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AN EXPERIMENTAL EVALUATION OF SUSTAINABLE DRAINAGE SYSTEMS

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Abstract: This paper investigates the behaviour of certain water and sediment quality indicators of a vegetated detention pond system located at Waterlooville, Hampshire, UK. The period of study was 2 years (March 2011-March 2013) with sampling carried out once a month. Statistical analysis was performed using Minitab™. The aim of the study was to examine the changes in quality of various constituents with time and possible linear associations between them. Pond sediments and pond water quality were monitored for a range of variables at each monthly visit. Results indicate that the system demonstrates low levels of pollution while not having a direct impact on the oxygen balance of the receiving water-body. Oxygen demanding substances along with suspended matter and certain metals/elements were found to accumulate in the system with time. Significant linear associations were observed for road salts (containing Na, Cl, Mg) and certain pollutants, suggesting that road salts have a major impact on SuDS water/sediment quality. Sorption characteristics of specific metals were also evaluated by means of adsorption isotherm equations. Three widely used sorption isotherms were employed in this study. It was found that the sorption behaviour of metals is highly variable. This study highlights the dynamic nature of vegetated ponds and the importance of understanding the behaviour of different pollutants for SuDS design.

Keywords: vegetated ponds, road runoff, road salts, pollution, SuDS, sorption isotherm models

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INTRODUCTION

Rapid urbanisation results in increased storm-water load and, consequently, higher pollution levels due to a preponderance of impervious surfaces (CIRIA, 2007). Road vehicles have become the most significant sources of pollutants such as copper and polycyclic aromatic hydrocarbons (PAHs) in the UK (Napier *et al.*, 2008). Through either direct or indirect deposition, vehicle related pollution can accumulate on roads and be transported by runoff. There is increasing concern about the impact that road runoff can have on aquatic ecosystems. The variety of pollutants in road runoff (including silt, organic matter, heavy metals and a range of PAHs) and intermittent loading mean that predicting this impact is very complex (Schäfer and Puchelt, 1998; CIRIA, 2007; Nanbakhsh *et al.*, 2007). Pollution in road runoff water results from dry and wet atmospheric deposition and the road and traffic itself (Boller, 1997).

A cost-effective way to treat storm-water runoff is the use of Sustainable Drainage Systems (SuDS) (CIRIA, 2007), and a commonly used device is the detention (or retention) pond, owing to its low maintenance requirements and efficient treatment performance (Persson, 2000; Hong, 2008). Ponds can be efficient systems for treating road runoff as they expose pollutants to a range of treatment mechanisms (Hares & Ward, 1999; Färm, 2002), including adsorption, volatilization, photolysis, biodegradation and sedimentation. Ponds have various layouts, vegetation cover and inflow/outflow control devices (CIRIA, 2007). Hydrological attenuation is relatively easy to address in design, but pollutant removal is more difficult and treatment can be highly dependent on site specific parameters. In general, the higher the removal efficiency, the higher the design complexity of waste management systems (Vianna *et al.*, 2012)

Concentrations of water quality indicators vary significantly between ponds. BOD and COD can range from 8-36 (mg/l) and 48-600 (mg/l) respectively (Terzakis *et al.*, 2008; Scholz & Yazdi, 2009), while Total Suspended Solids (TSS) and turbidity can range from 9-22 (mg/l) and 10-200 (NTU) respectively (Mallin *et al.*, 2002; Terzakis *et al.*, 2008; Pezzaniti *et al.*, 2012).

Recently the presence of road salts in road runoff has been the object of analysis due to its potential influence on mobilising pollutants such as metals (Nelson *et al.*, 2009). Many authors have demonstrated that pollution in ponds exhibits seasonality patterns (elevated concentrations during winter and spring) and is associated with road salts (Pontier, 2002; Herngren *et al.*, 2005; Nelson *et al.*, 2009). In addition, the presence of organic matter along with road salts may have detrimental effect on the road runoff quality (Cambonelli *et al.*, 2010). Pontier (2002) reported that seasonality patterns in metal concentrations could also occur due to the presence of favourable environmental physico-chemical characteristics.

Most of heavy metal ions are toxic to living organisms (Hares & Ward, 1999). These metal ions are non-degradable and are persistent in the environment. Therefore, the elimination of heavy metal ions from storm-water is important to protect public health. Sorption is considered a very effective and economical process for metal ion removal from storm-water (Zhao *et al.*, 2011); it is the process in which chemicals become associated with solid phases. In SuDS these solid phases are suspended solids. Sorption mainly occurs by absorption (into a three-dimensional matrix) and by adsorption (onto a two-dimensional surface), where positively charged groups interact electrostatically with negatively charged surfaces (Pontier, 2002). There are various kinds of adsorbents such as clay minerals, activated carbon, carbon nanotubes, biosorbents, metal oxides and zeolites (Zhao *et al.*, 2011). Sorption isotherm equations define the equilibrium between the concentration of a chemical in aqueous and solid phases (Pontier, 2002). The three most widely used environmental sorption isotherms are the linear equation (Kd), the Freundlich equation and the Langmuir equation (EPA, 2005; Zhao *et al.*, 2011). The mathematics of the calculation process in terms of sorption isotherms can be found in Zhao *et al.* (2011) and are not presented here for the sake of brevity. EPA (2005) reported values for various metals in terms of the sorption distribution coefficient (Kd) in the suspended matter/water interface; Ni, Cr, Cd, Pb, Cu, and Zn had Kd (l/kg) of 39810, 125892, 50118, 398107, 70000, 125892, respectively. It is however the Freundlich or the Langmuir isotherm equations which usually satisfy experimental data obtained from field studies (Pontier, 2002; Zhao *et al.*, 2011).

Due to the highly variable nature of road runoff, as indicated by the above research work, a “black box” approach in terms of pond design raises more questions than it answers, leading to the incontestable need for re-evaluating the SuDS design process. This paper aims to investigate and interpret the natural treatment mechanisms along with the behavioural patterns of pollutants within a vegetated detention pond. Our findings will contribute to further understanding the behaviour of such systems which, in turn, may inform civil and environmental engineering operational and design codes.

MATERIALS AND METHODS

Study Site

The study site at Waterlooville, Hampshire, UK (Latitude=50.881315, Longitude= -1.037575) is a Major Development Area (MDA) for 2500 new homes. The impermeable clay soil means the site will be served by storage SuDS. This study considers a pond which was constructed (in 2008) to control runoff from the access roads prior to house construction. The pond receives runoff from an urban commuter road (B2150), a roundabout and a site access road with pre-development peak hour flows of approximately 3100 cars and 100 lorries, which gives a daily traffic flow of about 40000 (unpublished Traffic Survey 2009, Mayer Brown Ltd.). While the traffic in the area is mainly free flowing, peak time traffic is characterised by stop/start congestion associated with nearby traffic lights. Construction activity began on the site in October 2011, with a significant increase in activity from late spring 2012, which will have increased the use of the access road by heavy vehicles; however, this traffic flow has not been quantified. The vegetated pond system receives road runoff from a swale, which receives piped inflow, as well as direct precipitation. **Figure 1** shows a schematic plan of the system with sampling points labelled by letters.

The pond plan area is 51 × 26 m². The two pond basins are connected by a berm with an invert level of 1.1 m relative to the pond bed. The berm is designed to reduce short circuiting and increase the overall retention times. The basins have fixed sediment traps (ST) to collect settling solids. Basin 1 (B1) has 2 ST (ST1-B and ST2-C) and Basin 2 (B2) has one trap (ST3-D). The storage capacity is 304 m³; the permanent water level is 1 m, rising to 1.6 m at the overflow (E). A "hydro-brake" regulates the outflow to the River Wallington (WR). The design inflow for the 1:30 and 1:100 year events are 70 l/s and 100 l/s respectively. The system was planted with Phragmites australis and Typha latifolia in spring 2009. By 2010 all the pond area was dominated by vegetation, differing in density with respect to depth of flow (Tsavdaris *et al.*, 2013).

Experimental Methods

Monitoring of conditions in the pond was undertaken for a period of 2 years (March 2011−March 2013). The monthly monitoring aimed to assess the baseline water quality in the pond and the characteristics of bed and settling sediments. The study focussed on water quality in the basins and the characteristics of settling solids (collected from B, C, D) and bed sediments (collected from A, E). Grab samples of water were collected from the pond system (B1&B2) and river (WR) via a hand pump to avoid aeration. Material accumulated in the STs was removed using an inflatable boat to avoid disturbance. Bed sediment was collected from the inlet/outlet bank using a trowel; the samples' volume was approximately 50mm x 120mm x 30mm (Pontier, 2002). Both settling solids and bed sediment were wet sieved in-situ through a 2mm and a 63μm stainless steel sieve using pond water (to avoid changes in partitioning) to two size fractions; namely the 2000 μm to >63 μm (coarse particles) and <63 μm fractions (fine particles) (Zanders, 2005).

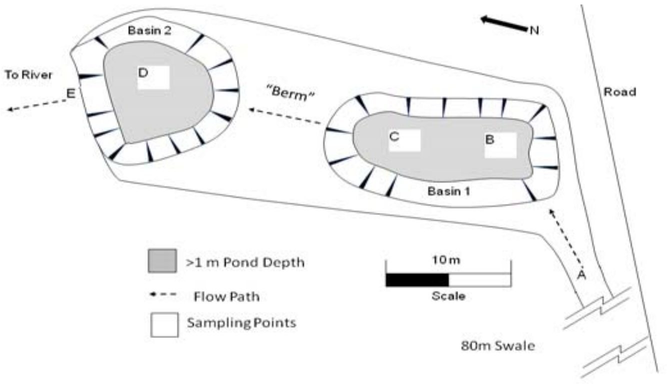

Fig 1. Schematic view of the pond system.

BOD, Soluble BOD (SBOD), TSS and Volatile SS (loss on ignition) were measured by standard methods (Greenberg *et al.*, 1992). Manufacturer defined methods were used for: COD and Soluble COD (SCOD) - Hach™ micro; turbidity - Eutech Instruments TN-100 meter; ammoniacal nitrogen (AmmN) - Palintest™; in situ probes were used for Electric Conductivity (EC) (Palintest Microcomputer 900), pH (Hanna HI1925) and DO (YSI 50B). 50 ml was filtered on-site through 0.45 μm Whatman cellulose nitrate filters using a hand pump to separate particulate matter and dissolved fractions for metal analysis, fractions were preserved with HNO3 (Pontier *et al.*, 2004). The Volatile Substances Content (VSC) was also measured for settling solids and bed sediment in both size fractions using a Carbolite Afterburner Ashing Furnace (Heiri *et al.*, 2001). Metal content (water, settling solids, bed sediment) was analysed using an Agilent 7500ce Inductively Coupled Plasma - Mass Spectrometer (ICP-MS) with octopole reaction cell using the semi-quantitative method in He mode. Samples were introduced using an integrated auto-sampler and calibration was by a tuning solution of 10 ppb of 6 elements across the mass range. The elements recorded for this study were Cd, Cl, Cr, Fe, Mg, Na, Ni, Pb, and Zn.

Particle Size Distribution (PSD) (settling solids, bed sediment) was performed using laser diffraction. The apparatus used was a calibrated Malvern Mastersizer 2000 with a lens range of 0.02-2000 μm on a volumetric basis, which offers a solution phase PSD. The samples were treated prior to analysis as in Bainbridge *et al.* (2012). Statistical investigation was performed using the Minitab™ statistical analysis software (Minitab™, 2009).

RESULTS AND DISCUSSION

General Water Quality

Table 1 shows the median, min, and max values of all the measured water quality indicators for the whole period of study (2 years). Upstream, the Wallington

River passes through a built-up area and so receives other sources of urban runoff; it is therefore not pristine with a BOD of up to 20 mg/l. Most pollutant concentrations in the pond basins were lower than the river, while AmmN, DO and EC were of greater values. This suggests that the pond will not have a significant impact on the oxygen balance of the receiving water, but increased EC could influence the toxicity potential of the river (Hares & Ward, 1999; Pezzaniti *et al.*, 2012). There was a notable increase in COD between B1 and B2 (162 mg/l compared to about 132 mg/l) and also smaller increases in TSS, VSS and BOD. The majority of solids suspended in the water column were composed of volatile matter (B1 69% and B2 67%).

This transformation between basins suggests that the nature of solids changes within the system, which could be due to preferential transport or accumulations of plant-derived debris. In addition, there were no significant differences between the pond system and WR for most elements (total) except for dissolved Phosphorus (Mood's Median Test – p=0.041) (Minitab™, 2009). This suggests that the pond has not increased the pollution loading to the river. The pollution levels within the pond system were of similar values with other relevant studies (Hares & Ward, 1999; Mallin *et al.*, 2002; Terzakis *et al.*, 2008; Scholz & Yazdi, 2009; Pezzaniti *et al.*, 2012). However, non-biodegradable matter, suspended matter and road salts seem to accumulate within the pond. **Figure 2** shows the increase in concentrations for COD, TSS, VSS, Na, Mg, and Cl with time. This has also been observed by other studies (Pontier, 2002; Pontier *et al.*, 2004). Na and Cl exceeded the Environment Agency chemical standards for surface water (http://evidence.environment-agency.gov.uk/chemicalstandards); however, in WR, Na did not pose an environmental threat, whereas Cl demonstrated high values. The most widely used road salts are NaCl and $MgCl_2$ (Nelson *et al.*, 2009). Na and Mg were strongly associated (linear regression; Minitab™, 2009) with Cl ($p = 0.000$, $R = 0.805$ and $p = 0.000$, $R = 0.839$ respectively), indicating source similarity. This observation implies that accumulation of pollutants with time might change the water quality within such systems, with possible negative impact on the receiving water-bodies. Some pollutants exhibited seasonality patterns with high concentrations occurring during winter, late autumn and early spring, when road salts were abundant (Pontier, 2002). Turbidity, Ni and Zn exhibited their highest concentrations in autumn; EC and SCOD in spring, while Cl in winter, autumn, and spring (**Fig. 3**). Seasonality patterns suggest that runoff quality is highly influenced by season related factors (e.g. road salts, rain intensity, antecedent dry period, etc.).

Table 1. Statistics of the water quality indicators and elements measured in the pond system (B1, B2) and the river (WR).

Variable	Statistics			Location
	Median	Min	Max	
BOD (mg/l)	11.6	1.62	24.88	B1
	13.04	1.68	28	B2
	6.47	1.08	20.82	WR
SBOD (mg/l)	7.89	0.5	16.2	B1
	7.41	0.4	12.78	B2
	3.06	0.24	12.72	WR
COD (mg/l)	118.5	30	1052	B1
	161.5	17	855	B2
	70.5	2	915	WR
SCOD (mg/l)	87	17	1018	B1
	73	7	607	B2
	38.5	2	502	WR
TSS (mg/l)	31.333	6.4	74	B1
	33.6	10.4	88.667	B2
	22.333	2.4	55.333	WR
VSS (mg/l)	21.667	5	35.1	B1
	22.605	6	78	B2
	9.358	1.2	49.333	WR
Turbidity (NTU)	16.64	2.01	66.3	B1
	12.115	2.54	68	B2
	4.825	2	61	WR
EC (μS/cm)	606	160	1886	B1
	527	337	1168	B2
	781.5	225	1217	WR
DO (mg/l)	5.065	2.11	16.6	B1
	4.985	1.79	10.5	B2
	6.95	2.77	8.3	WR
Temp. (°C)	11.9	2.5	20.1	B1
	11.9	4.2	19.7	B2
	12.35	5.3	17.6	WR
pH	6.875	6.54	7.63	B1
	6.895	6.61	7.25	B2
	7.225	6.4	7.65	WR
AmmN (mg/l)	0.075	0.01	1	B1
	0.045	0.01	0.47	B2
	0.175	0.04	0.96	WR

Various authors have shown the potential negative consequences of road salt on heavy metal mobility and water quality in general (Pontier, 2002; Herngren *et al.*, 2005; Nelson *et al.*, 2009). **Table 2** shows linear associations (in the form y=mx + c) between heavy metals and road salt elements (Cl, Mg, Na). It appears that most metals (Ni, Cr, Pb, Cd, Fe) were associated with Mg (road salts in the form of $MgCl_2$), while Cu was generally associated with Na (NaCl).

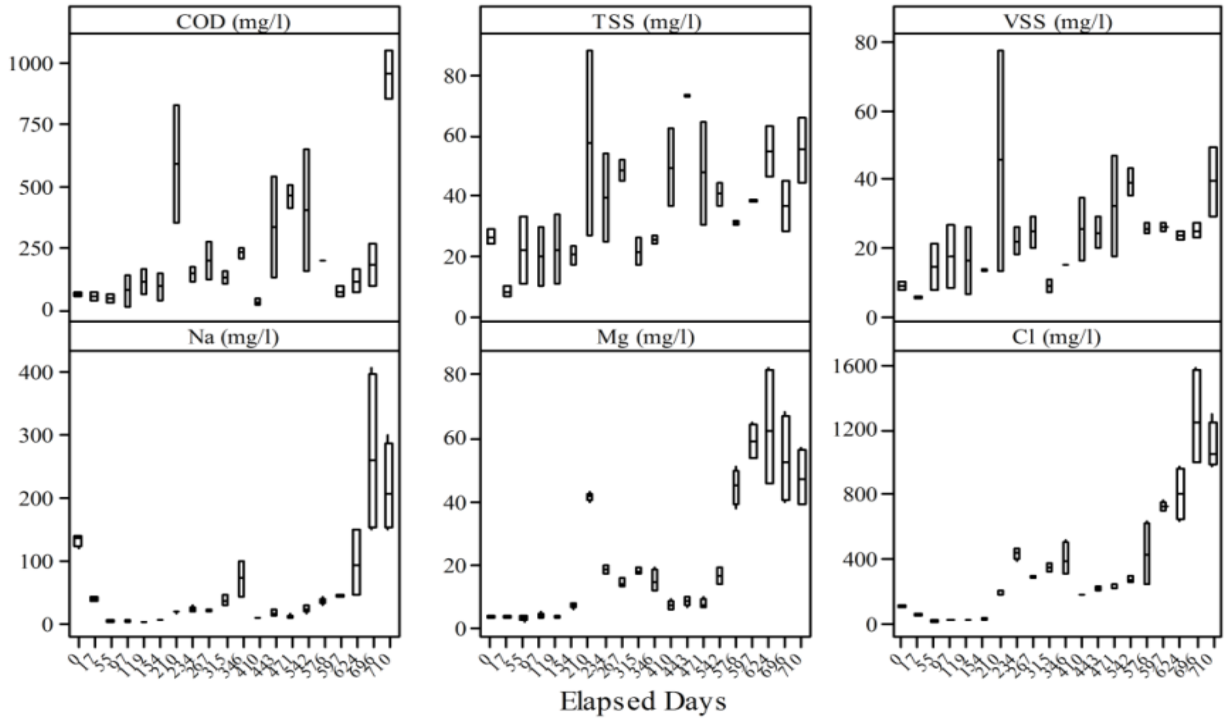

Fig 3. Box plots of water quality indicators and elements concentrations with time. The box plots show the inter-quartile range with the median shown as the horizontal line across the boxes. Whiskers show the upper (Q1− 1.5 [Q3 − Q1]) and lower limits (Q1− 1.5 [Q3 − Q1]) (Minitab™, 2009)

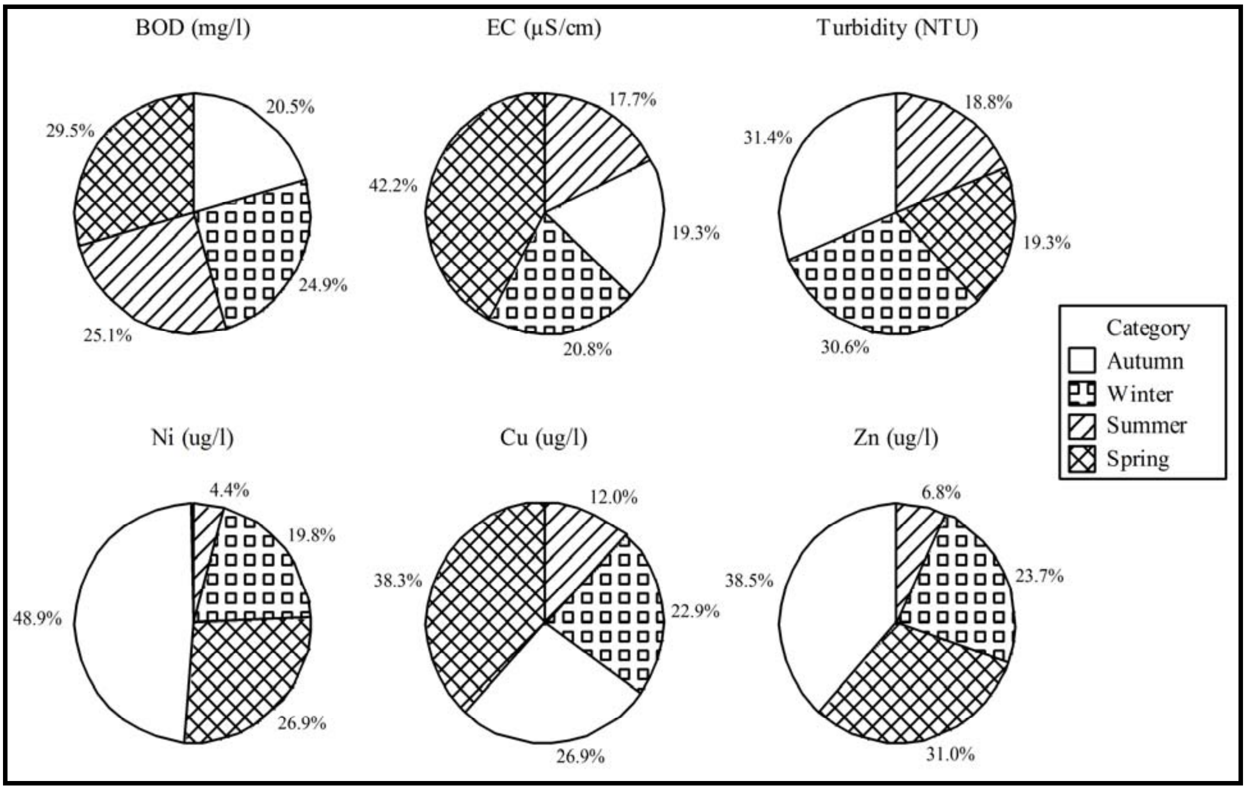

Fig. 4 Pie charts of pollutants concentration distribution in water with season.

Nelson *et al.* (2009) also found that sodium chloride resulted in the largest release of Cu, while magnesium salt had a great effect on mobilisation of Cd. These associations indicate that road salts concentrations may have a direct impact on the mobility of heavy metals found in road runoff (Herngren *et al.,* 2005; Nelson *et al.,* 2009). the association of most metals (Ni, Cu, Cr, Zn, Fe, Cd, Pb) to Na, Mg, and Cl suggests that the transport and mobility of specific pollutants was influenced by salinity and the presence of fine suspended particles/colloids; however, these correlations could simply imply that these metals and elements were sorbed on the same particles/colloids resulting in associations between them (Hounslow, 1995).

Settling Solids and Bed Sediment

There were no significant differences of d (0.1) and d(0.5) (Mood's median test) between the basins (settling solids) [d (0.1) – 10% of the volume distribution is below this value; d (0.5) – 50% of the volume distribution is below this value; d(0.9) – 90% of the volume distribution is below this value]; there were, however, differences (p=0.02, Chi-Square=5.4) of d(0.9) between the basins [d(0.9) in B2>B1] suggesting that heavier particles are transported either via re-suspension or preferential flow paths and increased turbulence (possibly caused by the presence of vegetation) (Tsavdaris et al., 2013). There were also no differences (Mood's median test) in particle diameter d(0.5) (bed sediment) found at the inlet/outlet banks. The sediment accumulation rate S (g/m² day) was much higher in B1 compared to B2, suggesting that sedimentation mainly occurred in B1. Furthermore, there seemed to be an increase of particle diameter (particles found in the STs) with time, suggesting that the pond gradually received heavier particles (**Fig. 5**).

This could be attributed to site specific factors such as the presence of heavy machinery and construction related activities that begun in October 2011. As can be seen from **Fig. 5**, major changes in particle diameter coincide approximately with the time that the construction begun. In addition, the heavier particles seemed to settle near ST2 (**Fig.1c**) and ST3 (**Fig.1d**), suggesting that preferential transport and/or re-suspension could be occurring during storm events. This accentuates how sensitive these systems are and that their performance is mainly influenced by site specific conditions (Pontier *et al.*, 2004).

Table 2. Linear regression of metals and road salt related elements

y	x	Gradient (m)	Intercept (c)	R	p
Ni	Na	0.0121	1.94	0.23	0.04
Ni	Mg	0.0739	0.95	0.379	0.001
Ni	Cl	0.00437	1.03	0.385	0
Cu	Na	0.0862	17.9	0.37	0.001
Cu	Mg	0.196	18.1	0.228	0.043
Cu	Cl	0.0113	18.5	0.223	0.046
Zn	Na	0.146	39.2	0.2	0.075
Zn	Mg	0.552	34.8	0.205	0.069
Zn	Cl	0.0465	30.5	0.295	0.008
Cr	Na	0.00346	1.21	0.141	0.213
Cr	Mg	0.0223	0.896	0.245	0.028
Cr	Cl	0.00118	0.971	0.221	0.048
Pb	Na	0.0256	11.9	0.104	0.36
Pb	Mg	0.212	8.57	0.23	0.039
Pb	Cl	0.0109	9.39	0.202	0.07
Cd	Na	0.00123	0.415	0.19	0.092
Cd	Mg	0.0157	0.134	0.651	0
Cd	Cl	0.000548	0.287	0.388	0
Fe	Na	0.00118	0.264	0.305	0.006
Fe	Mg	0.00929	0.122	0.646	0
Fe	Cl	0.00033	0.21	0.394	0

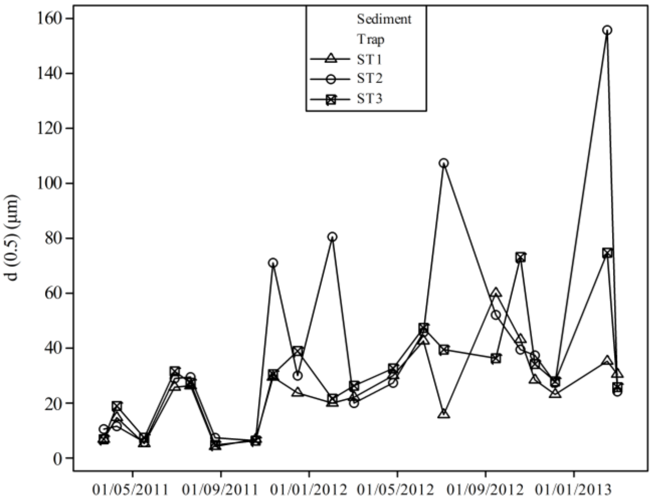

Fig 5. Changes in diameter d(0.5) of particles found in the sediment traps (STs) with time.

Furthermore, there were differences in VSC between settling material found in the basins and deposited sediment found at the inlet/outlet bank (**Fig. 6**). **Figure 7** demonstrates the differences in VSC (%) between settling material and bed sediment, in different size fractions.

The settling solids represent the material settling through the water column, while the bed sediments include pond soil as well as settled material. Consequently, the settling solids in the traps had a much higher VSC compared to the deposited sediment. Most of the volatile substances were found in the >63μm fraction of the settling solids, whereas no significant differences were observed for bed sediments (Pontier, 2002), suggesting that coarse particles consist primarily from volatile matter.

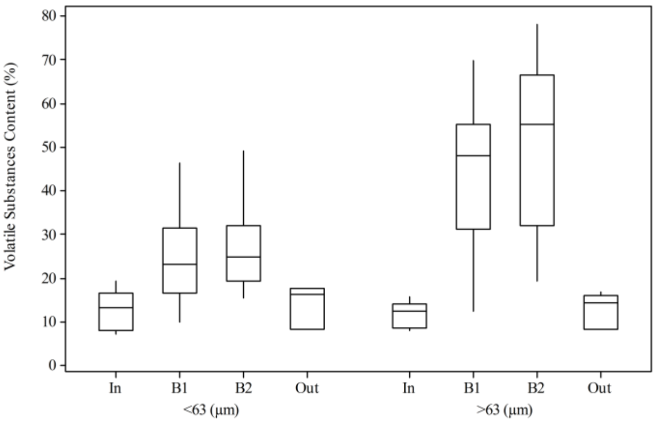

Fig. 6 Box plots of Volatile Substances Content of settling solids and bed sediment collected from the system and inlet/outlet bank, respectively, for each size fraction.

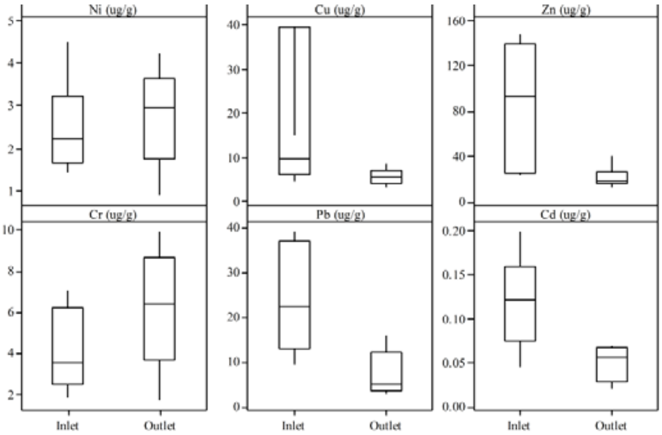

Fig 7. Box plots of metal concentrations in bed sediment found at the inlet and outlet bank.

Metals in settling solids did not demonstrate differences between size fractions (data not shown), as also observed by others (Clozel et al., 2006). Most metals show stronger linear associations with Mg (data not shown) compared to Na, as also observed in water, suggesting that road salt influenced the mobility of metals (Pontier, 2002; Nelson et al., 2009). VSC correlates with Na (r= - 0.233, p=0.01), Mg (r=0.182, p=0.047), Cu (r=0.288, p=0.001), Pb (r=0.248, p=0.006), and Fe (r=0.431, p=0.000). Other studies have reported the existence of correlations between metal concentrations in sediments and organic or clay fractions (Herngren et al., 2005). Moreover, all metals have significant association with each other, the strongest being Pb with Cr (r=0.930, p=0.000), Zn with Cu (r=0.923, p=0.000), and Pb with Zn (r=0.900, p=0.000). These different patterns and behaviours of metals in settling material suggest that their transport, sorption and deposition are driven by different processes depending on their physico-chemical properties. The sediment processes include ion exchange reactions or sorption and diffusion/advection of solutes through pore water (Zhao et al., 2011).

Moreover, the (as compared to the inlet) elevated Ni and Cr concentrations in the deposited sediment found at the outlet (**Fig. 7**) suggest that Ni and Cr bearing particles were conveyed either from the inlet deposits by re-suspension and preferential transport (under specific flow conditions) or by the conditions in the pond which caused enrichment of particles found at the outlet (Pontier et al., 2004). Other studies of different pond systems have also found elevated metal concentrations for Ni and Cr at the outlet (bed sediment) (Mallin et al., 2002). Generally, the metal concentrations (in both settling solids and bed sediment) were lower than in other studies (Pontier et al., 2004; Cambonelli et al., 2010); as regards the concentrations of Ni and Cr at the outlet, these were still negligible compared to the Environment Agency chemical soil standards of 130 ug/g and 21 ug/g respectively (evidence.environment-agency.gov.uk/chemicalstandards). Furthermore, an increase was observed in concentrations of metals and road salt related elements found in settling solids with time. **Figure 8** shows the concentrations of various metals/elements found in settling material within the pond for the whole period of study. Escalation of toxicity within the system with time suggests that ponds have a particular design life; further investigation is required on the issue of immobilising storm-water pollution and managing toxic pond sediments once the pond design life has been exceeded. The most significant increases were observed for Na, Mg, and Fe.

Sorption Isotherm Models

The Kd values for all metals (data not shown) demonstrated similar values to other studies (EPA, 2005). **Table 3** shows the adsorption isotherm models for each metal in the interests of identifying which sorption isotherm equation is satisfied by the data. **Table 3** shows the linear regression results (p-value, R) for each metal against each sorption isotherm equation employed in this study. A sorption isotherm best describes the experimental results when p-value<0.05 and when R is as high as possible, with R=1 being the best fit line (Minitab™, 2009). As can be seen from **Table 3**, different sorption isotherm equations were satisfied for different metals.

Table 3. Sorption Isotherm Model evaluation for the recorded metals on the basis of linear regression analysis

Element	Sorption Isotherm Model					
	Linear		Freundlich		Langmuir	
	p	R	P	R	p	R
Ni	0	0.854	0	0.614	0.768	0.045
Cu	0.01	0.405	0.005	0.438	0.701	0.063
Zn	0.017	0.377	0	0.530	0.129	0.245
Cr	0.023	0.359	0	0.559	0.361	0.148
Pb	0	0.744	0	0.657	0.786	0.045
Cd	0.101	0.263	0.067	0.293	0.135	0.241
Fe	0.007	0.422	0.001	0.526	0.146	0.237

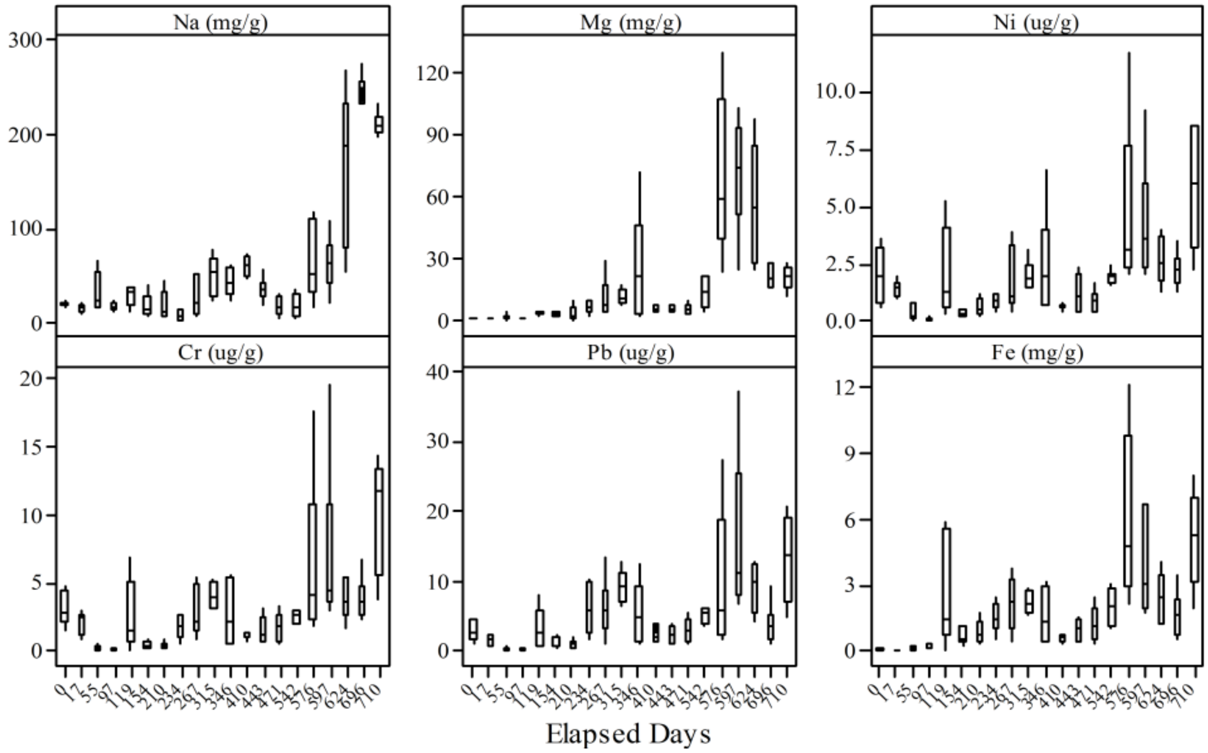

Fig 8. Box plots of metals/elements concentrations of settling solids found in the pond system with time.

CONCLUSIONS

The study presented herein evaluated the water and sediment quality of a detention pond system receiving road runoff located at Waterlooville, Hampshire, UK. Water quality indicators along with metals and road salts (Na, Mg, Cl) found in water and sediments were investigated for a period of 2 years.

The results obtained indicate that pollution levels in the pond system were generally lower than in the river (during the period of study), suggesting that the pond operates efficiently and has not had a negative impact on the river's quality. However, the increase in oxygen demanding substances, solids, some metals and road salt related elements found in water and settling solids raise concern regarding the pond's prospective treatment efficiency. Most metals (water and settling solids) were associated (by linear regression) with Mg/Na and, occasionally, with volatile substances indicating that road salts influence the mobility of pollutants. In addition, changes in diameter of particles found in the pond with time suggest that road runoff sediment quality can be altered by site specific factors and conditions. PSD results showed that preferential transport and/or re-suspension of some particles could be occurring within the system. This observation is consistent with our findings of heavy particles in ST3 and the elevated (compared to the inlet bank) Ni and Cr concentrations (at the outlet bank) of deposited sediments. It should also be highlighted that coarse solids (>63 µm fraction) consisted primarily of volatile substances, suggesting they are susceptible to preferential transport (within the pond system) due to their physico-chemical characteristics.

The sorption of certain metals in the suspended matter/water interface was also evaluated by employing various sorption isotherm equations. It was found that, while the linear adsorption isotherm equation is satisfied for Ni and Pb, the Freundlich adsorption isotherm equation is satisfied for Cd, Cr, Cu, Fe and Zn. This observation accentuates the highly variable sorption behaviour of metals found in road runoff.

The research outcomes suggest that road salts play an important role in mobilising certain pollutants. When other constituents (e.g. volatile substances) are also present, the water/sediment quality could be susceptible to transformations. Sorption properties of metals within such systems are highly variable due to multiple continuous chemical processes. Evaluation of the sorption kinetics in SuDS could be of extreme importance as it could explain changes in partitioning in a comprehensive manner. Environmental engineers should ideally update the existing SuDS design codes with specific guidelines concerning prevention measures and treatment recommendations for certain pollutants (e.g. road salts), while taking into account site specific conditions.

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