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Monitoring and Modelling SUDS Retention Ponds: Case Studies from Scotland

V. Krivtsov[1*], S. Arthur[1], J. Buckman[1], J. Bischoff[1], D. Christie[2], S. Birkinshaw[3], K. Takezawa[4], D. Chamberlain[5] and R. Pereira[1]

[1]Heriot Watt University, Scotland, UK
[2] Botanical Society of Scotland, UK
[3]Newcastle University, England, UK
[4]SRUC, Scotland, UK
[5]Royal Botanic Garden Edinburgh, Scotland, UK

ABSTRACT

SUDS (Sustainable Drainage Systems) retention ponds are an important part of Blue Green Infrastructure and provide multiple benefits, including flood risk alleviation, water quality improvements, recreation, amenity and biodiversity value. Characterisation of sediments and suspended particulate matter (SPM) is important for assessing SUDS functioning and understanding patterns of ecosystem dynamics because of its key role in pollutant adsorption, biogeochemical cycling and influencing light penetration. This paper gives an overview of our research on nine ponds, all of which represent important components of Blue Green Infrastructure. Most of the ponds have been specially designed as SUDS ponds, whilst the rest are used for comparative purposes. An important part of the presented research is analysis of SPM and particle size distribution. Water quality is assessed both by physico-chemical analysis and by regular sampling of aquatic invertebrates. Further current and planned ecological surveys include phyto- and zooplankton, vegetation, fungi, lichens and vertebrate animals. Modelling of the sites' hydrology and the responses to storm events is currently being undertaken using CityCat, and more programming effort is planned to interpret the patterns observed.

The results show that SPM in these ponds includes particles of both biological and abiotic origin; considerable proportion of SPM is smaller than 100 microns. The preliminary analysis indicates that the biological community is instrumental for water quality improvements, but may be experiencing both physical and chemical limitations. Although biodiversity of the SUDS ponds studied appears to be lower than that of natural ponds, their species richness constitutes up to 60-80% of that observed at the control sites. In particular, some of the ponds studied proved to have healthy amphibian populations, thus providing conservation value among other SUDS multiple benefits.

Keywords: SUDS ponds, suspended particulate matter, ecosystem services, SEM, biodiversity, water quality

INTRODUCTION

SUDS Retention ponds are important components of Blue Green Infrastructure (Allen et al 2018). They help to alleviate flood risks and to improve water quality of urban runoff. In addition, they provide further multiple benefits and ecosystem services, including biodiversity, recreation and amenity value, among others (Costanza et al, 2017). A considerable proportion of pollutants in aquatic ecosystems is adsorbed to sediment particles; suspended sediments also alter penetration of light, thus influencing the dynamics of primary producers (Krivtsov et al 2008). Hence characterisation of sediments, and in particular of suspended particulate matter, is important for describing technological performance of SUDS ponds as well as patterns of their ecosystem dynamics.

The research presented here aims to study the ecosystem functioning and services / benefits provided by SUDS ponds and compare them with non-SUDS ponds. In particular, we focus on characterising

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*Corresponding author: WA Modular Building, EGIS, Heriot Watt University, Edinburgh, Scotland EH14 4AS. Email vk26@hw.ac.uk or e96kri69@netscape.net

suspended sediments and understanding their impact on pond ecology. We also aim to study the provision of multiple benefits, including biodiversity and amenity values.

Within the project, it is intended to gather information on the biological community of the ponds and adjacent areas, hence a number of ecological surveys (e.g. vegetation, fungi, aquatic invertebrates) have been undertaken, and more surveys (e.g. vertebrate animals) are planned in that respect. We also intend to characterise the planktonic community of these ponds, and in particular the presence/absence of cyanobacteria, and the abundance of diatoms. For that, information on certain chemicals, in particular N and P species, is also being gathered.

SAMPLING

Currently, water quality sampling of 9 ponds is being undertaken monthly, whilst ecological surveys are conducted with variable frequency. Bottom sediment samples were taken in June 2018. The samples are being taken from the following sites (Figure 1):

- Granton Pond, Edinburgh. It is a drainage (SUDS) pond, which provides amenity and biodiversity benefits. The pond was established in 2005 and is situated in a park, close to a supermarket and a college, and has an area of approximately 2,600 m^2. It is managed by Capita Symonds/National Grid.
- Juniper Green Pond, Edinburgh. It is a SUDS pond which is situated in a residential area at Woodhall Millbrae (adjacent to flats 1-12) near the Water of Leith footpath, and has an area of approximately 220 m^2. According to Jarvie et al (2017), the pond was (re)established in 2005 (according to http://www.junipergreencc.org.uk/jg300-1/leaflet.html, previously there were old mill ponds in this area when the mill was operational), and is managed by James Gibb company.
- Oxgangs Pond, Edinburgh, is also a SUDS pond providing amenity and biodiversity values. It is located in a residential area adjacent to Firrhill Neuk, and has a surface area of approximately 1,750 m^2. Jarvie et al (2017) give the date of establishment as 2007–2010. The pond is owned by 'Dunedin Canmore', but management appears to be subcontracted to 'Water Gems' (https://www.watergems.co.uk/) – a landscaper and water features specialist based in central Scotland.
- SUDS pond at Eliburn, Livingston is located near a residential area and light industrial units at Appleton Place. This pond hereafter will be referred to as Appleton. It has a surface area of approximately 350 m^2. Jarvie et al (2017) give the date of establishment as 2007–2011. The site is owned by Gladmans.
- Another SuDS pond in Eliburn is located in Eliburn Park close by. It has an area of ~600 m^2. To our knowledge, this pond has not been studied by previous research. The site is owned by Gladmans.
- Blackford pond, located within Edinburgh Local Nature Reserve. This relatively large pond (surface area 7,780 m^2) which provides obvious biodiversity and amenity value, and is enjoyed everyday by many visitors. The pond is thought to be natural, and established in the 19th century (Jarvie et al 2017).
- A woodland pond in Goreglen, Midlothian is situated near the main road within a local biodiversity site (LBS) west of Gorebridge. The pond is relatively small (500 m^2 surface area reported by Jarvie et al 2017) and is in the flood plain of Gore Water. Creation of the pond dates back to 1794–1861 (Jarvie et al 2017) and was related to coal mining operations in the area. Older maps show connections of the pond to the river, but on inspection those are not current, and according to the rangers the pond has not received any surface inflow for the last few years. The area is currently managed by the Midlothian Ranger Service.
- RBGE pond, Edinburgh is situated within the botanic garden. Being near residential area, it provides an obvious amenity and educational value. The pond has surface area of 1,300 m^2. It appears to be mainly rain water and ground water fed, with no permanent inflow. Outflow pipe connects the pond to the Water of Leith.
- Inverleith Pond, Edinburgh is situated in Inverleith Park. It has surface area of 9,150 m^2 and supports model boat activities, recreation, and feeding wild fowl. The pond appears to be managed by the local authority. Although originally built for ornamental and recreational reasons, the pond now features a retrofitted constructed wetland which receives the diverted inflow stream.

It should be noted that our estimates of the ponds' surface areas are considerably smaller than those given by Jarvie et al (2017). The measured areas quoted above are from Bing Maps and Google Earth images. These change depending on the water levels.

Figure 1. Location of the sampling sites.

WATER CHEMISTRY AND HYDROBIOLOGY

A number of standard water quality parameters, including e.g. pH, T, conductivity and oxygen levels have been measured on site. Further chemical analyses are carried out on the water samples in the biogeochemistry lab of Lyell Centre. An important part of water quality assessment is regular sampling of aquatic invertebrates. In addition the project will characterise the planktonic community of these ponds, and in particular the presence/absence of cyanobacteria, and the abundance of diatoms. For that, information on certain chemicals, in particular N and P species has also been gathered. Microscopic investigations are undertaken on concentrated phytoplankton samples (sampled using a net) and occasionally on unconcentrated samples. These observations (see e.g. Figure 2) allow us to allocate a degree of relative abundance to the planktonic organisms observed, thus facilitating interpretation as regards their role in the overall ecosystem functioning.

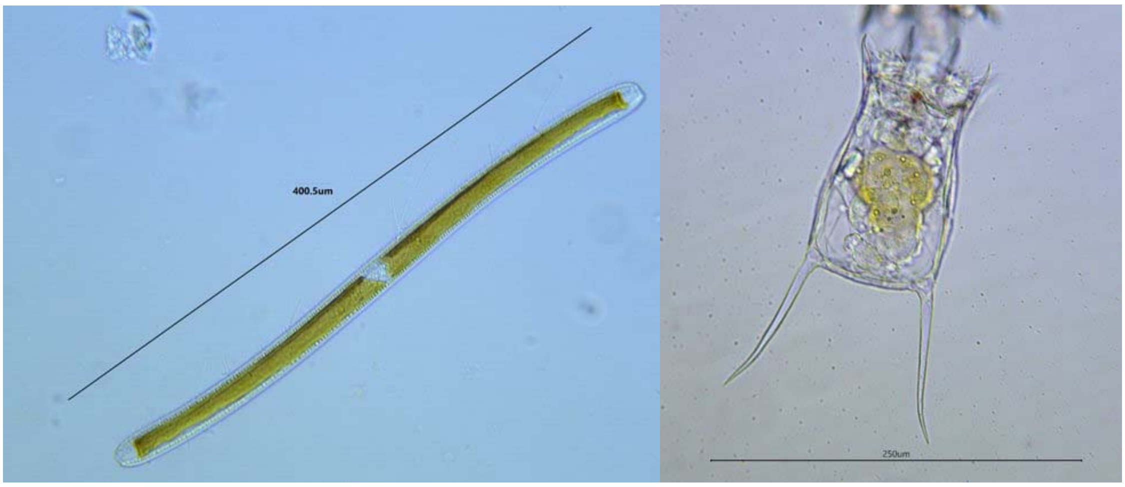


Figure 2. *Nitzschia sigmoidea* from Granton and *Keratella quadrata* from Blackford SuDS ponds.

PARTICLE CHEMISTRY AND SIZE DISTRIBUTION

PSD spectra have been derived for Suspended Particulate Matter (SPM) and for a limited number of bottom sediments samples using a laser diffraction technique - e.g. MastersizerS and MastersizerX instruments (Malvern) for the SPM samples. An example of PSD spectra for Appleton pond is given in Figure 3.

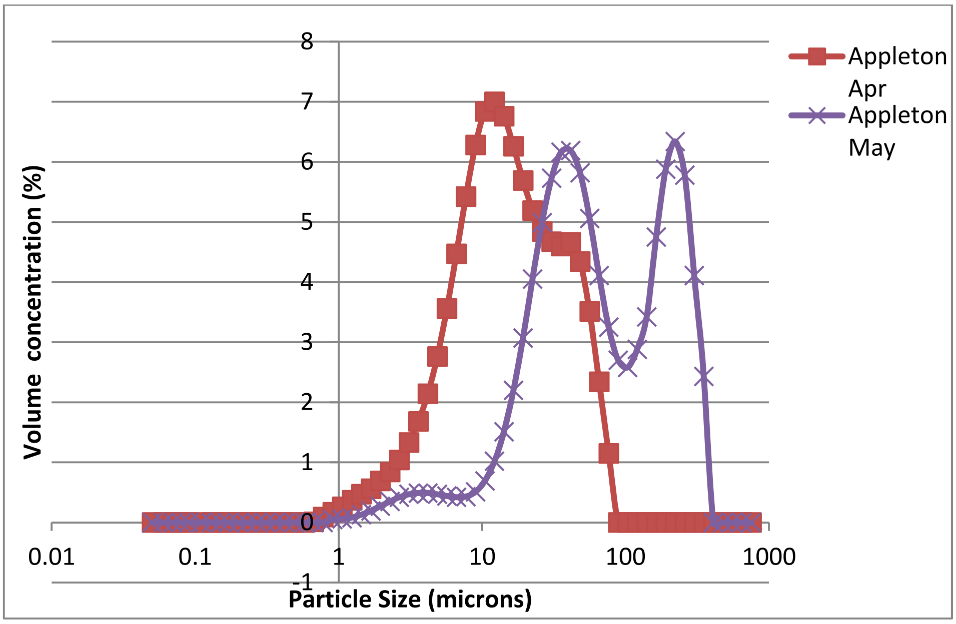
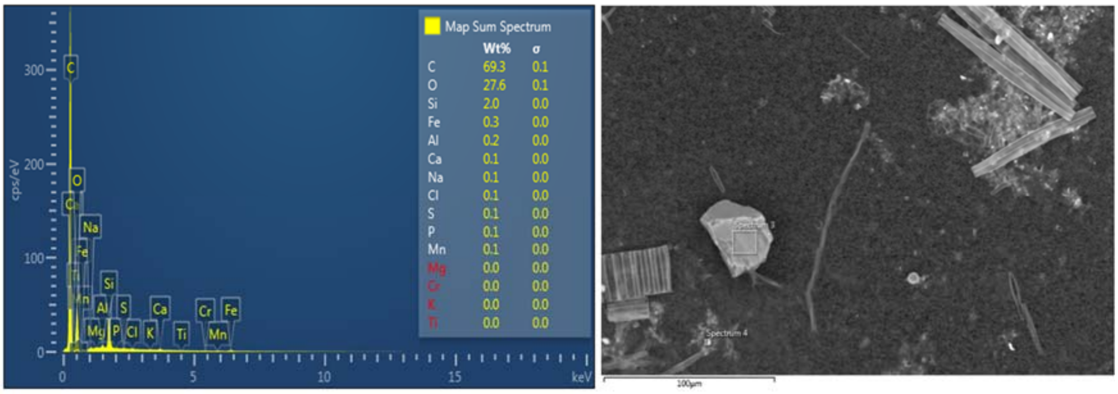


Figure 3. Example of observations of particle size spectra at Appleton Place SuDS pond.

Two interesting features can be seen in Figure 3. Firstly, there is normally a large fraction of small silt-sized particles, and often a considerable proportion of very fine particles (clay size). The abundance of fine particles has implications for adsorption of nutrients and pollutants, and is therefore relevant for biogeochemical cycling and for water quality issues (Ma and Singhirunnusorn 2012, Zafra *et al* 2017). Secondly, although for some spectra unimodal distribution has been observed, in many cases the revealed PSD was bimodal, and in some instances more than two modes were revealed. This multimodality may have reflected contributions from different sources, both abiotic and biological (Krivtsov et al. 2008). Furthermore, the PSD spectra are not static, but rather change between different sampling visits, thus reflecting the concurrent conditions, which is in line with previous studies elsewhere (Krivtsov et al. 2009). It should be noted that PSD of SPM in aquatic systems is influenced by a number of interlinked processes, including sedimentation, resuspension, precipitation, dissolution, flocculation and disaggregation (Krivtsov et al 2008). In the current study, both light and electron microscopy revealed interactions between microbiota and SPM (not shown).

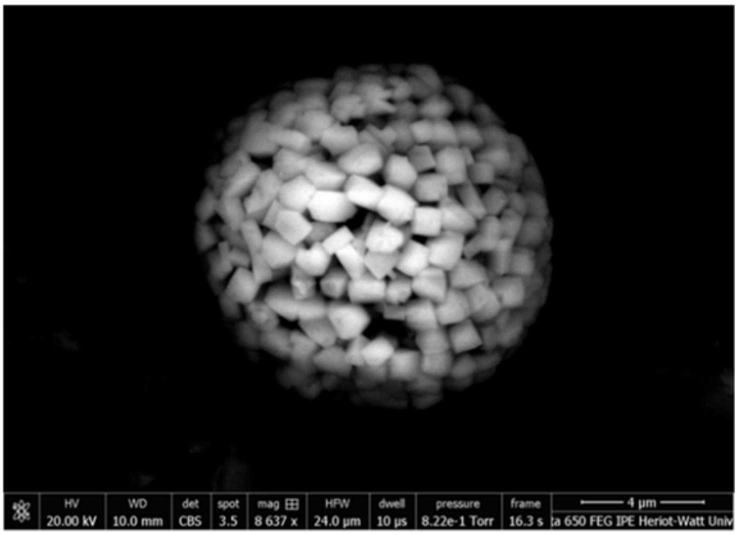


Map Sum Spectrum

	Wt%	σ
C	69.3	0.1
O	27.6	0.1
Si	2.0	0.0
Fe	0.3	0.0
Al	0.2	0.0
Ca	0.1	0.0
Na	0.1	0.0
Cl	0.1	0.0
S	0.1	0.0
P	0.1	0.0
Mn	0.1	0.0
Mg	0.0	0.0
Cr	0.0	0.0
K	0.0	0.0
Ti	0.0	0.0

Figure 4. An example of SEM micrograph and an EDX spectrum. Both organic and inorganic particles are observed, with organics being predominant, and also coating inorganic particles. Presence of certain elements (e.g. Ti) may be indicative of roadside or industrial pollution.

SPM samples have been analysed using SEM EDX (in IPE at Heriot Watt) whilst a selection of bottom sediments samples were analysed by Nottingham University using an XRF technique; the latter data are not shown here, but will be subject for further publications. An example of EDX spectrum is presented in Figure 4. Both organic and inorganic particles have been commonly observed, and many of smaller particles appear to be interconnected by detrital matter. Among chemical elements routinely detected within the SPM in significant concentrations are C, O, Si, Al, Ca, Mg, Fe, Mn, P, Cl and S. In a number of cases, however, there were less expected elements such as Ti, Y, Mo, Cr and even Au; these may have reflected the effect of car park and road runoff and/or industrial pollution. Crystals of pyrite FeS_2 detected in low oxygen conditions were confirmed by stoichiometric elemental ratios and by the presence of framboids (Figure 5).



HV	WD	det	spot	mag ⊞	HFW	dwell	pressure	frame	4 μm
20.00 kV	10.0 mm	CBS	3.5	8 637 x	24.0 μm	10 μs	8.22e-1 Torr	16.3 s	ta 650 FEG IPE Heriot-Watt Univ

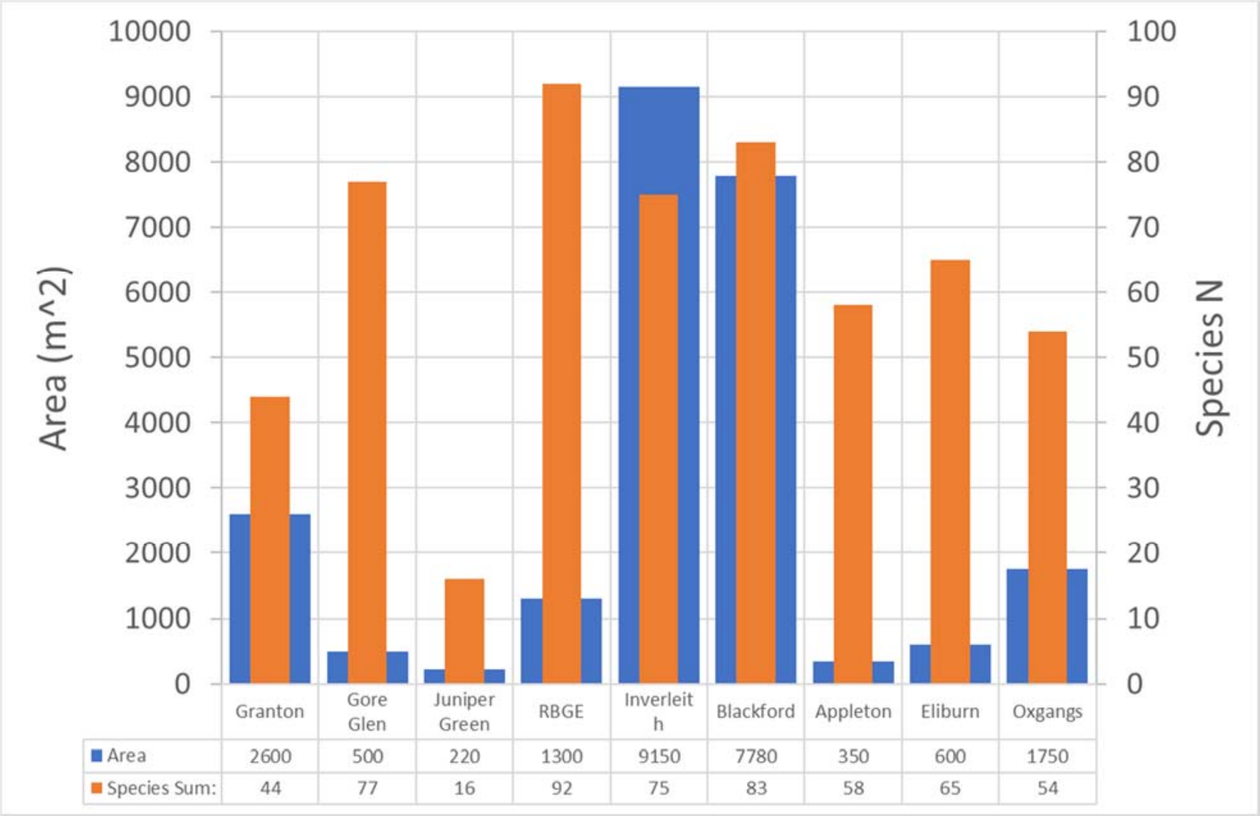
Figure 5. Pyrite framboids observed in Gore Glen pond under low oxygen condition.

BIODIVERSITY SURVEYS

In addition to the pond proper, these surveys cover an arbitrary 10 m zone around the water masses thus reflecting the effect of each pond on the immediate fringe of vegetation and man-made features such as asphalt paths and stonework.

Vegetation

Vegetation surveys were undertaken throughout the field season, and new plants records are made on each site visit. Currently, the species list of vascular plants ranges between 16 (Juniper Green) and 92 (RBGE). Although the smallest site has also the lowest number of plant species, the relationship with size is not clear cut (Figure 6). The species richness appears to be influenced by a number of factors, including area, pond age and planting regimes.



	Granton	Gore Glen	Juniper Green	RBGE	Inverleith	Blackford	Appleton	Eliburn	Oxgangs
■ Area	2600	500	220	1300	9150	7780	350	600	1750
■ Species Sum:	44	77	16	92	75	83	58	65	54

Figure 6. Species richness of vascular plants at the study site.

Other ecological surveys

Regular observations of plankton (monthly) and aquatic invertebrates (bimonthly) are an important part of the monitoring programme and help to characterise the overall ecosystem functioning. In addition, any vertebrate animals and fungi are duly noted when observed during site visits. Further surveying effort is planned with regard to lichens and bryophytes, and resources are being thought to also include terrestrial invertebrates.

Example of amenity and biodiversity assessment: Eliburn and Appleton ponds

An interesting comparison of biodiversity could be made for the two closely situated ponds, Eliburn and Appleton. Both ponds are fenced and not accessible to the public. Appleton pond also has a thicket of thorny shrubs preventing access, and is practically not visible from outside.

Figure 7. Eliburn pond. Photo by A.E. Sevilla

Eliburn pond has an open plan, and is currently at the early stages of ecological succession. Because of that, and also due to the ‘bomb crater’ type design (Figure 7), amenity value of the pond is low, and biodiversity value is expected to be low as well. Conversely, Appleton pond has a number of established aquatic macrophytes (Figure 8) and a pleasant appearance; a considerable biodiversity value is expected for that reason.

Figure 8. Example of vegetation at Appleton Place SuDS pond: *Aponogeton distachyos*.

In line with the initial expectations, Appleton pond was shown to have more species of aquatic plants and invertebrates. Vertebrate fauna also appears to be well-represented, with good numbers of frogs, newts and toads, and several species of birds inhabiting the site. However, contrary to the expectations, the species richness of terrestrial plants appears to be higher at Eliburn site (Figure 6). The reasons for that will be discussed in detail in our further publications.

MODELLING

As part of the study, information on the ponds' inflow and outflow, volumes, depth profiles and catchment areas is also being collected; for that, information from land managers and local authorities (e.g. West Lothian Council and City of Edinburgh Council) is being sought. That information will be combined with meteorological data (downloaded from the metoffice website) to run a simple hydrological model. This will allow estimation of the ponds' hydraulic loadings and retention times, and provide an indispensable background information for further analysis of ecological patterns and assessment of overall ecosystem functioning.

To date, CityCAT model (Glenis et al 2018) has been applied at the selected sites to simulate scenarios of 100 years return period storm, and an example result for Granton pond is provided in Figure 9. It should be noted that the ponds catchments are delineated by CityCat on the basis of topographic elevations. The information on the sewers network, however, could be added to the model's inputs thus improving the estimates of water inputs. These data are currently being sought from Scottish Water and SEPA.

It is evident that in this storm event most of the runoff concentrates along a local culverted water course (Caroline Burn) and misses the pond. However, the water volume of the pond is increased, and that the western part of the pond has high flow velocities which are likely to result in resuspension of accumulated sediments and remobilisation of any associated pollutants. In the Western part of the pond, however, flow velocities remain low, hence resuspension of bottom sediments there is less likely. These simulations provide an invaluable insight into the ponds' hydrology, and have, therefore, implications for a range of ecosystem processes as well as the management of the pond and surrounding areas.

Figure 9. CityCat modelling of a 60 minute 100 years return period storm at Granton Pond catchment. Flow velocities are in red, water depths are in blue. The simulation snapshot is at the end of the event.

CONCLUDING REMARKS

The monitoring and modelling programme described in this paper provides important information on the SUDS ponds studied, thus aiding interpretation of their overall functioning. The preliminary analysis indicates that the biological community in these ponds is instrumental for water quality improvements, but may be experiencing both physical and chemical limitations. Although biodiversity of the SUDS ponds studied appears to be lower than that of natural ponds, it constitutes up to 60-80% of the species richness observed at the control sites. In particular, some of the ponds studied (e.g. Juniper Green, Appleton) proved to have healthy amphibian populations, thus providing conservation value among other SUDS multiple benefits. Our further publications will provide a detailed analysis of the patterns observed at specific ponds.

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