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Runoff infiltration, a desktop case study

Infiltration des eaux de surface, une étude de cas

N.R.P. Bastien ⁽¹⁾, S. Arthur ⁽¹⁾, S.G. Wallis ⁽¹⁾, M. Scholz ⁽²⁾

⁽¹⁾ School of the Built Environment, Heriot-Watt University,
Edinburgh EH14 4AS, UK.

⁽²⁾ Institute for Infrastructure and Environment, School of Engineering,
The University of Edinburgh, Edinburgh EH9 3JL, UK.

* Corresponding author, email: nrb5@hw.ac.uk

RÉSUMÉ

L'utilisation de techniques alternatives est en hausse constante et devient très commune. Cependant, plutôt que d'utiliser ces techniques en série comme recommandé par les régulateurs environnementaux, beaucoup de nouveaux développements optent pour l'utilisation de contrôles régionaux seulement. Ce papier discute l'utilisation de techniques alternatives en série et compare leurs performances. L'occupation des sols, les caractéristiques du site et du bassin versant ont été utilisées en parallèle avec les dernières normes, Infoworks CS et MUSIC pour déterminer le coût au long terme, l'espace utilisé, la quantité et la qualité des eaux de ruissellement pour différentes combinaisons de techniques alternatives. Les résultats obtenus démontrent que l'utilisation de techniques alternatives peut présenter une alternative crédible au développement de contrôles régionaux seuls. Ainsi, une solution plus flexible peut être trouvée pour correspondre au mieux aux attentes des différents acteurs impliqués dans l'implémentation des techniques alternatives.

ABSTRACT

The use of Sustainable Drainage Systems (SuDS) or Best Management Practice (BMP) is becoming increasingly common. However, rather than adopting the preferred "treatment train" implementation, many developments opt for end of pipe control ponds. This paper discusses the use of SuDS in series to form treatment trains and compares their potential performance and effectiveness with end of pipe solutions. Land-use, site and catchment characteristics have been used alongside up-to-date guidance, Infoworks CS and MUSIC to determine whole-life-costs, land-take, water quality and quantity for different SuDS combinations. The results presented show that the use of a treatment train allows approaches differing from the traditional use of single SuDS, either source or "end-of-pipe", to be proposed to treat and attenuate runoff. The outcome is a more flexible solution where the footprint allocated to SuDS, costs and water quality can be managed differently to fully meet stakeholder objectives.

KEYWORDS

SuDS, Treatment train, BMP, Swale, Pond, Green roof, Permeable paving, Runoff quality

1. INTRODUCTION

The use of Sustainable Drainage Systems (SuDS) or Best Management Practice (BMP) has been made compulsory for virtually all new developments in Scotland. However, despite the design guidance (CIRIA, 2007), systems are often implemented using “end-of-pipe” or source controls SuDS rather than an integrated series of SuDS devices – a “treatment train”. Indeed, in 2002, over 70% of sites in Scotland were reported as using only a single SuDS component (Wild et al., 2002). The management of runoff using a treatment train is preferred by the UK’s environmental regulators as it provides the following advantages:

- using different and complementary removal techniques can achieve enhanced pollutant removal;
- pollutant spills can be detected and managed in a more efficient manner by making the drainage infrastructure visible;
- an enhanced level of treatment is achieved by treating pollutants closer to their source; and,
- the shock load effect on regional controls is reduced, thus enhancing biodiversity by providing a stable habitat.

Although the benefits of SuDS have been reported for some time, land take, construction costs, uncertainty regarding maintenance and adoption of SuDS are generally seen as barriers to implementation of source and site controls. In contrast, providing a good quality of life by improving environmental amenity and biodiversity in urban areas are key drivers for planners. By considering these views, the underlying philosophy of the presented research is that the development of a surface water management plan at an early stage, coupled with advances in how the treatment train is modelled, would help deliver water management and planning objectives. The aim of the reported study is therefore to evaluate the potential benefits of using different treatment train solutions for a case study. Holistic evaluation of the different solutions is undertaken by focusing on four key stakeholder objectives:

- minimise land take;
- minimise whole life costs;
- managing flood risk; and,
- water quality.

The potential benefits achieved by the use of source and site controls are then used to reduce regional treatment facilities size, thereby offering the opportunity for developers and planners to manage the footprint differently whilst still satisfying water quality and quantity objectives.

2. METHODOLOGY

The methodology developed can be divided into three modules:

1. Development of source, site and regional controls scenarios – this module focuses on selecting appropriate source and site controls that can be incorporated within the treatment train.
2. Treatment train assessment – this module aims to provide a novel holistic assessment of the treatment train based on key stakeholder objectives. The assessment of the treatment train aims to evaluate how the main stakeholder objectives are satisfied and is based upon:
 - a. Land take: Determination of the land occupied by the SuDS devices is undertaken using recent design guidance (CIRIA, 2007; Scottish-Water, 2007).
 - b. Costs: Whole life costs over a 50 year period (HM Treasury, 2003).
 - c. Water quality: To estimate the pollutant removal capacities of a range of SuDS, first order decay kinetics (Kadlec et al., 1996) will be used.
 - d. Water quantity: Evaluation of the potential for source and site control to attenuate the volume reaching regional control was undertaken.
3. Proposal for regional controls size reduction – this module discusses the possibility of reducing regional control size by objectively incorporating attenuation at source and site control level.

2.1. Case study

The Clyde Gateway, situated along the River Clyde in Glasgow, is a priority regeneration area for the Scottish Government. Recent flooding in Glasgow, poor watercourse quality and the need to regenerate this neglected area as a “sought after” location led to the development of a forward looking surface water management plan (Aukerman et al., 2008). The reported project uses a small part of the Clyde gateway, Dalmarnock Road area (Figure 1), to generate development scenarios. The study area comprises 20 hectares where 1500 houses will be constructed. If no source or site controls are used, a regional pond of approximately 2200m² will be required to treat runoff to an acceptable level, and an additional 2600m² will be required to store runoff up to a 100 year return period storm (2.5 % of the catchment area).

Development scenarios were investigated based on the assumption that infiltration of runoff would not be permitted due to the fact that the site was heavily industrialised in the past years and the soil may be contaminated as a result (Bastien et al., 2010). Preventing runoff infiltration would prevent migration of pollutants due to past activities. However, it was agreed that further soil investigations would have to be conducted for the environmental regulator to decide whether the infiltration should be prevented, discouraged or encouraged. In the absence of pollution into the soil, there would be no other barriers apart from those imposed by the land use and associated building regulations to prevent infiltration (BRE, 1991). Thus, this paper makes the assumption that infiltration will be encouraged in medium and low density areas.

The infiltration rate of the underlying soil is a key parameter in the design of infiltrating SuDS devices. However, in the absence of a survey reporting on the actual infiltration capacities for the site, a desk-based value for the infiltration has been adopted. The geology for the site has been reported as a sand and alluvium mix. CIRIA (2007) reports infiltration rates can vary between 0.5 and 100m.h⁻¹ for this type geology and that this range allows a wide range of potential SuDS options to be considered. However, for practicalities, an infiltration rate of 30 m.h⁻¹ is assumed for an early design solution until further investigations on pollutants containment and possible infiltration rate are undertaken.



Figure 1: The Dalmarnock Road area contained within the Clyde Gateway boundaries

Regarding current development plans for the Dalmarnock Road area, the northern extent of the site has been described as a “new destination and gateway” and will benefit from major public investment to develop public transportation (Glasgow City Council, 2007). Development density for the site suggests a decreasing density gradient from the north to the south: higher densities towards the city centre and then decreasing progressively towards the suburbs. Although more accurate development plans will be considered in the future, the view adopted in this paper is that development of SuDS will be dependent on existing pressure on land take due to development density:

- The northern part of the site will not see above ground SuDS devices unless they are part of the infrastructure (e.g. green roofs). Infiltration devices will be prevented to cope with building regulations recommending to no infiltrate within 5m of buildings (Building regulations, 1991).
- The central part is more likely to adopt SuDS devices where they present a relatively low land take (e.g. Infiltration trenches).
- The southern part of the site will be a low development area where development of low amenity and relatively high land take SuDS is acceptable (e.g. swale).

2.2. Selection of potential SuDS techniques

Based on potential land use, site and catchment characteristics, the following seven key SuDS source, site and regional controls have been considered:

- 1) Standard conveyance swales (SW) can be used in the southern part of the site where lower density development can be expected. Design follows CIRIA's recommendations (CIRIA, 2007).

- 2) Retention pond (RP) discharges into the River Clyde is the “default end of pipe” solution in the southern part of the site. Design of the regional pond is based on recently published guidance (Scottish-Water, 2007; CIRIA, 2007). The design may include a volume dedicated to attenuate events up to the 100 year return period level.
- 3) Green roofs (GR) can be used instead of exposed roofs in the north part of the development area where large roof surfaces are more likely to be considered due to the higher density.
- 4) Concrete Block Pavement (CBP) can be used where traffic speeds are below 60km.h⁻¹. As such, they can be used in very low density development and on a case-by-case basis in other areas. In this case, their use is applied in the low density development where a pavement distributed across the area will be able to drain water from pavements.
- 5) Soakaways (SO) can be used in low density development to infiltrate roof runoff.
- 6) Infiltration trenches (IT) can be used in the medium density area to drain roads pavement.
- 7) Subsurface storage (SS) can provide storage for attenuation of water runoff anywhere on the area.

Logical combinations of the different SuDS devices allow consideration of 19 different treatment trains comprising one to five SuDS which can be assessed to understand the impact of using source and site controls to reduce the size of regional controls. The typical locations of these devices is illustrated in Figure 2

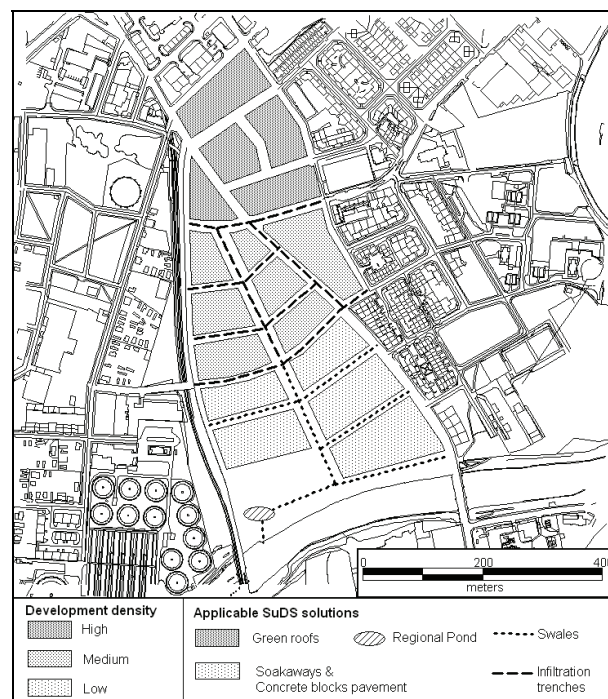


Figure 2: SuDS deployment for the Dalmarnock Road area

2.3. Treatment train assessment

Water quality, costs, land take will be assessed with the methodology previously developed in Bastien et al. (2010) and using hydrological modelling (Infoworks CS), water quality modelling (MUSIC) and up to date guidance in Scotland. The hydrological model will be tested for limited attenuation (30 years return period) and robust attenuation (100 years return period), whereas water quality models performances will be compared using a M1-60 event corresponding to 12 mm of runoff.

3. RESULTS AND DISCUSSION

3.1. Preliminary results

Based on the data determined for each SuDS device, assessment of the different treatment trains on the aspects of water quality, land take and costs can be found in Figure 3.

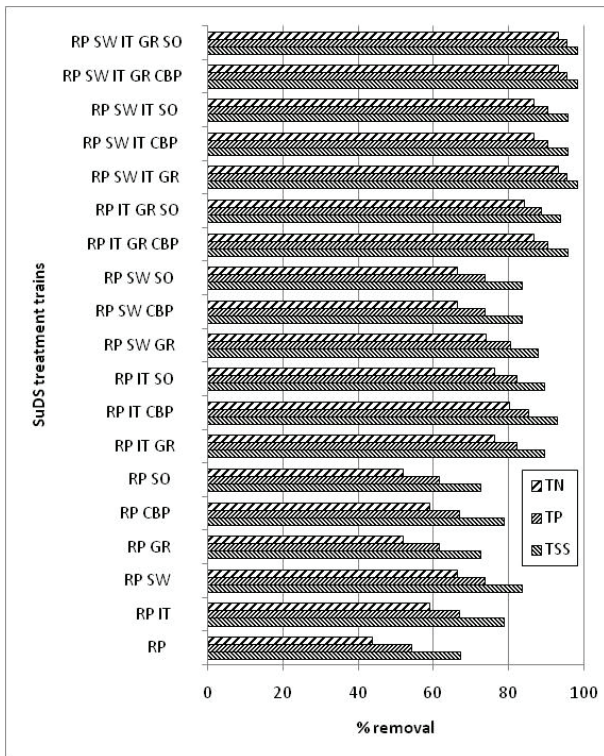


Figure 3a: Water quality estimation for the different SuDS treatment trains

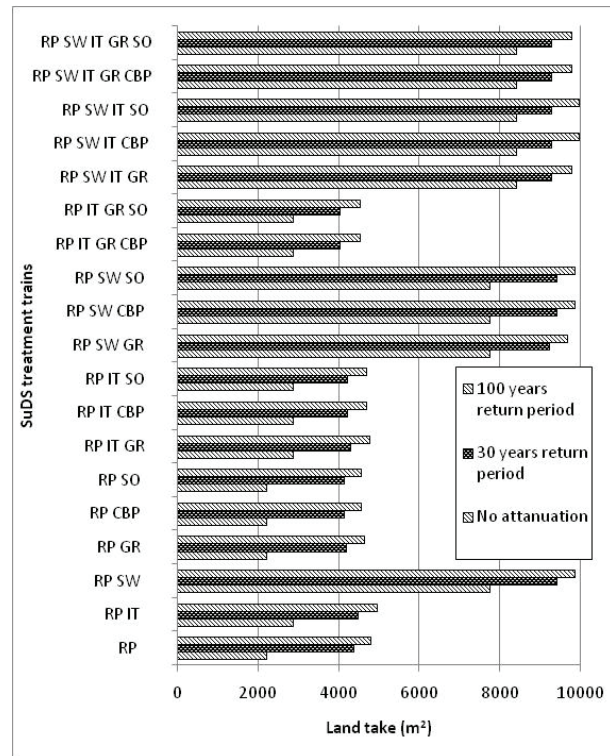


Figure 3b: Land take estimation for the different SuDS treatment trains

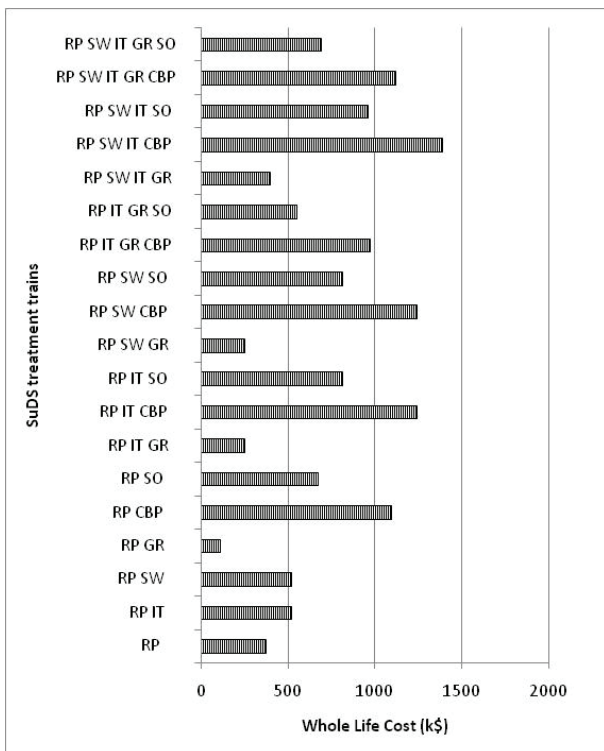


Figure 3c: Whole life cost estimation for the different SuDS treatment trains

With:

CBP - Concrete block pavement

GR - Green roofs

IT - Infiltration trenches

RP - Regional pond

SO - Soakaways

SW - Swales

Although the improvement in water quality is desirable, the whole life costs associated with the different treatment trains show that using multiple SuDS source and site controls has a significant cost impact and, in this case, can increase the cost of the initial project by a factor of 4. However, it should be noted that the implementation of green roofs appears to be financially beneficial in the long term. This view, supported by several authors (Carter et al., 2008; Acks, 2006), is based on the theoretical assumption that the choice of a

low maintenance vegetation associated with an extended lifespan can offset the construction and maintenance of an exposed roof. The longer term benefits may be reinforced by evaluating the extent to which green roofs provide better insulation and reduce heating and cooling costs as a result (Carter et al., 2008; Wong et al., 2003). Similarly, the implementation of swales in the low density area does not add a significant cost to the project. A further point to note is that unless SuDS are part of the infrastructure (e.g. Concrete Block Pavement or Green Roofs), they add significant land take to that of the initial regional control. The attenuation of different return periods also adds significant land take despite the opportunity to size some source and site SuDS to attenuate up to a 30 year period.

Overall, this section confirms the main stakeholder fears (e.g. whole life costs and land take) about using SuDS treatment trains rather than using only a single regional SuDS. Indeed, this initial analysis has shown that despite an estimated improved treatment of up to 31%, 41% and 49% for respectively TSS, TP and TN, some treatment trains add significant land take and/or costs to the project.

3.2. Reduction of regional control size

In new developments there is often pressure to reduce the size of a regional pond. Considering this, a reduction of land take can be achieved based on the use of source and site controls. Regional control size can be reduced by two different means:

- Reduction of the treatment volume by taking into account benefits of source and site controls.
- Reduction of the attenuation volume by providing attenuation at source and site control levels.

3.2.1. Reduction of the treatment volume.

Pond performance is largely driven by pond surface area (Wu et al., 1996). Consequently, reducing pond surface area will reduce pollutant removal by increasing the hydraulic loading. As shown previously, the use of a single pond, achieves 68% removal of suspended solids. Considering this removal adequate, then if the treatment train produces a level of treatment beyond that level, it follows that the regional pond may be reduced in size until the target performance is reached. Table 1 provides land take of source, site and regional controls achieving at least a reduction of 68% of total suspended solids. For some treatment trains, the regional control appears to be unnecessary, from a water quality perspective, because the upstream treatment train achieves a removal of suspended solids beyond 68%. However, this solution may not be acceptable as the pond is the last control before the runoff is discharged and could be considered as security in case source and site controls not perform to the required standards.

SuDS Treatment Trains (with CBP Concrete Block Pavement; GR Green Roofs; IT Infiltration Trenches; RP Regional pond; SW Swales; WB Water Butts; SO Soakaways)	Initial treatment train land take (m ²)	Achievable reduction of regional SuDS land take (m ²)	Achievable reduction of regional SuDS land take (%)	Achievable reduction of SuDS treatment train's land take (%)
RP	2200	0	0	0
RP IT	2871	1400	64	49
RP SW	7724	1400	64	18
RP GR	2200	300	14	14
RP CBP	2200	1400	64	64
RP SO	2200	300	14	14
RP IT GR	2871	1400	64	49
RP IT CBP	2871	1800	82	63
RP IT SO	2871	1400	64	49
RP SW GR	7724	1200	55	16
RP SW CBP	7724	1000	45	13
RP SW SO	7724	1000	45	13
RP IT GR CBP	2871	2200	100	77
RP IT GR SO	2871	1600	73	56
RP SW IT GR	8395	2200	100	26
RP SW IT CBP	8395	2200	100	26
RP SW IT SO	8395	2200	100	26
RP SW IT GR CBP	8395	2200	100	26
RP SW IT GR SO	8395	2200	100	26

Table 1: Achievable reduction of land take based on suspended solids removal of source and site controls

3.2.2. Reduction of the attenuation volume.

The attenuation of the runoff volume can be undertaken at source and site control levels. The land take associated with the storage of the 1, 30 and 100 year return period events in addition to the land take of the permanent pool is respectively of 3529, 4363 and 4788 m² for respective volumes of 2616, 5560 and 7220m³. Reduction in the runoff volumes reaching the regional control through the use of source and site control will help reduce land occupied by the regional control.

As shown in Table 1, the use of attenuation and infiltration source devices has a relatively poor impact on the overall land take. This is mainly due to two main reasons:

- The land take of source devices does not offset the land take reduction of the regional control (e.g. swales).
- Infrastructure SuDS, mainly green roofs (GR) and concrete block pavement (CBP) have a limited impact due the restrained area where they apply.

To further solve the land take issue linked to the attenuation of the different return periods, the use of hard engineering solutions (i.e. the use of subsurface storage) is considered for the area despite possible reluctance on the part of the environmental regulator. Subsurface storage can store the designed volume and impacts only on costs following equation 1 (Duffy et al., 2008):

$$WLC_{SS} = 220.7 \times V + 13259 \quad (1)$$

With:

- WLC: Whole Life costs (US\$)
- V: Stored volume (m³)

Overall, the choice of SuDS devices to attenuate runoff will depend on the design return period. Low return period events (<30 years) can be attenuated using source and site controls - increasing costs and/or overall land take. Attenuation of high return period (>30 years) will need dedicated structures and will be achieved at the regional control site or locally using hard engineering solutions (reducing the footprint but increasing the costs).

SuDS Treatment Trains (with : CBP Concrete Block Pavement; GR Green Roofs; IT Infiltration Trenches; RP Regional pond; SW Swales; WB Water Butts; SO Soakaways)	30 years return period attenuation		100 years return period attenuation	
	Regional control land take (m ²)	Total land take (m ²)	Regional control land take (m ²)	Total land take (m ²)
RP	4363	4363	4788	4788
RP IT	3810	4481	4270	4941
RP SW	3865	9389	4328	9852
RP GR	4179	4179	4621	4621
RP CBP	4122	4122	4562	4562
RP SO	4122	4122	4562	4562
RP IT GR	3614	4285	4088	4759
RP IT CBP	3539	4210	4020	4691
RP IT SO	3539	4210	4020	4691
RP SW GR	3679	9203	4144	9668
RP SW CBP	3865	9389	4328	9852
RP SW SO	3865	9389	4328	9852
RP IT GR CBP	3350	4021	3842	4513
RP IT GR SO	3350	4021	3842	4513
RP SW IT GR	3063	9258	3582	9777
RP SW IT CBP	3073	9268	3766	9961
RP SW IT SO	3073	9268	3766	9961
RP SW IT GR CBP	3063	9258	3582	9777
RP SW IT GR SO	3063	9258	3582	9777

Table 2: Footprint of regional and SuDS treatment trains

3.3. Cost, land take and flood risk management performance relationships

Based on the results outlined thus far, it is possible to consider how different attenuation and water quality improvement levels impact on both cost and land take. This is best undertaken by considering three design scenarios:

1. Where the design is for water quality improvement only.
2. Where the design is for water quality improvement and limited retention.
3. Where the design is for water quality improvement and robust retention.

Data for these three scenarios are presented in Figure 4 where relationship between land take, costs, water quality and water quantity can be identified.

These plots can serve as a basis for discussion between all the stakeholders involved in the drainage of the Dalmarnock Road area. More specifically, the following consideration can help decision maker to further implement SuDS on the area:

1. The costs appear to be mainly driven by the use of sub-surface storage and concrete block pavement in addition to the use of a regional control pond. Whereas land take is driven by the use of regional pond and swales. Where land take and costs are concerned, green roofs and soakaways have a relatively limited impact in comparison to the use of other SuDS.
2. Considering the Figure 4a, it can be seen that by using a treatment train, significant water quality improvements can be obtained compared to the initial solution of using an end-of-pipe pond: the initial removal rate, below 70% for TSS can be improved beyond 95% by either implementing a swale network or by using pervious pavement in the low density area. The first solution presents the advantage of managing efficiently the costs whereas the second solution offers the opportunity to reduce the land takes for an equivalent water quality improvement. For these specific solutions, a land take reduction of 5500m² can be achieved for an equivalent cost of ~ US\$600k.
3. A further 2000m² to 2400m² are necessary to attenuate the 30 and the 100 year return periods respectively. In addition to the reduction in land take achievable based on the water quality benefits of source and site controls, a further land take reduction can be achieved by using subsurface storage to attenuate runoff to the required standards. Thus maximum reduction of land take for a TSS removal rate beyond 90% can be achieved by the use of a swale network or concrete block pavement and sub-surface storage.
4. Within an increase in costs and land take limited to 35% of those initially planned for the development of an end-of-pipe solution, significant water quality improvements can be achieved with a TSS removal beyond 85%. These solutions include the use of green roofs and infiltration trenches.

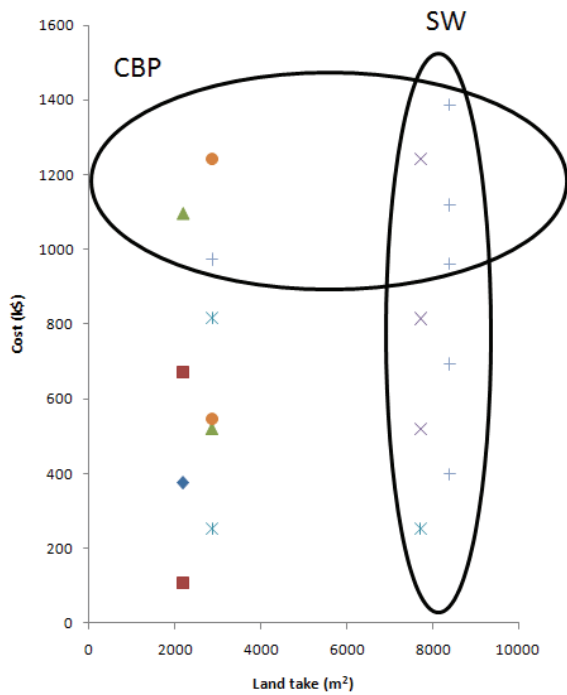


Figure 4a: Cost size attenuation relationship when no attenuation is required

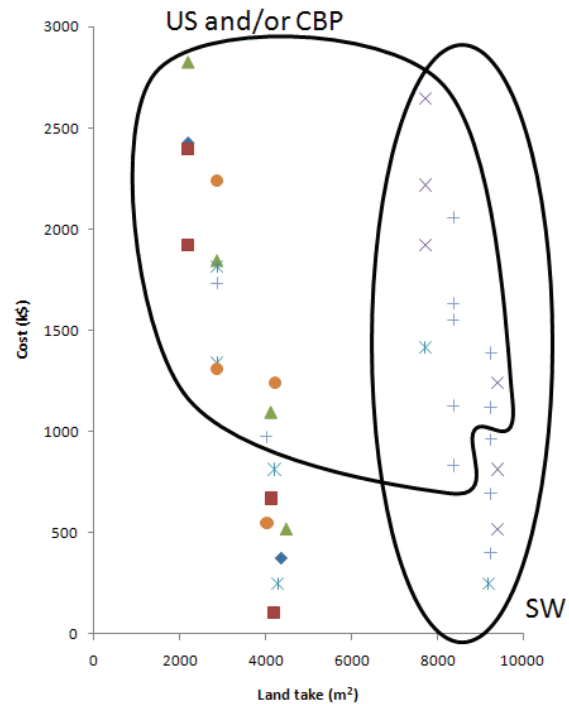


Figure 4b: Cost size attenuation relationship with 30 years attenuation

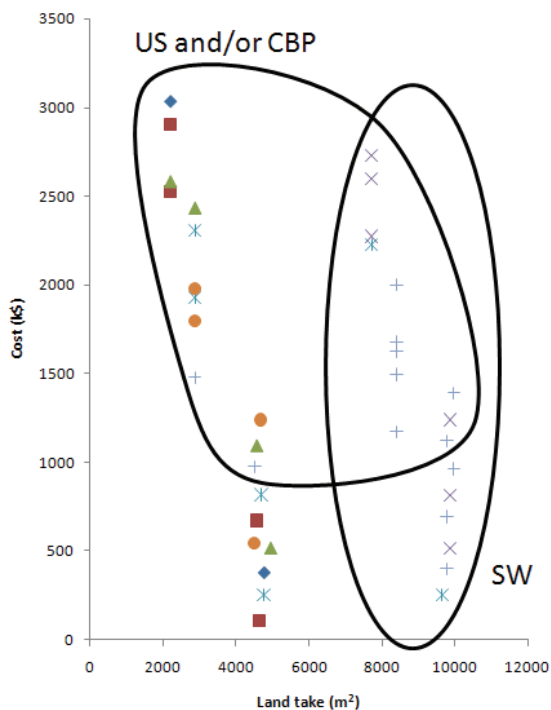


Figure 4c: Costs size attenuation relationship with 100 years attenuation

With:

TSS removal (%):

- ◆ 65 to 69
- 70 to 74
- ▲ 75 to 79
- × 80 to 84
- ✱ 85 to 89
- 90 to 94
- + > 95

CBP - Concrete Block Pavement
 US - Sub-surface Storage
 SW - Swales

3.4. Comparison of the cases where infiltration is prevented or encouraged.

By comparing these results with those presented in Bastien et al. (2010), where the same site was considered but infiltration was not permitted, it can be seen that:

- Infiltration of TP and TN at source level increase the overall removal for these pollutants reaching 95% and 93% removal for TP and TN respectively (in comparison with a maximum removal of 75% and 60% removal for TP and TN respectively). This result is due to the removal processes associated with source and site controls, mostly based on the filtration process either by substrate or

vegetation: these processes have a relatively low impact on the removal of TN and TP mostly found under dissolved forms (Taylor et al., 2005).

- Overall, the design of SuDS to prevent infiltration has very little impact on the overall cost (e.g. the lining of a swale to prevent infiltration only increases the whole life cost by 4%). As a result, the water quality and cost relationship are of a similar order of magnitude.

4. CONCLUSIONS

It can be concluded that a novel methodology has been presented which offers an opportunity for the key stakeholders involved in the drainage of surface runoff in urban areas to maximize the benefits of using SuDS in a treatment train. The reduction in regional land take can be achieved based on infiltration and/or attenuation of source and site controls. Despite the problems associated with offsetting regional land take with source and site controls, it has been shown that a different footprint for SuDS can be achieved by using SuDS in series rather than as an end-of-pipe control. The results obtained should be seen within the context of several SuDS related considerations which will vary greatly between catchments:

- land value in urban areas;
- increased amenity and biodiversity in urban areas;
- better management of accidental pollution; and,
- infiltration rate related to site geology and impacting on SuDS design.

Further work will comprise investigating the potential value of SuDS source and site controls from the point of view of people living in close proximity. This will enable the definition of preferred treatment trains for urban areas depending on land use, catchment characteristics and stakeholders objectives.

5. ACKNOWLEDGMENTS

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