Brunel University London

Department of Aerospace, Mechanical and Civil Engineering

Scuola di Ingegneria

Corso di Laurea Magistrale in Ingegneria per la Tutela dell'Ambiente e del Territorio

A.A. 2014-2015

Monitoring of Sustainable Drainage Systems in the Salmons Brook Catchment

Supervisors:

Prof. Ing. Claudio Lubello

Dr Evina Katsou

Prof. Ing. Riccardo Gori

Candidate: **MSc Thesis**

Stefano Folini   **December 2015**

Ai nonni Italo e Alberto,

Maestri di vita

ABSTRACT

Sustainable Drainage Systems (SuDS) is an established method for managing runoff in urban areas, mitigating the effects on the environment of the modified water cycle and reducing the amount of urban diffuse pollution washed into rivers.

This Thesis presents the performance of two different SuDS located in East London, in the Salmons Brook catchment, a tributary of river Lea, during their start-up period. It is demonstrated that the main sources of pollution for the area are misconnections, with household appliance connected into the separate sewage system.

The SuDS are evaluated by monitoring specific target parameters, chosen after a literature review for their ability to act as markers of different type of contamination.

The target markers are nutrients (Nitrate, Ammonia, Total Nitrogen and Total Phosphate), COD and Total Coliform, as markers of misconnections, and Total Petroleum Hydrocarbons (TPH) and Heavy Metals (Cadmium, Lead, Zinc and Copper), as markers of diffuse pollution and urban runoff. Other parameters, such as Dissolved Oxygen, Electrical Conductivity and pH, are monitored to gain a better understanding on the general biological conditions of the river. A particular focus is put on the TPH analysis, which are performed both on soil and on water samples. While in the case of the water samples a standard methodology was used, for the soil samples a new methodology was set up.

The systems perform well in term of organic content removal with an average COD reduction (relative to Glenbrook SuDS) during the 5-months sampling period of 61.3%. In terms of nutrients removal the SuDS are reducing the nitrogen compounds by 40-50% (depending on the specific compound) while the phosphorus proves harder to remove.

Since the study took place during the start-up period the efficiency is expected to increase as the vegetation in the ponds matures and the removal mechanisms become fully operative.

TABLE OF CONTENTS

LIST OF FIGURE

LIST OF TABLES

1 INTRODUCTION

Water makes life as we know it possible. Every drop cycles continuously through air, land, and sea, to be used by someone (or something) else "downstream." Water covers 70% of Earth's surface, but only 3% is fresh and only a fraction of one percent supports all life on land.

Everyone needs water – and not just for drinking. Society uses water to generate and sustain economic growth and prosperity, through activities such as farming, commercial fishing, energy production, manufacturing, transport and tourism. Water is at the core of natural ecosystems, and climate regulation. But the pattern of supply is particularly vulnerable to climate change.
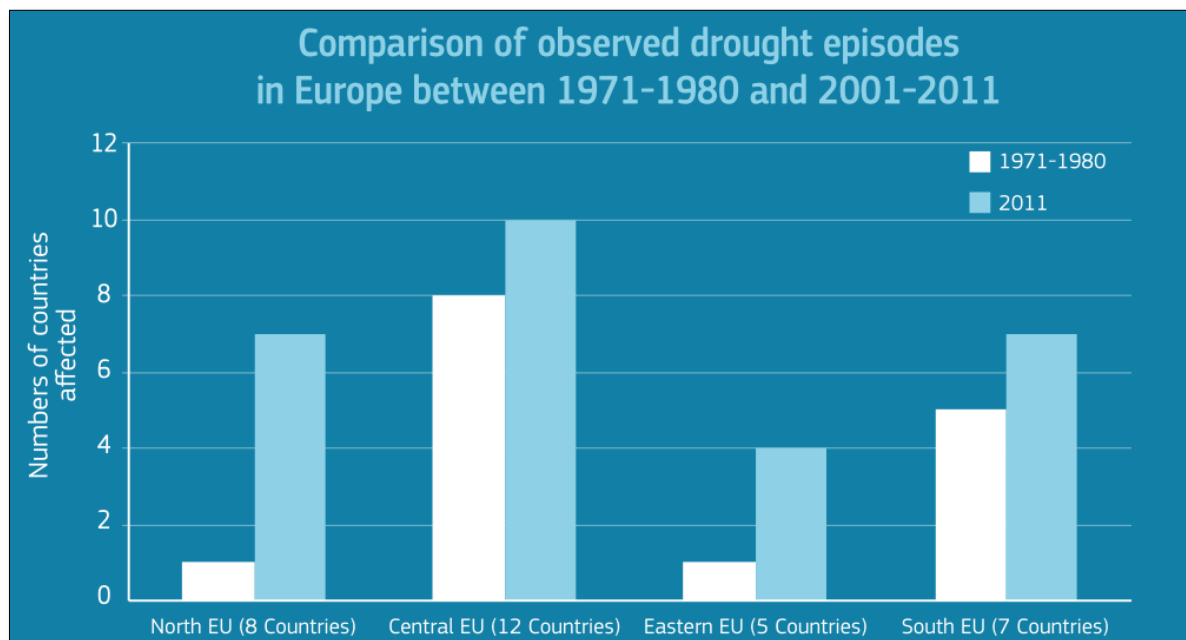
Figure 1-1 Comparison of observed drought episodes in Europe (source: EU WFD 4th Implementation Report)

Scientists warn of increased risk of both droughts and floods in the coming decades. Overall demand for water is growing, putting a strain on available supplies. As the fourth implementation report from the European Commission states, Water scarcity is an increasingly frequent and worrying phenomenon that affects at least 11 % of the European population and 17 % of EU territory. Since 1980, the number of droughts in Europe has increased, and they have become more severe, costing an estimated €100 billion over the past 30 years.

At the same time, threats to water quality come from pollution, over-abstraction and hydromorphological changes due to industry, agriculture, urban developments, flood defenses, power generation, navigation, recreation, wastewater discharge and more.

1.1 THE EU WATER FRAMEWORK DIRECTIVE

The EU Water Framework Directive (WFD), adopted in 2000, takes a pioneering approach to protecting water based on natural geographical formations: river basins. It sets out a precise timetable, with 2015 as the deadline for getting all European waters into good condition.

The definition of ecological status looks at the abundance of aquatic flora and fish fauna, the availability of nutrients, and aspects like salinity, temperature and pollution by chemical pollutants. Morphological features, such as quantity, water flow, water depths and structures of the river beds, are also taken into account. The WFD classification scheme for surface water ecological status includes five categories: high, good, moderate, poor and bad. 'High status' means no or very low human pressure. 'Good status' means a 'slight' deviation from this condition, 'moderate status' means 'moderate' deviation, and so on.

To define good chemical status, environmental quality standards have been established for 45 new and eight previously regulated chemical pollutants of high concern across the EU. In this respect, the WFD is backed up by other EU legislation such as the REACH regulation on chemicals, the Industrial Emissions Directive (IED) and EU regulations on pesticides.

The rules for groundwater are slightly different and good chemical and quantitative status is the objective set by the WFD. Member States must use geological data to identify distinct volumes of water in underground aquifers and limit abstraction to a portion of the annual recharge. Groundwater should not be polluted at all – any pollution must be detected and stopped.

In 2012, the European Commission published its third implementation report. It found that 43 % of surface water bodies were in "good status" in 2009 and that this is projected to increase to 53 % by 2015 based on the measures planned by Member States. Therefore, a 47% shortfall is expected in 2015 if no further action is taken.

1.2 THE IMPACTS OF URBANIZATION – CHANGE OF NATURAL FLOW PATTERNS

Development may reduce the permeability of the land surface by replacing free draining ground with impermeable roofs, roads and paved areas that are drained by pipe or channel systems (Konrad, 2003). Clearing of the area removes the natural vegetation that intercepts, slows and returns rainfall to the air through evapotranspiration. During development, the natural surface vegetated soils are removed and the subsoil is compacted. All these processes reduce the amount of water that can infiltrate into the ground, and significantly increase the rate at which water runs off the surface. (CIRIA, 2007)

Figure 1.2 shows the change in pre- and post-development hydrological processes, and Figure 1.3 demonstrates the impact of these changes on the resulting runoff hydrograph.
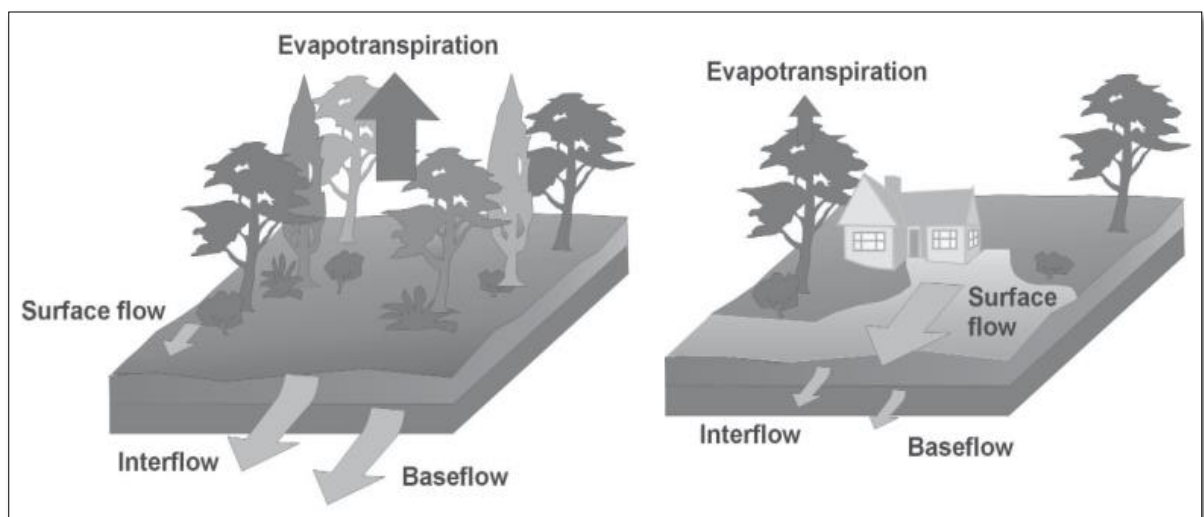
Figure 1-2 Pre and post development hydrological processes
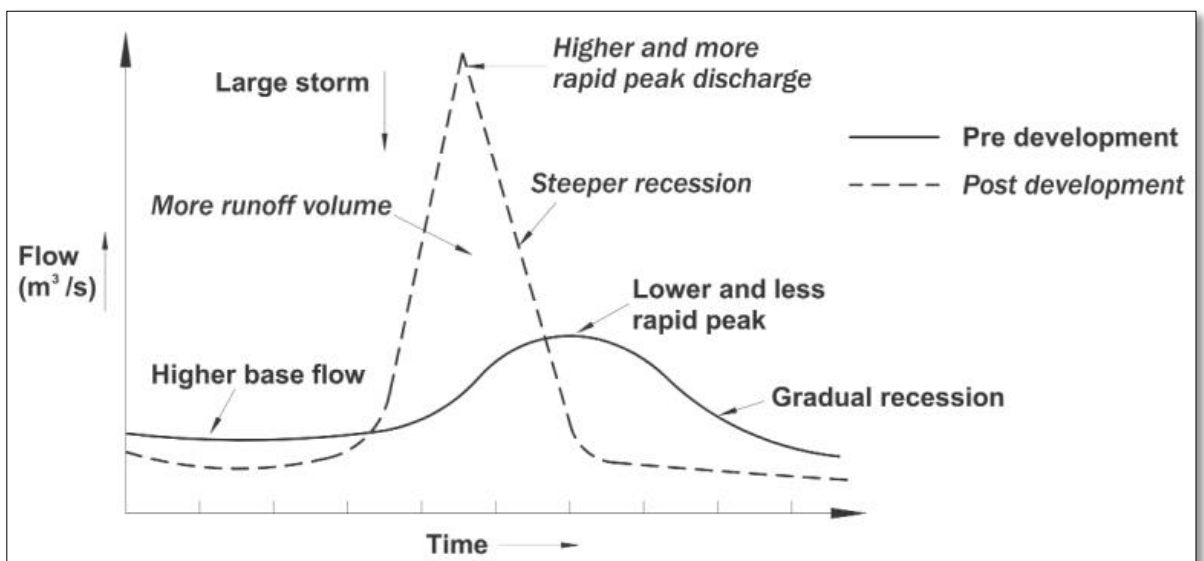
Figure 1-3 Pre and post development runoff hydrographs following storm rainfall

The alteration of natural flow patterns (in terms of both the total quantity of runoff and the peak runoff rates) may lead to flooding and channel erosion downstream of the development. The decrease in percolation into the soil can lead to low base flows in watercourses, reduced aquifer recharge, and damage to in-stream and streamside habitats. (Konrad, 2003)

Table 1.1 summarizes the impacts of urbanization on runoff quantity and quality and on the morphology of the receiving watercourse.

Table 1-1 Impacts of development (adapted from CIRIA, 2007)

	Processes	Impacts	Environmental effects
Changes to stream flow	- reduced infiltration and evapotranspiration - rapid urban area drainage - reduced infiltration, interflow, recharge.	- increased runoff volumes - increased peak runoff rates - increased downstream flooding - reduced baseflows.	Unrestrained discharges from a developed catchment can be orders of magnitude greater than those for an undisturbed catchment.
Changes to stream morphology	- increased stream profile instability - increased erosion rates - sediment deposition - increased flow rates and flood frequency - floodplain development (including in-channel structures, bridges, culverts).	- stream widening - stream erosion - loss of streamside tree cover - changes in channel bed profiles.	Channels widen to accommodate and convey the increased runoff. More frequent events undercut and scour the stream bank. Tree root zones are eroded and trees uprooted. Channel erosion and extra sediment sources cause deposition as sandbars or substrate.
Impacts to aquatic habitat	- increased flow rates and flood frequency - loss of riparian vegetation - increased erosion rates - sediment deposition - reduced habitat variability - reduced baseflows - stored runoff, from warm urban areas.	- degradation to habitat structure - loss of pool-riffle structure - increased stream temperatures - decline in abundance and biodiversity - siltation or sedimentation.	Higher flows can wash away biological communities. Streambank erosion and loss of riparian vegetation reduce habitat. Sediment deposits can smother stream-bed aquatic habitat, and pools and riffles are replaced with more uniform streambeds. Increased temperatures reduce oxygen levels and disrupt the food chain. Composition of the aquatic community will deteriorate with poorer quality waters.
Impacts to water quality	decomposition of organic matter present in runoff (uses up oxygen)	- reduced oxygen in receiving waters - nutrient enrichment (e.g. raised nitrogen, phosphorous concentrations)	Oxygen depletion weakens stream life and affects the release of toxic chemicals from sediments deposited in the watercourse.

	⬩ wash-off of fertiliser, vegetative litter, animal wastes, sewer overflows, septic tank seepage, sewage spills, detergents ⬩ dash-off of oils, greases, diesel/petrol ⬩ wash-off from industrial and commercial sites, rooftops, vehicles, household chemicals, landfills, hazardous waste sites.	⬩ pathogen contamination ⬩ hydrocarbon contamination (e.g. TPH, PAH, VOCs, MTBE) ⬩ increased levels of toxic materials (e.g. metals, pesticides, cyanides) ⬩ raised sediment loads, sedimentation ⬩ raised water temperatures ⬩ litter and debris ⬩ weed and algal growth.	Increased nutrient levels promotes weed, algal growth, eutrophication. Can result in fish kills. The level of bacteria found in urban runoff can exceed public health standards for water contact recreation. Toxic materials (including hydrocarbons) kill aquatic organisms and accumulate in the food chain. Their presence increases drinking water treatment costs. Construction site runoff, exposed soils, street runoff, and stream erosion are the primary sources of sediment in urban runoff. Debris, litter, weed, algae and sewage spills are aesthetically unattractive, obstruct flow paths and present risks to humans, flora and fauna.

1.3 THE IMPACTS OF URBANIZATION – DIFFUSE POLLUTION AND MISCONNECTIONS

As seen before, man's activities give rise to a large number of pollutants such as sediments, oils, grits, metals, fertilizers, pesticides, salts, pathogens and litter that, along with animal waste, can affect public health and cause environmental damage (CIRIA, 2007). Erosion poses additional problems, especially if the sediments washed out come from contaminated land, construction sites or land restoration sites. Another intermittent source can be accidental spills of liquids (e.g. oil or milk spills from tankers), or discharges coming from vehicular accidents and industrial process leakage. These pollutants are collectively termed "urban diffuse pollution" as they do not arise from a single source or activity, but are the product of all the land use and human activity in the urban area. Rainwater mobilizes these pollutants which are then washed into surface water sewers and eventually into rivers, or into groundwater. The loss of topsoil and vegetation removes a valuable filtering mechanism for runoff, and because traditional drainage systems are designed to carry water away quickly without treatment, they transfer pollutants rapidly to receiving waters downstream of the development (CIRIA, 2010).

Diffuse pollution produced from urban surface runoff is recognized as one of the major factors that can severely undermine the quality of receiving water bodies (Arnold and Gibbons, 1996;

14

Slonecker et al., 2001). The surface water recipients receive the storm water runoff through the local urban drainage system. The groundwater is affected by the seepage water, which is filtered through the soil. The filtration process is also a natural treatment process, improving the quality of water that ends up in aquifers. The level of purification that is accomplished depends on the pollutant retention capacity of the subsurface soil. The comparative investigation of the degree of environmental hazards on surface water, seepage water and groundwater, has been investigated through long-term numerical modelling (Zimmermann et al., 2005).

Table 1.2 on the next page presents the sources of pollution from impermeable surfaces, and the typical pollutant classes.

Table 1-2 Sources of pollution from impermeable surfaces (adapted from CIRIA, 2007)

Source	Typical pollutants	Source details
Atmospheric deposition	Phosphorous, nitrogen, Sulphur Heavy metals (lead, cadmium, copper, nickel, zinc, mercury) Hydrocarbons.	Industrial activities, traffic air pollution and agricultural activities all contribute to atmospheric pollution. This is deposited as particulates. Rain also absorbs atmospheric pollutants.
Traffic – exhaust	Hydrocarbons MTBE Cadmium, Platinum, Palladium, Rhodium	Vehicle emissions include polycyclic aromatic hydrocarbons (PAH) and unburned fuel and particles from catalytic converters
Traffic – wear and corrosion	Sediment Heavy Metals (Lead, Chromium, Copper, Nickel, Zinc)	Abrasion of tyres and corrosion of veichles deposits pollutants onto the road or car parking surfaces
Leaks and spillages (e.g. from road vehicles)	Hydrocarbons Phosphates Heavy Metals Glycolis, Alcohols	Engines leak oil, hydraulic and de-icing fluids and spillages occur when refueling. Lubricating oil can contain phosphates and metals. Accidental spillages can also occur.
Roofs – atmospheric depositions, bird droppings, corrosion and vegetation	Heavy Metals (Copper, Lead, Zinc) Bacteria Organic matter	Roof water is often regarded as clean. It can, however, contain significant concentrations of heavy metals resulting from atmospheric deposition or the corrosion of metal roofing or from other coatings such as tar.
Litter / animal faeces	Bacteria, viruses Phosphorous, Nitrogen	Litter typically includes items such as drinks cans, paper, food, cigarettes animal excreta plastic and glass. Some of this will break down and cause pollutants to be washed off urban surfaces. Dead animals in road decompose and release pollutants including bacteria. Pets leave faeces that wash into the drainage system.
Vegetation / landscape maintenance	Phosphorous, Nitrogen Herbicides, insecticides, fungicides Organic matter	Leaves and grass cuttings are an organic source. Herbicides and pesticides used for weed and pest control in landscaped areas such as garden, parks, recreation areas and golf courses, can be a major source of pollution.
Soil erosion	Sediment Phosphorous, Nitrogen Herbicides, insecticides, fungicides	Runoff from poorly detailed landscaped or other areas can wash onto impervious surfaces and cause pollution of runoff
De-icing activities	Sediment Chloride, sulphate Heavy Metals (Iron, Nickel, Lead, Zinc), glycol Cyanide Phosphate	De-icing salt is commonly used for de-icing roads and car parks. Rock salt used for this purpose comprises sodium chloride and grit. It can also include cyanide and phosphates as anti-caking and corrosion inhibitors, heavy metals, urea and ethylene glycol.
Cleaning activities	Sediment Phosphorous, Nitrogen Detergents	Washing vehicles, windows, bins or pressure washing hardstandings leads to silt, organic matter and detergents entering the surface water drainage.
Wrong sewer connections	Bacteria Detergents Organic matter	Wrong connections of foul sewers to surface water sewers where separate sewers exist.
Illegal disposal of chemicals and oil	Hydrocarbons Various chemicals	Illegal disposal of used engine oils or other chemicals can occur at small (domestic) or large (industrial) scales.

Misconnections occur when a drainage or a pipe intended for one type of effluent conveyance has been connected to the wrong sewer system. The first type of misconnection is when surface runoff water or stormwater outfalls (SWOs) get polluted by foul (contaminated) water coming from pipes intended for the sewage system.

The second type is when the surface runoff is connected to the foul sewer, leading to hydraulic overloading as well as placing increased burdens on treatment process downstream (DEFRA 2015).

The term misconnection is consequently misleading, as it covers a variety of urban sources including "greywater" and "blackwater" discharges as well as cross-connections between surface water and foul sewers. Other potential illicit wastewater sources to the surface water network (even though these are not strictly misconnections) can be spillages from septic tanks, industrial processes and sewer lines, water from vehicle wash and contaminated groundwater.

A principal focus in the misconnection issue has been on the wrong connection of household appliances (i.e., greywater discharges) into the separate surface water sewer although toilet (blackwater) misconnections present a particular problem due to their high pollution potential (Ellis et al., 2015).

Polluted stormwater outfall discharges from such misconnections might place receiving Water Quality Standards (WQSs) at risk of failure and prejudice good potential ecological status (Defra, 2012) in addition to causing aesthetic impacts. This potential source of urban receiving water pollution has been recently identified as a likely priority problem by the UK regulatory Environment Agency (Defra, 2012). In the United States, similar risks posed to receiving water bodies by such illicit discharges associated with municipal separate storm sewer systems (MS4s) have also been recognised (Brown et al., 2004). Illicit discharge detection and elimination (IDDE) regulations under Phase II of the National Pollutant Discharge Elimination System (NPDES) have specifically targeted misconnections as offenders prejudicing municipal permit consents (Brzozowski, 2004).

Despite this increasing perception that misconnections potentially is a major problem, the pervasiveness and severity of the problem is uncertain or misunderstood, even because many indirect discharges are caused by common residential behaviours and may not be classified as

"illicit" even though they can contribute to water quality problems. (Brown et al., 2004; Irvine et al., 2011). Urban catchment studies in both the UK and the United States of pollution loading from illicit discharges to SWO/MS4 sewers have demonstrated that the majority of such discharges are undetected primarily due to a lack of survey and monitoring data for urban surface water sewer (stormwater) pipes (Johnson and Tuoman, 1998; Stationery Office Ltd., 2011; Lilly et al., 2012). Given the mixed surface water and combined sewer inputs as well as sewer infrastructure malfunctions, there will inevitably be substantial difficulties in specifically differentiating and attributing source SWO impacts on the overall quality status of a receiving water body. Is it possible to distinguish between misconnection-derived sewage from that of cross-connections or exfiltrating sources when monitoring and analysing a polluted stormwater drain outfall.

Ellis et al. (2015) demonstrate that source backtracking and stringent compliance procedures are critical factors in elimination of illicit discharges although it is clear that these approaches must be accompanied by preventative and continual public awareness campaigns and related incentives. In the same paper the costs of misconnections were addressed, and in terms of equivalent annual value (EAV), surface water sewer misconnections have been estimated to cost the UK water industry about £235 M/year (€282 M/year) in terms of asset management and maintenance.

Type of pollution	Target Substance	Methodology	Conclusions	Paper
Urban run-off	Cd, Cu, Pb, Ni, Zn, TPH, Total PAH	Lysimeter soil core study	⬦ Inlet design influences the pattern of contamination in the basin soils, but not the average pollutant concentration. However it influences the average sediment quality ⬦ Degradation of organic pollutants in submerged sediments is slower than in exposed soil ⬦ Most pollutant are retained in the top 10 cm of soil	Evidence of traffic-related pollutant control in soil-based Sustainable Drainage System (Napier et al., 2008)
Urban run-off	pH, electrical conductivity, DO, TSS, TPH	ASTM D7066	⬦ Filtering effect of the SuDS confirmed	Comparative analysis of the

				High impact registered on water pollutants associated with solid particles	outflow water quality of two sustainable linear drainage systems (V. C. Andrés-Valeri et al., 2014)
Urban run-off	COD, TSS, Nitrogen, Phosphorus	Unspecified		Pollutant load actually increased after the treatment during the start-up period. The high loads were believed to be due to a combination of residues from the construction process and from the very long antecedent dry period before the first event observed.	SuDS Efficiency during the Start-Up period under Mediterranean Climatic Conditions (Perales-Momparler et al., 2013)
Jet-fuel contaminated run-off	Various hydrocarbons	Gas Chromatography		Subsurface infiltration of jet fuel-contaminated surface runoff has been shown to be a feasible treatment method. Biodegradation is believed to be the main process responsible for the observed removal of the hydrocarbons.	Treatment of Jet Fuel-Contaminated Runoff Water by Subsurface Infiltration (Gijs D. Breedveld, Gunnar Olstad & Per Aagaard ,1997)

1.4 ROLE OF THE SuDS

Sustainable Drainage Systems are technically regarded a sequence of management practices, control structures and strategies designed to efficiently and sustainably drain surface water, while minimising pollution and managing the impact on water quality of local water bodies.

The idea they are based on is to replicate as close as possible the "natural", pre-development drainage from a site.

The most authoritative guide to SuDS is currently *The SuDS Manual* (CIRIA, 2007), whose goal is to offer "comprehensive advice on the implementation of SuDS in the UK".

A Sustainable Drainage System can address many of the previous issues, thus mitigating many of the adverse effects on the environment of stormwater runoff. This is achieved through:

- reducing runoff rates, thus reducing the risk of downstream flooding (CIRIA 2007)

- reducing the additional runoff volumes and runoff frequencies that tend to be increased as a result of urbanisation, and which can exacerbate flood risk and damage receiving water quality (Jefferies et al., 2004; Scholes et al., 2008)

- encouraging natural groundwater recharge (where appropriate) to minimise the impacts on aquifers and river baseflows in the receiving catchment

- reducing pollutant concentrations in stormwater, thus protecting the quality of the receiving water body

- acting as a buffer for accidental spills by preventing a direct discharge of high concentrations of contaminants to the receiving water body

- reducing the volume of surface water runoff discharging to combined sewer systems, thus reducing discharges of polluted water to watercourses via CSO spills

- contributing to the enhanced amenity and aesthetic value of developed areas (Heal McLean & D'Arcy 2004)

- providing habitats for wildlife in urban areas and opportunities for biodiversity enhancement. (R.A. Briers. 2014, DEFRA 2006)

In the UK there are at least 56 case studies for SuDS, without considering all the systems for individual buildings.

In Scotland, where the acceptance of stormwater management advanced more rapidly than England and Wales (Fletcher et al., 2014), SuDS have been mandatory in most new developments since 2003 (WEWS, 2003) and aimed at improving water quality in receiving waters. In England and Wales the focus is switched more on the control of water quantity rather than quality (Defra, 2011).

An example of a success case study is related with the SuDS built in North Hamilton, Leicester. This system is surrounded by a residential development, located on former agricultural grassland. The aim of the project was to mimic natural drainage patterns in order to remove the need for traditional sewers and therefore reducing costs. The use of swales and retention pond was chosen to help solving existing flooding problems in the nearby Melton Brook.

The results have shown an increase in biodiversity and a benefit for the local flood risk management.

Another case study is the SuDS at Hopwood M42, Worcestershire. In this system, source control components trap most of the contaminants from the motorway service area before diverting the runoff from the car parking and the fuel filling area to a tributary of the Hopwood stream.

Both case studies are from CIRIA, 2010.

1.5 SUSTAINABLE DRAINAGE PRACTICES IN THE UK – THE SALMONS BROOK CATCHMENT

This Thesis is written and developed under the framework of the Salmons Brook Healthy River Challenge.

East London's rivers are some of the most polluted in Britain, running with high levels of E-coli sewage bacteria, waste water from homes and oils and chemicals from roads. Rivers of the Lea Catchment which fall within the boroughs of Tower Hamlets, Newham, Hackney, Waltham Forest, Haringey, and Enfield are being impacted daily. (Thames21, 2011). To deal with this issue Thames21 has launched the Love the Lea Campaign, in which the Salmons Brook Healthy River Challenge plays a major role.

The Salmons Brook Healthy River Challenge aims to improve the water quality in the Salmons Brook Catchment using Sustainable Drainage Systems (SuDS). Three community scales SuDS have currently been created as part of the Salmons Brook Healthy River Challenge. One more community scale SuDS is in the planning stage and expected to be delivered the summer of 2015.

The four sites chosen for this project are:

The woodland at Grovelands Park (Chapter 2.1.1), where the road run-off from Seaforth Gardens and Branscombe Gardens will be treated before it goes into Grovelands Stream.

The Spinney at Houndsden Rd, next to Houndsden Stream (Chapter 2.1.2)

The Glenbrook at Lonsdale Drive (Chapter 2.1.3)

The land next to the A10 northbound carriageway, a former council tree nursery, where the run off goes into the Salmons Brook (Chapter 2.1.4)

1.6 OBJECTIVES

This project aims to monitor and evaluate the efficiency of the existing and the new SuDS. This will be achieved through the determination of the removal of target contaminants by the SuDS. The target contaminants are nutrients (Nitrate, Ammonia, Total Nitrogen and Total Phosphate) COD and Total Coliform, as markers of misconnections, and Total Petroleum Hydrocarbons (TPH) and Heavy Metals (Cadmium, Lead, Zinc and Copper), as markers of diffuse pollution and urban runoff.

Nitrogen and Phosphorus are the principal nutrients of concern in urban storm water, and both are addressed in the Water Framework Directive. The degree to which they are present in a water body can determine the trophic status and amount of algal biomass produced. Excessive amount of nutrients can cause eutrophication, which is the general deterioration of a water body due to increased microbial respiration, resulting in reduced levels of Dissolved Oxygen in the water, therefore depriving other organisms and life forms of oxygen. Between the two, Phosphorus is usually the limiting element, as nitrogen is more soluble in water. The Total (Ortho)Phosphate level was chosen because it measures the phosphorus that is most immediately biologically available, and most of the soluble phosphorus in storm water is usually present in this form.

The Chemical Oxygen Demand determines the amount of organic pollutants found in waters.

The Total coliform level is used as an indicator of presence of pathogens in the water. Since they are associated mainly with fecal contamination of water, they can be used as markers of misconnections from houses coming into the separate sewage system.

TPH analysis will help to identify pollution sources and diffuse pollution, since chemicals that occur in TPH include hexane, benzene, toluene, xylenes, naphthalene, and fluorene, other constituents of gasoline, of jet fuels, of mineral oils, and of other petroleum products (Agency for Toxic Substances and Disease, 2014). For this reason, TPH are great markers of diffuse pollution and urban runoff.

Lastly, Heavy Metals are chosen as markers of diffuse urban pollution. In particular, atmospheric deposition is an important source for Cadmium, Lead and Copper. Zinc and Copper are traffic related pollutant, as they come from wear of brake pad and tyres, respectively (Quinn et al., 2014, Davis et al., 2001). Another major source of Zinc is roof

runoff (Gnecco et al., 2005). Copper and Cadmium can also be washed into water after the corrosion of galvanized pipes or household plumbings, discharge from metal refinery or runoff from waste batteries and paints (US EPA, 2013)

Suggestion for improvement of SuDS operation will be provided after the result evaluation.

1.7 NOVEL ASPECTS OF THE STUDY

A bibliographic analysis of the available methods for TPH determination revealed that the most used ones have been gravimetry (EPA Method 9071 B, 1998), infrared (IR) spectrophotometry (U.S. Environmental Protection Agency, 1996), and gas chromatography with flame ionization detection (GC-FID; U.S. Environmental Protection Agency, 2000), the first two being cheaper and quicker than the last one, but less precise and informative aswell.

In order to provide a simple, expeditious and economic tool that can be used as preliminary screening, IR spectrophotometry analysis combined with US extraction has been chosen as TPH determination method in this Thesis. Moreover, tetrachloroethylene (C_2Cl_4) was used as solvent for TPH extraction from the samples, since after a bibliographic analysis it showed environmental advantages on the other solvents commonly used (cheaper, less toxic, less quantity used per sample, no depletion of the ozone layer). Indeed, only three studies (Nascimento et al., 2008; Idodo-Umeh and Ogbeibu, 2010, Couto et al., 2014) that reported the use of C_2Cl_4 for TPH extraction were found, and only in one (Couto et al., 214) it was used in conjunction with IR spectrophotometry and US extraction.

Therefore, this work will try to establish a new methodology for TPH extraction from soil samples, based on the work from Couto et al.

Additionally, this Thesis will hopefully shed some light on the effectiveness of early stage SuDS. To the best of our knowledge, the impact of the start-up period on the accumulation of pollutant in SuDS and the treatment efficiency has not been sufficiently addressed in the reviewed literature.

Another expected outcome is to investigate the correlation between the selected markers of pollution. This will result in the development of a new and more cost-efficient monitoring strategy that can be used by water utilities and relevant stakeholders, in place of extensive sampling campaigns.

2 MATERIALS AND METHODS

2.1 THE CASE STUDIES

The case studies chosen in this work include the three new SuDS of Grovelands Park, Houndsden Spinney and Glenbrook, as well as the site for a future drainage system on the A10. As said before, this work is written in the framework of the Salmons Brook Healthy River Challenge, which aims to improve the quality of River Lea by tackling the pollution coming in its major tributary. Figure 2-1 is a scheme of the Lea Catchment where the three already existing SuDS on the Salmons Brook are circled in red.
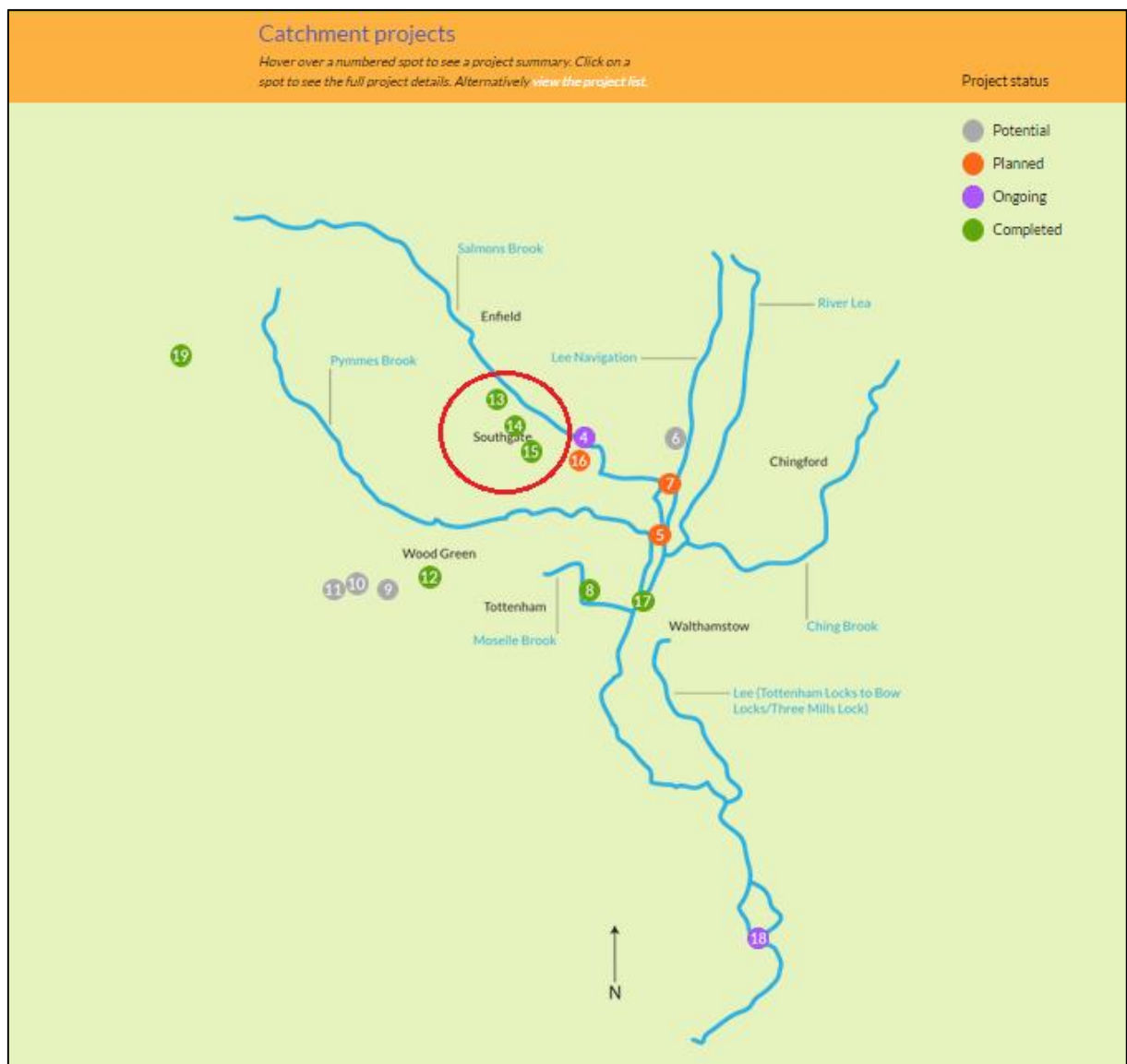
Figure 2-1 Lea Catchment

2.1.1 Groveland SuDS

The Groveland Park SuDS, with a total catchment area of 11 hectares, collects water from the stormwater sewers of Branscombe Gardens and Seaforth Gardens (marked in red in figure 2-2) before discharging it into the brook.

Figure 2-3 Aerial view of the Grovelands Park area

Figure 2-2 Grovelands Park SuDS

Samples were collected in correspondence of the two inlets, as close as emergence as possible, and from the stream, directly below the outfall from SuDS (see figure 2-3). This way, is possible to calculate the amount of pollution intercepted by the system as the difference between the levels in the brook and the levels from the inlets.

During high flow condition the SuDS outflow is sampled; however, these condition did not occur during the implementation of the present study and the flow was always contained in the vegetated pond.

In Figure 2-4, 2-5 and 2-6 the two inlets are presented, as well as the vegetated pond and the system outlet.

Figure 2-4 View of Inlet 1

Figure 2-5 View of Inlet 2

Figure 2-6 SuDS outlet

2.1.2   Houdsden Spinney SuDS
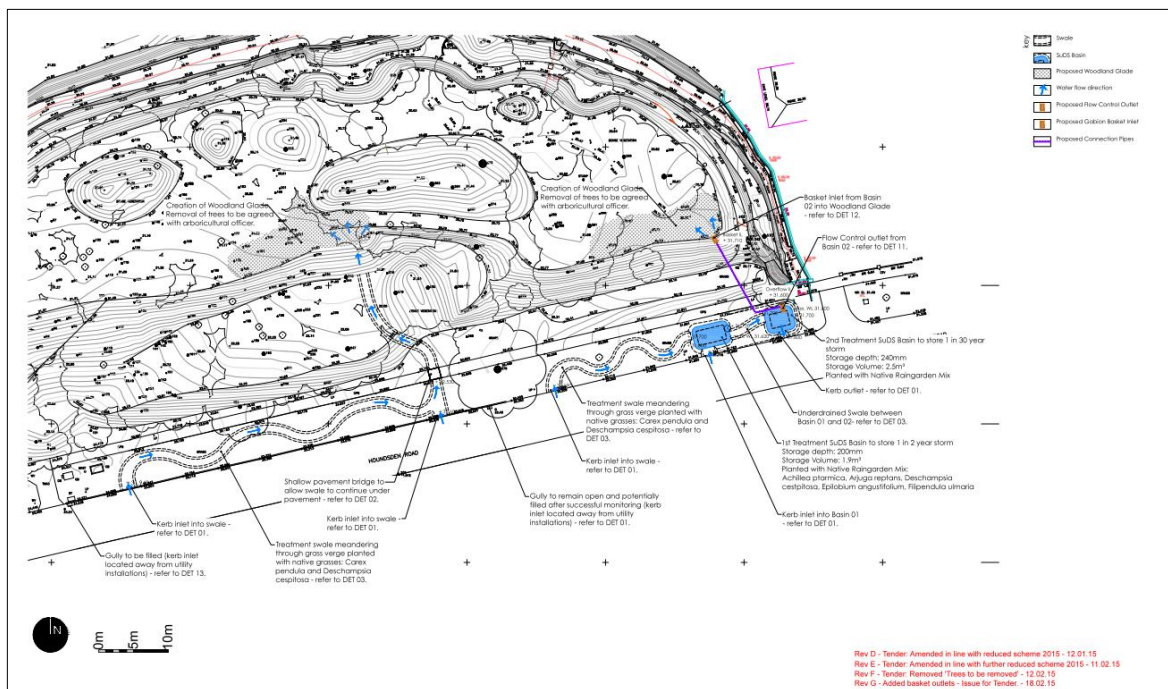
Figure 2-7 Houndsden Spinney SuDS

The highway drainage is intercepted and diverted into a meandering treatment swale, and from there into the woodland (Figure 2-6).

However, in the sampling period no flow was observed in the swale. For this reason, samples were taken only from the nearby stream, in two different points.

2.1.3   Glenbrook SuDS

The stream leading to Boxer's Lake is polluted with misconnections and road runoff, as evidenced by smell, colour and the presence of Sewer Fungus. This has been confirmed by Thames21 laboratory testing on nutrients and total coliform contents (See Appendix for complete results).

The SuDS diverts the flow by means of weirs into six new wetland areas, which treat the water using natural biologic and filtration process, as in the other SuDS.

This system is more complex that the others; it has one inlet that collects the water from a 42 hectares catchment, and 6 sub-basins in which the flow is diverted by means of weirs on the existing watercourse. This six new wetland areas treat the water using natural biologic and filtration process, as in the other SuDS.
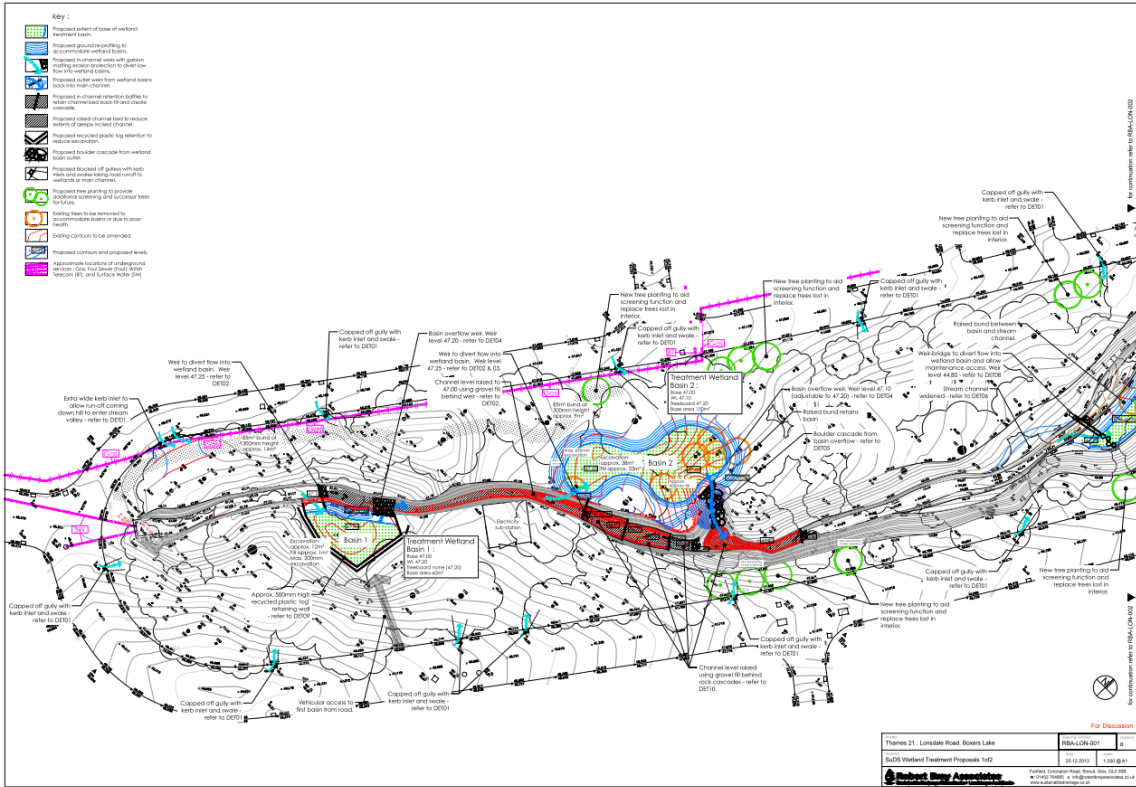
Figure 2-8 Glenbrook SuDS (part 1 of 2)
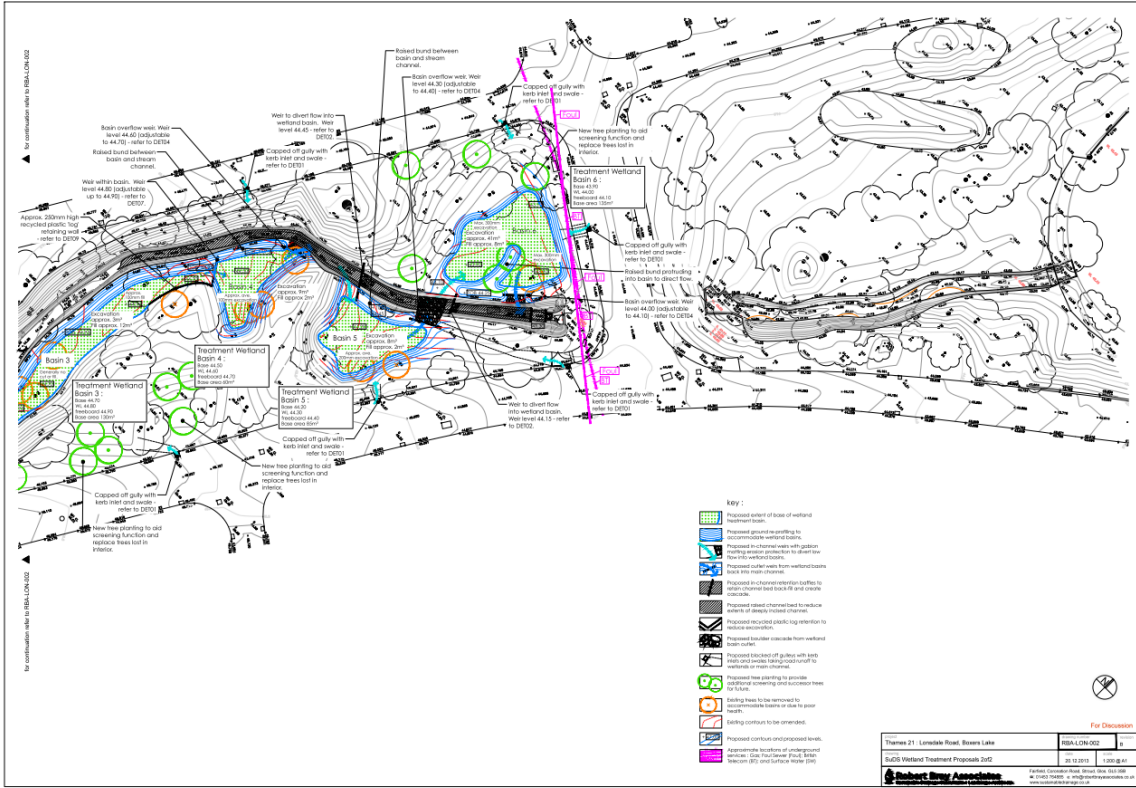
Figure 2-9 Glenbrook SuDS (part 2 of 2)

Figure 2-10 Cloudy effluent from the inflow pipe

The sampling points selected are the inflow pipe above the six treatment sub-basins (fig. 2-8), the SuDS outflow at the end of the system and the outflow to the lake, below the other non-SuDS outflow pipes (Fig. 2-9).

Moreover, each of the six basins is sampled during extended testing runs (approximatively once every 2 months), in order to gain a better understanding of the conditions and the pollution removal processes within the wetlands.

2.1.4   A10 (Great Cambridge Road) SuDS
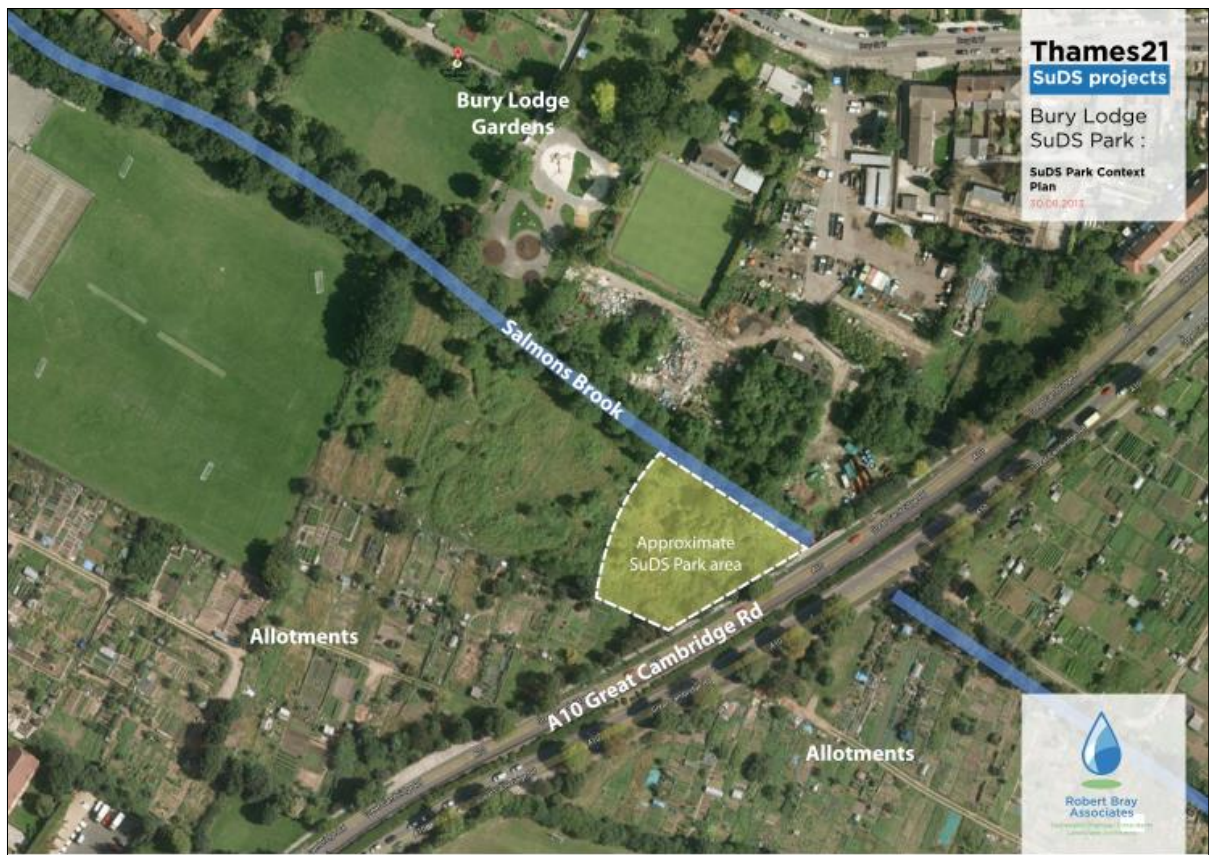
Figure 2-11 A10 SuDS Proposed Site
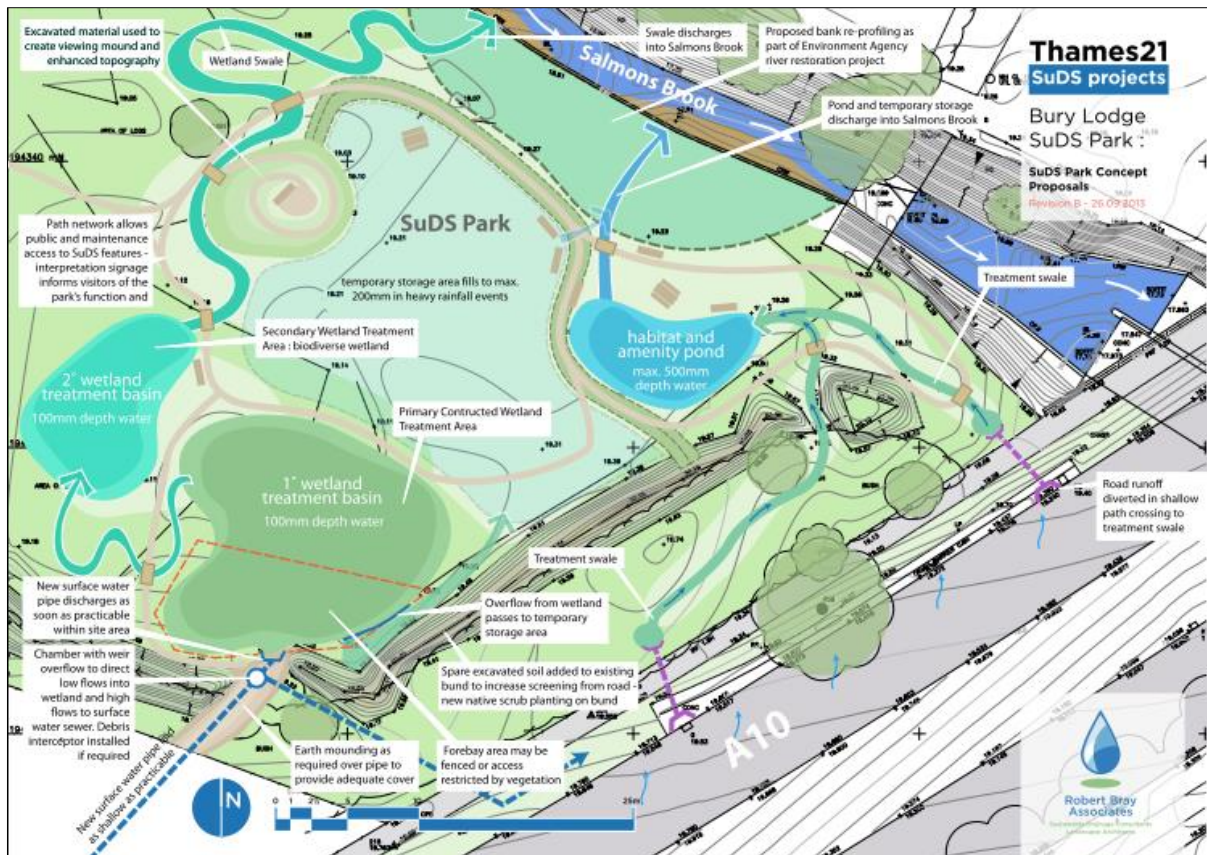
Figure 2-12 A10 SuDS Concept Plan

The A10 SuDS Park will become operative from spring 2016 and it will occupy a former council tree nursery. The system will intercept the road runoff from the A10 carriageway and prevent it from going into the Salmons Brook.

Figure 2-13 Drainage pipe collecting run-off from the A10

The first sampling points that were selected are upstream of the new proposed SuDS park, in order to obtain a baseline level of pollution not influenced by the carriageway. Another two sampling points are set directly upstream and downstream the A10 to gain a better understanding of the road impact on the brook. Lastly, the outflow from the drainage pipe in figure 2-13 is sampled during rainfall periods only.

2.2 DECISION OF A NEW MONITORING STRATEGY

The target areas presented in the previous paragraphs were the ones originally chosen at the beginning of this work, in May 2015.

However, the evaluation of the preliminary results showed the necessity of a change in the monitoring strategy.The results that led to this decision are presented in Chapter 3 – Results and Discussions.

2.2.1 Grovelands Park Lake

A new reed bed was constructed in June 2015, modifying the inlet of the lake to slow the pollution's diffusion through the basin.

As a consequence, 4 new points were selected in order to measure the levels of pollution around the new inlet and in various parts of the lake. The points are shown in figure 2-10.

Figure 2-14 Grovelands Park Lake sampling points

Point A is the main inlet, that collects runoff water from an approximate 100 ha catchment.

Point B is a sampling point on the right side of the lake, 30-40 m from the main inlet.

Point C is a secondary inlet, collecting water from the nearby Cafè and from the streets behind.

Point D is the lake outlet, that leads to the stream sampled as part of the Grovelands SuDS (see above). The distance between this point and the SuDS outflow sampling point is about 400 m.

The monitoring of the 4 new points will show the level of pollution entering the lake and how it varies between the different parts of the basin. It will also identify the beneficial impacts of the lake and the natural "cleaning" and depuration that occurs in the lake and along the stream.

Figure 2-15 Sampling point B

Figure 2-16 New Lake Inlet (Sampling point A) as seen from point B

2.2.2   Houndsden Spinney and the A10 site

Both sites were totally removed from the sampling campaign, as the results obtained were uninteresting.

With regards to Houndsden Spinney, no flow was observed in the SuDS, so samples collection could not be performed.

Concerning the A10, the pollution levels observed were very low, both in terms of Heavy Metals and TPH. The COD concentration was also similar to the ones detected in an urban river. The impact of the A10 was negligible for all of the measured parameters.

However, samples can be taken in both sites during rain events, when the runoff flow is sufficiently high, especially from the A10 drainage pipe.

The following table (Table 2-1) resumes the sampling point chosen in this work, the parameters measured and other informations

Table 2-1 Sampling points chosen

Point of detection	Parameter measured	Method of analysis	Sample type	Frequency
Groveland Park SuDS – Inlet 1	COD, Nutrients, Heavy Metals, Total Coliform, TPH, DO, pH, Temperature, Electrical Conductivity	Standard methods for water samples New TPH method for soil samples	Water Sediment	Once every two weeks
Groveland Park SuDS – Inlet 2	All of the above	//	Water Sediment	Once every two weeks
Groveland Park SuDS – Outlet	All of the above + Flow (if appropriate)	//	Water Sediment	In case of heavy rainfall (when water is actually flowing out of the system)
Groveland Park SuDS – Stream	All of the above + Flow (if appropriate)	//	Water Sediment	Once every two weeks
Groveland Lake – Outflow	COD, Nutrients, Heavy Metals, Total Coliform, TPH, DO, pH, Temperature, Electrical Conductivity	//	Water	Once every two weeks
Groveland Lake – Cafè inlet	All of the above	//	Water	Once every two weeks
Groveland Lake – Right side (Point B)	All of the above	//	Water	Once every two weeks
Groveland Lake – Main inlet (Point A)	All of the above	//	Water	Once every two weeks

	COD, Nutrients, Heavy Metals, Total Coliform, TPH, DO, pH, Temperature, Electrical Conductivity	Standard methods for water samples New TPH method for soil samples	Water	Once every two weeks
Glenbrook SuDS - Inlet				
Glenbrook SuDS – Outlet	All of the above	//	Water Sediment	Once every two weeks
Boxer Lake Inlet	All of the above	//	Water	Once every two weeks
Glenbrook - Intensive	All of the above	//	Water Sediment	Approx. once every two months

2.3 SAMPLING PROCEDURE

2.3.1 Sediment Samples

For the TPH analysis, both sediment and water samples were taken. The soil samples procedure followed the principles described in the Standard Method ASTM D7066.

The samples were collected using 60 ml glass bottles equipped with a screw cap having a fluoropolymer liner.

The soil collected from sites was as close to the water sampling point as possible, and always below the water level, in order to prevent loss of volatile compounds (Napier et al., 2008).

The samples were taken from the mud under the superficial armour layer (made by bigger grains and stones), since the TPH tends to accumulate in the smallest particles (Pitt et al., 1999) and in the first 8-10 cm of soil (Napier et al., 2008).

The samples were preserved in a cool box to keep them refrigerated until their storing in the university laboratory. Acid was not added, although the ASTM method suggested it, to avoid excessive risks in the field and during the carrying of the samples by London Underground services.

2.3.2   Water Samples

As for the soil samples, the collection of the water samples was performed according to the Standard Method ASTM D7066.

The samples were collected using 250 ml glass bottles equipped with a screw cap having a fluoropolymer liner, and as close as the emergence as possible, or directly from the pipes when feasible.

The samples were preserved in a cool box to keep them refrigerated until their storing in the university laboratory. Acid was not added, although the ASTM method suggested it, to avoid taking excessive risks in the field and during the carrying of the samples by London Underground services.

2.3.3   Measurement of target parameters

Besides the samples collection, the following parameters were analysed directly on the field:

- DO
    - Hanna HI9146 Portable Dissolved Oxygen Meter
    - Instrument calibrated in air
    - Water movement of at least 30 cm/s is required for accurate DO measurement. This can be achieved by manually stirring the probe.
- pH / Temperature / Electrical Conductivity
    - Using HI98129 pH/EC/TDS/temperature meter.
    - Instrument calibrated before the sampling
    - Measurements taken in plastic beaker to minimise electromagnetic interference.
- Flow
    - Surface flow velocity (V, [m/s]) measured by timing float to travel 10 m
    - Channel depth and width measured every 30 cm to create profile
    - Bulk flow velocity is related to the surface flow velocity by a factor of 0.8, such that discharge Q [m^3/s] can be calculated as Q = 0.8*V*A
- Time of the day
- Rainfall volume over previous fortnight

- Other notes or observations (such as presence of sewage fungus, issues/malfunctions within the system etc…)

2.4 COD METHODOLOGY

The COD test was performed using photometric evaluation of Hach LCI 500 cuvette

The detection limits of this test are $0 - 150$ mg / L O_2. The measurement was performed according to the Standard Method of Analysis.

2.4.1 Principle

Oxidizable substances react with sulphuric acid – potassium dichromate solution in the presence of silver sulphate as a catalyst. Chloride is masked by mercury sulphate. The reduction in the yellow coloration of Cr6+ is evaluated.

2.4.2 Steps

1. Preheat the thermostat to 148°C.

2. Bring the sediment into suspension by inverting the cuvette a few times.

3. Carefully pipette into the Cuvette test:

   Reagent blank: 2.0 mL COD-free water

   Sample cuvette: 2.0 mL homogenized sample

4. Close cuvettes, thoroughly clean the outside.

5. Invert.

6. Heat in the preheated thermostat at 148°C for 2 h.

7. Remove the hot cuvettes. Allow to cool to app. 60°C and invert a few times.

8. Allow to cool to room temperature.

9. Thoroughly clean the outside of the cuvettes and evaluate.

2.5 NUTRIENTS DETERMINATION

In order to test nutrients concentration in samples Hach Lange cuvette test kits are used. All tests involve a reaction that produces a colour change, which is then read automatically by Hach Lange DR3900 spectrophotometer.

All the nutrients test kits used come in two detection range, low and high. The first step consists in performing an analysis with the low range test kit, then if the result is over detection limits the test is reran using the high range test kit. The methodology for both is the same, the only difference is that a smaller volume of sample is introduced in the higher range test kits.

2.5.1 Ammonia

Tested with Hach LCK304 (low range: 0.015-2.0 mg/L NH4-N) and Hach LCK303 (high range: 2.0-47.0 mg/L NH4-N). Both tests measure dissolved quantities, not total, so they require the water sample to be pre filtered. This is done by drawing some sample in to a syringe, then attaching a membrane filter with pore width 0.45 µm to the bottom. The required amount of filtered sample is then pipetted into the test kit according to the working procedure instructions.

2.5.2 Nitrate

Tested with Hach LCK339 (low range: 0.23-13.5 mg/L NO3-N) and Hach LCK340 (high range: 5-35 mg/L NO3-N). As for Ammonium, both tests measure dissolved quantities, not total, so they require the water sample to be pre filtered. This is done following the same procedure as in chapter 2.5.1.

2.5.3 Total Phosphorus

Tested with Hach LCK349 (low range: 0.05-1.5 mg/L PO4-P) and Hach LCK350 (high range: 2.0 -20.0 mg/L PO4-P).

As an example the steps for the low range test are reported. The high range test follows the same steps, but with different volumes of sample and reagents.

1. Carefully remove the foil from the screwedon DosiCap Zip.
2. Unscrew the DosiCap Zip.
3. Pipette 2.0 mL sample.

4. Screw the DosiCap Zip back tightly; fluting at the top.

5. Shake firmly.

6. Heat in the thermostat. HT 200 S: in standard program HT for 15 min. Thermostat: 60 min at 100°C

7. Allow to cool to room temperature. Shake firmly.

8. Pipette into the cooled cuvette: 0.2 mL Reagent B (LCK 349 B). Close Reagent B immediately after use.

9. Screw a grey DosiCap C (LCK 349 C) onto the cuvette.

10. Invert a few times. After 10 min invert a few times more, thoroughly clean the outside of the cuvette and evaluate

2.5.4   Total Nitrogen

Tested with Hach Laton 138 (low range: 1-16 mg/L TNb) and Hach Laton2 38 (high range: 5 - 40 mg/l TNb). As an example the steps for the low range test are reported. The high range test follows the same steps, but with different volumes of sample and reagents.

1. Add in quick succession to a dry reaction tube: 1.3 mL sample, 1.3 mL solution A (LCK 138 A), 1 tablet B (LCK 138/238/338 B). Close immediately reaction tube. Do not invert.

2. Heat immediately. A) HT 200 S: in standard program HT for 15 min. B) Thermostat: 60 min at 100°C

3. Cool down and add 1 MicroCap C (LCK 138/238/338 C).

4. Close reaction tube and invert a few times until the freezedried contents are fully removed from the MicroCap C and all streaks are vanished.

5. Slowly pipette into the Cuvette Test: 0.5 mL digested sample.

6. Slowly pipette 0.2 mL solution D (LCK 138/238/338 D). Immediately close cuvette and invert a few times until no more streaks can be seen.

7. After 15 min thoroughly clean the outside of the cuvette and evaluate.

2.6   HEAVY METALS

In order to test nutrients concentration in samples Hach Lange cuvette test kits are used. All tests involve a reaction that produces a colour change, which is then read automatically by Hach Lange DR3900 spectrophotometer.

Hach Lange cuvette tests are designed to measure by means of a photometer the dissolved and non complexed ions. In waste water, however, heavy metals are often undissolved and complexly bound. In order to crack these bounds and analyse the metal load photometrically the Crack-Set LCW 902 was used. The principle followed is that undissolved and complexly bound heavy metals are dissolved by boiling in an acidic medium in the presence of an oxidising agent.

2.6.1 Cracking

10 ml of homogenized sample and 1 ml of sulphuric acid (LCW 902 A) are added into the enclosed reaction tube. A control of pH-value is performed and 2 dosing spoon of Potassium peroxodisulphate B (LCW 902 B) are added if necessary. The reaction tube is then closed and inverted a few times, and then heated in the thermostat at 100°C for 60 min. After the cooling down to room temperature, 1 ml of Buffer solution C (LCW 902 C) Is pipetted into the reaction tube. The tube is then closed and inverted a few times. The metal content of the sample prepared by cracking can now be analysed.

2.6.2 Copper

Tested with Hach LCK329

The detection limits of this test are 0.1 – 8.0 mg / L Cu.

1. Pipette 2.0 mL sample.
2. Close cuvette and invert a few times until the freeze-dried contents are completely dissolved.
3. After 3 min, invert a few times more, thoroughly clean the outside of the cuvette and evaluate.

2.6.3 Zinc

Tested with Hach LCK360

The detection limits of this test are 0.2 – 6.0 mg / L Zn.

1. Carefully remove the foil from the screwed-on DosiCap Zip.
2. Unscrew the DosiCap Zip.
3. Pipette 0.2 mL sample.
4. Pipette 0.2 mL solution A (LCK 360 A).

5. Immediately screw the DosiCap Zip back; fluting at the top.

6. Shake firmly.

7. After 3 min thoroughly clean the outside of the cuvette and evaluate

2.6.4   Lead

Tested with Hach LCK306

The detection limits of this test are 0.1 – 2.0 mg / L Pb.

1. Pipette 10 mL sample to a reaction tube.

2. Add 1 dosing spoon reagent A (LCK 306 A).

3. Close reaction tube, invert repeatedly and wait 2 min.

4. Pipette into the Cuvette Test: 1.5 mL solution B (LCK 306 B).

5. Pipette into the same cuvette: 4.0 mL preteated sample.

6. Close cuvette and invert a few times. After 2 min thoroughly clean the outside of the
   cuvette and evaluate

7. Pipette into the same cuvette: 0.3 mL solution C (LCK 306 C).

8. Close cuvette and invert a few times, thoroughly clean the outside of the cuvette.

9. After 1 min evaluate.

2.6.5   Cadmium

Tested with Hach LCK308

The detection limits of this test are 0.02 – 0.3 mg / L Cd.

1. Pipette 10 mL sample to a reaction tube.

2. Add 1 ml reagent A (LCK 308 A).

3. Close reaction tube, invert repeatedly and wait 2 min.

4. If the concentration of Calcium and Magnesium is above 50 mg/L use the Method LCW
   903 in order to separate Calcium

5. Pipette into the Cuvette Test: 0.4 mL solution B (LCK 308 B).

6. Close cuvette and invert a few times. After 2 min thoroughly clean the outside of the
   cuvette and evaluate

7. Pipette into the same cuvette: 4.0 mL pretreated sample.

8. Close cuvette and invert a few times, thoroughly clean the outside of the cuvette.

9. After 30 sec evaluate.

2.7 TPH METHODOLOGY

Soil and water contamination by petroleum hydrocarbons (PHC) is of environmental concern, as they can cause different kinds of stress on ecosystem and human health. Moreover, hydrocarbons are targets markers of urban runoff, since they are one of the main by-products of combustion engines. Therefore it is useful to set up a quick and reliable methods for their determination, in order to provide either rapid information on contamination levels or to monitor environment recovery rate after the application of a certain remediation technology. In most cases, information on levels of (TPH), without identification/quantification of individual compounds, is enough for that purpose. If after this preliminary screening more information are deemed necessary, in depth analysis can be performed. Total petroleum hydrocarbons is a commonly used parameter for quantifying environmental contamination originated by various PHC products such as fuels, oils, lubricants, waxes, and others.

A bibliographic analysis of the available methods for TPH determination revealed that the most used ones have been gravimetry (EPA Method 9071 B, 1998), infrared (IR) spectrophotometry (U.S. Environmental Protection Agency, 1996), and gas chromatography with flame ionization detection (GC-FID; U.S. Environmental Protection Agency, 2000), the first two being cheaper and quicker than the last one, but less precise and informative aswell. In the case of sediment analysis, a previous step for hydrocarbons extraction from the solid matrix is required. Available procedures include, among others, microwave assisted extraction (Shu and Lai, 2001), supercritical CO_2 extraction (U.S. Environmental Protection Agency, 1996; Morselli et al., 1999), ultrasonic (US) extraction (Liste and Felgentreu, 2006, Couto et al., 2014), as well as the more classic procedures such as soxhlet extraction (Gallego et al., 2006). Among them, US extraction offers some advantages, such as lower cost, time-consuming effectiveness or relatively low requirement of harmful solvents. For instance, soxhlet extraction requires relatively large volumes of organic solvents (Gallego et al., 2006), which is an ecological disadvantage. After the extraction step, TPH determination by gravimetry requires elimination (by evaporation) of the solvent before analysis, which can imply loss of analyte or inclusion of compounds that contribute to the final weight but that are not the target contaminant (Villalobos et al., 2008).

For all these reasons IR spectrophotometry analysis combined with US extraction has been chosen as TPH determination method in this work. The method is simple, fast and cost efficient.

In the IR spectrophotometry determinations the solvent used for the extraction step must be transparent in the target wavelength interval and must not include C-H bonds. Otherwise it could give false positive results. Potential options for solvent selection are Freon 113 (Liste and Felgentreu, 2006), carbon tetrachloride (CCl_4), tetrachloroethylene (C_2Cl_4 ; Farmaki et al., 2007, Couto et al., 2014) or dimer/trimer of chlorotrifluoroethylene (ASTM D 7066). Since the Montreal Protocol (1987) Freon 113 has been identified as one of the substances that may cause the depletion of the stratospheric ozone layer, so its use as solvent should be avoided. Moreover, CCl_4 must be avoided too owing to its toxicological effects (Farmaki et al., 2010) while chlorotrifluoroethylene increases the cost per determination. Therefore C_2Cl_4 is the better choice; however this solvent is not widely used for this type of analysis. Indeed, only three studies (Nascimento et al., 2008; Idodo-Umeh and Ogbeibu, 2010, Couto et al., 2014) that reported the use of C_2Cl_4 for TPH extraction were found.

2.7.1 Soil methodology

The soil samples are collected following the steps described in chapter 2.3.1.

2.7.1.1 Pre-treatments

After the collection, the samples are sieved through a 1 mm mesh, to filter and clean the sediment from potential extraneous elements (rocks, small pieces of wood, algae etc…), and then grinded in order to obtain a sample as homogeneous and representative as possible.

The sample is then dried and maintained at room temperature until extraction is performed.

2.7.1.2 Extraction

About 1 g of solid sample (soil or sediment) is mixed with silica gel (1:1 [w/w]) in order to chemically drying the sample. A suitable amount of C_2Cl_4 (1:10 [m sample / v solvent]) is added and Ultrasonic extraction is performed for 30 min. The obtained extract is decanted and refrigerated at 4°C until FTIR spectrophotometry analysis is performed.

2.7.1.3 Calibration

TPH were quantified by direct comparison with the calibration curve. For this purpose, calibration curves were developed using standard solutions that were prepared in C_2Cl_4, from a stock standard solution containing equal volumes of isooctane and octanoic acid, as per ASTM D 7066 methodology.

Preparation of Stock Solution: 0.55 mL of octanoic acid (density 0.9100 g/mL) and 0.72 mL of isooctane (density 0.6920 g/mL) are mixed in a 10-mL volumetric flask; the flask is then filled to the mark with solvent. A solution prepared with this volumes has a density of 0.998 g/mL, therefore the resulting concentration is 50 mg/mL of octanoic acid and isooctane each (100 mg/mL total oil and grease). This solution will be termed "Stock Solution".

Diluted Stock Solution: 2.5 mL of the Stock Solution are placed in a 50-mL volumetric flask and solvent is added until the flask is filled to the mark. Diluted Stock Solution = 5.0 mg/mL (5000 µg/mL).

Calibration Solution A: 1.0 mL of Diluted Stock Solution is placed in a 10-mL volumetric flask and the rest is filled to the mark with solvent. Calibration Solution A = 0.5 mg/mL (500 µg/mL), equivalent to 5000 mg/kg of oil and grease in a 1 g soil sample extracted into a 10 mL volume of solvent. Similar procedure was followed in order to acquire the other calibration solutions

Calibration Solution B: 0.25 mg/mL (250 µg/mL), equivalent to 2500 mg/kg of oil and grease in a 1 g soil sample extracted into a 10 mL volume of solvent.

Calibration Solution C: 0.1 mg/mL (100 µg/mL), equivalent to 1000 mg/kg of oil and grease in a 1 g soil sample extracted into a 10 mL volume of solvent.

Calibration Solution D: 0.050 mg/mL (50 µg/mL), equivalent to 500 mg/kg of oil and grease in a 1 g soil sample extracted into a 10 mL volume of solvent.

Calibration Solution E: 0.025 mg/mL (25 µg/mL), equivalent to 250 mg/kg of oil and grease in a 1 g soil sample extracted into a 10 mL volume of solvent.

The calibration solutions were poured into the sample cell, and FTIR spectroscopy was performed, in the range from 3200 cm^{-1} (3.13 microns) to 2700 cm^{-1} (3.70 microns).


Three different cells were used in this study. The first one is an Omni Cell from Specac, with a 1 mm path length (fig. 2-16).

The first run of the method showed that the detection limit achievable was above the calibration solution E concentration. Thus, in order to improve the detection limits two more cells were purchased: a 10 mm and a 40 mm path length silica cells from Starna.

Figure 2-17 Omni Cell (source: Specac)

Both the calibration and the sample reading was performed in the range from 3200 cm^{-1} (3.13 microns) to 2700 cm^{-1} (3.70 microns). This range was chosen since, normally, IR spectra of solutions containing hydrocarbons present characteristic bands of C-H bonds: 2853 cm^{-1} and 2926 cm^{-1} (C-H stretch of CH$_2$), 2962 cm^{-1} (C-H stretch of CH$_3$), and 3040 cm^{-1} (stretching vibration of C-H aromatic bonds) (Couto et al., 2014).

Figure 2-18 10 and 40 mm path lenght cells (source: Starna)

In a preliminary step, and with the 0.4 mm cell, measurements of the bands were carried out in terms of area of the peak in the interval, but at a later stage they were performed in terms of height of the highest peak in the interval. Both alternatives have been used to quantify oil and grease in water (Daghbouche et al., 1997) but maximum peak height is the most widely used (EPA Method 8440, 1996; Farmaki et al., 2007). Although, in theory, peak area could provide more accurate data than peak height (Couto et al., 2014), in the present work it was observed that data obtained using areas (by automatic integration) were not reproducible when the 10 and 40 mm cells were used (results not shown). Therefore, further measurements were carried out in terms of height of the highest peak, which appears around 2930 cm^{-1} .

Linear responses (correlation coefficient $R^2=0.9995$; n = 5) were observed for all the concentrations range tested.
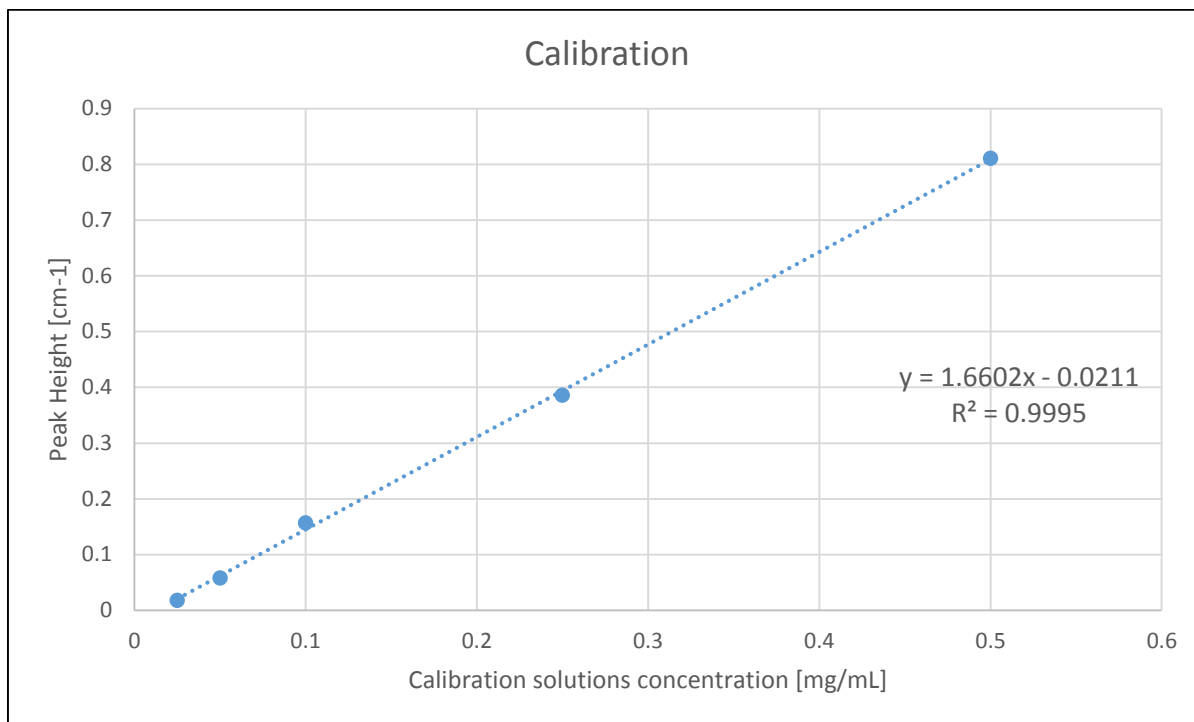
Figure 2-19 FTIR Calibration

Since the peak's height of the Calibration solution E (0.025 mg/mL) was so close to the one of the blank solvent, that concentration of 250 mg of oil and grease each kilogram of soil (250 ppm in weight) was used as Lower Detection Limit.

2.7.2   Water methodology

Water samples are collected following the steps described in chapter 2.3.2, and then extracted following the methodology presented in the ASTM D7066

2.7.2.1   Extraction

The sample is transferred from the sample bottle to a clean separatory funnel via a clean transfer funnel. A filter paper is placed in a filter funnel and approximately 1 g of Na_2SO_4 is added.

15 mL of solvent is added to the sample bottle. The bottle is then capped and shaked to rinse all interior surfaces. The solved is poured into the separatory funnel, rinsing down the sides of the transfer funnel.

The sample is then extracted by shaking the separatory funnel vigorously for 2 minutes with periodic venting into a hood to release excess pressure. The funnel has to be vented slowly to prevent loss of sample.

After some time, in order to allow the phases to separate, the solvent (lower) layer is drained from the separatory funnel through the sodium sulfate into a pre-cleaned 50-mL volumetric flask.

The extraction is then repeated twice more with 15-mL portions of solvent, and all the equipment used (separatory funnel, Na_2SO_4, filter paper, and filter funnel) is rinsed with a small (approximately 1-mL) portion of solvent which is then collected in the volumetric flask.

The solvent extract volume is brought to 50 mL by adding more solvent. The extract can now be measured in the FTIR.

The calibration step for the FTIR are the same followed in chapter 2.7.1.3.

.

3 RESULTS AND DISCUSSION

3.1 REMOVAL OF TARGET POLLUTANTS

In the following section the results of the sampling campaigns for each parameter have been reported, toghether with a brief analysis of the outcomes. Every parameter sub-chapter is organized by zone or system analysed. For a more in-depth description of each system please refer to chapter 2.1 and 2.2.

3.2 CHEMICAL OXIGEN DEMAND

Chemical oxygen demand (hereafter as COD) is a measure of the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water.

The last two implementation of the Water Framework Directive in the UK proposed the use of BOD_5 and not COD as standards for oxygen condition in rivers (DEFRA, 2014 and DEFRA, 2015). However, COD measurement are easier and can be made in a few hours, while BOD measurements take five days; moreover, COD values give a broader idea about the levels of organic matter found in the sample.

The main COD removal mechanisms that take place in SuDS are filtration, sedimentation and biodegradation (Wilson et al., 2004).

Sedimentation is one of the primary removal mechanisms in SUDS. Most pollution in runoff is attached to sediment particles and therefore removal of sediment results in a significant reduction in pollutant loads. Sedimentation is achieved by reducing flow velocities to a level at which the sediment particles fall out of suspension. Filtration within the soil and/or on the plants that grow in the SuDS can be another removal mechanism. Finally, in addition to the physical processes, the microbial communities that are within the ground and the plants roots also degrade the organic matter. The level of activity of such bioremediation will be affected by environmental condition and the supply of nutrients.

3.2.1 Groveland SuDS

In figure 3-1 the results for the SuDS in Groveland Park are presented.

Samplings on the 10/08 and 21/09 were not performed since the intensive sampling in Glenbrook took place in those days.
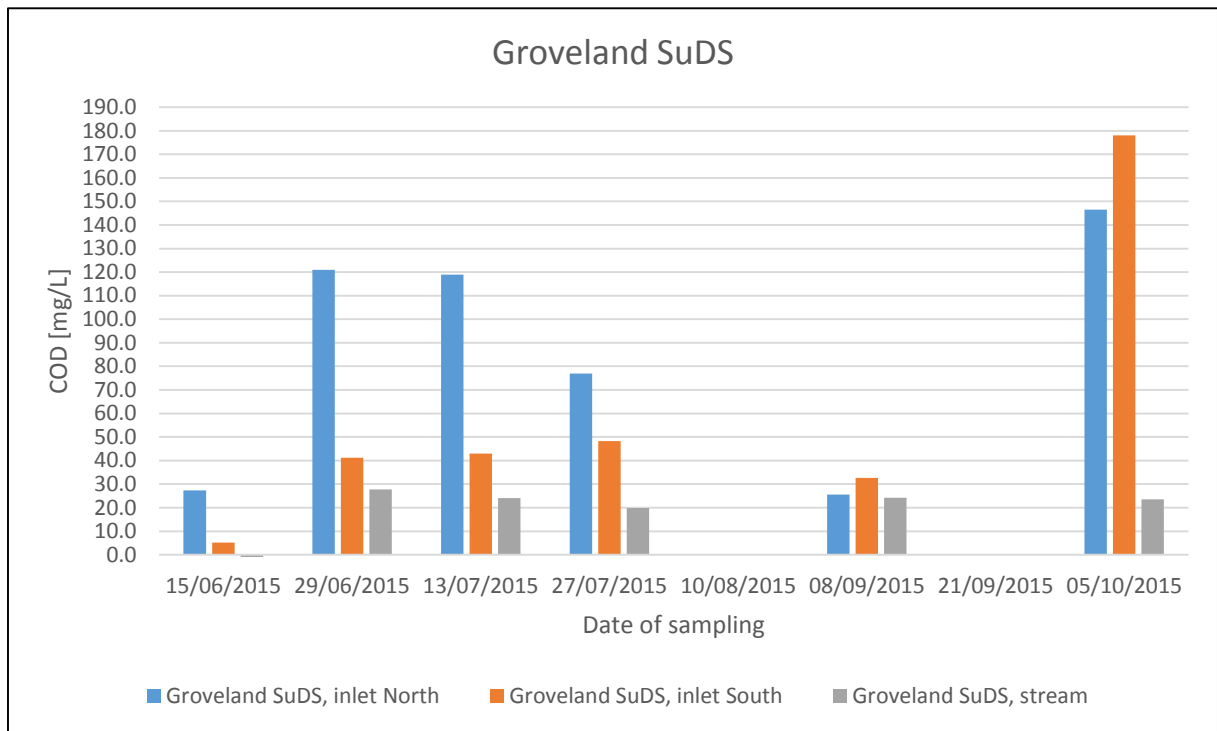
Figure 3-1 COD levels in Groveland SuDS

In terms of average Chemical Oxygen Demand, the north inlet results the most polluted (97.8 mg O_2 / L on average), while in terms of absolute values, the highest pollution was recorded on the 05/10/2015 coming out of the inlet south (178 mg / L). Table 3-1 shows the average an peak values for the COD levels in Groveland SuDS.

Table 3-1 Average and Peak values for COD in Groveland SuDS

Sampling point	Average [mg/l]	Peak [mg/l]
North Inlet	86.1	146.5
South Inlet	58.0	178.0
Stream	19.7	27.8

As expected, the COD concentrations are highly influenced by the weather condition. This is more evident in the 05/10 samples, which were collected during a storm event after a dry spell, therefore showing the typical "first flush" pollution spike.

The elimination efficiency can not be calculated, as no water is flowing outside the vegetated pond. Therefore, this site attained a "virtual" elimination efficiency of 100%, since no pollution coming into the SuDS is flowing out into the river.

3.2.2   Groveland Lake (new reed bed)
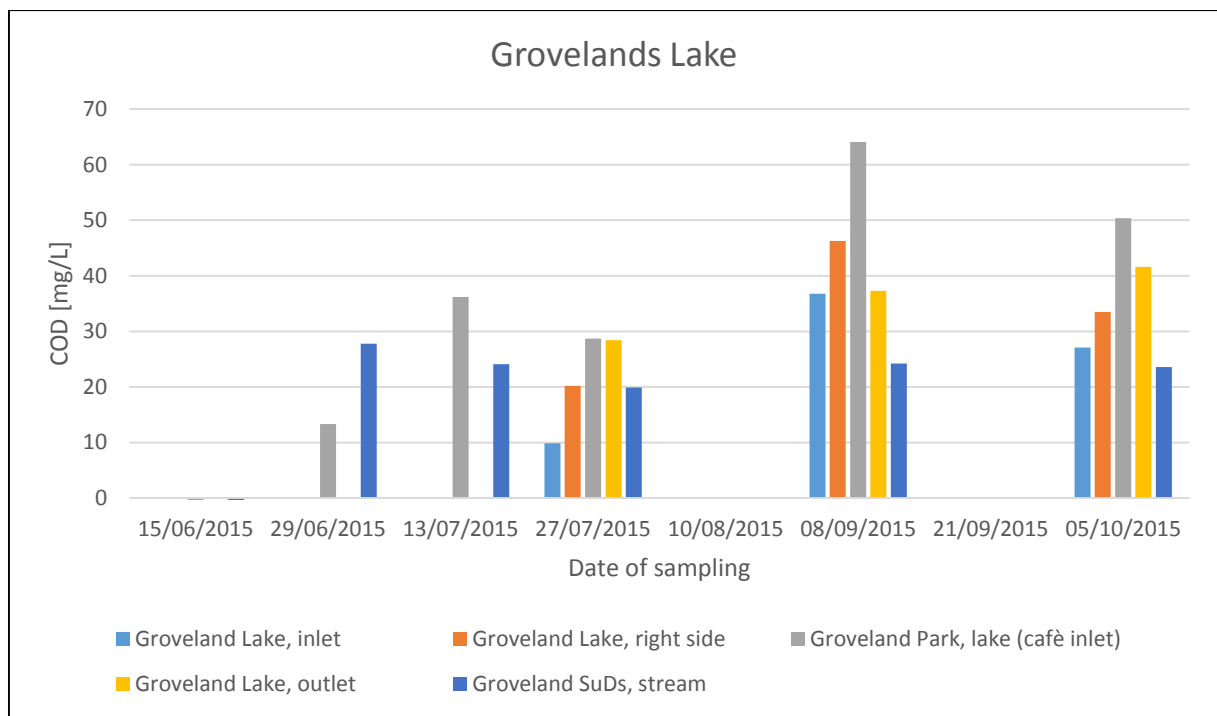
Figure 3-2 COD levels in Groveland Lake

A more in-depth sampling of the lake started only from the end of July 2015, after the construction of the new reed bed at the lake main inlet.

Starting from the main inlet (light blue column in fig. 3-2), an increase in the COD levels in time can be noticed. This might be a consequence of the new reed bed, which retains crescent levels of pollution, but since all the levels in the lake tend to rise in time it might also be just a consequence of the pollution coming into the system. Not enough data are available at the present time to give a definitive answer on this matter.

Rest assured that the highest levels of pollution come not from the main inlet but from the café inlet (grey column). This inlet collects water from the nearby café and from the street and houses located behind the park. Higher COD concentrations were detected in this inlet compared to the ones in the main inlet (see Table 3-2). The higher levels of COD measured

nearby this inlet are potentially attributed to the small distance between this structures and the lake.

Table 3-2 Average and Peak values for COD in Groveland Lake

Sampling point	Peak [mg/l]	Average [mg/l]
Main Inlet	36.8	24.6
Lake – Right side	46.3	33.3
Café Inlet	64.10	38.5
Lake - Outlet	41.6	35.8

The levels are lower than the ones coming out from the SuDS inlet (see previous chapter). Nonetheless, the café inlet should be one of the main priorities for upgrading the quality of the lake.

Finally, the stream effect was examined. Between the lake outlet (yellow column in fig. 3-2) and the SuDS outlet (dark blue column) there is a 400 m stream that runs through the park.

The COD concentration decreases between this two points in every sample examined, as shown in table 3-3. This can be explained with the natural COD elimination. The stream has various meanders and turns, as well as small waterfalls and steps just outside the lake. The stream bed is irregular, with rocks and wood logs that form riffles and turbulent zones. This of course helps improving the water quality along the stretch.

Table 3-3 Average COD reduction caused by "natural" effects

Sampling day	Lake outlet COD concentration [mg/l]	Stream near SuDS outlet COD concentration [mg/l]	Percentage reduction
27/07/2015	28.4	19.9	29.9 %
08/09/2015	37.3	24.2	35.1 %
05/10/2015	41.6	23.6	43.3 %
Total average	35.8	22.6	36.1 %

3.2.3   Glenbrook SuDS
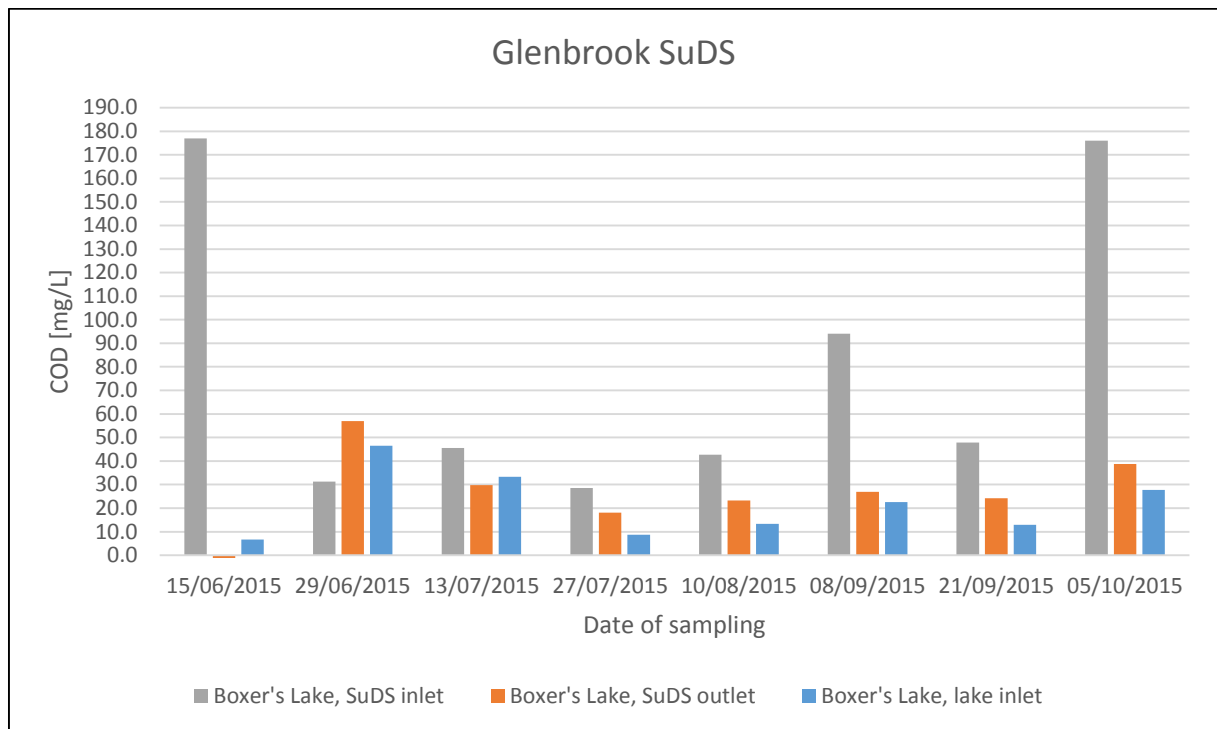
Figure 3-3 COD levels in Glenbrook SuDS

High levels of pollutants was observed for Glenbrook sampling area. The concentration of the target substances was the highest amongst all other points. In terms of COD, the average concentration coming into the system was 80.4 mg / L, as can be seen from table 3-4, while two peak level of about 177.0 mg / L were observed in the first and last sample. The 05/10 peak can be explained with a first flush pollution spike coming in, as seen in Groveland SuDS inlets. As for the 15/06 peak, no rain was registered during the sampling, and the flow was normal; the causes of this spike must have been an unusual discharge of organic matter from the area or from the houses around the inlet.

Generally speaking, the impact of the SuDS is beneficial. As shown in table 3-4, the COD levels are reduced between the inlet and the outlet in all but one occasion (29/06/2015). During that sampling the quality of the water at the outlet was poor, and the smell was stronger than usual both at the SuDS outlet and at the lake inlet, a few meters downstream. Hypothesis were made on a runoff plug or a pollution plume moving through the system exactly during the sampling, so that it was sampled only at the outlet but not at the inlet.

In the rest of the cases the SuDS helps visibly in reducing the COD levels in the stream, as can be seen from fig. 3-3. The highest reduction ratio achieved was measured during the 05/10 sample, with an 84.2 % decrease in COD. The other results are reported in the table below.

Table 3-4 Percentage COD reduction in Glenbrook SuDS

Sampling day	SuDS inlet	SuDS outlet	Percentage reduction
15/06/2015	177.0 mg O_2 / L	6.7 mg O_2 / L	96.2 %
29/06/2015	31.3 mg O_2 / L	57.0 mg O_2 / L	No reduction achieved
13/07/2015	45.5 mg O_2 / L	29.8 mg O_2 / L	34.5 %
27/07/2015	28.6 mg O_2 / L	18.1 mg O_2 / L	36.7 %
10/08/2015	42.7 mg O_2 / L	23.2 mg O_2 / L	45.7 %
08/09/2015	94.1 mg O_2 / L	26.9 mg O_2 / L	71.4 %
21/09/2015	47.9 mg O_2 / L	24.3 mg O_2 / L	49.4 %
05/10/2015	176.0 mg O_2 / L	38.7 mg O_2 / L	78.0 %
Total average	80.4 mg O_2 / L	31.1 mg O_2 / L	61.3 %

3.2.4 Intensive Glenbrook SuDS

The aim of the intensive sampling in Glenbrook is to get a deeper understanding on how each of the 6 sub-basins in this system work with respect to target parameters. Results for COD are shown below (figure 3-4).
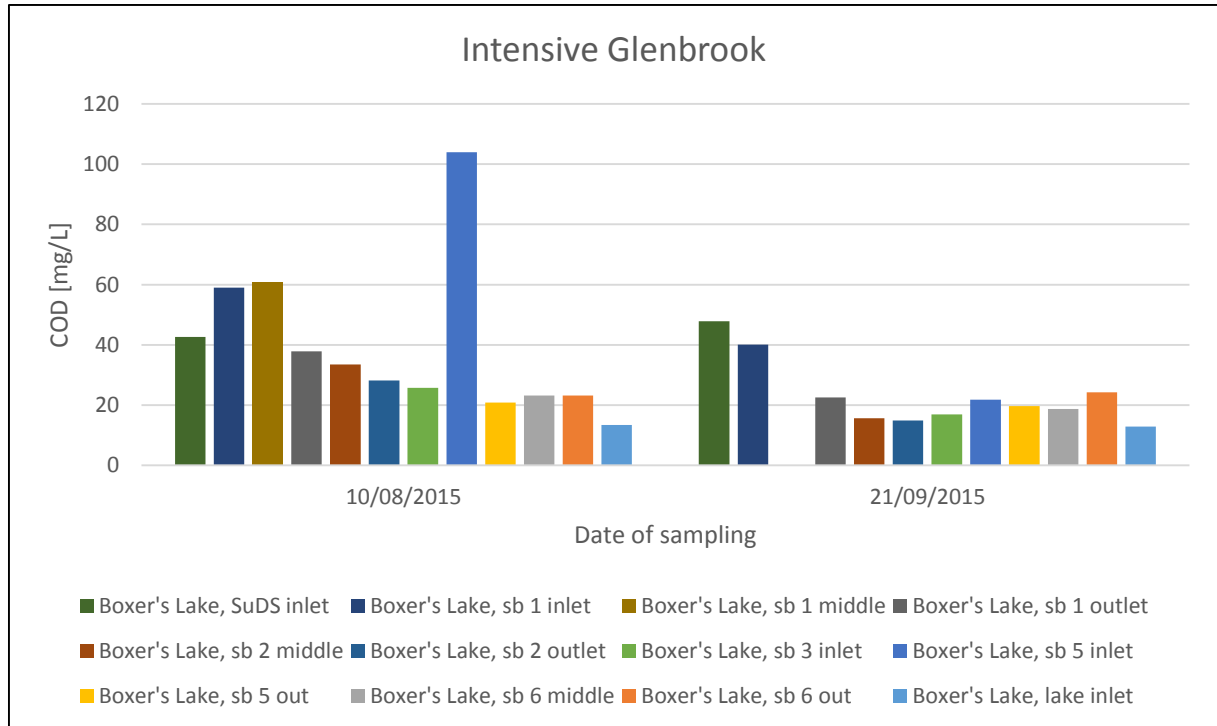
Figure 3-4 COD levels measured during intensive sampling in Glenbrook

The general trend in both graphs is a decreasing one, although not costant. The most "stressed" basin is the first one, which receives the highest levels of pollution.

Another pollution hot-spot is identified in the inflow of sub-basin 5. The dam that should deflect the flow from the "natural" course into the sub-basin 3 has been bypassed by the stream, and the water now runs straight below it. In figure 3-5 the Glenbrook SuDS scheme is presented; the original course of the stream in coloured in dark blue, while the light blue areas are the new wetlands. The red line is the weir bypassed by the stream, as can be seen in figure 3-6.
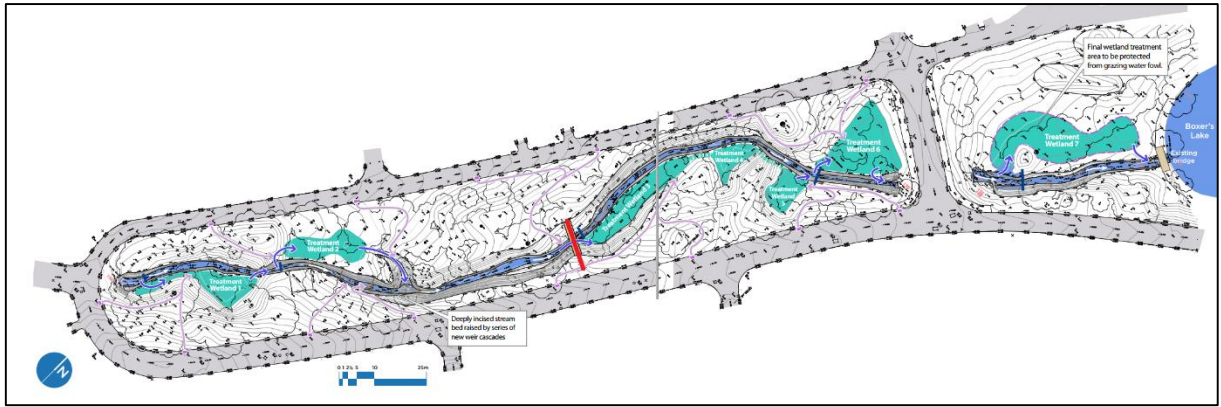
Figure 3-5 Glenbrook SuDS scheme (source: Thames21.com)

Figure 3-6 Weir bypass

Contractors have already been alerted of the issue, but as for now the sub-basins 3 and 4 are completely dry. This factor, together with the additional run-off that comes from the area around the stream, causes an increase of the pollution level inside the system. This is evidenced by the high COD level of 104 mg O_2 / L that was recorded going in sub-basin 5.

Despite this discontinuity in the system, sub-basin 5 present a significant COD reduction to around 20 mg / L.

In table 3-5 (below) the various levels at the inlet and at the outlet of every sub-basin are reported, as well as the percentage reduction.

Table 3-5 Percentage COD reduction in between sub-basins - Glenbrook SuDS

Sample point	10/08/2015		21/09/2015	
	COD concentration	Percentage Reduction	COD concentration	Percentage Reduction
Sub-basin 1 inlet	59 mg / L	35.8 %	40 mg / L	43.6 %
Sub-basin 1 outlet	37.9 mg / L		22.6 mg / L	
Sub-basin 2 inlet	37.9 mg / L	25.6 %	22.6 mg / L	33.8 %
Sub-basin 2 outlet	28.2 mg / L		15.0 mg / L	
Sub-basin 5 inlet	104 mg / L	79.9 %	21.9 mg / L	9.6 %
Sub-basin 5 outlet	20.9 mg / L		19.8 mg / L	
Sub-basin 6 inlet	20.9 mg / L	(increase)	19.8 mg / L	(increase)
Sub-basin 6 outlet	23.2 mg / L		20.3 mg / L	

During both intensive samplings a slight increase in the COD concentration has been recorded before and after sub-basin 6, even though not big enough to be considered an issue. Simply, the last wetland doesn't affect anymore the COD removal of the system.

3.2.5 Conclusion on the performance of SuDS on the organic content removal

The systems perform well in terms of COD removal. Groveland SuDS is able to stop all the pollution coming from the two inlets, mainly because of the outlet weir design. It will be interesting to sample water coming from the outlet during high flow conditions, when the water will flow out of the system and into the stream.

Glenbrook SuDS achieved 61.3 % average COD reduction during the sampling period. Since there are no permit limits for the discharge at Boxers Lake, this reduction cannot be compared to the law, but surely it is a big help in improving Boxer's Lake water quality.

The main problems in these two systems are the café inlet in Groveland Lake, that brings high levels of organic pollution into the lake, and the sub-basin 3 and 4 in Glenbrook SuDS that are totally bypassed, causing high levels of pollution coming into sub-basin 5.

A brief literature review has been done to compare the results of this work with other studies and papers.

Roinas et al. (2014) reported "significant removal" of COD in the case study of a pond in Hampshire, UK, with a median COD reduction of 62%.

Schmitt et al. (2015) observed an high COD removal (70-98%) in a wetland collecting stormwater from and urban residential watershed.

Finally, Zheng et al. (2014) studied a series of large wetland constructed near the confluence of an urban stream to a larger river in China, for treating the stream pollution before it enters the river. Regarding the COD, it was observed a removal of 72.7% ± 4.5%.

The performances of the case studies presented in this work are therefore in line, or slightly below the ones found in literature; this can be attributed partially to the low concentration coming into the systems that affects the removal, and partially to the "young age" of the SuDS, that are still in their start-up period.

3.3 NUTRIENTS

Phosphorus and nitrogen are the main nutrients encouraging the growth of organic matter and algae, which cause eutrophication in water bodies.

When possible, the removal ratio obtained in the SuDS is compared with the WFD limits or the local discharge limits.

The main removal mechanisms observed in SuDS with regards to nutrients are sedimentation, biodegradation and precipitation. Bacteria in the ground or in the plant roots play a crucial role in oxidising more complex forms such as ammonia and ammonium ions to form nitrate, which is readily used as nutrients by plants, and therefore not discharged into the river where it can lead to uncontrolled eutrophication.

3.3.1 Groveland SuDS

In figure 3-7 the nitrate results for the SuDS in Groveland Park are presented.

Samplings on the 10/08 and 21/09 were not performed since the intensive sampling in Glenbrook took place in those days.
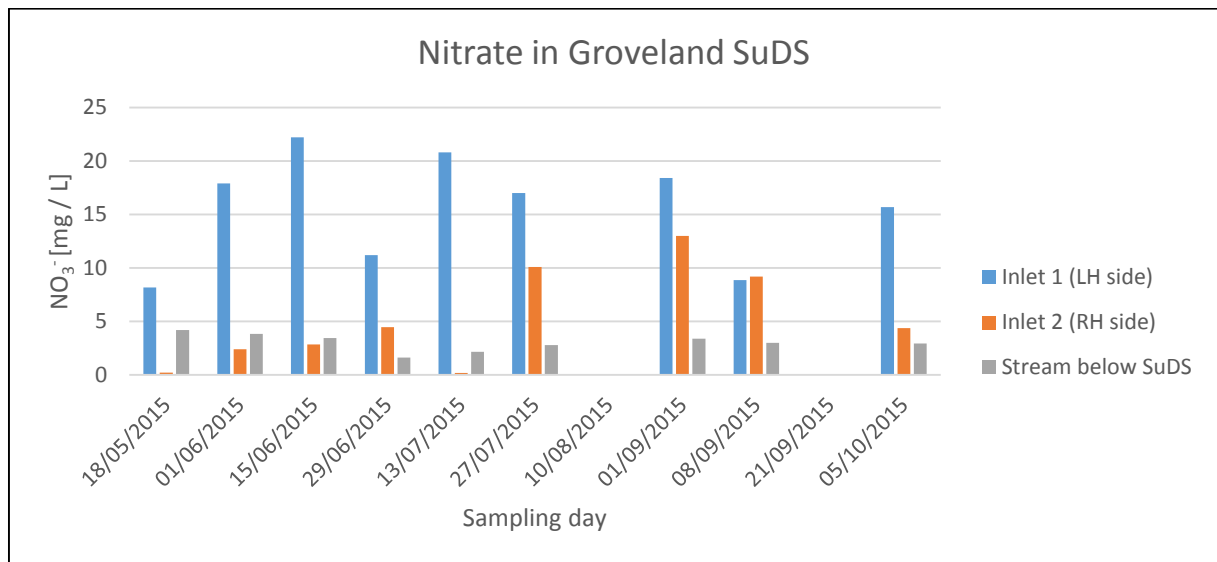

Figure 3-7 Nitrate in Groveland SuDS

Nitrate is one of the parameter listed in the Water Framework Directive (2000/60/EC) classification for assessing the river water quality. The standards used are shown in the table 3-6 below

Table 3-6 WFD classification scale for Nitrate

Parameter	Values and Classification					
Nitrate [mg/L]	5 Very Low	10 Low	20 Moderate	30 High	40 Very High	>40 Excessively High

The colours used are the same used in the Directive, going from blue (best quality) to dark red (worst quality).

As can be noticed from fig. 3-7, the nitrates concentration in the water samples are between "very low" (≤ 5 mg/L) and "high" (21 – 30 mg/L) conditions. The stream itself has a nitrate concentration that stays always under the 5 mg/L threshold. Comparing the two inlets, higher concentrations are observed in the first one, with levels in the "moderate" (11-20 mg/L) range, and in some case even higher values are observed. The second inlet is characterized by lower concentrations that increase during the summer (from the end of July to the beginning of September) from the "very low" range into the "moderate" range.

As said for the COD analysis, the elimination efficiency for this particular case study can not be calculated, as no water is flowing outside the vegetated pond.

In table 3-7 the minimum, maximum and average nitrate concentration are reported

Table 3-7 Nitrate in Groveland SuDS

Sampling point	Min	Max	Average
Inlet 1 (LH side)	8.17 mg/l	22.2 mg/l	15.58 mg/l
Inlet 2 (LH side)	0.19 mg/l	13.00 mg/l	6.31 mg/l
Stream below SuDS	1.63 mg/l	4.18 mg/l	3.07 mg/l

In figure 3-8 are presented the results for ammonia concentration in Groveland SuDS
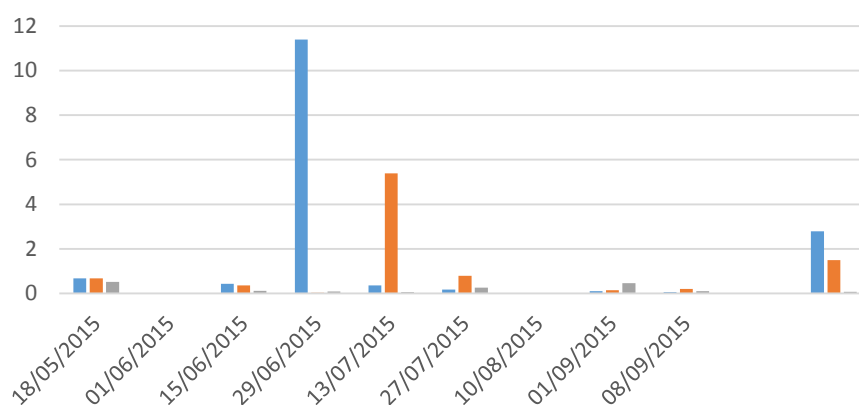
Figure 3-8 Ammonia in Groveland SuDS

In the case of NH_3, the Water Framework Directive sets limits based on annual average. The time period considered in this study is therefore too short to compare the data presented with the WFD limits.

Consequently, it was decided to compare the data presented in fig. 3-6 with the NH_3 in the treated effluent of the Deephams Sewage treatment works (NH_3: 4 mg/l), a nearby plant that discharges to Salmons Brook.

Comparing this with the data available, it was found that the values in two out of the eight samples collected from the inlet were above 4 mg/l, once for each inlet. The inlet 1 reached a value of 11.4 mg NH_3/L, almost 3 times above the maximum permitted. The inlet 2 reached a value a bit lower, 5.39 mg NH_3/L.

The average ammonia concentration in the stream was 0.18 mg NH_3/L; however, as said before this value cannot be compared to existing WFD standards, as the time period sampled was too short.

The results for ammonia are resumed in table 3-8
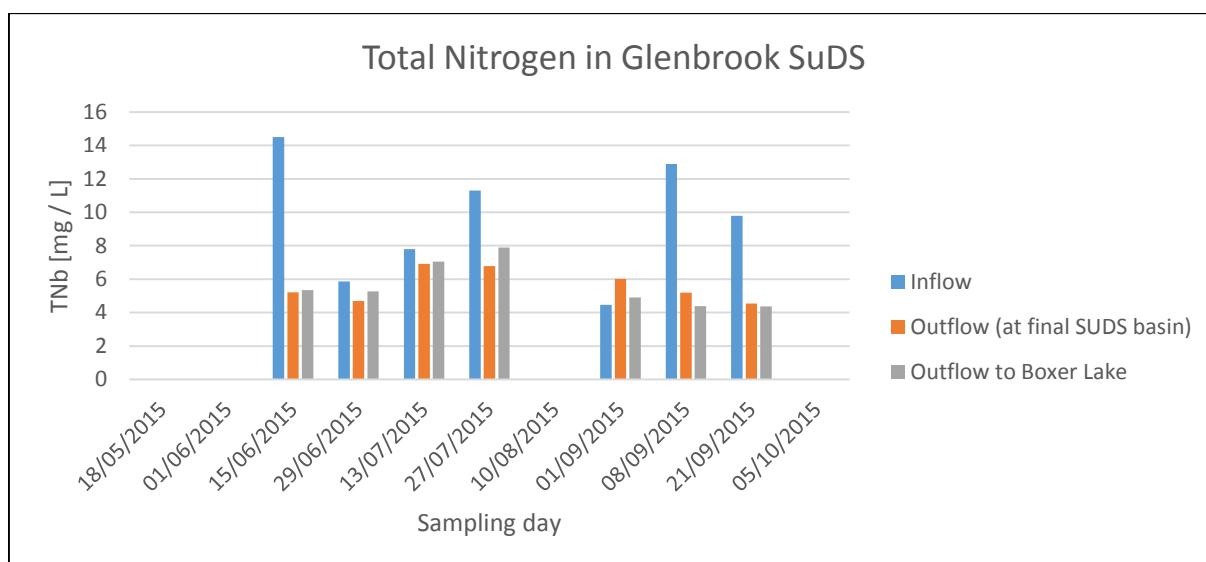
Figure 3-17 Total Nitrogen in Glenbrook SuDS

Table 3-22 resumes the results for the total nitrogen concentration in Groveland SuDS

Table 3-22 TNb in Groveland SuDS

Sampling point	Min	Max	Average
Inlet	4.47 mg/l	14.5 mg/l	9.52 mg/l
SuDS Outflow	4.55 mg/l	6.91 mg/l	5.62 mg/l
Boxer Lake Inflow	4.37 mg/l	7.89 mg/l	5.60 mg/l

As was observed for the nitrate, the system is performing well, with a Total Nitrogen average removal of 40.9 % and a maximum reduction of 64%. Again, the initial concentration plays a key role in the removal efficiency; the higher the total nitrogen concentration coming into the system, the higher the removal obtained at the outflow.

Figure 3-18 shows the levels of Total Phopshate registered in Glenbrook SuDS
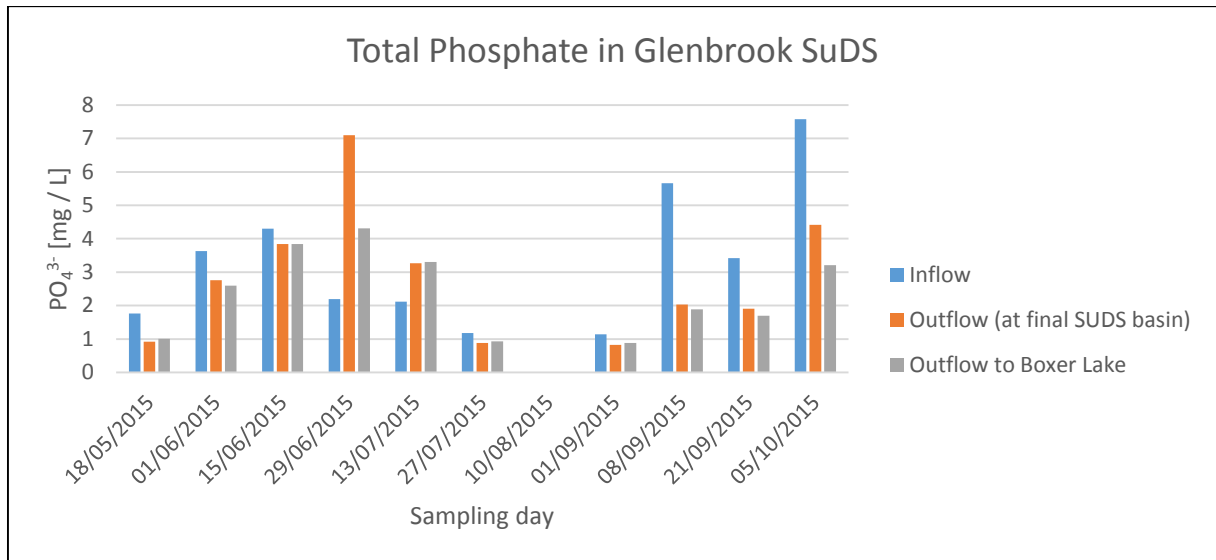
Figure 3-18 Total Phosphate in Glenbrook SuDS

Table 3-23 resumes the results for the total phosphate concentration in Groveland SuDS

Table 3-23 Total Phosphate values in Glenbrook SuDS

Sampling point	Min	Max	Average
Inlet	1.14 mg/l	7.58 mg/l	3.30 mg/l
SuDS Outflow	0.83 mg/l	7.10 mg/l	2.79 mg/l
Boxer Lake Inflow	0.88 mg/l	4.31 mg/l	2.37 mg/l

The phosphate removal is working not as good as the other nutrients, since the average removal is only 15.2%, and the peak reduction is 64.1%. This is in line with what has been registered in the other case studies.

The phosphate concentration at the outflow of the system is comparable to the one found in Groveland Lake, and its average is still in the "poor" range with regards to the WFD standards (table 3-24 below).

Table 3-24 Type-specific total phosphorus standards for freshwater and brackish lakes

Type	Annual mean concentration of total phosphorus (µg/l)			
Column 1	Column 2	Column 3	Column 4	Column 5
Geological and depth category	High	Good	Moderate	Poor
High alkalinity; shallow - Region 1	16	23	46	92
High alkalinity; shallow-Region 2	25	35	70	140
High alkalinity; very shallow – Region 1	23	31	62	124
High alkalinity; very shallow - Region 2	35	49	98	196
Moderate alkalinity; deep	8	12	24	48
Moderate alkalinity; shallow	11	16	32	64
Moderate alkalinity; very shallow	15	22	44	88
Low alkalinity; deep	5	8	16	32
Low alkalinity; shallow	7	10	20	40
Low alkalinity; very shallow	9	14	28	556
Marl; shallow	9	20	40	80
Marl; very shallow	10	24	48	96

Again, it should be noted that the class highlighted is just an hypothesis that might be prone to errors, and that the standards are presented in terms of annual mean.

3.3.4 Intensive Glenbrook SuDS

In this chapter, the results for the two intensive samplings done in Glenbrook SuDS are reported (fig. 3-19 and 3-20).

All the nutrients are arranged in the same graph, in order to get a better understanding of the general nutrient trend between each sub-basin.

Like the previous analysis, the target markers are Nitrate, Ammonia, Total Nitrogen and Total Phosphate.
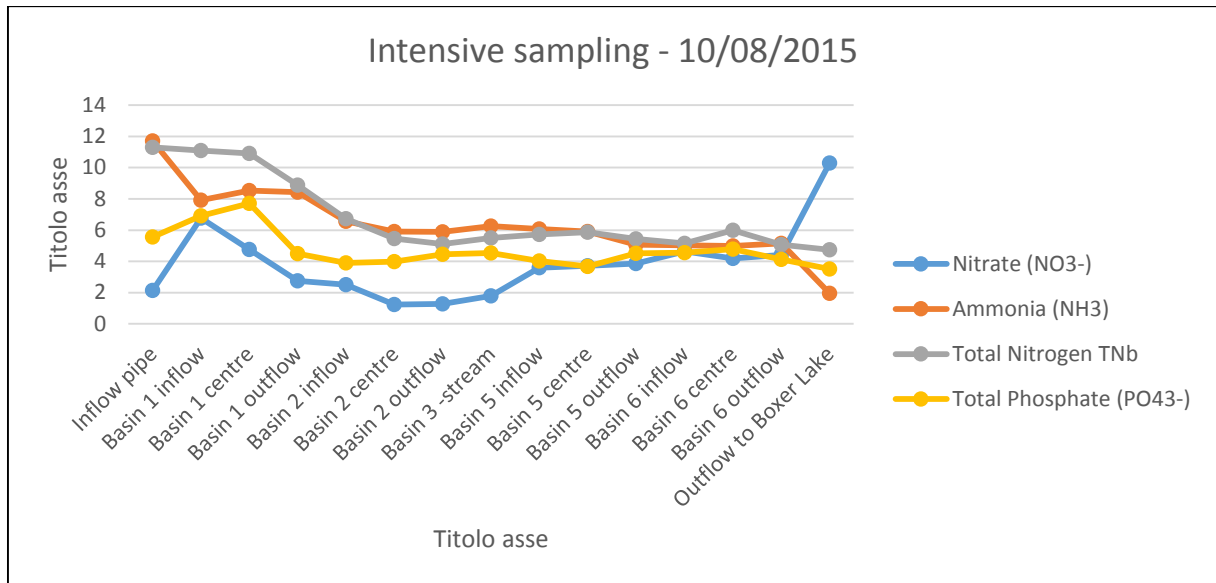
Figure 3-19 Glenbrook SuDS intensive sampling - 10/08/2015
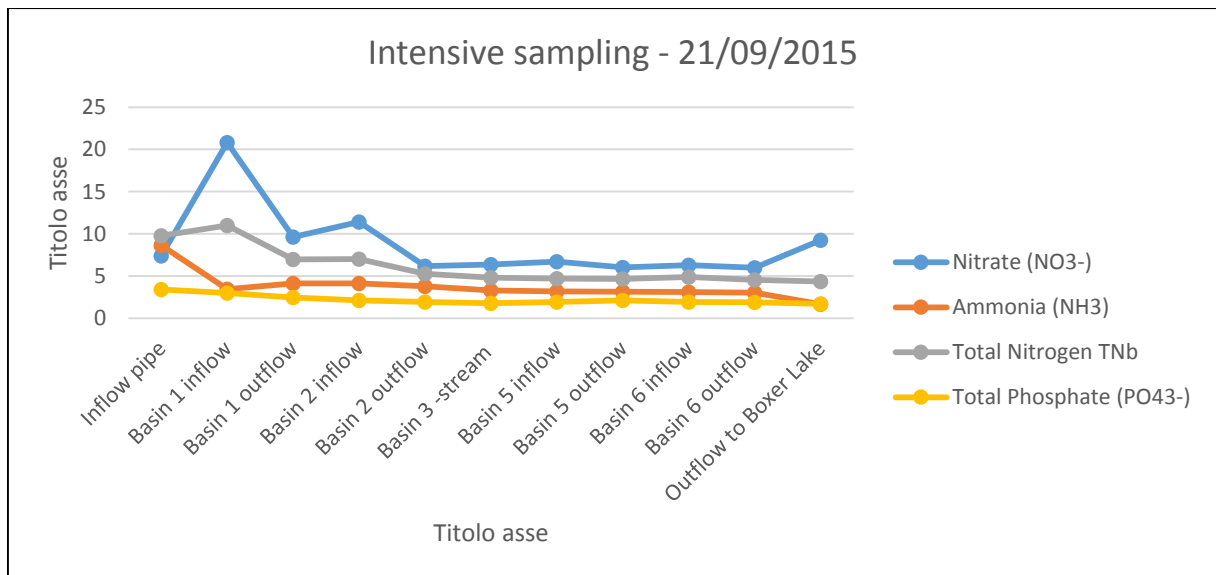
Figure 3-20 Glenbrook SuDS intensive sampling - 21/09/2015

In both of the intensive sampling campaigns an increase in the nitrate level in the stretch from the inflow pipe to the the first sub-basin inflow has been recorded. A smaller increase was observed between the sub-basin 1 outflow and the sub-basin 2 inflow. Finally, the nitrate concentration rise again at the end of the system, between the SuDS outflow and the lake inlet. During the 10/08 sampling another increase in correspondence with the basin 4 bypass has been recorded.

The ammonia has in both cases a steep decrease between the inflow pipe and the first sub-basin, and then a constant, almost linear decrease.

The Total Nitrogen has a decreasing trend between the ammonium and the nitrate.

The phosphate has shown two different trends during the two samplings. During the first one it had an increase between the inflow pipe and the first sub-basin, followed by a steep decrease at the sub-basin 1 outflow, and a more or less constant level up until the end of the system. During the second sampling, it showed a constant and slow decrease from the top to the bottom until the lake inflow.

3.3.5   Conclusion

Both systems are receiving a huge load of nutrients, once more time proving the fact that the water coming in is not just road runoff but it has even pollution coming from misconnected household appliances.

The SuDS are working quite well, with the exception of the total phosphate levels that are harder to reduce.

The new reed bed in Groveland Lake has proved useful in reducing the nitrogen levels in the lake ecosystem to more acceptable values.

With regards to Glenbrook SuDS and Boxer's Lake, the biggest problems here might come from the bypass of sub-basin 4 in Glenbrook SuDS and from the stretch between the SuDS outflow and the lake inlet, that are worsening the quality of the water that pass through the system.

In table 3-25 the result for the nutrients markers are reported, with the minimum, maximum and average concentration for each sampling point (intensive sampling not included).

Table 3-25 Nutrients summary table

Sampling point	NO_3^- average concentration (min – max) [mg/l]	NH_3 average concentration (min – max) [mg/l]	TN_b average concentration (min – max) [mg/l]	PO_4^{3-} average concentration (min – max) [mg/l]
Groveland SuDS - Inlet 1	15.58 (8.17 – 22.2)	6.25 (0.01 – 11.40)	7.09 (2.96 – 14.2)	1.72 (0.27 – 3.73)
Groveland SuDS - Inlet 2	6.31 (0.19 – 13.00)	1.15 (1.50 – 0.01)	5.02 (2.25 – 7.75)	1.49 (0.45 – 3.23)
Groveland SuDS - Stream below outflow	3.07 (1.63 – 4.18)	0.18 (0.51 – 0.09)	2.39 (1.66 – 3.06)	2.37 (1.62 – 3.90)
Groveland Lake - Main Inflow	13.76 (9.04 – 18.20)	2.19 (0.63 – 6.33)	5.28 (2.96 – 10.80)	2.67 (1.19 – 3.75)
Groveland Lake - Sampling point B	3.23 (1.61 – 6.31)	0.50 (0.02 – 0.99)	3.49 (1.83 – 6.03)	2.68 (1.72 – 4.07)
Groveland Lake - Café inlet	16.92 (13.00 – 23.1)	0.61 (0.12 – 1.00)	3.51 ($\leq$0.01 – 8.84)	1.84 (0.15 – 3.86)
Groveland Lake - Lake outflow	5.05 ($\leq$0.01 – 7.95)	0.21 ($\leq$0.01 – 0.92)	2.75 (2.05 – 6.10)	2.81 (0.71 – 4.34)
Glenbrook SuDS - Inflow	11.72 (1.50 – 21.10)	4.44 ($\leq$0.01 – 15.90)	9.52 (4.47 – 14.50)	3.30 (1.14 – 7.58)
Glenbrook SuDS - Outflow	7.92 (2.60 – 20.20)	2.43 (0.02 – 4.53)	5.62 (4.55 – 6.91)	2.79 (0.83 – 7.10)
Glenbrook SuDS – Boxer Lake inflow	10.35 (4.86 – 19.30)	2.54 ($\leq$0.01 – 10.90)	5.60 (4.37 – 7.89)	2.37 (0.88 – 4.31)

A brief literature review has been done to compare the results of this work with other studies and papers.

Perales-Momparler et al. (2013) compared the performances of three different kind of SuDS during their start-up period and, regarding nutrients, found out that the concentration increased before and after the SuDS. Total nitrogen increased by a factor of nine, and total phosphorus by a factor of 15 after the vegetated layer. However, when the vegetation matures, this results are expected to be better (Perales-Momparler et al., 2013).

Lucke et al. (2014) tested four different field swales to evaluate their performance in removing target pollutants from stormwater runoff. With regards to nutrients, the study found no reduction in TN concentrations due to treatment by the swales. However, it did demonstrate a reduction in measured TP levels of between 20% and 23% between the inlet and the outlet.

Mason et al. (1999) investigated the behaviour of various pollutants during percolation of roof runoff through an infiltration site. In their results, orthophosphate behaved essentially conservatively during infiltration, whereas NH4+ concentration decreased probably as a consequence of nitrification.

The case studies investigated in this work are therefore in line with what can be found in literature; the nitrogen compounds are generally easier to remove, while phosphorus presents more difficulties. Moreover, since the time period studied was during the start up period of the SuDS, a lower removal efficiency was expected. The situation might change when the vegetation matures.

3.4 HEAVY METALS

The heavy metals content in all of the case studies is much lower than the expectation. This can be seen as an additional proof of the presence of misconnections, since "pure" urban runoff should contain engine sub-products.

On almost 400 test ran during the sampling period on 4 different metals (Cadmium, Lead, Zinc and Copper) only 43 were above the detection limits. Copper is the most common, originating from the older pipework. Zinc is the second most common element found, coming probably from tire wear.

The complete testing results are included in the Appendix.

Because of this low concentrations entering the systems, the effect of the SuDS on the heavy metals levels cannot be evaluated. Nonetheless, a literature review on the specific topic showed that SuDS are able to affect the heavy metal concentration in the entering water. The main removal mechanisms are sedimentation, adsorption in the soil, filtration and precipitation (Wilson et al., 2004). Accumulation in vegetation is another possible removal mechanism, but its impact is virtually negligible and found to account for only between 0.5 and 3.3% of the retention (Quinn et al., 2013). Napier et al. (2008) observed the behaviour of traffic-related pollutant in two detention basins serving a motorway in Scotland, and calculated a retention percentage of Zinc and Copper of 99.69% and 99.55%, respectively. Bressy et al., (2012) demonstrated that SuDS can attain a reduction of the Zinc concentration varying between 72 and 80%, depending on the incoming concentration and SuDS characteristics. Many papers agree that the first 10 cm of soil are the most important with regards to heavy metal adsorption and sedimentation (Napier et al., 2008; Quinn et al., 2013) and that the percolation of these pollutants through the soil is really slow. Finally, Roinas et al., (2014) observed a Copper and Zinc removal ration of around 70%

3.5 TPH

As explained in Chapter 2.7, a new methodology for analysing Total Petroleum Hydrocarbons both in water and in sediment samples has been set up. The detection limits achieved with this methodology is 250 ppm in weight.

TPH concentration for all the collected samples (5 months sampling campaign) was below the detection limit of this methodology

The main problem faced in the process to increase the precision of this method was the solvent used, that was not transparent to infrared when used in combination with the 40 mm cell, absorbing almost 100% of the incoming radiation just by itself.

Consequently, in order to lower again the detection limits, it was decided to try with a new solvent specifically made for use with FTIR machines. This new solvent was not delivered at Brunel University lab in time to be used in this work, but will be surely of help in continuing this study in future.

As for now, what can be said about TPH in the systems analysed is that the concentration is lower than 250 μg / g (of soil or water), which by itself is an interesting fact. It means that the bulk of the pollution that is flowing into the SuDS comes mainly from misconnections and not from the "normal" road run-off.

The main TPH removal mechanisms in SuDS are sedimentation, filtration and adsorption in the soil (Wilson et al., 2004). The first two are especially impactful, since TPHs easily attach themselves to sediment particles, and therefore removal of sediments and filtration through plants result in a significant reduction in pollutant loads.

Similar studies have highlighted how difficult is to evaluate SuDS effect on TPH. Andres-Valeri et al. (2014) reported very low TPH values at the experimental site due to a light traffic flow (such as the one in the case studies presented here), with some of their results falling below the detection limit of 0.1mg/l. However, comparing two different kind of SuDS, significant differences were found between a filter drain (higher removal) and a swale (lower removal).

Bressy et al. (2014) observed a PAH removal of 60 – 70% in four case studies (depending on the type: green roof, swale, detention pond) in a residential area, characterized by low-density traffic and no industrial activity. The PAH concentration registered in sediment varied between 0.33 and 1.1 μg/g.

Napier et al. (2008) observed a TPH removal >90% in two systems collecting stormwater from a Scottish highway, and therefore with much higher pollutant concentration than the ones reported in this study.

Roinas et al. (2014) compared the effluent and influent of two vegetated detention ponds receiving runoff from the M27, a major motorway in Hampshire, UK, and a system of two detention basins connected by swales in a residential development. In the case of the motorway, the ponds influenced the TPH levels registered only during spikes events, when the ponds reduced the pollution coming in by 58 and 67%, respectively. In the residential development, no clear pattern of TPHs were found.

4 CONCLUSION

The aim of this project was to evaluate the efficiency of two Sustainable Drainage Systems located in the Salmons Brook catchment, London. This two systems are part of a bigger project called the Salmons Brook Healthy River Challenge

East London's rivers are some of the most polluted in Britain, and to deal with this issue Thames21, an environmental charity working with communities to improve London's rivers and canals, has launched the Love the Lea Campaign, in which the Salmons Brook Healthy River Challenge plays a major role.

The Challenge aims to improve the water quality in the Salmons Brook Catchment using Sustainable Drainage Systems (SuDS). Three community scales SuDS have currently been created as part of the Salmons Brook Healthy River Challenge.

The SuDS should act as a buffer and stop the pollution collected from the separate sewage system from entering the river; what actually happens is that a lot of houses in the catchment are misconnected, and discharge their black and grey waters into the stormwaters drains. This causes a higher and different load of pollutants in the water coming into the systems, raising the need for a constant monitoring to see how the SuDS affect this kind of pollution.

The evaluation has been done by monitoring specific target parameters, chosen after a literature review for their ability to act as markers of different type of contamination.

The target markers are nutrients (Nitrate, Ammonia, Total Nitrogen and Total Phosphate), COD and Total Coliform, as markers of misconnections, and Total Petroleum Hydrocarbons (TPH) and Heavy Metals (Cadmium, Lead, Zinc and Copper), as markers of diffuse pollution and urban runoff. Other parameters, such as Dissolved Oxygen, Electrical Conductivity and pH, are monitored to gain a better understanding on the general biological conditions of the river.

A particular focus is put on the TPH analysis, which are performed both on soil and on water samples. While in the case of the water samples a standard methodology was used, for the soil samples a new methodology was set up. The purpose was to set up a quick and reliable methods for the TPH determination, in order to use it as a preliminary screening tool after which, if deemed necessary, in depth analysis can be performed.

The TPH determination method set up in this Thesis is therefore a simple, expeditious and economic tool based on IR spectrophotometry analysis combined with US extraction. Moreover, tetrachloroethylene (C_2Cl_4) was used as solvent for TPH extraction from the samples, since after a bibliographic analysis it showed environmental advantages on the other solvents commonly used (cheaper, less toxic, less quantity used per sample, no depletion of the ozone layer). Indeed, only three studies (Nascimento et al., 2008; Idodo-Umeh and Ogbeibu, 2010, Couto et al., 2014) that reported the use of C_2Cl_4 for TPH extraction were found, and only in one (Couto et al., 214) it was used in conjunction with IR spectrophotometry and US extraction.

The TPH analysis performed with the standard (water samples) and new methodology (soil samples) showed no TPH concentration above the detection limit of 250 µg/g. This is in line with what has been found in the literature, since the area around the SuDS studied is a residential zone with low traffic flow. A more specific solvent has been ordered by Brunel University Institute for Environment laboratory, and the improving of the detection limits of this new method might be object for future studies.

The systems perform well in term of organic content removal (Chapter 3.2), in line with similar cases presented in literature. The average COD reduction in Glenbrook SuDS during the 5-months sampling period was 61.3%.

In terms of nutrients removal (Chapter 3.3), both systems are receiving a huge load of nutrients, once more time proving the fact that the water coming in is not just road runoff but it has even pollution coming from misconnected household appliances (this fact is also confirmed by the Total Coliform analysis). The SuDS are reducing the nitrogen compounds by 40-50% (depending on the specific compound) while the phosphorus proves harder to remove. The results are in line with what can be found in literature (Perales-Momparler et al.,2013, Lucke et al., 2014, Mason et al., 1999); the nitrogen compounds are generally easier to remove, while phosphorus presents more difficulties.

Concluding, the Sustainable Drainage Systems studied in this Thesis are working quite well in terms of target pollutants removal, preventing the pollution from going into the lakes and stream of the Salmons Brook. Moreover, since this study took place during the start up period of the SuDS, a lower removal efficiency was expected. The efficiency might therefore increase in the future, when the vegetation matures.

5 REFERENCES

Andrés-Valeri, V.C., Castro-Fresno, D., Saudo-Fontaneda, L.A., and Rodriguez-Hernandez, J., 2014. *Comparative analysis of the outflow water quality of two sustainable linear drainage systems. Water Sci. Technol., 70(8), p. 1341-1347.*

Arnold Jr., C.A. and Gibbons, C.J., 1996. *Impervious surface coverage: the emergence of a key urban environmental indicator. Journal of the American Planning Association, 62(2), p. 243–258.*

Breedveld, G.D., Olstad, G., and Aagaard, P., 1997. *Treatment of Jet Fuel-Contaminated Runoff Water by Subsurface Infiltration. Bioremediation J., 1, p. 77-88.*

Bressy, A., Gromaire M.C., Lorgeoux, C., Saad, M., Leroy, F., Chebbo, G., 2014, *Efficiency of source control systems for reducing runoff pollutant loads: Feedback on experimental catchments within Paris conurbation, Water Research 57 (2014) 234 - 246*

Briers R.A., 2014. *Invertebrate Communities and Environmental Conditions in a Series of Urban Drainage Ponds in Eastern Scotland: Implications for Biodiversity and Conservation Value of SUDS. Clean – Soil, Air, Water 2014, 42 (2), 193 – 200.*

Brown, E.D., Caraco, D., and Pitt, R., 2004. *Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments. Center for Watershed Protection. Report EPA X-82907801-0. Ellicott City, Maryland, US.*

Brozozowski, C., 2004. *Illicit discharge detection and elimination. Stormwater Journ. Centre for Watershed Protection (CWP), Ellicott City, Maryland, US (March/April, 2004).*

Council of the european communities *Council directive of 21 May 1991 concerning urban watewater treatment 91/271/EEC*

Couto, M. N. P. F., Pinto, D., Basto, M. C. P., and Vasconcelos, M. T. S. D. (2012). *Role of natural attenuation, phytoremediation and hybrid technologies in the remediation of a refinery soil with old/recent petroleum hydrocartbons contamination. Environ. Technol. 33: 2097–2104.*

Couto, M. N., Borges, J. R.,. Guedes, P., Almeida, R., Monteiro, E., Almeida, C. M. R., Basto, M. C. P. & Vasconcelos, M. T. S. D., 2014, *An Improved Method for the Determination of Petroleum Hydrocarbons From Soil Using a Simple Ultrasonic Extraction and Fourier Transform Infrared Spectrophotometry*

Daghbouche, Y., Garrigues, S., Morales-Rubio, A., and de la Guardia, M. (1997). *Evaluation of extraction alternatives for Fourier transform infrared spectrometric determination of oil and greases in water. Anal. Chim. Acta 345:161–171.*

Davies, G. R., 2011. *A water quality analysis of the River Lee and major tributaries within the perimeter of the M25, from Waltham Abbey to Bow Locks*

Davis A. P, Shakouhian M, and Ni S. (2001). *Loading estimates of lead, cadmium, and zinc in urban runoff from specific sources. Chemosphere, 44, 997 – 1009.*

Davis, A., Shokouhian, Sharma, H., Minami, C., 2001, *Laboratory Study of Biological Retention for Urban Stormwater Management, Water Environ. Res. 2001, 73 (1), 5 – 14.*

Defra, 2011. *National standards for sustainable drainage systems - designing, constructing, operating and maintaining drainage for surface runoff.*

Defra., 2006. *Improved air quality can extend life expectancy. Defra News Release.*

Defra., 2012. *Tackling Water Pollution from the Urban Environment. Dept. of Environment & Food & Rural Affairs Consultation Report. London.*

Dickie, S., McKay, G., Ions, L., and Shaffer, P., 2010. *Planning for SUDS – making it happen. CIRIA. C687. London.*

Ellis, J.B. and Butler, D., 2015. *Surface water sewer misconnections in England and Wales: Pollution sources and impacts. Science of the Total Environment 526, p. 98–109.*

European Commission, *4th WFD Implementation report,* 2015

European Commission, *Proposal for a directive of the european parliament and of the council amending directives 2000/60/ec and 2008/105/ec as regards priority substances in the field of water policy (COM(2011) 876), 2011*

Farmaki, E., Kaloudis, T., Dimitrou, K., Thanasoulias, N., Kousouris, L., and Tzoumerkas, F. (2007). *Validation of a FT-IR method for the determination of oils and grease in water using tetrachloroethylene as the extraction solvent.*

Fletcher, T. D., Shuster, W., Hunt, W.F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J., Mikkelsen, P.S., Rivard, G., Uhl, M., Dagenais, D. Viklander, M., 2015, *SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage, Urban Water Journal, 12:7, 525-542*

Gallego, J. R., Gonz´alez-Rojas, E., Pel´aez, A. I., S´anchez, J., Garc´ıa-Mart´ınez, M. J., Ortiz, J. E., Torres, T., and Llamas, J. F. (2006). *Natural attenuation and bioremediation of Prestige fuel oil along the Atlantic coast of Galicia (Spain). Org. Geochem. 37:1869–1884.*

Gnecco, I., Berretta, C., Lanza, L.G., and La Barbera, P., 2005. *Storm water pollution in the urban environment of Genoa, Italy, in 6th International Workshop on Precipitation in Urban Areas. Genoa, Italy*

Göbel, P., Dierkes, C., and Coldewey, W.G., 2007. *Storm water runoff concentration matrix for urban areas. Journal of Contaminant Hydrology, 91, p. 26–42*

Heal, K., McLean, N., and D'Arcy, B., 2004. *SUDS and sustainability. in 26th Meeting of Standing Conference on Stormwater Source Control. Dunfermline*

Idodo-Umeh, G., and Ogbeibu, A. E. (2010). *Bioaccumultaion by the heavy metals in Cassava tubers and plantain fruits grown in soils impacted with petroleum and non-petroleum activities. Res. J. Environ. Sci. 4:33–41. ISO. (2004). Soil quality: Determination of content of hydrocarbon in the range C10 to C40 by gas chromatography. ISO/DIS Method 16703:2004. Geneva, Switzerland: ISO.*

Irvine, K., Rossi, M.C., Vermette, S., Bakert, J., and Kleinfelder, K., 2011. *Illicit discharge detection and elimination: low cost options for source identification and trackdown in stormwater systems. Urban Water J., 8(6), p. 379–395.*

Jefferies, C., 2004. SUDS in Scotland. *The Monitoring Programme of the Scottish Universities SUDS Monitoring Group. Scotland & Northern Ireland Forum For Environmental Research. Report No SR (02) 51.*

Johnson, B., Tuoman, D., 1998. *From theory to implementation: finding illicit connections. Proc. Watershed Management. Conf Water Environment Federation, Denver, Colorado, US, pp. 1–10.*

Lilly, L., Stack, B.P., Caraco, D.S., 2012. *Pollution loading from illicit discharges in two Mid-Atlantic subcatchments and implications for nutrient and bacterial total maximum daily loads. Watershed Sci. Bull. 3 (1), 7–12 (Spring 2012).*

Liste, H.-H., and Felgentreu, D. (2006). *Crop growth, culturable bacteria, and degradation of petrol hydrocarbons (PHCs) in a long-term contaminated field soil. Appl. Soil. Ecol. 31:43–52.*

Lucke, T., Mohamed, A. K. M. and Tindale, N., 2014, *Pollutant Removal and Hydraulic Reduction Performance of Field Grassed Swales during Runoff Simulation Experiments, Water 2014, 6, 1887-1904*

Mason, Y., Ammann, A.A., Ulrich, A. and Sigg. L., 1999, *Behavior of Heavy Metals, Nutrients, and Major Components during Roof Runoff Infiltration, Environ. Sci. Technol., 1999, 33 (10), pp 1588–1597*

Morselli, L., Setti, L., Iannuccilli, A., Maly, S., Dinelli, G., and Quattroni, G. (1999). *Supercritical fluid extraction for the determination of petroleum hydrocarbons in soil. J. Chromatogr. A 845:357–363.*

Nadim, F., Liu, S., Hoag, G. E., Chen, J., Carley, R. J., and Zack, P. (2002). *A comparison of spectrophotometric and gas chromatographic measurements of heavy petroleum products in soil samples. Water Air Soil Pollut. 134:97–109.*

Napier, F., Jefferies, C., Heal, K.V., Fogg, P., D'Arcy, B.J., and Clarke, R., 2008. *Evidence of traffic-related pollutant control in soil-based Sustainable Urban Drainage Systems (SUDS). in 11th International Conference on Urban Drainage. Edinburgh, Scotland, UK.*

Nascimento, A. R., Ziolli, R. L., Ararun, J. T., Pires, C. S., and Silva, T. B. (2008). *Validation of method for the determination of TPH (total petroleum hydrocarbon) by infrared detection. Ecletica Qu´ımica 33:35–42.*

Perales-Momparler, S., Hernández-Crespo, C., Vallés-Morán, F., Martín, M., Andrés-Doménech, I., Álvarez, J.A., and Jefferies, C., 2014. *SuDS Efficiency during the Start-Up Period under Mediterranean Climatic Conditions. CLEAN – Soil, Air, Water, 42, p. 178–186.*

Quinn, R., Dussaillant A. J., 2014 *Modeling Heavy Metal Behavior in Sustainable Drainage Systems: A Case Study, Clean – Soil, Air, Water 2014, 42 (2), 160 – 168*

Roinas, G., Mant, C. and Williams J.B., 2014, *Fate of hydrocarbon pollutants in source and non-source control sustainable drainage systems, Water Science & Technology 69.4 2014*

Roinas, G., Tsavdaris, A., Mant, C. and Williams J.B., 2014, *Fate and Behavior of Pollutants in a Vegetated Pond System for Road Runoff, Clean – Soil, Air, Water 2014, 42 (2), 169 – 177*

Romero, M. T., and Ferrer, N. (1999). *Determination of oil and grease by solid phase extraction and infrared spectroscopy. Anal. Chim. Acta 395:77–84.*

Schmitt, N., Wanko, A., Laurent, J., Bois, P., Molle, P., Mosé, R., 2015, *Constructed wetlands treating stormwater from separate sewer networks in a residential Strasbourg urban catchment area:Micropollutant removal and fate. Journal of Environmental Chemical Engineering 3 (2015) 2816–2824*

Scholes, L., Revitt, D.M., and Ellis, J.B., 2008. *A Systematic Approach for the Comparative Assessment of Stormwater Pollutant Removal Potentials. J. Environ. Manag., 88(3), p. 467 – 478.*

Shu, Y. Y., and Lai, T. L. (2001). *Effect of moisture on the extraction efficiency of polycyclic aromatic hydrocarbons from soils under atmospheric pressure by focused microwave-assisted extraction. J. Chromatogr. A 927:131–141.*

Slonecker, E.T., Jennings, D.B., and Garofalo, D., 2001. *Remote sensing of impervious surface: a review. Remote Sensing Review, 20, p. 227–235.*

Stationery Office Ltd., 2011. *The Water Industry (Schemes for Adoption of Private Sewers) Regulations. HMSO, London, UK.*

Thompson, M., Ellison, S. L. R., and Wood, R. (2002). *Harmonized guidelines for single laboratory validation of methods of analysis. Pure Appl. Chem. 74:835–855.*

U.S. Environmental Protection Agency. (1996). *Total recoverable petroleum hydrocarbon by infrared spectrophotometry.*

U.S. Environmental Protection Agency. (1998). *n-Hexane extractable material (HEM) for sludge, sediment, and solid samples. United States Environmental Protection Agency, SW-846 Manual. EPA Method 9071 B.Washington, DC: US Government Printing Office.*

U.S. Environmental Protection Agency. (2000). *Nonhalogenated Organics using GC/FID. United States Environmental Protection Agency, SW-846 Manual. EPA Method 8015 C. Washington, DC: U.S. Government Printing Office.*

United States Environmental Protection Agency, *SW-846 Manual. EPA Method 8440. Washington, DC: US Government Printing Office.*

US EPA *National management measures to control nonpoint source pollution from urban areas*

Villalobos, M., Avila-Forcada, A. P., and Gutierrez-Ruiz, M. E. (2008). *An improved gravimetric method to determine total petroleum hydrocarbons in contaminated soils. Water Air Soil Pollut. 194:151–161.*

WEWS, 2003. *Water Environment and Water Services Act (2003). Edinburgh, Scotland: Scottish Government.*

Wilson S, Bray R and Cooper p (2004) *Sustainable Drainage Systems: Hydraulic, Structural and Water Quality Advice (Report C609) (CIRIA), London*

Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R., and Shaffer, P., 2007. T*he SUDS manual. CIRIA. C697. London.*

Zheng, Y., Wang, Y., Xiong, J., Liu, Y., Zhaon, Y., (2014) *Hybrid constructed wetlands for highly polluted river water treatment and comparison of surface- and subsurface-flow cells. Journal of Environmental Sciences 26 (2014) 749–756*

Zimmermann, J., Dierkes, C., Göbel, P., Klinger, C., Stubbe, H., and Coldewey, W.G., 2005. *Metal concentration in soil and seepage water due to infiltration of roof runoff by long term numerical modelling Water Sci. Technol., 51(2).*