Lessons Learned From Over Two Decades of Global Swale Use

F.C. BOOGAARD[1,2,6*], Terry LUCKE[3], H. SOMMER[5], J. DE BEER[4], N.C. VAN DE GIESEN[1], F.H.M. VAN DE VEN[1]

[1]Department of Water Management, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands

[2]TAUW BV, Zekeringstraat 43, PO 20748, Amsterdam, The Netherlands

[3]Stormwater Research Group, University of the Sunshine Coast, Australia

[4]Geological Survey of Norway, P.O. Box 6315 Sluppen, 7491 Trondheim, Norway

[5]Ingenieurgesellschaft Prof. Dr. Sieker mbH, Rennbahnallee 109A, 15366 Hoppegarten,Germany

[6]Hanze University of Applied Sciences (Hanze UAS), Zernikeplein, Groningen, The Netherlands

[*]Corresponding author

Email: Floris.Boogaard@tauw.nl

ABSTRACT

Swales are a type of sustainable urban drainage system that have been used for over two decades globally to provide stormwater conveyance and improve stormwater quality. The main design objectives of swales, and the purpose of their installation, can often vary considerably from country to country. This paper presents a brief overview of four different swale case studies from the Netherlands, Germany, Norway and Australia. The environmental conditions at each of the four swale locations, the main design objectives, the swale performance and the results of preliminary monitoring are examined. In the Dutch and German studies, the main purpose of swales was to improve hydraulic performance, that is, to reduce velocities of stormwater runoff and increase storage capacity. In the Norwegian and Australian studies, there was an additional focus on improving the quality of stormwater runoff. In all cases, swales were shown to be effective. However, to achieve the desired objectives and ensure that the required swale performance is achieved, it is recommended that some basic guidelines are followed.

KEYWORDS

Swale, urban stormwater, water quality, infiltration, sustainable urban drainage systems

INTRODUCTION

The principles of sustainable urban drainage are centred on achieving integrated water cycle management for the development or redevelopment of urban areas. This is achieved by mitigating the adverse effects of urban stormwater runoff such as increased urban flooding and deteriorating receiving water quality. Best practice urban stormwater management requires the development of a suite of integrated treatment measures, each designed for specific uses or to target specific pollutant types (Fletcher et al., 2002). Worldwide, local government authorities and developers now routinely incorporate various stormwater treatment devices into the urban landscape to assist in achieving Sustainable Urban Drainage System (SUDS) objectives.

Swales are one type of SUDS that have been used for well over two decades globally to provide stormwater conveyance and water quality treatment. Swales are shallow (often < 300 mm deep), vegetated (generally grass-lined) channels that receive stormwater runoff laterally through gentle side slopes and convey this stormwater downstream by way of longitudinal slopes that are typically less than 5% (Davis & Jamil 2008; Davis et al. 2012; Stagge et al. 2012). Water quality treatment in a swale occurs through the process of sedimentation, filtration, infiltration and biological and chemical interactions with the soil (Winston et al. 2012). Swales have been shown to be very efficient in removing sediment particles from urban runoff (Barrett et al. 1998; Deletic 2005).

Swales are relatively simple SUDS devices and they are installed for a variety of reasons including: stormwater transport, water quality improvement, infiltration for groundwater or aquifer recharge, flood mitigation, aesthetics and cost. There are generally two main types of swales: 1) grassed or densely vegetated swales with natural soils below; or 2) swales with filter media or porous soils whose major treatment mechanism is infiltration. The type of swale selected depends on site physical conditions (soils, slopes, land use, water table depth, depth to bedrock), contaminants of concern and maintenance infrastructure.

The main design objectives of swales, and the purpose of their installation, can often vary considerably from country to country. Local environmental conditions are obviously very different across the world and the rationale for selecting a swale SUDS option in one country may not be appropriate in another country. This paper presents a brief overview of four different swale case studies from the Netherlands, Germany, Norway and Australia. The environmental conditions at each on the four swale locations, the main design objectives, the swale performance, and the results of preliminary monitoring are examined. The outcomes of each of the four swale case studies are discussed and compared, and a summary of the main lessons learned are presented.

CASE STUDY 1 – ENSCHEDE, THE NETHERLANDS

Swale Location, Description and Objectives

According to the design requirements, all runoff from houses and roads in the 1994, 400 lot development in *Ruwenbos* (Enschede) is conveyed through street gutters to a system of swales, soak-a-ways and infiltration units located at the end of the streets (see Figure 1 and Table 1 for details, - Boogaard et al., 2006).

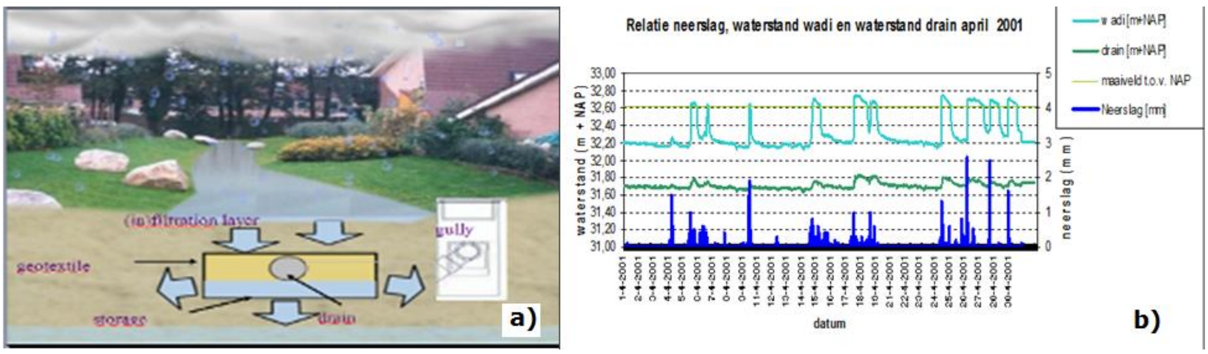

Figure 1: a) Swales in Ruwenbos; b) Hydraulic performance monitoring data

Study Methodology and Results

From 1996 to 2006 the hydraulic performance of three swales was monitored. Quantity and quality of precipitation, run-off, groundwater and overflows were analysed. Local residents were also surveyed to establish their level of appreciation and general perceptions pertaining to this innovative urban drainage system.

The study found that the swales, soak-a-ways and infiltration units generally emptied within 24 hours (Figure 1b). This was confirmed by observations by the local residents. However, the monitoring results showed that the observed hydraulic performance of the swales was significantly different to the design expectations. The main difference are shown in Table 1.

Table 1: Storage volume swale in Ruwenbos (Netherlands)

Design Parameter	Design	Actual
Connected surface/ houses	65 m^2	83 m^2
Storage swale till discharge slokop	20 mm	6 mm
Storage depth before ponding on street	40 mm	19.4 mm

Conclusion and Lessons Learned

- Any increases in groundwater levels due to the SUDS devices were localised and minimal. At peak storage capacity, a maximum increase of only 2 cm was recorded around the swales and this did not cause any problems for the houses on site.
- The measured concentrations of pollutants found in stormwater runoff from the development before treatment were higher than permitted (Dutch MAC values). However, these were improved to acceptable levels by the swale treatments.
- No significant accumulation of pollutants was found after ten years of monitoring. All measured concentrations were below the Dutch MAC values limiting values.
- Results of local resident surveys conducted in 1999 and 2005, found that 94% of the residents were satisfied with the performance of the swales and preferred to live in a housing district with swales in 1999. The 2005 survey showed that the residents were even more satisfied with the swales (98%).

CASE STUDY 2 – HOPPEGARTEN, GERMANY

Swale Location, Description and Objectives

In 1992 a new 100 ha commercial area development was constructed in Hoppegarten (east of Berlin). The case study area contains small and medium sized business plots with infiltration type swale systems for drainage. The infiltration capacity of the site soil is relatively low and the ground water table is relatively deep. A modern stormwater management approach was required due to the limited capacity of a small existing creek which drains the entire catchment area. Swale-trench-systems are therefore widely used in the streets, as well as on the privately-owned properties (Figure 2). Due to a local planning regulation private properties require on-site stormwater management (Panning, Sieker., 1998).

Figure 2: Hoppegarten, retention measures on private properties (a) and public roads (b)

Study Methodology and Results

From 1996 to 2000 the complete hydrology of the system was monitored and evaluated by comparing the expected results from the planning phase with the results from the observed measurements. No specific water quality analysis was performed. However, the influence of one minor oil spill on the site was evaluated by soil and trench runoff samples.

Conclusion and Lessons Learned

The results demonstrated that the observed performance of the system was comparable to the anticipated design performance. In addition:

- The water balance achieved with the decentralized stormwater management systems was close to the natural pre-development conditions;
- The infiltration sites were not clogged;
- The reduction in runoff volumes and velocities agreed with design predictions;
- The temporary ground water can be adequately managed by the swale system;
- The swale system is capable of retaining maximum discharge volumes from the site;
- The system worked satisfactorily in during both summer and winter; and
- The water regime in the small river (Wernergraben) downstream of the development has improved in both dry and wet weather conditions.

The case study shows that a modern stormwater management approach incorporating infiltration swales is an effective way of reducing stormwater runoff from catchments with low-permeability soils.

CASE STUDY 3 - NORWAY

Swale Location, Description and Objectives

The swale described in this case-study is part of the historical World Heritage Site: Bryggen in Bergen, on the west coast of Norway. The average annual rainfall in Bergen is 2,250 mm/y and annual mean temperature of 7.6 °C, varying from 1.3 to 14.3 °C. Dry swales in this area are predominately used increase the groundwater level and humidity in the top soil cost-effectively to avoid oxygenation and loss of highly organic cultural deposits in the subsurface. The study swales consist of two grassed areas positioned side by side. Each swale is approximately 20 m long, 6 m wide and has an average slope of 1:2 (Figure 3). The swales are primary installed to capture and treat stormwater runoff from upstream roofs and roadway areas and convey most of the water to the groundwater and the further downstream underground infiltration-transport system.

Study Methodology and Results

Since the primary target of the swale system at Bryggen is to increase groundwater infiltration for preservation of organic archaeological assets, particular focus was placed on removal efficiency of oxidizing agents such as oxygen and sulphate, as those may induce increased decomposition of organic material. A baseline study was performed to characterize the stormwater quality from the upstream roofs and road areas. Results showed a large variation in the amount of pollutants bound and unbound to suspended solids compared to previous study results. Lead in particular, showed a low average percentage of bound pollutants and could be the result of mobilization by road salt. Pollutants also appeared to be more dissolved than previous research results. This may inhibit single-step treatment performance. Therefore, a "treatment train" of several SUDS devices was developed in order to achieve high pollution removal rates and prevents loss of valuable archaeological assets and consequential subsidence. The initial hydraulic monitoring results showed that the condition of the cultural deposits was improved (wet conditions with lack of oxygen) by infiltration of stormwater.

Figure 3: a) Site plan of Bryggen; b) Swales on Unesco world heritage site.

Conclusion and Lessons Learned

The use of shallow SUDS to protect and preserve subsurface organic cultural deposits in a historical urban area with significant legal limitations for (modern) constructions and deeper excavations is not only cost-effective, but also a robust and practical solution. A monitoring program will be implemented in the near future to evaluate the effectiveness of the treatment-train in protecting the cultural deposits. This is expected to produce more valuable results.

CASE STUDY 4 - AUSTRALIA

Swale Location, Description and Objectives

The swale described in this case-study is part of a sporting field complex on the Sunshine Coast (SSC) in Australia. The SSC is an urban area in South East Queensland and experiences frequent, short-duration, high-intensity rainfall events. The average annual rainfall on the SSC is 1,464 mm/y and annual mean temperatures range from 15.8 to 25.2C°. The study swale was grassed, approximately 40 m long, 10 m wide and had an average slope of 1.25% (Figure 5a). The swale was installed to capture and treat stormwater runoff from adjacent car parking and roadway areas and convey it to the downstream underground stormwater drainage system. Swales (including the case-study swale) are predominately used on the SSC to convey large runoff volumes quickly and cost-effectively, while at the same time providing some basic water quality treatment functions.

Study Methodology and Results

A series of controlled field experiments was undertaken to quantify the effect that swale length had on the pollutant removal performance of total suspended solids (TSS) from the synthetic stormwater used in the study. Pollutants were introduced into the synthetic stormwater based on literature values for typical Australian urban runoff quality data (Duncan 1999; Wong 2006). A control test was performed without any pollutants to determine the background concentrations found in the swales. The TSS concentrations of Test 2 replicated typical urban Australian concentrations. The third and fourth tests were five times, and ten times the typical TSS concentrations, respectively. These two tests were included to ensure measurable results would be obtained in the results. However, these pollutant concentrations are not representative of typical Australian stormwater conditions.

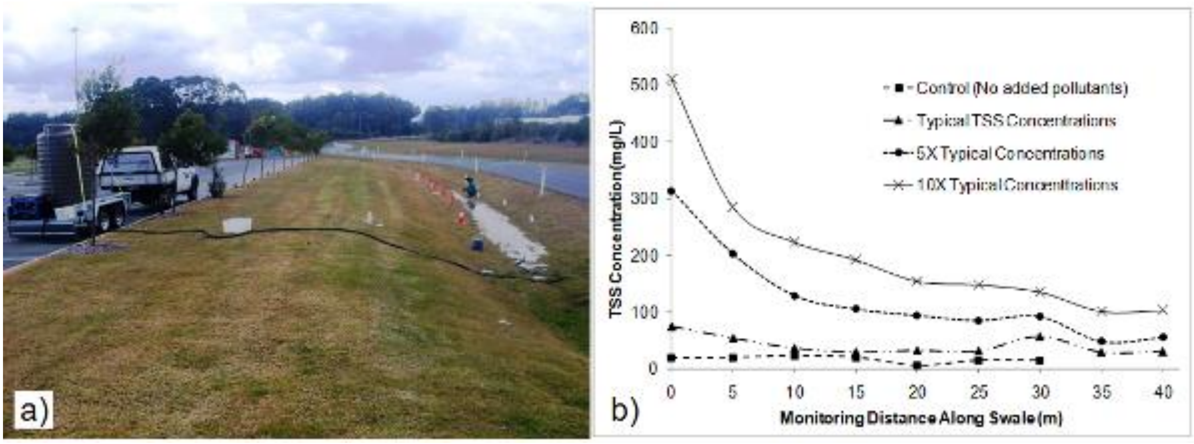

Figure 4: a) Water quality monitoring; b) Monitoring Results.

Figure 4b shows that between 50% and 75% of the TSS was removed within the first 10 m of the swale length. It can also be seen that there was a significant decline in the TSS removal efficiency after the first 10 m and the removal rate was minimal from that point on. Another series of experimental test results showed that swales were only of limited effectiveness in the removal of nutrients from the synthetic stormwater used in this study.

Conclusion and Lessons Learned

The study showed a distinctive exponential decrease of TSS concentration along the grass swale and that between 50% and 75% of the TSS was removed within the first 10 m of the swale length. These results suggest that installation of excessively long swales to treat stormwater TSS pollution may not be the most cost effective solution. Beyond 10 m, only a further approximately 20% reduction can be expected, regardless of the total length.

DISCUSSION

The main design objectives of swales, and the purpose of their installation, can often vary considerably from country to country. The four case studies discussed in this paper from the Netherlands, Germany, Norway and Australia are therefore difficult to compare directly. The environmental conditions, the main design objectives, and the swale performances are different at each of the four swale locations, and the results of preliminary monitoring can not be evaluated using the same methodology. The study swales were shown to effectively achieve their performance objectives in all of the case studies. However, in order to achieve required performance objectives, it is recommended that designers follow the basic design guidelines given in Table 2.

Table 2: General international design guidelines for swales

Design Parameter	Unit	Netherlands	Germany	UK	Belgium
Organization		(RIONED)	(ATV)	(CIRIA)	(VLARIO)
Distance ground water	m	> 0.5	>1	--	--
Swale area/drained area	Ratio	5 – 10	> 7	--	5 – 10
Distance to houses	m	>1	1.5 depth		
Swale water depth	m	<0.3	<0.3	<0.1	<0.3
Spare capacity	m	0.1	--	0.15	--
Width of bottom	m	>0,5	0.6	--	0.5 - 1
Longitudinal slope	V:H	1 : 3 or less	1:4 or less	--	1:3 or less
Max velocity	m/s	--	--	1 - 2	--
Thickness of filter soil	m	0.3 – 0.5	>0.1	--	0.3 – 0.5
Humus in top layer	%	3-5		--	
Infiltration capacity	m/day	> 0.5	0.86 < Kd < 86.4	--	> 0.086
Overflowing frequency	n/yr	1 to 2	0.2	--	0.2 – 0.5
Time to empty	hour	<24	<24	> 10 min	<24

CONCLUSIONS

This paper presents the outcomes of four swale installation case studies in the Netherlands, Germany, Norway and Australia. In all cases the swales were found to be effective. The main outcomes and lessons learned for each of the studies included:

- The Dutch study swale was primarily installed to act as storage for stormwater. The study showed that design parameters were not realistic and flexibility in the design and operation (real time control) is strongly advised. Study results also showed that nearly all residents surveyed (98%) were satisfied with the performance of the swales and preferred to live in a housing district with swales.
- The German study swale was primarily installed to mitigate potential flooding due to the runoff from a new development. The study showed that a modern stormwater management approach incorporating infiltration swales is an effective way of reducing stormwater runoff from catchments with low-permeability soils.
- The Norwegian swales were primarily installed to preserve cultural deposits by improving wet conditions by infiltration. The study showed that use of shallow SUDS to protect and preserve subsurface organic cultural deposits was not only cost-effective, but also a robust and practical solution.
- The primary use of swales in Australia is to easily convey stormwater runoff and to provide basic stormwater treatments. The main lessons learned from the case study was that the installation of excessively long swales to treat stormwater TSS pollution may not be the most cost effective solution as between 50% and 75% of TSS is removed within the first 10 m of the swale length.

This paper presented a brief description of some of the lessons learned in the last 20 years and the main points to consider when installing swales in various countries with different environmental and climatic conditions. It is hoped that this study and the presented guidelines will be of benefit to stormwater managers and SUDS designers worldwide.

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