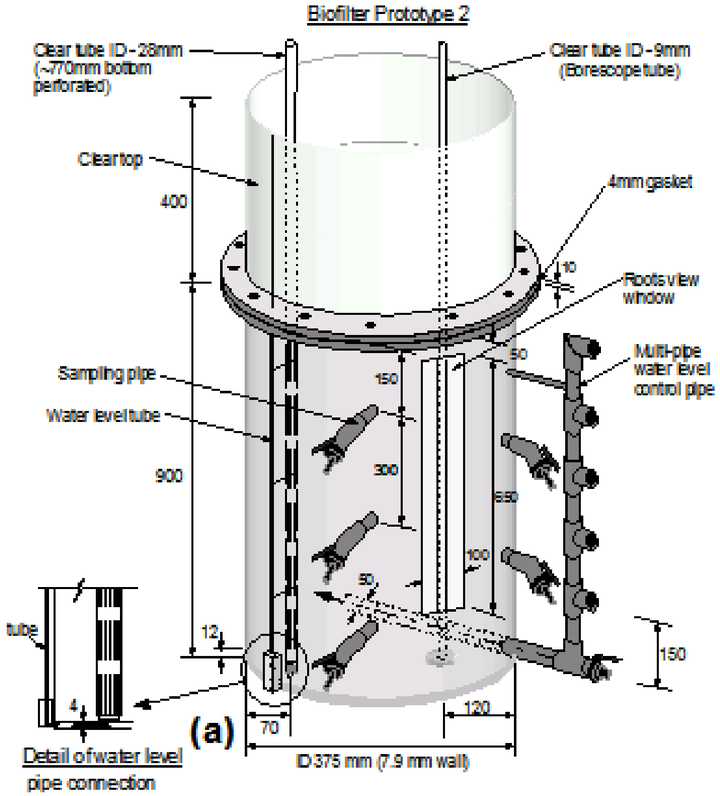
BLIGH TANNER

Facing the MUSIC

Implications of recent research on stormwater quality targets and practices



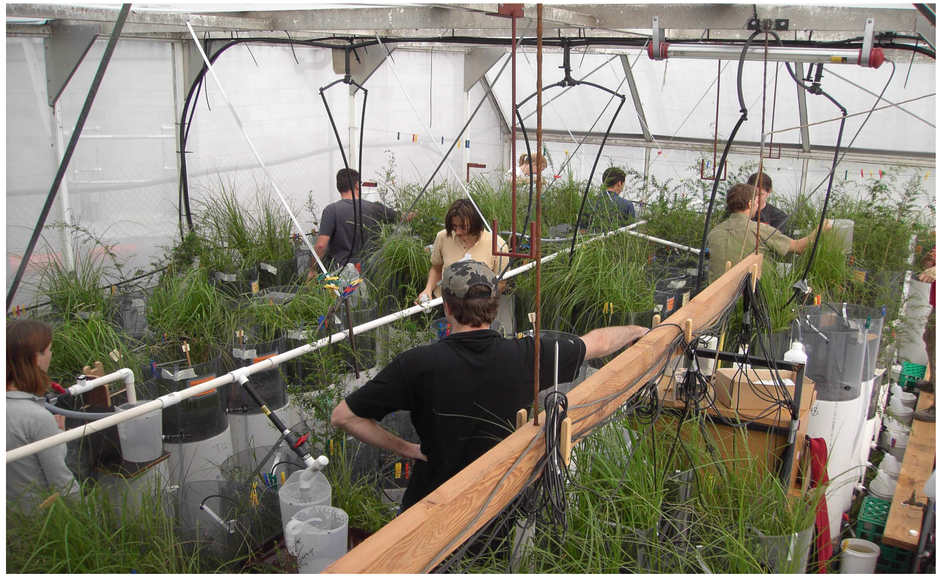


Figure 2: (a) biofilter column assembly (b) biofilter columns in the greenhouse

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Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale

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SUMMARY

Biofiltration systems are a recommended and increasingly popular technology for stormwater management; however there is a general lack of performance data for these systems, particularly at the field scale. The objective of this study was to investigate the hydrologic and pollutant removal performance of three field-scale biofiltration systems in two different climates. Biofilters were shown to effectively attenuate peak runoff flow rates by at least 80%. Performance assessment of a lined biofilter demonstrated that retention of inflow volumes by the filter media, for subsequent loss via evapotranspiration, reduced runoff volumes by 33% on average. Retention of water was found to be most influenced by inflow volumes, although only small to medium storms could be assessed. Vegetation was shown to be important for maintaining hydraulic capacity, because root growth and senescence countered compaction and clogging. Suspended solids and heavy metals were effectively removed, irrespective of the design configuration, with load reductions generally in excess of 90%. In contrast, nutrient retention was variable, and ranged from consistent leaching to effective and reliable removal, depending on the design. To ensure effective removal of phosphorous, a filter medium with a low phosphorus content should be selected. Nitrogen is more difficult to remove because it is highly soluble and strongly influenced by the variable wetting and drying regime that is inherent in biofilter operation. The results of this research suggest that reconfiguration of biofilter design to manage the deleterious effects of drying on biological activity is necessary to ensure long term nitrogen removal.

Introduction

Widespread recognition of negative impacts of urban stormwater (Hatt et al., 2004; Leopold, 1968; Meyer et al., 2005) has resulted in the identification of two important related goals for its management, that is, maintaining stormwater quantity (flood peak and total volume) and quality (pollution) as close to pre-development levels as possible. A range of stormwater treatment technologies have been developed in response, for example, stormwater wetlands, sedimentation ponds, sand filters, infiltration systems and, more recently, biofiltration systems (e.g. Davis, 2005; Wong, 2006).

Biofiltration systems (also known as biofilters, bioretention systems, and rain gardens) operate by filtering diverted runoff through dense vegetation followed by vertical filtration through soil filter media. Treatment is achieved via a number of processes including sedimentation, fine filtration, sorption, and biological uptake (PGC, 2002). Water is then collected in under-drains at the base of the filter media for discharge to receiving waters or storage for re-use. Biofilters are receiving increasing interest due to their design flexibility, small footprint, and landscape improvements, such as aesthetic enhancement. However, to date, performance data for biofilters have generally been limited to the laboratory-scale, with few studies reporting on field-scale testing (Dietz and Clausen, 2005)

Past studies generally
metals, and phosphorus, b
larly nitrate. Laboratory
2003, 2006) demonstrate
of heavy metals (>90%,
ammonium (60–80%, 200
65%), largely due to poor
of nitrate (2006). Henders
formance of three differe
loam) in vegetated and
the vegetated columns
of phosphorus loads, but
to leach nitrogen. Hatt
nitrogen and phosphorus
filter media. In a very rec
et al. (2007) investigated
tion selection on pollut
concentrations were con
phosphorus by an averag

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E-mail address: belinda.hatt@eng.monash.edu.au (B.E. Hatt).

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Evaluating Bioretention Hydrology and Nutrient Removal at Three Field Sites in North Carolina

W. F. Hunt[1]; A. R. Jarrett[2]; J. T. Smith[3]; and L. J. Sharkey[4]

Abstract: Three bioretention field sites in North Carolina were examined for pollutant removal abilities and hydrologic performance. The cells varied by fill media type or drainage configuration. The field studies confirmed high annual total nitrogen mass removal rates at two conventionally drained bioretention cells (40% reduction each). Nitrate-nitrogen mass removal rates varied between 75 and 13%, and calculated annual mass removal of zinc, copper, and lead from one Greensboro cell were 98, 99, and 81%, respectively. All high mass removal rates were due to a substantial decrease in outflow volume. The ratio of volume of water leaving the bioretention cell versus that which entered the cell varied from 0.07 (summer) to 0.54 (winter). There was a significant ($p<0.05$) change in the ratio of outflow volume to inflow volume when comparing warm seasons to winter. Cells using a fill soil media with a lower phosphorus index (P-index), Chapel Hill cell C1 and Greensboro cell G1, had much higher phosphorus removal than Greensboro cell G2, which used a high P-index fill media. Fill media selection is critical for total phosphorus removal, as fill media with a low P-index and relatively high CEC appear to remove phosphorus much more readily.

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CE Database subject headings: Stormwater management; Best management practice; Water quality; Nutrient loads; North Carolina; Hydrology; Abatement and removal.

Introduction

Stormwater runoff is a primary factor in the degradation of many streams and other water bodies (USEPA 2000). The adverse impacts of this and other sources of pollution include closures of shellfish waters, fish kills, and a reduction of aesthetics, which consequently reduce fishing and recreational values of downstream waters. Stormwater runoff contains nitrogen, phosphorus, and heavy metals (Pitt et al. 1995; Wu et al. 1998).

In coastal areas of the eastern United States, nutrients are a particular concern. Excess nitrogen and phosphorus loading in coastal North Carolina (NC) is blamed for fish kills in NC estuaries (Gray 2000). Similar impacts were noted in the Chesapeake Bay ("Chesapeake" 2001), where government officials from Chesapeake Bay watershed states have declared a nitrogen reduction goal of 50% by 2010. State and federal regulations force mitigation of pollutants in stormwater by requiring new developments to install structural stormwater treatments called best management practices (BMPs). Examples of stormwater BMPs include stormwater wetlands, sand filters, wet ponds, and more recently, bioretention areas (Coffman et al. 1993b). Some states, such as North Carolina, require that all stormwater BMPs within sensitive watersheds reduce nitrogen loads (NCDENR 1999). Having accurate mass removal efficiencies for BMPs, such as bioretention, is essential in practice selection.

Stormwater practices, particularly those installed in areas frequented by pedestrian traffic, not only must reduce pollution, but must also be aesthetically pleasing. Communities in many states require up to 15% of large commercial developments to be set aside for medians and other open space. Bioretention may be able to meet both water quality and landscape objectives.

An illustration of construction of a bioretention cell is found in Fig. 1. A bioretention area is initially an excavated basin, at the bottom of which underdrains are laid and covered with a gravel envelope. Between 0.7 and 1.2 m of fill soil media is placed over the gravel envelope, and then plants and mulch are added to the surface. Typically, runoff is captured and infiltrates the bioretention media. Captured water leaves the cell by underdrain outflow, exfiltration, or evapotranspiration; whereas high flows, occurring when the bioretention cell is full, nominally when a minimum of 25 mm of precipitation has fallen, are bypassed, either around or through the bioretention area. Viewed from the surface, the bioretention cell can
properly. Pollutic
deeper soil media
a vegetated sand
Compared to
effective (Wossin
pal stormwater p
(Hager 2003). Ho
the field do not su
mass) of nitrate-n

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J. Irrig. Drain Eng., 2006, 132(6): 600-608

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Performance characterisation of a stormwater treatment bioretention basin

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ABSTRACT

Treatment performance of bioretention basins closely depends on hydrologic and hydraulic factors such as rainfall characteristics and inflow and outflow discharges. An in-depth understanding of the influence of these factors on water quality treatment performance can provide important guidance for effective bioretention basin design. In this paper, hydraulic and hydrologic factors impacting pollutant removal by a bioretention basin were assessed under field conditions.

Outcomes of the study confirmed that the antecedent dry period plays an important role in influencing treatment performance. A relatively long antecedent dry period reduces nitrite and ammonium concentrations while increasing the nitrate concentration, which confirms that nitrification occurs within the bioretention basin. Additionally, pollutant leaching influences bioretention basin treatment performance, reducing the nutrients removal efficiency, which was lower for high rainfall events. These outcomes will contribute to a greater understanding of the treatment performance of bioretention basins, assisting in the design, operation and maintenance of these systems.

1. Introduction

Bioretention basins are among the most commonly used stormwater treatment measures using filtration as the primary mechanism for pollutant removal, supported by evapotranspiration, adsorption and biotransformation (Davis, 2007). Additionally, a bioretention basin attenuates runoff peak flow and reduces runoff volume through detention and retention. As noted by past researchers (Davis, 2008; Hunt et al., 2008), the water quality treatment performance of bioretention basins closely depends on hydrologic and hydraulic factors such as rainfall characteristics and inflow and outflow parameters. In this context, an in-depth understanding of the influence of hydrologic and hydraulic factors on treatment performance can provide important guidance for effective bioretention basin design.

Researchers using both, field and laboratory scale studies have assessed the performance of bioretention basins, highlighting the influence of hydrologic and hydraulic factors on pollutant removal processes (Dietz and Clausen, 2005; Heasom et al., 2006; Hsieh and Davis, 2005). In terms of field scale studies, past researchers have commonly evaluated the long term treatment performance rather than event-based performance (Hunt et al., 2006; Hatt et al., 2009a). This limits the detailed understanding of treatment performance, as only lumped characteristics of hydraulic and pollutant treatment processes are considered. Research studies focussing on developing an in-depth understanding of processes in bioretention basins have primarily been undertaken at the laboratory scale (Hatt et al., 2008). However, these studies can be far from reality in terms of replicating field conditions. This results in knowledge gaps relating to field performance, influential factors and event-based pollutant removal processes.

This research study was undertaken to create new knowledge relating to the influence of hydraulic and hydrologic factors on pollutant removal processes. The study was undertaken in a monitored bioretention basin in the field serving a small residential

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Urban stormwater treatment using bioretention

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Runoff
Stormwater BMP

SUMMARY

Urban stormwater has negative environmental and ecological effects. Bioretention systems are starting to be used in efforts to mitigate these effects. A bioretention system receiving water from a light industrial catchment and a busy road was designed, built and monitored for changes in soil physics as well as hydrological and hydrochemical efficiency. The soils in the bioretention system were designed to have high metal removal potential and high permeability to compensate for undersized bioretention volume. The inflow hydrograph was a series of sharp peaks with little baseflow, typical of runoff from impervious surfaces. The bioretention system smoothed the hydrograph by reducing peak flow and volume for all 12 events monitored in detail. Overflow occurred in 10 events indicating the increased permeability did not fully compensate for the undersized volume. Runoff was heavily polluted with sediment and heavy metals, in particular zinc. The majority of the zinc, lead and Total Suspended Sediments were removed from the stormwater that flowed through the bioretention system, with TSS and total zinc concentrations reducing by orders of magnitude. Despite high removal efficiency, median concentrations of zinc exiting the bioretention system still exceeded ecosystem health guidelines and the bioretention system was both a source and sink of copper.

1. Introduction

Bioretention systems, also known as biofilters or raingardens, are the most widely used stormwater 'best management practice' in the US (Davis et al., 2009) and are widely promoted and used elsewhere (Fujita, 1997; Wong, 2006; Woods-Ballard et al., 2007). Bioretention systems filter polluted stormwater through biologically active plants and soils thereby removing contaminants from the water. They have played an important role in the implementation of low impact development or water sensitive urban design as they are generally small, aesthetically pleasing and are reported to achieve a number of more sustainable stormwater management objectives (Muthanna et al., 2007; Bratieres et al., 2008; Davis et al., 2009; DiBlasi et al., 2009; Li et al., 2009). These objectives include the management of stormwater peak flow, runoff volume and stormwater pollution and maintenance of groundwater recharge and stream baseflow. The primary outcomes are reported to be the protection of receiving waters from pollution and erosion (Davis et al., 2009).

The water quality performance of bioretention systems has mainly been assessed in laboratory conditions (e.g. Sun and Davis, 2007; Bratieres et al., 2008; Lucas and Greenway, 2008). These studies generally report high removals of sediments, heavy metals and phosphorus from synthetic stormwaters. The removal of nitrogen, and particularly nitrate, has been variable (Hatt et al., 2007; Henderson et al., 2007). Recent studies have suggested that laboratory-scale filter columns do not satisfactorily replicate field-scale conditions leading to calls for in situ evaluation of bioretention systems (Hatt et al., 2008).

Measurements at two bioretention field sites showed variable, sometimes high, load reductions for suspended sediments and heavy metals (Hatt et al., 2009). High load reductions were observed during four simulated storms using synthetic stormwater. Runoff in response to rainfall was measured during small storms only using composite samples and resulted in variable load reduction. It was clear that variability in load reduction occurred because the concentrations in the influent were low; and very low compared with the synthetic stormwater.

The more robust efficiency metric of effluent quality (Strecker et al., 2001) was reported in the same study (Hatt et al., 2009) from a single field site which was again tested using synthetic stormwater. A consistent reduction in the concentrations of TSS, Cu, Pb and Zn between the influent and effluent was observed. The reduction in concentration was not so clear when non-synthetic polluted road runoff was examined. While the concentrations of Cu and Zn

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The pollution removal and stormwater reduction performance of street-side bioretention basins after ten years in operation

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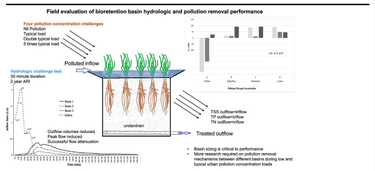
HIGHLIGHTS

- Hydrologic and pollution removal performance of 10 year old bioretention basins evaluated.
- The basins successfully reduced peak flow, and runoff volumes.
- Pollution removal performance successful for TSS and TP across some pollution concentrations.
- Bioretention basins found to contribute both TSS and TN to downstream aquatic environments.

GRAPHICAL ABSTRACT



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ABSTRACT

This study evaluated the pollution removal and hydrologic performance of five, 10-year old street-side bioretention systems. The bioretention basins were subjected to a series of simulated rainfall events using synthetic stormwater. Four different pollution concentrations were tested on three of the bioretention basins. The four concentrations tested were: A) no pollution; B) typical Australian urban pollutant loads; C) double the typical pollution loads, and; D) five times the typical pollution loads. Tests were also undertaken to determine the levels of contaminant and heavy metals build-up that occurred in the filter media over the 10 year operational life of the bioretention systems. Although highly variable, the overall hydrological performance of the basins was found to be positive, with all basins attenuating flows, reducing both peak flow rates and total outflow volumes. Total suspended solids removal performance was variable for all tests and no correlation was found between performance and dosage. Total nitrogen (TN) removal was positive for Tests B, C and D. However, the TN removal results for Test A were found to be negative. Total phosphorus (TP) was the only pollutant to be effectively removed from all basins for all four synthetic stormwater tests. The study bioretention basins were found to export pollutants during tests where no pollutants were added to the simulated inflow water (Test A). Heavy metal and hydrocarbon testing undertaken on the bioretention systems found that the pollution levels of the filter media were still within acceptable limits after 10 years in operation. This field study has shown bioretention basin pollution removal performance to be highly variable and dependant on a range of factors

usc.edu.au (T. Lucke).

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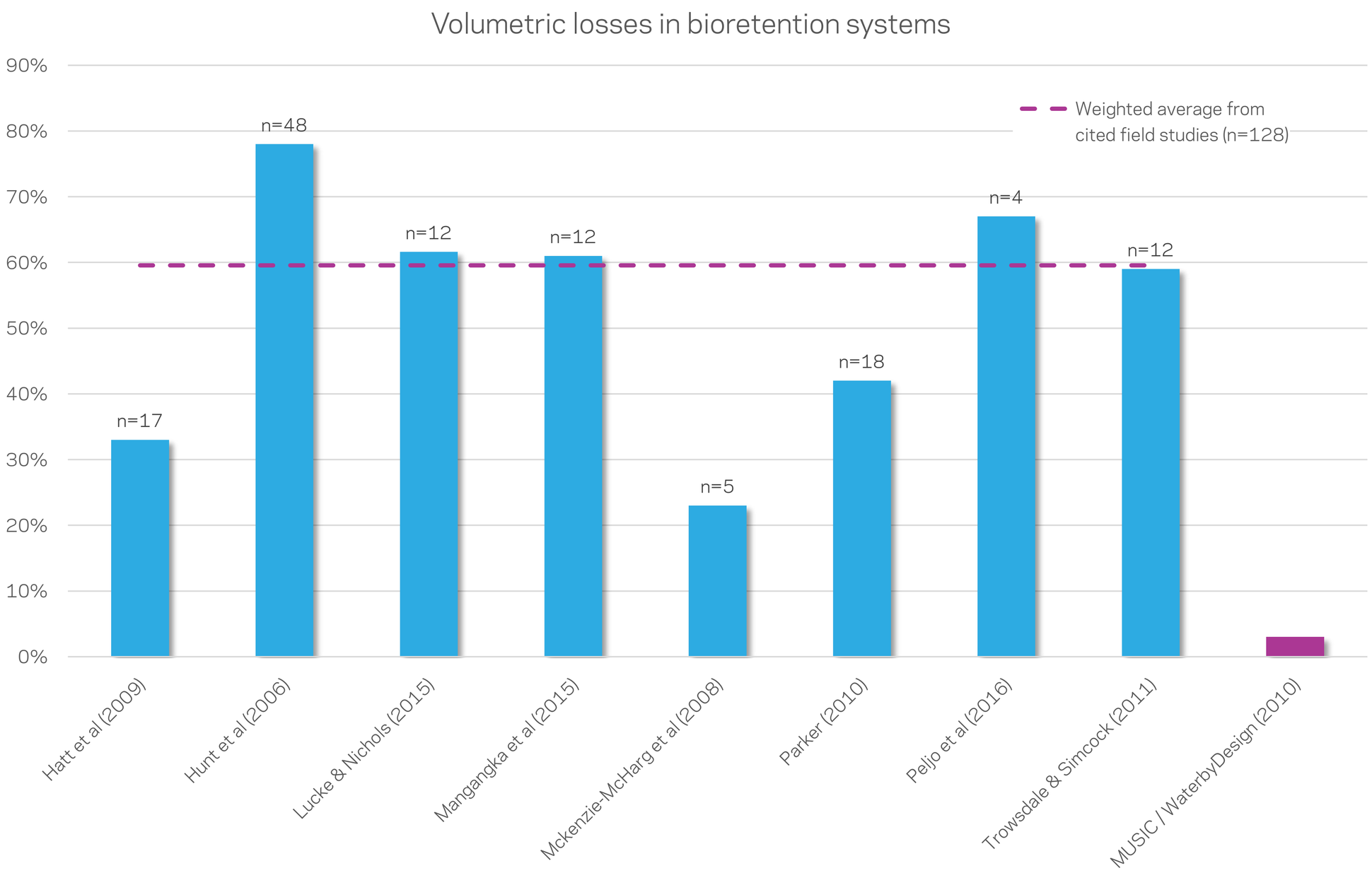
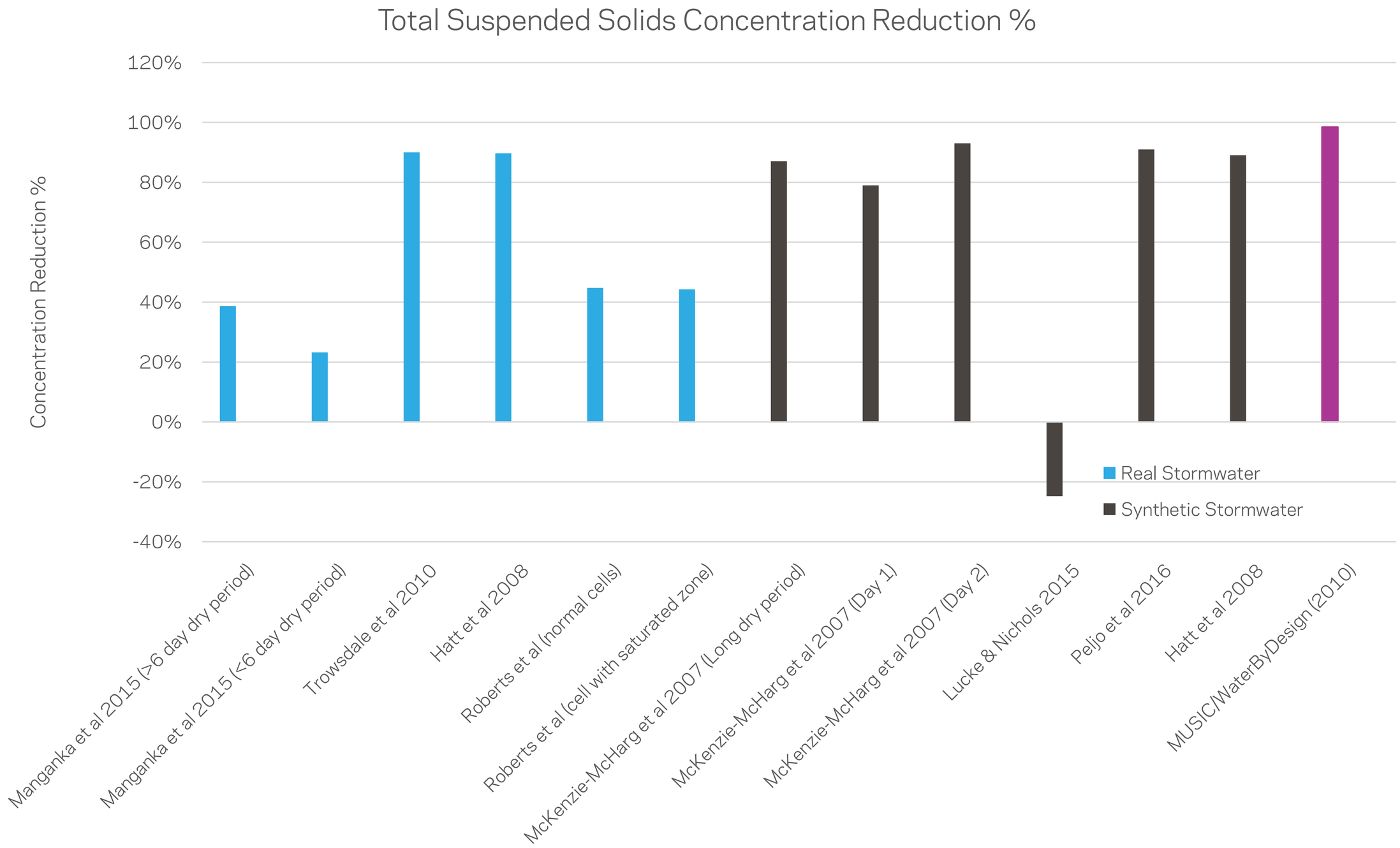
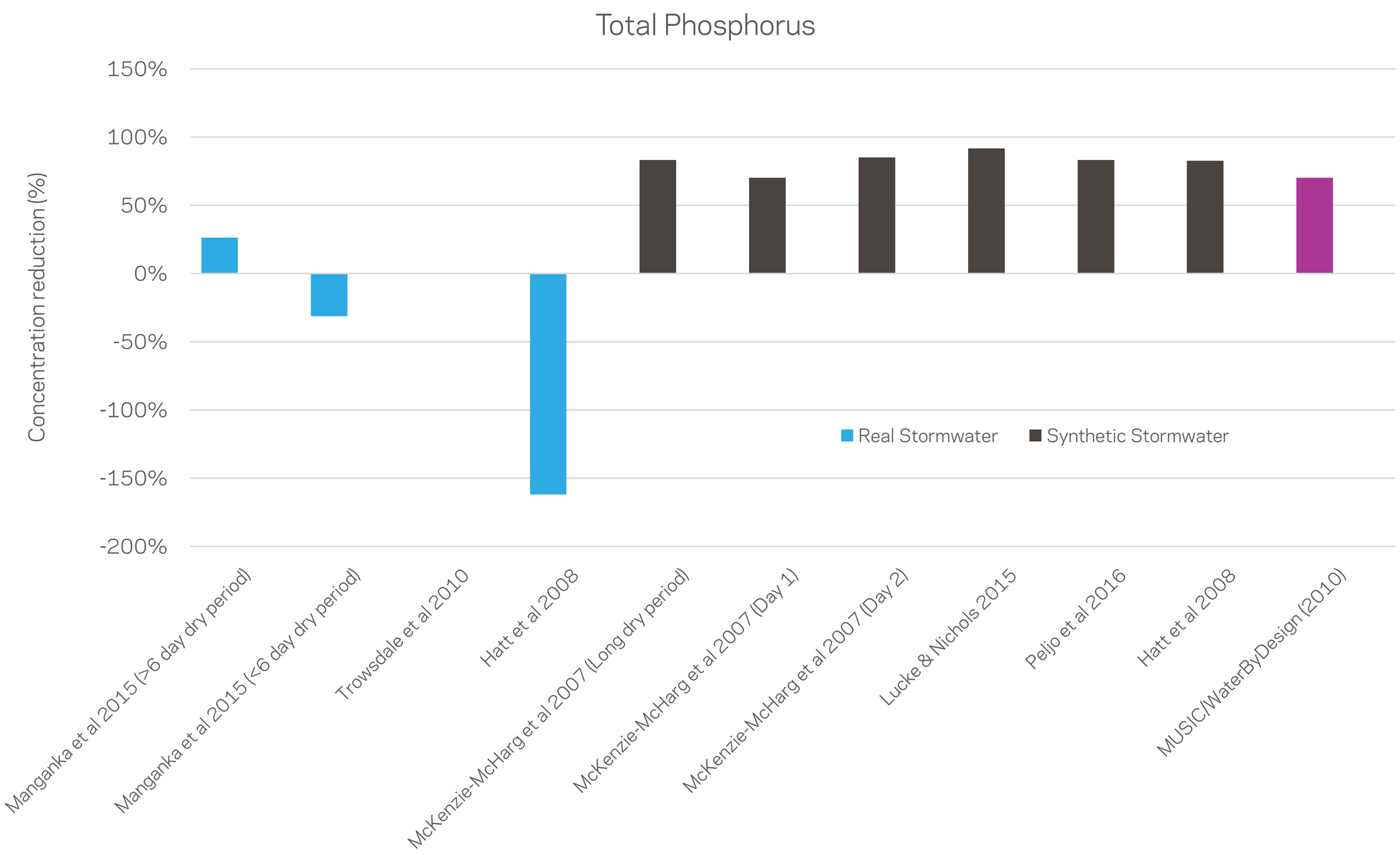
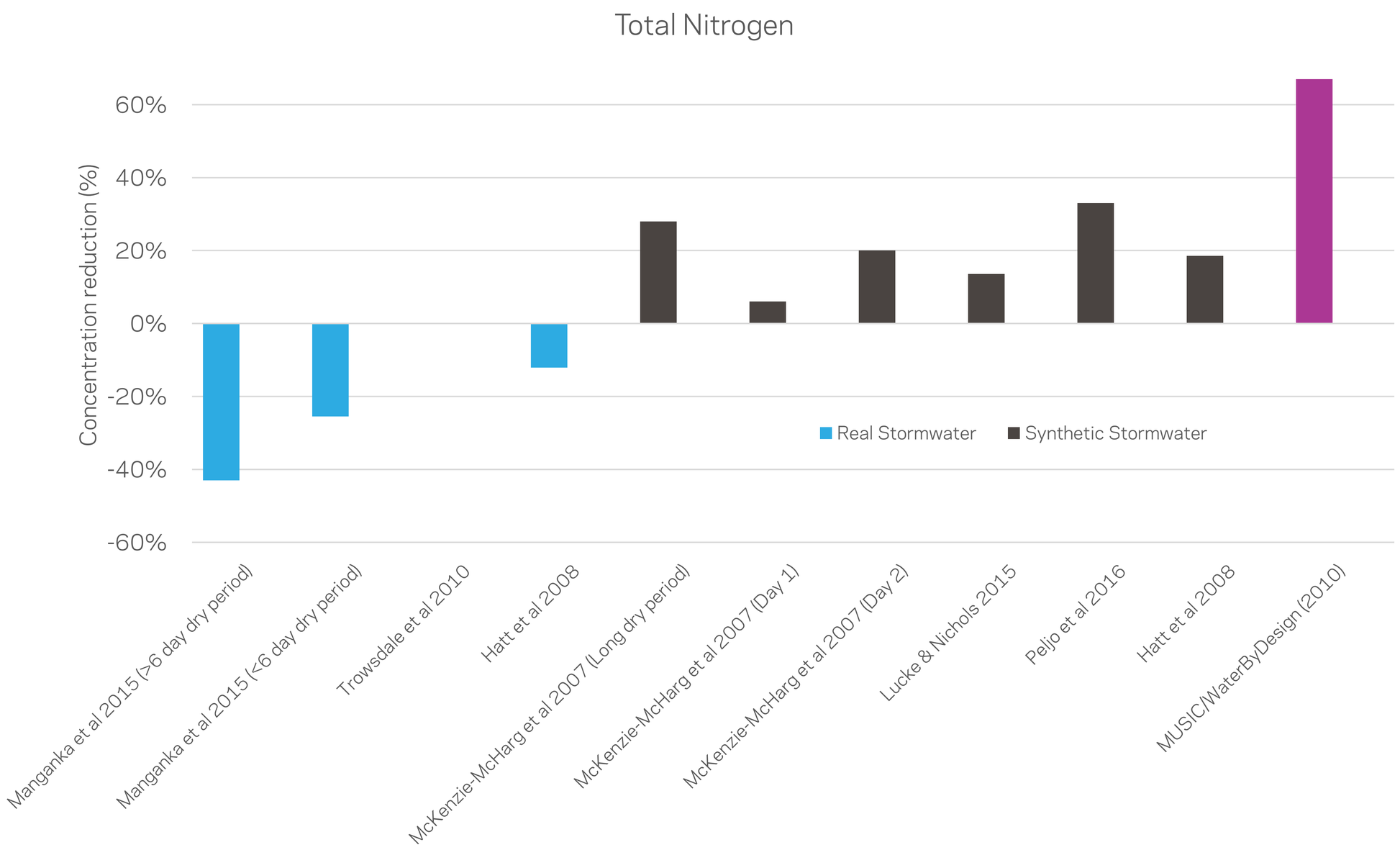
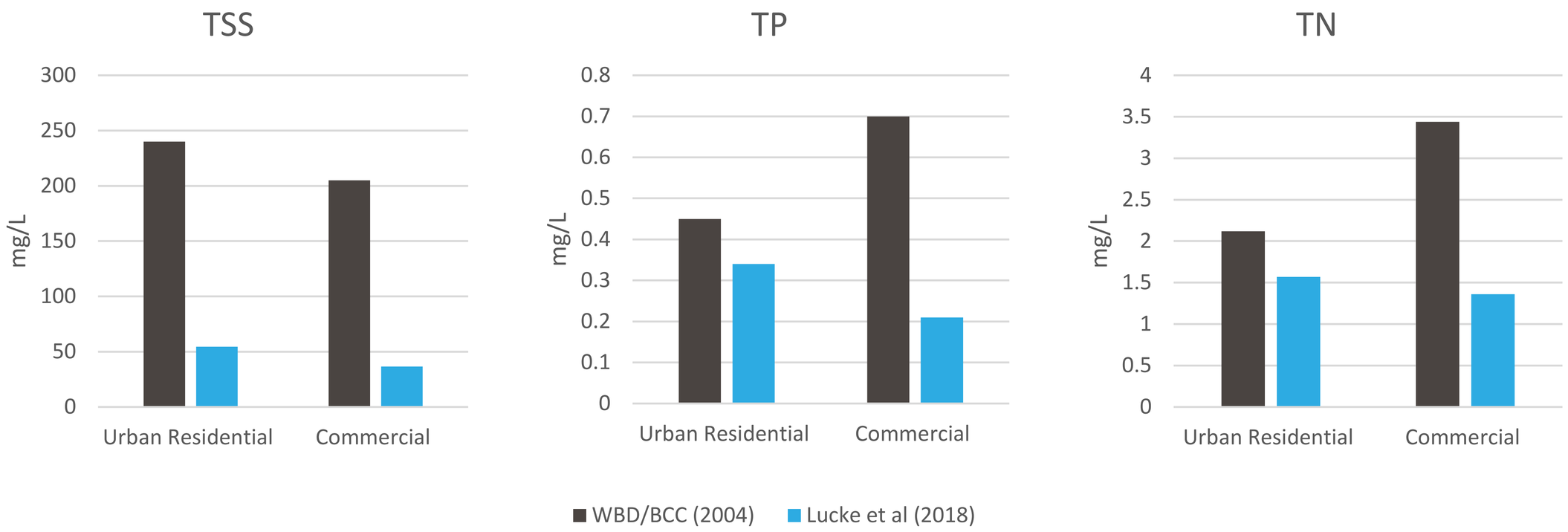

Volumetric losses in bioretention systems
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Weighted average from cited field studies (n=128)
n=17
n=48
n=12
n=12
n=5
n=18
n=4
n=12
Hatt et al (2009)
Hunt et al (2006)
Lucke & Nichols (2015)
Mangangka et al (2015)
Mckenzie-McHarg et al (2008)
Parker (2010)
Peljo et al (2016)
Trowsdale & Simcock (2011)
MUSIC / WaterbyDesign (2010)

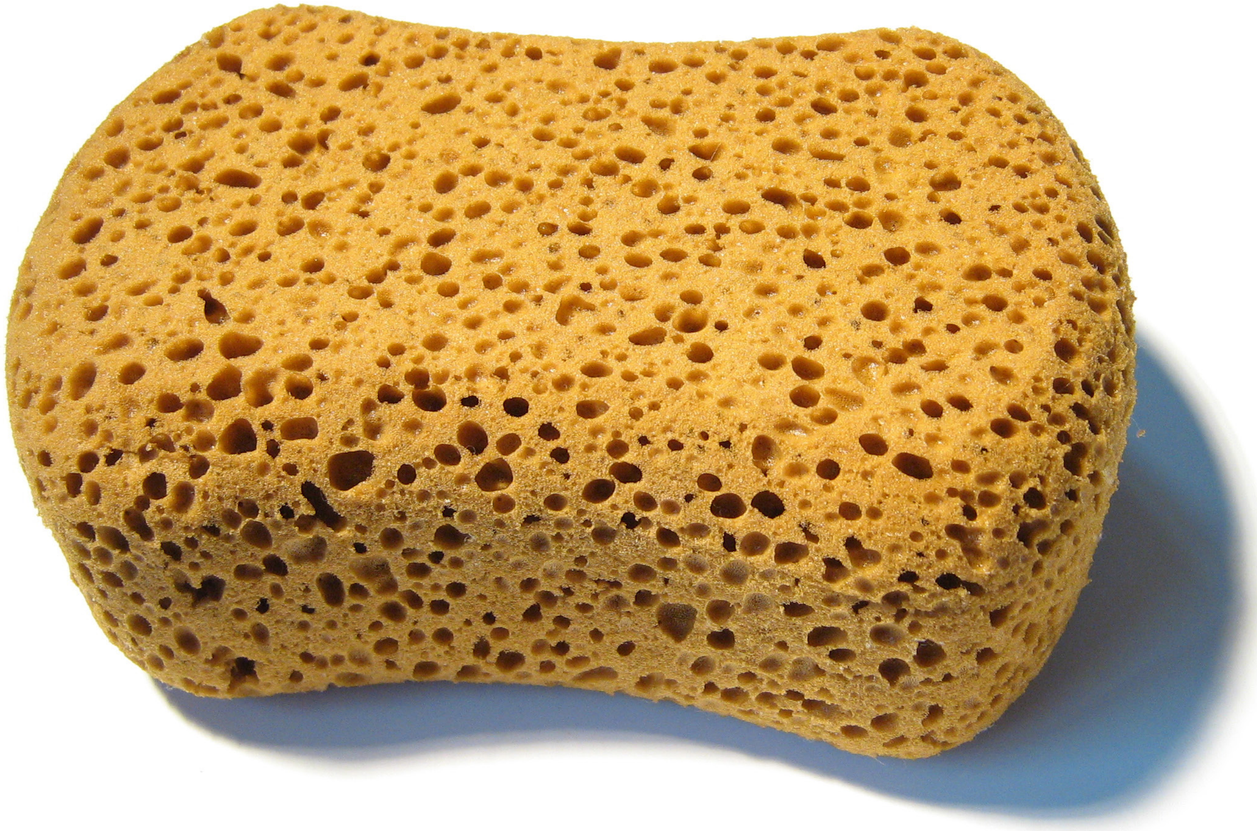
Study	Location	System details		Storm Type	No.	Volumetric Losses	Peak Flow Attenuation
		Lining	Age				
Hatt et al (2009)	Vic, Aust.	Impervious liner	4 yrs	Real storms	17	33% (15% – 83%)	80%
Hunt et al (2006)	NC, USA	Clay soils with very low permeability soils (0.0014-0.0042 mm/hr) with perched water table	5 yrs	Real storms ~1EY in magnitude. Rainfall events less than 6 mm were excluded from the analysis	48	78% (19% - 100%)	Not reported
Lucke & Nichols (2015)	Qld, Aust	Impervious plastic liner	10 yrs	Controlled dosing to simulate 30min 39% AEP event	12	61.6% (33% - 84.3%)	79.5% - 93.6%
Mckenzie-McHarg et al (2008)	Qld, Aust.	Unspecified	2 yrs	Controlled dosing, reflecting a 4EY storm (3kL)	5	23% (14% - 30%)	75%
Parker (2010)	Qld, Aust.	Clayey soils	3 yrs	Real storms	18	42%	94%
Peljo et al (2016)	Qld, Aust.	Clayey soils	2 yrs	Controlled dosing of four streetscape pods <50 m² each.	4	67% (39 - 87%)	Not reported
Trowsdale & Simcock	Auckland	Impervious Plastic Liner	1 yr	Real Storms	12	59&	

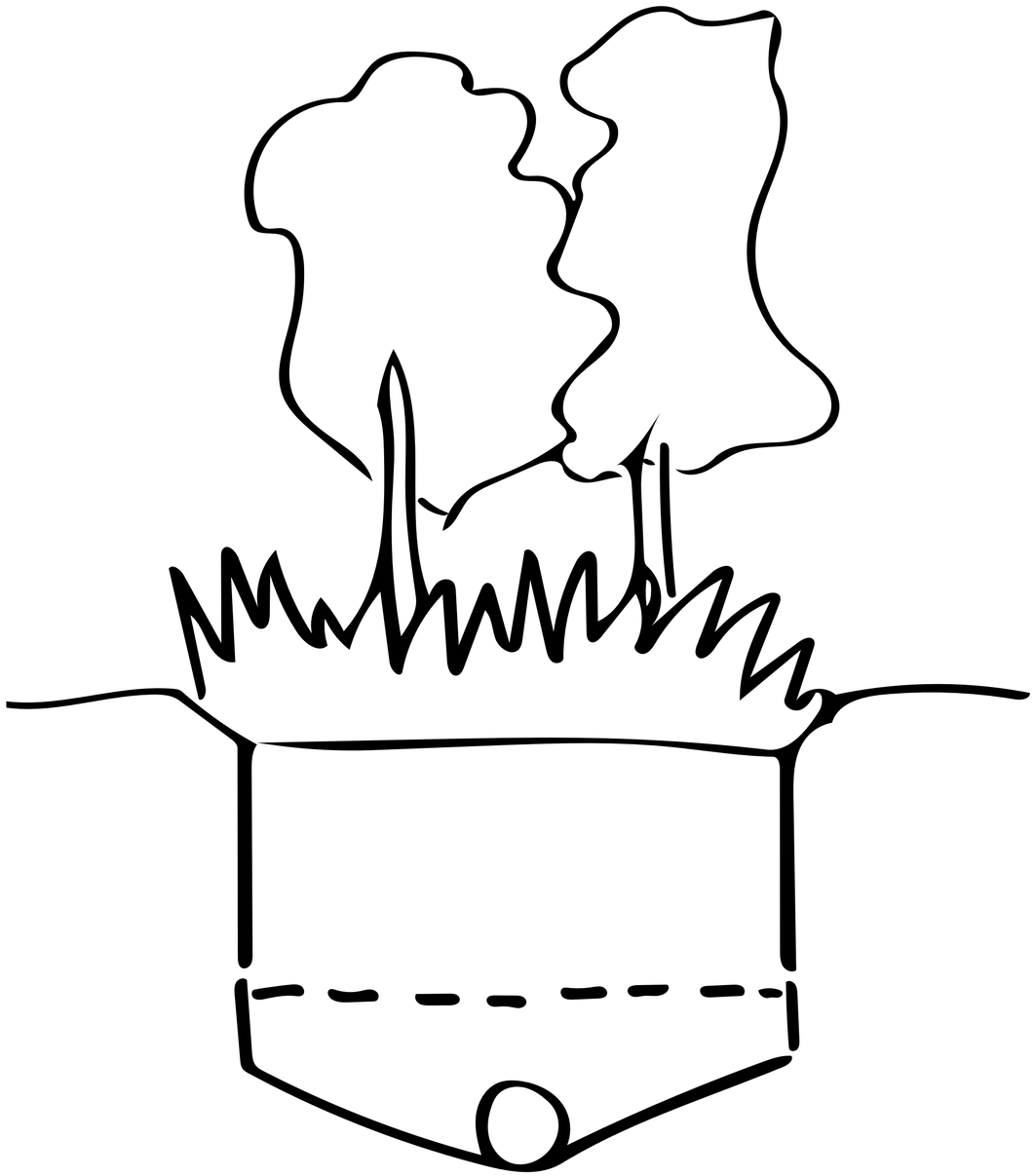

Total Suspended Solids Concentration Reduction %
Concentration Reduction %
120%
100%
80%
60%
40%
20%
0%
-20%
-40%
Real Stormwater
Synthetic Stormwater
Manganka et al 2015 (>6 day dry period)
Manganka et al 2015 (<6 day dry period)
Trowsdale et al 2010
Hatt et al 2008
Roberts et al (normal cells)
Roberts et al (cell with saturated zone)
McKenzie-McHarg et al 2007 (Long dry period)
McKenzie-McHarg et al 2007 (Day 1)
McKenzie-McHarg et al 2007 (Day 2)
Lucke & Nichols 2015
Peljo et al 2016
Hatt et al 2008
MUSIC/WaterByDesign (2010)

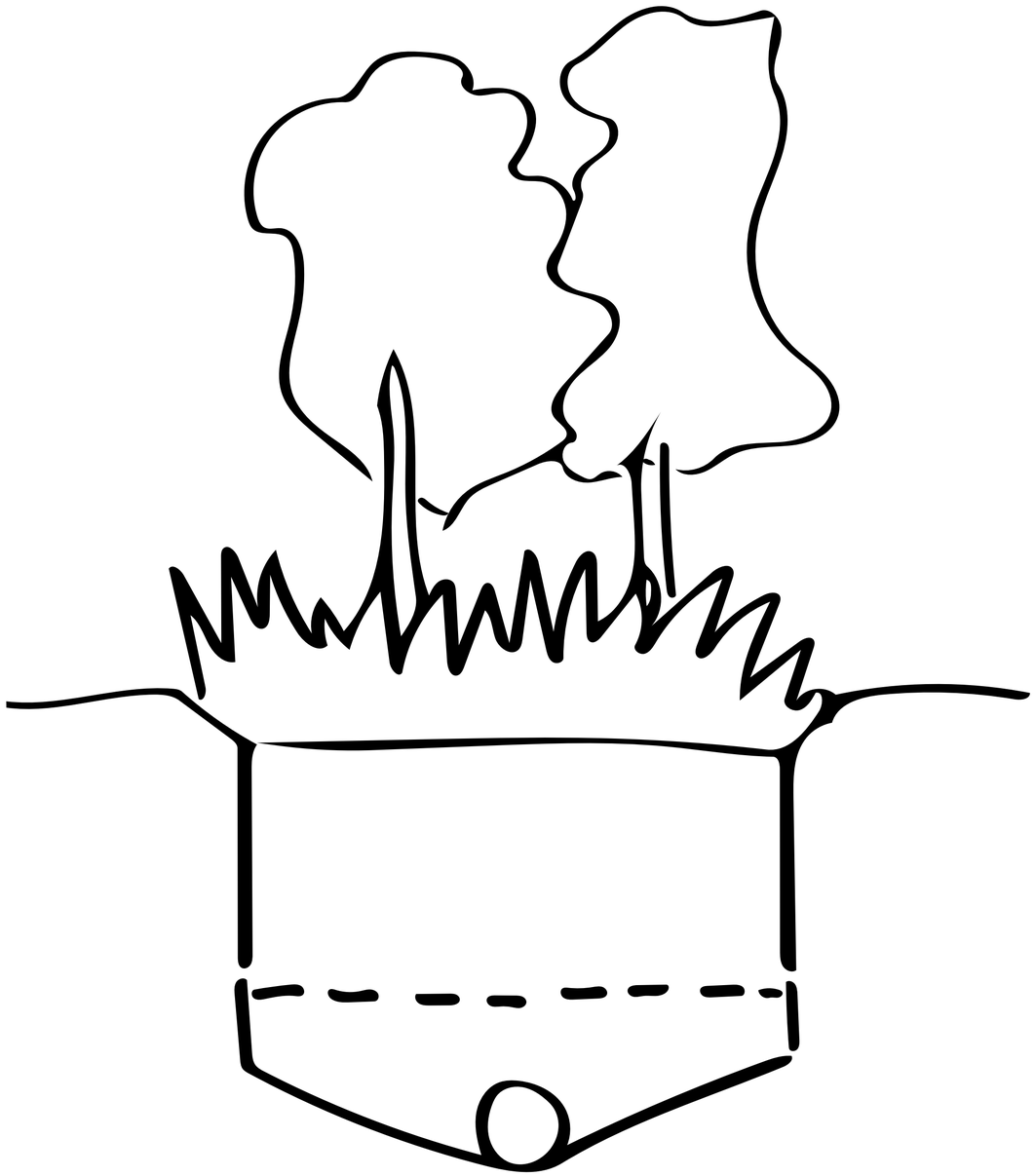

Total Phosphorus
150%
100%
50%
0%
-50%
-100%
-150%
-200%
Concentration reduction (%)
Real Stormwater
Synthetic Stormwater
Manganka et al 2015 (>6 day dry period)
Manganka et al 2015 (<6 day dry period)
Trowsdale et al 2010
Hatt et al 2008
McKenzie-McHarg et al 2007 (Long dry period)
McKenzie-McHarg et al 2007 (Day 1)
McKenzie-McHarg et al 2007 (Day 2)
Lucke & Nichols 2015
Peljo et al 2016
Hatt et al 2008
MUSIC/WaterByDesign (2010)

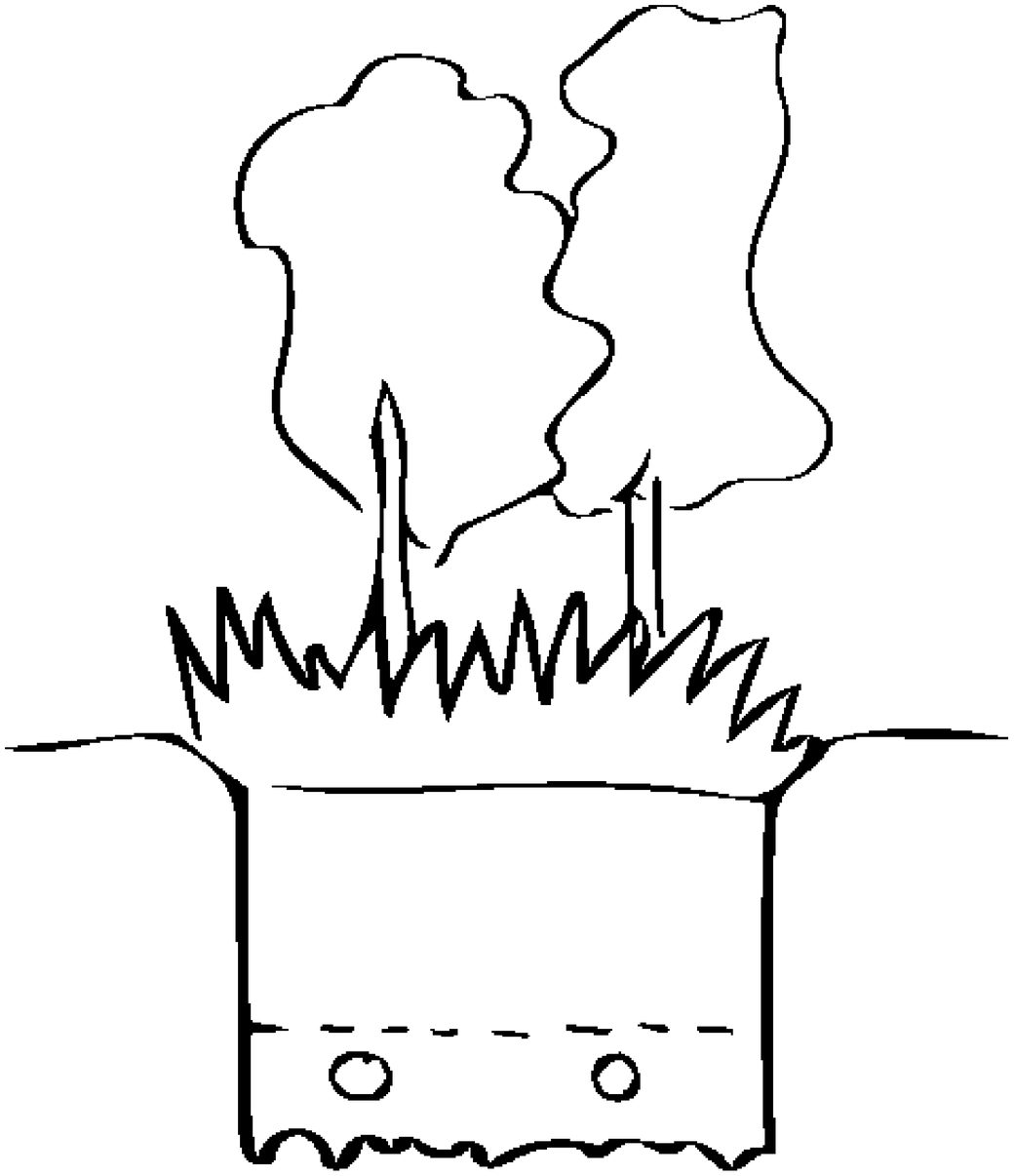

Total Nitrogen
Concentration reduction (%)
60%
40%
20%
0%
-20%
-40%
-60%
Real Stormwater
Synthetic Stormwater
Manganka et al 2015 (>6 day dry period)
Manganka et al 2015 (<6 day dry period)
Trowsdale et al 2010
Hatt et al 2008
McKenzie-McHarg et al 2007 (Long dry period)
McKenzie-McHarg et al 2007 (Day 1)
McKenzie-McHarg et al 2007 (Day 2)
Lucke & Nichols 2015
Peljo et al 2016
Hatt et al 2008
MUSIC/WaterByDesign (2010)


TSS
300
250
200
150
100
50
0
mg/L
Urban Residential
Commercial
TP
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
mg/L
Urban Residential
Commercial
TN
4
3.5
3
2.5
2
1.5
1
0.5
0
mg/L
Urban Residential
Commercial
WBD/BCC (2004)
Lucke et al (2018)













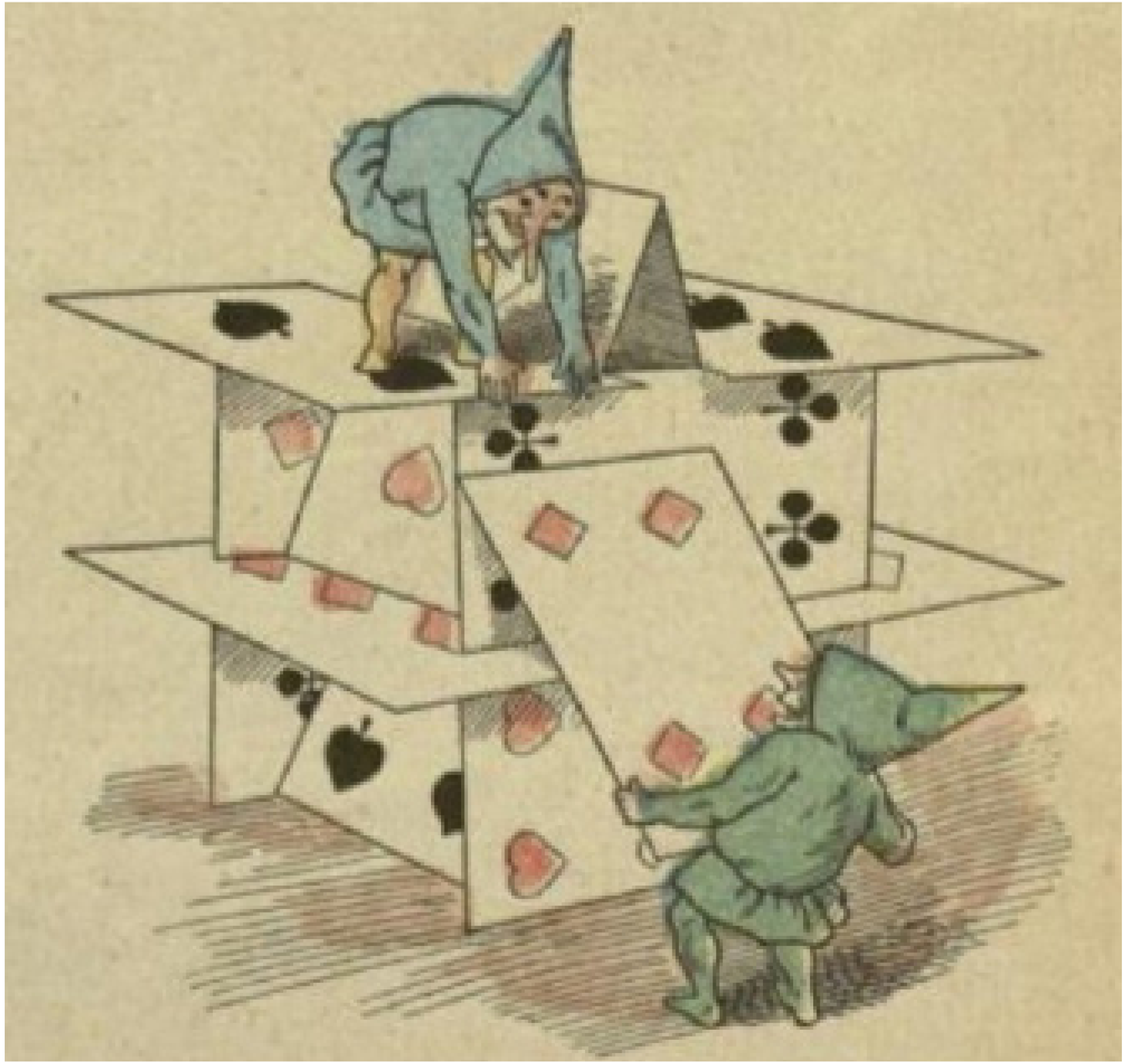




TOYOTA
HUSKI


DISPLAY
VILLAGE
NOW OPEN



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