Aerial view of the Kraaifontein Integrated Waste Management Facility in Cape Town

An early performance analysis of a bio-swale and litter-silt-traps

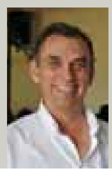
as components of sustainable drainage systems

Readers are also referred to pages 18–22 of the December 2012 edition of *Civil Engineering* where the Kraaifontein Waste Management Facility was featured as the joint winner in the technical excellence category of SAICE's 2012 project awards.

Michael Vice
Candidate Engineer
Municipal and Sustainable Engineering Divisions
Jeffares & Green (Pty) Ltd
vicem@jgi.co.za

Richard Emery
Executive Associate
Solid Waste Management Division
Jeffares & Green (Pty) Ltd
emeryr@jgi.co.za

Colin Hall
Head
Contract Management Services
Solid Waste Disposal Branch
City of Cape Town
colin.hall@capetown.gov.za



OVERVIEW

During the construction of the Kraaifontein (Integrated) Waste Management Facility (KWMF) in Cape Town, alternative stormwater management options, which included litter-silt-traps and a bio-swale, were implemented. Stormwater runoff from the site is collected in several litter-silt-traps and discharged into the bio-swale, which is located at the lowest corner of the site. Polished stormwater subsequently discharges into an existing retention pond downstream of the site. The bio-swale is categorised as a 'local control' Sustainable Drainage Systems (SuDS) option, and is the amalgamation of selected properties of two local control SuDS options, namely bio-retention areas and swales. As a result of the unique waste operations onsite the quality of stormwater that is discharged into the bio-swale is highly contaminated, in some instances replicating landfill leachate at over 17 000 mg COD/ℓ. Stormwater samples were taken at four six-monthly intervals at the beginning and end of the Cape's wet and dry seasons. The results clearly demonstrate the efficacy of these SuDS options in reducing, *inter alia,* heavy metals, suspended solids, total phosphorous and COD, with over 80% removal efficiencies. These results have exceeded the treatment requirements stipulated in the City's latest stormwater management policy.

BACKGROUND TO THE FACILITY

The facility (Figure 1) is located in the suburb of Kraaifontein in Cape Town, and is an *integrated waste management facility*, meaning that the facility encompasses waste handling and transfer in addition to other solid waste minimisation activities, such as a materials recovery facility, a garden refuse chipping area, a domestic recycling facility, a public drop-off facility and advanced container handling operations (Emery & Hall 2012).

It also contains a workshop, wash bay, diesel storage, security facilities, entrance building and weighbridges, which all contribute uniquely to stormwater runoff. Space has also been demarcated for a future Resource Park/Eco-Industrial Park, as well as other 'alternative technologies', such as possible Energy-from-Waste (EfW). The design capacity currently allows for a maximum of 100 t/day Materials Recovery Facility (MRF – for recyclables sorting and beneficial use) and a 1 000 t/day Refuse Transfer Station (RTS).

Arising from a study conducted by USA Consultants, Wright-Pearce (1999), it was recommended that the City develop a single

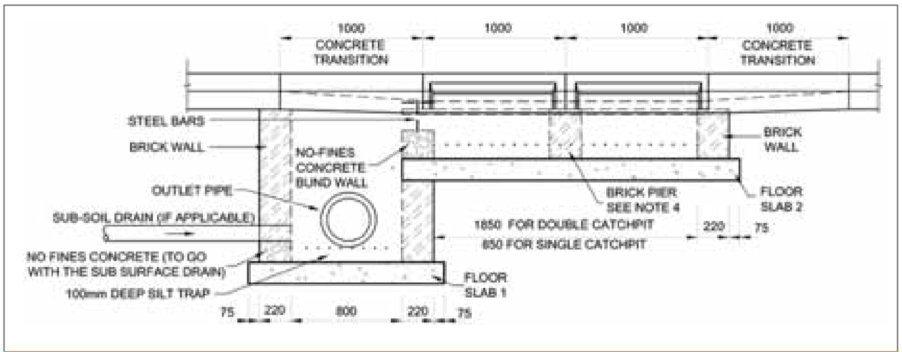


Figure 2 Double-chamber litter-silt-trap combination inlet (Copyright: Jeffares & Green)

Figure 3 Supernatant free of most settleable solids from runoff (September 2011)

Figure 4 Settled litter, debris, silt and other particulates to be cleaned out (April 2012)

regional waste disposal facility, and as the existing landfills reach their capacity, they would be replaced by satellite refuse transfer stations, with waste being compacted into containers and transported by either road or rail to the proposed regional landfill (Emery & Hall 2012).

The KWMF is currently owned and operated by the City of Cape Town, with the exception of the transfer of containerised waste and the operation of the MRF, which is handled by private contractors. The facility began principal operations in late 2010, followed soon thereafter by other integrated operations.

POLLUTION MANAGEMENT SYSTEM

Special attention had to be paid to pollution prevention and the management thereof, due to the nature of the facility's function as a waste transfer station. Therefore, the site development included a number of silt/sand traps, oil traps and litter traps, collectively referred to as litter-silt-traps. These point-source pollution interventions prevent pollution particulates and contaminated effluents from having to be controlled and treated outside the bounds of the development by an 'end-of-pipe' type solution. Key pollution prevention actions are the capture of oils, litter, sand/silt, and to lower the organic and inorganic load of the final effluent discharged from the site into the existing municipal retention pond.

The litter-silt-trap combination inlet was specially designed for ease of access, and the trapping and cleaning of litter in a shallow compartment and silt in the deeper compartment before any stormwater discharges from the unit. Between the two chambers are vertical steel bars to 'jail-in' the litter and large fractions, and a no-fines wall to allow water to 'leak' from the litter trap to the silt trap compartment. Weep holes were also included in this wall. Figure 2 provides a technical illustration of the above-mentioned intervention (unit), illustrating, *inter alia* a no-fines bund wall, double catch-pit litter trap and silt trap.

In addition to its design concept, Figures 3 and 4 illustrate the applied post-rainfall state of the litter-silt-trap unit. Litter and silt are typically only cleaned out of the unit once a rainfall event has occurred or on a scheduled basis according to the stormwater operations manual. Therefore, during a relatively long rainfall event or extended rainfall period there is likely to be a considerable quantity of litter, debris and silt that is passed through the unit and piped to the bio-swale.

Theoretically, liquid discharge from the RTS, MRF, compaction hall, workshop, wash bays and bunded areas (at drop-off centre) flows into the underlying sewer system. All the remaining runoff is directed through the aforementioned silt and sand collection units, litter collection devices and filtration media, before it discharges into and through the bio-swale at the northern, lower-lying edge of the development. Therefore the litter-silt-traps provide sufficient pre-treatment to the bio-swale for the less intense, minor storm events (1:5 RI event). The pre-treatment performance of the litter-silt-traps are, however, less likely to be as effective during the more intense, major storm events that exceed a recurrence interval of 1:5. In this instance the velocity of stormwater runoff entering the kerb inlets results in an observed 'churning' effect in the siltation compartment of the litter-silt-traps, thereby causing a considerable amount of litter, silt and debris to be sent downstream to the bio-swale. Minor adaptations to the existing litter-silt-trap design are unlikely to remedy this problem.

BIO-SWALE DESCRIPTION AND PERFORMANCE

In the following section the technical characteristics of the KWMF bio-swale are introduced and its salient stormwater treatment performances highlighted.

Introduction

The stormwater bio-swale is located at the northern edge of the KMWF and discharges stormwater into an existing detention pond downstream of the developed site, as is illustrated in Figure 5.

A bio-swale is categorised as a 'local control' Sustainable Drainage System (SuDS), and is typically the amalgamation of selected properties of two local control SuDS, namely a bio-retention area and a swale. It can be used to manage surface water drainage in line with the principles of sustainable development (Vice *et al* 2011; Vice & Armitage, 2011), and in terms of the City of Cape Town's *Management of Urban Stormwater Impacts Policy* (Roads and Stormwater Department 2009a).

Technical characteristics

Due to the nature of the development, the stormwater system includes the pollution control measures in the form of a treatment train. The minor storm flows (1:5 year recurrence interval) are managed by means of an underground pipe system and the major storm flows (1:50 year recurrence) are managed as surface flow, guided by the design grades of the paved areas and roadways around the buildings. The development has been designed to direct both the minor and major storm flows through the litter-silt-traps and inevitably the bio-swale as a last resort. The Mean Annual Precipitation (MAP) value being used for this development is 518 mm. The bio-swale (depicted in Figures 6 and 7) is approximately 120 m long, 4 m wide and 2 m deep, with a trapezoidal cross-section. The bio-swale incorporates conventional drainage components, including piped subsoil drains, a 'hard' (yet porous) Armorflex block base, and terraced gabion walls for stability. Indigenous vegetation (primarily *Typha capensis*) (Roads and Stormwater Department 2011) was planted in October 2010, which has spread extensively to date (July 2013).

Figure 8 illustrates the cross-sectional design of the bio-swale, with principal features such as the gabion side walls, preselected filter media layers, geo-synthetic lining materials and perforated subsoil drainage pipes.

Stormwater treatment performance

Four stormwater samples have been retrieved to date (May 2013), which include

Figure 5 Location map showing bio-swale located at the northern edge of the KWMF

Figure 6 Trapezoidal cross-section of bio-swale with gabion side walls (October 2010); note vegetation sprigs

Figure 7 Growth of numerous vegetative species one year from inception (September 2011)

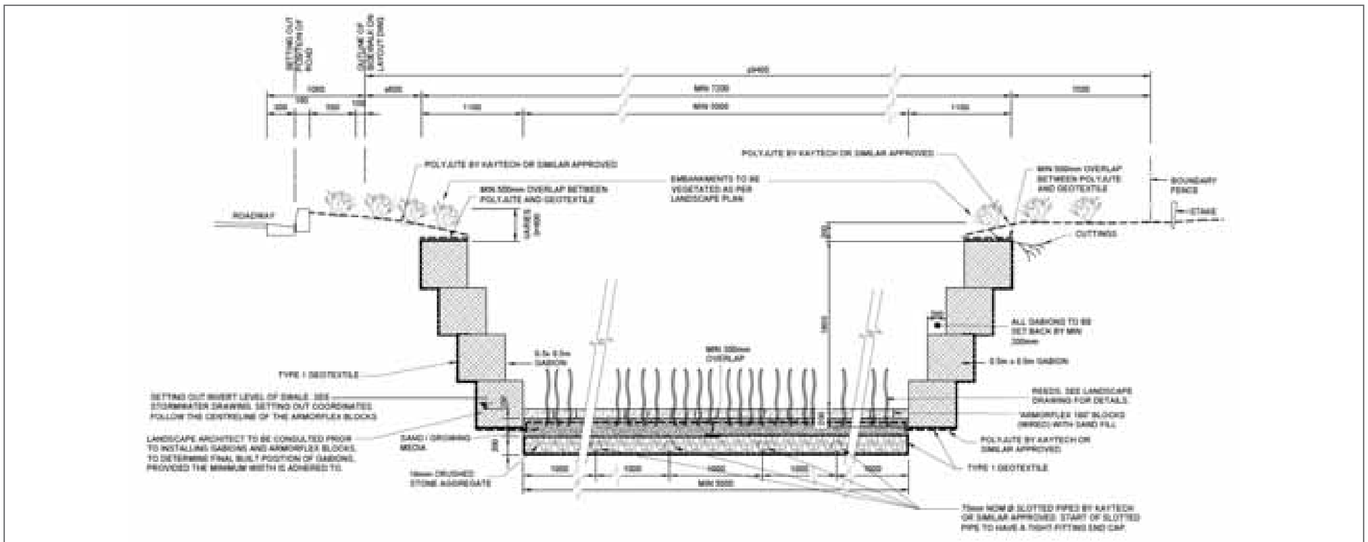


Figure 8 Cross-sectional design of bio-swale at lowest point (Copyright: Jeffares & Green)

stormwater entering the bio-swale from each of the four primary piped inlets, as well as 'polished' stormwater exiting the bio-swale's subsoil drainage system. The samples were tested by the City of Cape Town's Scientific Services, and the results are listed in Table 1. The stormwater quality results presented in Table 1 are also presented graphically in Figure 9.

According to the pollutant removal requirements specified in the interim criteria for achieving sustainable urban drainage system objectives in various development scenarios (Roads & Stormwater Department 2009a&b) greenfield developments must reduce the suspended solids (SS) and total phosphorous (TP) in stormwater runoff to undeveloped catchment levels or achieve a reduction of 80% SS and 45% TP (by selecting the higher level of treatment). The results clearly show that the bio-swale reduced SS by well over 95% between September 2011 and April 2013. These removal efficiencies are indicated in the cells highlighted in green and yellow in Table 1. The percentage reduction for TP, however, fell marginally short of the specified 45% target at approximately 43% in September 2011 and 40% in April 2012, but made a significant recovery in performance to approximately 92% in September 2012 and 96% in April 2013.It must be noted that there are limitations to the apparatus used to measure the total phosphorous and total nitrogen quantities, which resulted in the summation of a standardised quantity of < 0.1 mg/ℓ, which is not inclusive of the relevant significant figures necessary to make sufficient inferences about these particular performance characteristics.

Two other significant typical stormwater quality indicators were also measured, namely heavy metals (HM) and the chemical oxygen demand (COD). These recorded reductions of well over 80% in

Table 1 Stormwater quality results (four sets: September 2011 – April 2013)

SAMPLE SET 1: 1 SEPTEMBER 2011

Measured item	Unit	Avg contributing sample[3]	Outlet sample[4]	% Reduction
Heavy metals[1](HM)	mg/ℓ	20.74	3.70	82.2
Chemical oxygen demand (COD)	mg/ℓ	539.50	29.00	94.6
Total phosphorus[2](TP)	mg/ℓ	0.18	0.10	42.9
Suspended solids (SS)	mg/ℓ	597.00	10.00	98.3

Notes 01-09-2011
5 SW samples were taken: 4 represent the *Average contributing sample* and 1 is the *Outlet sample.*
Sample taken during antecedent dry weather conditions: 01-09-2011, 09:00–09:30.
Where values < 0.01 or 0.1 mg/ℓ, a value of 0.01 or 0.1 mg/ℓ was used respectively.
% Reductions recorded are conservative as the spatial context of contributing samples was not considered.

SAMPLE SET 2: 1 APRIL 2012

Measured item	Unit	Avg contributing sample[3]	Outlet sample[4]	% Reduction
Heavy metals[1](HM)	mg/ℓ	76.46	2.26	97.0
Chemical oxygen demand (COD)	mg/ℓ	716.50	59.00	91.8
Total phosphorus[2](TP)	mg/ℓ	0.50	0.30	40.0
Suspended solids (SS)	mg/ℓ	1 065.00	28.00	97.4

Notes 01-04-2012
3 SW samples were taken: 2 represent the *Average contributing sample* and 1 is the *Outlet sample.*
Sample taken during antecedent dry weather conditions: 01-04-2012, 09:00–09:30.
Where values < 0.01 or 0.1 mg/ℓ, a value of 0.01 or 0.1 mg/ℓ was used respectively.
% Reductions recorded are conservative as the spatial context of contributing samples was not considered.

SAMPLE SET 3: 11 SEPTEMBER 2012

Measured item	Unit	Avg contributing sample[3]	Outlet sample[4]	% Reduction
Heavy metals[1](HM)	mg/ℓ	203.40	4.14	98.0
Total nitrogen[2](TN)	mg/ℓ	6.05	0.50	91.7
Chemical oxygen demand (COD)	mg/ℓ	9 008.00	85.00	99.1
Total phosphorus[2](TP)	mg/ℓ	1.20	0.10	91.7
Suspended solids (SS)	mg/ℓ	6 845.00	1.00	100.0

Notes 11-09-2012
3 SW samples were taken: 2 represent the *Average contributing sample* and 1 is the *Outlet sample.*
Sample taken during antecedent dry weather conditions: 11-09-2012, 08:30–09:00.
Where values < 0.01 or 0.1 mg/ℓ, a value of 0.01 or 0.1 mg/ℓ was used respectively.
% Reductions recorded are conservative as the spatial context of contributing samples was not considered.

SAMPLE SET 4: 18 APRIL 2013

Measured item	Unit	Avg contributing sample[3]	Outlet sample[4]	% Reduction
Heavy metals[1](HM)	mg/ℓ	191.54	8.22	95.7
Total nitrogen[2](TN)	mg/ℓ	2.50	0.90	64.0
Chemical oxygen demand (COD)	mg/ℓ	5 849.00	47.00	99.2
Total phosphorus[2](TP)	mg/ℓ	2.53	0.10	96.0
Suspended solids (SS)	mg/ℓ	4 813.30	9.00	99.8

Notes 18-04-2013
4 SW samples were taken: 3 represent the *Average contributing sample* and 1 is the *Outlet sample.*
Sample taken during antecedent dry weather conditions: 18-04-2013, 08:30–09:30.
Where values < 0.01 or 0.1 mg/ℓ, a value of 0.01 or 0.1 mg/ℓ was used respectively.
% Reductions recorded are conservative as the spatial context of contributing samples was not considered.

Notes
[1]Heavy metals include: aluminium, cadmium, copper, iron, lead, manganese, nickel and zinc.
[2]Sample size too small to report accurately (% reduction problematic – need to specify quantity in policy).
[3]Average contributing sample is the representative sample that is discharged into the bio-swale.
[4]Outlet sample is the SW sample taken at the outlet of the bio-swale.

all four sample set results. The COD was reduced to well below its national water quality standard limit of 75.0 mg/ℓ. Taking a closer look at the removal of COD, it is hypothesised that the un-biodegradable, soluble fraction of COD comprises a majority (+95%) of the effluent COD (U.S. EPA 1988). The other three COD fractions, namely the un-biodegradable and particulate (UP), biodegradable and soluble (BS), and biodegradable and particulate (BP) fractions are removed as follows:
(1) the UP is trapped physically in the filter media and will need to be removed when the filter media is replaced according to the maintenance schedule (12–15 years),
(2) the BS is removed by both anaerobic micro-organisms (fungi and bacteria) in the soil and by aerobic bacteria adjoining the roots of the bio-swale's reeds, and
(3) the BP is removed physically and then subjected to the same anaerobic and aerobic degradable methods as the BS fraction (S.A. WRC 2005).

The graphical trends presented in Figure 9 do not indicate any significant increase or decrease in removal efficiencies as yet, with the exception of TP. However, theory suggests that there is likely to be a noticeable decrease in pollutant removal efficiencies after six to eight years of operation (Wilson *et al* 2004; Woods-Ballard *et al* 2007). In addition to the quality performance and trends illustrated in Table 1 and Figure 9, respectively, the visual quality of the influent SW and effluent SW from the bio-swale is depicted in Figures 10 and 11. These support the tabulated pollutant removal efficiencies displayed in Table 1.

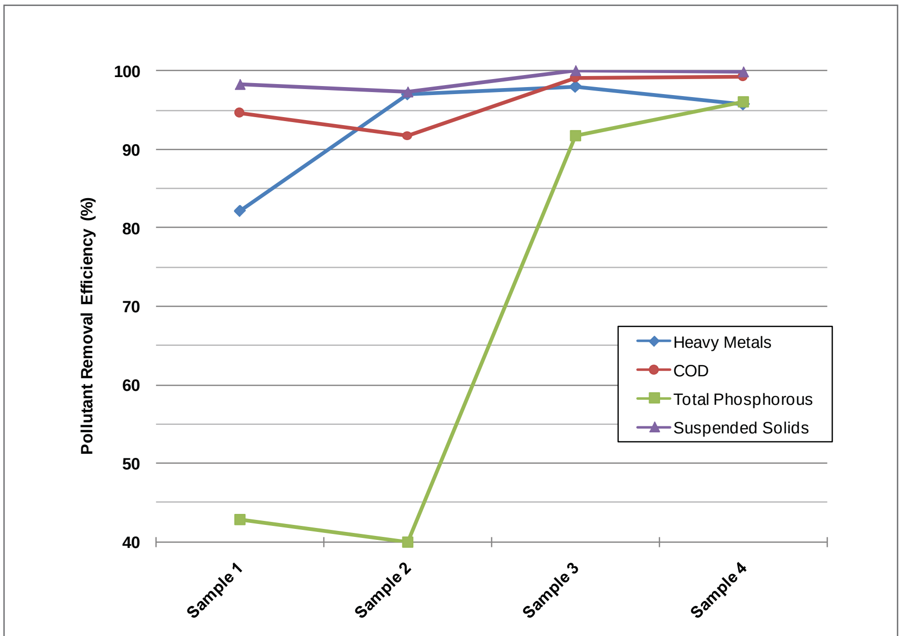


Figure 9 Pollutant removal efficiency of bio-swale for selected pollutant characteristics (September 2011 – April 2013)

Figure 10 Visual contrast between influent and effluent SW samples (April 2012)

Figure 11 Visual contrast between influent and effluent SW samples (April 2013)

Amenity and biodiversity benefits

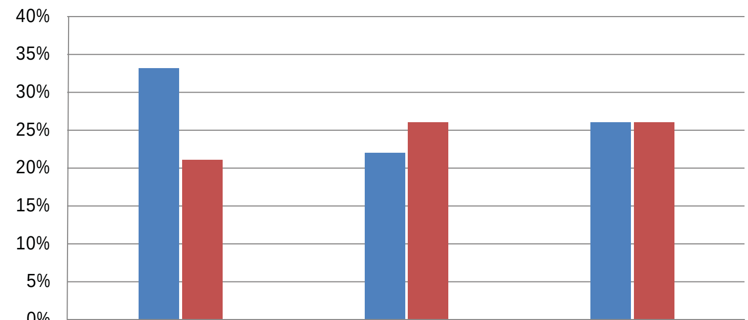
Vegetation choice is critical to the efficacy of SuDS, as is advocated in the City of Cape Town's Landscape and Indigenous Plant Species Guideline (Roads and Stormwater Department 2011). The resilience of the *Typha capensis* (Cape bulrush) in this respect is pivotal to the performance of the bio-swale (Figure 12 depicts the growth of the bulrush). It ensures that stormwater is physically intercepted whilst flowing down the swale, allowing the runoff time to infiltrate into and through the bio-swale's filter media, and supplying oxygen to the micro-organisms to enable the biodegradable processes near the reed's root structure.

Relative to a conventional piped stormwater system, the vegetation provides significant amenity to daily users and staff by way of vastly improved aesthetics. The bio-swale is also home to multiple bird and amphibian species, in addition to a plethora of insect species.

Maintenance requirements and procedures

According to Wilson *et al* (2004), SuDS options require regular maintenance in order to manage stormwater runoff quantity and quality effectively in the longterm. A lack of regular maintenance is likely to significantly reduce the performance and design life of the bio-swale. With reference to Figure 9 it became evident after two sample sets that there was a slight decline in the water quality performance of the bio-swale in terms of the four selected SW quality criteria, with the exception of the HM. It was originally hypothesised that this was largely due to a lack of maintenance, as the City was in the process of establishing a regular maintenance programme for the facility's bio-swale. However, subsequent results indicated that this inference was incorrect, as removal efficiencies began to improve in spite of the lack of maintenance.

It is also important to note that the second sample set was recorded during the first seasonal rainfall event after the dry season (typically six months between October and March each year). The average contributing sample into the bio-swale was significantly more contaminated for April 2012 than for September 2011; therefore, the bio-swale may be marginally less capable of handling a greater quantity of contaminants as can be reasonably assumed. This may suggest that the relationship of the pollution reduction potential of the bio-swale is not necessarily proportional for varying pollutant loads, and has a marginally better performance at minimising smaller pollutant loads.



	Sediment Buildup	Litter & Debris	Invasive Vegetation
Bio-retention Areas	33%	22%	26%
Swales & Filter Strips	21%	26%	26%

Figure 13 Elements that typically reduce the performance of bio-retention areas and swales (after Weiss *et al* 2011)

Figure 12 *Typha capensis* during a relatively strong growth period (April 2013)

The City of Cape Town has instituted a unique operation and maintenance manual that is specific to the bio-swale and the contributing litter-silt-traps. The scheduling of appropriate maintenance activities is assigned by the facility's maintenance manager, and corresponds to the most significant elements that contribute to system failure, as stipulated in the facility's stormwater maintenance manual (Jeffares & Green 2013). According to Weiss ***et al*** (2011) the key elements that significantly reduce the performance of bio-swales are namely (in order of magnitude): (1) sediment build-up, (2) invasive vegetation, and (3) litter and debris, as is indicated in Figure 13.

CONCLUSION

The modified kerb-inlets (litter-silt-traps), in combination with the 'local control' bio-swale, were both designed in light of the treatment train concept of sustainable drainage systems (SuDS). The litter-silt-traps facilitate sufficient pre-treatment of stormwater runoff during minor storm events (recurrence intervals less than 1:5), but are less effective during more intensive rainfall events. Litter, debris and silt collect in the unit's dual chamber and sump and can be manually cleared after rainfall events to improve the performance of the system.

It is clear from the four sets of water quality results that this treatment train has had a significantly positive impact on the quality of stormwater being discharged from the waste management facility into the downstream retention pond. The SW system achieved relatively large pollutant removal efficiencies in suspended solids (SS), total phosphorous (TP), COD and heavy metals (ranging from 80% to 99% reduction of 'raw' stormwater). TP removal improved particularly well over the four-sample set to record, with removal efficiencies of 40% in 2011 to over 90% in 2013.

Figure 14 The bio-swale has also improved the aesthetics of the facility and has created a natural habitat for many animal and insect species

Figure 15 Training of staff in maintaining the bio-swale is an ongoing process

The soluble and particulate biodegradable COD fractions are removed both anaerobically and aerobically through interactions between the bio-swale's growing media and the reeds' root structures. The particulate, un-biodegradable COD fraction is physically retained in the filter media, whilst the soluble, un-biodegradable fraction passes through the bio-swale to represent the majority (+95%) of the bio-swale's effluent COD. The effluent COD quantity was well below the national limit of 75.0 mg/ℓ in the first, second and fourth sample sets, and only marginally above the limit at 85.0 mg/ℓ in the third sample set.

The maintenance procedures for the facility's stormwater treatment train are inexpensive, but are relatively more frequent in nature than conventional piped systems, in order to ensure that the system remains effective over the long term, such as a 12–15 year period in operation. In addition to the bio-swale's ability to control and treat stormwater runoff, its aesthetic appeal is pleasing to the facility's daily users and staff, and has created an improved habitat for many animal and insect species, as has been observed over two and a half years. The litter-silt-traps and bio-swale collectively provide an alternative approach and positive advance in the control and treatment of contaminated stormwater runoff using natural means.

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NOTE

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