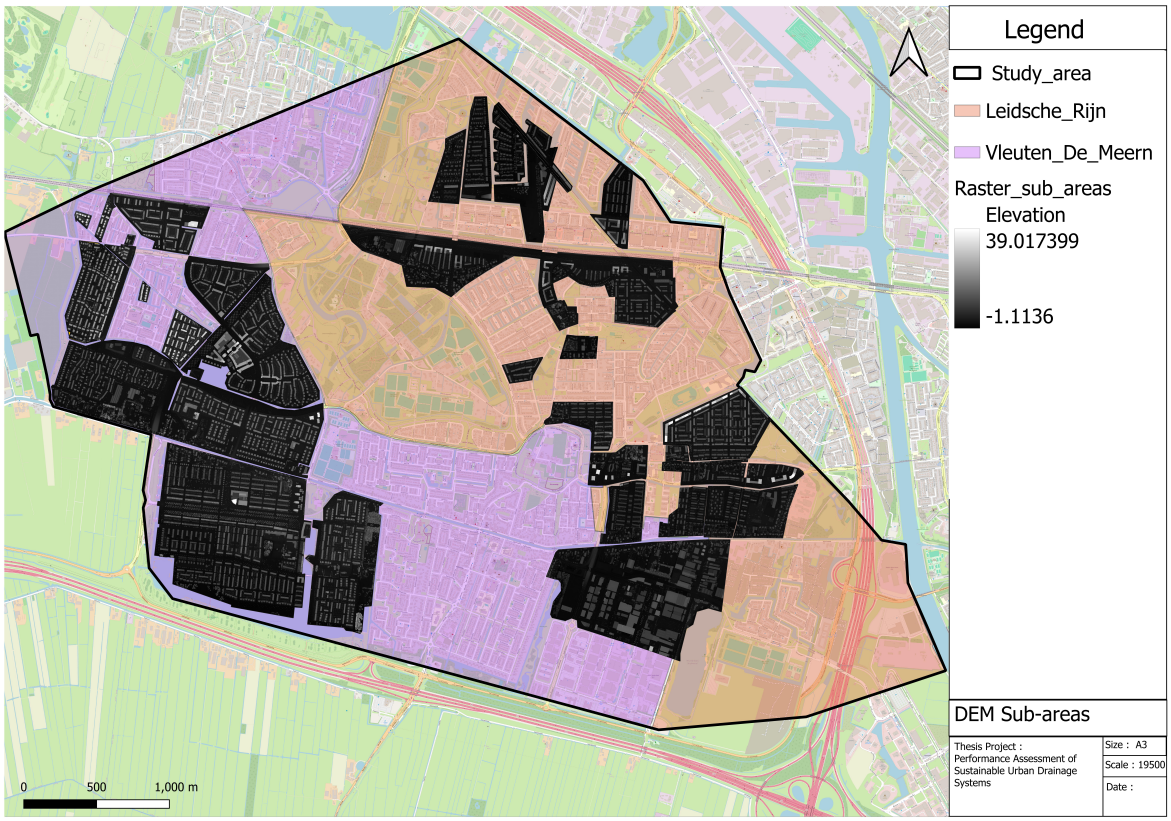


Figure 5.5: DEM of the sub-areas

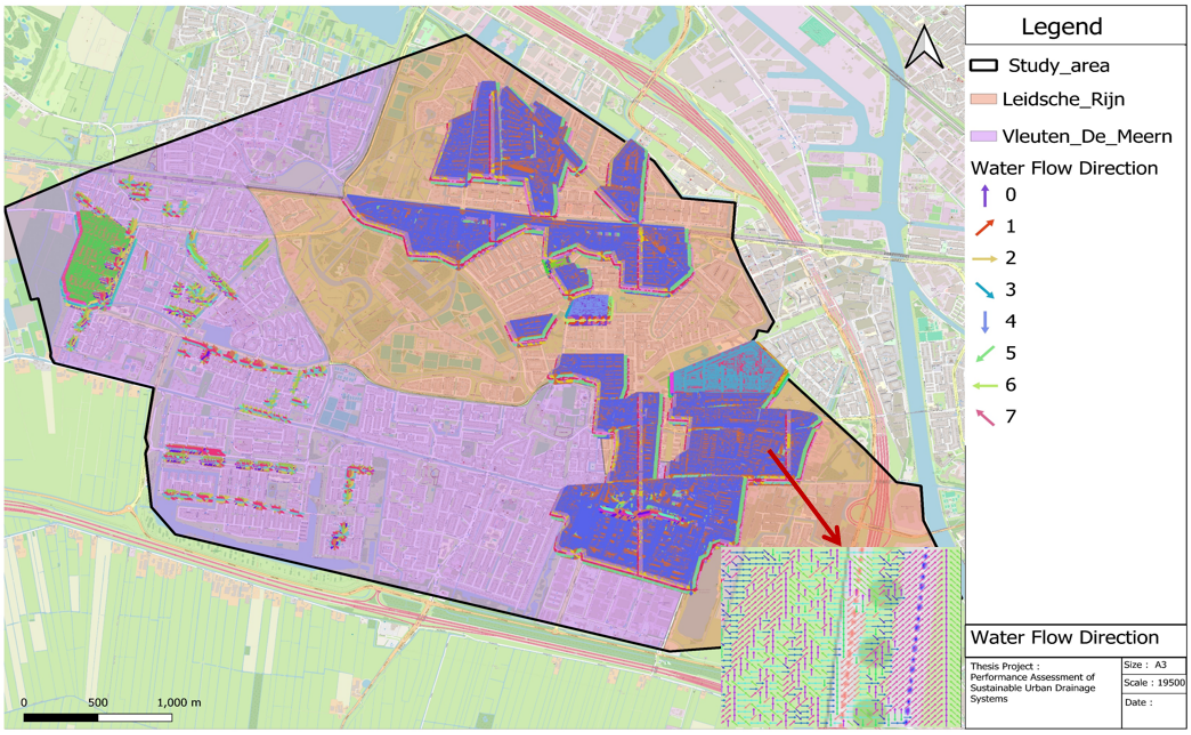


Figure 5.6: Flow direction in each pixel in the sub-areas

To identify the primary streams in the stream network, it is necessary to classify them. This process also shows the network's size and the strength of individual water channels. Thus, in this case, the Strahler order algorithm is applied. The Strahler order uses a hierarchy of tributaries to rank the data (Khatun & Sharma, 2018). The following rules are followed in the ordering process:

1. When the stream has no tributaries a Strahler order of 1 is assigned, primarily at the upstream sources.
2. If a network node has two tributaries and one of them has a higher Strahler order than the other, the node retains the higher Strahler order.
3. If a node has two tributaries with the same Strahler order i, the node takes Strahler order i + 1.

Figure 5.7 demonstrates an example of how the Strahler order is made (Pradhan et al., 2024).

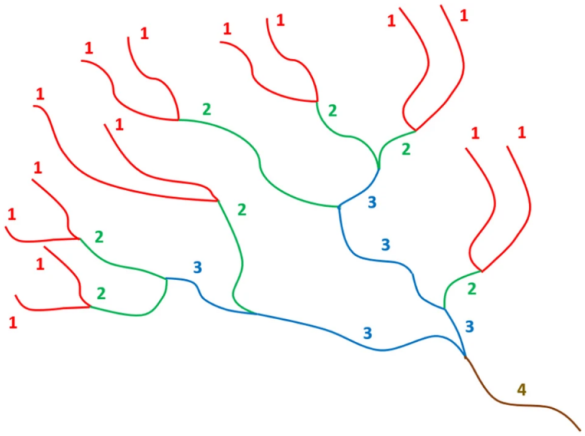


Figure 5.7: Strahler order for stream network tributaries (Pradhan et al., 2024)

For visualizing water flow paths, the entire network can be mapped using the QGIS tool 'Channel Network and Drainage Basins' which requires a DEM layer. To simplify the channel network, tributaries with orders less than 4 will be excluded. This approach helps avoid complexity and reduces the time required for catchment analysis. Figure 5.8 shows the channel network in the sub-areas.

The catchment area for each swale can be identified using the QGIS tool 'Upslope Area' which utilizes the DEM layer as an input. By specifying the coordinates of the outlet points where water flow paths intersect the swale downstream along with the water flow direction map which displays the upstream and downstream area, the tool calculates all contributing water flow paths and tributaries for the catchment area. The output from the Upslope Area tool is a raster layer, which needs to be converted to a polygon layer using the Polygonize tool. Consequently, the catchment area represents the swale drainage basin size and helps in understanding the swale's inflow load and the extent of the drainage area. Nevertheless, it should be noted that the size of the catchment area varies based on the surrounding urban and area characteristics, even for similar swale surfaces. Figure 5.9 highlights the catchment area in a sub-area within the channel network.

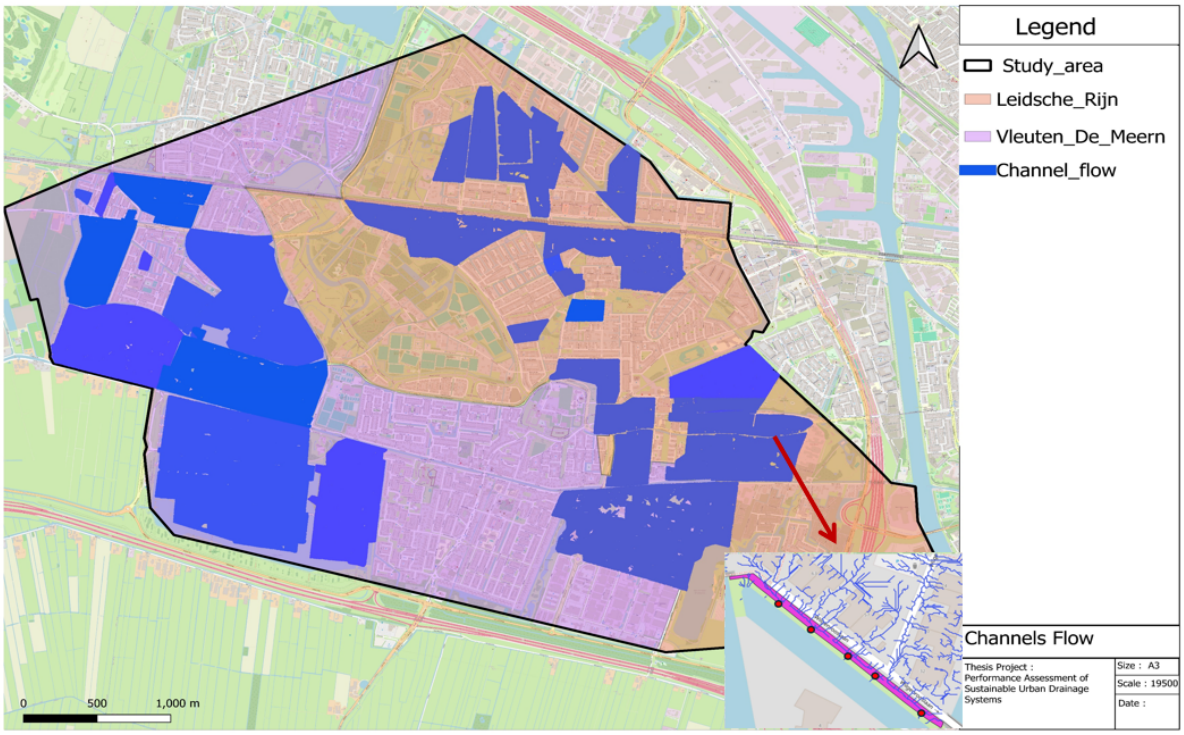


Figure 5.8: Water flow paths and channel network in the sub-areas



Figure 5.9: Catchments area in sub-areas within the channel network

5.4. Land use

Urbanisation and changes in land use influence the intensity of runoff, impacting various water flow paths and the estimation of the catchment area (Mayou et al., 2024). The study area identifies three key types of land use: urban areas, which include buildings, roads, pavements, and sealed surfaces; green areas, comprising parks, trees and planted spaces; and waterbodies which determine downstream discharge points and outlets. Unlike the urban and green areas, water bodies do not directly affect the intensity of the runoff or the size of catchment areas. The land use map was created by using the municipality of Utrecht data and it matches with the open street map. Figure 5.10 below demonstrates the three types of land use.

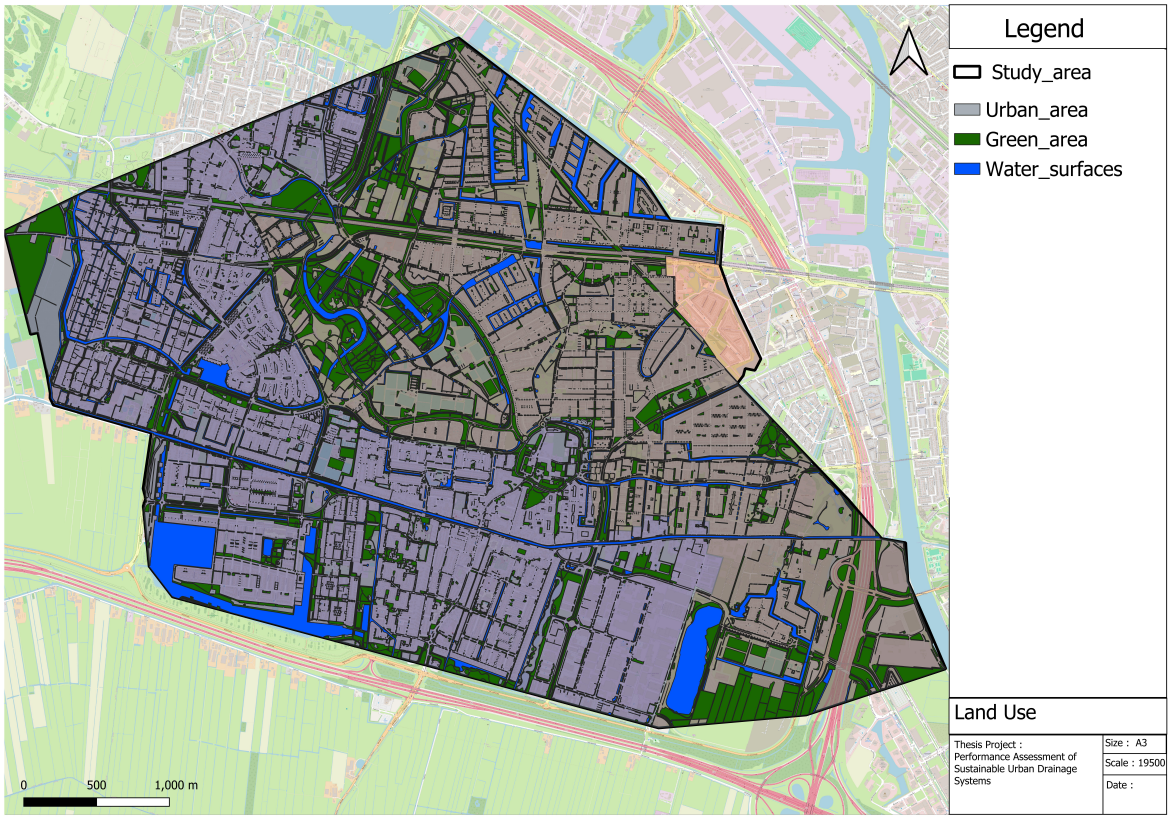


Figure 5.10: Land use within the study area

5.5. Trees distribution

In highly dense urban areas, higher flow peaks are caused by runoff occurring quickly due to the lack of permeable areas and reduced infiltration. For this reason, introducing green areas such as trees can have considerable benefits in mitigating severe rainfall events and reducing surface runoff (Zabret & Šraj, 2019). Regarding the water quality, the presence of trees can decrease the total nitrogen (TN) and the total phosphorus (TP) nutrient concentrations which improve the discharged water quality in the waterbodies (Hutchins et al., 2023). However, the degeneration of litter leaves on the soil surface can increase the organic matter (OM) content in the soil. This process depends on the plant functional type (Lu et al., 2021), and the presence of OM in the soil can influence the soil properties. Specifically, OM contributes to drought-resilient soils and enhances soil water retention (Lal, 2020). Nevertheless, plant litter like leaves, impacts infiltration due to alterations in the litter's water repellency. The increased water repellency of the litter decreased the soil's infiltration rate. In contrast, covering the soil surface with litter led to a lower runoff coefficient (Wang et al., 2020). For this research, the tree distribution map has been created based on an open street map (OSM) and data provided by the municipality of Utrecht. Further, the number of trees in each catchment will be determined, enabling a comparison between tree density and swale locations. The figure 5.11 below displays the distribution of trees in the study area.

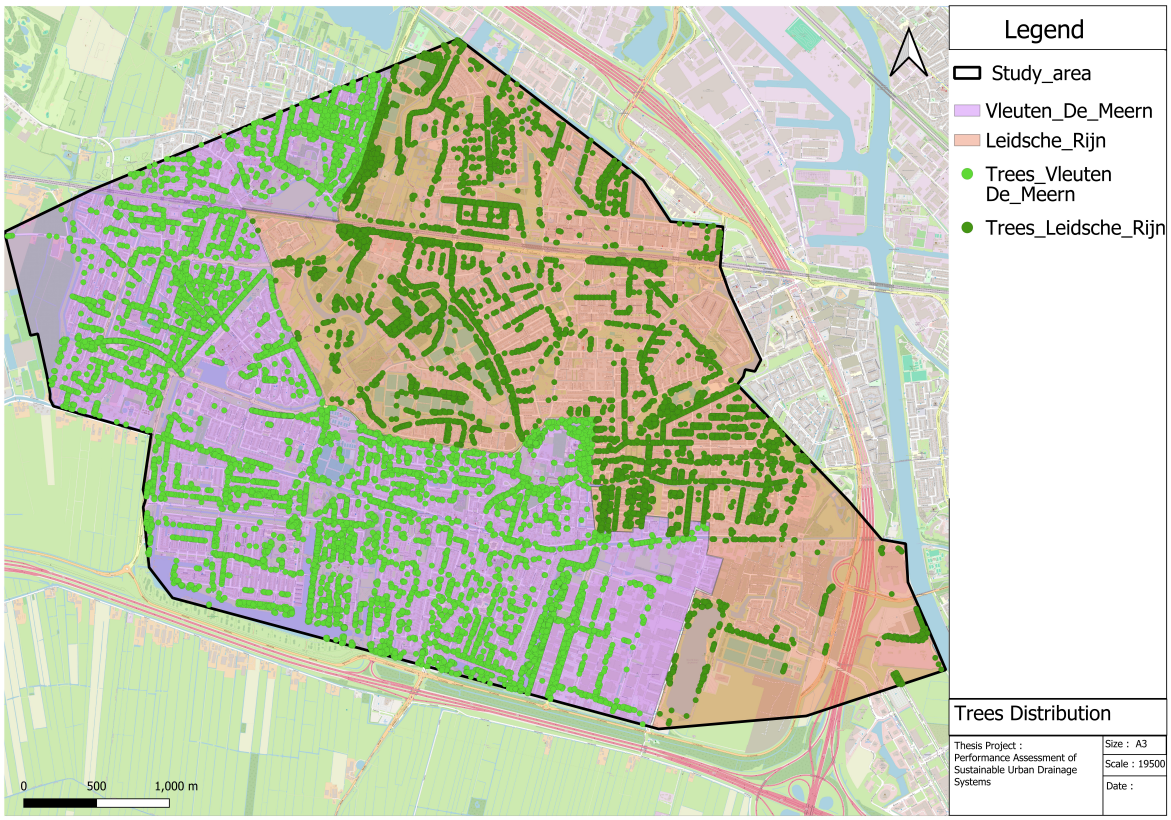


Figure 5.11: Trees distribution within the study area

5.6. Underground soil type

The primary goal of implementing SUDS in urban areas is to manage runoff and stormwater effectively. Although the top layer of soil in SUDS is often engineered to enhance infiltration, the underlying soil also plays a crucial role in this process. The stormwater should infiltrate through the underground soil to replenish groundwater, a process influenced by the soil's physical properties. Key properties include bulk density and porosity. Higher bulk density and lower porosity reduce the soil infiltration capacity, resulting in a lower infiltration rate (Cleophas et al., 2022). Eventually, increases in soil infiltration rates in urban permeable areas can considerably decrease the runoff coefficient and runoff peak, thereby reducing the risk of urban flooding and water accumulation. In contrast, urban impermeable areas negatively impact soil infiltration and increase surface runoff (Ren et al., 2020).

Changes in the type of underground soil can affect the long-term infiltration rate of swales. To assess this, an underground soil-type map for the study area was created using data from DINIloket. Figure 5.12 illustrates the distribution of various underground soil types within the area. The map reveals that the majority of the soil consists of light and heavy clay, with some regions containing sulfur. The average infiltration rate of clay soils found ranges from 0.004 mm/s to 0.076 mm/s, which may lead to water ponding (Adnan et al., 2017), while the infiltration rate of sulfur clay soil was low at 9.26×10^{-6} mm/s due to its properties (Hicks et al., 2010). Nonetheless, certain areas lack soil type data, which may be due to dense urban development or the soil type not being identified during data collection. This comprehensive mapping is essential for understanding how different soil types may influence the effectiveness of swale infiltration over time.

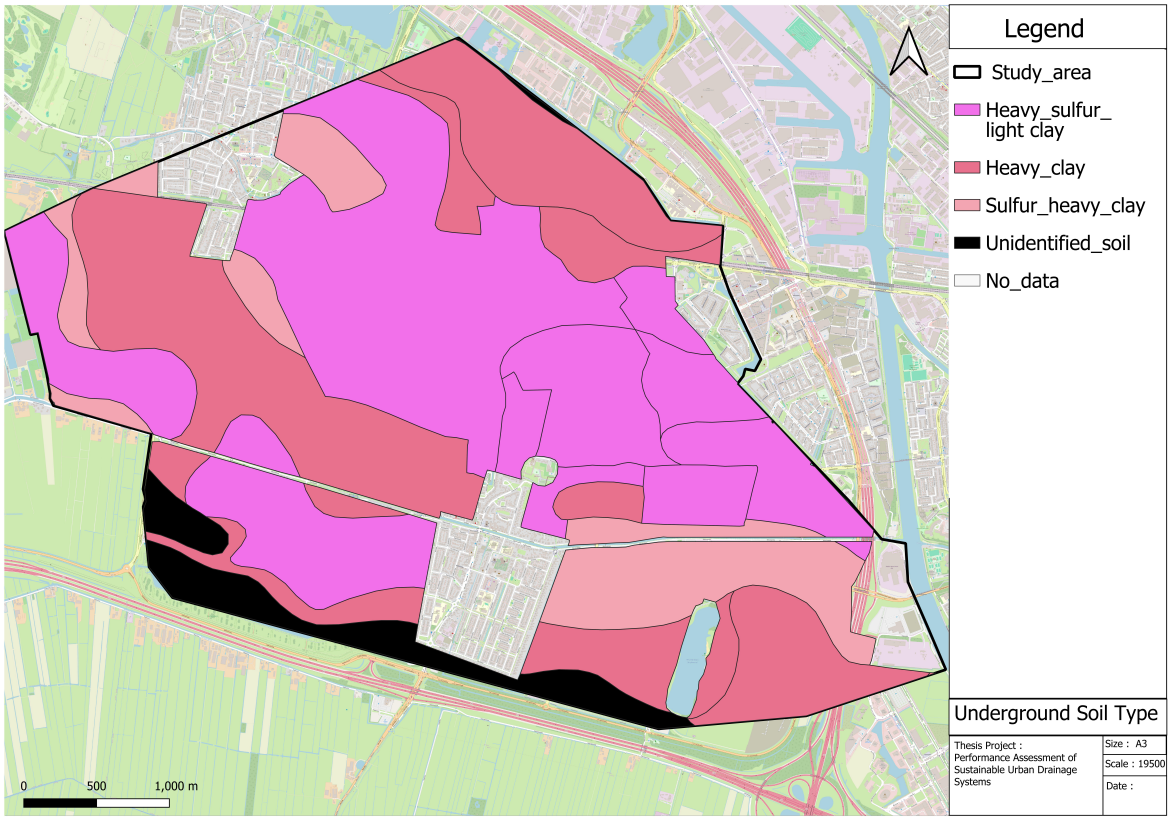


Figure 5.12: Underground soil type distribution in the study area

5.7. Soil subsidence

Soil subsidence is increasingly recognized as a global issue that governments must address in future development plans. In the Netherlands, various regions are affected by subsidence, primarily due to soil compaction, peat oxidation, and groundwater depletion (Bruna, 2020). However, the soil subsidence does not directly impact swale functionality but it may create physical obstacles that hinder runoff from flowing into the swales. To estimate this issue, a soil subsidence rate map was created using data from Bodemdalingskaart. The data shows that the majority of the study area has a low subsidence rate ranging from -7mm per year to -3 mm per year, while a few areas have a higher subsidence rate from -7 mm per year to -27 mm per year. The figure 5.13 below highlights the subsidence rate in the study area.

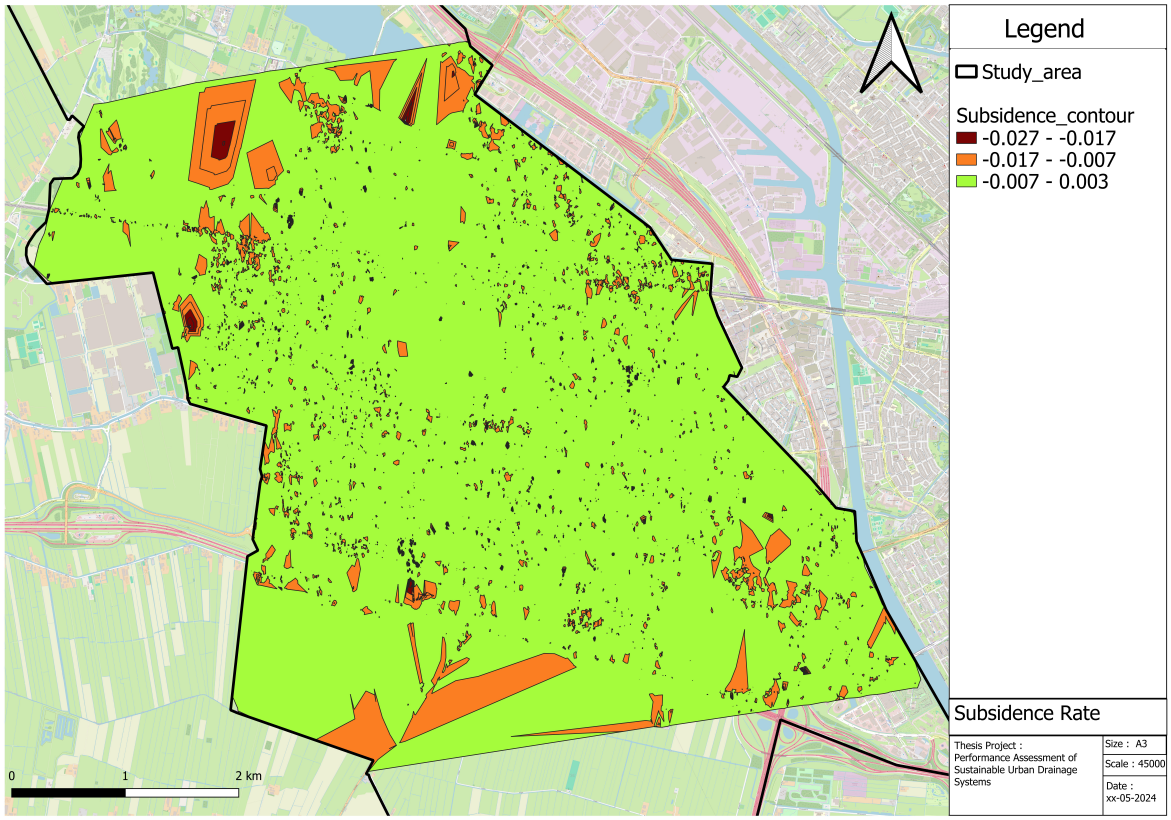


Figure 5.13: Subsidence soil rate in the study area

For this reason, to ensure an equitable distribution of samples, it is essential to inspect swales located in areas with high subsidence rates. This inspection will help assess the impact of subsidence on water flow alignment. Taking into account these specific regions will provide a better understanding of how subsidence may alter the intended pathways of water flow, potentially creating obstacles or redirecting water away from the swales. This comprehensive assessment is crucial for accurately evaluating the functionality of swales in affected areas and analysing the scale of damages that might occur due to subsidence.

6

Swales Data

This chapter delves into the swale documentation provided by the municipality of Utrecht, encompassing recorded data, construction details, failures, and maintenance activities. By integrating this data with area characteristics and conducting a thorough inspection, more comprehensive insights can be gained into the implications of the current asset management approach. This analysis is crucial for assessing the effectiveness of swale asset management and its current condition.

6.1. Swales documentation

In the Netherlands, the municipalities are responsible for managing sewerage systems, swales and other SUDS practices. These responsibilities encompass various tasks including planning, operation, and asset management. Regarding swale documentation, the municipality of Utrecht provides good documentation of swales, as well as the following components such as outlets, overflows, and drain pipes. The database covers swale construction year, surface, perimeter, ID code, administrator, neighbour, and street. In addition, data for inlet, outlet, overflows and additional components cover diameter, ID code, pipe type, and location information. This detailed documentation is critical for the effective management and maintenance of these infrastructure elements. The information is shown in the appendix A.1.

For the provided data, the type of sampled swales showed that a total of 210 swales, 50 are categorized as dry swales without overflows and 160 are classified as dry swales with overflows. The analysis of swale construction years revealed that the age of swales ranges from just 1 year to 25 years, with the average age calculated to be approximately 17 years. The figure 6.1 below illustrates the distribution of the swales by age, providing a clear visual representation of the data. In addition, swales' effectiveness and durability can be affected over time. These infiltration systems often experience a decline in their infiltration capability (F. C. Boogaard, 2022). For instance, the ability of infiltration trenches to manage stormwater diminishes over time, often leading to increased instances of overflow. It is estimated that, after 100 years of operation, they can handle only about 60% of the total runoff volume, which is significantly lower than their intended capacity (Bergman et al., 2011).

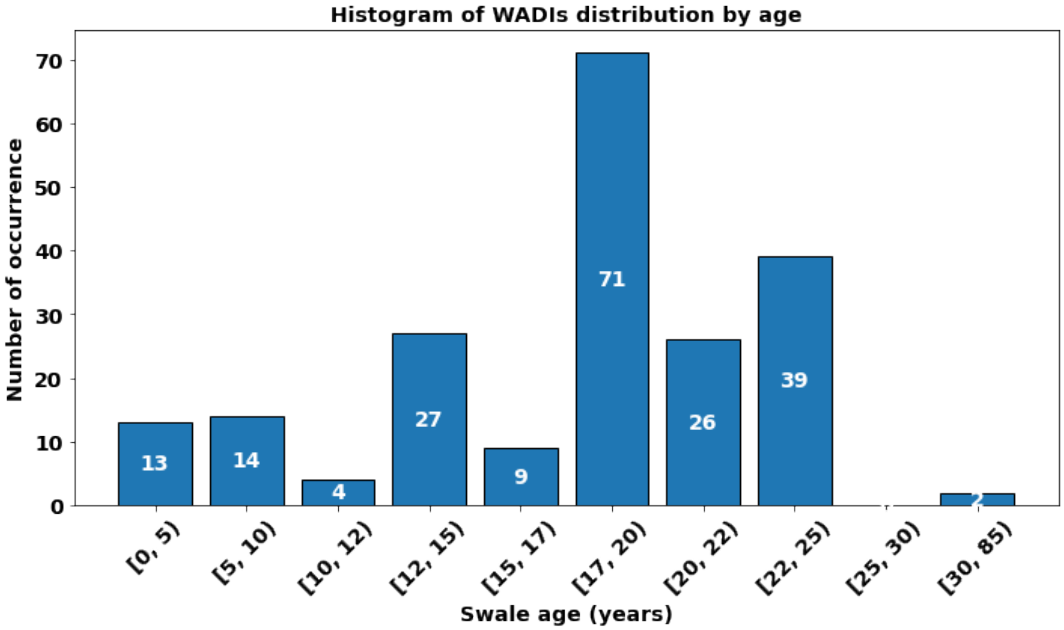


Figure 6.1: The Histogram distribution of swales by age

6.2. Construction details

When it comes to swale construction, there are specific design recommendations and requirements that should be followed. These guidelines emphasize the importance of hydraulic performance and the overall objectives of swales. The cross-section of the swale can be either parabolic or trapezoidal, with a width of 0.5 meters to a maximum of 2 meters and a depth between 40 and 60 centimetres, while the side slopes should be as flat as possible to promote stability and function (Woods Ballard et al., 2015). For effective infiltration, the lowest part of the swale should be above the level of groundwater at least 1 meter to ensure proper water infiltration. To prevent the occurrence of sediment lip, there should be an edge of 50 centimetres between a hard surface and a vegetated area. Regarding the infiltration rate, a k-value below 1 m/day indicates low permeability, which restricts water movement through the soil and limits its capacity to store groundwater effectively (Stibinger, 2016). A typical drainpipe consists of a perforated PVC pipe with a minimum diameter of 125 mm, covered by at least 150 mm of clean gravel (Woods Ballard et al., 2015). During the initial phase of operation, the vegetation layer should be fully established before the swale begins receiving any runoff. This vegetation should be planted at a time of year that allows for successful growth without the need for irrigation, and measures should be taken to prevent rapid siltation due to the sediment loads from the construction site (Woods Ballard et al., 2015).

On the other hand, despite these guidelines, research and practical experience continue to explore the best approaches to maximize the effectiveness of swales. Consequently, there remain numerous unresolved issues regarding optimal swale design and type for achieving comprehensive stormwater management and treatment objectives (Ekka et al., 2021).

Unlike data on swales, there is a lack of attention to the documentation of construction details, with only 25 swales out of 210 having complete construction information as swales were constructed by different companies and contractors. Hence, the absence of this data could impact data analysis and asset management strategies. Nonetheless, the drain pipes are well-documented including details such as their connection to the sewer or stormwater network, diameter, inlet, outlet and type. The swale construction details should include a cross-section that clarifies the type of section, enhanced soil type and thickness, filter basin system, and other components. Figure 6.2 shows one of the few registered swale construction details.

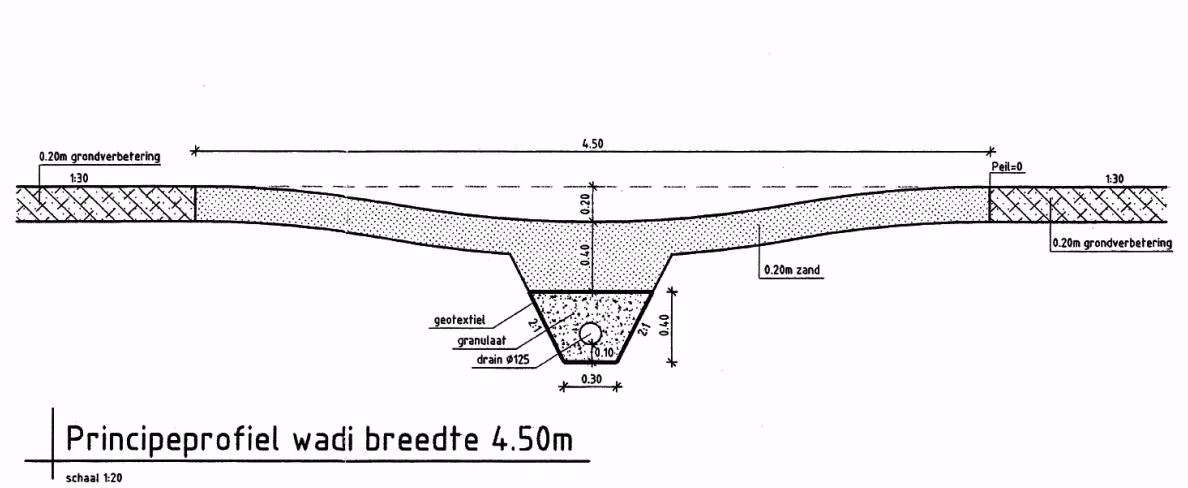


Figure 6.2: Construction details one of the built swales in the study area

To overcome this hurdle, a general assumption must be made that the swales in the study area were all built according to the municipality of Utrecht's manual. This assumption encompasses the main components of the swale, the slope of the swale sides is 1:3 in most cases, and the width of the swales varies depending on location and surrounding area. Sand soil is used to enhance the infiltration process, with a thickness of no less than 30 centimetres. Similarly, for filter basins, the trapezoidal shape is always adopted, incorporating geotextiles and granules. This manual distinguishes between two main types of swales: one shows the cross-section of a pre-planted swale and the other illustrates the cross-section of a grassed swale with a double row of trees. The figure 6.3 below provides the construction details of the swale as outlined in the municipality Utrecht manual.

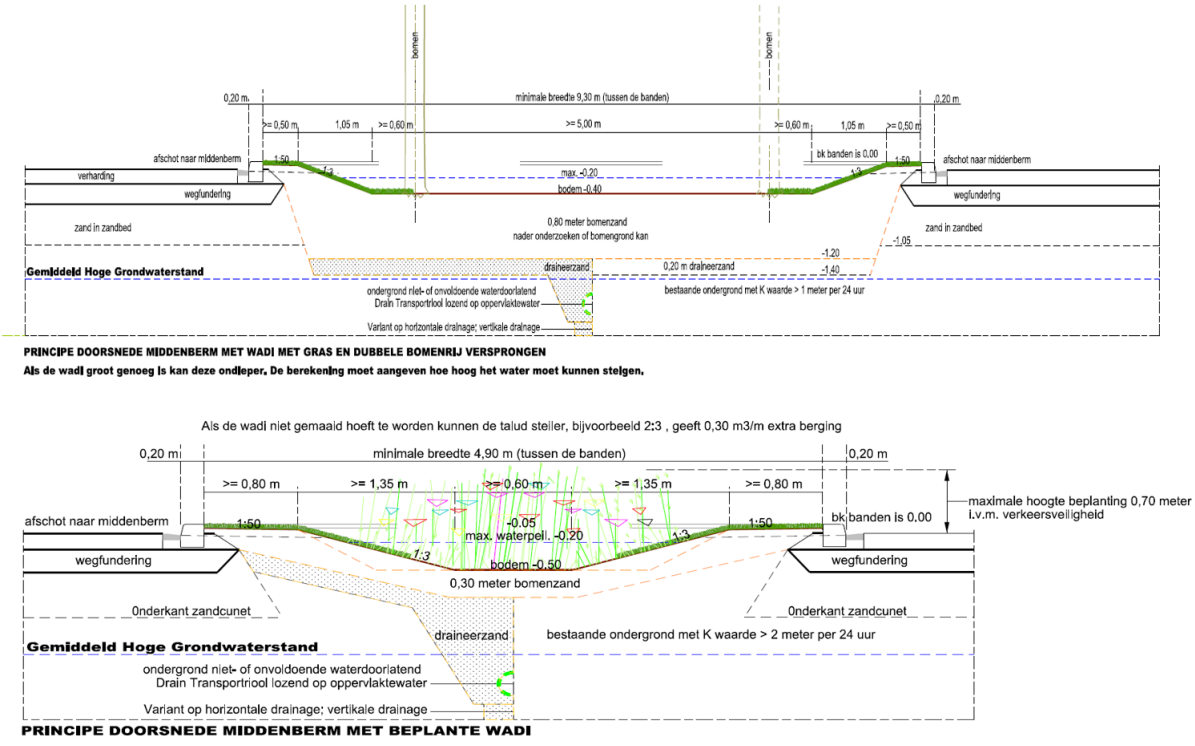


Figure 6.3: The construction details of the swale as outlined in the Utrecht manual

6.3. Maintenance data

In general, any SUDS' performance will gradually deteriorate over time without proper maintenance, eventually failing to meet operational requirements and reaching a failure state. Therefore, planning SUDS should include a maintenance plan and allocate a fund for it (Erickson et al., 2013). Maintenance activity is intended to sustain SUDS and preserve their lifespan, ensuring an appropriate level of performance. The type of maintenance and frequency needed for SUDS is determined by a variety of circumstances (McDonald, 2018). These circumstances can be influenced by several factors, including the type of SUDS implemented, the size of the catchment areas, and the percentage of permeable and impermeable within those areas. In addition, the land use associated with the contributing catchment plays a crucial role, as do specific planting schemes and the visual requirements area (Woods Ballard et al., 2015). The figure 6.4 below distinguishes between different types of maintenance activity (Erickson et al., 2013):



Figure 6.4: The SUDS practice operation and maintenance (Erickson et al., 2013)

- Regular maintenance (Routine): is implemented frequently based on schedules considering simple activities like vegetation management, mowing grass, and debris and litter removal.
- Occasional maintenance (Non-routine): includes periodically necessary activities after a significant rain event such as sediment removal and filter replacement.
- Remedial maintenance (major): involves unpredictable actions that aim to address the system's flaws or significant maintenance requirements.

Maintainability requires coordinating all efforts to minimise the number of regular maintenance activities while ensuring that repairs can be conducted easily and feasibly. Additionally, every maintenance activity should aim to reduce the need for unusual or emergency maintenance and help sustain finite resources (Sauer & Auken, 2022).

Nevertheless, optimal maintenance and timing may not always restore the SUDS performance level at the start of operation. Therefore, there will be a need to do major maintenance activities such as changing the filter basin and replacing the soil layer. Maintenance activities like rehabilitation, replacement, renovation, and reconstruction will become necessary at some point, regardless of whether routine or non-routine maintenance has been carried out. A well-planned maintenance program should prevent such major maintenance as much as possible (Erickson et al., 2013).

Regarding the maintenance cost associated with swales' life costs, swales have the lowest construction and maintenance costs compared to other SCMs. Furthermore, during the first year of operation gravel wetlands and bioretention incur higher capital costs and annual maintenance expenses than grass swales, while gravel wetlands are greater by 1.5 to 2.5 times. The bioretention is up to 4 times more expensive (Ekka et al., 2021). Above all, a benefit-cost analysis of SUDS reveals that they are cost-effective options compared to conventional sewerage systems. This cost-effectiveness stems from their ability to manage stormwater in an environmentally friendly manner. While some SUDS may have life-cycle costs that exceed their benefits, their selection is often based on site-specific conditions and available budget (Nordman et al., 2018). Despite the possible higher initial investment or maintenance expenses associated with certain types of SUDS, their long-term environmental benefits frequently justify the costs.

Adapting the reactive asset management approach by the Utrecht municipality has resulted in maintenance activities that are largely unplanned. Maintenance involves a combination of technical procedures and administrative efforts designed to keep a system or an asset in optimal performance condition or restore it to such a state. These actions ensure the system can reliably perform its intended functions (Sánchez-Silva et al., 2016). The last maintenance activity conducted by the municipality of Utrecht was approximately 2 years ago. These maintenance efforts encompassed three main types of maintenance: routine, non-routine, and urgent. Routine maintenance includes tasks such as cleaning sediments from overflows and litter and debris removal. Non-routine maintenance involved more substantial tasks like rearranging elevation and repairing overflows. While overflow replacement was carried out as part of urgent maintenance works. Figure 6.5 illustrates the various types of maintenance activities in the study area for the sampled swales.

During maintenance work to clean sediments from the overflows, the volume of removed sediments was measured. This additional data can be analyzed to explore potential correlations between sediment accumulation and the size of the catchment areas, as well as the percentage of impermeable surfaces that contribute to sediment load. Furthermore, potential failures such as clogging, could be related to this data. Figure 6.6 shows the volume of cleaned sediments in all swales within the study area.

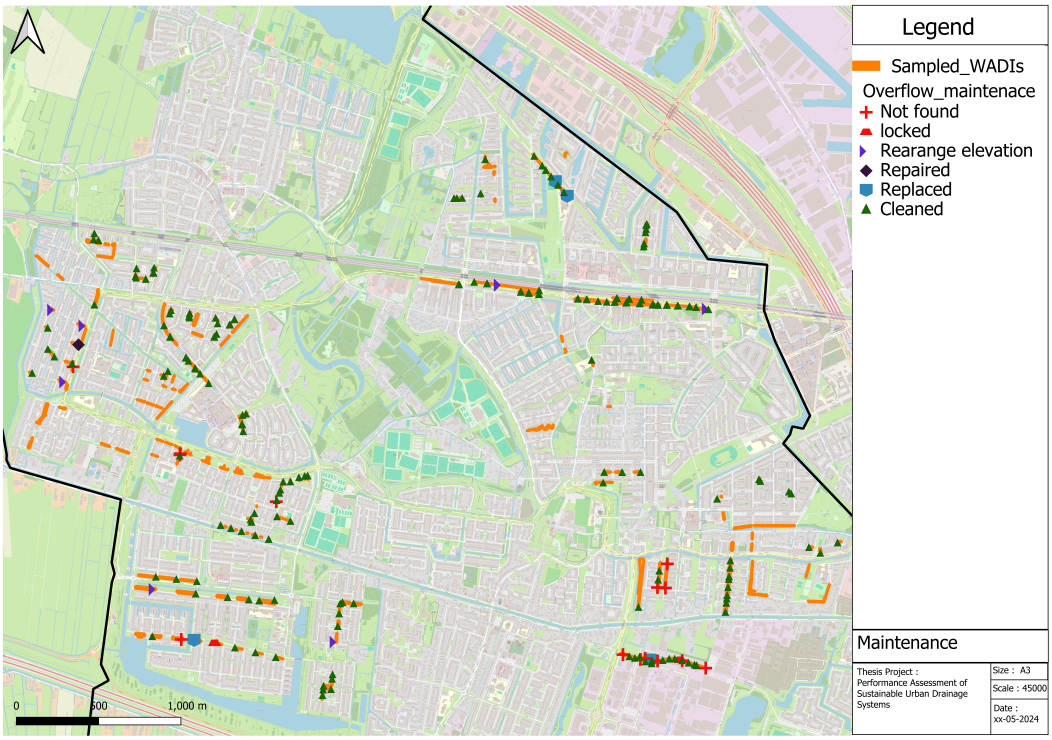


Figure 6.5: The type of maintenance work carried out by the municipality of Utrecht in the study area for the sampled swales.

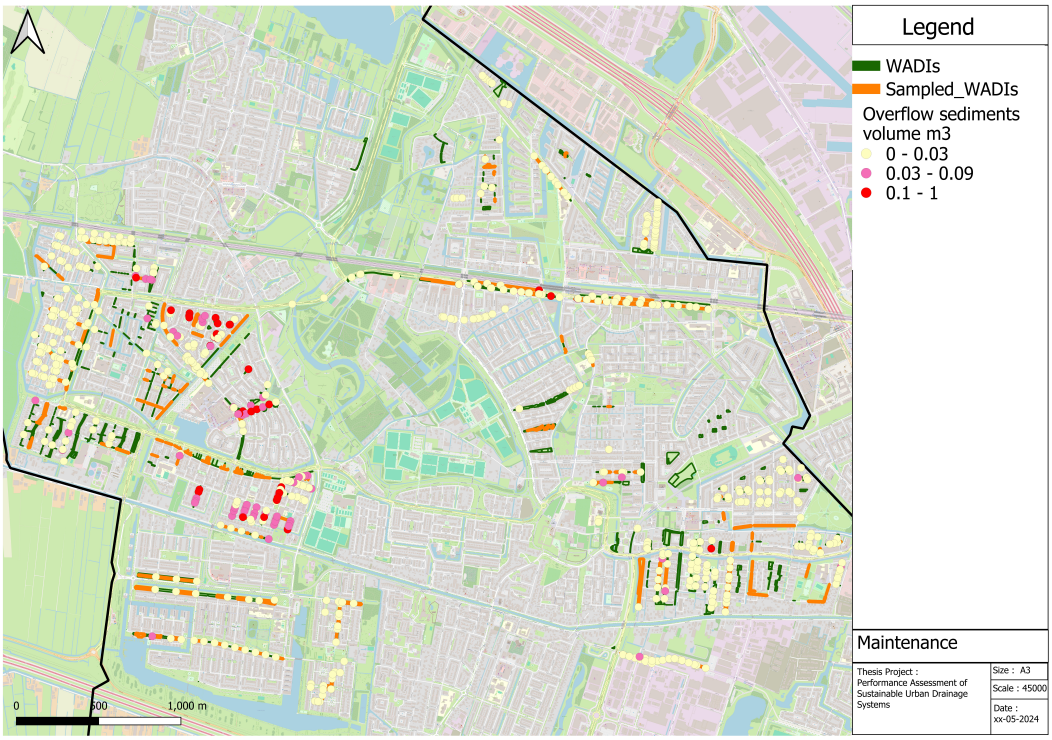


Figure 6.6: The volume of cleaned sediments in all swales within the study area.

6.4. Failure data

Many different vital services are provided by the infrastructure that society relies on. Over time, both this infrastructure and each of its components start to deteriorate. This degradation can impact the reliability and efficiency of the provided services (Rehak & Hromada, 2018). Hence, failure occurs when a system or component is unable to perform a necessary function or service according to its intended design and standard requirements (Mohammed et al., 2018). If a typical SUDS asset management strategy has been employed, it has primarily depended on reactive maintenance, which deals with service issues and failures after they arise (Bahrami et al., 2024).

The main differences between adopting reactive and proactive approaches can be clarified using the P-F curve. This curve consists of two distinct points: point P (potential failure) and point F (functional failure), the asset condition assessment can identify damage at point P, indicating the possibility of losing functionality. From this point, the likelihood of failure increases dramatically until it reaches point F, which signifies a 100% loss of functionality. It is important to note that the term 'failure point' refers to the complete loss of an asset's functionality, which does not always refer to total physical damage. Consequently, the specification of functionality and related services significantly influences the position of point F on the curve. Whereas, the level of detected damage and their reasons can be seen at point P (Zofka, 2020). Figure 6.7 below demonstrates the basic concept of the P-F curve.

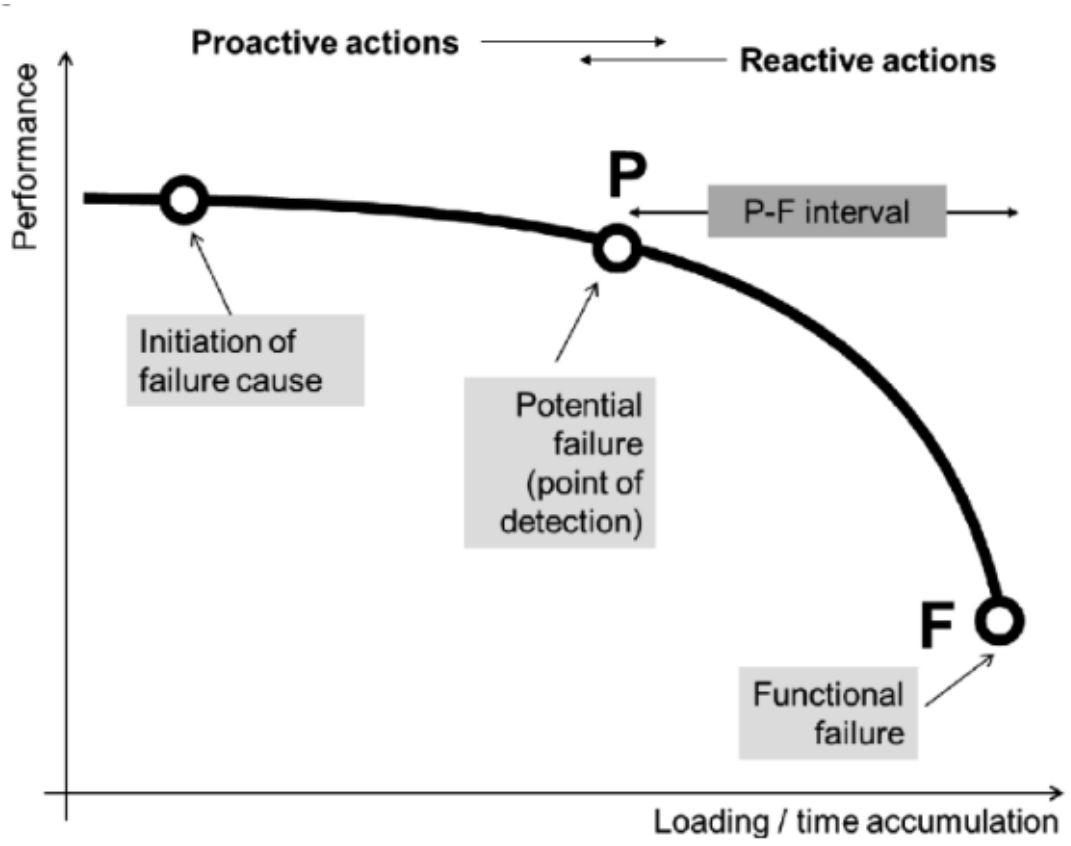


Figure 6.7: The P-F curve (Zofka, 2020)

It is preferable to adopt strategies and approaches to shift Point P to the left and extend the P-F interval as much as feasible because Point P represents a transition between proactive and reactive actions. By doing so, there are more opportunities for preventative measures, resulting in more reliable and predictable asset performance (Zofka, 2020). This strategic shift allows for earlier detection and intervention, ultimately enhancing the overall efficiency and longevity of the assets. Undoubtedly, the Utrecht municipality has adopted a reactive approach, which has resulted in a significant number of failures in swales and other components related to the SUDS system. From 2017 to 2023, a total of 128 failures have been recorded. Additionally, swale failures are rarely reported by citizens, who may not recognize when design criteria are exceeded. Furthermore, maintenance crews may misclassify failures, perceiving them as issues related to traditional grey infrastructure.

Utrecht's lack of a formal failure notification system relies heavily on information from residents or maintenance staff, as regular assessments are not conducted. Despite the varying severity of these failures, maintenance remains essential to restore the functionality of the swales. The figure 6.8 below shows the distribution and types of failures in the study area.

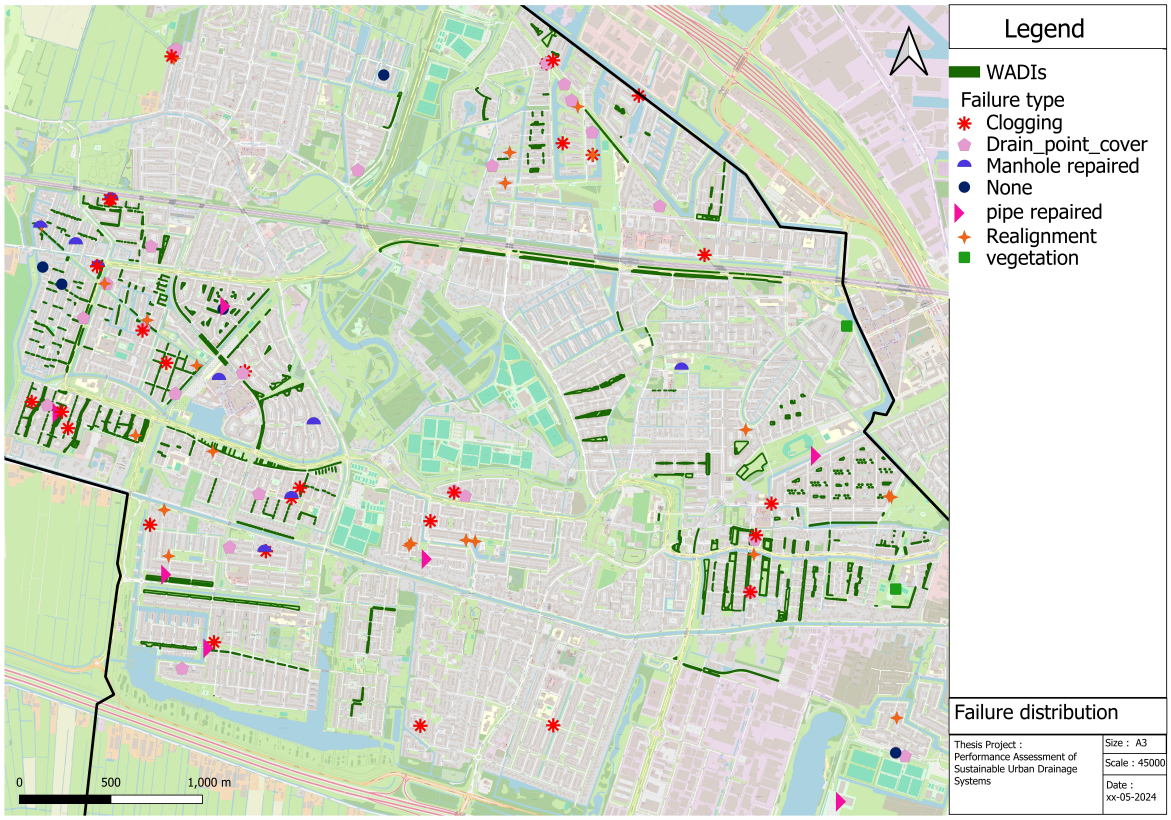


Figure 6.8: The distribution of failure points in the study area.

In more detail, the registered failure data for the past seven years shows a total of 128 failures. Among these, clogging failure was the most common, with 38 failures. This was followed by drain point cover failures, which occurred 31 times, and realignment failures, with 26 occurrences. Drain point maintenance and pipe repairs each contributed to 12 failures. Vegetation failures were the least common, with only 2 reported cases. Finally, there were 7 cases categorized as unknown. Figure 6.9 illustrates the types and the number of failures occurring as documented by the municipality.

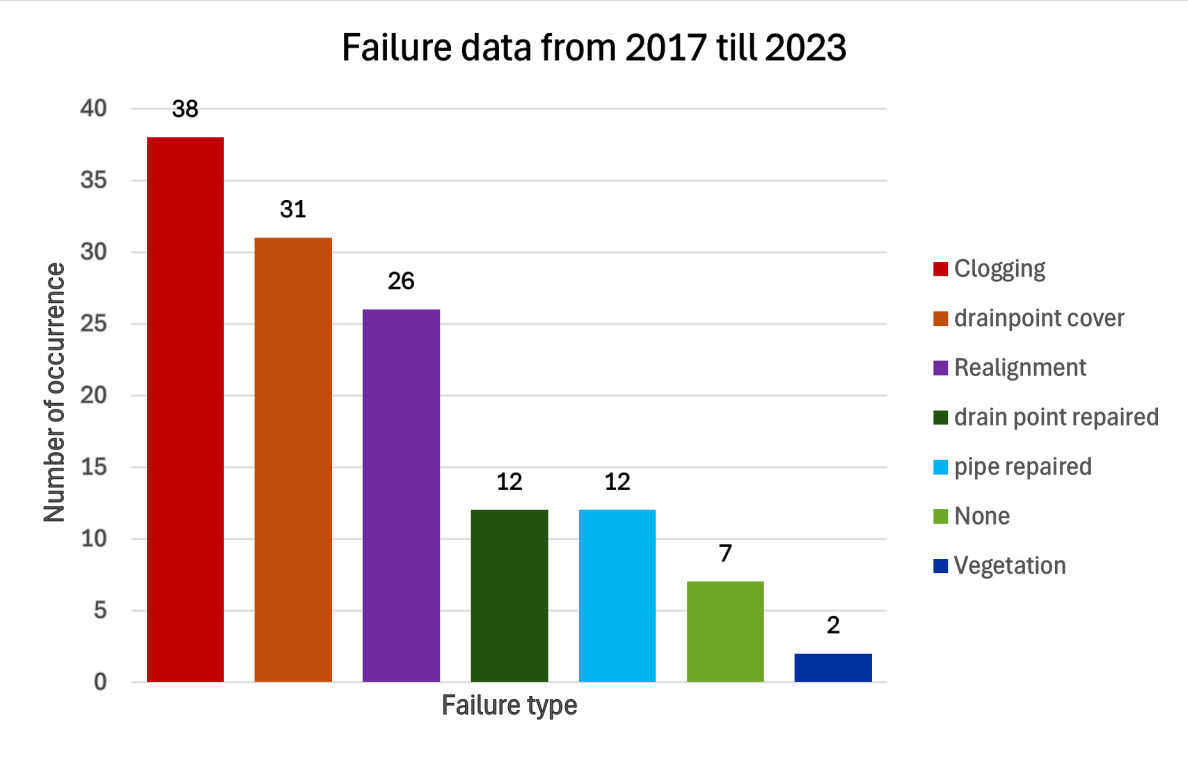


Figure 6.9: The types of failures and their number of occurrences recorded in the municipality data.

7

Visual Inspection Implementation

This chapter will thoroughly discuss the assessment of sampled swales and the implementation of swale visual inspections, including the primary concerns related to the process. The results of the inspections will be examined, and finally, the frequency and condition of the inspections will be evaluated for future assessments.

7.1. Inspection applicability

Although all the swale locations were accessible on-site, some swales were not inspected for several reasons. Firstly, two abandoned swales were found on Utrecht Terwijde Street with such dense vegetation that inspecting any of the swale components was impossible. A similar situation was found on street Van Dongendingel Street, where two swales, despite being constructed properly in the Google Map images, were found to be overgrown with vegetation and trees in the middle of the filter basin, preventing the completion of the inspection. Lastly, on AB Harrewijnstraat Street, a swale was repurposed by a resident into a small yard with various plants, and it is not usable as an infiltration facility. These cases highlight a lack of swale monitoring rather than maintenance. As a result, five swales were excluded from the data analysis, leaving only 205 swales available for evaluation. Figures 7.1 below show the condition of swales that could not be inspected.



(a) Swale with dense vegetation on Utrecht Terwijde street



(b) Miss using swale



(c) Swale with massive vegetation and trees in the middle of the filter basin on Kess Van Dongendingel Street

Figure 7.1: Swales can not be inspected

7.2. Inlet & outlet inspections

The inflow into a swale can be either channel flow, typically from roof drain pipes, or lateral flow from the sides of the swale. As roof drain pipes are considered private properties, they are excluded from the inspection. However, issues related to these drain pipes such as channelization and clogging will be addressed during the inspection. Meanwhile, issues with lateral flow, particularly, those concerning water flow alignment will be evaluated separately and in detail.

On the other hand, swale outlets come in various structures but they are mostly constructed to discharge into aligned water bodies. However, accessing and inspecting these outlets is challenging due to dense long vegetation and the need for special equipment to reach these locations. Therefore, different methods of assessment and inspection are required for outlets. Nevertheless, if there is a clogging issue at the outlet, it can be detected by observing a high water level at the overflow. The figure below 7.2 shows the location of the swale's outlet where it discharges but is not found. For these reasons, the swales' outlet and inlet are excluded from the inspection as they cannot be inspected properly.



(a) Hidden outlet in dense long vegetation



(b) Outlet discharges at the water body not being inspected

Figure 7.2: Outlets are not inspected

7.3. Water flow alignment

The water flow alignment inspection concerns the actual water flow paths around the swale and identifies any obstacles that could block stormwater from flowing into the swale. The inspection result of 205 swales in the study area indicated that 14% of the swales have an obstacle blocking the water flow. These blockages could be partial, meaning a swale cannot receive water from one side, or complete, which means the runoff cannot access the swale at all. Table 7.1 shows the number and types of blockages for both types of dry swales.

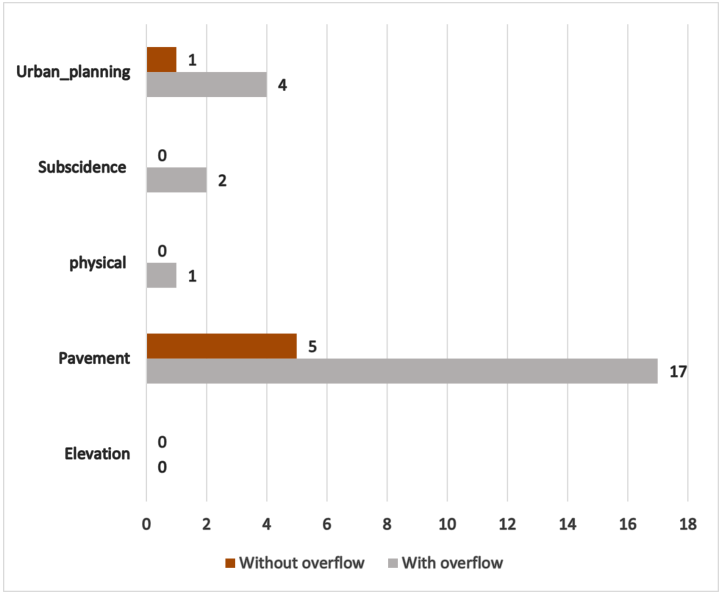
Table 7.1: The number of blockages issues in swales

Dry swale type	blocking	number of occurrence
With overflow	completely	1
	partially	23
Without overflow	completely	0
	partially	5

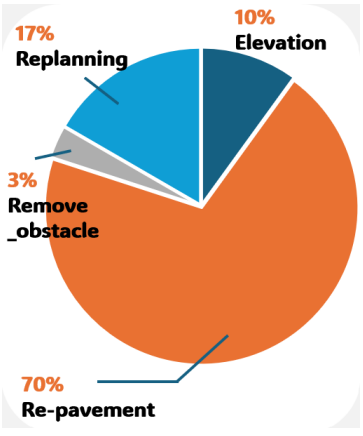
These blockages can be caused by a variety of objects and even the integration of a swale with the surrounding infrastructure obstruct water from flowing into the swale. To account for all the potential causes of blockages, five categories have been identified:

- **Urban planning:** Includes, for instance, the presence of trash containers or stormwater gully pots.
- **Subsidence:** A phenomenon that can cause the lowering of the swale side and change the flow direction.
- **Pavement:** An infrastructure that is often misaligned with the swale.
- **Elevation:** The constructed swale's elevation should be properly aligned with its surroundings.
- **Physical objects:** Any objects inside or outside the swale that block water flow.

The inspections revealed that pavement misalignment is the most common issue in the study area, followed by problems arising from urban planning. Subsidence and physical objects were less frequent, with 2 and 1 occurrences, respectively. Figures 7.4 and 7.5 show some examples of misalignment with the swale's surrounding environment. To overcome these issues, several maintenance activities are necessary, including re-pavement, elevation correction, urban re-planning, and removing obstacles. Figure 7.3 below illustrates the alignment issues, and their number of occurrences and the corresponding maintenance needed.



(a) Alignment issues and the number of occurrences



(b) Alignment issues maintenance

Figure 7.3: Swale misalignment issues and needed maintenance



(a) Trash container in the middle of a swale



(b) Subsidence cause lowering the road elevation



(c) Gully pot placed in front of the runoff flow



(d) Pavement blocks the runoff from the cycling path flows to a swale

Figure 7.4: Examples of misalignment



Figure 7.5: Misalignment cause a complete block of water runoff flow

7.4. Vegetation inspection

The inspection of the vegetation layer can provide indicators of the swale's condition and soil health. Changes in plant colour, soil compaction, and plant density are all indicators of potential issues, either related to the quality of runoff water or soil nutrient levels (Erickson et al., 2013). Problems like bare spots and overgrown vegetation can also arise due to inadequate vegetation monitoring. For this research, inspections of the vegetation layer resulted in the detection of several issues including long grass, invasive and weeds plants, erosion, bare spots, and the presence of plants in the filter basin. The figure below 7.6 highlights some of the vegetation issues that have been detected. Table 7.2 below illustrates the vegetation problems and number of occurrences in both types of swales and the possible reasons for these issues.



(a) Long vegetation



(b) Invasive plants and weeds



(c) Erosion and low density of vegetation



(d) Plants in the filter basin



(e) Bare spots due to crossing a swale by pedestrians



(f) Bare spots due to standing water

Figure 7.6: Vegetation issues

Table 7.2: Vegetation issues in swales study area and their frequency

Vegetation issue	Dry swale type	Number of occurrence	Potential reasons
Long vegetation	With overflow	46	Grass exceed 150mm maximum length due to lack of maintenance and monitoring.
	Without overflow	21	
Bare spots	With overflow	27	Bare spots formed due to a drop in the swale infiltration capacity and standing water for a long time damaging the vegetation which a swale is not dry properly.
	Without overflow	4	Pedestrians path crossing the swale, damaging the vegetation layer and creating bare spots in the paths
Erosion	With overflow	17	Water flow through a swale and cleaning the surface over time, creating uncovered soil, increasing sediment load in the swale and the overflows, raising the risk of clogging.
	Without overflow	7	Erosion due to residents interfering such as parking cars over the side of a swale.
Invasive weeds and plants	With overflow	17	Undesirable plants growing due to lack of vegetation management and monitoring.
	Without overflow	8	
Plants in filter basin	With overflow	1	Mainly because of the misuse of swale by residents.
	Without overflow	0	

Reflecting on the vegetation issues detected during the inspection, it was found that around 50% of the swales' vegetation layers function well, and 43% require routine maintenance. Furthermore, 6% are approaching failure due to the severity of the vegetation damage, while 1% have reached a failure state, indicating that the vegetation layer is in an unacceptable condition. Therefore, swale vegetation elements are the most important components that require continuous maintenance and monitoring. Degradation of this element can lead to other issues such as sediment accumulation and clogging. The required maintenance activities include mowing, which accounts for around 50% of the vegetation maintenance, planting and replacing dead plants at 33%, and vegetation management, which makes up the remaining 18%. Figure 7.7 demonstrates the current vegetation condition for the inspected swales and their maintenance requirements.

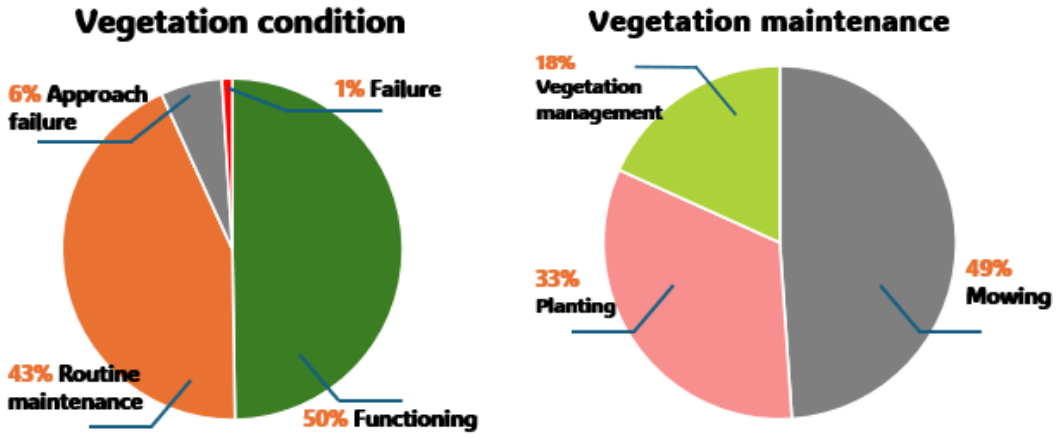


Figure 7.7: Inspected swales vegetation condition and required maintenance

On the other hand, some measures have been taken to address vegetation issues such as erosion and bare spots. These measures aim to mitigate these problems while aligning with the surrounding area. One solution is to install a metal fence on the side of a swale to protect it from being crossed over by cars. Adding a barrier can also protect the swale vegetation in parking lots. However, in all cases, these barriers should not block the runoff water flow or alter the inflow velocity. Figure 7.8 demonstrates some measures applied in the study area to protect vegetation layers.



(a) Barrier in parking lot



(b) Protection fence



(c) Sticks to protect swale from cars crossing over

Figure 7.8: Vegetation protection measures

7.5. Filter basin inspection

Part of the inspection involves examining the processes and conditions at the filter basin. Like other swale components, filter basins are prone to issues and malfunctions. These issues arise due to the degradation of the filter basin over time and a lack of maintenance. Therefore, stormwater management issues were inspected, including sediment accumulation, channelization, standing water, slope sides, and litter and debris. Figure below 7.9 highlights some of the filter basin issues. Table 7.3 shows the number and types of filter basin issues.



(a) Sediment accumulation



(b) Channelization by lateral flow



(c) Leaves in filter basin



(d) Misalignment soil sides slope



(e) Standing water



(f) Channelization by drain roof pipe

Figure 7.9: Filter basin issues

Table 7.3: Filter basin issues in swales study area and their frequency

Filter basin issue	Dry swale type	Number of occurrence	Potential reasons
Sediment accumulation	With overflow	7	Receiving stormwater runoff loaded with sediment and possible changes in the land use in the catchment area cause an increase in sediment rate.
	Without overflow	5	Sediment build-up due to the lack of filter basin cleaning
Channelisation	With overflow	7	high inflow velocity from a pipe directly discharge into a swale.
	Without overflow	0	Runoff stormwater accumulates at one point due to changes in the elevation and flow into a swale with high velocity.
Standing water	With overflow	3	Standing water for longer than 24 hours could be a sign of a decrease in filtration rate.
	Without overflow	4	Clogging the top layer of the soil and closing soil pores because of sediment.
Litter and debris	With overflow	6	Lack of cleaning.
	Without overflow	0	
Soil sides slope	With overflow	5	water flow, erosion and loads lead to changes in the filter basin side slopes.
	Without overflow	4	Damages cause misaligned side slope.

The overall condition of the filter basin appears better than other swale components, with 87% of inspected filter basins functioning properly. A low percentage, about 6%, requires routine maintenance. However, a few filter basins 5% are approaching a failure state, while only 2% of the inspected filter basins have reached a failure condition, indicating that runoff water is not infiltrated properly, posing a flood risk in case of high-intensity rainfall. In terms of maintenance, the inspection revealed that there is no need to construct new filter basins, as the damages are not severe. Nevertheless, maintenance activities like cleaning and reshaping the slide slope are the most needed, with 60% and 40%, respectively. Figure 7.10 illustrates the overall condition of swales' filter basins and the required maintenance.

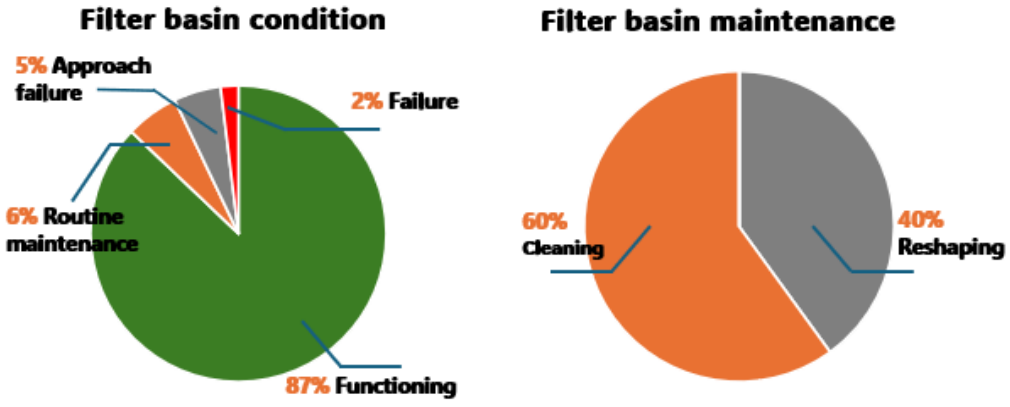


Figure 7.10: Overall condition of swales' filter basins and the required maintenance

7.6. Overflows inspection

Some dry swales are equipped with one or more overflow structures. A different data set was used in the QField during the inspection to determine their location within a swale. A total of 275 overflows were inspected in 155 out of 210 swales, revealing some issues with the overflow documentation, Seventy-one percent of the overflows were found, and 9% were not found. While some overflows recorded in the data were identified during the inspection as not being overflows—mainly manholes—around 5%. Moreover, 40 overflows, representing 15% of the total, were not registered and were observed to be in poor condition. Figure 7.11 demonstrates the inspected overflow data documentation.

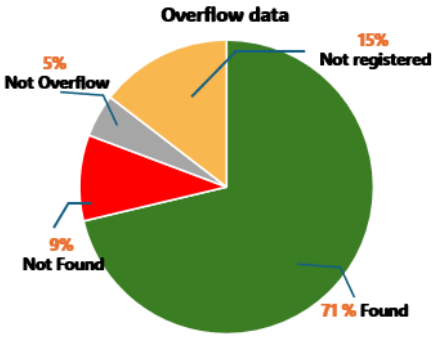


Figure 7.11: Overflows data documentation

The assessment of overflows, both individually and as a system, provides a different perspective on overflow failure. Although the issues remain the same, the overall condition of the overflow system can differ. For instance, if a swale has two overflows and one is completely clogged, the system is approaching failure. An overflow system is considered to be in a failure state only in the case of complete clogging of all overflows.

The overflow inspection revealed multiple issues to which overflows are exposed. Clogging is the most common, either partially (35 cases) or completely (14 cases). Other observed issues include broken lids (12 cases), elevation alignment (11 cases), and structural damage (5 cases). Issues like spilling and design flaws were not found. The bar chart in Figure 7.12 illustrates the number of occurrences of these overflow issues. By considering the individual overflow issues and the number of overflows in a swale, an estimation of the overflow system condition can be made. Similarly, it turns out that clogging is the most prevalent issue, affecting 36 swales. Elevation alignment and broken lids were each responsible for affecting 11 swales, whereas structural damage was the least common issue, affecting only 5 swales. The figures show 7.13 examples of overflow failures in the inspected swales.

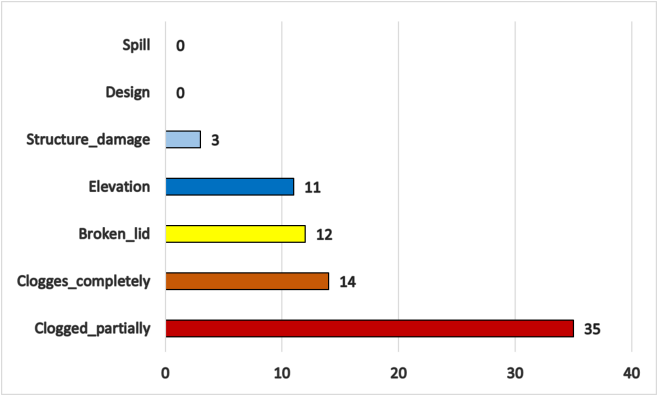


Figure 7.12: The number of occurrences of overflow failures



(a) Structural damage



(b) Complete clogging



(c) Broken lid



(d) Partial clogging



(e) Elevation alignment



(f) Not found overflow covered by layers of soil

Figure 7.13: Examples of various overflow issues

Looking at clogging issues as the most common problem in overflows requires an analysis of the underlying reasons. The inspection identified three main causes of clogging: sediment, vegetation, litter, and debris. There is also the possibility of a combination of two or more reasons. The table below 7.4 illustrates the number of occurrences of overflow system clogging, reasons and types of clogging.

Table 7.4: Clogging reasons

Clogging reason	clogging type	Number of occurrences
Vegetation	Partially Completely	17 5
Sediments	Partially Completely	1 2
Litter& debris	Partially Completely	0 1
Vegetation& sediments	Partially Completely	4 3
Litter& vegetation	Partially Completely	0 1
Misused	Partially Completely	2 0

Considering the overflow issues and the maintenance needs, it can be seen that the generated issues are typically due to overflow deterioration such as broken lids and structure damage, whereas clogging is due to a lack of cleaning activities and vegetation management. In terms of the overall condition of the overflow systems, the inspection statistics show that 63% of overflows are functioning properly, and 15% need routine maintenance, while 14% of overflow systems are approaching failure, and 5% have reached a failure state. The remaining 3% are in an unknown state due to unfound overflows. Figure 7.14 below shows the condition of the overflow system in the inspected swales.

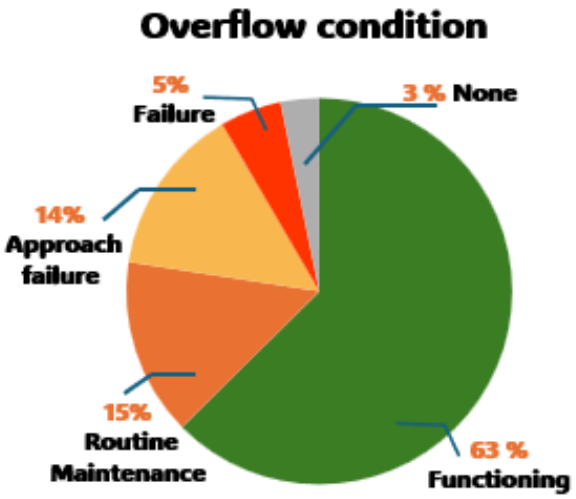


Figure 7.14: Overflow systems condition

7.7. Overall swales condition

After inspecting the issues of swale components, the overall condition of the swales can also be estimated based on the condition of these components. To provide a more objective estimation, routine maintenance issues were neglected as they are regularly addressed by the Utrecht municipality. Consequently, this condition evaluation is based on the critical conditions of all components. For instance, if even one of the swale components has reached a failure state, the entire swale is estimated to be in a failure state. In general, the condition of the swale is determined by the state of its most compromised component.

The overall swale condition evaluation shows that 147 swales, accounting for 67% of the total inspected swales, are functioning in good condition. Meanwhile, 53 swales, representing around 24% of the total, are approaching failure. Additionally, 16 swales have reached a failure state in one of their components, accounting for 7% of the total. Lastly, 5 swales were not inspected, representing about 2% of the total swales. Figure 7.15 below shows the overall swale condition in the study area, while the map 7.16 illustrates the swale condition distribution in the study area.

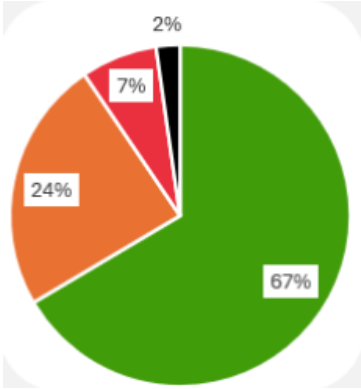


Figure 7.15: Overall swales condition in the study area

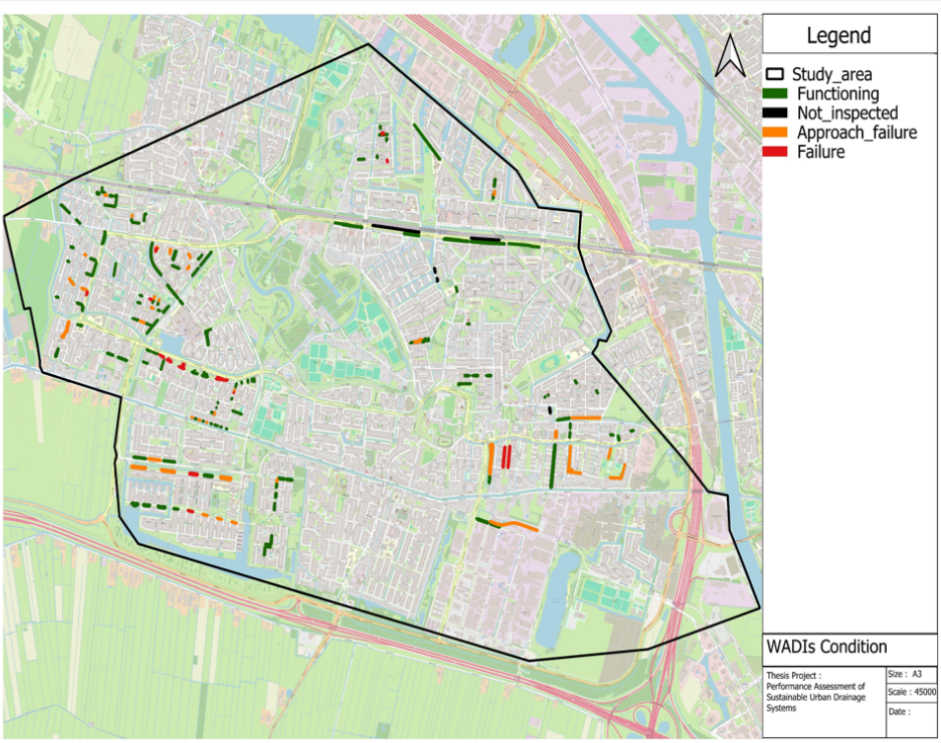


Figure 7.16: Map of the overall swales condition distribution in the study area

7.8. Inspection repetition & maintenance indicators

Shifting asset management from reactive to proactive requires increasing investments, implementing effective policies, enhancing risk management, conducting regular assessments and scheduling inspections (Sileo, 2022). Therefore, presenting a systematic approach to infrastructure maintenance can provide insight into considering factors for long-term sustainability and boosting system efficiency (Robles-Velasco et al., 2024).

The presented inspection framework is made to evaluate various swale components throughout their operational lifespan. It provides a structured approach to maintenance, differentiating between regular, occasional, and remedial activities based on the specific needs and conditions of each component. This framework is pivotal in identifying and addressing potential failures at different stages, which helps in mitigating risks and ensuring the effective performance of swales. The table 7.5 offers a comprehensive overview of the inspection and maintenance requirements for swale components, including vegetation, filter basins, inlets, outlets, overflows, and the alignment of the catchment areas. It details the indicators for maintenance, corrective actions, associated risks, maintenance types, and the recommended frequency of inspections.

By categorizing maintenance activities into routine, non-routine, and remedial tasks, this framework aims to ensure that all aspects of swale functionality are regularly reviewed and addressed. Routine maintenance, such as trimming overgrown vegetation or removing debris, helps to keep the swale operating efficiently and prevent minor issues from becoming major problems. Non-routine maintenance, like addressing invasive plants or repairing structural misalignments, deals with less frequent but significant issues that can impact swale performance. Remedial maintenance, performed upon failure or significant decline in functionality, focuses on restoring the swale to its optimal condition and addressing severe problems that can affect its overall effectiveness.

Implementing this structured approach not only enhances the longevity and reliability of swales but also contributes to more effective stormwater management. By proactively managing and maintaining swales, municipalities and organizations can better handle stormwater runoff, reduce the risk of flooding, and maintain the ecological balance within these critical infrastructure components.

Table 7.5: Inspection framework

Component	Maintenance indicator	Corrective maintenance	Risk	Maintenance type	Repetition
Vegetation	Longer grass than 150 mm	Trim and mow the grass to sustain the grass length within the design standard	Long grass and overgrown vegetation can reduce the swale's storage capacity and create obstacles that block runoff water from flowing into the filter basin.	Routine maintenance	Monthly or 26 times per year
Vegetation	Overgrown vegetation block water at the inlet, outlet, overflow, and drainage	Trim and mow the vegetation length as appropriate	Blocking the water flow at either the inlet or outlet can lead to immersion conditions, increasing the risk of flooding	Routine maintenance	Monthly or quarterly
Vegetation	Invasive & weed plants	Remove undesired plants and replant as appropriate	Invasive and weed plants can overtake other species, damaging the vegetation layer and reducing its overall density. This can negatively impact the health and coverage of the vegetation, leading to a less effective system for controlling runoff and maintaining ecosystem balance	Non-routine maintenance	Semi-annually
Vegetation	Vegetation cover and bare spots	Replant and reseed as required if the bare spots are more than 10% of a swale area	Uncovered soil can lead to increased sediment accumulation in both the filter basin and the overflow system	Non-routine maintenance	Semi-annually
Vegetation	Erosion and dead/drying vegetation	Re-turf and reseed	The absence of vegetation cover can increase the velocity of stormwater runoff and reduce the infiltration rate in swales, leading to the discharge of untreated water	Non-routine maintenance	Semi-annually

Filter basin	Standing water longer than 24 hours	Inspect infiltration surfaces and soil compaction. Clean the topsoil and the drain pipe or replace the topsoil if it is needed.	Standing water for more than 24 hours poses risks such as mosquito breeding, health issues, and environmental concerns. It can also lead to soil erosion, degradation of infiltration surfaces, and potential structural damage	Routine maintenance	Monthly or as required
Filter basin	Litter, debris and sediment accumulation	Clean and remove the sediments	Accumulation of litter, debris, and sediment can block drainage systems, increasing water velocity and reducing infiltration. This leads to potential flooding, erosion, and water pollution	Routine maintenance	Semi-annually or as required
Filter basin	Soil sides slope are settled or uneven	Fill and reshape the swale sides to design level	Leading to poor water flow and inadequate drainage. This can cause increased erosion, reduced infiltration, and potential flooding	Remedial maintenance	As required
Filter basin	Channelization, presence of rills and gullies	Inspect and address the upstream area	Lead to increased erosion and poor water management. They can disrupt the intended flow and effectiveness of drainage systems	Non-routine maintenance	Semi-annually
Inlet & Outlet & overflows	Structural failure and damage	Repair or replacement	Problems with inlets, outlets, and overflows can cause structural failure and damage to drainage systems. Blockages or malfunctions may lead to inadequate water flow, resulting in erosion, flooding, and potential system collapse	Remedial maintenance	Quarterly
Inlet & Outlet & overflows	Blockages	Clear and clean if required	Blockages at inlets, outlets, and overflows can impede water flow and cause drainage issues	Routine maintenance	Monthly

Inlet & Outlet & overflows	Structure misalignment	Inspect for structural integrity	Misalignment of inlets, outlets, and overflows can compromise the structural integrity and effectiveness of drainage systems	Non-routine maintenance	Quarterly
Catchment area	Check the upslope area where the stormwater runoff enters the swale	Use permanent soil stabilization and remove accumulated materials	Potential issues such as increased erosion, sediment buildup, and reduced effectiveness of the swale	Remedial maintenance	Annually
All swale	Drop in filtration rate and unclean soil	Perform rehabilitation and excavate the top layers to expose clean soil	Lead to reduced effectiveness in managing stormwater. This can cause issues like increased runoff, erosion, and flooding	Remedial maintenance	Upon failure
(Lemmen et al., 2008), (Sauer & Auken, 2022), (Woods Ballard et al., 2015), (American Society of Civil Engineers, 2019), (Erickson et al., 2013)					

8

Data analysis & Results

In this chapter, the data analysis of this research will be explained, illustrating the analysis of combined data from area characteristics, municipal-documented data, and inspection data. Further, the utilization of various parameters in the analysis of the potential spatial correlation between swale's different components and failures will be discussed. Consequently, the links between failures, sediment accumulation and catchments will be examined.

8.1. Catchment area analysis

8.1.1. Catchment size analysis

The catchments analysis statistics for 205 swales revealed that the mean size of the catchment is around $2900\,\mathrm{m}^2$ with a standard deviation of $8700\,\mathrm{m}^2$, the catchment ranges vary widely, ranging from $19\,\mathrm{m}^2$ to $12\,000\,\mathrm{m}^2$ for both types of dry swales. Notably, more than 75% of the swale's catchment areas are around the mean value with $3000\,\mathrm{m}^2$. The figure 8.1 below shows the distribution of swales catchment areas.

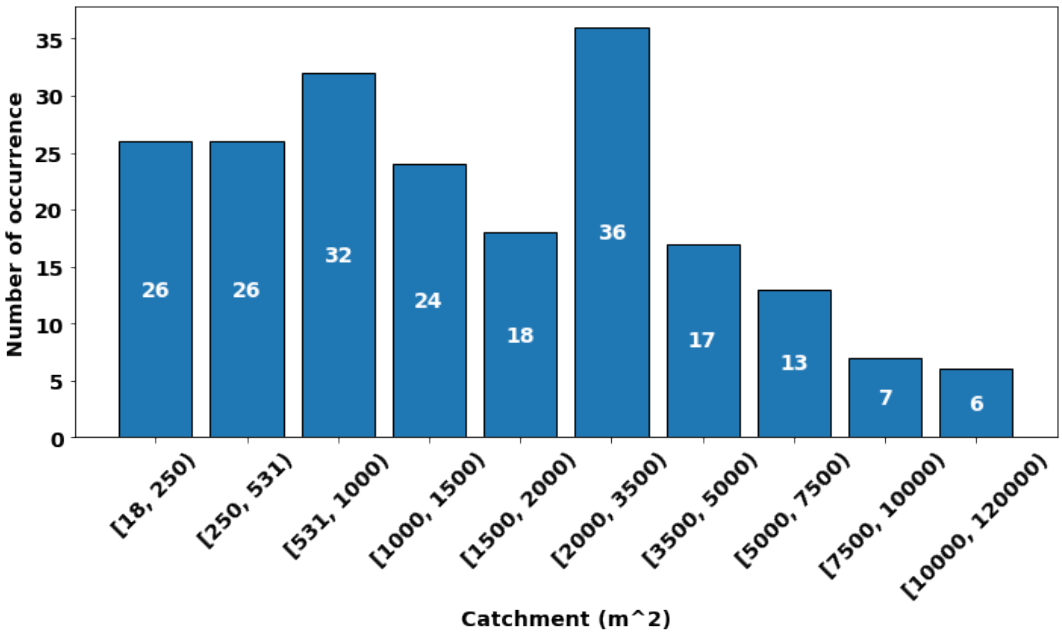


Figure 8.1: Histogram of swales catchment area distribution

8.1.2. Impermeable & Permeable catchment area analysis

The catchment areas are significantly influenced by urban planning with impermeable and permeable areas affecting swale functionality and potential failures. Therefore, for each swale catchment, the size and percentage of impermeable and permeable areas were identified by intersecting the catchment area layer with urban and green areas. After identifying the impermeable and permeable areas, it was found that the percentage of the impermeable area in a catchment is considerably larger than that of the permeable area. In fact, 82% of swales are associated with catchment areas where more than 70% of the total area is impermeable. This highlights the crucial role of swales in runoff management and underscores their importance in stormwater treatment. In contrast, the percentage of permeable areas in 82% of swale catchment does not exceed more than 32% in the sampled swales. This analysis helps to enhance the understanding of the correlation between swale failures and their associated catchment types. Figure 8.2 shows the percentage of impermeable areas in swale catchments

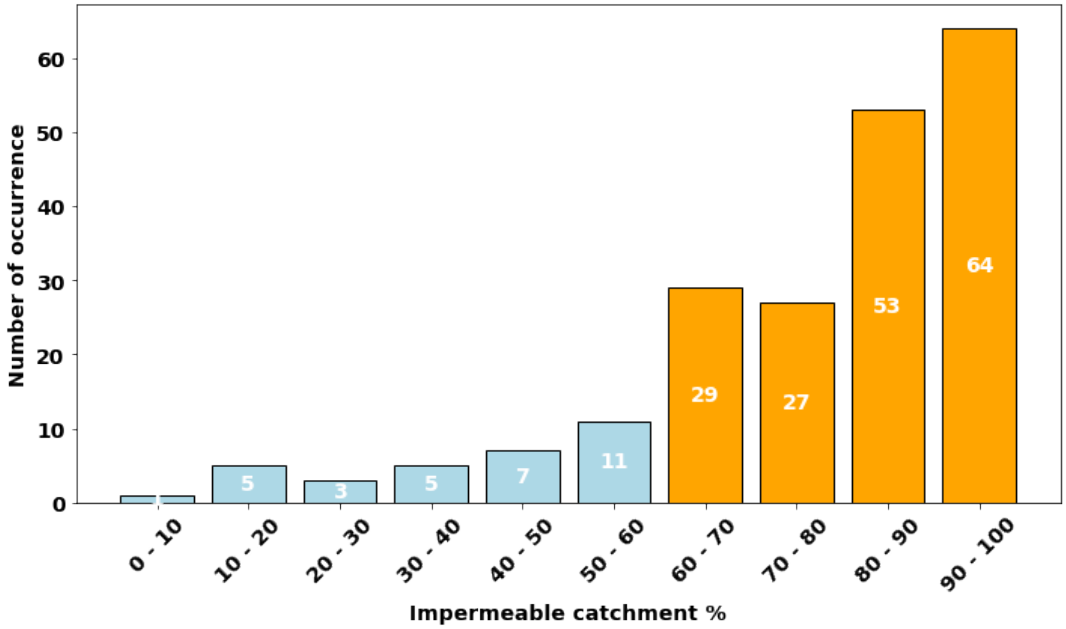


Figure 8.2: Histogram of the distribution of impermeable area percentages in swale catchments

8.1.3. Impermeable surface & Swale surface scale

To explore the potential correlation between runoff load and a catchment, a scale has been selected that accounts for the size of the impermeable area within the catchment relative to the surface area of the swale. This scale highlights the proportion of the impermeable area compared to the swale. Statistical results show that, on average, swales are connected to impermeable areas that are approximately 19 times larger than their surface. Moreover, more than 75% of swales are connected to impermeable areas around 16 times larger than their surface. However, the permeable areas were not included in this scale because the permeable areas do not contribute as significantly to rainfall-runoff as impermeable areas. The figure 8.3 below shows the histogram distribution of the swales' scale (impermeable area/surface).

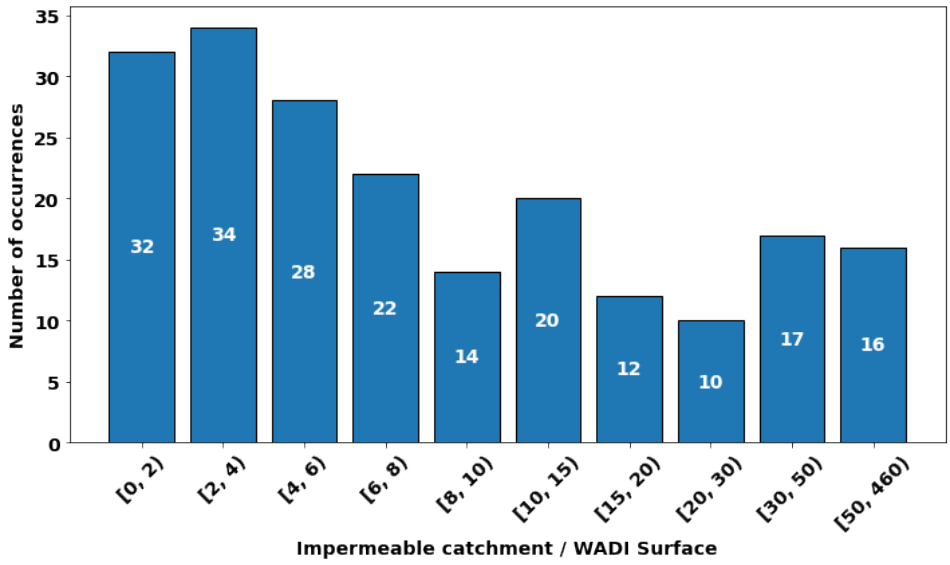


Figure 8.3: Histogram of swale impermeable area-to-surface ratio distribution

8.2. Swale length/width scale analysis

Swales are generally designed as linear structures intended for stormwater management and enhancing ecological functions (Abida & Sabourin, 2006). While their design is predominantly linear, swales can include additional features, such as perforated pipes or elevated structures. These modifications may alter their appearance but do not change their primary function as linear water management systems (Kania et al., 2012).

To explore a potential correlation between swale dimensions and failure rates, an analysis was conducted comparing swale length to width. The results show that, on average, the length of the sampled swales is approximately 32 times greater than their width, with a standard deviation of 62. Notably, more than 75% of the sampled swales have a length that is over 31 times greater than their width. Figure 8.4 shows the histogram distribution of the swales length/width ratio.

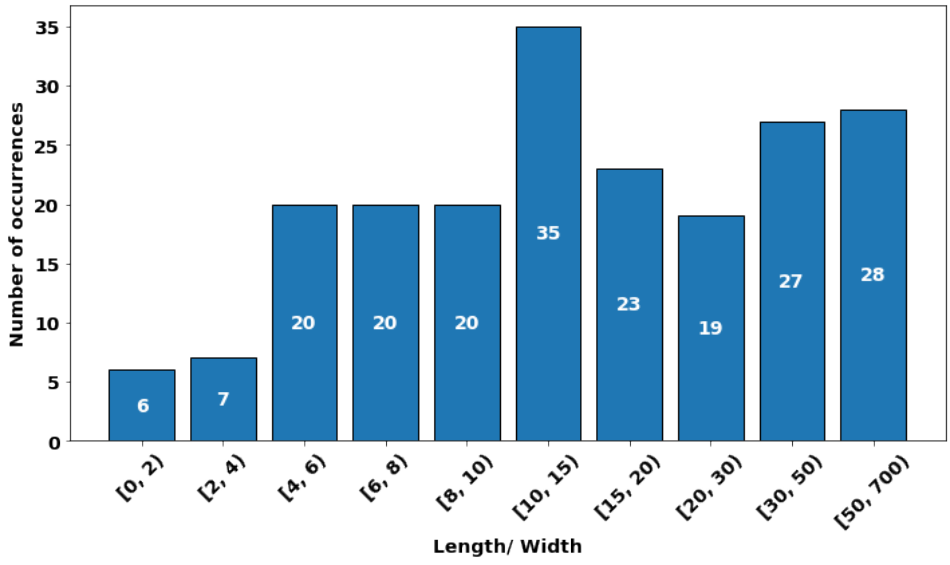


Figure 8.4: Histogram of swale length-to-width ratio distribution

8.3. Vegetation failure analysis

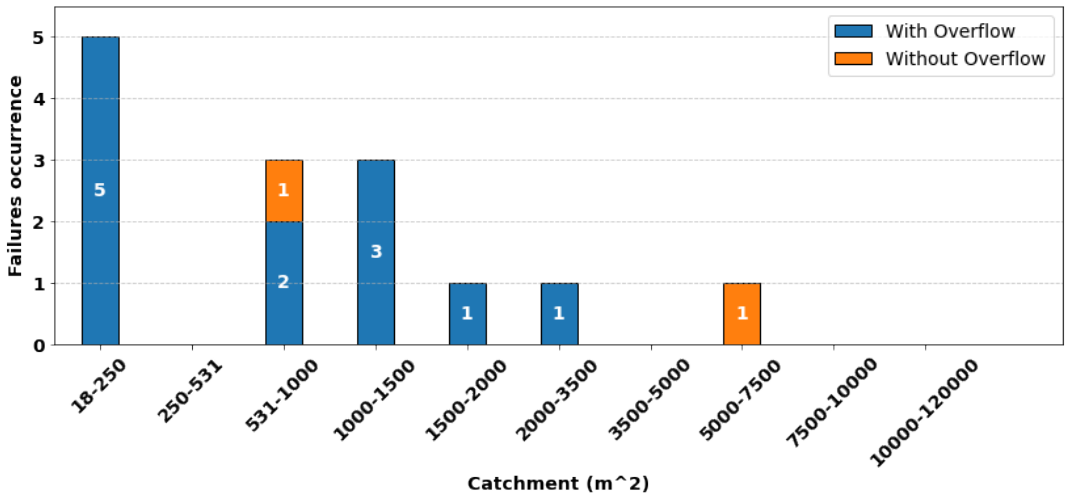
Swale vegetation degradation is a complex issue influenced by various environmental factors and human activities. This degradation can significantly reduce the efficiency of swales, particularly in urban and construction settings. As swale vegetation becomes stressed, its ability to filter water effectively reduces (Lhamidi et al., 2024).

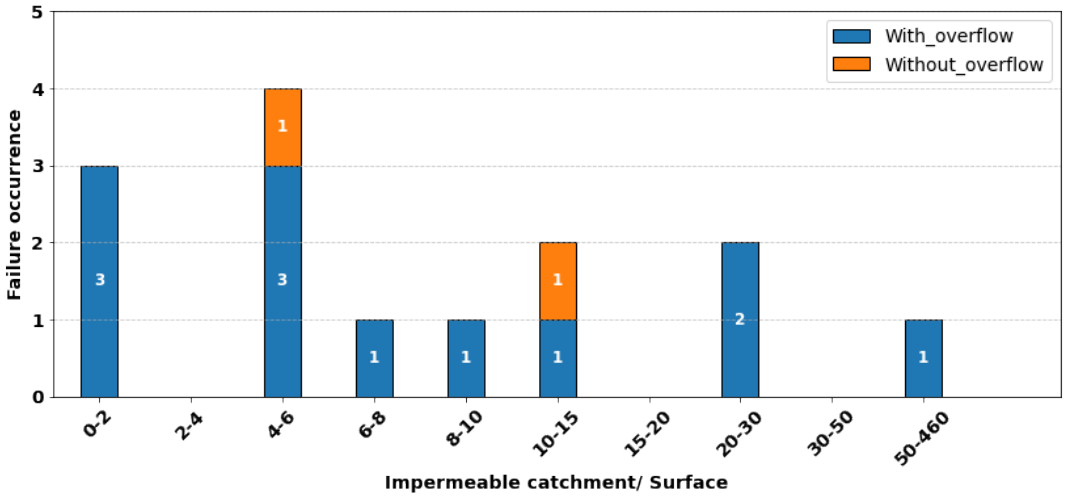
The deterioration of the vegetation layer to an unacceptable condition may be linked to the swale's environment, particularly when it impacts the swale's ability to manage stormwater runoff. Additionally, the type of catchment and the ratio of permeable to impermeable areas within a catchment can offer insights into potential correlations. However, some swale failures are caused by human activities, such as bare spots and erosion resulting from foot traffic across the swale or parking cars on its edges. The analysis of vegetation failures focuses solely on swales where vegetation has either reached or is approaching a failure state. Table 8.1 displays the number of swale cases that have been analyzed for both types of inspected swales.

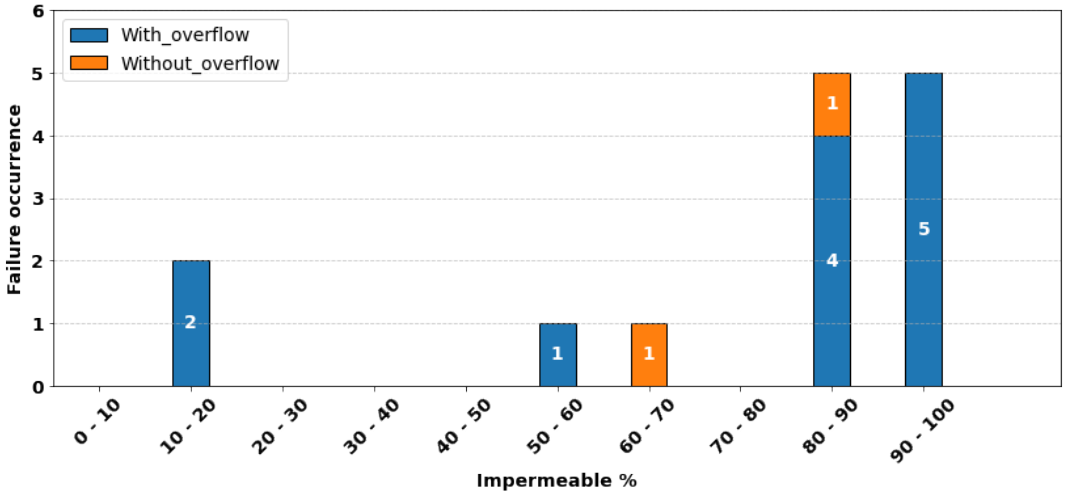
Table 8.1: Swales vegetation condition used in vegetation failure analysis

Dry swale type	vegetation condition	Number of occurrences
With overflow	Approaching failure	10
	Failure	2
Without overflow	Approaching failure	2
	Failure	0

For this vegetation failure analysis, four types of analysis were considered: the size of the catchment area, the scale of the impermeable area and swale surface, the percentage of impermeable area in the catchment, and the scale of swale length-to-width. Furthermore, looking at the distribution of the vegetation failure occurrences within the four analysis ranges, it can be seen that failures in catchment areas and the scale of the impermeable area and swale surface look quite similar, with three more failures in larger scales for dry swales with overflow. However, in the percentage of impermeable areas, most vegetation failures are located in the ranges of 80-90% and 90-100%. In the length-to-width scale analysis, vegetation failures were most common when the swale's length was 4 to 30 times greater than its width, with notable peaks in the 4-6 and 6-8 ranges, corresponding to 5 and 4 vegetation failures, respectively. Figure 8.5 shows the distribution of vegetation failure in these four types of analysis.







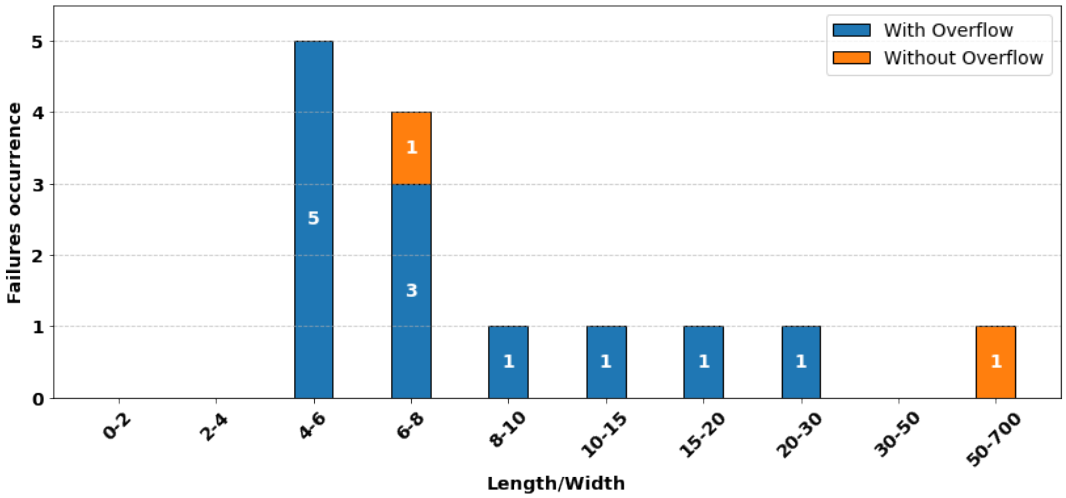
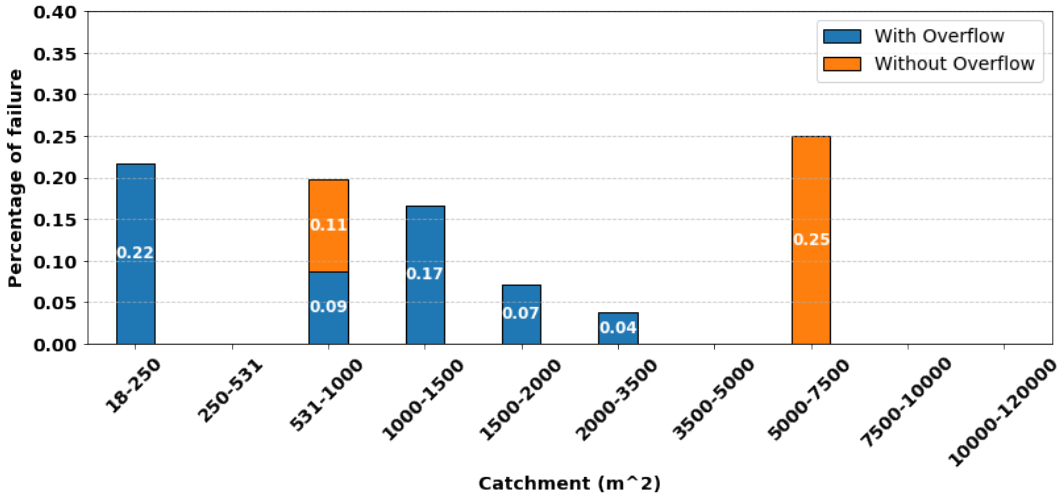
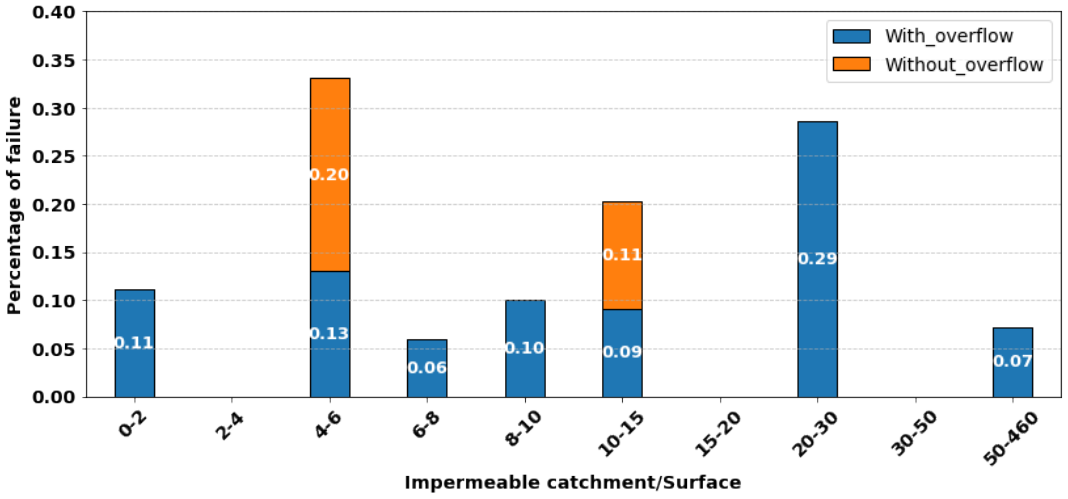


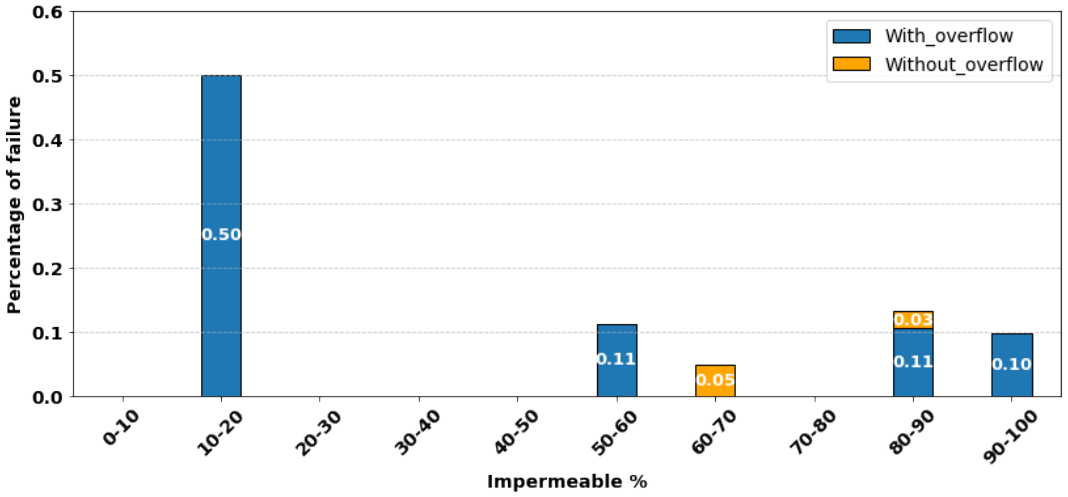
Figure 8.5: Vegetation failures in four types of analysis

To be more precise, the number of failure occurrences distribution is divided by the same analysis distribution. Consequently, the normalized distribution reflects the percentage of total failures that fall into each specific range of analysis type. Further, the higher the percentage, the stronger the correlation between vegetation failures and the range of the type analysis. The normalised failure distributions revealed no clear correlation between vegetation failures and catchment area, the scale of impermeable surface or the length-to-width scale. However, for impermeable percentage, it can be seen that the distribution is more concentrated in high impermeable percentage areas. In the length-to-width scale analysis, failure percentages were highest in the 4-6 and 6-8 ranges but decreased at higher scales. Figure 8.6 shows the percentage of vegetation failure with different analyses.

The vegetation failure analyses did not provide a clear correlation or pattern, as the percentage of vegetation failures is too low due to the limited number of failures, with a total of 14 cases compared to the total inspected dry swales(155 with overflow and 50 without overflow). Regardless of the high percentage of vegetation failure 0.50 in impermeable catchment 10-20% because of failure 2 vegetation layers out of 4, also high percentages could be seen in dry swales with overflow their length 4-6 and 6-8 times larger than their width with 0.36 and 0.18, respectively. Nevertheless, a possible correlation between vegetation failures and higher impermeable percentages in catchment areas can be noted.







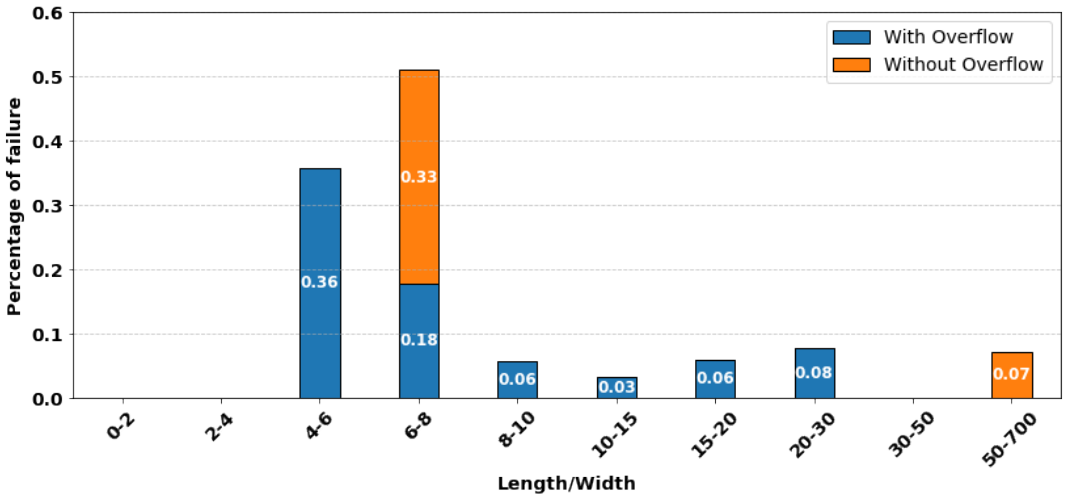


Figure 8.6: The percentage of vegetation failures in four types of analyses

8.4. Filter basin failure analysis

8.4.1. Failures analysis

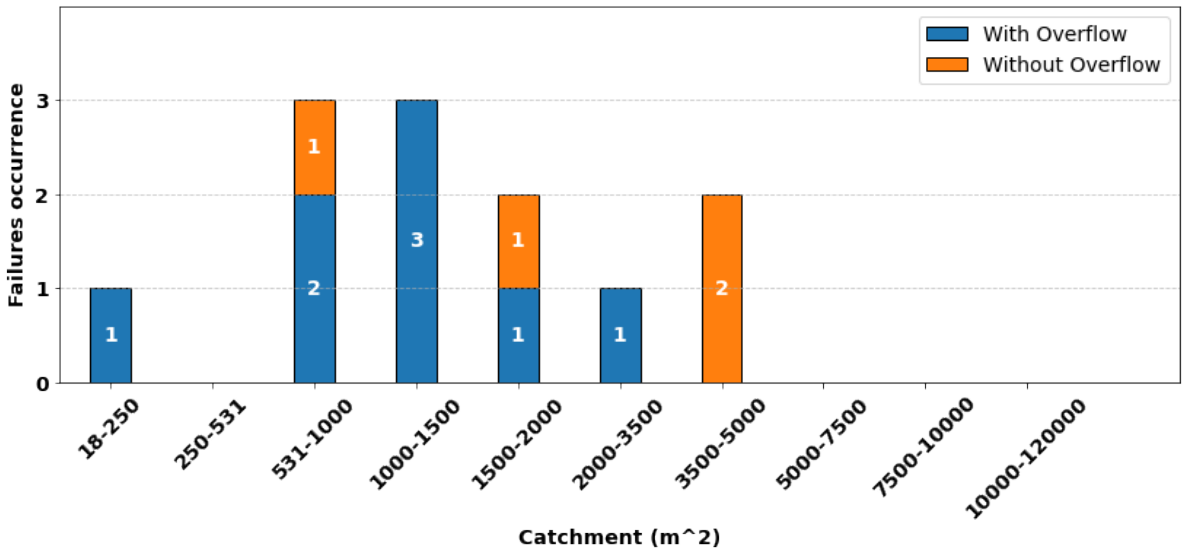
Filter basins are critical components of swale systems, designed to receive and manage stormwater runoff by promoting water infiltration. Over time, however, these basins can degrade due to a combination of environmental stressors and human activities. The degradation of a filter basin reduces the swale's ability to effectively manage stormwater volumes. Additionally, the filter basin may reach a failure state when infiltration issues arise, such as standing water remaining for more than 24 hours after a rainfall event. This indicates that the swale is unable to effectively manage subsequent stormwater events.

Similar to the vegetation failure analysis, the same approach was applied to the analysis of filter basin failures, with the same analyses taken into account. For the filter basin condition, only cases classified as failure or approaching failure were included in this analysis. Table 8.2 below presents the number of filter basin cases analyzed

Table 8.2: Swales filter basin condition used in filter basin failure analysis

Dry swale type	Filter basin condition	Number of occurrences
With overflow	Approaching failure	6
	Failure	2
Without overflow	Approaching failure	0
	Failure	4

With only 12 failure cases, the distribution of filter basin failures within the four analysis range shows that failure distribution follows the distribution of the catchment size and the scale of impermeable area/surface, while in the filter basins failures tend to occur at 40-50% of impermeable area in swale catchment. Whereas the four filter basin failures in swales without overflows occurred at a length-to-width scale greater than 50 times, an equal number of failures—half of all filter basin failures in swales with overflows—occurred in the 6-8 scale range. Figure 8.7 illustrates the distribution of filter basin failures in these analyses.



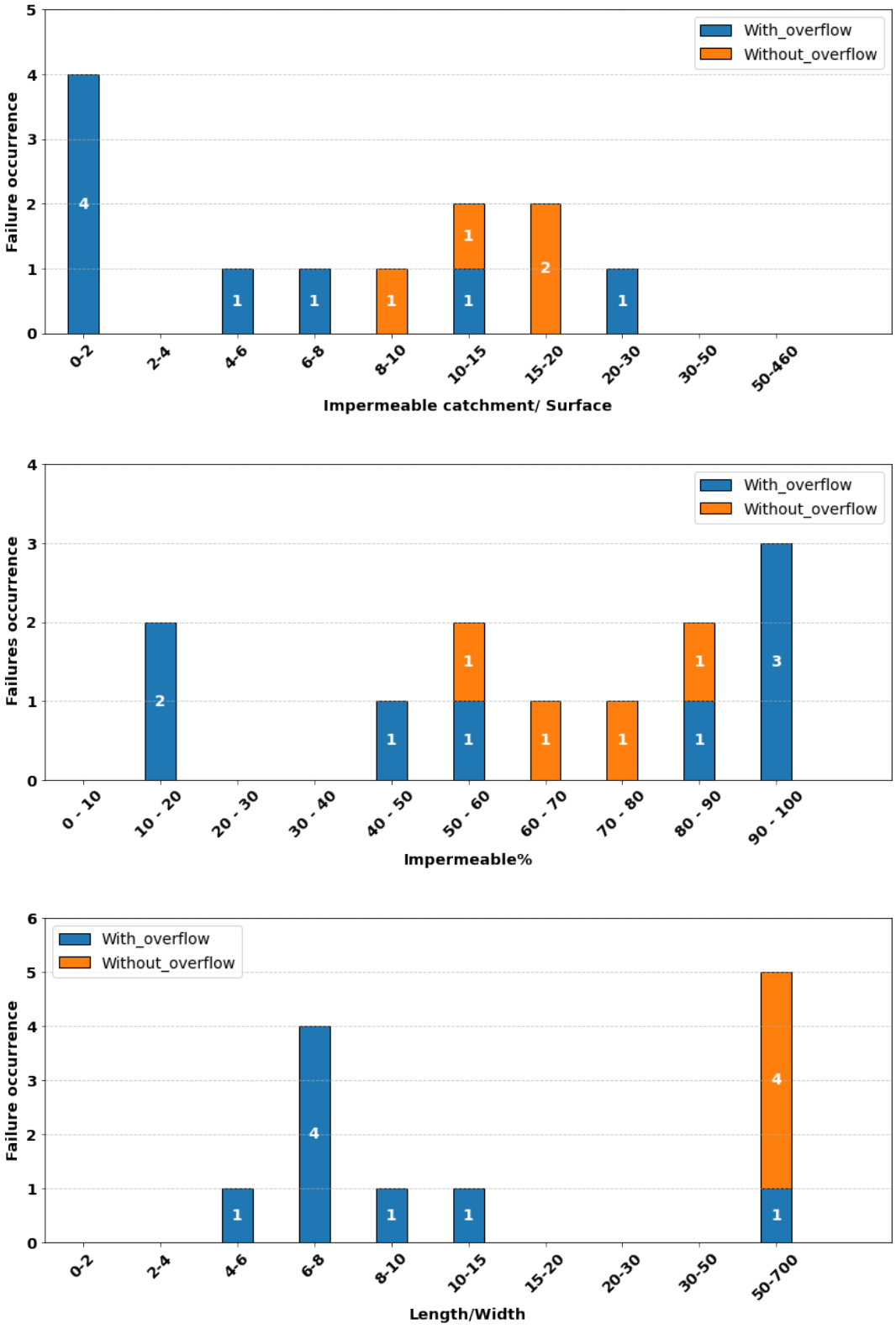
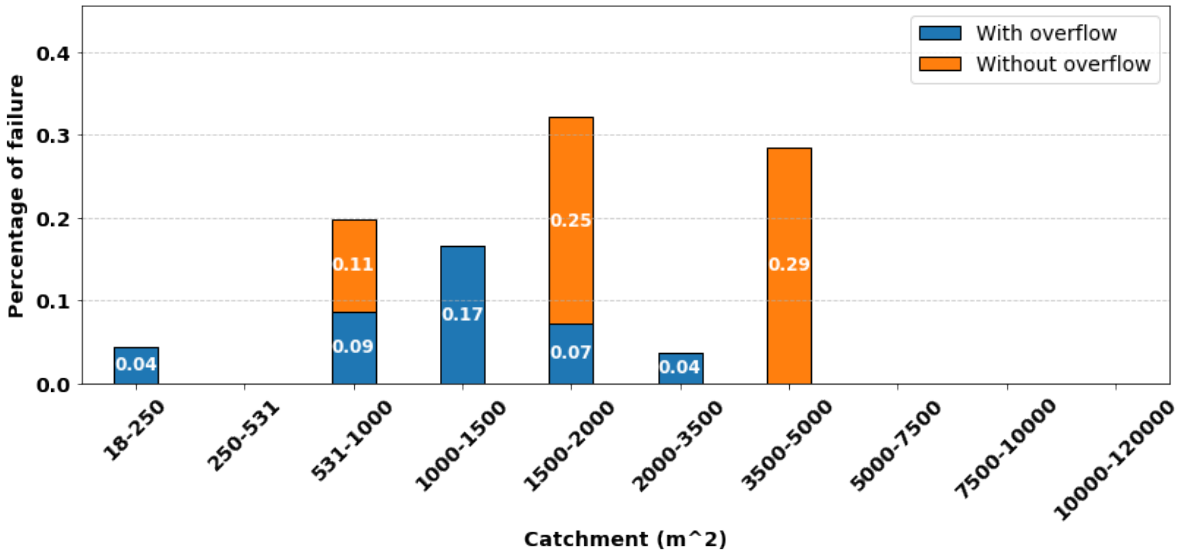


Figure 8.7: Filter basins failures in four types of analyses

Undoubtedly, the normalised filter basin failure distributions revealed not a clear correlation between filter basin failures and catchment area, the scale of impermeable area/surface or the scale length to width. However, for the impermeable percentage, it can be seen that the failures are more concentrated in high impermeable percentage areas. Figure 8.8 shows the percentage of filter basin failure distributions in relation to different analyses. The correlation between filter basin failures and the catchment analysis is not clear due to the low number of failure cases—only 12 failure cases compared to the total of 205 inspected swales. Nevertheless, a potential link can be observed between filter basin failure and high impermeable percentages in the catchment area. Moreover, the percentage of filter basins in dry swales without overflows is highest when the length-to-width ratio is between 50 and 700.



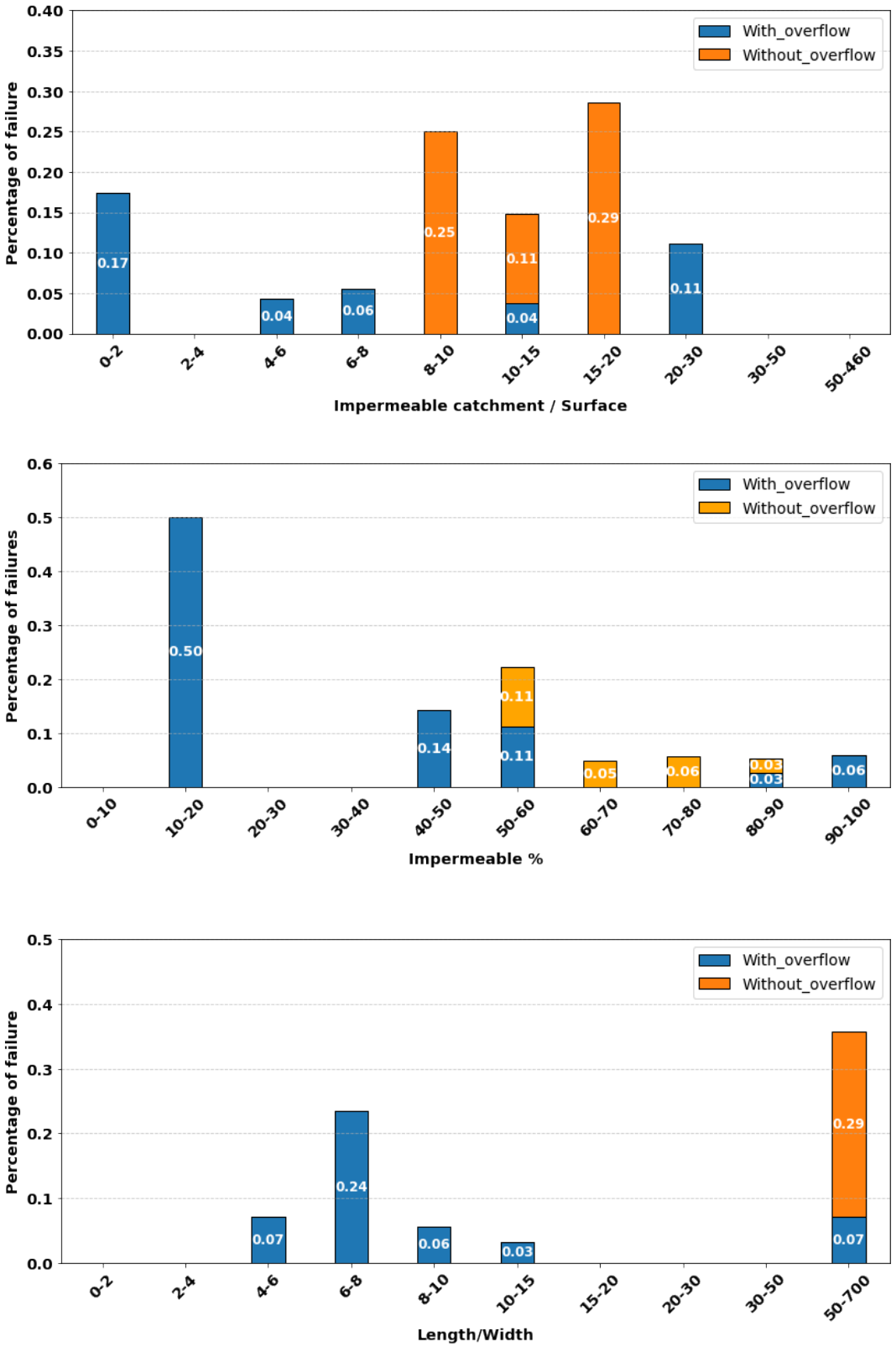


Figure 8.8: The percentage of filter basins failures in four types analyses

8.4.2. Filter basin failures & age & tree density analysis

The performance of swales during their lifespan cannot only be associated with the catchment size and area characteristics, as other parameters can also impact swale performance. For instance, surrounding vegetation, such as trees, has been shown to affect surface filtration capacity (F. C. Boogaard, 2015). While plant roots can increase the soil's infiltration rate by enlarging pore sizes, an increase in organic matter (OM) due to the degradation of leaves can reduce the soil's infiltration capacity (Cleophas et al., 2022). Consequently, the number of trees in the swale's catchment was considered in this analysis by calculating the tree density. However, the analysis did not take into account the types or ages of the trees

Another parameter considered in the analysis of filter basin failure was the age of the swales, which refers to the deterioration of the swale condition over time. However, conducting maintenance activities can restore the swale's desired performance by addressing issues such as cleaning the filter basin and sediment removal (Allen et al., 2017). In contrast, the topsoil layer of the filter basin can lose its ability to infiltrate stormwater runoff because of the accumulation of pollutants, which causes clogging of the soil pores and impedes water flow (Gonzalez-Merchan et al., 2012). Clogging is known to be one of the main issues leading to standing water and frequent ponding (Gonzalez-Merchan et al., 2012).

To understand the influence of the tree density and the swale's age on the condition of the filter basins, a plot was created considering the swales with filter basins in the following states: 10 cases needing routine maintenance, 6 cases approaching failure, and 6 cases that have reached a failure state. The figure 8.9 below illustrates the condition of the swale filter basins concerning the age and the tree density. From the plot, it can be concluded that swale aging impacts filter basin performance, and all the filter basins that are not functioning well are older than 15 years. Interestingly, five out of six filter basins that have reached a failure state show a high tree density, ranging from 50 to 225 trees per hectare. This suggests a reduction in filtration capacity and an increase in the occurrence of standing water.

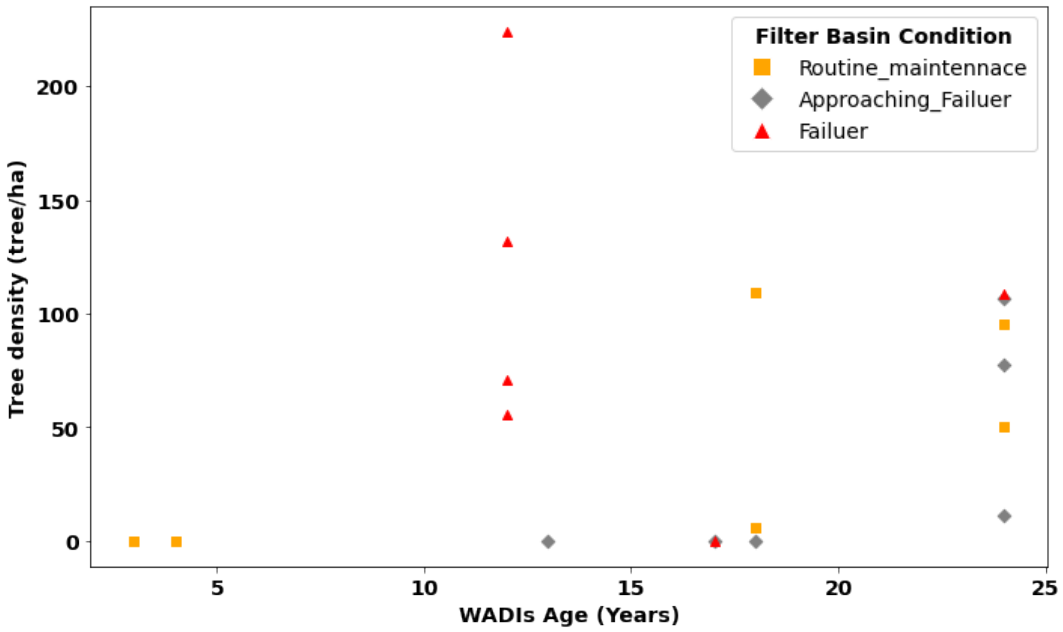


Figure 8.9: The swale filter basin condition concerning the age and the tree density

8.5. Overflows failure analysis

The analysis of the overflow failures follows the same approach as the vegetation layer and filter basin analyses with catchment analysis. Despite this, dry swales without overflow are eliminated from this analysis, overflow failures, caused by the deterioration of overflows such as broken lids, structural damages, and elevation misalignment, are also excluded, considering only clogging issues. The reason behind this is that catchment analysis does not have an impact on these types of failures, unlike clogging. If the database were larger and included more overflows with structural deterioration issues, it could be possible to conduct a different analysis of the age of overflows and these failures.

8.5.1. Overflows clogging analysis

Clogging is the most common failure observed in the inspection results of the dry swales' overflow, as shown in Figure 7.12. The number of clogging failures corresponds to the individual overflow points within the swale. In this analysis, clogging failures have been estimated based on the condition of all overflows in the swale. Additionally, a distinction has been made between two types of clogging: partial clogging and complete clogging. This distinction was made because partial clogging requires routine cleaning maintenance and, in severe cases, can make the overflow reach an approaching failure state, while complete clogging refers to overflows that have reached a failure state and are not functioning anymore. Table 8.3 below presents the number of occurrences of partial and complete clogging failures in the inspected swales, which are included in the overflow clogging analysis.

Table 8.3: The number of occurrences of swale overflow system partial and complete clogging failures

Clogging type	Overflow condition	Number of occurrences
Partial clogging	Approaching failure	24
Complete clogging	failure	12

Examining the distribution of overflow clogging failures within the different analysis ranges, a total of 36 clogging failures were identified, both partial and complete. In the first analysis, which considers the size of the swales' catchment area, failures appear to be relatively equally distributed. The highest number of partially clogging failures occurs in catchments between $2000\,\mathrm{m}^2$ and $3500\,\mathrm{m}^2$, which corresponds to the highest frequency of swales (27 swales) within the same catchment size range. Figure 8.10 shows the distribution of dry swales with overflow catchments and the occurrences of failures. Additionally, the distribution of clogging failures by impermeable area/surface scale is similar to the previous catchment size analysis. Notably, the peak of partial clogging failures, which occurs within the 0-2 range, also corresponds to the highest number of swales (27) in this range. Figure 8.11 illustrates the distribution of dry swales with overflow based on the impermeable area/surface scale and the occurrences of failures.

The analysis of impermeable area percentage in catchments aligns more closely with the overall distribution of failures. This suggests that the impermeable/surface scale and impermeable percentage in catchments might have an impact on overflow clogging failures. Figure 8.12 shows the distribution of dry swales with overflow based on the percentage of impermeable areas in catchments and the occurrences of failures. In contrast, in the analysis of length-to-width distribution the complete clogging failures tend to occur at smaller length-to-width scales, less than 10, whereas partial clogging failures are more likely to happen at larger scales, greater than 10. Figure 8.13 illustrates the distribution of dry swales with overflow based on the length-to-width scale and the occurrence of clogging failures.

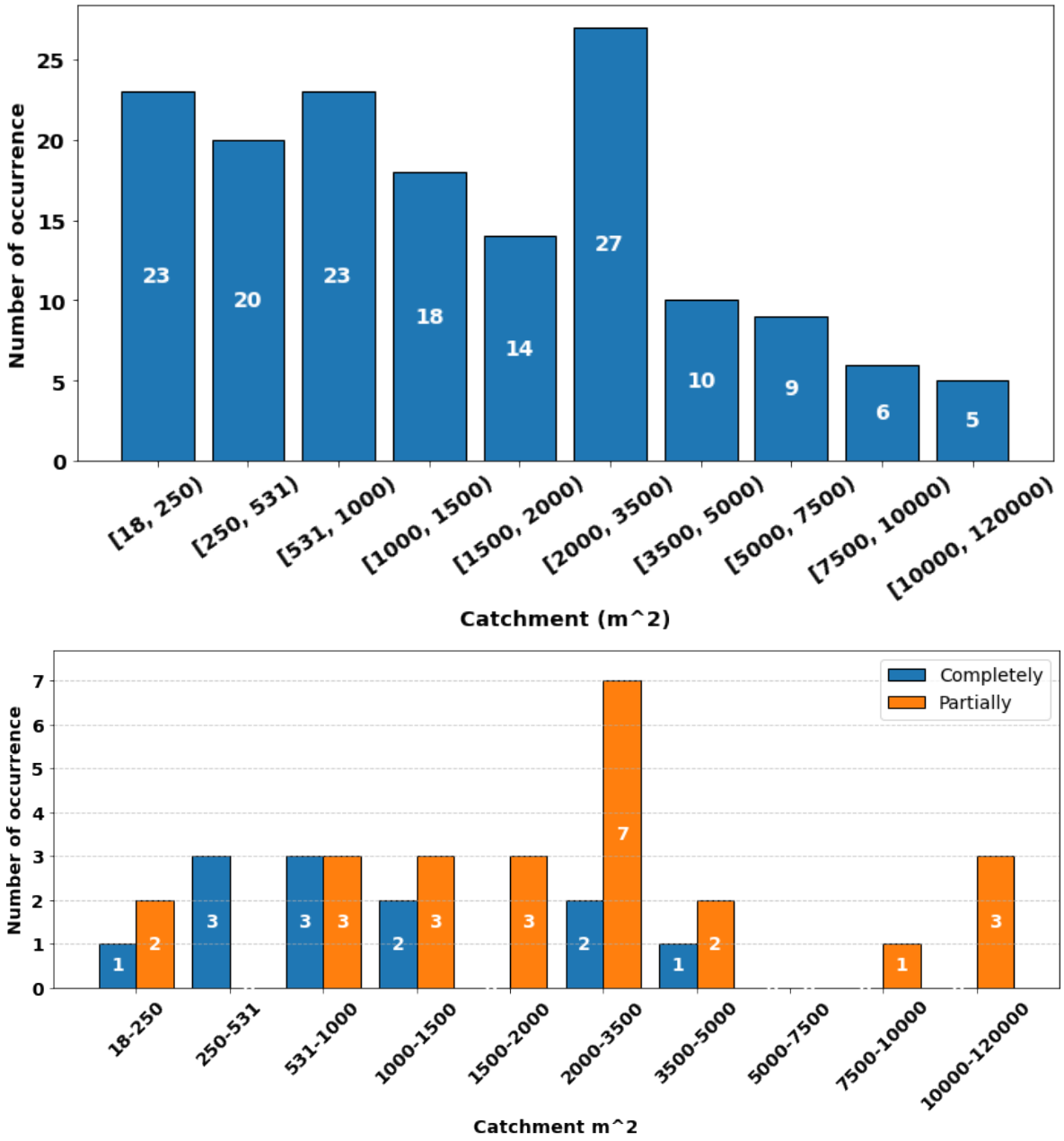


Figure 8.10: The distribution of dry swales with overflow catchments and the occurrences of clogging failures

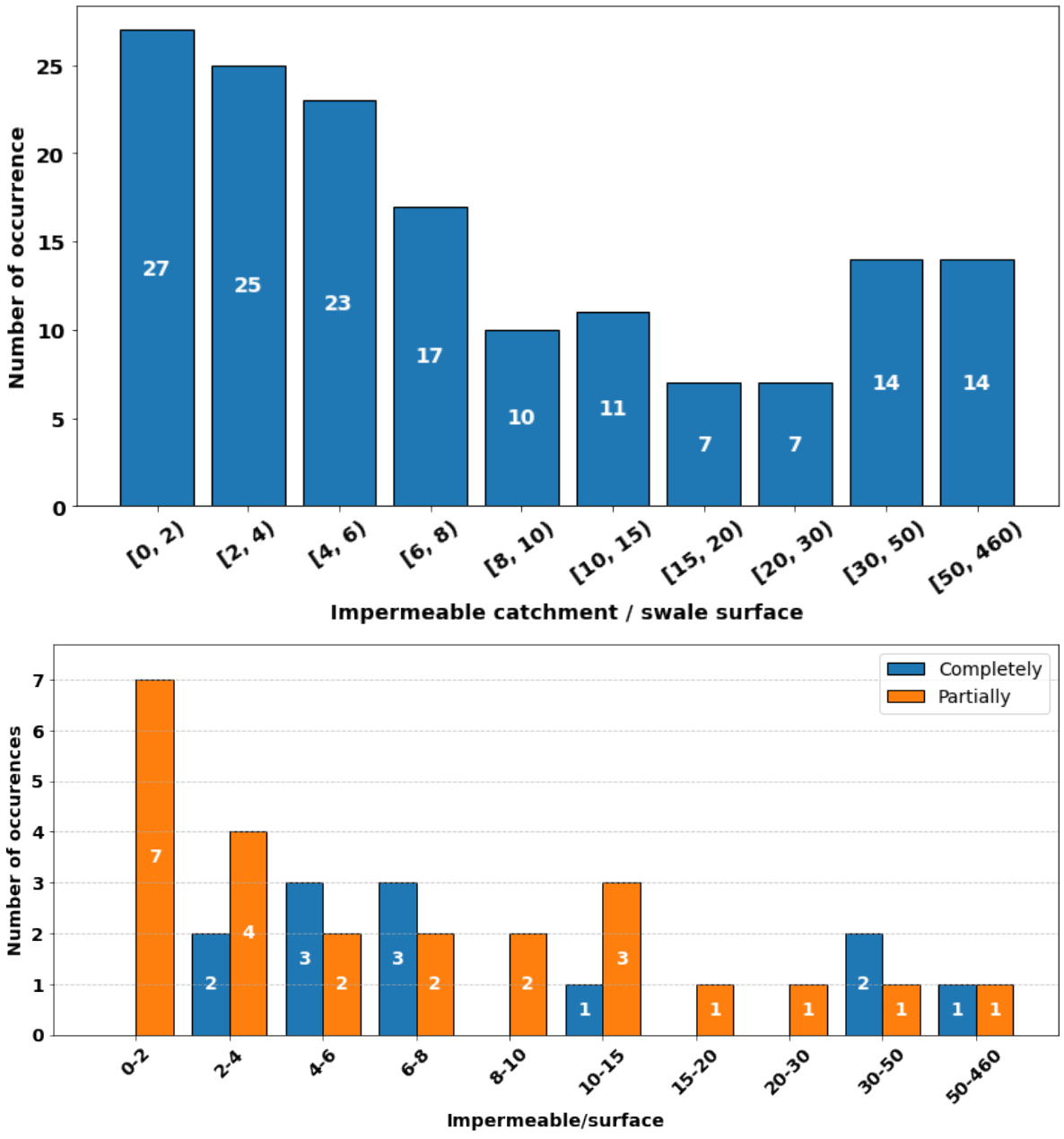


Figure 8.11: The distribution of dry swales with overflow based on the impermeable area/surface scale and the occurrences of clogging failures

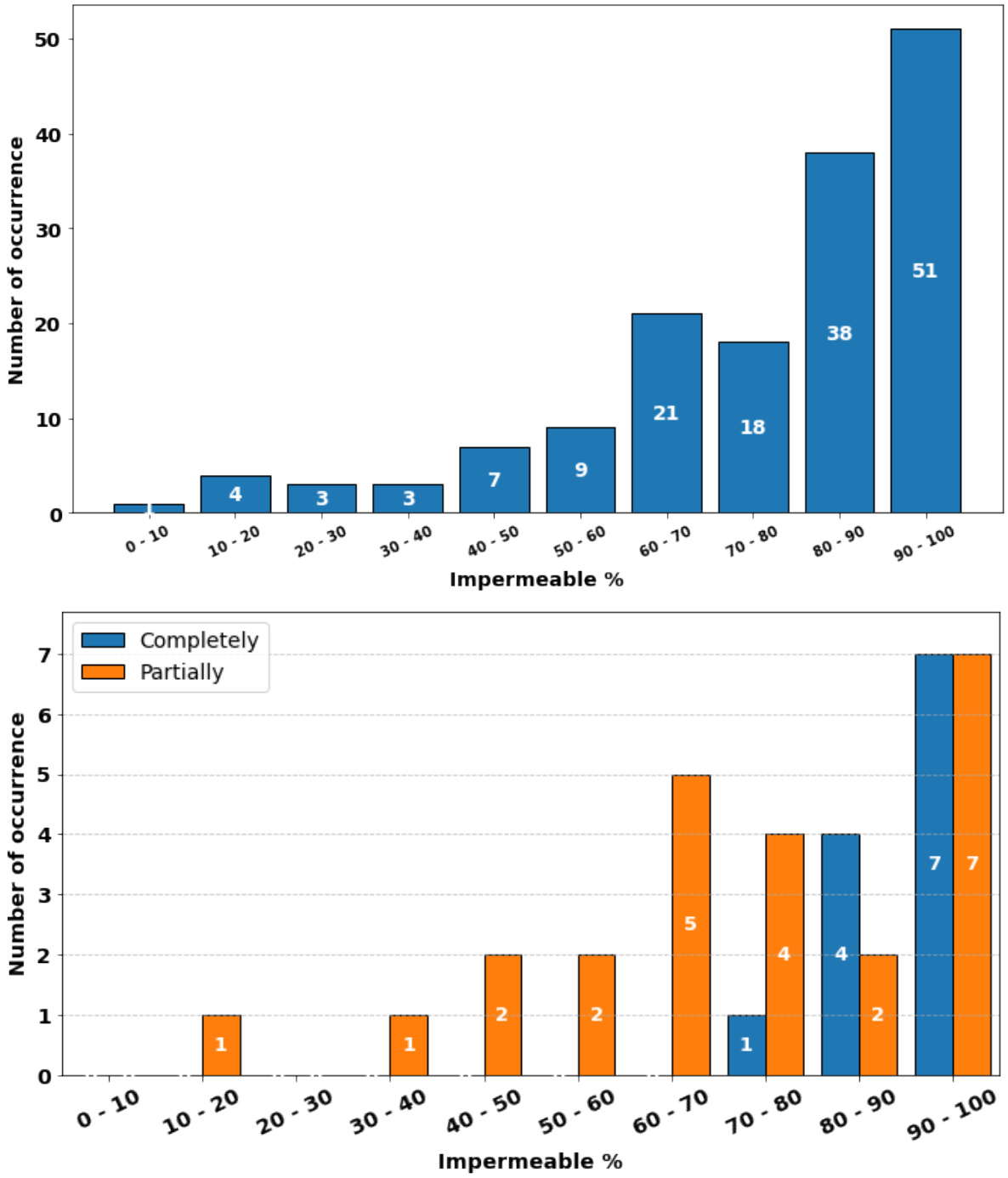


Figure 8.12: The distribution of dry swales with overflow based on the impermeable percentage in catchments and the occurrences of clogging failures

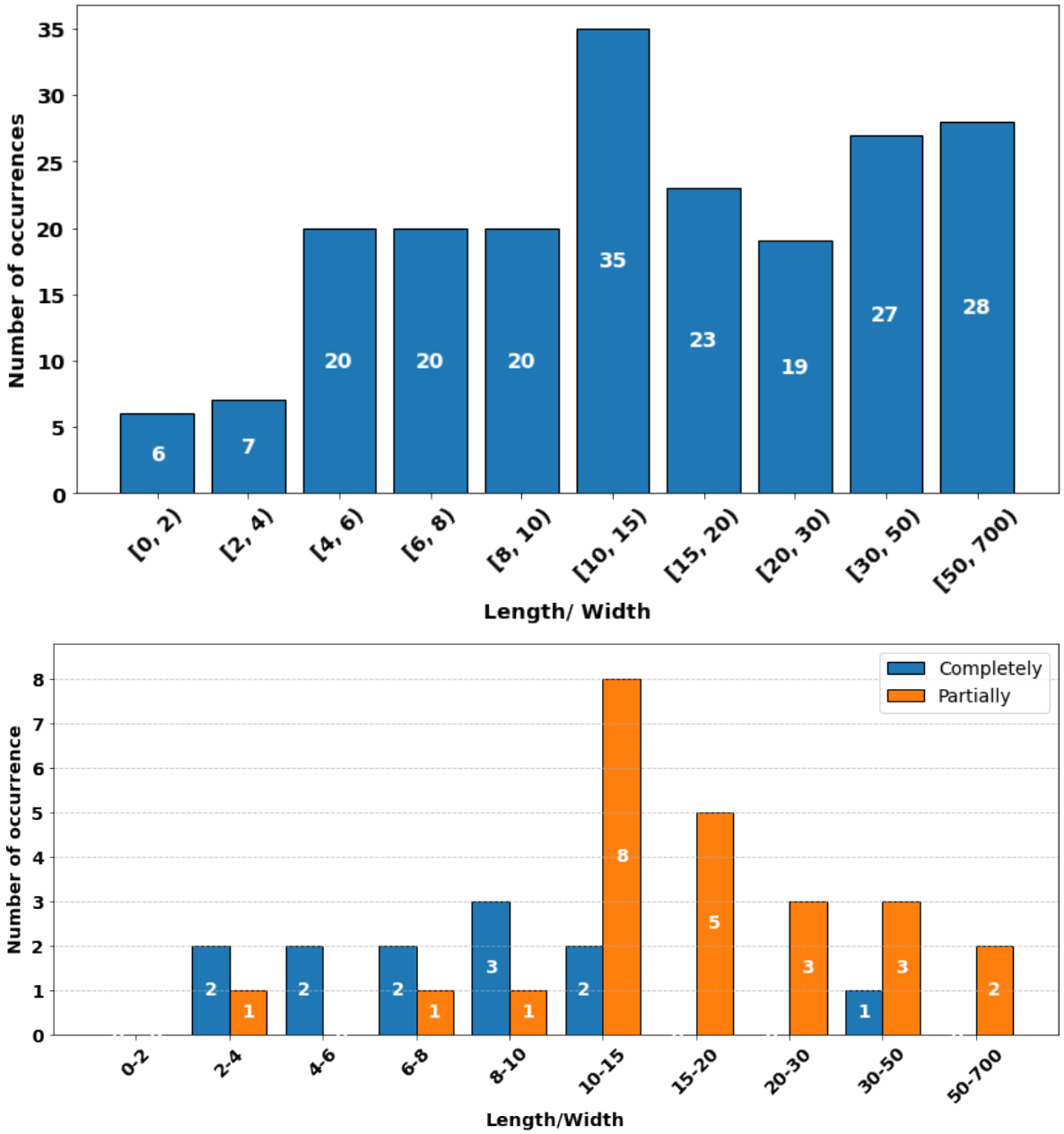
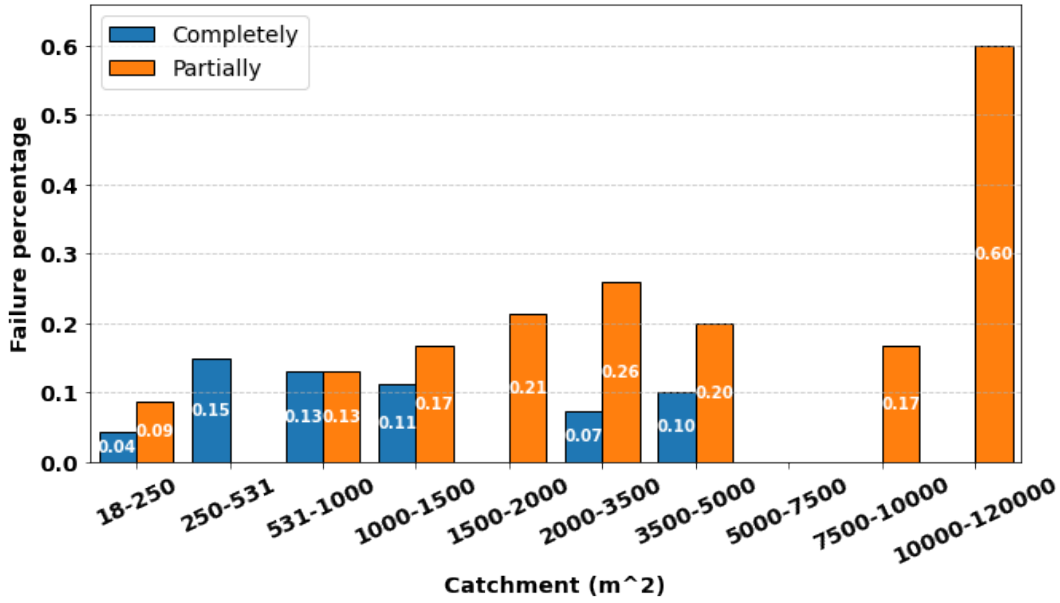


Figure 8.13: The distribution of dry swales with overflow based on the length-to-width scale and the occurrence of clogging failures

After dividing the number of clogging failures in each range by the same distributions, It can be seen in the first figure 8.14 that the percentage of failures in partially clogged tends to increase with larger catchment sizes reaching 0.60 for 10000- 12000 m^2 catchments. While, in the analysis of the impermeable/surface scale, the failure percentages do not show a clear pattern, suggesting random distribution for both types of clogging failures.

In the analysis of clogging failures related to the percentage of impermeable areas in catchments, a more definitive trend emerges. The failure percentage for complete clogging begins at 0.06 in the 70-80% range and rises to 0.14 in the 90-100% range. This indicates that with an impermeable percentage of 70% or higher in the catchment, the probability of complete clogging increases. Conversely, the percentage of partial clogging failures starts at 0.3 in the 30-40% and decreases to 0.14 in the 90-100% range. Figure 8.14 shows the percentage of clogging failures within each range across the different catchment analyses, highlighting these potential correlations.

On the other hand, the length-to-width scale analysis reveals that complete clogging failures tend to occur at smaller scales, with the highest percentage of 0.33 in the 2-4 range. This percentage decreases as the scale increases. In contrast, partial clogging failures are more prevalent at larger scales, reaching a peak of 0.29 in the 15-20 range.



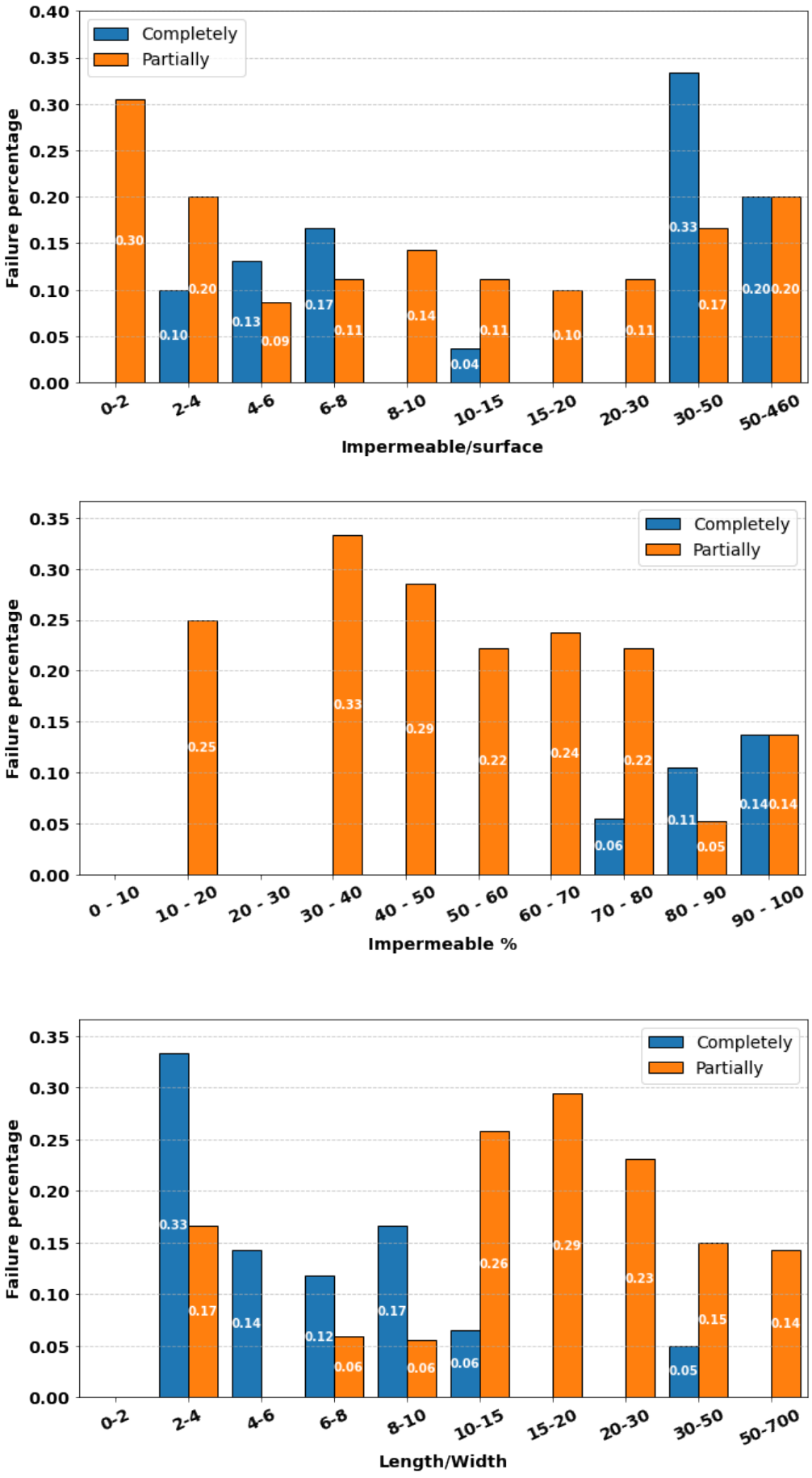


Figure 8.14: The percentage of overflow clogging failures in four types of analyses

8.5.2. Overflow clogging & impermeable catchment & tree density analysis

One of the most common causes of overflow clogging is vegetation, as indicated by the inspection results in table 7.4. Therefore, the number of trees in the swales' catchment was evaluated by calculating the tree density to explore a potential correlation with clogging issues. This was done alongside analyzing the impermeable area and its percentage within the swale's catchment. With the same number of clogging issues (12 for complete clogging and 24 for partial clogging), it is observed that tree density does not significantly influence complete clogging failures, particularly in areas with low tree density. In contrast, the percentage of impermeable area has shown a clear impact, as illustrated in Figure 8.14.

On the other hand, partial clogging failures seem to have a potential correlation with the tree density, which ranges between around 5 to around 100 trees per hectare in most cases. Figure 8.15 demonstrates the correlation between clogging failures, the tree density, and the impermeable area percentage in a catchment.

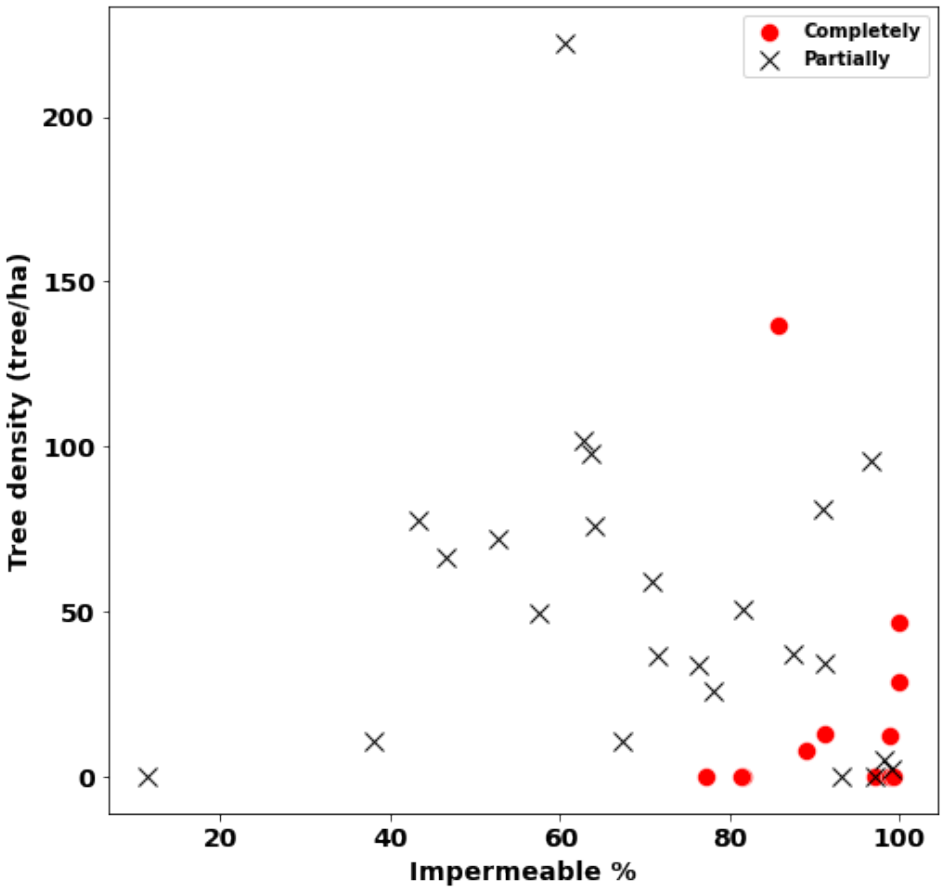


Figure 8.15: The Clogging cases regarding the tree density and impermeable percentage

8.5.3. Sediments accumulation analysis

Sediments accumulations & overflow distance from nearest inlet

During overflow inspections, sediments were not directly measured. However, maintenance data from the Utrecht municipality provided insight into the sediment volume in the swale overflows, which ranged between 0 and $0.75\ \mathrm{m}^3$ figure 6.6. While the vegetation layer is effective in managing sediment, sediment transport does not cease after stormwater runoff events, as most settled sediments do not stay within the swale (Allen et al., 2015). To analyze sediment accumulation in overflows, the distance between overflows and the nearest inflow inlet was measured. The assumption is that closer proximity to the inlet results in a higher sediment accumulation in the overflows. The analysis here focuses exclusively on the overflows that were found on the site and the sediment volume was measured during the last maintenance activity, totaling 201 overflows. Figure 8.16 illustrates the sediment accumulation and the distance of overflow from the closest inlet.

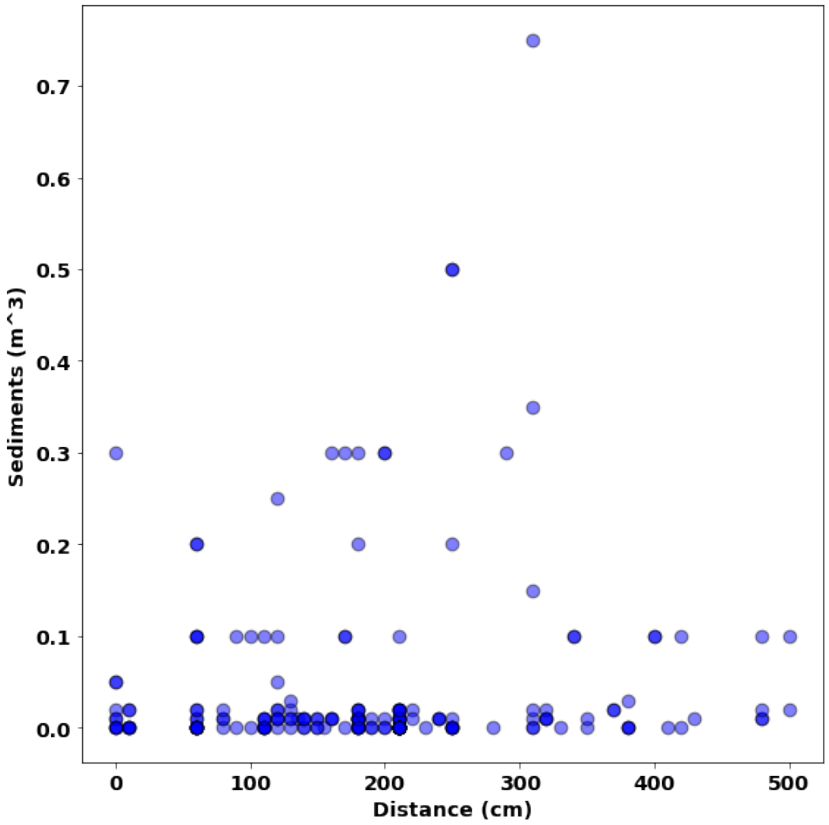


Figure 8.16: The sediment accumulation and the distance of overflow from the closest inlet

From the previous figures, it appears that as the distance decreases, the sediment volume tends to increase. However, the majority of swales receive runoff water laterally, and water discharges to the overflow from the filter basin after a retention period, particularly when the swale's capacity is exceeded. Although the distance from the input to the outlet is a potential factor, it is not the only parameter that should be considered. Other factors, such as vegetation type, inflow velocity, and catchment area, also need to be included in the analysis to provide a more comprehensive understanding

Sediments accumulation & catchment analysis

In this analysis, the catchment size of the swales is one of the key factors in sediment accumulation, given that impermeable areas such as pavements and roads tend to generate more sediment and urbanized areas undergoing construction or development are particularly susceptible to increased sediment production (Moraes et al., 2024). Additionally, sediments in the upstream areas of the impermeable areas are produced at a rate of 3 to 5 times higher than in downstream areas (Pappas et al., 2008). With 155 dry swales and 201 recorded overflows, the correlation between the catchment area for each swale and the impermeable area percentage was analysed considering the sediment volume in the overflows shown in figure 8.17.

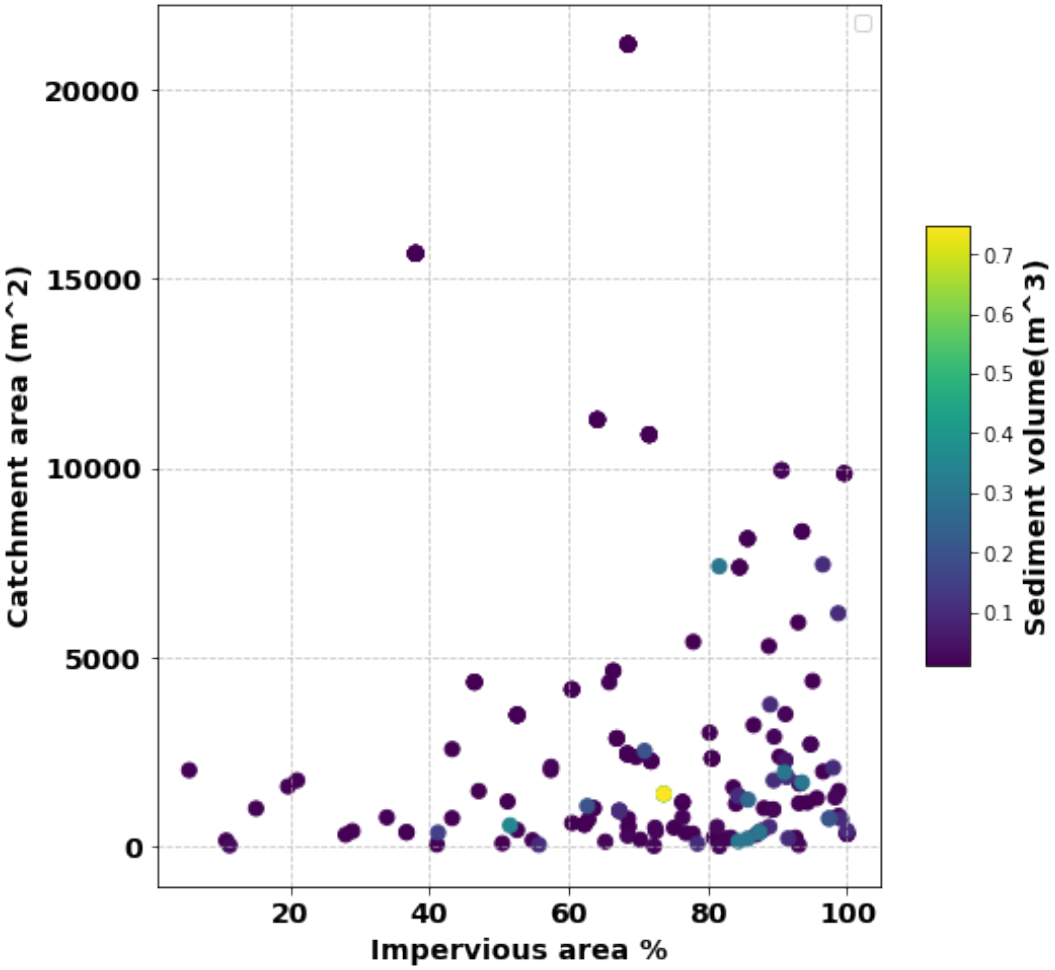


Figure 8.17: Analysis of swale catchment area and impermeable percentage in relation to sediment volume in overflows

The analysis reveals that sediment tends to accumulate more in swale overflows located in catchment areas with a higher percentage of impermeable surfaces compared to permeable ones. However, additional factors such as the intensity, duration, frequency of rainfall events, and the characteristics of the connected area can also influence sediment transport and accumulation (Rietveld et al., 2020). Consequently, modeling sediment accumulation requires accounting for a broader range of variables to better understand the mechanisms behind sediment transport and buildup. This accumulation ultimately affects swale performance and the quality of infiltrated water.

8.5.4. Overflows maintenance data analysis

Tracking the last maintenance activity and comparing it with the current situation of overflows can provide insight into the effectiveness of the current asset management and maintenance strategy. Repeated failures may indicate that either the maintenance activity was insufficient or the overflows in certain locations are more vulnerable than others.

The comparison reveals that, despite overflow cleaning, 35 overflows still have partial clogging, and 14 overflows have reached a state of complete clogging. Regarding elevation element issues, 7 overflows had this problem initially, and 3 of these still face the same issue. The total number of overflows with elevation alignment problems has increased from 7 to 11. Structural damage also appears to be a growing concern: initially, there were 5 failures, including 2 repeated ones. Since then, the number of structural damage failures has tripled, now totalling 15.

Moreover, the number of lost overflows on the site has increased from 15 to 26. Overall, the condition of the overflows is deteriorating, indicating that the current asset management approach is not effective. This situation suggests that maintenance expenses are likely increasing. Figure 8.18 demonstrates the worsening situation of overflows and the increase in high numbers of overflow failures since the last maintenance.

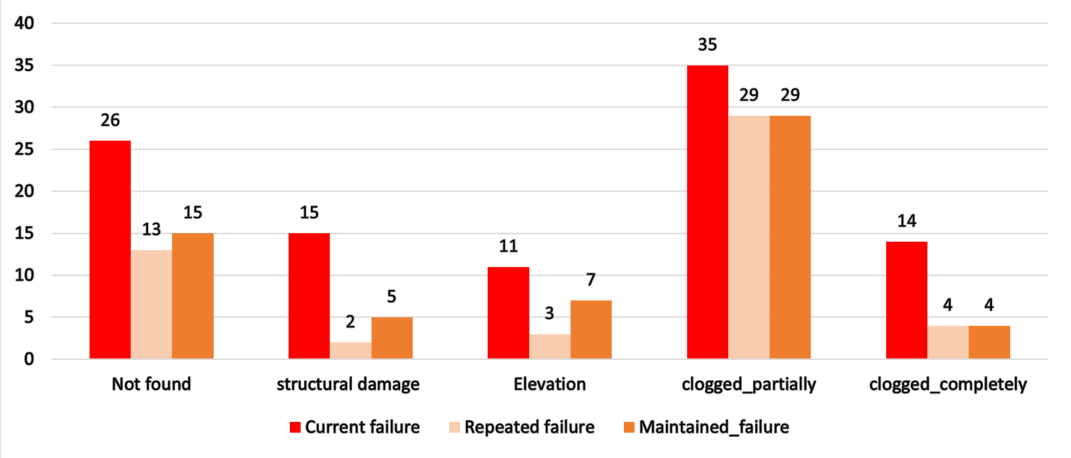


Figure 8.18: The worsening situation of overflows and increases in high numbers of overflow failures since the last maintenance

9 Discussion

This study investigates the possible spatial correlation between swale area characteristics and swale component failures by considering the reactive asset management approach of Utrecht municipality.

Swales common failures & spatial correlation

The inspection results of 210 swales revealed that overflow failure is the most common issue, particularly due to clogging, with only 67% of swales' overflows functioning properly and 5% reaching a failure state. In contrast, the vegetation layer is identified as the component requiring the most continuous maintenance, with half of the swales maintaining a well-functioning vegetation layer, while failure in this aspect is relatively rare, occurring in just 1% of the inspected swales.

Interestingly, the filter basin demonstrates the highest percentage of functioning components, underscoring the critical role of the infiltration process within this part of the swales. However, deterioration in the filter basins, even though detected in only 2% of cases, could significantly affect the overall performance efficiency of the swales. Additionally, factors such as tree density and swale age appear to influence the degradation of the filter basin.

The findings indicate that a larger impervious area within a swale's catchment correlates with an increased likelihood of failure in various swale components. Although failures in the vegetation layer and filter basin were relatively few, the association between these failures and the impervious area was not thoroughly explored. Clogging issues, particularly complete clogging of swale overflows, appear to be associated with a high percentage of impermeable areas within the catchment and a smaller length-to-width scale. In contrast, partial clogging tends to be more prevalent as the catchment size increases and when the length of the swales is significantly greater than their width.

Regarding sediment accumulation at the overflows, the analysis of 201 overflows suggests that proximity to the inlet leads to greater sediment build-up. Moreover, swales associated with more impermeable areas, as opposed to green spaces, tend to experience quicker sediment accumulation. It is important to note several factors, such as rainfall intensity, duration, and the type of vegetation layer, which can influence sediment accumulation, were not included in this analysis. Despite this, the impermeable area has emerged as a significant parameter in this context.

Result comparison with literature

The results of this research indicate that clogging is the most prevalent failure in infiltration practices like swales, consistent with the findings of previous studies by (Erickson et al., 2013), (American Society of Civil Engineers, 2019), and (DelGrosso et al., 2019). Additionally, misalignment appears to be a significant issue for Sustainable Urban Drainage Systems (SUDS). Although misalignment is not a component of swales themselves, it is a critical design criterion. This research reveals that 14% of the inspected swales have an obstacle blocking the water runoff flow into the swales, primarily due to misalignment with surrounding urban infrastructure, such as pavement. Both clogging and interference with obstacles have been identified in prior research by (Vollaers et al., 2021) as significant technical challenges facing SUDS.

Data collection through inspections

Visually inspecting swales can provide a rapid and quantitative assessment of their condition. However, this approach often overlooks critical components, such as drain pipes and outlets. Failing to inspect these elements may lead to undetected issues that significantly impact the effectiveness of the swales. Furthermore, not examining these failures and their correlation with catchment and area characteristics limits the understanding of how various factors influence swale performance.

Dataset influence on the results

The sampled data considered in this research represents approximately 27% of the total swales in the study area, covering about $55\,000\,\mathrm{m}^2$ out of $202\,000\,\mathrm{m}^2$. Due to missing data on overflows, dry swales with overflows were more heavily sampled, with 160 instances compared to only 50 dry swales without overflow. Consequently, analyzing the potential correlation between the failures of dry swales without overflow and catchment characteristics did not reveal a strong correlation, particularly due to the limited number of detected failures in the small data set.

Practical implication

This study underscores the importance of improving swale asset management. This improvement is especially important, as only 67% of the inspected swales are functioning properly, while 7% have at least one component that has reached a failure state. Regular inspections are a key method in adopting proactive asset management, helping to identify and address issues before they escalate.

Study limitation

This research was conducted in March, at the end of the wet season in the Netherlands. This period is characterized by few rainy days and potentially lower rainfall intensity. Conducting this research in a different season could have led to different findings and a variation in failures occurrences such as standing water at the filter basin. Furthermore, the use of satellite images with 0.25 m^2 resolution influenced the analysis of swale catchment, undoubtedly using higher resolution data could have improved swale catchment estimations. Additionally, the challenge of accessing swale outlets during inspection led to their exclusion from the analysis. As a result, the condition of these components was not assessed, leaving potential failures unexamined and unaddressed in this study. Another limitation of this study stems from the incomplete documentation of swale data, the absence of construction details for most of the swales and the lack of documentation for 15% of inspected overflows which constrained the analysis and reduced the dataset, impacting the validation of research findings.

Result interpretation

The results of this research are heavily reliant on the findings from visual inspections and the assessment of failures. While meeting operational standards suggests that swales are functioning well, the estimation of their condition such as the need for routine maintenance, approaching failure state and the severity of any damage—can be subjective and dependent on the inspector's judgment. The design of the inspection form, including different factors and how failures are categorized, could also influence the results, leading to potential variation in how certain failures are interpreted. However, some causes of failure were not related to the natural deterioration process. For instance, bare spots in the vegetation layer were often caused by pedestrians or vehicles crossing over the swales, rather than by ageing and degradation of the swales themselves. These factors were excluded during the analysis.

Additionally, the size of the dataset and the number of swales sampled should be considered when comparing these findings to larger datasets. Besides that, some characteristics of the swales' areas, such as subsidence and underground soil type, were not included in the analysis due to the limited detection of related failures. However, this exclusion does not mean these factors are irrelevant; they could influence certain types of swale failures and more investigation is needed in future research.

10

Conclusion & Recommendation

This chapter describes the conclusions that are drawn from the results of the swales visual inspection in chapter 7 and the analysis of the area characteristic and the inspection data in chapter 8. The conclusions are based on the research questions described in chapter 3. Further, some recommendations for aspects that were outside the scope of this study are to be taken into account in future research during the analysis and modelling of SUDS failures.

10.1. Conclusion

This study set out to assess the performance of two types of dry swales: with and without overflow in Utrecht, Netherlands, by evaluating their performance in managing stormwater under the current reactive asset management approach. This research focused on determining how the area characteristics of the swale's location and catchment area affect the susceptibility of its components to failure over time. The visual inspection and condition assessment aimed to identify the types and causes of failures in the swale's components, as well as determine whether these failures are correlated with the spatial characteristics of the swale's surrounding environment.

The findings of this research indicate that all components of swales are susceptible to failure over time, with varying failure rates. These failures are primarily attributed to a lack of maintenance activities and a reactive approach to swale asset management in the Utrecht municipality. Additionally, flawed design alignment with surrounding infrastructure causes missing the beneficial use of swasles. This study also reveals that overflows, often situated in catchment areas with a high percentage of impermeable surfaces and swales with a length-to-width ratio close to four, are particularly vulnerable to clogging failures. Factors such as ageing and tree density in a catchment area also contribute to issues like standing water in filter basins. However, the analysis of dry swale without overflow, which accounts for one-third of the sample, did not show a clear correlation between impermeable area percentage and failures in vegetation or filter basins, likely due to the limited number of observed failures. These inspected failures aligned with reported data showing clogging and misalignment are the most frequent types of failures among others.

The impervious area in a swale catchment was used in the analysis because it generally increases with the catchment size and shows a strong correlation with a higher percentage of failures, unlike the impermeable/surface scale which did not reveal any clear pattern or link with the different types of failures.

Sediment accumulation at swale overflows suggests that sediment tends to build up more in catchment areas with a higher percentage of impermeable surfaces. However, this alone cannot fully explain sediment accumulation, as it is influenced by multiple factors. Further research is necessary to identify and incorporate these variables into more comprehensive models for a clearer understanding. The study does affirm that the extent of impermeable areas is a significant factor in sediment build-up, even though it is not the sole determinant.

The outcomes of this study offer a practical approach for estimating the swale catchment areas in urban settings and swale failures through visual inspection and analysis of potential causes. These findings underscore the need to shift from the current reactive asset management approach to a proactive approach. This necessity is evident when comparing the number of overflow failures identified during the last maintenance activities with the current situation, which shows a significant increase in failures and, consequently, in maintenance costs.

Additionally, establishing a database of inspection data will facilitate future research and support the implementation of predictive asset management applications to better understand swale failure mechanisms. Parameters such as the percentage of impermeable area in the swale catchment, tree density, and the age of the swale could be incorporated into machine learning models to predict swale failures, contributing to the development of a more comprehensive and accurate model.

The importance of swales can be easily seen by their wide application in urban areas and their crucial role in managing stormwater runoff. Implementing an effective asset management approach not only enhances the efficiency of swales but also mitigates the risk of urban flooding. Therefore, regular inspection and monitoring measurements are essential for gaining insight into swales' functionality and degradation as well, which can inform improvements in swale design and promote the adaptation of more sustainable urban drainage systems. In conclusion, robust asset management for SUDS contributes to creating more resilient and sustainable urban environments.

10.2. Recommendation

Inspection planning

When inspections are planned and conducted regularly, they serve specific purposes in assessing the condition of swale components. The goals and methods of inspection differ depending on whether the maintenance is routine, non-routine, or remedial. Each type of maintenance requires distinct measures and the inspection of different indicators. During the design of an inspection plan, it is recommended to consult the table 7.5. This table provides valuable information on the appropriate type of inspection for each maintenance type and the timing of these inspections regarding the swale's lifespan.

Record documentation

Data related to swales, such as design and maintenance should be systematically documented, and securely stored. Moreover, failure data need to be collected quantitatively and qualitatively. Therefore, it is recommended to establish a database for previous inspections, as this record helps in effective swales management and in planning future maintenance activities.

Sharing responsibility

Vegetation maintenance tasks, such as mowing the grass and managing vegetation, can be shared with residents living near the swales. This collaborative approach can significantly reduce maintenance and operational costs. However, regular inspections are still necessary to address technical failures and to ensure that swale areas are not misused, such as inappropriate planting in the filter basin—a practice that has been observed on a few occasions during inspections.

Examine different vegetation layers

During the inspection conducted for this research, various vegetation layers were observed. However, the specific types of plants and their impacts were not within the scope of this study. Future research could explore the effects of different vegetation types on swale performance, particularly in areas such as sedimentation removal, infiltration rates, and resistance to drought or inundation. This could provide a deeper understanding of how vegetation choices influence the effectiveness and resilience of swales.

Infiltration load

In this research, swale catchment areas were estimated using QGIS software. By integrating these estimations with rainfall data in a model, valuable insights could be gained into the volume of stormwater runoff entering the swales and its correlation with the measured infiltration capacity. This analysis could help assess swale functionality and condition. However, the lack of a comprehensive model that accurately represents SUDS and conventional sewerage systems remains a significant challenge, requiring further research and extensive model calibrations. Additionally, the accuracy of these estimations depends on accounting for various parameters, such as roughness coefficients and highly accurate DEM models.

Infiltrated water quality

The quality of infiltrated water and pollutant removal was beyond the scope of this research. Nonetheless, employing a similar approach to investigate spatial correlations related to contamination in the swale top layer could offer valuable insights into pollutant accumulation and the overall effectiveness of swales in managing water quality.

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A

Appendix

A.1. Municipality registered swales data

WADI_id	Construction_year	Perimeter	Surface	Guid	IMGEOID	Administrator	Neighbour	Street
174	2022	134.1151531	287.672325	{83B41CCA-7FDF-4ABB-ABC8-C21F9EFD3F0A}	G0344.0884012cc0314a92a0519281da2b7fe3	Gemeente Utrecht	VLEUTEN - DE MEERN	Coelhorst
241	2007	174.15	749.74	{141F2744-4487-45ED-AA45-37BC57157F5A}	G0344.e9ae4bb61a43400f90af4c7f8173f218	Gemeente Utrecht	VLEUTEN - DE MEERN	Eyckenstein
472	2007	81.91951582	205.053986	{54260240-0228-4357-B221-9B658A7DD39E}	G0344.24c4bb3388384ac0bb7acd5ba14590a0	Gemeente Utrecht	VLEUTEN - DE MEERN	Beukenburgplaats
473	2007	60.20832106	142.8695835	{E60AC06E-BCCB-4163-B5D3-F3689D937A36}	G0344.144a12f6611b49afa4e1ea5d95ee0963	Gemeente Utrecht	VLEUTEN - DE MEERN	Beukenburgplaats
1023	2007	114.32	66.8091305	{03DE53CE-9C81-4AE6-A245-00201D3D2DFA}	G0344.be74793ff5f04b3587671cb41998e605	Gemeente Utrecht	VLEUTEN - DE MEERN	Splinterenburgplaats
1024	2007	50.68	54.4524815	{C32487D4-AECC-48C2-B33F-E72F75E82F1B}	G0344.5031ce28df9a4217b898fbcabd758b69	Gemeente Utrecht	VLEUTEN - DE MEERN	Soesterveenplaats
1038	2007	19.12	18.251911	{862F01C1-DCCB-4F4B-AEA6-BCF82527FA19}	G0344.90342479569148 92be9fa898f9f21ae4	Gemeente Utrecht	VLEUTEN - DE MEERN	Soesterveenplaats
1051	2007	65.25	154.95612	{98F6F3E1-62ED-47D1-9BD5-D0FD52A6B72E}	G0344.d92bae39519043119eb949bafaa13301	Gemeente Utrecht	VLEUTEN - DE MEERN	Bokkeduinenplaats
1058	2007	32.31	18.8037065	{C9AD67BE-EA67-4CE9-BE16-D75DDF3102B4}	G0344.3d499e9209224e6eab64418c0b91dad2	Gemeente Utrecht	VLEUTEN - DE MEERN	Beukenburgstede
1060	2007	36.42	65.41119	{5B869C3B-1AF8-4464-BF84-237B53EE82A8}	G0344.38082918f7684f2c95e01bf0144c91a2	Gemeente Utrecht	VLEUTEN - DE MEERN	Beukenburgstede
1061	2007	47.29	91.3050915	{630E5A2F-B175-40C1-BA90-5827ACCFBDD4}	G0344.b991f7501070482f848ef2a5ce25b36b	Gemeente Utrecht	VLEUTEN - DE MEERN	Beukenburgstede
60	2009	26.59	42.505597	{83E91CF9-D4BF-49B0-B9D4-650FFA95CD6F}	G0344.2a6474ee38b54d6188e88d7384c941ee	Gemeente Utrecht	LEIDSCHE RIJN	Dillestraat
102	2002	26.59	42.7169335	{0366E2CF-1A9E-42FA-B7B5-FEDEAE10DA22}	G0344.7c875ea961c74cbfa61a03595d36e53c	Gemeente Utrecht	LEIDSCHE RIJN	Selderiestraat
147	2002	27.07	44.09	{C3241E21-B5D5-4481-B392-20A0E49F466C}	G0344.e0971e3cdc9543f09d530278da824032	Gemeente Utrecht	LEIDSCHE RIJN	Dragonstraat
444	2002	26.59	42.896332	{796F1B96-DE32-4972-9614-A8A2FE0FEE2B}	G0344.133b04f5d1224cc28a0e26130e5dcc25	Gemeente Utrecht	LEIDSCHE RIJN	Selderiestraat
449	2002	20.19	26.4776645	{FF7B8360-BD75-4308-82B0-F13B417969DE}	G0344.35f024a5dff8491eb7de1452c0185520	Gemeente Utrecht	LEIDSCHE RIJN	Dillestraat
626	2002	26.17	41.64266798	{0F04B99C-A6C6-4B8E-893D-86733962AAE5}	G0344.dc3f7aec36bd4e06a85b4cccec0cce9b	Gemeente Utrecht	LEIDSCHE RIJN	Dragonstraat
1309	2007	38.06	19.7214725	{5B58E8C5-D88A-43A3-A5A9-2662486B154E}	G0344.4404f6d57b22404993611ffb90933a19	Gemeente Utrecht	LEIDSCHE RIJN	Vogelvlinderweg
1341	2021	66.68	60.96843581	{E2FDAA6B-2B16-4579-9729-4DC93414F945}		Gemeente Utrecht	LEIDSCHE RIJN	Kees van Dongensingel
1342	2021	83.05	108.2288355	{08D17084-1481-476B-8973-45A4BB758E7C}	G0344.9cc35dc533f44c68b493e241a88eacd4	Gemeente Utrecht	LEIDSCHE RIJN	Kees van Dongensingel
22	2006	258.8591925	470.50993	{FD5ED38B-3942-420B-A054-CD288D43E903}	G0344.f3eeaab7c9064a95a58ac776da06368e	Gemeente Utrecht	VLEUTEN - DE MEERN	Busbaan Vleuterweide
144	2006	139.13	280.18	{D1492483-6E36-480D-B369-553FD8950537}	G0344.a07acf315f4b4f63b019a10d7db9ed54	Gemeente Utrecht	VLEUTEN - DE MEERN	Mattenbieslaan
238	2006	59.73	129.16	{30C03E2E-5C74-4FF7-BC40-080392CCBB62}	G0344.b39797d1c71446b19a50935ea8ca890e	Gemeente Utrecht	VLEUTEN - DE MEERN	Knolruskade
737	2004	178.558382	353.3951505	{11AF3510-B0E6-4BAF-8BA5-3323FA89EE81}	G0344.167730302e6c4c218618e4ee7971a978	Gemeente Utrecht	VLEUTEN - DE MEERN	Souvenirperenlaan
738	2004	123.2146006	248.630997	{313F7AE7-FFE0-4F56-AEBF-C794AC6149D0}	G0344.f74d4e37abf44ddc91d132d5dd827924	Gemeente Utrecht	VLEUTEN - DE MEERN	Mostperenlaan
1148	2006	40.12	26.457697	{64033133-FD9C-4D33-B88F-EC076651A4A1}	G0344.848db5adcd404bd482f75ef09b9b15bb	Gemeente Utrecht	VLEUTEN - DE MEERN	Veldruskade
1290	2004	31.68	23.4870505	{4F8AC325-0DE0-4AF9-ABC3-EF487F5C8461}	G0344.33f3cbc1479e47a3b2f15b4fa42bddc1	Gemeente Utrecht	VLEUTEN - DE MEERN	Conferenceperenlaan
1291	2004	66.12	130.914819	{F4E97350-3691-48DA-A28C-28364CA40FC8}	G0344.3ca8fb58a4804ab29b225c6ac1bdaa0c	Gemeente Utrecht	VLEUTEN - DE MEERN	DoyennÃ©perenlaan
1307	2006	69.42	174.485225	{CB00FFF9-F026-4998-8A1B-48A70B895A0A}	G0344.64e4e8a2e0e34d138d7ef6197d2a30f6	Gemeente Utrecht	VLEUTEN - DE MEERN	Utrechtse Heuvelrug
1308	2006	67.59	28.102289	{CBF9AF13-F749-4DA4-AE24-46740FF47774}	G0344.07c10c4051a1420193c5fbb150dbd67f	Gemeente Utrecht	VLEUTEN - DE MEERN	Utrechtse Heuvelrug
1353	2006	44.06	44.4910795	{34230F45-5C6C-444F-A3E4-D7DBD28A5F46}	G0344.5606cca316d44da18651f196d721f54f	Gemeente Utrecht	VLEUTEN - DE MEERN	Zilverschoonlaan
619	2010	98.53	249.82955	{01B2E515-54CB-49B6-9739-FA01E26D0385}	G0344.3d895a7aad594ef88f040ea16e9e7478	Gemeente Utrecht	LEIDSCHE RIJN	Ab Harrewijnstraat
175	2000	516.27	289.1587205	{57A3A653-F243-49B1-9531-5CF4457CE362}	G0344.3efa5dd611ca4c4e947dfe84c23f6658	Gemeente Utrecht	LEIDSCHE RIJN	
899	2000	141.96	23.689028	{FEDCEAB4-4E98-4B93-B702-1C7696E32073}	G0344.9affff68ace848fcb273e49ca8e1877f	Gemeente Utrecht	LEIDSCHE RIJN	
1356	2000	95.93	17.360777	{1D79E2B6-5900-4D17-B259-3598F0232EAE}	G0344.dcfbd4277b9543bfbf8d2452bf7e1500	Gemeente Utrecht	LEIDSCHE RIJN	
953	2010	295.73	457.678458	{786DB3B4-B1C6-45B8-8FB2-D0748AE37B51}	G0344.f90b26a849fb4aab9034fd9b9dfe580f	Gemeente Utrecht	LEIDSCHE RIJN	Cuypersplantsoen
955	2010	254.7	379.197474	{2A591AB6-3AD5-449D-B019-88B824B4E865}	G0344.837f75c3779c4cfbadec83dcef986486	Gemeente Utrecht	LEIDSCHE RIJN	Cuypersplantsoen
957	2010	68.43	45.493912	{0673539F-CFD2-40E1-BECA-F9F5CF972F1B}	G0344.cdf369e41e8d4ad28ef847bdf6886dbc	Gemeente Utrecht	LEIDSCHE RIJN	Cuypersplantsoen
1013	2000	69.19		{333A7F89-CF71-4E67-945C-A4E15CA5BC4F}	G0344.fd551b2331ef4a11ad1c4081cb3a99e9	Gemeente Utrecht	LEIDSCHE RIJN	
1016	2000	163.99		{8795A1F0-8EA9-4FC6-BE73-2C090AD6E380}	G0344.49bd665d4cb446ea91c9e7a495b49d00	Gemeente Utrecht	LEIDSCHE RIJN	
410	1975	85.13	86.78	{5C578AB0-A858-43EE-8846-696A4ADD7CDE}	G0344.d26f974b388f4e7ebc89fd6fdf7e144b	Gemeente Utrecht	LEIDSCHE RIJN	't Zand (M)
269	2000	255.16	1074.293103	{AF9D9648-D37D-4A95-BBB9-C5FDADF4C580}	G0344.5681d1e43f4b4c11a8756146466a8b8e	Gemeente Utrecht	LEIDSCHE RIJN	Klifrakplantsoen (U)
278	2000	216.52	950.642094	{0E8660D0-EACB-45FC-8276-A501791937D3}	G0344.6d04808a6d8242e9b7ead6376e6a3cb4	Gemeente Utrecht	LEIDSCHE RIJN	Klifrakplantsoen (U)
311	2000	116.86	511.4944106	{EAACA5B8-13F2-4267-AF48-2FF2B6E63DEC}	G0344.e00034a3f1f448a383cbe50566af68ee	Gemeente Utrecht	LEIDSCHE RIJN	Klifrakplantsoen (U)

WADI_id	Construction_year	Perimeter	Surface	Guid	IMGEOID	Administrator	Neighbour	Street
453	2000	248.71	1102.396903	{AF5282EC-45E0-422B-AEA6-0A6BABD12B08}	G0344.cd079a7056634a1f9d7c4fca05b83e81	Gemeente Utrecht	LEIDSCHE RIJN	Klifrakplantsoen (U)
936	2023	149.63	64.025315	{7DEAC564-415B-450D-BF47-E5650C9F0C33}	G0344.b09718a347c94f9e81404990caadab59	Gemeente Utrecht	LEIDSCHE RIJN	Woudsenderraklaan
938	2000	108.54	50.249638	{6E7E3DE0-AAB1-42D3-8BD9-46A0C8D208C1}	G0344.e7810ea53579437786e4821aabf42864	Gemeente Utrecht	LEIDSCHE RIJN	Koldijksterraklaan
950	2000	109.74	56.934715	{882F543C-8081-4460-B9A4-8F2113C68178}	G0344.a9d4fc06377845b29ceefa6c19b05102	Gemeente Utrecht	LEIDSCHE RIJN	Woudsenderraklaan
590	2003	253.8995512	231.08146	{AC831E3C-370F-4140-A507-47566B94E536}	G0344.3d37ea1dd7c14535bb1a2a895144e0f3	Gemeente Utrecht	VLEUTEN - DE MEERN	Koolwitjeslaan
94	2000	94.37	98.72	{60CBAC86-8C7D-43A1-A2BC-BAF11E6D9D82}	G0344.ef882057c3c84c37912171648837328e	Gemeente Utrecht	LEIDSCHE RIJN	Scheurraklaan
379	2000	85.01	111.17	{6D3A49B6-B121-4A86-92A1-A4531013BBB7}	G0344.41d5753224eb434d8d50bdb884e9d4c8	Gemeente Utrecht	LEIDSCHE RIJN	Scheurraklaan
149	2009	483.5823941	2995.540389	{068DF9F9-59A0-403D-8F1A-D5B4F4B21D8C}	G0344.a176c080ae244b1f9a4f95960101b1c6	Gemeente Utrecht	LEIDSCHE RIJN	Kreekraklaan
235	2009	148.66	372.01	{29F4B0E1-74AC-4785-AF62-788F52FF2FAD}	G0344.30e996d5b16e4798af413a97581e14d9	Gemeente Utrecht	LEIDSCHE RIJN	Slingeraklaan (U)
448	2009	124.23	330.6	{05D93D3D-C1A2-46DA-BC87-6AFC5B9E186C}	G0344.b134339f95194102bb88cb4a2d90168d	Gemeente Utrecht	LEIDSCHE RIJN	Slingeraklaan (U)
164	2000	640.9122822	945.51362	{FCF5484E-965F-41B7-9A9C-5A99509E89FE}	G0344.211ea4df64af4b44a0b45d4c1e41936c	Gemeente Utrecht	LEIDSCHE RIJN	Kreekraklaan
385	2000	347.87	894.07	{9CB12F0C-309D-4471-9842-1D59A8E2ADF0}	G0344.7ca17a09eddf4b678b29a90869992717	Gemeente Utrecht	LEIDSCHE RIJN	Houtrakgracht
573	2006	528.04	681.15	{B8BEC1F9-5163-4DC9-B732-6BB7558BB695}	G0344.d2b03a2d9fab440b80359aa24d21fe30	Gemeente Utrecht	LEIDSCHE RIJN	Vleutensebaan
574	2006	593.2488162	2604.342108	{972DB5AA-9BAF-4AC9-BA7D-7DED5D6BC4EC}	G0344.954aed759f144e34aa10f50b0d425119	Gemeente Utrecht	LEIDSCHE RIJN	Vleutensebaan
580	2006	500.16	480.41787	{BAB19008-FE4B-43B2-B4F1-F4F03B84354F}		Gemeente Utrecht	LEIDSCHE RIJN	Vleutensebaan
581	2006	443.3657955	1801.116802	{9BF1ABAB-9124-4E46-8891-B4C143D41A10}	G0344.ef317c72742148a89d2a37064b6851d7	Gemeente Utrecht	LEIDSCHE RIJN	Vleutensebaan
583	2006	593.2671887	867.393825	{CAEF245E-FA42-4835-9083-48E01871C3D5}	G0344.f5791109efa6449c8aa22750a4764005	Gemeente Utrecht	LEIDSCHE RIJN	Vleutensebaan
584	2006	820.09	934.884174	{F0B01031-052F-4560-8F4E-A8C6626C5CF9}	G0344.2e2adeb0dc134631a9de9153acb6d999	ProRail	LEIDSCHE RIJN	Vleutensebaan
585	2006	274.7038409	1210.543854	{C44E73F0-5A0B-4CDE-874E-CE92DFBE43C5}	G0344.47710480f3ea48de8b5235fe5bfb509c	Gemeente Utrecht	LEIDSCHE RIJN	Vleutensebaan
136	2003	95.81	220.6	{20BEE873-9ED1-45B8-B684-189F7ADD12DA}	G0344.827729993a294372848fe28c90c734db	Gemeente Utrecht	LEIDSCHE RIJN	Zandooghof
298	2003	106.44	259.69	{9067DCB3-582B-45B1-AF75-74462A63478A}	G0344.39fb6511cf3d4ce7bfb1889658eb0616	Gemeente Utrecht	LEIDSCHE RIJN	Zandooghof
351	2003	96.65	218.53	{C5CD8015-0183-4671-BA62-5BF7F45D8279}	G0344.763587a3904744b89bb22780d89973c2	Gemeente Utrecht	LEIDSCHE RIJN	Keizersmantelhof
5	2004	90.06	182.6688392	{6E4708D3-4606-4478-AB50-803A9C04ACD2}	G0344.999fde8ad471408cabf1aeccabe67d81	Gemeente Utrecht	LEIDSCHE RIJN	Franz von SuppÃ©hof
115	2004	48.37	60.290278	{24227B67-080B-4C2A-86BE-32CF6EB287E3}	G0344.5141527da39846de86a117db1c935b99	Gemeente Utrecht	LEIDSCHE RIJN	Paul Linckehof
342	2004	48.97	66.19	{98663A83-DD70-4FC6-8CFE-E41DA8EB8D1A}	G0344.a7230c8faa2c4f41b340d344a1560965	Gemeente Utrecht	LEIDSCHE RIJN	Jara Beneshof
383	2004	56.01	85.6935235	{86778E6D-D7F6-4D4B-BEBE-0B726D8CD420}	G0344.5f51f38e12824e7e8e47737d747b9234	Gemeente Utrecht	LEIDSCHE RIJN	Franz von SuppÃ©hof
393	2004	52.55	69.12	{19C93C08-BD5A-447D-BA4D-651197481137}	G0344.523f95edd6ec4881b4fea6427c40e820	Gemeente Utrecht	LEIDSCHE RIJN	Arthur Sullivanhof
424	2004	196.82	348.106014	{DB8BCC67-C033-4D5E-8E4D-2843FE7F98E1}	G0344.101a293dcb0145e0aac900561c335dab	Gemeente Utrecht	LEIDSCHE RIJN	Franz von SuppÃ©hof
40	2000	192.7	452.12	{A0272F3F-F9A1-499E-BD82-173FAD0D12FE}	G0344.dace1372e5dd40c795353a87f15bd43a	Gemeente Utrecht	LEIDSCHE RIJN	Stobberakplantsoen
392	2000	88.87	137.46	{4639F195-55C4-4602-948E-23ED8F894E64}	G0344.2d16cf230efb465d8a73af1df00e9568	Gemeente Utrecht	LEIDSCHE RIJN	Stobberakplantsoen
420	2000	245.0474452	345.5023035	{C5816A8E-BC83-4448-B6F1-CBB8541221C1}	G0344.a5da7ed2874f4a7d989a1dcfad2cb66b	Gemeente Utrecht	LEIDSCHE RIJN	Stobberakplantsoen
927	1940	118.54	144.6514075	{2CF42F63-B07F-42A9-AD8D-2C10D645AB47}	G0344.cc7b27b7cac943698244b68807023385	Gemeente Utrecht	LEIDSCHE RIJN	Stobberakplantsoen
33	2004	61.24	80.1012055	{863E7D7A-3C3C-4A56-A4C0-66A893E177DF}	G0344.ef813e119d2b4cd3baaf31927fc46783	Gemeente Utrecht	LEIDSCHE RIJN	Edmund Eyslerstraat
451	2004	57.51	88.52	{459C1624-2060-4611-82DB-B7D33D58AE4C}	G0344.fb33f0faa11e4e08aedfd55f8b260a7f	Gemeente Utrecht	LEIDSCHE RIJN	Edmund Eyslerstraat
18	2003	465.55	697.34	{BEE35086-C324-487F-900C-924FFE1F67AF}	G0344.bdffb0a8e5ca4335b12cd970fe8293a6	Gemeente Utrecht	LEIDSCHE RIJN	Jean Gilbertlaan
319	2003	237.986054	418.0386545	{7BCEB644-D824-403F-B977-FE088E49431E}	G0344.9ebe0f1551eb4948831ed165319e00a8	Gemeente Utrecht	LEIDSCHE RIJN	Jean Gilbertlaan
247	2018	54.66	150.23	{98A06DF4-420D-4723-9A50-E7D91161CCAA}	G0344.947b577d21504d54b9e33245bb0b5019	Gemeente Utrecht	LEIDSCHE RIJN	Jerome Kernplantsoen
348	2018	73.66	179.5	{9858CA08-E5B9-422C-BA9D-B6338757BB0F}	G0344.c7451e1f731e46d097d6955e61370f4d	Gemeente Utrecht	LEIDSCHE RIJN	Jerome Kernplantsoen
77	2018	86.55	150.41	{95D4D133-CF02-4C6C-B147-F6F6C2F41008}	G0344.c0dec2981f3f4a56a19ee24622581131	Gemeente Utrecht	LEIDSCHE RIJN	Jerome Kernplantsoen
315	2018	63.93	143.69	{D263864B-C8AC-45F2-A813-7B563E411BCA}	G0344.3b07707ff9f64597b1a3e10c6d1db83e	Gemeente Utrecht	LEIDSCHE RIJN	Jerome Kernplantsoen
855	2003	502.2024252	823.5446893	{6BC482D6-AE29-45E4-BAE6-4BA002D225C9}	G0344.fff30f04582a49ba94b94d950d1c129e	Gemeente Utrecht	LEIDSCHE RIJN	Rozemarijnsingel
1431	2003	229.5923203	572.748104	{21F5EB95-A39E-40ED-A86A-34975A1EB83B}		Gemeente Utrecht	LEIDSCHE RIJN	Rozemarijnsingel
83	2006	121.93	115.2060425	{9C6DC445-33A4-41F1-96A9-D4C1366635F0}	G0344.30396debf3e54110a7f3883616097258	Gemeente Utrecht	VLEUTEN - DE MEERN	Amabilispad
186	2006	85.61	175.39	{D62CB212-ECAC-4CEC-95E6-5AC04EA6E15E}	G0344.6fb42e26e59a44a29a699b99308fdb06	Gemeente Utrecht	VLEUTEN - DE MEERN	Minorpad

WADI_id	Construction_year	Perimeter	Surface	Guid	IMGEOID	Administrator	Neighbour	Street
188	2006	124.32	112.640075	{21545E86-7398-41BA-BAF6-3A002DC0C077}	G0344.0f0919e159164ebf91307250ff61ad6a	Gemeente Utrecht	VLEUTEN - DE MEERN	Amabilispad
212	2006	85.51	175.16	{FC2FDC9F-0CE8-470C-AC38-0086C25640DC}	G0344.2dbc2e392ab84b95b6bd220cd6027c99	Gemeente Utrecht	VLEUTEN - DE MEERN	Minorpad
390	2006	62.12	101.119881	{74899D4D-36ED-468B-B2DA-5BBB4D54AEE4}	G0344.e15366696c97439fb0af8ba6e94fe36c	Gemeente Utrecht	VLEUTEN - DE MEERN	Corbulopad
396	2006	99.22	270.7	{3FFB73C6-4FD3-4EA2-A470-200024569E72}	G0344.e6cce6413e2a4e68b3f515ffaceb88a1	Gemeente Utrecht	VLEUTEN - DE MEERN	Corbulopad
49	2012	22.40942	15.4865365	{23F3B549-6DAE-4166-920A-E3866554354B}	G0344.d8f4472051de4b02bdaf6a4d538ee3f3	Gemeente Utrecht	VLEUTEN - DE MEERN	Beeldentuinlaan
177	2012	21.73340918	15.7417275	{63ECB9D9-5564-4E6C-BB17-CDC7C2D1E10B}	G0344.1f068503a8b94e4fb8703e12006ee921	Gemeente Utrecht	VLEUTEN - DE MEERN	Beeldentuinlaan
288	2012	53.73017369	43.0840855	{1C9AAA5D-3B2E-41B1-A4C5-2EEBA6A76ACE}	G0344.6064b20480ca428c8d196a8cef0383ba	Gemeente Utrecht	VLEUTEN - DE MEERN	Beeldentuinlaan
1457	2012	32.35297795	19.1738195	{901761A9-82D8-4F74-8B91-0DA99DFE84D1}		Gemeente Utrecht	VLEUTEN - DE MEERN	Beeldentuinlaan
505	2007	153.32	302.12	{154B3793-D280-48F2-981A-1356E6E19E6E}	G0344.a01da30de22940618eab4b9a3601180b	Gemeente Utrecht	VLEUTEN - DE MEERN	Burchtpromenade
527	2007	95.88	102.27	{5FFC994D-81B7-4218-8568-6F2C60EB6531}	G0344.4ae6353253a34203a43266601e9329b6	Gemeente Utrecht	VLEUTEN - DE MEERN	Trilgraslaan
534	2007	34.96	37.35	{B0520594-DF47-4F77-A603-0F8D0F1E48C2}	G0344.66950b2295c941f0b86786e3dd43fffe	Gemeente Utrecht	VLEUTEN - DE MEERN	Zwenkgraslaan
535	2007	53.64	50.47	{07A74EA8-8DDC-4BBD-ABA0-CCAEFFBBDB94}	G0344.c054103ce4f14aee8629b96be8d8e86a	Gemeente Utrecht	VLEUTEN - DE MEERN	Pampasgraslaan
542	2007	58.25	61.29	{DF15568B-C297-47F3-8AC3-5239EB0FBB1D}	G0344.2cb2e7e3fb7a4826988e85abce7383b1	Gemeente Utrecht	VLEUTEN - DE MEERN	Siergrassenpad
549	2007	48	55.86	{52D4844B-260D-42AF-8F3C-EAA8BC1FCC03}	G0344.64e241dccfc94312ab1604968248ecef	Gemeente Utrecht	VLEUTEN - DE MEERN	Zwenkgraslaan
551	2007	51.81	61.07	{E51649A2-49DA-4625-BE8D-F5B99D99F473}	G0344.38faaf649f734007b6b47bd9975348c7	Gemeente Utrecht	VLEUTEN - DE MEERN	Zwenkgraslaan
557	2007	50.22	66.89	{6CBDC917-F8B1-4F50-B069-FD75F9D2ABAE}	G0344.72aa8d41c8c54342bd368805370e8be3	Gemeente Utrecht	VLEUTEN - DE MEERN	Siergrassenpad
560	2007	52.53	51.46	{138738A4-3BC5-4369-8237-99A9530E2812}	G0344.da42e73bfc9b497aba3b08b319c68872	Gemeente Utrecht	VLEUTEN - DE MEERN	Trilgraslaan
561	2007	70.12	73.94	{DC8AD3B0-F423-4D70-A3DE-06DDBFD553A0}	G0344.9427fd1f259b43ed90c69fc807b8961b	Gemeente Utrecht	VLEUTEN - DE MEERN	Trilgraslaan
587	2007	129.85	151.81	{2A25A5E1-F576-406F-81F4-6A13F3DB25CF}	G0344.668d6ac78bd3418495b59be9e9cba54b	Gemeente Utrecht	VLEUTEN - DE MEERN	Trilgraslaan
593	2007	58.02558944	32.984829	{7F81BEAE-7401-4E9C-A6B4-3048CE704B39}		Gemeente Utrecht	VLEUTEN - DE MEERN	Zwenkgraslaan
1278	2007	61.67	40.6764425	{FC4F6E26-063F-40AF-89EB-A27752740FA8}		Gemeente Utrecht	VLEUTEN - DE MEERN	Pampasgraslaan
1287	2007	278.86	280.7431095	{B04E6DAF-4D26-4090-A0BB-166E03C59142}	G0344.0c6b3db59f4d4aef9a9059aafc85efc7	Gemeente Utrecht	VLEUTEN - DE MEERN	Beemdgrassingel
1516	2007	65.2600199	42.017545	{964351EA-9044-467F-B9C1-D3A99A65660A}		Gemeente Utrecht	VLEUTEN - DE MEERN	Pampasgraslaan
108	2011	74.08259373	65.6644855	{AC8854B5-F280-4DB5-92A1-0A5D31DC6D43}	G0344.60ea8d7e4488468ca3b091cf274b46da	Gemeente Utrecht	VLEUTEN - DE MEERN	Cantharellaan
112	2011	93.3	113.9019795	{EBA01E45-9680-45B5-BBC5-DB6AF3362F44}	G0344.f64a5d5a4e544c469435511b8e229a79	Gemeente Utrecht	VLEUTEN - DE MEERN	Cantharellaan
178	2011	129.24	155.248533	{B6153FD2-88B1-464E-9EED-FF68B1DA7985}	G0344.1163fe839ba3476fad583e2b918eda9c	Gemeente Utrecht	VLEUTEN - DE MEERN	Cantharellaan
290	2011	90.01	106.2921855	{C107CAE9-FAB6-4704-B49F-21739F1BC906}	G0344.bc4510a8ffad4569a812ec60100d7477	Gemeente Utrecht	VLEUTEN - DE MEERN	Cantharellaan
603	2015	195.61	262.0374235	{EEB5A422-6EE5-41FC-ABA3-A438558A5DD5}	G0344.70bb25e2f00b4321b486f0f65c6e3136	Gemeente Utrecht	VLEUTEN - DE MEERN	Bundelzwam
1554	2015	122.7412418	21.8314755	{29CB8B49-0E2A-4A22-AB1D-2D39D09813F0}		Gemeente Utrecht	VLEUTEN - DE MEERN	Beurszwam
611	2013	61.29	34.480251	{1BB25A4C-5538-4FF3-954F-55AA8D5C46CD}	G0344.b21f6810930744f38df5b6c9b82133cf	Gemeente Utrecht	VLEUTEN - DE MEERN	Cantharellaan
853	2013	75.51	35.784588	{DA8DC60E-916A-4994-BFBB-62F3491DFDB6}	G0344.a733a255bd5846099f0d699b443dfcfe	Gemeente Utrecht	VLEUTEN - DE MEERN	Cantharellaan
846	2017	42.1	21.65665	{CE8FF4FB-9625-49F3-AC0F-1662E387EBD6}	G0344.179f7d27c621409da05f783399ac8fb1	Gemeente Utrecht	VLEUTEN - DE MEERN	Chinesetuinlaan
848	2017	11.52	4.7585165	{D3DE2495-1E5F-4E06-AF62-3CBA94142215}	G0344.5da2042822bc448eb4339149f96e9329	Gemeente Utrecht	VLEUTEN - DE MEERN	Chinesetuinlaan
850	2021	21.1	8.9474845	{4A65EED0-634F-486E-9AAB-2ECC4A599A65}	G0344.0fe0e737a1ec4aa6980a2698d86078b4	Gemeente Utrecht	VLEUTEN - DE MEERN	Chinesetuinlaan
1019	2017	55.09	61.2335945	{37274CF5-EDFE-4BD1-BF4E-8302F3DFB4D1}	G0344.bb5e648eb55e439793d1f2adfc0a912b	Gemeente Utrecht	VLEUTEN - DE MEERN	Chinesetuinlaan
99	2000	158.15	896.06	{F927A13F-8BF0-4259-86CF-595ED718CA34}	G0344.d30db8d311b14b2c92cb5d7c944c166c	Gemeente Utrecht	VLEUTEN - DE MEERN	De Milan Viscontilaan
103	2000	151.21	582.43	{4B4A6506-5EE0-4C0F-BCB1-2598106A5825}	G0344.d536af7297cd4727ae9acd3480516888	Gemeente Utrecht	VLEUTEN - DE MEERN	De Milan Viscontilaan
399	2000	155.8931451	659.7587515	{551DBF7F-B255-46F8-A186-9E34AC0B9145}	G0344.193426b8694348c881d9492eb3be6d2c	Gemeente Utrecht	VLEUTEN - DE MEERN	De Milan Viscontilaan
1492	2000	94.20167291	126.5175735	{E8A8F6C8-FCEF-4E2E-A3D9-F6FB660E5D8D}		Gemeente Utrecht	VLEUTEN - DE MEERN	De Milan Viscontilaan
1495	2000	97.35220644	122.452472	{0CFF95F1-F500-42BB-A192-DF53E09C9413}		Gemeente Utrecht	VLEUTEN - DE MEERN	De Milan Viscontilaan
1497	2000	98.07263112	176.982874	{85517545-9466-429A-A522-D6FD993EBEBD}		Gemeente Utrecht	VLEUTEN - DE MEERN	De Milan Viscontilaan
1499	2000	92.83424138	152.672257	{1C99C024-699B-49C7-B056-B97524F3A196}		Gemeente Utrecht	VLEUTEN - DE MEERN	De Milan Viscontilaan
1500	2000	97.74656456	143.978668	{C1D06A97-F164-40AF-9044-87A9C53952BE}		Gemeente Utrecht	VLEUTEN - DE MEERN	De Milan Viscontilaan
36	2017	36.29	27.27372477	{98F00BEC-8835-44F0-9215-2AA811016B47}	G0344.ad0173ff25c346b2b9f3e97bffd4c597	Gemeente Utrecht	VLEUTEN - DE MEERN	Droomtuinlaan

WADI_id	Construction_year	Perimeter	Surface	Guid	IMGEOID	Administrator	Neighbour	Street
622	2017	52.62	47.35576464	{C310890E-B625-4AD1-9813-A95A7A6D5397}	G0344.287c820ddece445091daa5154dcb91e3	Gemeente Utrecht	VLEUTEN - DE MEERN	Droomtuinlaan
624	2017	52.77	38.90361518	{343E8824-94B1-412A-8B76-0E1E01267780}	G0344.4ff9b200793e4173b32ccabf3b9ca6ff	Gemeente Utrecht	VLEUTEN - DE MEERN	Droomtuinlaan
625	2017	62.39	54.62618985	{60242604-51D0-47A9-85C3-459DEA7C69D0}	G0344.b449e0d5fc114447aaf94fd15a9bbe06	Gemeente Utrecht	VLEUTEN - DE MEERN	Droomtuinlaan
38	2006	123.31	433.27	{7E67462C-51F8-4C33-AC9B-8D571BC3A599}	G0344.fe8c802810144d5f97ee04ca2dc50994	Gemeente Utrecht	VLEUTEN - DE MEERN	Heldammersingel
110	2006	57.5	85.166718	{3E79BDC8-4436-4668-BC20-3BD6DCDDED80}	G0344.19122d67496f4f8da08016dceabbbdfb	Gemeente Utrecht	VLEUTEN - DE MEERN	Corbulopad
121	2006	125.52	429.150644	{68E85D13-377A-4164-95B9-D4249652BB40}	G0344.13efc0612f6b4fd38fa9f7a5cf95d4fc	Gemeente Utrecht	VLEUTEN - DE MEERN	Heldammersingel
397	2006	94.11	164.080422	{6A30707F-E000-4F06-9FA5-2017748B0A59}	G0344.7afb5067a7124fec9efc530c77bbef75	Gemeente Utrecht	VLEUTEN - DE MEERN	Corbulopad
440	2006	149.94	265.756993	{155498B7-98DF-45E6-B06A-99A2A83B566A}	G0344.d416a25054c54e338cc2e2528f516fca	Gemeente Utrecht	VLEUTEN - DE MEERN	Corbulopad
994	2006	61.51	60.9038965	{42DE9BE5-9FF3-4817-B073-79C144C78FBB}	G0344.07f692e35ea44ec0bb85ad19191ea287	Gemeente Utrecht	VLEUTEN - DE MEERN	Corbulopad
998	2006	106.78	96.5745805	{A79079EB-193C-4392-822D-43CD77BEBB23}	G0344.233fa9a34abc4370be19f8724825b207	Gemeente Utrecht	VLEUTEN - DE MEERN	Corbulopad
1184	2007	1.73	0.168535	{93E7F87F-A017-4B61-82B9-14F40B3C09DB}		Gemeente Utrecht	VLEUTEN - DE MEERN	Helmbloemlaan
1324	2014	38.41	19.3081485	{A40DD350-182A-4505-A6F3-777197157CDD}	G0344.2f8480e122744e9d99834784bd8813ef	Gemeente Utrecht	VLEUTEN - DE MEERN	Moestuinlaan
1328	2014	38.17	17.273134	{C08FB024-40FB-4602-AA06-03AA926AE1B7}	G0344.7b3a19bb8fb24447ab13eab81fdfdb08	Gemeente Utrecht	VLEUTEN - DE MEERN	Moestuinlaan
232	2009	93.75907962	53.244013	{2596338E-1DBF-46AA-AA11-EDED29A14E29}	G0344.3fafc98b6f2a4c6390d3a302ab6bc612	Gemeente Utrecht	VLEUTEN - DE MEERN	Kruidentuinlaan
357	2012	163.0474081	100.4305	{BE72233B-70C1-4532-9EB4-65C18469CF3C}		Gemeente Utrecht	VLEUTEN - DE MEERN	Bloementuinlaan
414	2009	96.37024381	45.4333125	{F0331D9E-543E-41E4-81ED-3FC5D40F528B}	G0344.a668d18982cf44a1ae7b723d1a7cb020	Gemeente Utrecht	VLEUTEN - DE MEERN	Landschapsbaan
980	2012	247.5718218	301.0138135	{A0282D52-C87D-46C1-AF3C-EF001E5F66DA}	G0344.dd7be628c203466c8d228a3111a6946a	Gemeente Utrecht	VLEUTEN - DE MEERN	Seizoentuinenlaan
981	2012	311.7562129	162.3434	{B0DACCA5-DC4F-454E-AA60-A8A048E2E919}	G0344.ab9a6bf493604090803l4e754b948aee	Gemeente Utrecht	VLEUTEN - DE MEERN	Landschapsbaan
982	2012	121.39	48.7073695	{21A4792F-E3F8-496D-8A14-A402CB4AE081}	G0344.65945d4a4a7648c3be5dd001b9029d28	Gemeente Utrecht	VLEUTEN - DE MEERN	Landschapsbaan
1470	2012	161.6401798	79.6993195	{EBC93D8F-1572-4766-9595-3F5E73325222}		Gemeente Utrecht	VLEUTEN - DE MEERN	Bloementuinlaan
1478	2012	342.3076587	394.859915	{0B922D36-42DF-45E4-A2F3-E65A1E4A3FC6}		Gemeente Utrecht	VLEUTEN - DE MEERN	Seizoentuinenlaan
690	2004	141.7526831	168.2001405	{FA261A61-C866-43FF-93A8-3AE2CC8637FC}	G0344.6ab6518ef0ce4216922effcb8b99b15a	Gemeente Utrecht	VLEUTEN - DE MEERN	Madameperenlaan
691	2004	141.149404	150.139778	{B4972131-FE9D-4C03-BEB2-9A4302C6D2F1}	G0344.93b01518a6f048aa87f1038018b07e9e	Gemeente Utrecht	VLEUTEN - DE MEERN	Madameperenlaan
692	2004	189.4149244	123.2258835	{EB643E2E-D86C-4249-AD1C-C6EDF98EFDBB}	G0344.100020b927b84d95b667625c840ff003	Gemeente Utrecht	VLEUTEN - DE MEERN	Madameperenlaan
693	2004	188.71	136.3873215	{9085E50E-7C04-49E8-8DE7-6DD7CF088C26}	G0344.16bb5b25f23e491e9b7030a1f5c30846	Gemeente Utrecht	VLEUTEN - DE MEERN	Madameperenlaan
703	2004	142.8393548	113.0326125	{30A811E2-9015-4C8F-A2BD-3B3B44B67E86}	G0344.26b86919b38b4f6ab103463931011532	Gemeente Utrecht	VLEUTEN - DE MEERN	Madameperenlaan
707	2004	106.3298975	95.4925995	{5CE96D26-8CAC-47A2-980F-A8D0EF030FE1}	G0344.f94a0021e06d4accadc36686e5354638	Gemeente Utrecht	VLEUTEN - DE MEERN	Madameperenlaan
1068	2011	145.19	142.4358815	{09151274-9951-430A-8354-CB0C63DD24B0}	G0344.e9d6fd61424346b6a5799172a3534d01	Gemeente Utrecht	VLEUTEN - DE MEERN	Honingzwam
1428	2011	37.14331317	38.07745	{0B26F2C5-7269-43CF-9369-FABAE6933B74}		Gemeente Utrecht	VLEUTEN - DE MEERN	Paddenstoelenlaan
1429	2011	44.74557455	82.9702985	{83B7F29D-71E4-43EF-AC54-0C786E506788}		Gemeente Utrecht	VLEUTEN - DE MEERN	Paddenstoelenlaan
1544	2011	76.18626152	69.001307	{82B2CD02-8AE3-43EF-B196-0569102DDCF7}		Gemeente Utrecht	VLEUTEN - DE MEERN	Koraalzwamplantsoen
1549	2011	72.21145378	52.0673795	{70BB300E-A7ED-4395-85D5-77B3951D06C3}		Gemeente Utrecht	VLEUTEN - DE MEERN	Koraalzwamplantsoen
74	2009	1615.508216	971.2197285	{56AAA062-A102-44E6-8D8C-EC20FF66ADB7}	G0344.dc1774e6017f45d5baa1fb0fd3446172	Gemeente Utrecht	VLEUTEN - DE MEERN	Busbaan Oudenrijn
75	2009	413.6967131	321.472685	{D8C113FE-66D3-48FA-95AC-C80095DAFB9E}	G0344.185813392bd0402b84a5fbeeeb6e358b	Gemeente Utrecht	VLEUTEN - DE MEERN	Busbaan Oudenrijn
1551	2009	296.5127825	226.7431145	{C0145625-874B-45B0-AD10-A087FFEE0EB2}		Gemeente Utrecht	VLEUTEN - DE MEERN	Busbaan Oudenrijn
1021	2007	279.35	297.2249745	{7720ACFF-A86C-473C-8F51-4D70C9B43558}	G0344.088e70ed0b53491a804aa98a9b336dbc	Gemeente Utrecht	VLEUTEN - DE MEERN	Pleinesbos
1022	2007	158.1	163.466347	{B84B02FB-2120-457B-BDB8-2CCBCCBF49B4}	G0344.6dfe25c1d8ec4334aa575c4117b22d78	Gemeente Utrecht	VLEUTEN - DE MEERN	Pleinesbos
167	2000	216.34		{5DE3E05B-CD53-47DE-B7D4-2AFFADAA9AAB}	G0344.95b3b46eebdd4b3590eff6dce16a3f32			
230	2000	170.265264		{B398B792-D1EB-4D11-9804-00F59DE8ABC4}	G0344.b42e4ea77e6144278c9f0b2424eefd24			
293	2000	170.81		{85EECA1F-BB53-48F8-842F-6B20D126D8A3}	G0344.fbe278d0cdbb42f1ad92f524134dfc5b			
301	2000	273.83		{BF3AC110-9912-47B8-8BB0-AA58DC070692}	G0344.2cc76f816a654fba873df4cda8e891f2			
406	2000	270.12		{4374ACF7-2A0E-41FF-A25F-5645C4D20F7F}	G0344.5e191467b67b4a0d91857e009b6c9c59			
31	2005	107.95	240.2	{ED077844-9461-4BCF-A853-9D9DBF8CEB17}	G0344.e807750df4814dc8a9b8c8c89a03f278	Gemeente Utrecht	VLEUTEN - DE MEERN	Knolruskade
276	2006	105.35	238.46	{1CD9EBEE-CA4D-46B5-8A9E-356F493D9F70}	G0344.fdbedbd2ee6d4db9942c83d364e14f61	Gemeente Utrecht	VLEUTEN - DE MEERN	Veldruskade

WADI_id	Construction_year	Perimeter	Surface	Guid	IMGEOID	Administrator	Neighbour	Street
276	2006	105.35	238.46	{1CD9EBEE-CA4D-46B5-8A9E-356F493D9F70}	G0344.fdbedbd2ee6d4db9942c83d364e14f61	Gemeente Utrecht	VLEUTEN - DE MEERN	Veldruskade
339	2006	105.11	225.27	{7EEFC587-F36F-4686-96A5-C987A5C124D9}	G0344.630199a60659426ea616acc814d785c7	Gemeente Utrecht	VLEUTEN - DE MEERN	Waterbieslaan
389	2006	105.51	226.2	{609FC4C8-A099-4FD9-99FF-63C5240631D6}	G0344.40fa5000dd1346aba49752de433fdeca	Gemeente Utrecht	VLEUTEN - DE MEERN	Waterbieslaan
470	2006	93.02654286	204.8003795	{D52D55F1-111E-4BE4-AFCE-5A53412D8EB8}	G0344.b0d8fb5c79aa4bcea7f0fa7491b5e1ab	Gemeente Utrecht	VLEUTEN - DE MEERN	Rivierkom
475	2006	114.97	159.03	{3D4FCD50-54EC-48D1-9CD0-0CCB8793DC1F}	G0344.9701549dc4f64541a23840785a0c4bd3	Gemeente Utrecht	VLEUTEN - DE MEERN	Duizendknooplaan
566	2006	115.32	169.58	{91F2668D-484E-44FB-A14F-834915514A53}	G0344.5ac88788ce144dbea080db89fc631c5a	Gemeente Utrecht	VLEUTEN - DE MEERN	Duizendknooplaan
572	2007	304.52	696.203016	{D22BA5AA-EFDC-442D-9E80-A783158DE4E6}	G0344.1e741b47fc7d42adb2fd79b16373fa11	Gemeente Utrecht	VLEUTEN - DE MEERN	Rivierkom
586	2006	68.35	99.15	{5976B98F-6F3D-48E6-A5F0-30B29626A913}	G0344.1c9cbbc07226485eb112a6c7a8b7632d	Gemeente Utrecht	VLEUTEN - DE MEERN	Rivierkom
828	2012	24.26	12.129539	{27791F81-4FAB-4FDE-BC7B-DA24A730EF1A}	G0344.16ed68db30e24c1bb957536c11f18230	Gemeente Utrecht	VLEUTEN - DE MEERN	Sculpturentuinlaan
831	2012	14.67	5.109633	{AA6799C2-DBB6-4020-B4ED-6A6E57E73FE8}	G0344.e123d84cbd224e2ead8012b2999163a5	Gemeente Utrecht	VLEUTEN - DE MEERN	Sculpturentuinlaan
833	2012	14.04	4.642481	{30941C69-FC4F-4E9D-82BC-BEAB8AC82DE9}	G0344.ac0f86481b894aeda61b8a22aee35f8b	Gemeente Utrecht	VLEUTEN - DE MEERN	Sculpturentuinlaan
835	2012	60.61	22.418407	{048CA865-F35C-4402-A776-3FC6E0C5D74C}	G0344.384acccebf2c49a896ed7d201ffc77bf	Gemeente Utrecht	VLEUTEN - DE MEERN	Sculpturentuinlaan
839	2017	173.26	146.731778	{6B9145AB-26AC-4ED1-9EBA-8DAAC0AE2E75}	G0344.82594f99e1ad499e86bba68fd12d8241	Gemeente Utrecht	VLEUTEN - DE MEERN	Paradijstuinlaan
199	2006	259.3446831	432.463819	{DE044899-8845-48B5-AB41-6AA23DCE9A5B}	G0344.a5beb574ef6a42879a4f5867810cff1f	Gemeente Utrecht	VLEUTEN - DE MEERN	Utrechtse Heuvelrug
1135	2006	231.19	300.0322265	{A5E11FA0-B78A-444F-9990-9A3B11F6980D}	G0344.e5e3894b49fc49b39fd532db798dac98	Gemeente Utrecht	VLEUTEN - DE MEERN	Utrechtse Heuvelrug
1136	2006	175.49	261.3100105	{F3212164-E615-4F00-8FFC-794FEBF71780}	G0344.b21dfb95d72e4d83982a0173c860c12e	Gemeente Utrecht	VLEUTEN - DE MEERN	Utrechtse Heuvelrug
57	2000	225.62		{72493437-2347-462A-B483-79DBA337A1AB}	G0344.2645b36a6a5a4ce0b7bd7c271c6bafb7			
229	2000	221.17		{6D142FDD-CFB4-4F5A-AC1D-A3ADEFF72EDA}	G0344.b6746d40a9fe4965b6f62ac3e062a628			
352	2000	213.63		{8CD69DCA-2EEC-4FD4-8ED3-AF9F16B4C1F6}	G0344.a36a13481f25467c9dd6a81c4125e56e			
139	2006	100.6821038	144.5378055	{8B271C9A-D6F1-4BE8-B4D1-21368EC6EB12}	G0344.9de2373d6a184bd3b15a3b426ca3fa54	Gemeente Utrecht	VLEUTEN - DE MEERN	Wilgenrooslaan
317	2006	207.22	300.81	{E4B4707B-D8D6-4BE8-AA47-DCF8D1097103}	G0344.760cef600575423291465df76cc88e5a	Gemeente Utrecht	VLEUTEN - DE MEERN	Wilgenrooslaan
1380	2020	33.73622277	39.413725	{B97BB08D-0809-4060-AE5D-3E4B8C11F7F3}		Gemeente Utrecht	VLEUTEN - DE MEERN	Zandweg (M)
1381	2020	23.8135662	23.458665	{3886D8AD-144C-4212-8CEC-76AE33ACBE7C}		Gemeente Utrecht	VLEUTEN - DE MEERN	Zandweg (M)
1383	2020	31.48392997	31.81709	{F13CD223-F654-4E0C-88D7-705055075EAD}		Gemeente Utrecht	VLEUTEN - DE MEERN	Zandweg (M)
1385	2020	26.38775714	23.558841	{DE2E0538-9E70-4FF2-BCE2-B831B26BB510}		Gemeente Utrecht	VLEUTEN - DE MEERN	Zandweg (M)
1533	2020	31.28317786	34.6711315	{4971806A-63C7-4CFA-9733-0650FFE8A76C}		Gemeente Utrecht	VLEUTEN - DE MEERN	Zandweg (M)
1535	2020	24.55090392	26.2901835	{402C5299-A82E-4021-A472-D1F3B1FCBD74}		Gemeente Utrecht	VLEUTEN - DE MEERN	Zandweg (M)
1537	2020	25.64411145	24.654136	{EC522532-FA43-4F58-9ED8-06A34EC10F7A}		Gemeente Utrecht	VLEUTEN - DE MEERN	Zandweg (M)
1539	2020	25.22654022	24.578612	{EBBD5C6A-7513-4AC9-9B56-AA7DA9D49453}		Gemeente Utrecht	VLEUTEN - DE MEERN	Zandweg (M)
1541	2020	31.57487336	34.8972355	{D7810507-C0CD-4668-97A9-D93CCA634F6B}		Gemeente Utrecht	VLEUTEN - DE MEERN	Zandweg (M)
1542	2020	23.22371651	17.69414	{74E898FE-A327-4C0E-8D82-1BBF6C722A47}		Gemeente Utrecht	VLEUTEN - DE MEERN	Zandweg (M)
324	2006	132.4440855	317.3550505	{37565065-B001-42B5-A6AA-296AB8F6B578}	G0344.d01bd16f2d124d60a6559523fa983069	Gemeente Utrecht	VLEUTEN - DE MEERN	Busbaan Vleuterweide
1137	2006	163.78	399.9577535	{373DE4D0-C6D1-4B8E-AD7D-2530914F341F}	G0344.74840e2356da42c2b9d1bd30cecb9346	Gemeente Utrecht	VLEUTEN - DE MEERN	Busbaan Vleuterweide
1344	2011	100.8401228	199.22256	{474E0EBE-41E5-445F-B958-987F23C5C9E7}	G0344.dafcef01dee04dbeb884c03b6f51d62f	Gemeente Utrecht	VLEUTEN - DE MEERN	Busbaan Vleuterweide

A.2. Inspection form

Vegetated Swale Inspection Form

Gemeente Utrecht TU Delft

Inspector: _____ Date of inspection: _____

Swale details & Geographical Information

Swale Data:

Dry swale type: ☐ With overflow ☐ Without overflow

Swale ID: _____

Construction year: _____

Total Swale size(m²): _____

Side slope: _____

Cross-section shape: ☐ Rectangular ☐ Trapezoidal

Swale connected to: _____ swales

Swale width (m): _____ Swale length(m): _____

Swale construction details:

Number Inlet: _____

Inlet type: ☐ Roof drain ☐ Upstream swale ☐ drainage pipe ☐ other: _____

Inlet material: ☐ PVC ☐ Beton ☐ Polypropylene ☐ other: _____

Number outlets: _____

Outlet material: ☐ PVC ☐ Beton ☐ Polypropylene ☐ other: _____

Number overflows: _____

Overflow material: ☐ PVC ☐ Beton ☐ Polypropylene ☐ Polyester ☐ other: _____

Swale location Characteristics:

District/City: _____

Address/street name: _____

Coordinate: _____

Accessibility: _____

A map photo (QGIS)of Swale (including inlet, outlet, water bodies, overflows, pipes and direction. Etc)

Downstream and Upstream parts:

Inflow type: ☐ channel ☐ lateral ☐ both

Drain area size (m²):

Permeable surface(m²):

Impermeable surface (m²):

Connected to: ☐ street ☐ pavement ☐ roof drain ☐ garden ☐ other: _____

Discharge to water bodies: ☐ Yes ☐ No

Average subsidence rate:

Number of trees:

Underground soil type:

Weather condition

Current weather condition: _____

Date last rainfall: _____

Last rainfall intensity: _____

Has it rained the last 48 hours: ☐ Yes ☐ NO

Maintenance record

Swale has been inspected before: ☐ Yes ☐NO

If yes, Date of the last inspection: _____

Swale has been maintained before: ☐ Yes ☐NO

If yes, Date of the last maintenance: _____

Last maintenance work involves:
☐Vegetation cover ☐Outlet ☐Overflow
☐ inlet ☐infiltration basin ☐Other: _____

Comment on maintenance work:

_____

_____

_____

Assessing swale condition

Vegetation cover:

Vegetation type: ☐salt-tolerant ☐normal ☐other:__
Percentage of the vegetation cover: _____%
The vegetation cover is healthy: ☐Yes ☐ No
Appropriate size and density: ☐Yes ☐ No

Is there a presence of:
☐Weeds ☐Invasive vegetation ☐ Long vegetation
☐Bare spots ☐ inappropriate tree location
☐Other: _____
☐None of the above

Maintenance required:
☐Vegetation management
☐Planting
☐Mowing
☐None of the above

Vegetation condition state:
☐ Failure
☐ Approaching fail
☐ Routine maintenance
☐ Functioning

Documentation photo is taken: ☐ Yes ☐ No

Aligned Waterflow to Swale

There is a water flow obstacle: ☐Yes ☐ No

If yes what type of obstacle:
☐ Physical ☐ Subsidence ☐Pavement
☐ Other: _____

The water flow is blocked: ☐ Partially ☐ Completely

Maintenance required:
☐Removing Obstacle
☐Elevation alignment
☐Re-pavement

Documentation photo is taken: ☐ Yes ☐ No

Filter basin:

Main channel aligned with design: ☐Yes ☐ No
Side slopes aligned with design: ☐Yes ☐ No

There is standing water: ☐Yes ☐ No
If yes, does the water have:
☐ Surface sheen (from oils or gasoline)
☐ Murky colour (from suspended solids)
☐ Green colour (from algae growth)
☐ Mosquito habitat (from long retention time)
☐ None of the above

There is indication of illicit connection:
☐ Yes ☐No ☐Unknown
Potential source: _____

There are indicators of the following within the swale filter basin:
☐Sediments deposition
☐Erosion or channelisation
☐Litter or debris
☐Soil slides or bulges
☐Excessive animal burrows
☐ Seeps and wet spots
☐ Other: _____
☐None of the above

Maintenance required:
☐Reconstruction
☐Cleaning
☐ Reshaping filter basin
☐ Removing animal nest
☐other : _____
☐None of the above

Filter basin condition state:
☐ Failure
☐ Approaching fail
☐ Routine maintenance
☐ Functioning

Documentation photo is taken: ☐ Yes ☐ No

Upstream inlet:

Number of inlets: _____

	Inlet:	Inlet:	Inlet:	Inlet:	Inlet:
Design alignment	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
Elevation alignment	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
Clogging	☐Partially ☐Completely ☐ None	☐Partially ☐Completely ☐ None	☐Partially ☐Completely ☐ None	☐Partially ☐Completely ☐ None	☐Partially ☐Completely ☐ None
Type of clogging	☐Sediments ☐Vegetation ☐ Litter/debris	☐Sediments ☐Vegetation ☐ Litter/debris	☐Sediments ☐Vegetation ☐ Litter/debris	☐Sediments ☐Vegetation ☐ Litter/debris	☐Sediments ☐Vegetation ☐ Litter/debris
Spalling	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
Pipe condition					
Structural damage	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No

Maintenance required:

☐Reconstruction ☐Cleaning ☐ Pipe replacement or accessories ☐ other:_____☐None

Upstream inlets condition state:

☐ Failure ☐ Approaching fail ☐ Routine maintenance ☐ Functioning

Documentation photo is taken: ☐ Yes ☐ No

Overflow points:

Number of overflows: _____

	Overflow:	Overflow:	Overflow:	Overflow:	Overflow:
Design alignment	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
Elevation alignment	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
Clogging	☐Partially ☐Completely ☐ None	☐Partially ☐Completely ☐ None	☐Partially ☐Completely ☐ None	☐Partially ☐Completely ☐ None	☐Partially ☐Completely ☐ None
Type of clogging	☐Sediments ☐Vegetation ☐ Litter/debris	☐Sediments ☐Vegetation ☐ Litter/debris	☐Sediments ☐Vegetation ☐ Litter/debris	☐Sediments ☐Vegetation ☐ Litter/debris	☐Sediments ☐Vegetation ☐ Litter/debris
Spalling	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
Pipe condition					
Structural damage	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No

Maintenance required:

☐Reconstruction ☐Cleaning ☐ Pipe replacement or accessories ☐ other: _____☐None

Overflow condition state:

☐ Failure ☐ Approaching fail ☐ Routine maintenance ☐ Functioning

Documentation photo is taken: ☐ Yes ☐ No

Downstream Outlet:

Number of outlets: _____

	Outlet:	Outlet:	Outlet:	Outlet:	Outlet:
Design alignment	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
Elevation alignment	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
Clogging	☐Partially ☐Completely ☐ None	☐Partially ☐Completely ☐ None	☐Partially ☐Completely ☐ None	☐Partially ☐Completely ☐ None	☐Partially ☐Completely ☐ None
Type of clogging	☐Sediments ☐Vegetation ☐ Litter/debris	☐Sediments ☐Vegetation ☐ Litter/debris	☐Sediments ☐Vegetation ☐ Litter/debris	☐Sediments ☐Vegetation ☐ Litter/debris	☐Sediments ☐Vegetation ☐ Litter/debris
Spalling	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
Pipe condition					
Structural damage	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No

Maintenance required:
☐Reconstruction ☐Cleaning ☐ Pipe replacement or accessories ☐ other:_____☐None

Outlet condition state:
☐ Failure ☐ Approaching fail ☐ Routine maintenance ☐ Functioning

Documentation photo is taken: ☐ Yes ☐ No

Other components:

Number of components: _____

Type of components:
☐Check dams ☐ Flow spreader ☐ Gravel diaphragm ☐ Leaf screen ☐ Level spreader

Type of failure:
☐Elevation alignment ☐ Clogging ☐ Spalling ☐ Damage ☐ other: _____

Maintenance required:
☐Reconstruction ☐Cleaning ☐ Pipe replacement or accessories ☐None of the above

Components condition state:
☐ Failure ☐ Approaching fail ☐ Routine maintenance ☐ Functioning

Documentation photo is taken: ☐ Yes ☐ No

Summary and general observations: