Evaluation of the Ecosystem Services and Multiple Benefits provided by SUDS and Non SUDS Ponds

Joy Ann Kean

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Heriot-Watt University

School of Energy Geoscience Infrastructure and Society

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ABSTRACT

This thesis explored the potential of four Sustainable Urban Drainage (SUDS) ponds, and four non-SUDS pond, to deliver key Ecosystem benefits, and services. Sustainable Urban Drainage Systems are designed to improve water quality, and provide amenity, biodiversity, and flood alleviation benefits. Ecosystem Services (ES) refer to the end user benefits associated with an ecosystem, and which are of direct use for humans. Within the context of this study, the key Ecosystem Service (ES) is *water quality regulation* which was considered using the proxies of macroinvertebrates and diatoms. An additional Ecosystem Service is *wild species diversity* which involved monitoring and evaluating flowering plants in relation to pollination.

The project had four main research questions (RQ), and each was supported by its own research methodology. First the effectiveness of water quality regulation in SUDS and non-SUDS ponds using Average Score per Taxon was monitored (RQ1); secondly, nutrient removal services was observed between pond inlets and outlets, and potential indicators for reference, disturbed, and toxicity (RQ 2) for the ES of w*ater quality regulation*. RQ3 considered the potential for ponds to support flowering plants suitable for pollinators for the ES of w*ild species diversity*. RQ4 focussed on the public perception survey, and willingness to pay for the *multiple benefits* of ponds and evaluated these in relation to the *Whole Life Cost* of the pond.

RQ1 revealed that median values were higher for SUDS ponds than non SUDS ponds but not of statistical significance ($p>0.05$). For RQ2, median diatom counts were not statistically significant between SUDS and non SUDS ponds ($p>0.05$). There was a statistical difference between median observations for plants suitable for insect pollinators ($p<0.05$) but not for wind pollination ($p>0.05$). RQ4 revealed that habitat provision benefits outweighed costs for SUDS and non SUDS ponds in relation to *Whole Life Cost* analysis.

The proposed framework, resulting from this research, may be used to inform local decision making and policy for SUDS design. This research aids the understanding of valuing ponds in relation to ecosystem benefits and services. It also highlights the significance of incorporating disadvantages into economic assessment; particularly where direct comparisons are made between ponds.

DEDICATION

For Mum

ACKNOWLEDGEMENTS

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DECLARATION STATEMENT

Research Thesis Submission

Name:	Joy Ann Kean		
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LIST OF PUBLICATIONS

The publications will be in Appendix A.1 which follows on from the references.

Journal article:

Jarvie, J., Arthur, S., and Beevers, L.C., (2017): Valuing Multiple Benefits and the Public Perception of SUDS ponds. *Water*, 9, 2, 128.

Conference proceedings:

Jarvie, J. A., Arthur, S., and Beevers, L. C., (2015). *A Field approach for comparing the Ecosystem Services from SUDS and non-SUDS ponds: preliminary results*. Paper presented at 36th IAHR World Congress, The Hague, Netherlands.

Jarvie, J. A., Arthur, S., and Beevers, L.C., (2015). An Ecosystem Services approach: how does rainfall variation influence habitat provision in ponds? In *Proceedings of the Infrastructure and Environment Scotland 3rd Postgraduate Conference* (pp. 65-70). Edinburgh: Heriot-Watt University.

Poster presentations:

Jarvie, J.A., Arthur, S., and Beevers, L.C., (2014) A valuation of the Ecosystem Services that Sustainable Urban Drainage Systems provide. Poster presented (prize awarded) at the annual Heriot Watt Postgraduate Research conference, Edinburgh, United Kingdom.

Jarvie, J.A., Arthur, S., and Beevers, L.C., (2015) Valuing the Ecosystem Services from engineered and non-engineered ponds. Poster presented at BES annual meeting, Edinburgh, United Kingdom.

Jarvie, J. A., Arthur, S., & Beevers, L.C., (2015). *Valuation of the Ecosystem Services provided by natural looking Sustainable Urban Drainage Systems (SUDS)*. Poster presented at 15th IWRA World Water Congress 2015, Edinburgh, United Kingdom.

Chapter 1 – INTRODUCTION

1.1 Overview

The chapter will focus on the theoretical background to the thesis; introduce the research aim, objectives, and research questions. It will then provide an overview of the thesis structure.

1.2 Background

Ponds are temporary or permanent water features with a surface area between $1m^2$ and 2ha ($20,000m^2$), (Biggs *et al.,* 2005; Hill *et al.,* 2016). For the purpose of this thesis, the ponds studied are Sustainable Urban Drainage (SUDS) or non SUDS which include ponds not designed for drainage.

Non SUDS ponds may include recreation ponds, mill ponds, distillery (waste water), conservation and rural ponds. Some ponds have been established for many centuries, with use during the industrial revolution to power mills and provide a source of water for industrial operations (Wood *et al.*, 2001). In the last century, the number of ponds has decreased significantly (Cerighino *et al.*, 2008) and the way in which the land is managed has changed in relation to population and land-use pressures. Protecting existing ponds for enhancing recreation or providing local conservation is important. However, the older non SUDS ponds could have deteriorating water quality; for example, pollutants and heavy metals stored in the pond sediments (Liebens, 2001), which is also the case for SUDS (Heal *et al.,* 2006). For the purpose of this thesis, the comparison will include SUDS and non-SUDS ponds.

Creating new ponds is important for species diversity and conservation, but little is known about the water quality of the developed site (Williams *et al.*, 2008). Sustainable Urban Drainage (SUDS) ponds, however, were created with the intention to mimic the natural water cycle, as well as providing water quality, water quantity and amenity benefits (D'Arcy, 1998). Innovations in SUDS pond design and construction guidance could lead to improved biodiversity at ponds without poor water quality (CIRIA, 2015), which is a concern for current pond developments designed for treating stormwater runoff (Hassall, 2016).

SUDS ponds provide an array of Ecosystem Services and multiple benefits. Ecosystem Services refers to the benefits that humans obtain from ecosystems (Costanza *et al.*, 1997; Daily *et al.*, 1997), and cover a wide range of terrestrial and aquatic environments. Assessing the multiple benefits provided by SUDS ponds is of importance and provides more opportunities to convince the developers to build new ponds. It also enhances the argument that SUDS offer multiple functions and benefits from ecosystems which are of direct importance to human health and wellbeing (Wade and McClean, 2014). It was decided to see whether non SUDS ponds offer the same type and variety of benefits. The theme of the thesis is to compare the results within each chapter to determine whether SUDS are functioning well and capable of providing the multiple benefits in line with CIRIA guidance.

Another type of non SUDS pond is characterised as existing depressions in landscapes (karst regions) or kettleholes (formed during de-glaciation). These ponds are more likely to have good water quality due to the fact that these are not designed for treating diffuse pollution. The ponds will be established and are likely to offer biodiversity benefits; for example, native wetland plants, fish, and damsel and dragonflies. However, this will depend on the situation of the ponds, as some previously natural ponds may be subjected to anthropogenic activity; for example, nutrient release from nearby allotments and gardens. Some authors argued that ponds are not protected enough from the effects of anthropogenic pressures; for example, industrial and agricultural activity reducing the water quality of freshwater ecosystems and putting fish and invertebrates under stressed conditions.

1.3 Problem/ purpose

The motivation for the thesis was to address research concerns relating to quantifying pond Ecosystem Services, through field monitoring. Ecosystem Services are the benefits that humans obtain from ecosystems. SUDS pond research was limited with respect to measuring and monitoring Ecosystem Services through field monitoring (Lundy and Wade, 2011). However, the recent research pertaining to urban ponds has recovered some of the gaps, with respect to habitat provision and connectivity with wetlands (Moore and Hunt, 2012), as well as biodiversity for conservation (Hill *et al.*, 2015; 2016)- some of which was addressed in stormwater management ponds/ SUDS (Hassall and Noble, 2014; Briers, 2014; Hill *et al.*, 2015).

Previous research focused on water quality issues in urban drainage, with no direct link with Ecosystem Services, or water quantity. The aspects of amenity and biodiversity were under researched and provision of monitoring data for ponds is limited. Studies exist in water quality management, with very few studies relating to the process of water quality regulation between the pond inlet and outlet (Chapter 4), but this is slowly changing with more recent efforts focussing on water quality in stormwater ponds in the USA and spatial variation in Phosphorus, and thus nutrient loading within the pond (Song *et al.*, 2017). Additionally, there is a study which focuses on the operational status of 25 Swedish stormwater ponds which compares the inlet to outlet (Blaszczak et al., 2018). Specifically, this thesis will compare the inlets and outlets of SUDS and non SUDS ponds to assess how well SUDS regulate water quality.

There are some recent studies which support field monitoring of ponds in an Ecosystem Service context, but there is an inherent lack of long-term monitoring data-so comparisons and conclusions are tentative due to a paucity of spatio-temporal data. This is an issue in terms of the quality of data provided to support decision making in relation to the operation and maintenance of SUDS ponds (see Chapter 7).

1.4 Research aim and Research Questions

This section outlines the research aim and the questions addressed throughout the thesis.

Aim:

The overall aim is to compare SUDS and non-SUDS ponds in relation to their Ecosystem Services, and Multiple Benefits. This was achieved by monitoring the key Ecosystem Services in the field (Chapter 3) and by using the results to define the scoring matrix (Chapter 8) for each pond evaluated.

Research Question 1

1a: How effective is water quality regulation in ponds between the inlet and outlet of SUDS and non-SUDS ponds, with respect to: -Average Score per Taxon (ASPT), influence of rainfall, and nutrient loading?

1b: How do these ponds compare in relation to water quality regulation, and is there a statistically significant difference between SUDS and non SUDS ponds?

Research Question 2

Do SUDS ponds have more potential than non SUDS ponds for regulating Water Quality through algae removal processes (using diatoms as proxies)?

- Are the key functions (water quality regulation) performed better in SUDS or non SUDS ponds?
- What are the seasonal trends with diatoms and how does this influence the functioning of SUDS ponds?
- Are there challenging geo-chemical disturbances which could reduce the expected Ecosystem Service delivery; for example, conductivity levels.

Research Question 3

Do SUDS ponds have more potential than non SUDS ponds for plant diversity to support flowering plants suitable for pollinators?

Research Question 4

a. What is the public perception of the potential benefits and disadvantages of living near a pond?

b. How much value is placed on supporting multiple benefits at their local pond (their Willingness to Pay for benefits), and are these values capable of offsetting costs?

1.5 Layout of the thesis

Chapter 1 provides an introduction to the research problem and the importance of resolving these questions. Chapter 2 outlines the literature in the field of Sustainable Urban Drainage (SUDS), Ecosystem Services (ES) and multiple benefits. Methodology is discussed in chapter 3 with an overview of the framework which will be presented, and evaluated, in chapter 8. Chapter 4 and 5 focuses on the Ecosystem Service of water quality regulation in relation to the proxies of macroinvertebrates (Chapter 4) and diatoms (Chapter 5). Species diversity will be explored in relation to pollination of plants (Chapter 6). Chapter 7 presents and evaluates the results from the Contingent Valuation surveys (postal and online) through Whole Life Cost (WLC) analysis – with reference to the multiple benefits of ponds. This is an extended chapter of the publication: Valuing Multiple Benefits and the Public Perception of SUDS ponds (Jarvie *et al.,* 2017). Chapter 8 discusses the results, and evaluates these in relation to the framework, with reference to key literature and provides answers to the research questions (1.3). Chapter 9 provides conclusion for the thesis, and states recommendations for future research; as well as outlining the main limitations of the research project.

Appendices and materials will be referenced within the chapters, as appropriate, and will be numbered sequentially (e.g. Table/ Figure A4.1).

Chapter 2– LITERATURE REVIEW

2.1 Overview

The aim of the literature review is to address what has been done in the literature in relation to SUDS, and specifically ponds, while assessing the key gaps in research. This will be done in relation to the research aim and questions provided in Chapter 1.

There has been considerable research effort investigating diffuse pollution and water quality in Sustainable Urban Drainage Systems (SUDS). Until recently, however, there was less focus on the multiple benefits and Ecosystem Services which are gained from SUDS. This chapter begins with a history of SUDS and discusses the development of the terminology. It then goes on to discuss Ecosystem Services (ES) by relating to previous studies and challenges faced by quantifying ES. The topic of multiple benefits is discussed and reference to the existing studies is made. The final ES of water quality regulation and species diversity are discussed with reference to the main ecological processes (sometimes referred to as intermediate services, NEA, 2011; 2014); such as water purification, nutrient cycling, and pollination.

2.2 SUDS

Sustainable Urban Drainage systems (SUDS) are designed to treat stormwater pollutants, attenuate runoff, and promote biodiversity and amenity wherever possible (CIRIA, 2015). SUDS features include source control, conveyance and regional control or retention and detention basins (CIRIA, 2015). SUDS mimic ecological systems as well as creating space for biodiversity to flourish.

The terminology associated with urban drainage evolved locally with a transition from narrow mind-set (water quality objectives) to multiple benefits (Fletcher *et al.,* 2015). With this evolution of language, the level of confusion and miscommunication increased- as stakeholders developed their own interpretation of the drainage jargon at a local and regional level (Fletcher *et al.,* 2015). Changes in urban drainage, and related planning legislation, were actively encouraged by Scottish stakeholders and Scottish Environment Protection Agency (SEPA) in the 1990s with the introduction of Best Management Practices (BMPs) from the USA (e.g Urbonas and Stahre, 1993). The objective of BMPs was to reduce pollution and monitor pollution prevention activities with respect to Pollution Prevention Act- where pollution was reduced or managed as close to the source as possible (EPA, 2016). The source control measures of SUDS relate to this.

Scottish Water formalised the SUDS concept (Fletcher *et al.*, 2015), following on from the 'sustainable drainage triangle' (water quality, flooding and amenity), by suggesting design guidelines which would later be published by CIRIA (2015). The uptake of SUDS was mandatory for planning applications from 2003 with the introduction of the Water Environment and Water Services (WEWS) Act.

The primary rationale of SUDS adoption in Scotland was to treat urban diffuse pollution and improve the quality of stormwater being released into drains and neighbouring water bodies. Diffuse pollution refers to pollution from widespread activities with no one discrete source in the water environment (e.g. industrial and agricultural). Point source pollution refers to pollution from a single source of air/ water/ thermal/ noise or light pollution. The fact that it is not quantifiable poses problems for the environment under scrutiny (e.g. water environment). D'Arcy and Frost (2001) considered the issues with environmental modelling of contaminants, and, in particular, focused on the issue of quantifying the levels of trace metals and oils within a water environment. illustrates the treatment train, which considers the three main levels of treatment:

- Source control
- Site control
- Regional control

The level of treatment varies according to the level of pollution risk/ contamination as well as the population at risk; for example, a small housing development may require a different level of treatment from an industrial location (McKissock *et al.*, 2009). Furthermore, the level of water body sensitivity (see Table 2-1) is factored into selecting an appropriate treatment train.

Managing water quantity is performed by the processes of attenuation, infiltration, and storage (permanent- retention Ponds; temporary- detention basins). With the increasing concerns about flooding- as a result of climate change- these systems are designed to cope with exceedance and reduce intensity of runoff. In light of recent concerns regarding pluvial flooding (surface water ponding, Houston *et al.*, 2011), the drive for

SUDS has been to integrate the measures as close to the source as possible. Source control methods were critically evaluated (Duffy *et al.,* 2013) with a strong focus on the benefits for homeowners at a house-plot scale (Campbell *et al.*, 2012).

Notwithstanding this progress, amenity and biodiversity are under researched components of SUDS in terms of ecological systems; but are of importance to home owners (Apostolaki *et al.*, 2006; Bastien *et al.*, 2012; Jose *et al.*, 2015). A recent review of SUDS suggested this may be due to poor stakeholder engagement: in reference to the relationship between ecologists and engineers (D'Arcy, 2016). This refers to the need for disciplines to work together to design SUDS. Briers (2014) was the first study to focus on biodiversity of SUDS ponds in detail with a strong emphasis on the need for effective monitoring and management- as species richness declined in these ponds over time. Furthermore, the need for better design of SUDS ponds was emphasised with reference to the notion that these ponds may not be able to treat water and provide a strong biodiversity function (Briers, 2014).

2.2.1 Treatment train concept

Figure 2-1 highlights the treatment train process in relation to SUDS. This concept is derived from the theory that best management of water is as close to the site as possible. In other words, it is essential to consider treatment at source or site control. Regional control treatment may depend on the size of the development, and underlying factors controlling pollution treatment requirements- such as a former industrial site.

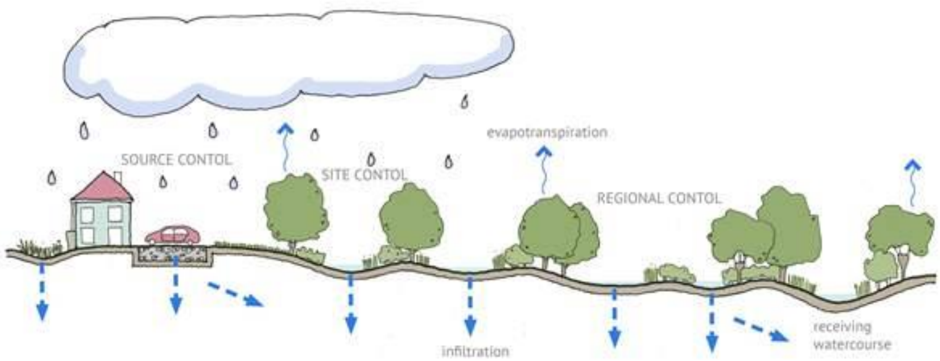

Figure 2-1: The treatment train concept, SUSdrain (2013)

Table 2-1.: SEPA SUDS selection table, adapted from Jefferies *et al.*, (2009)

No of houses/ car park spaces	**Water body sensitivity**		
	Low	**Medium**	**High**
<25	Source control	Source control	Source control
25-49	Source control	Source control	Source control plus detention basin
50-99	Source control	Source control plus detention basin	Source control plus detention basin
100-249	Source control plus detention basin	Source control plus pond	Source control plus pond
250-1000	Source control plus pond	Source control plus pond	Source control plus pond
>1000	Source control plus pond	Source control plus detention basin and pond	Source control plus detention basin and pond

2.2.2 Water quality drivers:

In terms of the water environment, the 'original' and probably leading argument for SUDS is the prevention of deterioration of water courses- due to increasing urbanisation (MacDonald and Jefferies, 2003). A wealth of literature, therefore, focuses on water quality drivers in terms of diffuse pollution (Jefferies *et al.*, 1999; D'Arcy and Frost, 2001; Jefferies *et al.*, 2008; Duffy *et al.*, 2012; Duffy *et al.*, 2013). Diffuse pollution refers to the sources of pollutant which cannot be readily quantified (D'Arcy and Frost, 2001; Howe and White, 2004), and exclude those which can (point sources), e.g. industrial and agricultural effluent (Howe and White, 2004). The fact that it is not quantifiable poses problems for the environment under scrutiny (e.g. water environment). D'Arcy and Frost (2001) consider the issues with environmental modelling of contaminants, and, in particular, focus on the issue of quantifying the levels of trace metals and oils within a water environment. Jefferies *et al.*, (2008) argue that the SUDS allow the diffuse pollution sources to be trapped within the system. An example of this is the oil levels found near areas of heavy traffic.

While it is difficult to quantify, diffuse pollution and monitoring of sources and levels forms an important component of the legislation pertaining to SUDS. Jefferies *et al.*,

(2008) discuss the importance of legislation, and, in particular, the Water Framework Directive in shaping the role of SUDS in planning regulations. This is central to the development of diffuse pollution legislation, and it is now a necessity to monitor, and evaluate, sources of diffuse pollution (Jefferies, 2008). Table 2-2 summarises the main legislative drivers in terms of water quality, in relation to SUDS, for Scotland. The Water Frame Work Directive is the main piece of European legislation, and the other legislative pieces stem from this. Water Environment and Water Services Act (WEWS) (2003) remains the main piece of legislation for water bodies in Scotland.

2.2.3 Legislation relating to water quality:

Table 2-2 summarises the main Acts and Directives relating to water quality. This is important to highlight as this is a fundamental driver in regulation of water quality within the UK.

Table 2-2: Summary of main legislative drivers for water quality

Legislation	Date enacted	Purpose
Water Framework Directive	2000	Protect and manage the water environment and promote 'good' ecological and chemical status.
Water Environment and Water Services (Scotland) Act	2003	Transposes the Water Framework Directive into Scot's Law.
Water Environment (Controlled Activities) (Scotland) Regulations	2011	Forms General Binding Rules for activities which, through direct or indirect influence, "have a significant (adverse) impact on the water environment" (p6).
Water Environment (Controlled Activities) (Scotland) Amendment Regulations	2013	Amendment of previous legislation.
The Water Environment (Diffuse Pollution) (Scotland) Regulations	2008	Control of diffuse pollution from agricultural activities.

2.2.4 Water quantity:

Water quantity refers to the volume of water from a given storm event and considers the relevance of flooding hazards. The issue of pluvial flooding has more attention following the 2007 floods in England, and the production of the Pitt Review (2008) which informed local authorities of the risks and the need to act upon these. This is increasingly important with recent changes in climate and the rise in flood events.

Houston *et al.,* (2011) discuss this in terms of pluvial flooding. Pluvial flooding occurs when an intense period of rainfall cannot be infiltrated and may also result in ponding. Pluvial flooding is coupled with the inability for drainage systems to cope with an increase in pressure (JRF, 2011). Furthermore, the volume of water makes drainage systems saturated thereby reducing their functions (JRF, 2011; SEPA, 2013). Stovin *et al.*, (2013) discuss the issue of increased pressure on CSOs (Combined Sewer Overflows) and sewage systems in London as a result of climate change. The key message is that an alternative measure is needed to reduce the pressure, on the systems, and thereby minimising the socio-economic and environmental implications.

Table 2-3 Drainage type, possible implications of pluvial flooding, and possible solutions, based on own interpretation

Drainage Type	**Social implications**	**Economic implications**	**Environmental implications**	**Possible Solutions**
Combined Sewer Overflow (CSO)	Health and well-being	Loss of property, damages to household infrastructure, and furniture.	Pollution of urban streams and neighbourhoods. Loss of habitat and biodiversity	Grey:Green Initiative (Portland example, Oberndorfer et al., 2007; Foster et al., 2014)
Victorian Sewer	Health and well-being	Loss of property and commercial/industrial buildings. Damage may be caused to infrastructure.	Widespread pollution of urban streams etc. Loss of habitat and biodiversity.	Upgrade sewage systems but cost £millions (Thames Water: Stovin et al., 2013)
SUDS	Health and well-being	Maintenance of drainage systems, minimal household damage	Pollution Loss of some habitat and biodiversity.	Ensure SUDS are well-maintained and take responsibility for own drainage (curtilage)

Table 2-3 summarises the social, economic and environmental implications; as well as suggesting some existing solutions from the literature. Socio-economic implications are discussed thoroughly in the literature with respect to fluvial (Penning-Rowsell *et al.,* 1988; Tapsell *et al.,* 2002; Werritty *et al.,* 2006), coastal (Ball *et al.,* 2009), and pluvial flooding (Houston *et al.,* 2011; JRF, 2011). Pluvial flooding is a key challenge in terms of climate change, as mentioned previously, but also in terms of demographic change. The population is likely to increase, and, with this, there will be more pressure on planners to accommodate this increase (Houston *et al.,* 2011). The main legislative drivers play a key role in reducing the barriers associated with climate and demographic change.

2.2.4.1 Water quantity legislation:

Table 2-4: Summary of the main legislative drivers for SUDS in terms of water quantity

Legislation	**Date enacted**	**Purpose**
The Flood Prevention Act	1961	Allow counties or Burghs in Scotland to take actions to prevent floods in non-agricultural areas.
The Flood Prevention and Land Drainage (Scotland) Act	1997	An amendment of the 1961 Flood Prevention Act
EU Floods Directive (2007/60/EC)	2007	To assess all water courses and coastlines and decide whether they are at risk from flooding.
Flood Risk Management (Scotland) Act	2009	Promotion of Sustainable Flood Risk Management
SPP (Scottish Planning Policy)	2010	Supersedes SPP7 (flooding and planning). More rigorous in its assessment.

Table 2-4 highlights the legislative controls pertaining to SUDS in terms of water quantity. In terms of climate change, there are guidelines for exceedance of rainfall

(20%) within planning policy for urban areas. However, recent literature from SEPA suggests that current estimates need to be revised, as most areas within Scotland have used up 20% exceedance. This is in relation to the Flood Risk Management Act, 2009, which streamlines former planning Acts (Kenyon and Reid, 2008). This Act is the main piece of legislation for Scotland, in terms of water quantity drivers. The Act promotes Sustainable Flood Risk Management practice and policy in Scotland. SUDS, therefore, form a key component in this political agenda; as it incorporates sustainable stormwater management into its remit (Scottish Government, 2011). Important measures are in place to minimise the impacts of flooding from pluvial sources, and the legislative controls help to police these measures. Issues exist with the dissemination of information to the public and having the ability to explain why these measures are important. The integrated approach to Flood Risk Management will hopefully reduce some of the social, economic and environmental issues; as well as enabling the public to become more aware of flooding issues and developments in local and national policy (Scottish Government, 2011).

Natural floodplains are effective at storing flood water and reducing peak discharge (Hamill, 2011). Natural wetlands typically include areas of marsh, ponds and reed beds. Their functions include storage of water, attenuation of floods and providing an improvement to the water quality through settlement, adhesion (sticking of sediment), and decomposition (Hamill, 2011). In terms of SUDS, Ponds and wetlands are categorised under the wider term “Regional Control”, and these features are not suited to urban areas near airports- due to presence of wading and other birds (Hamill, 2011; SEPA, 2015; CIRIA, 2007) Balancing ponds refer to deeper, permanent, bodies of water with aquatic vegetation and shallower areas which fill up during storm events (Hamill, 2011). Ponds and Wetland also incorporate ecological and amenity value, but one of the main drawbacks is the initial capital cost associated with designing and installing these features (Hamill, 2011).

Constructed wetlands require the following characteristics (CIRIA, 2007; Hamill, 2011; CIRIA 2015):

- Continuous flow
- Large, flat, sites
- Impermeable lining
- Inlet and outlet structures.

- Making space for nature

The above characteristics contribute to amenity functions (Table 2.5) as well as corresponding to fundamental legislative requirements for the Nature Conservation Act (2004)- as the CIRIA design promotes development of habitat through establishing continuous flow through the wetland; as well as providing large, flat, areas to encourage nesting of wild birds and wild fowl (ducks, moorhens, swans, coots).

2.2.5 Amenity Legislation (in relation to habitat)

Table 2-5: Summary of the main legislative drivers for SUDS in terms of amenity

Legislation	**Date Enacted**	**Purpose**
The Habitats Directive 92/43/EEC	1992	Conservation of habitats and wild flora and fauna.
Habitat Regulations	1994	The Habitats Directive was transposed into UK Law
Nature Conservation (Scotland) Act	2004	New offences introduced for intentional or reckless damage to habitat or for disturbance to species.
Amendment 1 & 2	2007	1) Assess development plans in relation to NATURA sites. 2) Assessment of all plans and projects which potentially affect NATURA sites.

Table 2-5 highlights the main legislation relating to amenity drivers of SUDS. Habitat regulations, 1994, have been superseded in Scotland by the Nature Conservation (Scotland) Act, 2004. According to SNH (2013) the regulations were updated to include candidate Special Areas of Conversation (cSACs). In terms of SUDS, it is useful to know the legislation drivers when working near sensitive areas.

2.3 Ecosystem Services

Costanza *et al.*, (1997; 1998) discuss the importance of nature and placing a value on services. The term Ecosystem Services refers to the benefits that the environment provides- in terms of social, cultural, economic and environmental benefits. This is similar to the multiple benefit approach for SUDS (Section 2.3). Key insights from this paper led to the establishment of the Millennium Ecosystem Assessment framework in 2005 (Figure 2-2).

Figure 2-2 shows that there are four categories used in the assessment, and these are: provisioning, regulating, supporting and cultural services. Provisioning services refer to the products derived from ecosystems, for example freshwater supplies provide fish and meat (Lundy and Wade, 2011). Regulating services relate to the benefits derived from regulating ecosystem processes, and an example of this is flowering plants for pollination (Liss *et al.*, 2013). Supporting services are critical for successful operation of other services. Cultural services refer to the products with no material benefit and it is sometimes argued that these should be valued in non-monetary terms (Bateman *et al.*, 2011).

Different typologies:

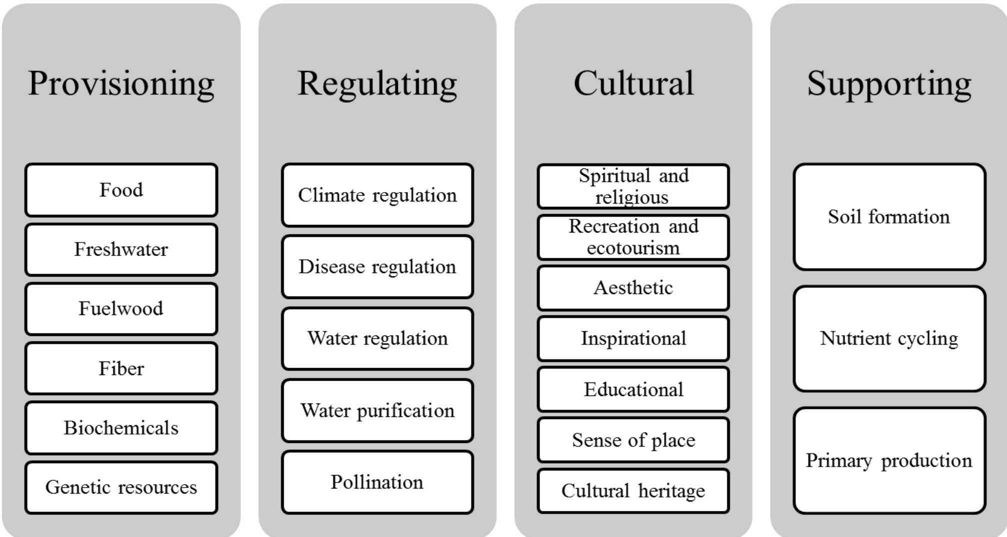

Figure 2-2Millennium Ecosystem Assessment, adapted from UNEP (MA, 2005)

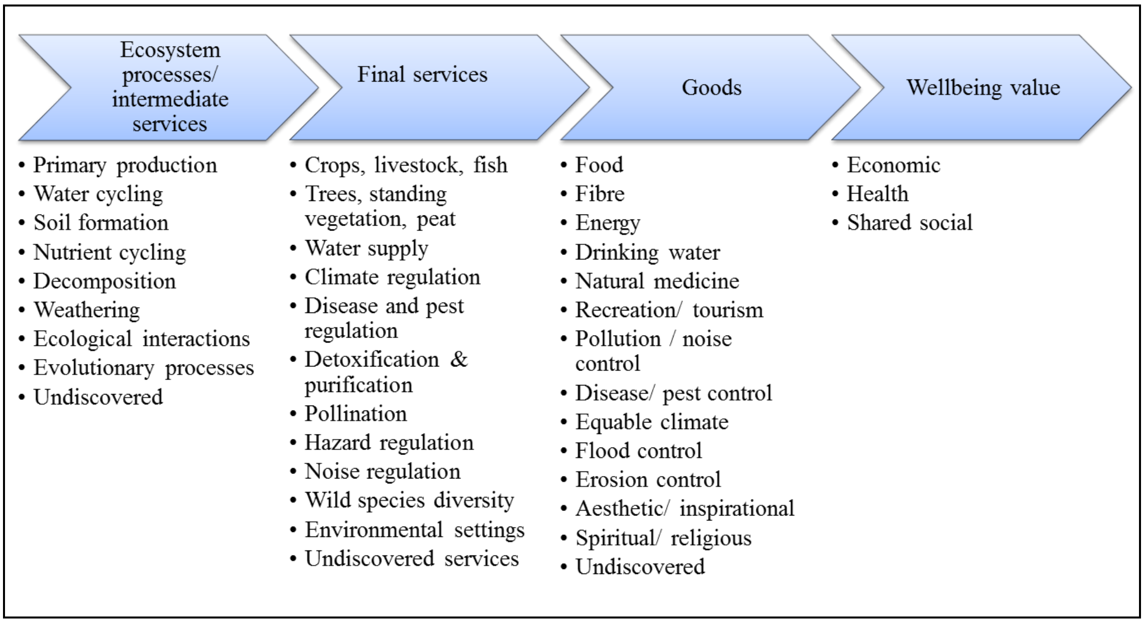

Figure 2-3 National Ecosystem Assessment, adapted from NEA (2011; 2014)

There is another school of thought adopted by a recent framework in the UK. The National Ecosystem Assessment is a framework which defines the concept as: processes, intermediate services, final Ecosystem Services, goods derived and value for well-being (Figure 2-3). Bateman *et al.*, (2011) argues that the role of the NEA is to provide a wholesome economic assessment which feeds into well-being values (Figure 2.3). Wellbeing value is separated into three categories: economic, health and shared-social values (NEA, 2011).

However, some scholars (Fisher *et al.*, 2010) prefer the TEEB (The Economics of Ecosystems and Biodiversity, 2009) framework for valuing Ecosystem Services. The UK implements their own version of TEEB which is the National Ecosystem Assessment which complements the objectives set up in 2010 by the Convention of Biological Diversity (NEA, 2011; NEA, 2014). The key question is: is it important to take a Global/ National approach to valuing Ecosystem Services? How is a decision reached on which approach is more suited to a study, or is this an individual preference? The TEEB approach is sometimes combined with the Millennium Ecosystem Assessment framework, for example, where a rigorous economic assessment of Ecosystem Services is favoured (in terms of urban planning assessment) (Gomez-Baggethun and Barton, 2013). Gomez-Baggethun and Barton (2013) identify that there is an abundance of biophysical and economic studies, but there is a lack of non-economic based studies; for example, social, cultural and insurance-based values. Integration at different policy levels, therefore, is inconsistent and a research gap exists in incorporating the values into the assessment. This remains a key challenge for

Ecosystem Services (Table 2-6) where the interface between scale of delivery and policy (Figure 2-4) is inconsistent.

Some authors argue that the global and national frameworks are useful for quantification when the metrics and purpose is clear (Bateman *et al.*, 2011; Liss *et al.*, 2013). Liss *et al.*, (2013) discuss the variability in Ecosystem Service measurements using pollination services as a case study. It is fundamental to have an Ecosystem Service framework for research which identifies: 1) Key Ecosystem Services, 2) Various components pertinent to research goals, and 3) appropriate metrics which will be later quantified. The third component is vital as this underpins future decisions and possible policy (Liss *et al.*, 2013). It is therefore good practice to ensure that the framework and selected metrics is representative of the research project and its objectives. Furthermore, Liss *et al.*, (2013) argue that secondary data should be used with caution as these may be outdated, and, thus, may not be an accurate representation of reality. Equally, primary data (field or laboratory based) should be consistent to allow comparability between studies (Liss *et al.*, 2013).

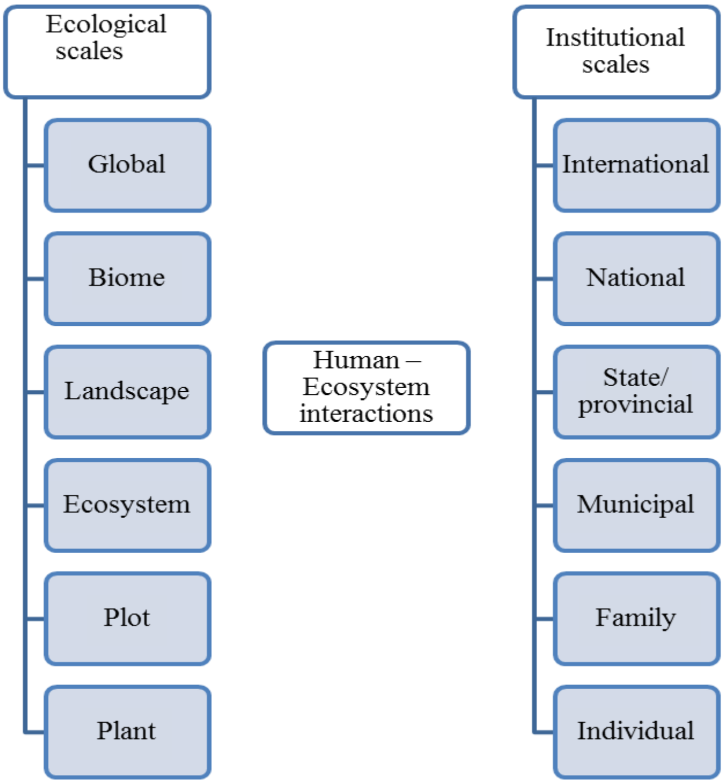

Figure 2-4 Scales of delivery of Ecosystem Services (ecological and institutional), adapted from Hein *et al.*, (2006)

2.3.1 Issues with Ecosystem Services

Table 2-6 main issues for Ecosystem Services, as observed in the literature

Main problems identified	**Study authors**	**Potential solutions**
Coherence of policy	Carpenter *et al.*, (2009); Mace *et al.*, (2012)	Communication between stakeholders
Confusion/ narrow interpretations	Brauman *et al.*, (2007); Reyers *et al.*, (2012); Sander and Haight (2012)	Clear explanations of findings A distinction between biodiversity and Ecosystem Services (Reyers *et al.*, 2012)
<u>**Lack of consistency**</u>		
Definitions	Kremen and Ostfeld (2005); Boyd and Banzhaf (2007); Wallace (2007); Martin-Lopez *et al.*, (2009); Liss *et al.*, (2013)	A decision should be reached on appropriate definitions (Liss *et al.*, 2013)
Metrics chosen	Dale and Polasky (2007) Brauman *et al.*, (2007); Liss *et al.*, (2013)	Metrics should be chosen carefully and reflect the scope of the study.
Typologies	Wallace (2007); Fisher *et al.*, (2009); Brauman *et al.*, (2009); Seppelt *et al.*, (2011); Liss *et al.*, (2013)	These should be clear from the outset
Scale of delivery	Hein *et al.*, (2006); Dale and Polasky (2007) Brauman *et al.*, (2009); Martin-Lopez *et al.*, (2009); Ernstson *et al.*, (2010)	The scale should be clear and methods should reflect this.
Incomplete framework	Fisher *et al.*, (2009); Chan *et al.*, (2012)	Integration between existing frameworks and exploration of new ideas.
Stakeholder Engagement	Chee *et al.*, (2004); Daily *et al.*, (2009); O'Farell *et al.*, (2010); Vortius and Spray (2015)	Stakeholders should be consulted, particularly during the valuation stage, and at all levels.
Double counting of services	Costanza *et al.*, (1998)	Clarity in methods chosen for valuation. Consulting an economic expert if necessary

Table 2-6 summarises the main issues for Ecosystem Services, as observed in the key literature papers, as well as some possible solutions to these obstacles. One of the main issues is the lack of consistency in the definition of 'Ecosystem Services', 'Natural capital' and 'Ecosystem Functions' (Martin-Lopez *et al.*, 2009). Daily (1997) describes

Ecosystem Services in terms of human well-being and integrating ecology and biodiversity; whereas, Costanza *et al.*, (1997) argue it is the presence of capital that is fundamental in providing 'services' for nature. MA (2005) describes 'Ecosystem Services' as the benefits obtained from the environment. NEA (2011), however, defines 'Ecosystem Services' in terms of human well-being and processes and services. Ecosystem processes and services are often misunderstood (Wallace *et al.,* 2007). Costanza (2008) refutes the idea that there should be a clear distinction between means and ends; whereas, Wallace (2007) argues it is an important aspect of defining Ecosystem Services- as the process and benefits are often confused in the literature.

In terms of Ecosystem functions, however, this depends on the scale at which these 'services' are delivered, for example, Figure 2.4 highlights a variety of ecological and institutional scales. Choosing an appropriate scale for the study is useful and it allows for comparison of case studies; as it is hoped that the studies, and associated frameworks, should be replicable, scalable, credible, and conform to sustainability (Daily *et al.,* 2009; Vortius and Spray, 2015). Furthermore, the issue of an incomplete framework (Fisher *et al.,* 2009), in terms of outliers and missing data points (Chan *et al.,* 2012), may be reduced if an appropriate scale and metrics are chosen (Dale and Polasky, 2007; Brauman *et al.,* 2009; Liss *et al.,* 2013).

2.3.2 Relationship with SUDS

SUDS and Ecosystem Services is a relatively new school of thought in the literature (Lundy and Wade, 2011; Wade *et al.,* 2012; Uzomah *et al.,* 2014; Jose *et al.,* 2015) which stems from the multiple benefit approach whereby SUDS provide a wealth of benefits for ecosystems at various scales, as discussed by Ashley *et al.,* (2014). An example of this is a swale. It provides amenity benefits as well as water quality advantages for SUDS, but it also has a range of ecosystem functions and services- for example, vegetated swales harness nutrients for recycling (Wade *et al., 2*012).

To date, very few studies have considered this combined approach to assess the environment (Wade *et al.,* 2012; Uzomah *et al.,* 2014). The application of Ecosystem Services within SUDS theory is understood with some authors providing a framework which maps SUDS on to Ecosystem Services (Wade *et al.,* 2012). However, as Liss *et al.,* (2013) argue it is important to the combine the framework with consistent metrics, rather than provide a review of Ecosystem Services for SUDS. Moreover, it is useful to comment on the effectiveness of the chosen framework. While it identifies the key relationships between Ecosystem Services and SUDS, it does not allow for inter site comparability due to some of the measurement units chosen. It does, however, provide a robust overview of the key Ecosystem Services and benefits available from selected SUDS features. On the other hand, the framework adopted by Uzomah *et al.,* (2014) may be applied to multiple sites- for example, the application of public and academic perception to assess habitat function, and ES, of SUDS.

2.4 Valuing the multiple benefits, and public perception of ponds (RQ 4)

Multiple benefits refers to the main benefits humans receive from ecosystems; so in the case of chapter 7, these will refer to the several benefits associated with habitat provision, flood risk reduction, or recreation (for example).Wright and Thorne (2014) discusses the concept of blue green cities and the value that the project will provide to key stakeholders; for example the provision of blue, green, infrastructure (which includes SUDS). One of the contributions of this project was to quantify and monetise the multiple benefits provided by a SUDS system, which was later carried out in relation to the BeST (Benefits for SUDS tool) methodology which evaluated a case study in Newcastle (O'Donnell *et al.*, 2017). A separate study focused on the uptake of SUDS (as a retrofitting approach) for provision of multiple benefits in London. Prior to 2017, no one had placed a monetary value on the multiple benefits provided by SUDS. However, in the case of this review, no one had placed monetary values using a combination of household and online surveys which were then validated through Whole Life Cost assessment.

Each benefit category has further benefits associated, for example the multiple benefit of habitat (Jarvie *et al.,* 2017) focuses on whether the pond supports mammals, insects, fish, plants, and creates habitats suitable for birds.

2.4.1 How are the multiple benefits assessed?

This section will discuss the methods defined in the literature for assessing multiple benefits, in relation to conceptual, non-monetary and monetary assessment.

2.4.1.1 Conceptual Assessment

Benefits from SUDS (Apostolaki *et al.,* 2006) were assessed in relation to public perception and attitudes, and concerns. The main concerns with SUDS ponds were in relation to safety, for example children slipping and falling into deep water. The research revealed the need to improve and safeguard community safety and provide more barrier protection (plants and higher fences) when constructing new ponds.

A cultural ecosystem (conceptual) framework was devised, based on the methodology of Church *et al*., (2014). It was revealed that more research was needed to assess the different cultural benefits associated with types of green infrastructure. The need to distinguish which benefits occur in certain places, and also allow the public to understand which benefits could be provided. Gaps in dis-services, and the importance of understanding how these disbenefits influence society (O'Brien *et al.,* 2017) and particularly their behaviour, as some communities feel marginalised due to increasing rental and ownership costs (Teedon *et al.,* 2014).

Hoang *et al.,* (2016) developed a framework to assess the multiple benefits from SUDS in relation to a flood risk catchment within Portland, Oregon, USA. The benefits included: habitat connectivity, recreational accessibility, traffic movement, noise propagation, Carbon sequestration and pollutant trapping. Benefit profiles, intensities, and dependencies were assessed using a combination of GIS and hydraulic models, and it was revealed that benefits and disbenefits were variable across the site. However, the main benefits of traffic reduction, habitat and access to recreation were favoured, in addition to the purpose of flood reduction (Hoang *et al.*, 2016).

2.4.1.2 Non-monetary assessment

Non-monetary assessment of multiple benefits could involve using participatory methods, such as community engagement and GIS tools (Jose *et al.,* 2015) or within spatial planning of green infrastructure (e.g. Lennon and Scott, 2014). Public Participatory Geographic Information Systems (PPGIS) uses GIS to make the public more involved in decision making as well as providing stakeholders with more evidence to use GIS in planning and policy making (Sieber, 2006). It also provides participants with local information, and allows engagement in public meetings (Sieber, 2006). Jose *et al.,* (2015) used a traffic light system, so that participants could select their favourite, middle choice, and their least favourite place. This was a useful approach as it allowed the analyst to then use this information and make informed decisions based on the community responses. This is a positive approach, as it allows the community to interact in development and post development phases of construction (Jose *et a*l., 2015), and is used widely in SUDS research (Everard, 2012). However, it may be subject to subjective bias (depends on design, see Keleman *et al.,* 2014). Another approach was to conduct interviews (O'Donnell *et al.,* 2017), and the aim of these was to evaluate the barriers to implementing blue green infrastructure. The recommendation was to place SUDS within the multiple benefit contexts, as well as to enable the monetisation of benefits.

2.4.1.3 Monetary assessment

There are many possible ways to monetise the benefits associated with a project, and this review will cover some of these, but it is acknowledged that other methods do exist but are not relevant to this chapter. However, for the purpose of this section, the focus will be on contingent valuation and implementing BeST (Benefits from SUDS Tool) to enable whole life cost assessment of SUDS, with a view to valuing ponds.

Contingent valuation

Contingent valuation is usually applied in local planning policy and provides respondents with a hypothetical scenario where they are asked to state their willingness to pay for an improvement to an environmental issue or programme (Arrow *et al.*, 1993) with an appropriate payment vehicle (e.g. taxation, annual or monthly payments). This process is cost effective and requires no additional market data and could be applied at a local scale for decision making. There may be some bias associated with participants providing unrealistic and 'pleasing' responses to valuation questions (Hausman, 2012). Furthermore, there could be bias with lack of responses and also from responses, which may result in unrealistic results (Arrow *et al.,* 1993; Hausman, 2012). Within this review, contingent valuation will be validated by referring to case studies where whole life cost assessment is applied. Very few studies focus on whole life cost assessment of SUDS ponds (Duffy *et al.*, 2008; Wolf *et al.,* 2015; 2016; Jarvie *et al.,* 2017).

The wider benefits from ponds were assessed using contingent valuation methods for ponds in the East of Scotland (Bastien *et al.,* 2012), and these valuations also included ponds within Edinburgh (Chapter 7). It was expected that public perception, and value, placed on ponds would be higher where the ponds were appropriately maintained. The study also assessed the effectiveness of management at ponds and discussed the implications for future operation and maintenance using whole life cost assessment. However, another study (Wolf *et al.,* 2014) assessed whole life cost of SUDS ponds focused on the case study of Dunfermline East Expansion (DEX), within East Scotland, and within this paper they concluded that SUDS (including ponds) were able to offset the initial capital (CAPEX) and operational (OPEX) costs during the construction phase. Wolf *et al.*, (2014; 2015) also focussed on the wider benefits associated with ponds, but this was applied in an Ecosystem Service context. Their study revealed that Ecosystem Services provided a valuable asset for SUDS but also had uncertainty in relation to monetising. Jarvie *et al.,* (2017) assessed whole life cost of ponds, and discovered that for three of four SUDS ponds, the value of habitat could offset the CAPEX and OPEX costs. This study demonstrated the importance of monetising the multiple benefits from ponds.

BeST

Literature with respect to implementing the BeST method is limited in its approach, with only a few case studies where this has been tested so far. Ashley *et al.,* (2015) review SUDS practices with reference to the past, present, and future policy developments. The main benefits are outlined as well as an indication of whether these are monetised within the tool, within the value transfer approach (Ossa Moreno *et al.,* 2017). This is an Excel, decision making, tool which appraises different drainage options without the need for a full market or economic assessment (O'Donnell *et al.,* 2017). The tool enables benefits to be screened and the main benefits, of significance, could then be chosen and valued. Site specific data are needed to operate the tool, and this could be a drawback for example where detailed maintenance schedules for sites are necessary (Duffy *et al.*, 2008).

Monetary valuation was discussed in O'Donnell *et al.,* (2016; 2017) for blue green infrastructure in Newcastle, UK, and the study assessed potential values. Monetary assessment is based on the Green Book (HM Treasury, 2013), with the discount rate of 3% in the first 30 years and a subsequent discount of 3.5% applied (Duffy *et al.,* 2008; Bastien *et al.,* 2012). In this case study, the multiple benefits are estimated and calculated using the BEST assessment and then evaluated with a GIS toolbox (O'Donnell *et al.*, 2016); which compares the benefits of a potential SUDS site with the expected operation and maintenance costs (through whole life cost assessment). The GIS toolbox revealed that benefit intensity (e.g. Hoang *et al.,* 2016) may change, spatially, in response to environmental factors. BeST was also applied to the case study of London (Decoy Brook Catchment, Ossa Moreno *et al*., 2017, and it was revealed that London has potential for providing multiple benefits (when assessed using BEST; Ossa

Moreno *et al.,* 2017). The most valued benefits, annually, were supply fees reduction and flood risk reduction.

2.5 Public perception of ponds

Public perception of SUDS is a well-established research area, but it has some controversial findings. Several authors have critiqued the social impacts of storm water management techniques (Apostolaki *et al.*, 2006; Apostolaki, 2007; Todorovic *et al.*, 2008). Apostolaki (2007) examines the issues in her PhD thesis. She adopts a survey approach to assess public and professional perceptions of storm water management techniques, and these views are integral to social acceptability of SUDS. Her chosen methodology combined qualitative and quantitative data from three different phases of research, and the questionnaires were analysed using "Sphinx" software (Apostolaki *et al.,* 2006; Apostolaki, 2007).

2.6 Water quality regulation

This section will discuss what has been done in relation to water quality regulation. It will begin with an introduction to biotic factors, and assessment of bioindicators using Biological Monitoring Working Party (BMWP) and Average Score per Taxon (ASPT) scoring systems. This feeds into the first research question which was to monitor the Ecosystem Service of water quality regulation using the proxy of macroinvertebrates, and also looking at the physico-chemical conditions of the ponds and comparing these to existing water quality standards. The section on water chemistry and abiotic factors feeds into research question one and two; as the parameters were important for analysis of both macroinvertebrates and diatoms.

2.6.1 Biotic factors: BMWP and ASPT (RQ 1)

Biological Monitoring Working Party (BMWP) is a scoring system which assesses indicator species (invertebrates) based on their tolerance or sensitivity to organic pollution. Each sample is analysed and then the scores are added together to provide a score for each site assessed. For example, a score of > 100 would indicate that the freshwater enevironment is more likely to be clean/ unimpacted by pollution.

It is important to monitor organic pollution in freshwater, as the scores are useful to determine whether a certain ecosystem is stressed or not. From this approach Average

Score per Taxon (ASPT) was derived, and these metrics account for the average sensitivity of a sample or site, and SEPA scores of 6 or above are an indicator of cleaner (good) water quality, but scores below this indicate that there is a disturbance to the ecosystem. Macroinvertebrates are good indicators of how stressed an ecosystem is, and is thus the preferred method (in this thesis) for assessing water purification for the provision of clean, safe, water in SUDS ponds.

Literature which focuses on ASPT is relatively scarce for pond environments. It should be noted that some of the studies refer to urban ponds which include SUDS (e.g. Noble and Hassall, 2014); where as one study is exclusively SUDS (Heal *et al.,* 2006). Table 2-7 outlines some case studies where ASPT values were observed in the field which follows the guidelines of the National Pond Survey and the British standards for macroinvertebrate sampling (Chapter 3).

Table 2-7 BMWP and ASPT values for pond studies

Study authors	Type of Pond	BMWP range	ASPT range	Case Study area
Sriyajarav and Shutes (2001)	Urban-constructed wetland/ pond	11 – 24	3 - 4	Turkey Brook, Pond, London
Heal *et al*., (2006)	SUDS	24 – 37	4 - 4.63	Cessnock, Ayrshire
Batty *et al.*, (2010)	Urban	5 -25	2.5 - 6.5	Various in England
Noble and Hassall (2014)	Urban	None reported	2.3 - 4.3	Bradford

2.6.2 Water chemistry and abiotic factors (RQ 1 & 2)

Table 2-8 represents some of the findings for pH in pond and wetland environments. Vermonden *et al.,* (2009) established that there were four categories of pond, and these included: turbid, nutrient poor, richly vegetated, and nutrient rich (eutrophic) conditions, with nutrient poor and richly vegetated conditions having higher pH observed than turbid or nutrient rich ponds. Gao *et al., (*2016) assessed the effects of seasonality on the pH observed and found a lower (more acidic) pH in winter than in summer months. Noble and Hassall (2014) observed the highest pH in an urban pond in Bradford, with a maximum value of 10.45, which could be stressful for pond ecology, due to high alkalinity, and is an indicator of poor water quality. Briers (2014), however, studied ponds in the East of Scotland and observed a circum neutral pH, which could be due to the neutral pH of rain water. This could also be a reflection of the underlying geology in Fife, with a local geology type of limestone (SNH, 2017).

Table 2-8 pH readings from the literature under various conditions

Study authors	Conditions	min pH	max pH
Szoszkiwicz *et al.*, (2010)	Variable	7.3	8.3
	Small sandy substrate	7.6	8
	Small stony substrate	8.1	8.3
	Large siliceous	7.8	8.1
	Organic	7.3	7.7
Read *et al.*, (2015): parameters in Neal et al., (2012)	Lowland	6	9
Vermonden *et al.*, (2009)	Turbid (taxa poor) pond	7.5	8.1
	Nutrient poor (taxa rich)	7.4	9.2
	Richly vegetated (taxa rich)	7.1	8.6
	Nutrient rich (taxa poor)	7.1	7.9
Venkatachalapathy and Karthikeyan (2015)	Cauvery River (India) pre-monsoon	7.8	8.7
	Post monsoon	7.9	8.8
Noble and Hassall (2014)	Urban ponds, Bradford UK	6.62	10.45
Stubbington et al., (2009)	Headwater streams	7	8.1
Hassall and Anderson (2015)	Unmanaged urban pond, Canada	7.7	8
	Stormwater management pond	7.9	8.4
Vincent and Kirkwood (2014)	Canadian stormwater management	7.7	8.57
Beutal and Larson (2015)	Biofilters/ outflow of pond, USA	7.3	8.3
Gao et al., (2016)	Summer and autumn (eutrophic)	7.5	9.6
	Winter	3	7.9
Nakanishi et al., (2013)	Irrigation ponds (high P & N likely)	5.6	9.3
Briers (2014)	Various ponds: East Scotland	7.3	7.9

Table 2-9 outlines the findings in the literature for Electrical Conductivity (EC) in ponds. The lowest observed EC values are 0, which could be classed an anomaly, and 26 for irrigation ponds. The highest observed EC values are 3800 (Hassall and Anderson, 2015) and 3978 (Vincent and Kirkwood, 2014) in stormwater management ponds (SUDS). Briers (2014) observed a minimum EC value of 539, which is similar to the findings in the New Zealand study for summer (min= 533). The highest value of 752 is similar to the highest level in a Polish lake, where diatoms are present, (values= 789; Elzbieta *et al.*, 2012). This could suggest that the ponds in the East of Scotland also have diatoms present.

Table 2-9 Electrical Conductivity readings in the literature under different conditions

Study authors	Conditions	min EC (μ/s cm^{-1})	max EC (μ/s cm^{-1})
Stubbington *et al.*, (2009)	Headwater streams	227	662
	Outliers	0	1200
Hassall and Anderson (2015)	Stormwater management	800	1800
	Outlier 1		2600
	Outlier 2		3800
Hamer *et al.*, (2012)	Stormwater management ponds	240.5	1228
Vincent and Kirkwood (2014)	Stormwater management ponds	270	3978
Elzbieta *et al.*, (2012)	Periphyton/ diatoms- Polish lake	388	789
Beutal and Larson (2015)	Clark's creek, Wisconsin	226	228
Nakanishi *et al.*, (2013)	Irrigation ponds	26	306
Sutherland *et al.*, (2014)	NZ pond: winter	390	512
	NZ pond: spring	506	576
	NZ pond: summer	533	590
Briers *et al.*, (2014)	Various ponds: East Scotland	539	752

Monitoring Turbidity is an important aspect of water quality in ponds and lakes. Table 2-10 outlines the studies where different measurements of turbidity are recorded, and these include:

- FNU- Formazine Nephelometric Units
- NTU- Nephelometric Turbidity Units

Ponds with duckweed have values which range from 22 to 167, which could be due to greater plant biomass present in the water. Marttila and Kløve (2012) have the highest observed turbidity with a value of 814, when three field sites are compared. Studies where flocculant is added to the water tend to have lower turbidity observed than studies where no flocculant was added (Gutiérrez *et al.*, 2015).

Table 2-10: Turbidity readings from the literature under different conditions

Study authors	Conditions	Min value (NTU)	Max value (NTU)
Atiz *et al.*, (2014)	Solar ponds	1	100
Tu Nyugen *et al.*, (2014)	Micro macro algae solution	0	419
Mathuraman and Sasikala (2014)	drinking water tests, using synthetic waste water	100	500
Lee *et al.*, (2013)	mine drainage	100	500
Gutiérrez *et al.*, (2015)	flocculant (*) no flocculant (+)	2.2*	385+
Näykki *et al.*, (2014)	107 natural water samples	0.24	67.3
Marttila and Kløve (2012)	Variance across 3 field sites (multiple samples taken at each)	3	814
Waajen and Lürling (2014)	3 ponds - eutrophic conditions	44	92
Xu and Boyd (2016)	Fish monitoring: ponds, fisheries centre, Auburn	0.9	132.3
Prygiel *et al.*, (2014)	Algistatic treatment of cyanobacteria	4.9	29.6
Vanitha *et al.*, (2013)	Duckweed to improve water purification (Nitrate and Phosphate)		167
Ran *et al.* ,(2004)	Wastewater wetlands: duckweed	22.6	48.2
Alam *et al.*, (2016)	Drainage water (irrigation purpose)		16.67
Bokhari *et al.*, (2016)	Phytoremediation of heavy metals	5.3	13.6

2.6.3 Nutrient loading and removal

Total Nitrogen (TN) and Total Phosphorus (TP) removal was examined in a recent study in China (Zhang *et al.,* 2016). The ponds consisted of an inlet and outlet system with a connecting artificial wetland. TN removal efficiency was variable from May to October, with the lowest recorded in mid-May and June. However, the highest TN removal was recorded in July and August, with 63.4% and 37.4% respectively. It was argued that the efficiency of the TN removal by the presence of plants being able to purify the water, which was also the case for a wetland nutrient removal study (Fisher and Acreman, 2004). TP removal studies in India revealed that wastewater purification of wetlands changed the trophic status from eutrophic to meso-trophic (Das Gupta *et al.,* 2016). Rapid removal of TP assisted with the process, and the study provided an insight into how wetlands could reduce the risks associated with eutrophication; for example, lower Dissolved Oxygen and ecological stress (Das Gupta *et al.,* 2016). Evidence from other wetland studies suggests that the removal rate of phosphorus (TP) is variable in natural wetlands; for example, some wetlands had a reduction in TN but not TP (Fisher and Acreman, 2004). It was also revealed that some of the wetlands increased the level of nutrient loading, and there were some which did not have net retention or release, which could also be applicable in a SUDS context, or in an agricultural catchment.

2.7 Nutrients (water quality regulation)

This section will discuss the importance of nutrients in relation to regulating water quality and review the studies which assess algae and diatoms and the contribution to the Nitrogen cycle. This section introduces the proxy of diatoms and algae and discusses these with respect to current monitoring in freshwater systems. It also discusses the importance of monitoring eutrophication and the implications which this has on the freshwater environment; thus, relating to research question three which compares the ponds in relation to nutrient pressures, and uses diatoms to achieve this.

2.7.1 Algae and their contribution to the Nitrogen cycle

There is an overlap between studies which explore nutrient removal and those which assess algal blooms. This review will focus on the importance of the Nitrogen cycle and its stages in the development and support of two proxies: diatoms, and algae. No previous review focuses on the importance of recycling nutrients to provide clean, safe, water in pond environments. However, there are existing studies which support the monitoring of algae species (Bellinger and Sigee, 2015) and diatoms (Kelly and Whitton, 1995; Kelly *et al.,* 2001) for the protection of freshwater environments. This review will also focus on the importance of understanding what algal blooms are and the likely environmental and physical conditions which promote development (Paerl and Otten, 2012). Previous studies have focussed on the need to monitor toxic algal blooms with the development of cyanobacteria (Carvalho *et al.,* 2012) within lake and river environments. Very little knowledge is known about cyanobacteria in pond environments, and the importance of monitoring annual changes for human and wildlife health concerns. This review will primarily focus on monitoring harmful algal blooms and the implications these have for freshwater ecosystems; as well as human health.

2.7.2 Diatom and Algae proxies

Diatoms are silica rich organisms, which have glass cell walls known as frustules (Kelly and Whitton, 1995; Kelly, 2001). Diatom species are known as *Bacillariophyta* and flourish in spring (Ward and Dufford, 1979). Paerl and Otten (2012) discuss that diatoms thrive in temperatures between 15°C and 20°C, and blooms are unlikely to occur in dystrophic conditions, which refer to acidic conditions where life is less likely to be supported. Health of diatoms and conditions of stress could be assessed using toxicity tests to determine sensitivity to copper (Cu) and zinc (Zn) (Pandey and Bergey, 2016). Diatoms are important indicators for nutrient sensitivity; particularly of phosphorus (Kelly and Whitton, 1995), but also for intracellular uptake of Nitrogen (Kamp *et al.,* 2011).

Algae are simple organisms which are observed in freshwater ecosystems and have different morphologies and appearances (Bellinger and Sigee, 2015). Algae may be branched (filamentous) or not. These species are characterised by their ability to act as symbionts for cyanobacteria; as well as their contribution to the Carbon cycle.

2.7.3 Eutrophication (Research Question 2)

Studies have focussed on the issue of eutrophication in freshwater and marine environments, but for this review, pond and lake studies will be discussed. Eutrophication refers to the process whereby a water body becomes over enriched with nutrients- phosphorus and nitrogen- and remains an issue within Europe, despite the tightening of regulations for lakes with the Water Framework Directive (Polkane *et al.,* 2014). Eutrophication results in reduced Oxygen supply to the water body, an increase in undesirable plants and vegetation, and an overall decrease in flora and fauna diversity (Singh *et al.*, 2017); thus, it is important to reduce the threat of eutrophication in freshwater environments.

2.7.3.1 Harmful algal blooms and their impact on health and wellbeing

Brooks *et al.*, (2015) reviewed the effect of algal blooms of inland water quality, and asked the question: "are algal blooms becoming the greatest threat to inland water quality?" (p7). Intrinsic factors relate to climate change, hydrological regime shifts (flooding to drought periods) and anthropogenic influences, such as stormwater runoff and contaminants (Paerl and Otten, 2012; Brooks *et al.*, 2015). Other factors which govern the natural process of algal bloom development include nutrient enrichment of water, increased levels of light and photosynthesis (as a result), and a decrease in available oxygen (Heinonen *et al.*, 2001; Paerl and Otten, 2012).

In addition to this, there are an increasing number of ponds and lakes which are classified at eutrophic status (Carmichael *et al.*, 2004; Brooks *et al.*, 2015). This is likely to worsen with the need and demand for stormwater management (Lewitus *et al.*, 2008), and provision of SUDS ponds. A Dutch study discovered that monitoring of urban ponds revealed that three species of cyanobacteria were responsible for the observed blooms, and these were: *Microcystis*, *Anabaena* and *Planktothrix* (Waajen *et al.*, 2014). In their study, they identified key bloom forming cyanobacteria species using light microscopy, as well as monitoring the chlorophyll-a levels using a fluoro-probe.

It is important that algal bloom awareness is increased, perhaps through educating the public, or providing a platform where questions or worries may be addressed (Hardy *et al.*, 2016). Currently, monitoring and risk assessment programmes relating to harmful algal blooms are limited in developed and developing countries, so action should be taken to improve this (Brooks *et al.*, 2015). Furthermore, it is of fundamental importance that urban ponds are monitored and their level of toxicity in relation to algal blooms is assessed (Waajen *et al.*, 2014). A study in South Carolina also supported this view, as they monitored storm detention ponds near the coast and found that there was an abundance of harmful algal bloom species present within recreation and residential ponds (Lewitus *et al.*, 2008).

Harmful algal blooms and their development is an important aspect to consider when assessing algae in ponds and lakes. The health implications for animals and humans should not be overlooked, as there is frequent contact with the waterbody for recreation and pets and children could be at risk (Lewitus *et al.,* 2008). Health issues include the development of neuro (brain) and hepatic (liver) toxins which could reduce the quality of life for those in contact with the toxic waterbody, and also there could be stomach disorders, such as gastroenteritis (Heinonen *et al.*, 2001). Watson *et al.*, (2015) discussed the topic of harmful algal blooms in detail and referred to the economic consequences as well as the inherent loss of diversity within ecosystems, and human health implications. Harmful algal blooms containing cyano-toxins also render drinking water supplies unsuitable, and not safe, for human consumption (Smith and Schindler, 2009). However, there are other types of harmful algae, for example some diatom species produce domoic acid including *Pseudo Nitzchia* (Watson *et al.*, 2015). Diatom species could influence the water treatment process, for example by clogging up filters and increasing turbidity (Watson *et al.*, 2016; Boyd, 2015). Other species of algae which may impair drinking water quality include *Crysophytes*, which have been reported to have a cucumber odour, but these species also feed on some cyanobacteria; so their presence in water is of benefit to health- as the toxicity of the bloom could be reduced (Watson *et al.*, 2016). *Euglenales* are fatal to fish in small ponds, as these species produce toxins which harm fish but no known effect on human health (Watson *et al.*, 2016; Zakrys *et al.*, 2017).

2.7.3.2 Algal growth - Cladophora Glomerata (SUDS ponds, Dunfermline)

Johnson (2006) examined the rate of algal growth in SUDS ponds within the Dunfermline East Expansion (DEX) site in the East of Scotland. Algal growth was monitored seasonally, and the rates were mapped within a GIS (Geographical Information System). Additional water quality parameters were assessed and these included chlorophyll- a levels in the ponds studied (verified at SEPA). The study indicated that there was dominant cover of *Cladophora Glomerata* in some ponds but not in all ponds. There was no reference to other algal types made in this study, but there were inferences made that other groups of algae could be present in ponds where *Cladophora Glomerata* species were not observed.

2.7.4 What needs to be done?

The following key gaps were discovered in the literature with respect to nutrient enrichment, and diatoms. Some of these gaps were not able to be addressed within the thesis due to time and capital constraints (Chapter 3), but it is useful to point out areas which should be considered in research.

- SUDS ponds: monitoring of proxies and their relationship with nutrient cycling
- Diatoms and their relation to N cycle → intracellular nitrite and nitrate uptake
- Cyanobacteria in SUDS ponds → nitrogen fixing capabilities
- Fluxes measured in ponds (not feasible within the limits of this research project)
- Site specific factors which determine whether an algal bloom is likely (frequent monitoring→ seasonal differences)
- Monitoring strategies → cost effective → inform public of health risks

Two of the most important gaps in the literature are: 1. site specific factors which determine whether an algal bloom is likely; particularly in reference to new developments and determining whether ponds need to be managed more effectively, and 2. Monitoring strategies and informing the public of health risks from nutrient enrichment- specifically in the summer months with seasonal growth of algae.

2.8 Pollination (species diversity of plants, Research Question 3)

This section will focus on the process of pollination to deliver the Ecosystem Service of wild species diversity, and this forms Research Question 3, which evaluated the potential of SUDS ponds to provide pollinating plants; particularly wind and insect vectors of pollination. It will begin with a brief overview with why pollination is important to monitor then discuss the types of pollination, and end with a discussion on the importance of monitoring pollinators for the Ecosystem Service.

2.8.1 Why is pollination important?

Pollination is an important ecosystem process involved in the ecosystem service delivery of plant species diversity. In general, pollination is a key component of urban and rural plant diversity, and food production (global scale). The factors affecting diversity of plants range from biological – predation, competitions, nutrient availability, and light for photosynthesis- to economic factors – resource availability, capital and expenditure. Climate change also influences changes in plant diversity, and the availability of rainfall is another key factor in determining where and when a plant grows. This is applicable to ponds (Stewart *et al.,* 2017), and wetlands (Hill *et al.,* 2016).

Furthermore, the process of pollination is vital to the functioning of aquatic ecosystems; for example, an abundance of wetland plant species contributes to the overall diversity where pond and wetland sites are connected (see Hill *et al.*, 2016). Wetland plant species are important indicators of local diversity and could contribute to local conservation goals and interests (more generally).

Previous studies have explored pollination potential in wetland environments, with only one recent study focussing on ponds (Stewart *et al.,* 2017). This study involved assessing pollination and the connectivity between terrestrial and aquatic plants. The main outcome was that it is possible to quantify pollination potential at a local scale which is not dissimilar to other studies, (Philbrick and Les, 1996; Fink, 2007), which focused on the importance of pollination within aquatic ecosystems. Stewart *et al.,* 2017 discovered that there were significantly more bees and syrphids (hoverflies) near pond ecosystems than in control environments (agricultural). To the knowledge of the author, there are no pollination related studies (in detail) within drainage ponds (SUDS).

2.8.2 Pollinator Types

Two types of pollination will be discussed, and these are:

- animal pollination; and,
- wind pollination

Wind pollination is an important process, as it allows transfer of pollen without the need for flowers or insects (Friedmann and Barrett, 2009). Wind pollinating plants such as sedge grasses (*Carex, spp.)* and Reed mace/ Cattails (*Typha Latifolia)* have smaller flowers and these are of less interest to insects, due to the scentless and dull coloured morphology (Friedmann and Barrett, 2009). Furthermore, there is less chance to capture multiple pollen grains than insect pollination vectors (Friedmann and Barrett, 2009), but honey bees cannot do it by themselves due to increased demand and pressure (Garibaldi *et al.*, 2011; Vanbergen, 2013). Hayter and Cresswell (2006) observed that some of this change was seasonal and wind pollination was in place in spring where the air temperature was less warm.

Animal pollination is under threat due to the discussed factors above. Animal pollinators, in general, refer to native insects, birds, and bats which provide the process of pollination to enhance local and regional species diversity. However, there are increasing concerns of non-native insects and birds reducing the efficiency and potential for pollinating plants (Vanbergen, 2013).

2.8.3 Ecosystem Service (ES) delivery in aquatic ecosystems

Ecosystem Services for ponds is a difficult task to monitor and quantify; especially in relation to the concept of pollination. Pollination is defined by some authors as an Ecosystem Service, for example: "provision of pollinators for reproduction of plant community" (Costanza *et al.,* 1997, p254), with the National Ecosystem Assessment viewing pollination as an intermediate service, which relates to the process involved to allow the main benefit of species diversity to happen. Others have referred to the process of pollination as: "Mobile agent-based Ecosystem Services (MABES)", which refers to services or benefits which occur at a localised scale due to the presence of mobile organisms (Kremen *et al.,* 2007, p300). This process may occur between or within a given habitat (Kremen *et al.,* 2007; Naidoo *et al.,* 2008). Farber *et al.,* (2008) classify the process of pollination within supportive functions and structures, which is accepted as the supporting Ecosystem Services by other authors- as the processes and functions required for the whole ecosystem to function (Kremen *et al.,* 2007; Bonmarco *et al.,* 2013) . This classification (Section 2.2) process is stigmatised by poor understanding of the key processes involved to provide the end user defined benefit/ service. This approach is common at landscape and national scales where disagreement in terminology (Fisher *et al.,* 2009) and classification could cause confusion to policy makers (Mace *et al*., 2012), academics, and the general public. Within the context of the review and the results (Chapter 6), the definition according to the National Ecosystem Assessment will be referred to; as this should reduce some of the uncertainty associated with defining pollination as an ecosystem service. For simplicity, pollination will be reviewed as the process which provides indirect benefits to humans through enhancing local plant, species, diversity.

Pollination has a direct and indirect value to ecosystems, and humans by extension of the provision of key benefits. The direct value to humans is in relation to the increased plant diversity which in turn provides valuable crops and related assets (e.g. agricultural land, Stewart *et al.*, 2017). Indirect values could include the conservation value (e.g. Chan *et al.*, 2006) or enhancing local plant species diversity (Knapp *et al.*, 2008; Venjakob *et al.*, 2016).

2.9 Chapter Summary

This chapter provided a history of SUDS with reference to evolving terminology (Fletcher *et al.*, 2015), as well an overview of the main legislation pertaining to SUDS in Scotland (Table 2.2, 2.3, and 2.4). It also discussed Ecosystem Services and multiple benefits (Chapter 7) in relation to SUDS and the public perception of ponds. The main Ecosystem Services that the thesis addresses (Chapter 4, 5, and 6) were discussed in detail; as well as examples from existing studies in ponds or lakes. This research is of importance because no field evalauation studies exist in relation to quantifiying the water quality regulation benefits in relation to macroinvertebrates (RQ 1) and diatoms (RQ 2). Furthermore, no studies have quantified SUDS ponds in an Ecosystem Service framework (Chapter 8) or related these to the main Water Framework Directive objectives, because very little legislation exists for small water bodies. Chapter 3 will build on this discussion by presenting the key methods involved in data collection for the field monitoring and qualitative components of the research.

Reviewing the existing literature pertaining to Ecosystem Services and SUDS identifies key gaps in knowledge which should be examined:

- Identifying key metrics for the Ecosystem Services of SUDS
- Quantifying ecosystem processes and services through field and laboratory studies
    - Water quality improvement (inlet to outlet) → water quality regulation (RQ 1 & 2)
    - Nutrient removal → water quality regulation (RQ1 &2)
    - Pollination → plant species diversity (RQ 3)
- Providing an innovative framework comparing SUDS and non-SUDS ponds.

Chapter 3- METHODS AND DATA COLLECTION

3.1 Overview

The literature review established the importance of ponds; particularly in the context of SUDS. Ecosystem Service (ES) monitoring of SUDS ponds is important to demonstrate the wider benefits and values associated with ponds, and how well-functioning ponds can offer multiple benefits to communities.

The methods for monitoring the Ecosystem Service of Water Quality Regulation will be evaluated in this chapter, with reference to biological, physical, and chemical proxies. Although, work exists to define ponds in a water quality and specifically diffuse pollution control context for SUDS, there is limited research into the Ecosystem Service delivery of the ponds between the inlets and outlets (Crimmins, 2015). Furthermore, the work which exists does not quantify these Ecosystem Services in relation to the Water Framework Directive. It is hence the nature of this research to compare SUDS ponds and non SUDS ponds in relation to their ecosystem service delivery (Chapter 4,5) but also within the context of multiple benefits (Jarvie *et al.*, 2017; Chapter 7).

The second Ecosystem Service of wild species diversity (NEA, 2011; 2014) will be discussed in relation to flowering plants and the potential for pollination. This Ecosystem Service is chosen to demonstrate the importance of choosing plants at ponds with the potential for increasing wild plant diversity. A recent study documented this importance within an agricultural context (Stewart *et al.*, 2017) and others have discussed the potential from a theoretical perspective (Jose *et al.*, 2015). However, the association between field-based research and pollination potential remains to be quantified for SUDS ponds; so, Chapter 6 will discuss the importance of planting pollinating species. Figure 3-1 highlights the methodology map chosen for the chapter. Section 3.4 will also provide details of field methods explored but not adopted within the final thesis; due to limitations and financial constraints.

The distinction between intermediate and final services is often confused (La Notte *et al.*, 2017) with the possibility for double counting, and this will be highlighted (

Figure 3-2). In addition to this, the methodology associated with the public perception study for the multiple benefits of ponds will be discussed. A framework which evaluates the key multiple benefits (based on field results) will be presented (Figure 3-10).

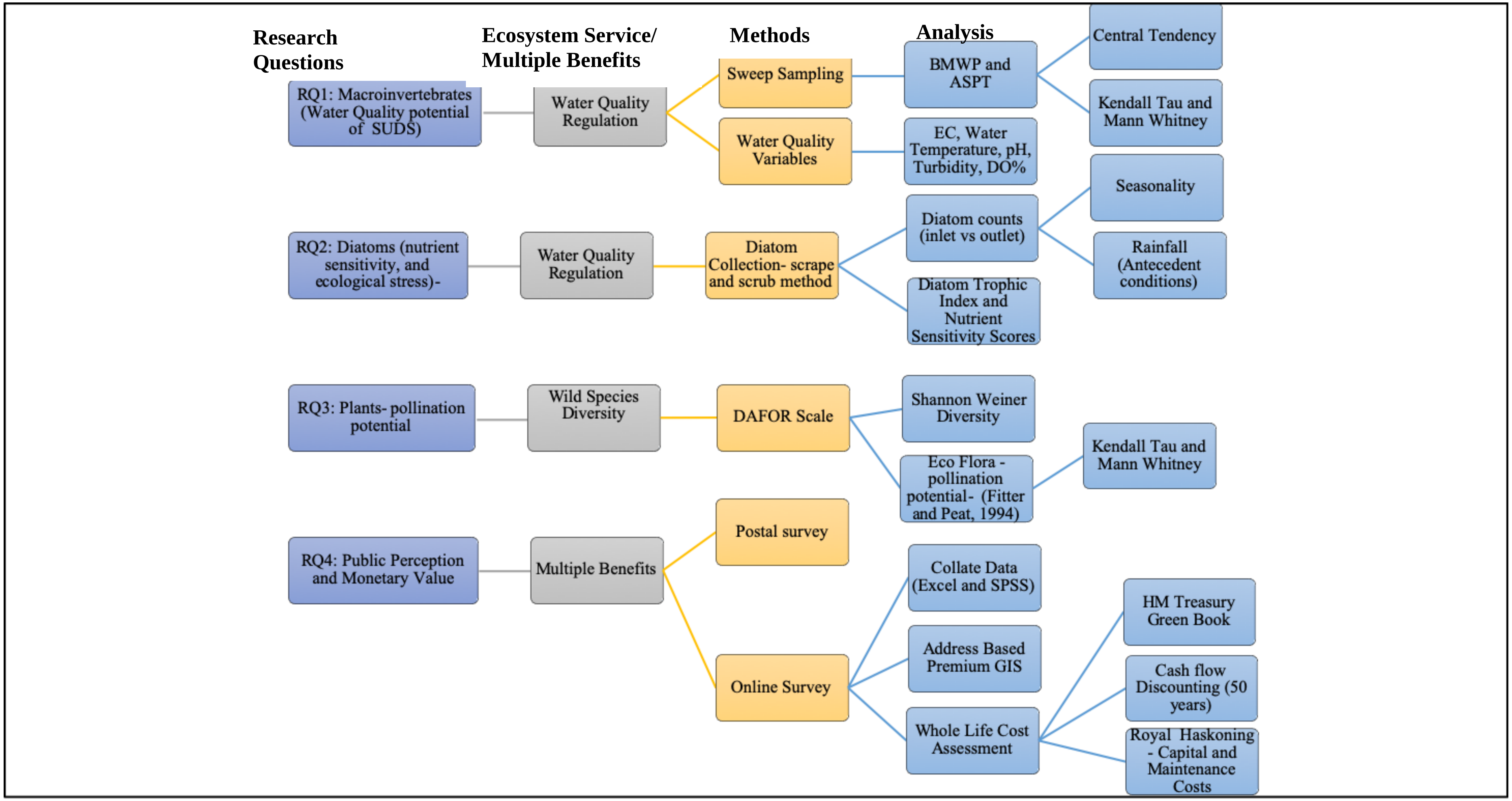

Figure 3-1: Conceptual Map of methodology (ASPT= Average Score per Taxon; EC= Electrical Conductivity, WT= Water Temperature, DO= Saturated Dissolved Oxygen; DAFOR (Dominant, Abundant, Frequent, Occasional and Rare)

SUDS are designed as a system and it is important to monitor their biology and chemistry. Few papers highlight the importance of SUDS for biodiversity (e.g. Viol *et al.,* 2009; RSPB, 2012; Briers, 2014) but none of these focuses on the importance of Ecosystem Services. It is therefore important to quantify all of the ES for existing SUDS pond systems. However, the feasibility of this idea was reduced due to sampling effort and affordability of equipment to capture all of the necessary Ecosystem Services (e.g. flood reduction and Carbon capture). The solution to this issue was to scale down the number of ES captured within field monitoring (Figure 3-1) and to focus on a larger number of ponds. Until 2015, quantifying ES in the context of urban drainage was very limited (Moore and Hunt, 2012) even though studies existed which focused on urban pond studies (Viol *et al.,* 2009; Hassall *et al.,* 2014). Some studies focus on species diversity with reference to macroinvertebrates (Viol *et al.,* 2009), but in order to reduce overlaps, the methodology will use macroinvertebrate abundance for pond water quality regulation only. Nutrients are explored in the context of ponds but have not been quantified in terms of potential for Ecosystem Services. Hence, it was decided to focus on the key gaps in the literature, and these were: Water Quality Regulation in SUDS ponds using macroinvertebrates, and diatoms as proxies. An additional gap was quantifying pollination potential at SUDS ponds with respect to promoting the ES of Wild Species Diversity. Lundy and Wade (2011) demonstrated the importance of quantifying ES within an urban context, and to date very little information supports this statement in relation to SUDS ponds, and their potential ES delivery.

Furthermore, to date, the multiple benefits of SUDS have not been quantified in monetary value, but had been discussed in other public perception contexts (e.g. Wade *et al.*, 2012; Jose *et al.*, 2015); so these were evaluated using Whole Life Cost assessment as a follow up from the public perception study and Contingent Valuation (Section 3.4.2). The Multiple benefits categories focused on the aspects of the original conceptual framework (see IAHR paper in *appendix*), which is now updated (Figure 3-1) to evaluate overlaps (Figure 3-2), as well as areas which were difficult to quantify through field assessment (Cultural benefits).

3.2 Double Counting

In order to deal with potential overlaps from collected data (during the field work), a decision was made to integrate the ecosystem processes of detoxification and purification (identified as supporting service in MEA, 2005). This is because of the potential for macrophytes (as a proxy) to overlap with nutrient enrichment. Also, the proxy of macroinvertebrates overlapped between purification and nutrient enrichment (especially *gastropods* and *chironomids*, which are evidence of tolerance to polluted conditions). Macroinvertebrates are of importance to the ponds studied, as presence not only provides an indication of the water health; but these contribute to the purification process by feeding on detritus and dead plants (Covich *et al.,* 1999). Furthermore, macroinvertebrates sustain the ecosystem and assist with the cycling of nutrients through bioturbation processes (Boyd, 2015), as well as through egestation and natural decay (Palmer, 1997). The function of macroinvertebrates as nutrient cyclists and purifiers therefore should be considered as one ecosystem function- as a combination of the processes results in Water Quality Regulation. Clean water is the ecosystem service as this is of direct or indirect benefit to humans- e.g. health benefits to humans or pets.

Algae as a proxy overlapped with photosynthesis, and monitoring primary productivity within ponds, but in order to fully assess this contribution, Chlorophyll-a measurements were needed. However, this was out with the scope of the research project, due to funding constraints, so the issue of double counting could not be avoided. Overlaps could also have occurred between the proxy of macroinvertebrates and the relationship with species diversity. For this reason, it was decided to consider the proxy of macroinvertebrates and diatoms for Water Quality Regulation, and to use macrophyte results for Wild Species Diversity only. This was with a view to evaluate whether the SUDS ponds had flowering plants suitable for pollinators (Eco-Flora; Fitter and Peat, 1994) Pollination of flowering plants by insects, seed dispersal by birds, and by water is essential for the provision of wild species diversity.

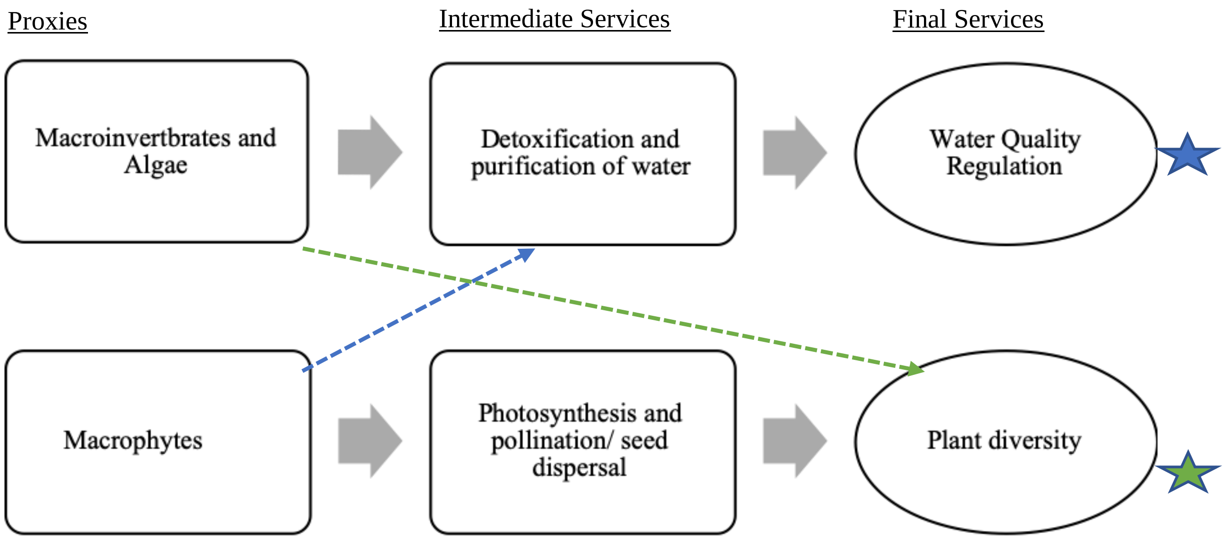

Figure 3-2 Proxies, Intermediate Ecosystem Services (main processes) and Final Ecosystem Services (adapted from NEA, 2011; 2014) are represented. Potential overlaps and solutions to these uncertainty aspects are provided. MI represents macroinvertebrate taxa, MP represents macrophytes/ pond plants, and Algae represents diatoms.

3.3 Ponds and their characteristics

This section outlines the type of pond studied and their general catchment characteristics. Field monitoring happened between July 2014 and August 2016. Eight ponds were chosen to allow comparison of the key Ecosystem Services of water quality regulation and wild species diversity; as well as their associated intermediate services (processes). Data collection (Table 3-1) started at different times due to consent and access issues, and some health and safety factors, for example some private owners perceived the ponds to be dangerous or not suitable for field work. Other owners were concerned with on-going maintenance work. Figure 3-4 shows the location of the ponds This resulted in some pond having longer data sets than others. Uncertainty was reduced by comparing the median values of the ponds to highlight differences between ponds and to see whether key trends and differences were observed (Section 3.7).

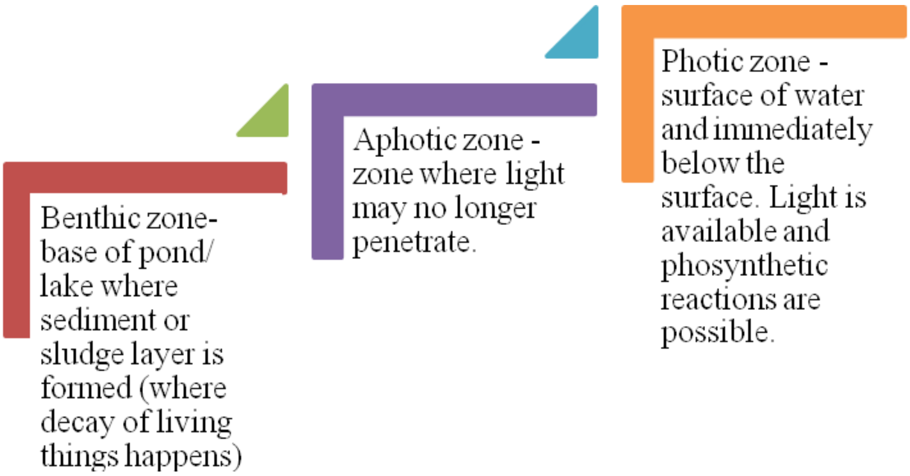

Figure 3-3 Zones of the ponds (adapted from Oertli *et al.*, 2008)

The benthic and photic zones were sampled (Figure 3-3) during the field work for each pond. Benthic refers to the base of the pond- within the sediment, and surrounding substrate. Photic is the area where light is available.

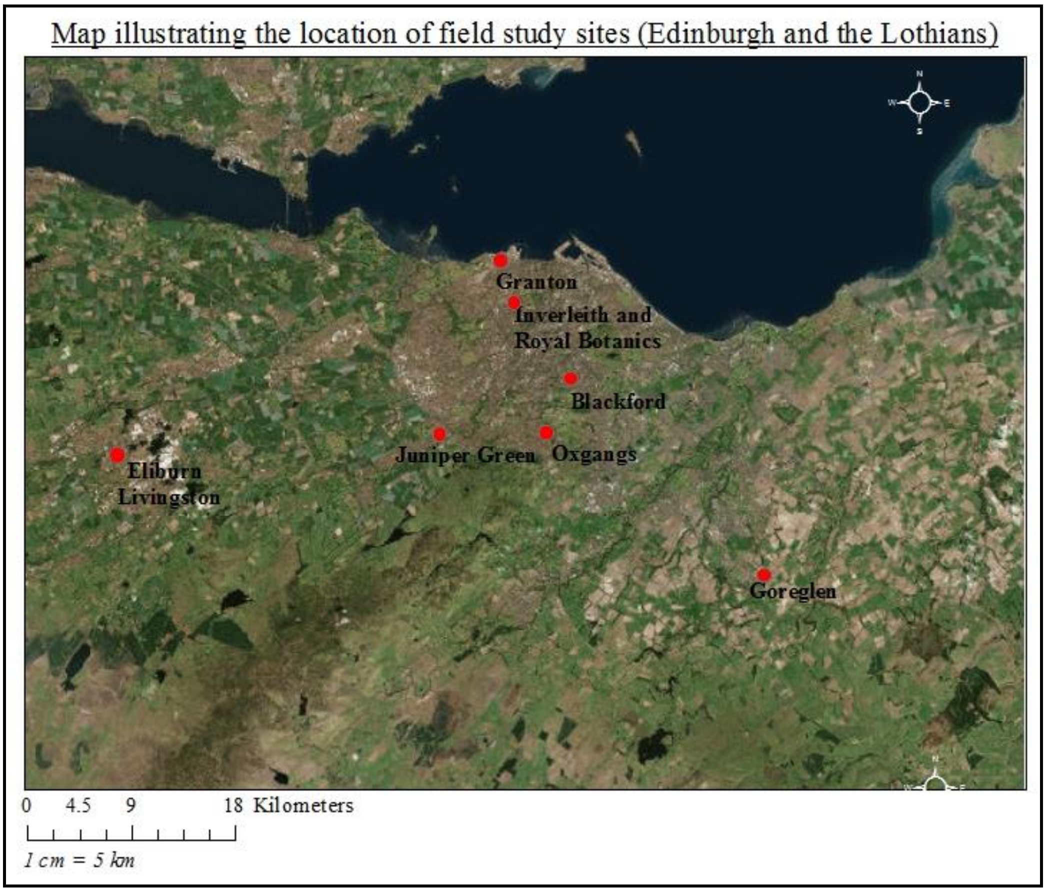

Figure 3-4 Map illustrating the location of the eight study sites for the data collection: ecological survey (Chapter 4, 5, and 6) and public perception of multiple benefits (Chapter 7). Inverleith and Royal Botanic Gardens are illustrated as one point- as these locations are very close together.

Table 3-1: Pond characteristics (setting, use, and surface area), date established, and the monitoring period

Case Study (Edinburgh unless stated otherwise)	Pond Setting	Pond Type	Use of pond	Surface Area (m^2)	Date Established	Timetable and Frequency (n=)
Granton Pond	Park. Near supermarket and college.	SUDS pond	Primary function is to enhance biodiversity	12,000	2005	2014 (n=5) 2015 (n=10) 2016 (n=8)
Juniper Green Pond	Residential area. Situated near the Water of Leith footpath.	SUDS pond	Provides amenity (focal point from flats)	240	2005	2015 (n=11) 2016 (n=7)
Oxgangs Pond	Residential area.	SUDS pond	Amenity and flood risk benefits.	8,099	2007-2010	2015 (n=9) 2016 (n=6)
Eliburn Pond (Livingston)	Residential area. Near light industry.	SUDS pond	Not accessible to the public	1675	2007-2011	2015 (n=10) 2016 (n=6)
Blackford Pond	Local Nature Reserve	Non SUDS pond	Biodiversity and amenity	13,500	1800-1900	2015 (n=10) 2016 (n=8)
Goreglen Pond	Woodland setting. Near main road.	Non SUDS pond	No use currently. Flood plain.	500	1794-1861	2015 (n=8) 2016 (n=7)
Royal Botanic Gardens Pond	Former estate. Near residential area.	Non SUDS pond	Amenity and education. Outflow pipe to the Water of Leith. Feeding wildfowl.	4,560	1880	2015 (n=8) 2016 (n=3)
Inverleith Pond	Park setting Near residential area.	Non SUDS pond	Model boat activities, recreation, and feeding wildfowl.	43,554	1870	2015 (n=8) 2016 (n=7)

3.4 Field work

In this chapter, the chosen methodology to enable monthly ecological sampling at the eight ponds is discussed (Figure 3-1; Figure 3-2). Whilst, efforts were made to collect field data at monthly intervals, this was not always possible due to adverse weather conditions (some months), or inability to access due to overgrown vegetation, or colleagues unable to assist. An additional issue was that the pond at the Royal Botanic Gardens (Edinburgh) had an issue with their pump and the pond was inaccessible in months where this was drained. The field campaign for all eight ponds ran from April 2015- August 2016 (except for conditions outlined above, see Table 3-1 for a calendar). The four main research questions will be re-introduced, and the methods will refer to how these are addressed in the thesis.

3.4.1 Macroinvertebrate collection and water quality parameters

<u>Research Question 1</u>

How effective is Water Quality Regulation in ponds between the inlet and outlet, with respect to: -water chemistry, influence of rainfall, and nutrient loading?

To answer this question, water purification (water quality regulation) was monitored by collecting macro-invertebrate data at monthly intervals (where possible, Table 3-1) and identifying these samples in the laboratory to family level in line with the requirements set out by British standards (BS EN ISO 10870 (2012).

3.4.2 Methods considered for sampling macroinvertebrates

In the earlier stages of project development, several methods were considered (Table 3-2) by consulting the literature and also external experts. There were several possible methods which could have been adopted for field work. However, due to budget and time constraints, some of the methods were infeasible. These would either have required extensive training to carry out the method; for example, Surber sampling- which would be excellent for capturing benthic dwellers. Kick sampling was also considered, but there is relatively limited flow for this method to be employed in full. It would also be more difficult to capture surface dwellers- which the chosen method is able to encapsulate. Given the nature of the ponds studied, the method discussed below is most suited to the needs of the project within the defined timescale and budget.

Table 3-2 Methods considered for macroinvertebrate sampling

Method/ approach	**Vegetation**	**Shallow water**	**Collection of surface dwelling macro-invertebrates**	**Soft substrate**	**Hard substrate**
Handnet	Good	Excellent	Only active method	Suitable	Suitable
Surber sampler	Limited	Depends on flow	Not suitable	Suitable	Suitable
Box sampler	Designed for vegetation & macro-invertebrates may be collected	Limited use in slow flowing/ no flow environments	Not suitable	Suitable	Suitable
Cylinder sampler	Used for vegetation strands	Dependent on flow	Not suitable	Suitable	Suitable
Naturalist's dredge	Limited in dense vegetation	Less suitable	Not suitable	Suitable	Suitable
Eckman Birge grab	Not suitable	Pole mounted version needed	Not suitable	Suitable	Suitable for particles <16mm
Ponar grab	Not suitable	Not suitable	Not suitable	Suitable	Suitable for particles <16mm
Van veen grab	Not suitable	Not suitable for water <0.5m	Not suitable	Suitable	Suitable for particles < 16mm
Polyp grab	Not suitable	Not suitable	Not suitable	Suitable	Suitable
Air lift	Not suitable	Limited use- due to rising air	Not suitable	Suitable for fine substrate	Not suitable
Core and tube sampler	Not suitable	Suitable	Not suitable	Suitable	Limited by diameter of tube
Colonisation sampler	Suitable	Suitable	Not suitable	Suitable	Suitable

The method chosen was using a hand net for sweep sampling- which was modified to suit the habitat of the pond and a minute was spent kicking the substrate of the pond to capture benthic dwellers; as well as the macro-invertebrates in the middle and surface of the pond water. A sample was taken at the inlet and outlet for each pond to see if there was a statistically significant difference between observed inlet and outlet conditions. These differences were then compared between the SUDS and non SUDS ponds.

3.4.2.1 Sampling procedure for macro-invertebrates

Sampling was carried out monthly (where possible) and macro-invertebrates were separated from the pond net (standard mesh size of 2mm, NHBS, 2016) and placed in a sorting tray. The pond net head had a diameter of 250mm, depth of 260mm, and a length of 280mm (NHBS, 2016). A long handle, with telescopic extension, made sampling feasible in deeper water. However, the net was more difficult to use in coarser vegetation, and in these cases the timed sampling would be interrupted to empty the net contents into the white tray.

Excess debris and sediment were washed, with pond water, to search for macro-invertebrates; as well as live fish and amphibians, or their spawn (depending on the season). Any identified amphibians or fish were separated and later placed carefully into the pond water. This ensured that fish or amphibians that were caught were returned unharmed, in line with ethical procedures, and this was of particular concern during the spring and summer seasons where spawn and tadpoles are present in abundance. With reference to this, it was important to note where possible spawning grounds (within the ponds) were and avoid these. One area of note was at Granton pond (North Edinburgh) where small fish were found under the bridge near the pond inlet.

Figure 3-5 sampling procedure summarised for collection of macroinvertebrates (where chemistry data collection happened in the field before sweep sampling, and sorting and identification occurred in the laboratory). Photographs: author's own.

To ensure all pond dwellers were included in the sample vials, an additional check was made before emptying the remaining contents into the pond. Sample vials were then filled 100% with supermarket ethanol (40% volume) and preserved until identification in the laboratory (Figure 3-5). Usually, this occurred the next available day or the same day if time permitted. This was to facilitate the identification process (as it is haphazard to identify most families in a field environment), and to minimise damage to legs and wings that may occur in transportation. Sorting was carried out in the field environment, but identification was left to the laboratory (unless the family type was easier to identify- *Gammaridae* (shrimp) or *Notonectidae* (large water boatmen). In some studies, it was suggested that the macro-invertebrates should be sorted whilst alive (and not necessarily in the field, Lenat (1998)), but this promoted predation and increased the time required to sort the macro-invertebrates in the laboratory (Hasse *et al.,* 2004).

The laboratory procedure involved sieving the samples to remove sediment. A standard household sieve (0.5mm) was used for this purpose- as this was inexpensive and had a suitable mesh size. Re-washing the sediment was a useful process as this liberated any organisms that were entrained in thicker silt or vegetation substrates. This was applicable to all organisms- as larger macro-invertebrates may be hidden from view- but the number of midge larvae, for example, may be underestimated if this process was not repeated (Ruse *et al.,* 2002).

Once the samples were sieved, and washed, the next step was to use tweezers or forceps to remove individual macro-invertebrates from the sampling tray and place these into groups. This process reduced the time taken to count a sample and was particularly useful for summer seasons with higher numbers of macro-invertebrates expected. In addition to this, as there were eight ponds this reduced the time spent in the laboratory to a considerable extent. However, it was important where more species were present that the sample was counted twice to ensure it was correct, and to minimise sample bias. This was particularly useful where there was an abundance of shrimp observed in the pond samples.

Identification was facilitated by using defined keys for freshwater macroinvertebrates (Croft, 1986) and field guides (e.g Field Studies Council). An attempt was made to identify chironomids to species level using specialised keys, e.g (Ruse *et al.,* 2002), but this required more input from external experts and was out with the scope of the study. The British Standard for lentic (no or limited flow conditions) environments requires macro-invertebrates to be identified to family level, and hence was suitable for the purpose of the research.

a)

Flatworms
- Planarlidae (5)
- Dendrocoelidae (5)

Worms

Oligochaete (1)

Snails, limpets and mussels
- Neritidae (6)
- Viviparidae (6)
- Ancylidae (6)
- Unionidae (6)
- Hydrobiidae (3)
- Sphaeridae (3) – pea mussel
- Lymnaeidae (3)
- Planorbidae (3)
- Valvatidae (3)
- Physidae (3)

Beetles

Gyrinidae (5)
Scirtidae (5)
Dryopidae (5)
Elmidae (5)
Hydrophillidae (5)
Dytiscidae (5)
Haliplidae (5)
Hygrobiidae (5)

Bugs
- Apheloceiridae (10)
- Hydrometridae (5)
- Gerridae (5)
- Mesovilildae (5)
- Nepidae (5)

Naucoridae (5)
Pleidae (5)
Notonectidae (5)
Corixidae (5)
Pleilidae (5)

Megaloptera

Sialididae (4)

Leeches
- Piscicolidae (4)
- Glossiphonidae (3)
- Erpobdellidae (3)
- Huridinidae (3)

Crayfish, shrimp and slaters
- Astacidae (8)
- Corophilidae (6)
- Gammaridae (6)
- Asselidae (3)

Caseless caddis

Philapotamidae (8)
Polycentropodidae (7)
Rhyacophilidae (7)
Psychomillidae (8)
Hydropsychidae (5)

b)

Mayflies
- Siphlonuridae (10)
- Heptageniidae (10)
- Ephemeridae (10)
- Leptophlebiidae (10)
- Ephemerellidae (10)
- Potamanthidae (10)
- Caenidae (7)
- Baetidae (4)

Caddisflies (cased)

Odonotoceridae (10)
Lepidostomatidae (10)
Goeridae (10)
Brachycentridae (10)
Sericostomatidae (10)
Baraeidae (10)
Molannidae (10)
Leptoceridae (10)

Phryganeidae (10)
Limnophellidae (7)
Hydroptillidae (6)

Stoneflies
- Perlidae (10)
- Chloroperlidae (10)
- Taeniopterygidae (10)
- Perlodidae (10)
- Capniidae (10)
- Leuctridae (10)
- Nemouridae (7)

True flies

Simulidae (5)
Tipulidae (5)
Chironomidae (2)

Damselflies
- Calopterygidae (8)
- Lestidae (8)
- Platycnemididae (6)
- Coenagriidae (6)

Dragonflies
- Cordulegasteridae (8)
- Aeshnidae (8)
- Libelludidae (8)
- Cordulilidae (8)
- Gomphidae (8)

Figure 3-6. a, and b: BMWP ID Map, indicating scores for expected Taxa (adapted from SNIFFER, 2011). Family names are expressed in Latin.

The referred to approach was ASPT (Average Score per Taxon, Figure 3-6) which calculated the sensitivity of each macro-invertebrate subgroup to organic pollution and is now standard practice in UK freshwater bio-monitoring (Clarke and Bowker, 2014). This well tested method used Biological Monitoring Working Party (BMWP) scores; as highlighted by Armitage *et al.*, (1983). Scores for tolerant species are below 4 with less tolerant between 4 and 6 and sensitive above 7, with a score above 8 being rare (Clarke and Bowker, 2014). SEPA have water quality (discharge consent) guidelines for rivers which suggest that an ASPT value of greater than 6 is associated with good status for the Water Framework Directive (SEPA, 2016). ASPT was calculated by dividing the BMWP score by the number of families present. Although, the scoring systems were semi-quantitative, they provided an initial guide to the ecological conditions in the pond. Collection procedure and equipment is illustrated in Figure 3-7 and Figure 3-8

Figure 3-7 sampling net (L) with a standard net mesh diameter of 2mm (NHBS, 2016). Sweep sampling in action (R). Photographs, author's own.

Figure 3-8 White sampling tray for assisting with the separation of larger sections of macrophytes or sediment (and ensuring all relevant taxa are captured and hidden fish or amphibians are returned to the pond unharmed) as suggested in BS 2012 guidance and within wider pond literature (e.g Nicolet *et al.*, 2004). Photograph, author's own.

3.4.3 Physico-chemical parameters and rainfall

Physical and chemical measurements were taken in the field to ensure that the research focused on possible factors which could cause a disturbance to the water chemistry. The chosen parameters (within the scope and budget of the field work) included: pH, Electrical Conductivity (EC), water temperature. It was also decided that dissolved oxygen- which is the most important chemistry variable (Boyd, 2015) - should also be monitored. Turbidity measurements were also taken as these were of importance for ponds with fish (Boyd, 2015); as well as for detecting issues with water quality. Water temperature was tested for comparing seasons.

Rainfall was also collected as secondary data from the Meteorological Office for the duration of the field studies. The locations chosen were Edinburgh Botanic Gardens, and Edinburgh Gogarbank stations. Rainfall data were recorded by the Met Office with durations of 15 seconds, 1 minute and 1 hour. The disadvantage to this approach was that the station data was not likely to pick up catchment and localised variability.

3.4.3.1 pH

pH scales refer to the acidity or alkalinity of a chemical and, in this case, water bodies (pond environments). pH is measured on a logarithmic scale with 1 being highly acidic and 14 base (alkaline). It was important to record pH as this could influence the rate of purification and by extension the ecological quality of the pond. The Water Framework Directive, WFD, standard for rivers in Scotland is a pH value between 6 and 9 which is dependent on the underlying soil and geology. Values above or below these suggested guidelines would increase the chance of ecosystem stress and in some cases may cause irreversible damage to certain species (damselflies, shrimp, fish) - by damaging their gills (Boyd, 2015). Invertebrates, without gills, may survive in stressed conditions but are more susceptible to sudden changes in water chemistry (Bury *et al.*, 2002; Boyd, 2015).

pH was monitored using a pre-calibrated hand-held combi-tester. The hand-held device required very little maintenance and was supplied with instructions on how to use in a field or laboratory environment. It was important to clean the probe after use to ensure no sediment was clogged between the probe and the electrodes. Furthermore, regular cleaning with electrode fluid- as suggested in the manufacturer's instructions ensured that measurements were more representative. It was also important to allow the instrument to stabilise in the water to minimise sample bias.

3.4.3.2 Electrical Conductivity (EC)

Electrical Conductivity (EC) is the ability of water to conduct an electrical current. Lower EC is associated with better water quality. EC was measured at the inlet and outlet of each pond using the hand-held combi-tester.

Conductivity levels may be influenced by background soil or geology conditions (Boyd, 2015). In terms of SUDS ponds, this could indicate that there was a change in the concentration of pollutants or salt conditions from road or pavement runoff with likely consequences for pond life (Viol *et al.*, 2009). Elevated levels or spikes observed during monitoring could have arisen from seasonal fluctuations or an increase in antecedent rainfall prior to field work (Chapter 4).

3.4.3.3 Dissolved Oxygen

Dissolved Oxygen is the most important water chemistry component to assess in freshwater (Boyd, 2015), and refers to the level of free moving Oxygen. Saturated Dissolved Oxygen fluctuates from season to season, and so it was important to capture this as often as possible. Instrument error prevented accurate measurements being recorded in summer 2016 (so these were omitted from the final analysis). A set of measurements from Edinburgh University (Crimmins, 2015) was available for spring and summer 2015, and these were converted from mg/l to percentage saturation. These data were available as the researcher assisted with the field work in this thesis. To supplement the findings of Crimmons (2015) additional measurements were taken in autumn, winter (2015), and spring (2016).

Monitoring Dissolved Oxygen was of fundamental importance when studying the ecology of the ponds; as variations in measurements may be related to differences in abundance of species. However, this was also important to relate the findings with nutrients and the availability of light in summer months for primary productivity (algae and diatoms). Some ponds had issues with purification, and this was evident where algae were the dominant surface cover in spring and summer months- where proliferation and diatom cycles occur (Boyd, 2015).

Dissolved Oxygen levels were also an important consideration for ponds with fish- as lower Dissolved Oxygen reduces the presence of fish and life in freshwater, and in this case, it may be applicable to ponds. Equally, it is important that Dissolved Oxygen levels exceed the minimum threshold (above 2mg/l) to support macro-invertebrates.

3.4.3.4 Water Temperature

Water Temperature, which is a physical parameter for ecosystem function, was measured using the Hanna combi-tester. There may be seasonal variation in water temperatures. This parameter is of particular importance for monitoring fish habitat and changes to local ecosystems- which was a requisite from the Freshwater Fish Directive (EU, 1996) which was superseded by legislative requirements for fish within the EU Water Framework Directive (EU, 2000). Furthermore, water temperature and algae presence is positively associated- i.e. as temperature increases so does the presence of algae (Charette and Derry, 2016; Salomoni *et al.,* 2017).

3.4.3.5 Turbidity

Turbidity measurements were collected from each pond between August 2015 and August 2016. An increase in turbidity suggests that water quality regulation processes are less effective, but a decrease suggests that the bio-chemical processes (including *rotifers* and *ciliates*) improve the quality of the water between the inlet and outlet. Turbidity levels may increase following a change in local weather, for example rainfall, which de-stabilises soil near water bodies (Chang *et al.,* 2015); or an increase in algal activity (Hayes, 2015; Boyd, 2015). It should be noted that clear looking water may not have better water quality (Boyd, 2015); as some of the ponds studied appeared clear but had suspended sediment (very fine) floating in the water samples.

3.4.3.6 Rainfall

Part of research question 1 relates to the influence of rainfall on the water purification from the inlet and outlet of each pond. Rainfall data were provided by the Meteorological (Met) Office at hourly and daily intervals for established weather station sites near the ponds. The Royal Botanic Gardens weather station was used as an indication for each Edinburgh pond and with less certainty for Livingston (although there is a station at Gogarburn). This was suitable for the purpose of this project, but it is not without its limitations and site data is usually preferable.

Processing of the data involved assessing the Antecedent Dry Weather Period (ADWP) conditions for each month where water chemistry data were collected. A chosen period of five days was selected and coincides with the relevant literature for hydrology and engineering (e.g. Ferreira *et al.,* 2015). The total rainfall for the five-day period was then used to analyse the previously mentioned biology, water, and physical parameters in R programming software.

3.4.3.7 Nutrient enrichment/ balance of N (ammonia and Nitrate)

Nutrient data were available for spring and summer, 2015, (Crimmins, 2015) for seven of eight ponds. This data was processed in the laboratory at Edinburgh University and has been analysed in this thesis in terms of whether the nutrients have increased or decreased between the inlet and outlet. Fairchild *et al.,* (2001) suggested that it was possible to investigate nutrient deficiency or enrichment in water using a nutrient balance equation, which was applied to the available data. Unfortunately, there is no data for the Juniper Green pond.

The method is:

$$((\text{Inflow- Outflow})/\ \text{Inflow}))\ {*}100$$

Equation (3.1)

Essentially, the method (Equation 3.1) investigates whether there is a net retention or export (removal) of nutrients and indicates whether a pond is oligotrophic/ in balance/ or eutrophic. This is based on the nutrient balance equation presented in Fairchild (2001).

Additional Nitrogen data were collected in spring and summer 2016 (using chemical strips)- although this is not easy to quantify, and therefore may only be used as semi-quantitative measurements; for example, to indicate whether the pond has nitrite present, as this has implications for the aquatic ecosystem (Boyd, 2015).

Nutrient enrichment was monitored in summer 2015 and 2016, and spring 2016 by collecting diatoms.

Algae proliferated during late spring and summer, and it is well-acknowledged that this is in relation to an increase in nutrient supply and exposure to sunlight (Boyd, 2015). Summer conditions were of particular importance to monitor, and to ensure that no algal blooms developed during this time- as these may have toxins in cyanobacteria strains, which are harmful to human and pet health (WHO, 2014). As Cox (2012) argues, the development of algae is facilitated through an increase in day light (exposure) and with this the reduction for water to flush out excess nutrients. Algae collection is an important proxy for nutrient cycling- as diatoms are a food source for fish and protists or ciliates which regulate the nitrogenous compounds within the pond (Bellinger and Sigee, 2010). If there is an abundance of ammonia present, the nutrient cycle is ineffective, which also relates to the purification process of the pond.

3.4.4 Field Preparation of algae and diatoms

Field preparation of diatoms (BS EN 13946:2014) was a straightforward procedure, and the methods in this section relate to research question two.

<u>Research Question 2</u>
Do SUDS ponds have more potential than non SUDS ponds for regulating Water Quality through algae removal processes (using diatoms as proxies)?
Sub questions:

- Are the key functions (Water Quality Regulation) performed better in SUDS or ponds with natural origins?
- What are the seasonal trends with diatoms and how does this influence the functioning of SUDS ponds?
- Are there challenging geo-chemical disturbances which could reduce the expected Ecosystem Service delivery; for example, conductivity levels.

Diatom collection was regarded as an important component of nutrient removal/ reduction-based field work. Due to field equipment issues (access to microscopes), this collection process was fraught with uncertainty. Initially, samples were collected in late summer/ autumn 2015 – but were unable to be analysed due to equipment issues. Unfortunately, these samples were not analysed and considered within the results of Chapter 5.

Spring and summer samples for 2016 were collected and analysed using the available equipment at the time. Chapter 5 will therefore compare SUDS ponds and non SUDS ponds in relation to the diatom counts available to see whether key trends and differences are observed. Differences will also be explored in relation to antecedent rainfall data- which is of importance for comparing seasons.

Field collection process involved collecting five small pebbles or small stones from the inlet and outlet of the pond. Pebbles (where available) were placed in the sorting tray and were scrubbed vigorously with a toothbrush to remove the microscopic film (BS EN 13946:2014). This procedure was in line with the British Standards.

3.4.5 Laboratory identification

Laboratory identification was facilitated by existing keys (Cox *et al.,* 2012; Belliger and Sigee, 2010) and advice from ecology experts at an external course at the Natural History Museum. In addition to this, light microscopy was carried out at x400 magnification, so that photographs of algae could be taken.

Standard methods (BS EN 13946:2014) suggested that to observe the structure of the diatoms, a powerful microscope was needed. The recommended level of magnification was x1000, but the microscope suite had a suitable setting at x400 magnification- which was suitable for the intended purpose. Unfortunately, the original teaching microscope (used for macro-invertebrates) was not powerful enough to easily identify the structures or count individual frustules.

The Carl Zeiss Axiophot microscope was useful as the lighting could be altered by changing the level of contrast- which made it easier to identify algae and diatoms. Cox *et al.,* (2012) suggested that differential interference contrast (DIC) was useful for diatoms. On numerous occasions, the Zeiss software was not working, so images for July 2016 were not available. It should be noted that some of the images were discounted due to blurring when the lens needed replaced. This had some implications on the final data being presented in the thesis, so a full library of images could not be assessed. It was decided therefore to discount images from the final thesis and instead a summary of the counts is provided (Appendix A.5).

The following factors were important to consider when identifying the diatom and algae samples, according to the guidance provided by Bellinger and Sigee (2010), and these included: sample shape, size of colony, colour, presence of flagella, hair like structures (cilia), season of collection and substrates chosen.

3.4.6 Wild Species Diversity (pollination potential)

<u>Research Question 3</u>

Do SUDS ponds have more potential than non-SUDS ponds for pollination by wind and insect pollinating plants?

The monitored plants were used to assess the potential of wild species diversity as an Ecosystem Service at each pond; particularly to investigate whether there were more wind and insect pollinators present at SUDS ponds than non SUDS ponds. This was first evaluated in the field using specialised field guides to macrophytes (Haslam *et al.*, 2013). Changes in plant abundance were recorded monthly to assess changes in condition and maintenance (where applicable). For this purpose, the metric DAFOR was applied. DAFOR is an acronym for Dominant, Abundant, Frequent, Occasional and Rare. This was the standard approach for pond macrophytes and allowed data to be collected efficiently. Following on from this, the Shannon Wiener Index was applied to provide a comparable index based on the macrophytes. Appendix A.6 presents this data; as chapter 6 will focus on the median differences in diversity and the potential for attracting pollinators.

3.4.6.1 DAFOR

DAFOR is the British Standard approach for macrophyte abundance in still water environments, and hence applicable to this project. Vegetation was mapped along a transect which varied from 30m to 100m stretches, depending on the size of the pond studied. Figure 3-9 summarises the DAFOR approach. FBA discusses additional methods which could be used for mapping and monitoring changes in plant abundance.

Table 1 — Example of a macrophyte abundance scale (DAFOR)

Scale	Abundance Descriptor[a]	Percentage Cover
1	**R**are	< 1 %
2	**O**ccasional	1 to 10
3	**F**requent	10 to 25
4	**A**bundant	25 to 75
5	**D**ominant (very abundant)	> 75 %
[a] Abundance of Species X on DAFOR scale (see [8].		

Figure 3-9: Abundance Scale (DAFOR), BS EN 15460:2007 (E), p16

3.4.6.2 Shannon Wiener Index

Shannon Wiener is an information-based method which is used in species diversity assessments (Spellerberg and Fedor, 2003), and is applicable in a pond context (Briers, 2014; O'Brien, 2015; Hill *et al.,* 2016). Originally, the method was used within information science to see whether it was possible to predict the next letter in a line of communication (Spellerberg and Fedor, 2003). This method is illustrated in Equation 3.2 where the diversity score is calculated on a natural logarithmic scale where higher scores indicate better diversity, and in the context of this thesis (Chapter 6) refers to the diversity of plant species at each pond.

$$H=\sum (pi)\ [\ln pi]$$

pi= proportion of species/ total number of samples

ln = natural logarithm

H= diversity score

Equation (3.2)

Additionally, EcoFlora (Fitter and Peat, 1994) was consulted to evaluate the potential of the pond plants for the Ecosystem Service delivery of wild species diversity (pollination, NEA, 2014). Potential was assessed by comparing the number of plants at each pond, and to test whether there were differences observed between median diversity values observed at SUDS and non SUDS ponds.

3.5 Qualitative observations and survey procedure

This section will focus on the qualitative observations made during the field monitoring period, and then go on to discuss the household and online survey procedure used for the monetary assessment of multiple benefits.

3.5.1 Observations

Field observations were recorded during the July 2014- August 2016 (Table 3-1) field data gathering process at each of the studied ponds (Figure 3.10). It was important to walk around the area near the pond and note down some issues with each pond; for example, there is vandalism of plants (*Typha Latifolia*) observed at Granton pond. Rodent issues are an increasing concern for residents and some of the ponds have issued signage and a pesticide box (which was located in a safe place from wildlife) but has been moved. Oxgangs pond had issues with litter including a trolley which was dumped in the pond. Site walkovers also identified the provision of suitable health and safety signs- for example, presence of deep water (Blackford, Granton, and Eliburn) - and lifelines (Granton). Other pond signs warned against feeding the water birds (Inverleith, Granton and Oxgangs), and some had barrier vegetation in place (Oxgangs) or were fenced in (Juniper Green and Eliburn) with no public access. Overgrown, and poorly maintained, vegetation was observed at Oxgangs (Spring-Summer) which could be connected with the nutrient enrichment (Chapter 4, 5), and Eliburn pond. This was evidenced by the fact that there were more of one plant species, so it looked over-crowded. Presence of nettles was found at Eliburn and Blackford pond, which sometimes could be an obstacle for getting in and out of the water safely.

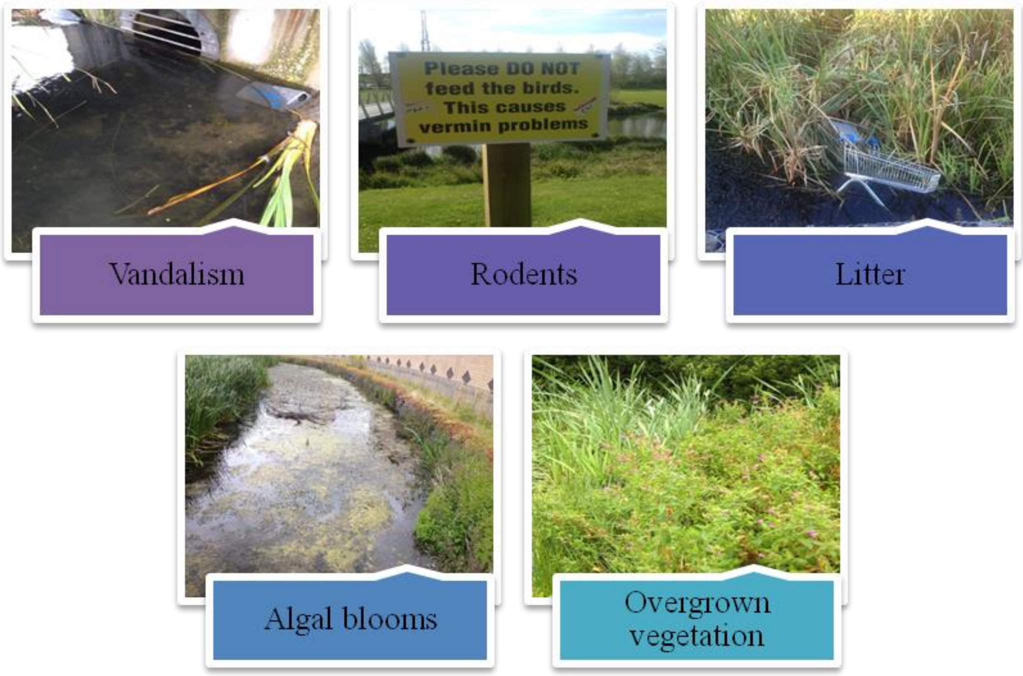

Figure 3.10 Factors identified in the field environment which contributed to the design of the survey, as well as the general qualitative observations for the study sites.

3.6 Survey methods

This survey methodology was required so that the ponds could be compared in relation to the multiple benefits which they provided. The secondary objective of this set of methods was to inform whether the public liked or disliked their local pond, and how much value was placed on these benefits. Surveys were developed on the framework which underpinned this thesis which is an extension of the methodology map (Figure 3-1) and Table 3-3

The Contingent Valuation analysis is based on a survey which was undertaken to understand how the public perceive multiple benefits so that these principles may be incorporated into the future design of SUDS ponds. Studying urban ponds in a UK context is not new (Briers, 2014; Hassall, 2014; Hill *et al.*, 2015). Urban pond research has historically played a fundamental role in developing planning policy and, with this in mind; the following questions guided the development of the research:

1. What is the public perception of the potential benefits and disadvantages of living near a pond?
2. How much value is placed on multiple benefits at their local pond (their Willingness to Pay for benefits), and are these values capable of offsetting costs?

3.6.1 Survey methods

Data collection, the design, and dissemination of surveys via the postal system and online to the survey areas are presented. Ponds within Edinburgh and the Lothians (UK) were chosen as these also formed the case studies for the doctoral field work between 2014 and 2016 (Table 3-1). SUDS and non SUDS ponds were considered and the analysis section discusses the method of calculating the values from each individual in the survey, and the population values extracted from the statistical bulletin of the Census (Scottish Government, 2016).

3.6.2 Postal Survey Format

Surveys focused on the multiple benefits of ponds within an ecosystem context. The reason for this was to highlight the existing gap in knowledge with respect to the management and delivery of the multiple benefits within the public domain.

The main focus was on the ecosystem benefits and underlying issues associated with living near a pond. Participants selected the benefits that they valued most and how much they were willing to pay to receive similar benefits elsewhere. This is in reference to moving to a new home or visiting different ponds. The valuation was carried out using a matrix with multiple values for each assigned benefit [Leggett *et al*., 2003; Bastien *et al*., 2012; Chui and Ngai, 2016]. This proved to be invaluable as it provided more detail with respect to the individual perceived benefits and provided some context for the respondents (Chui and Ngai, 2016).

Incorporation of images allowed the participant to identify key benefits of the pond (for example, the addition of animals and plant life at your local pond). However, the length of the survey was somewhat longer than other authors (Apostolaki, 2006; Bastien *et al.*, 2012) which may have hindered the response.

3.6.3 Postal Survey Pilot

The survey was tested on ten individuals living close to a pond. This included colleagues at Heriot Watt University. Furthermore, the survey was tested on an NHS development officer within Edinburgh who also lived in the vicinity of one of the ponds being assessed. Comments were taken into consideration and minor revisions were made prior to the surveys being issued to the public. Some of the language was altered to make these surveys more accessible.

Each survey area was assigned a code so that the returned surveys could be tracked and included a business reply envelope to encourage a higher response rate. Whilst attempts were made to retrieve surveys in areas with lower response rates, it is unethical to pester participants to return surveys (Murdoch *et al.,* 2014). Reminder slips with instructions to leave completed surveys in their local library were the chosen solution for this. A potential problem with this approach is that a participant may provide more than one response, which results in multiple responses from the participant and yields unrealistic data in the results. In addition, all libraries in the survey areas were contacted and library staff arranged sessions where the research could be explained, and surveys were handed out where appropriate. Views and comments from the public at these sessions were welcomed and provided some invaluable feedback. This included being invited along to interactive sessions in the library where parents were happy to contribute to the research. Engagement at morning library classes was useful as some parents with young children completed the survey online during the morning session.

3.6.4 Development of an Online Survey

The online survey encouraged more participation from areas with a lower response rate by targeting local libraries and community centres (where access was permitted). This was facilitated by handing out flyers with survey links within the local libraries and community centres. However, this approach was not suitable for all libraries with some of the lowest responding areas not participating.

Participants were asked to select their nearest pond (within walking distance). This approach was facilitated through social media and contacting local council representatives. Social media included local nature and conservation groups; as well as university and schools near the chosen ponds. Over 100 people were contacted by email or telephone to encourage wider participation in the survey. A map was included in social media adverts to allow participants to identify their closest pond more easily.

3.6.5 Post-Processing

Postal survey responses were integrated into the online survey sites (E-Survey) for comparability reasons, and to ensure that all survey responses were processed in the same way. Critically, the main section of benefit valuation remained the same. Comments from respondents were added, and these related to questions where an additional benefit was possible; for example, are there other habitat benefits available at your local pond?

Within this thesis, the survey responses are compiled for each individual assessing their willingness to pay for the multiple benefits pertaining to habitat provision, flood risk reduction, nutrient cycling, education, recreation and spirituality. The individual ponds are considered, too, to see if there are clear differences in the way that the public perceive SUDS and non-SUDS ponds. As suggested in the literature, the valuation of the ponds was based on annual or monthly payments (Verbic *et al.,* 2016).

3.6.6 Analytical Techniques

Economic values were calculated by summing the values associated with each benefit type. Values ranged from £0 to >£25 (with a selection of £0, £1, £2, £5, £10, £15, £25 and >£25) as a monthly payment, as supported by (Bastien *et al.,* 2012). The values were sorted into tables with the habitat provision benefits. To prevent the risk of double counting, whole life cost (Duffy *et al.,* 2008) was implemented to add more certainty to the contingent valuation estimates. It should be noted that only the multiple benefits are calculated but there is associated uncertainty as willingness to pay may be influenced by protest zeros (Arrow *et al.,* 1993) which may be in relation to maintenance issues (Duffy *et al.,* 2008; Bastien *et al.,* 2012).

Capital and maintenance costs were calculated according to surface area and pond volume, as suggested by the United Kingdom Water Industry Research, cited in (Royal Haskoning, 2012). Whole life maintenance costs were calculated using a discount rate of 3.5% for the first 30 years, and 3% for the remaining 20 years, as recommended by the HM Treasury Green book for projects of 30–50 years (HM Treasury, 2013), and supported by other studies (Bastien *et al.,* 2012). This was to investigate whether current benefits outweigh the replacement and maintenance costs for ponds.

Address-based information was acquired from the 2011 Census relating to the number of residents within close proximity to the pond (assumed by a 500 m radius from each pond). This process was facilitated by E-spatial (2016), which produces maps for user defined places or postcodes. The street names were then noted, and the corresponding postcodes were found. The address source data were then analysed using the Census bulletin (Scottish Government, 2016) to investigate the total population living within a 500 m radius for each pond. This is consistent with a previous study which used a walking distance of 5 min, which is approximated by field evaluation (Bastien *et al.,* 2012). The data from the amenity study (Bastien *et al.,* 2012) was used as a baseline to compare the thesis findings. Furthermore, the Scottish Index of Multiple Deprivation (SIMD) (SIMD, 2016) was consulted to place values into a meaningful social context: where a decile score of 1 is most deprived and 10 is least deprived.

3.7 Data Analysis

Data analysis was carried out in SPSS and R, and this section will discuss the processes and associated equations involved in this process for the Ecosystem Services considered. Firstly, data were assessed to determine whether the distributions were parametric or non-parametric. Missing values were ignored where these represented less than 10% of the final sample as discussed within statistical literature as an approved methodology. An alternative was to impute the values with the median or average value of the data set; however, this also has disadvantages- such as the final data set may be misrepresentative in relation to the smaller sample size adopted or provide misleading conclusions. Imputation of median values may have been misleading in the case of the data analysed in this thesis; because of the chosen approach to consider the median values within the main results chapters.

3.7.1 Water Quality Regulation (RQ 1 & 2)

This section will discuss the main data analysis techniques adopted for research question 1 and 2. The main techniques chosen were Kendall Tau and Mann Whitney U Test- Wilcoxon, because the data were of a non-normal distribution.

3.7.1.1 Kendall Tau

Tau is a non-parametric process which assumes there is a monotonic relationship between the two variables under consideration (Chok, 2010). This is useful for seeing whether a non-linear relationship exists in the data set without the influence of outliers.

Tau correlations (Equation 3.3) were performed to see if there was a statistically significant difference between inlets and outlets of SUDS and non SUDS ponds. This was important as the research question focused on the differences in water chemistry, and whether there was an improvement, between the inlet and outlet of SUDS and non-SUDS ponds.

$$\tau = \frac{C-D}{C+D} = \frac{C-D}{\frac{n(n-1)}{2}} = \frac{C-D}{\binom{n}{2}} = \frac{C-D}{\frac{n1}{21(n-2)^1}}$$

C= Concordant pairs
D= Discordant pairs
n- number within sample

Equation (3.3)

3.7.1.2 Mann Whitney U Test/ Wilcoxon

Mann Whitney tests were used to compare the two samples (SUDS and non SUDS ponds), and is used to test the null hypothesis that two samples come from the same population, or alternatively whether the median value is significantly greater between the two samples. This test assumes that the populated values follow a similar distribution; so is not suitable in all cases. The technique uses unpaired data and assumes that the data come from two distinctive populations.

Mann Whitney was a useful test to use as it highlights differences between sample medians and tests for significance. This technique assesses the differences between the sample medians in relation to water quality variables. W= the smaller of the summed difference between the data ranks.

$$z = \frac{R - \mu R}{\sigma R}$$

where:

$$\mu\mathcal{R} = \frac{n1(n1 + n2 + 1)}{2}$$

and:

$$\sigma\mathcal{R} = \sqrt{\frac{n1n2(n1 + n2 + 1)}{12}}$$

Equation (3.4)

3.8 Wild Species diversity (Research Question 3)

This section will discuss the methods used to compare flowering plants between SUDS and non SUDS ponds. It should be noted that Kendall Tau and Mann Whitney tests were also applied here for consistency.

3.8.1 Kendall's Tau

Correlations were performed to see whether there was a statistical association between plant diversity at SUDS and non SUDS ponds.

3.8.2 Mann Whitney Test

Mann Whitney tests were computed in R to see whether statistically significant differences existed between SUDS ponds and non SUDS ponds in relation to plant diversity. This test was also conducted to see whether differences (in observed median values) exist between SUDS and non SUDS ponds in relation to flowering plants and their suitability for wind and insect pollinators.

3.9 Evaluation

In addition to this analysis, a framework was designed to evaluate the ecological findings from the field monitoring and informed by the available literature. This framework (Figure 3.11) could facilitate the monitoring at ponds by local authorities and companies with private ownership of SUDS ponds. The high, medium and low potential for each Ecosystem benefit is based on key pond ecology literature (Chapter 2); as well as general observations during field work. such as the presence of litter, dog faeces, signs of vandalism and crime. The disadvantages may also be referred to as Ecosystem Disservices (Uzomah *et al.*,2014), where these are of direct harm or consequence to human well-being.

The framework sets the same style for Chapters 4, 5, and 6 with an additional focus on potential issues and Ecosystem dis-services. The final section of the chapter outlined the aspects of uncertainty and how to reduce potential overlaps within the field monitoring; as well as establishing the distinction between intermediate services (processes) and the final services (service of value to humans). This was important as the literature critiqued studies where overlaps occurred and, in this study, it was important to use standardised methods to reduce measurement uncertainty within field site monitoring.

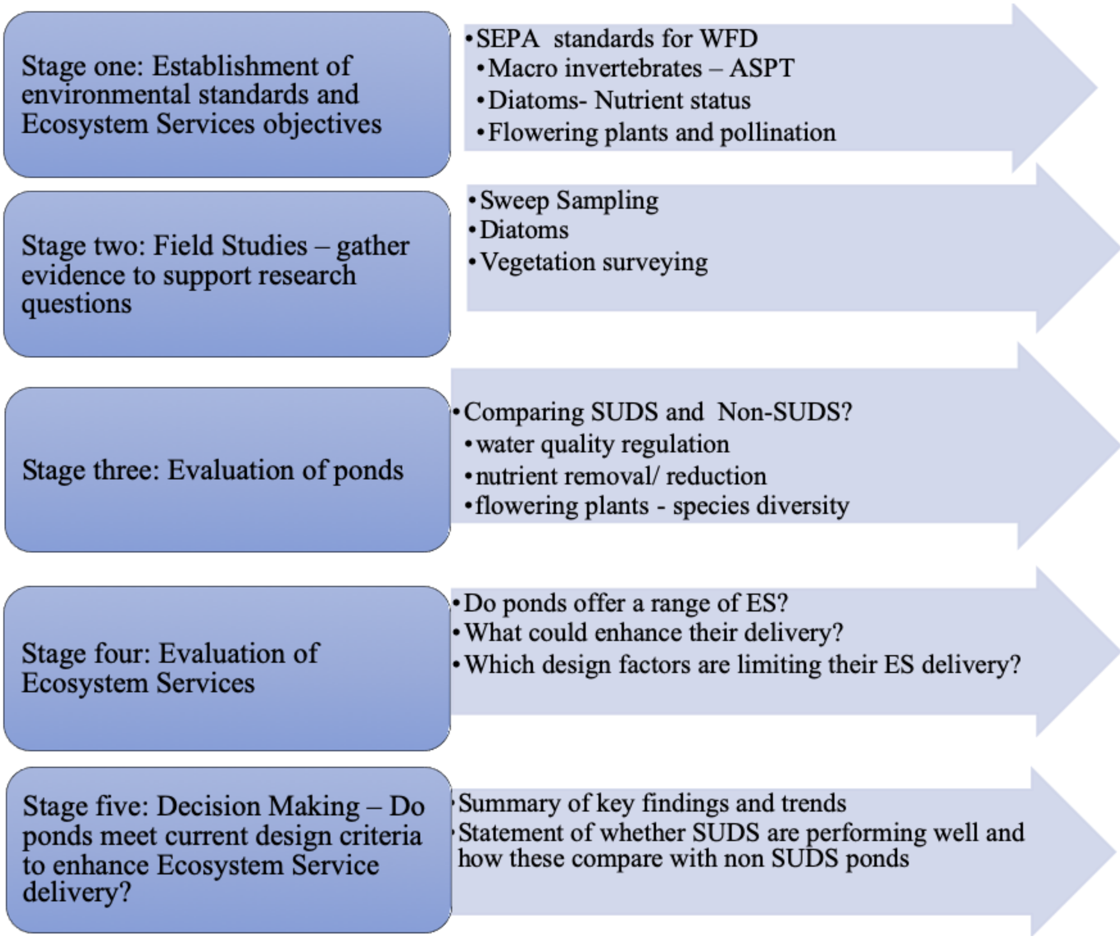

Figure 3-10 Summary of Evaluation frameworks (see discussion Chapter- 8)

Table 3-3 shows an example table to address stage four and five of the framework identified in Chapter 8. This matrix was designed based on the output of the research chapter results, Chapter 4-7. It also aligns with key CIRIA factors such as: amenity provision through education benefits; nutrient removal; water quality regulation, and diversity of plants (suitable for pollinators).

These measurements are central to the development of the above framework (Figure 3-10), and the scoring matrix is the key deliverable of the thesis which allows the study to be replicated by experts. The matrix considers the quantified measurements in the thesis and then adds value by considering benefits and disbenefits of pond identified within the CV Survey (Section 3.6). These pond scores (Chapter 8) will then be compared to highlight which ponds provide more Ecosystem Services.

A separate table allows analysts to assign additional points based on benefits or the absence of a particular disadvantage. Monitoring ecosystem disservices is key to valuing and understanding multiple benefits; as Uzomah *et al.*, (2014) discuss in relation to their planning tool for SUDS. Unique data based on the factors identified within the contingent valuation survey were used to design the additional table which adds more value to the overall framework. For example, a pond which scored lower for water quality regulation benefits may be have added value in relation to green space and situated within or near a park. The scoring strategy is discussed more fully within Chapter 8. However, this approach is not without its limitations- for example some of the methods chosen within the framework involved extensive training in field and laboratory practices; so, this may not be of value to some practitioners.

3.10 Mitigation strategy and implications:

Uncertainty with time of sampling is reduced by visiting ponds at similar times of the day on each field visit. Availability of equipment was an issue sometimes, and where it was not possible to use equipment (microscopes), equipment was borrowed from other schools within the university. Where access was not permitted or dangerous then the data set would be compromised.

Human and mechanical errors were considered in the project design and minimised where possible. For example, it was possible to minimise counting errors (with macroinvertebrates) by asking a colleague for verification. In addition, uncertainty was reduced by ensuring that one person collected the data for a given sample site- for example the same person would collect samples from the inlet and outlet.

3.11 Limitations

It is important to discuss the key limitations within this research and unfortunately due to resource and budget constraints these could not be eliminated. One of the limitations is that all chemical influences measured reflect surface water run-off. There was no scope within the project budget to consider groundwater influences, airborne pollutants, or chemicals deposited in precipitation. However, these would be useful considerations for assessing water quality of ponds.

Another limitation to project design and data collection is that data were collected at the inlet and outlets of ponds, and no consideration was given to the catchments which could influence the inflows and water quality results. Similarly, the size of the ponds varies considerably which influence the results from the water quality sampling.

With reference to the Contingent Valuation Survey and Whole Life Costs analysis undertaken in the project, which facilitated the design of the framework, there was no budget to enable stakeholder engagement. However, it is important to acknowledge that this would benefit future studies and result in less uncertainty within final results. Additionally, testing could have provided a more robust framework to compare the benefits of ponds. As discussed previously this framework would be of benefit to practitioners, so engagement would be essential if this framework is taken forward.

3.12 Summary

This chapter focused on the main methods used for field monitoring between 2014 and 2016. It also discussed alternative approaches which were discounted for time, training, or budget limitations. Measurement uncertainty lies in the data collection within the field, and the following considerations will be referred to in the following Chapters (4, 5, 6):

- Time of sampling
- Availability of equipment
- Access to ponds
- Human and mechanical errors.

It also provided a detailed account of the procedures involved in creating the postal and online surveys (Jarvie *et al.,* 2017); as well as highlighting the evaluation framework (Chapter 8) for ponds with reference to the key field and laboratory parameters. It should be noted here that the field research was based on the concepts of Ecosystem Services (Chapter 2).

Table 3-3 example matrix for comparing ponds.

Factors based on CIRIA SUDS manual	**Scale**										
	Measurement	**1 (Very Poor)**		**2 (Poor)**		**3 (Fair)**		**4 (Good)**		**5 (Very Good)**	
Plant Diversity	Counts of flowering plants suitable for pollnators	0		2 - 4		5 - 7	□	8 - 10		>10	
Amenity	Annual NPV Benefits (£)	< 0		0 - 1000		1000-9999		10000-50000		> 50000	□
Water Quality Improvement	Macroinvertebrate proxies, using Average Score per Taxon (median)	0 - 2		2-4		5	□	6 - 7		8 - 10	
Nutrient Removal	Nutrient Sensitivity Scores using diatom proxies (median)	5		4		3		2	□	1	
Sub Total / 20											

Chapter 4 WATER QUALITY REGULATION IN SUDS AND NON SUDS PONDS

4.1 Introduction

This chapter focuses on water quality regulation as an Ecosystem Service and its applicability to pond treatment and design of SUDS. Water purification refers to the ability for water to be treated and suitable for discharge into freshwater environments, as Chapter 2 outlined in more detail, and is thus an important consideration for monitoring SUDS ponds. Monitoring water quality parameters is one of the available methods, within wider studies, to assess the effectiveness of treatment and purification in ponds. SUDS ponds will be compared with non SUDS ponds.

The results from the field work will be presented, in Chapter 4, as SUDS ponds, and non-SUDS ponds. For the purpose of this chapter, only median values will be presented and compared between ponds, with a wider goal of showing the key differences between the ponds studied. The reader is directed to Appendix A.4 for a breakdown of results for the individual ponds identified in Chapter 3.

Diffuse pollution is extensively studied with reference to SUDS ponds (Heal *et al.,* 2006; Duffy *et al.,* 2013) but water chemistry is also considered in a wider urban pond context (Hassall, 2014; Hill *et al.,* 2015; 2016). Existing literature has not monitored water quality with respect to the efficiency of treatment between the inlet and outlet of the pond within an Ecosystem Service context. Hence, the purpose of this chapter is to highlight the importance of monitoring ponds and to address the following research question.

<u>Research question 1:</u>

1a: How effective is water quality regulation in ponds between the inlet and outlet of SUDS and non-SUDS ponds, with respect to: -Average Score per Taxon (ASPT), influence of rainfall, and nutrient loading?

1b: How do these ponds compare in relation to water quality regulation, and is there a statistically significant difference between SUDS and non SUDS ponds?

Table 4-1 A comparison of macroinvertebrate presence and absence between SUDS and Non SUDS ponds, and their Biological Monitoring Working Party Scores (BMWP)

Macroinvertebrate Family	BMWP Score	Water Quality	SUDS Inlet	SUDS Outlet	Non SUDS Inlet	Non SUDS Outlet
Mollanidae	10	Excellent	√	√	√	√
Phyrganeidae	10	Excellent	√	√	√	√
Leptoceridae	10	Excellent	√	√	√	√
Calopterygidae	8	Very good	√	√	x	√
Philapotamidae	8	Very good	√	√	√	√
Aeshinidae	8	Very good	√	√	x	x
Polycentropididae	7	Good	x	x	√	x
Gammaridae	6	Good	√	√	√	√
Unionidae	6	Good	√	√	√	√
Coenagriidae	6	Good	√	√	√	x
Tipulidae	6	Good	√	√	x	x
Hydrophillidae	6	God	x	√	x	x
Neritidae	6	Good	√	√	x	x
Viviparidae	6	Good	x	x	√	x
Corixidae	5	Fair	√	√	√	√
Dytiscidae	5	Fair	√	√	√	√
Notonectidae	5	Fair	√	√	√	√
Gerridae	5	Fair	√	x	x	x
Simulidae	5	Fair	√	x	x	x
Sialididae	4	Poor	x	√	x	x
Piscicolidae	4	Poor	√	x	x	x
Asselidae	3	Poor	√	√	√	√
Lymnaeidae	3	Poor	√	√	√	√
Sphaeridae	3	Poor	√	√	√	√
Planorbidae	3	Poor	√	√	√	√
Valvatidae	3	Poor	√	√	√	√
Hydrobiidae	3	Poor	x	√	x	√
Huridinidae	3	Poor	√	√	x	√

Macroinvertebrate Family	BMWP Score	Water Quality	SUDS Inlet	SUDS Outlet	Non SUDS Inlet	Non SUDS Outlet
Erpobdellidae	3	Poor	√	√	√	x
Physidae	3	Poor	√	x	√	x
Glossiphonidae	3	Poor	√	x	√	x
Chironomidae	2	Bad	√	√	√	√
Oligochaete	1	Bad	x	√	√	√
Chaoboridae	0	Bad	√	√	√	x

Table 4-1 highlights the difference between the macroinvertebrates observed at the inlet and outlet. As Chapter 3 discussed, these are useful proxies to indicate whether a freshwater environment is stressed. Lower scores indicate more pollution and tolerance to changes in biology, but higher scores show that the ponds are sensitive to environmental stress- for example changes in conductivity are harmful to some families with gills- caddis larvae, such as *Mollanididae*, and *Gammarididae*..

4.2 Water Quality results

Results will be presented with respect to the key water quality measurements, and these include: Average Score per Taxon values (ASPT), pH, Electrical Conductivity, Water Temperature, Dissolved Oxygen and Turbidity. Water quality data were analysed using the non-parametric statistical tests of Kendall Tau correlation and Mann-Whitney Wilcoxon tests to see whether there were significant differences between the inlet and outlet with the tested parameters. Furthermore, this is used to compare the ponds, and determine whether significant differences exist between SUDS and non SUDS ponds in relation to water quality.

An additional section of analysis will be with reference to Antecedent Dry Weather period, or antecedent conditions and how rainfall influences the water chemistry in the ponds. Nutrient loading data will be presented and analysed with reference to net export or import of nutrients between the inlet and outlet of the ponds studied. Results will be presented with a view to compare pond types in relation to providing the Ecosystem Service of Water Quality regulation. The pertinent section of the literature review is Section 2.6, and the reader is directed here to tables of water quality parameters.

4.3 ASPT values

This section will present the results for Average Score per Taxon, for more details the reader is directed to Chapter 3 (Section 3.2.1). The results will be presented as SUDS ponds and non-SUDS ponds, with a view to compare the pond types, and evaluate their potential in relation to Water Quality regulation. This chapter will provide an overview of the main results for SUDS and non SUDS ponds. The medians for each pond type are compared for each water quality parameter studied. SUDS and non SUDS ponds are evaluated in relation to water quality regulation to determine whether the pond provides actual ecosystem benefits. The appendix (A.4) provides the reader with more detail, and a breakdown of the results for each pond studied.

4.3.1 Pond Inlets

This section will highlight the results for ASPT in relation to the pond inlets studied. Appendix A.4 provides individual pond results for more detail on the ponds considered within the analysis. The values represented in the following results are based on the median values between July 2014 and August 2016. It should be noted that there was only one pond considered, as a test, prior to the start of 2015 and following a rigorous review process. For statistical robustness, the median values used in the statistical tests consider the months of April 2015 to August 2016 where data collection was at its optimum.

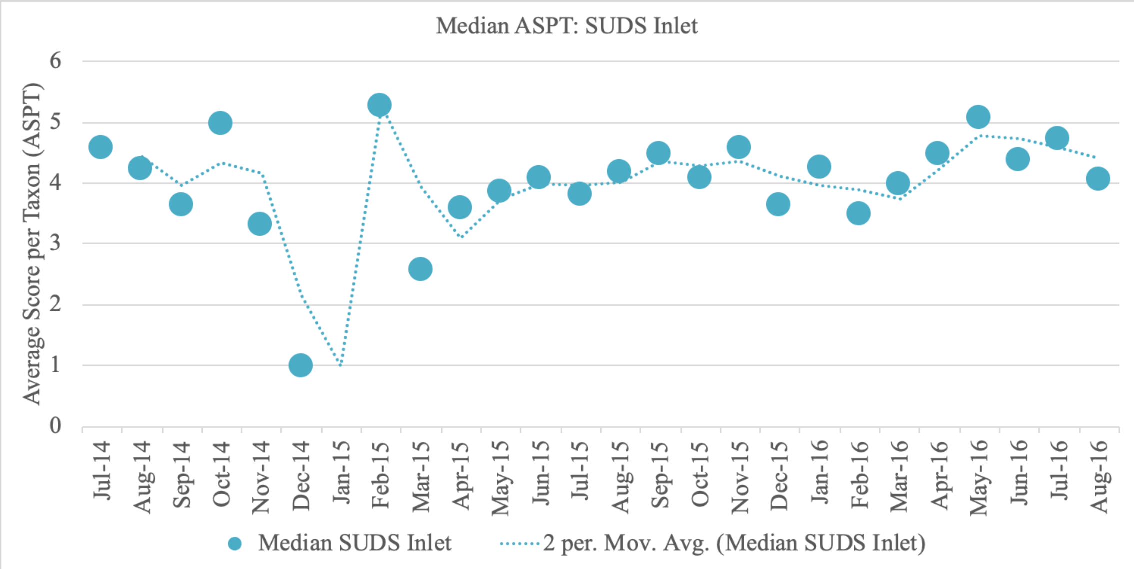

Figure 4-1 ASPT results for the inlets of SUDS ponds

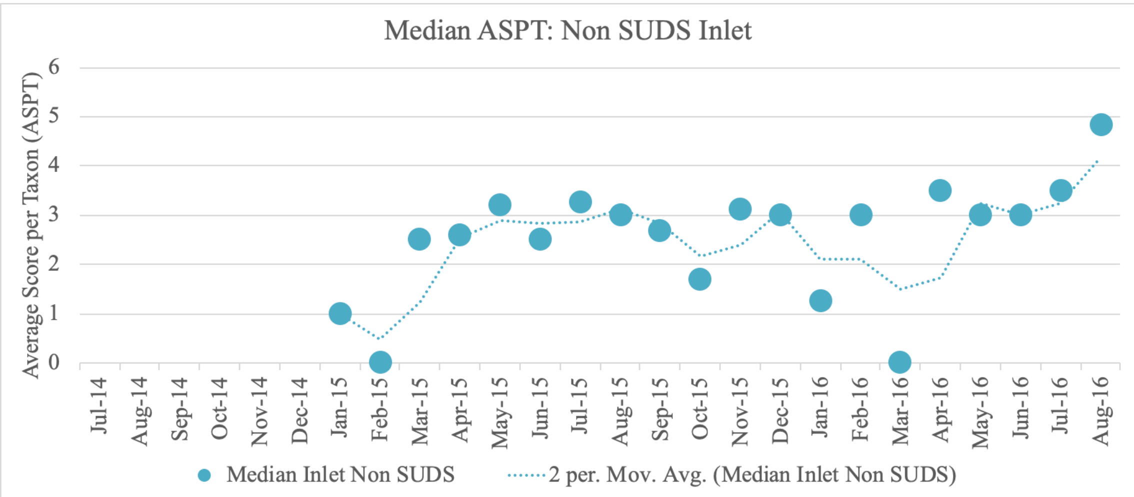

Figure 4-2 ASPT results for inlets of Non SUDS ponds

ASPT is higher for SUDS Ponds inlets (Figure 4-1), than non-SUDS Ponds inlets (Figure 4-2). ASPT scores for SUDS ponds are similar to the findings of three other urban pond studies (max =4; Sriyajarav and Shutes, 2001; max=4.63; Heal, 2006; max=4.3; Noble and Hassall, 2014). No SUDS pond outside of the winter season, had a value lower than 1 (very poor quality). For Non SUDS ponds, inlet median values are generally lower than 4 with the exception of August 2016 where there was a value of 4.9. Figure 4.1 and 4.2 highlights there is a difference between median values at the inlets of SUDS and non SUDS ponds which could be due to the design of individual ponds, and the maintenance requirements of SUDS ponds.

4.3.2 Pond outlets

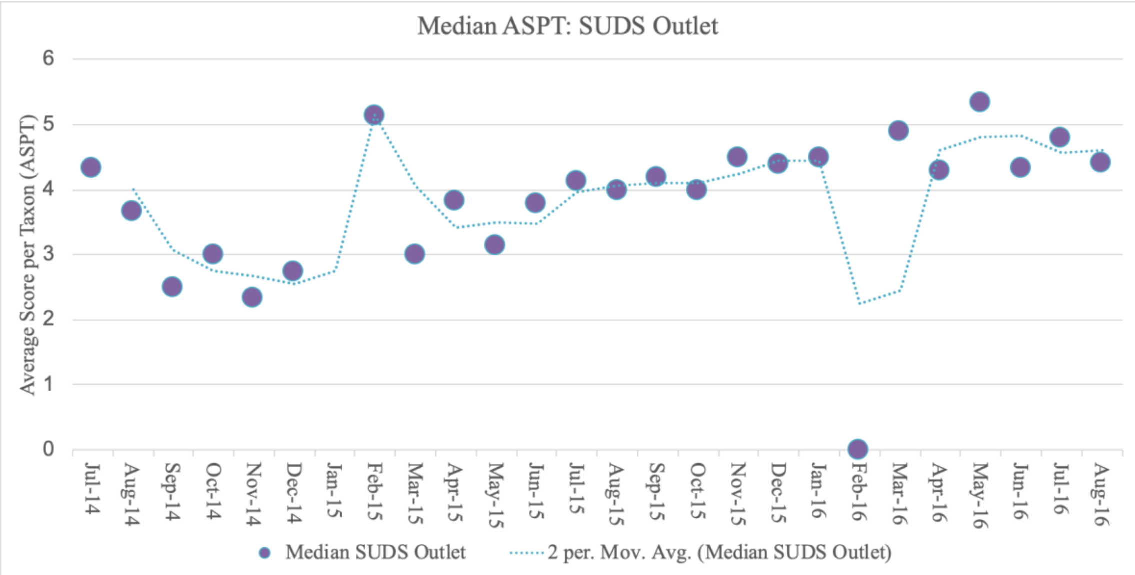

Figure 4-3 ASPT results for outlets of SUDS ponds

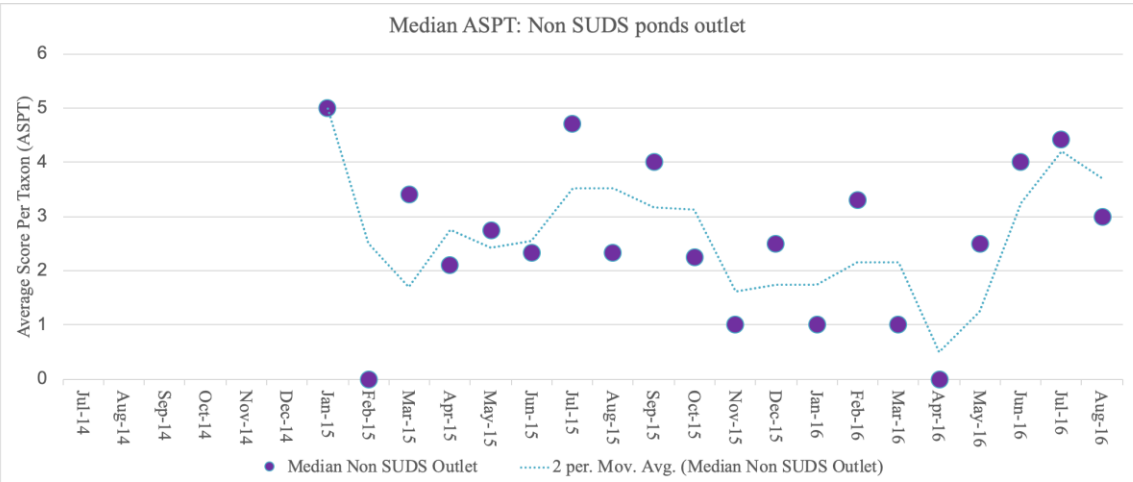

Figure 4-4 ASPT results for outlets of Non SUDS ponds

Figure 4-3 highlights that the SUDS ponds generally have higher median ASPT values than non SUDS ponds (Figure 4-4). SUDS ponds have high values of 5 which is fair in relation to water quality and low values of 0. It should be noted that the 0 value is in the month of February where weather conditions did not permit sampling of all ponds. The same story applies with the median 0 values in February 2015 for non SUDS ponds where sampling had not started in some of the ponds and seasonality also factored in to this lower ASPT value. SUDS ponds have a smoother trend of values than non SUDS ponds do, resulting in visual differences in the sample medians.

Statistical tests reveal that there is a statistically significant association between inlet ASPT for SUDS and non SUDS ponds ($p<0.05$) but there is no significant association between outlet ASPT for SUDS and non SUDS ponds. For Mann-Whitney- Wilcoxon Test, there is no significant difference between sample medians for SUDS and non SUDS ponds for inlets ($p > 0.05$) and ($w=135.5$) suggesting that these ponds are different but not of significance. Additionally, there is no statistical significance between outlet ASPT for SUDS and non SUDS ponds ($p >0.05$) and ($w=182.5$).

4.4 pH

This section will present the results for the pH observations for SUDS, and non-SUDS ponds.

4.4.1 Pond inlets

This section will explore the results for the pond inlets in relation to median pH observations. Figure 4-5 highlights that median pH values for SUDS pond inlets are between the values of 7.5 and 8.9. Non SUDS pond inlet (Figure 4-6) pH values vary between 7 and 8.8. In this case, the values are similar which is perhaps due to similar geological conditions and soil types in the study sites.

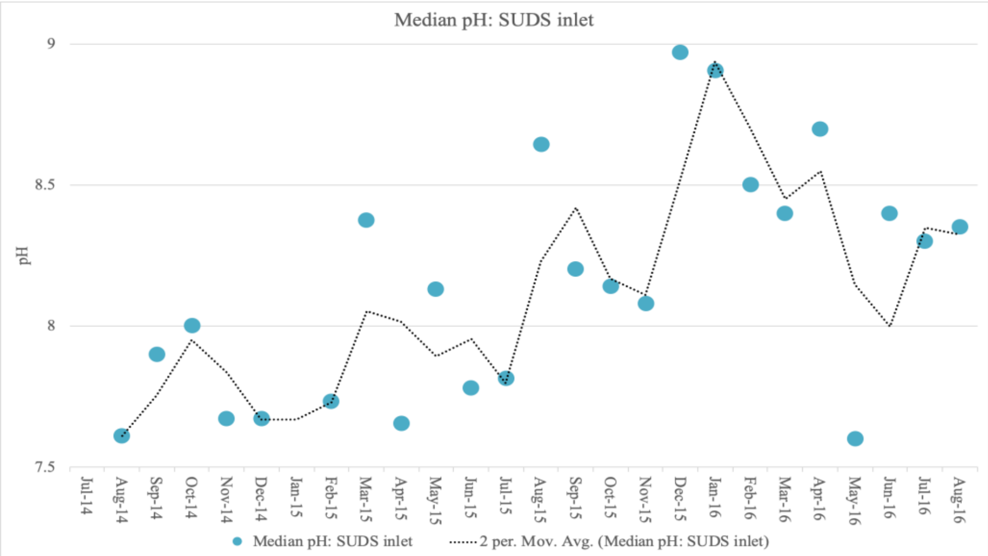

Figure 4-5 Median pH for inlets of SUDS ponds

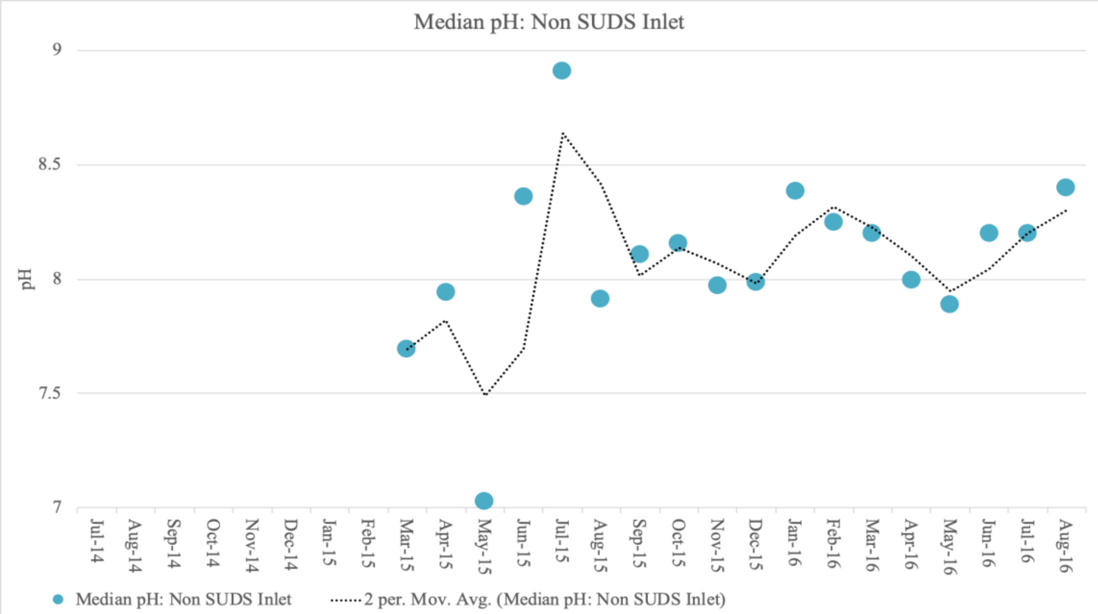

Figure 4-6 Median pH for inlets of Non SUDS ponds

4.4.2 Pond Outlets

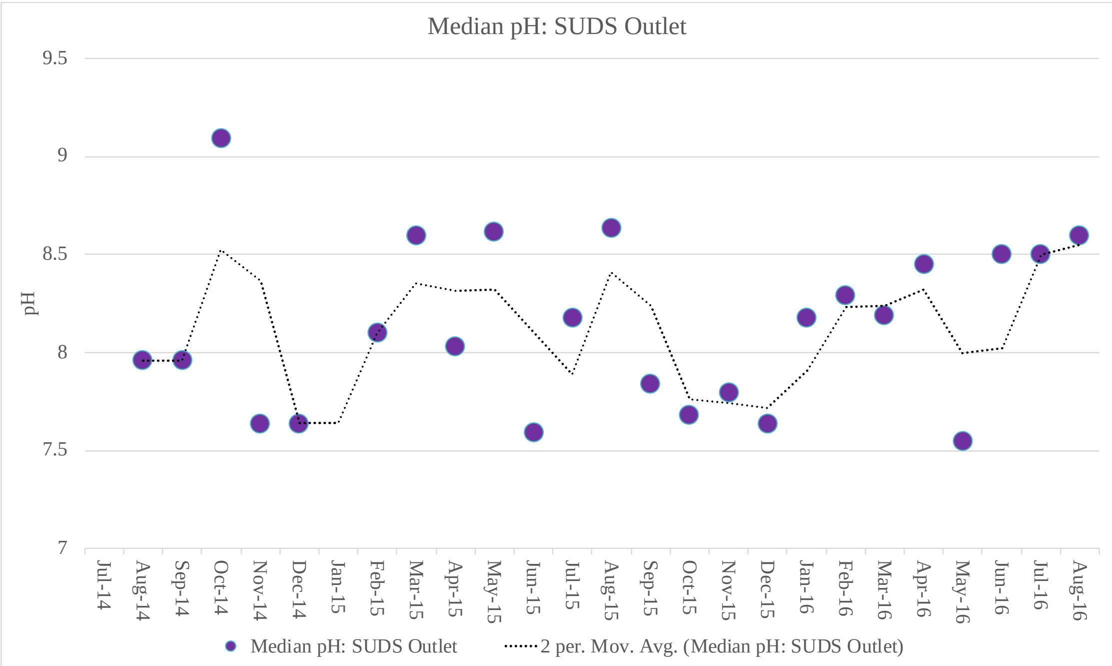

Figure 4-7 Median pH for outlets of SUDS ponds

Figure 4-7 highlights the median pH values for outlets of SUDS ponds. With the exception of four months, the median pH values are less than 8.5. The outlets of non

SUDS ponds (Figure 4-8) also have values which are less than 8.5 with the exception of April 2015 and August 2015.

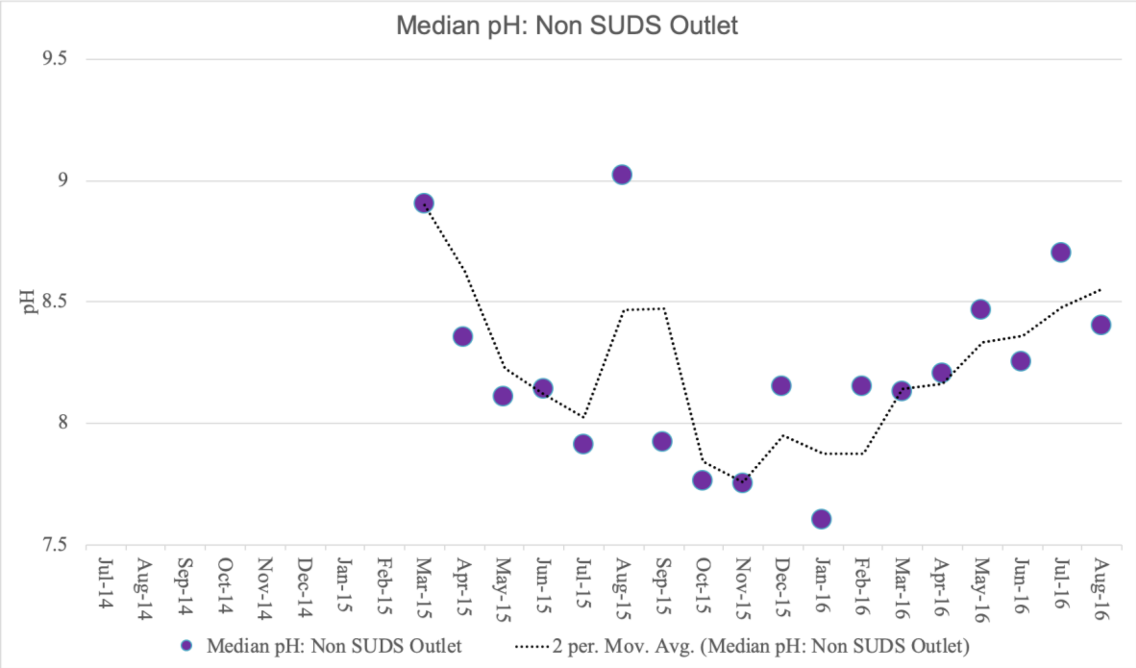

Figure 4-8 Median pH for the outlets of Non SUDS ponds

4.4.3 Comparing Ponds

SUDS pond studied has a similar range of pH values to previous urban pond studies where the reported pH values range from 6-10. pH variation is likely to be driven by the untreated water, so with treatment through adsorption and sedimentation, the pH is likely to become more neutral. However, in some months, the outlet pH value is higher reflecting that there may be unsettled solids in the water column.

The non-SUDS ponds, (Figure 4.5) studied have differing values for pH but with lower values than those expected in eutrophic conditions (Gao *et al.*, 2016, pH=7 to 9.4). pH values for SUDS and non SUDS ponds are typically within alkaline conditions, with most pH values exceeding 8.

Median pH values range from 7 to 9.4 for the inlet and outlets of non SUDS ponds. Median pH values indicate that there is a decreasing trend for non SUDS ponds. The Water Framework Directive (2000, WFD) recommends that the pH levels for lakes/ rivers should be between 7 and 9. This is broadly in line with the median values reported for SUDS and non SUDS ponds.

Statistical tests reveal that there is a statistical association between inlet pH for SUDS and non SUDS ponds ($p < 0.05$), and (Tau=0.56).

Figure 4-6 and Figure 4-8 reveals that there are more stable values for the non SUDS ponds than for SUDS ponds. This may be due to the geological conditions of the pond. However, there is not a statistical association between outlet pH for SUDS and non SUDS ponds ($p > 0.05$) and (Tau =0.29), showing there is a weaker association between the two median data sets. There is no significant difference between median pH for SUDS and non SUDS inlets ($p > 0.05$) and for outlets ($p > 0.05$)

4.5 Electrical Conductivity

This section will present the Electrical Conductivity results for the SUDS ponds, and non-SUDS ponds studied.

4.5.1 Pond inlets

This section will focus on the median Electrical Conductivity (EC) values for pond inlets of SUDS and non SUDS ponds. It is likely that the values will be higher for SUDS ponds outlets because of their purpose, and treatment requirements, than non SUDS ponds. Figure 4-9 highlights that median EC values vary with a high value of 880µs/ cm^{-1} (June 2015) and a low value of 200µs/cm^{-1} (February 2015). However, the inlets of non SUDS ponds (Figure 4-10) have more consistent values with only two values exceeding 500µs/ cm^{-1}. The variation occurs in May 2015 and October 2015.

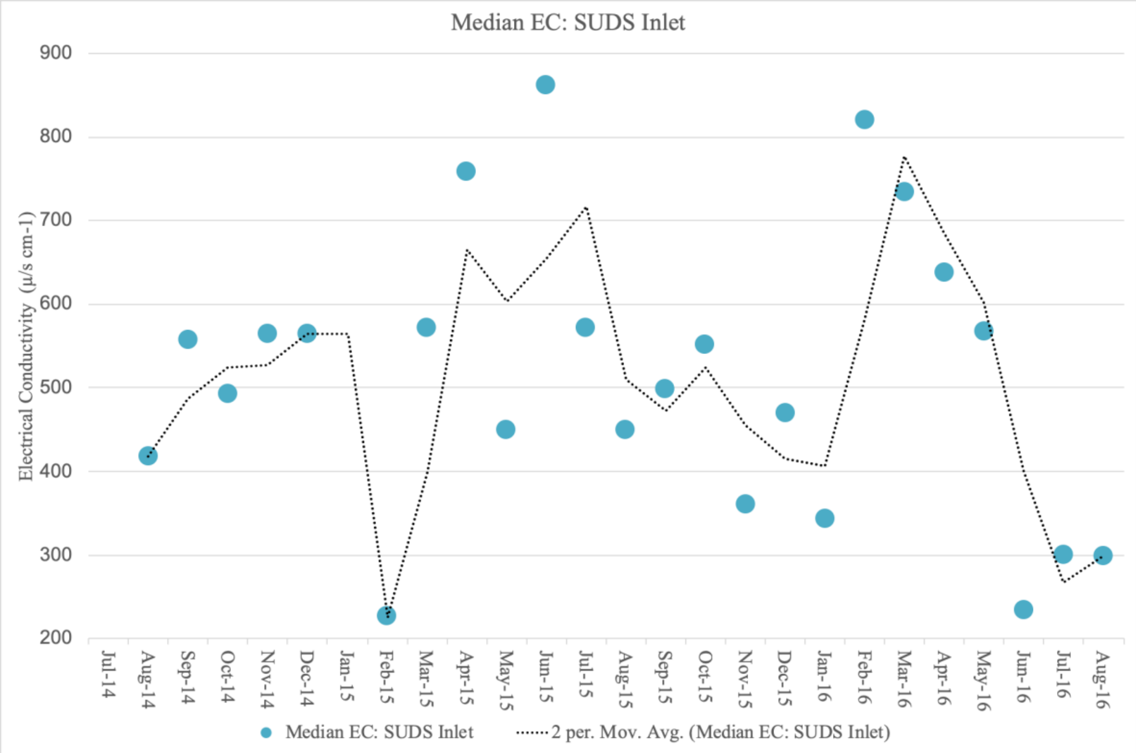

Figure 4-9 Median Electrical Conductivity values for inlets of SUDS ponds

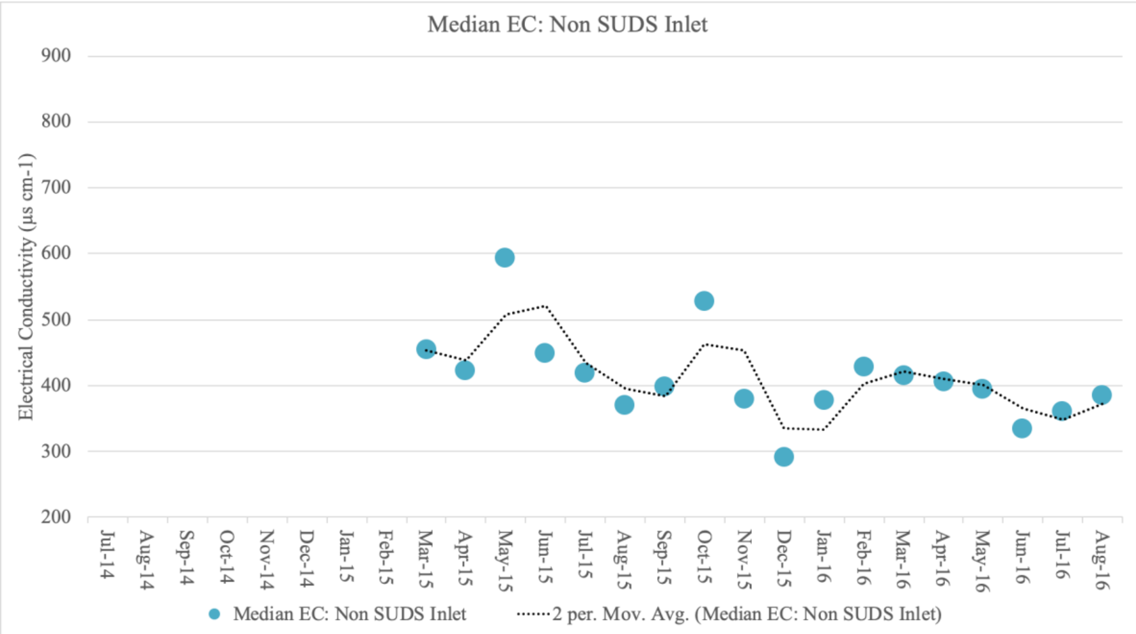

Figure 4-10 Median Electrical Conductivity values for inlets of Non SUDS ponds

4.5.2 Pond outlets

The median EC values for pond outlets are shown below. Figure 4-11 highlights that with the exception of four months (March 2015; February 2016; March 2016, and April 2016) EC SUDS outlet values are less than 600µs/ cm^{-1} showing there is decreasing trend in EC for SUDS ponds. However, Figure 4-12 shows that in relation to EC, non SUDS ponds have more stability in relation to their outlets, with only one value (May 2016) exceeding 600µs/ cm^{-1}.

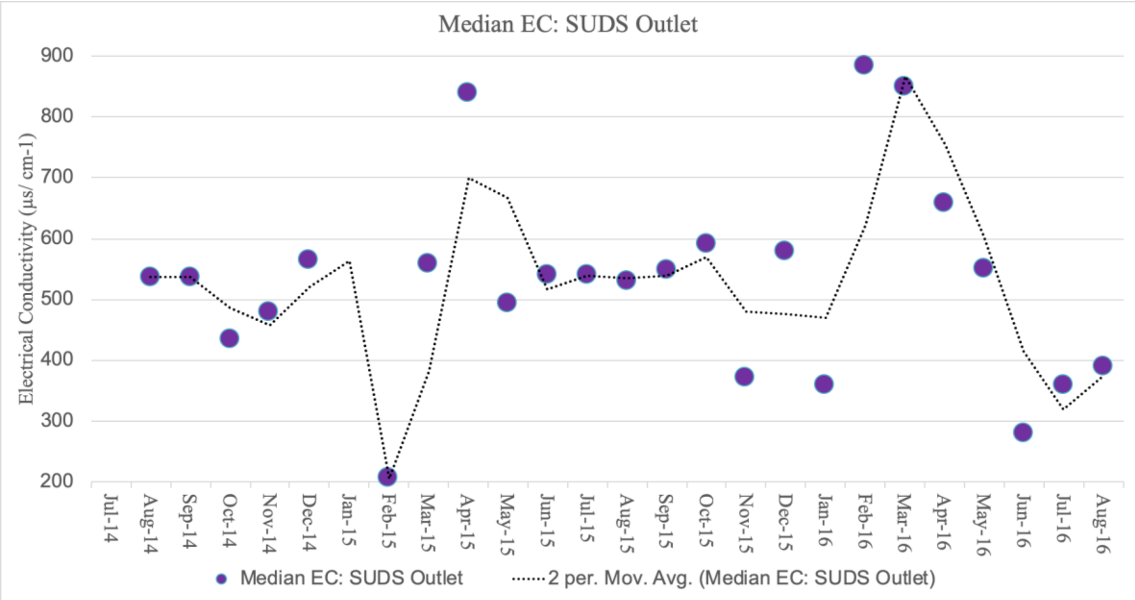

Figure 4-11 Median Electrical Conductivity values for outlets of SUDS ponds

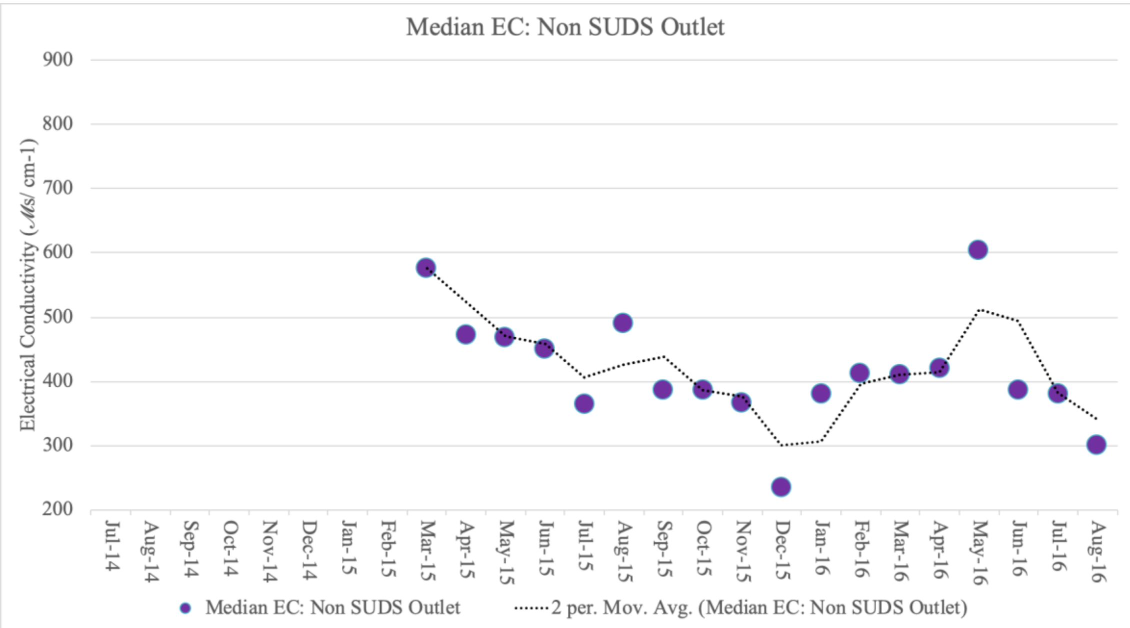

Figure 4-12 Median Electrical Conductivity values for outlets of Non SUDS ponds

4.5.3 Comparing Ponds

Median EC values for SUDS ponds studied have a range of values between 200µs and 880µs. The median inlet and outlet values for SUDS ponds have lower values to those reported for urban ponds in Bradford; for example where min value = 800µs and max =

1800μs; (Hassall and Anderson, 2015) There are similar values to those reported for other stormwater management ponds (min = 240.5μs and max= 1228μs; Hamer *et al.,* 2012). Again, with the exception that the median values reported for inlets and outlets, respectively, (Figure 4-9; Figure 4-11) do not exceed 880μs/ cm^{-1}. This shows that the SUDS ponds studied are comparable to other urban pond studies within the UK.

Non- SUDS ponds inlets and outlets (Figure 4-10; Figure 4-12) have lower and stable conductivity levels than SUDS ponds. Median EC values are generally less than 600μs/ cm^{-1}. This is consistent with findings in the literature where minimum values are less than 600μs/ cm^{-1}; for example in the East of Scotland study where EC = 533μs/ cm^{-1} (Briers, 2014). Median values for non SUDS outlets are typically lower than a lake study which is rich in diatoms (Elzbieta *et al.,* 2012).

By examining the median of each variable, there is variability between each site. This could be in relation to the land-use characteristics or background geology. Non SUDS ponds have good potential for water treatment, in relation to Electrical Conductivity values, as the levels are below the threshold in the Water Framework Directive, and typically within Freshwater limits (<750 μ/s cm^{-1}). There is more stress evident with SUDS ponds, but typically EC values are less than this threshold for outlets with the exception of three months (April 2015; February 2016; March 2016). This is perhaps to be expected due to the purpose of the ponds which is to treat diffuse pollutants, and road and path grit is washed into the ponds during winter and spring; resulting in higher conductivity values. Higher conductivity values are expected at the SUDS ponds inlets,

Statistical tests reveal that there are no statistically significant associations between inlet Electrical Conductivity for SUDS and non SUDS ponds ($p > 0.05$) and outlets ($p > 0.05$). For Mann-Whitney, there is not a statistically significant difference between median inlet populations ($p>0.05$), but there is a statistically significant difference between median outlet populations for SUDS and non SUDS. This highlights that the median outlet values are from two distinctive populations.

4.6 Water Temperature

This section presents the results for water temperature observations taken during the field work campaign between July 2014 and August 2016. These results are presented as SUDS ponds, and non-SUDS ponds.

4.6.1 Pond Inlets

This section will focus on the median water temperature results for SUDS and non SUDS pond inlets. Figure 4-13 shows that the temperature is influenced by seasonality. Higher temperatures are observed in June, July and August for 2015, and June 2016. Median lower temperatures are found in the winter months with a low of 5°C. For non SUDS pond inlets (Figure 4-14), a similar pattern is observed with seasonal high and low water temperatures observed. This variable is of particular relevance to the ASPT values explored in Section 4.3 as there were seasonal differences found in the summer months in relation to the ASPT values with median values >4 for inlets and >5 for outlets. Summer months typically had more families of macroinvertebrates than winter months, for example. Appendix A.4 provides more details of macroinvertebrate counts and ASPT scores for individual ponds.

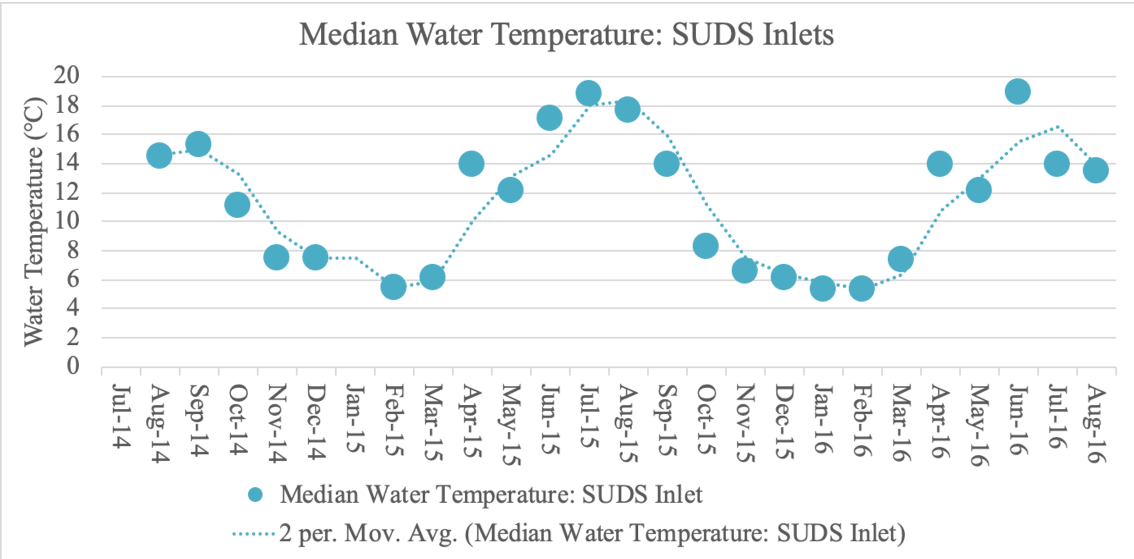

Figure 4-13 Median Water Temperature for inlets of SUDS ponds

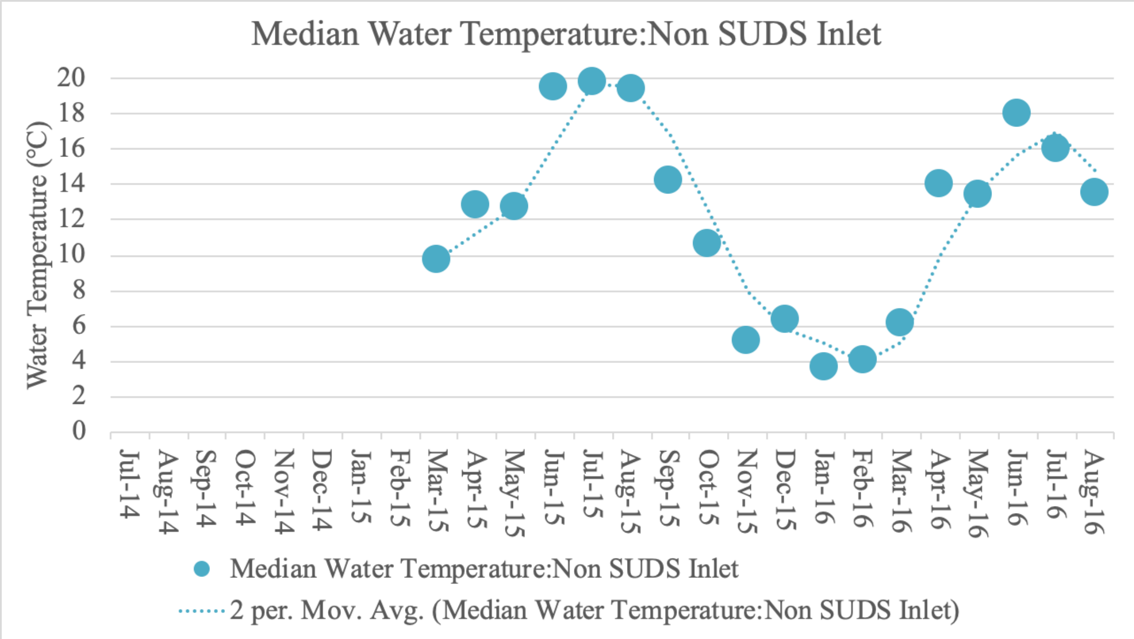

Figure 4-14 Median Water Temperature for inlets of Non SUDS ponds

4.6.2 Pond Outlets

This section will compare median water temperature values for SUDS and non SUDS pond outlets. Pond outlet water temperature is influenced by seasonality in a similar way to pond inlets. Figure 4-15 and Figure 4-16 have similar temperatures with the exception that the non SUDS outlet has a high median water temperature value of 21°C in July 2015.

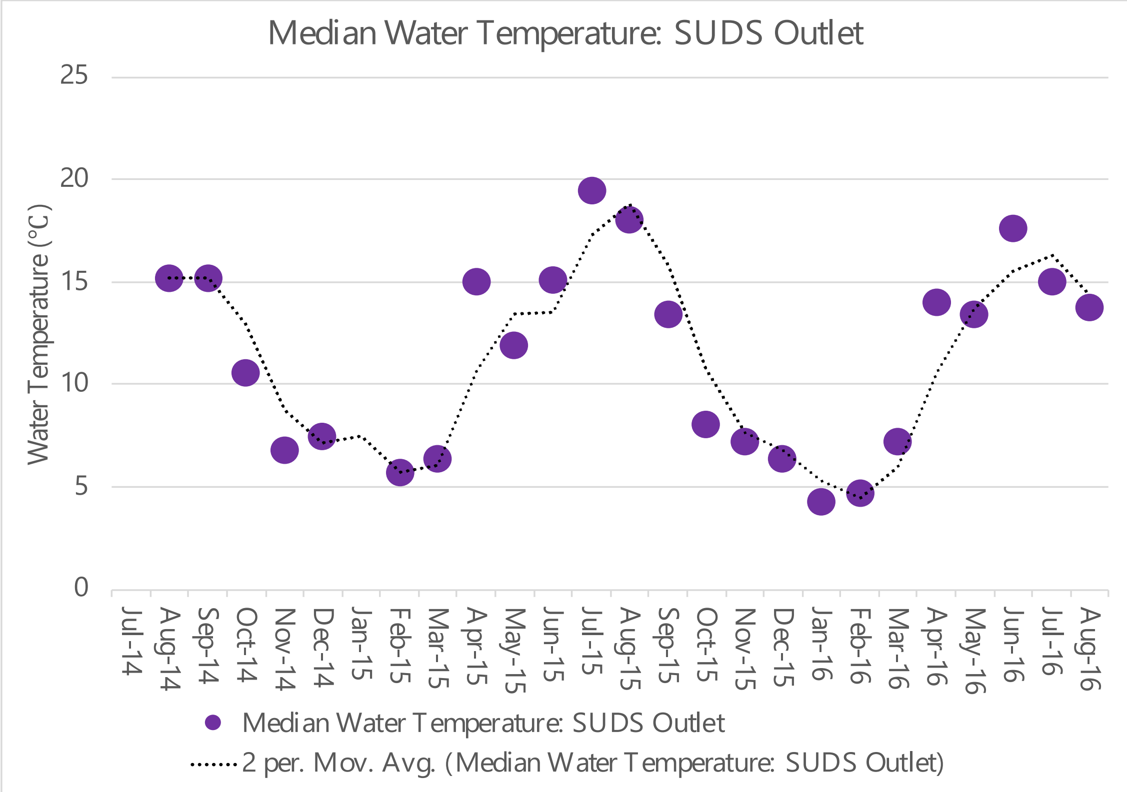

Figure 4-15 Median Water Temperature for outlets of SUDS ponds

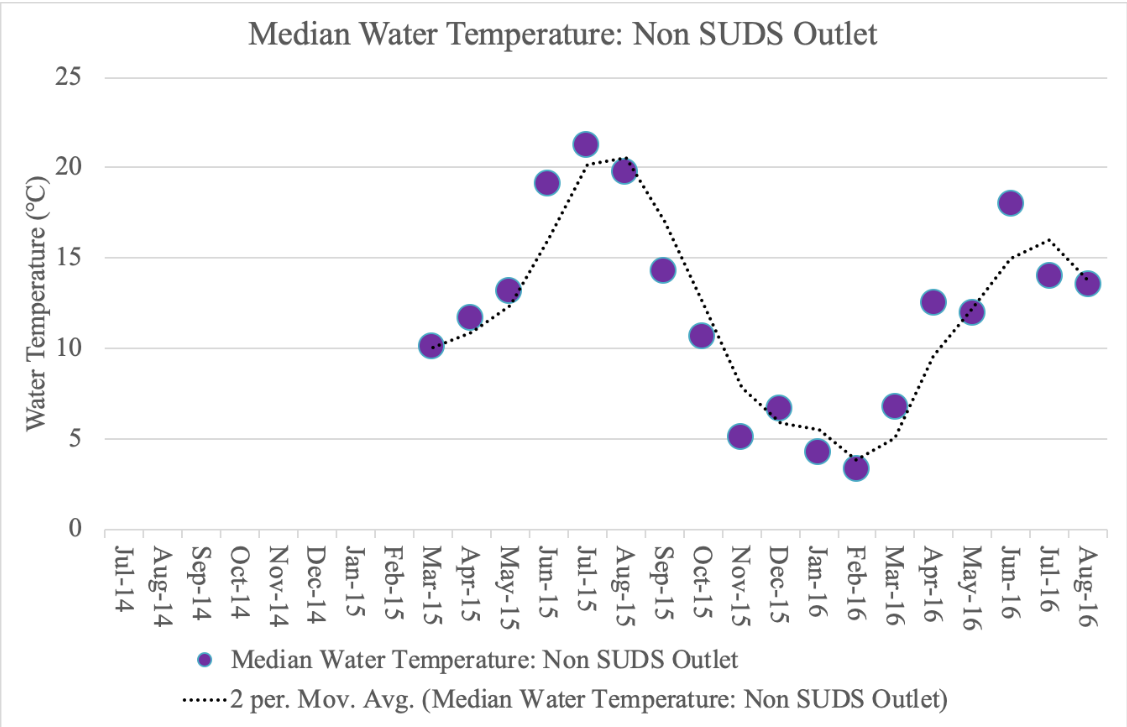

Figure 4-16 Median Water Temperature for outlets of Non SUDS ponds

4.6.3 Comparing Ponds

Spring and summer season water temperatures are warmer in 2015 than 2016. Warm and cooler pond temperatures are associated with different communities of diatoms, which in turn will influence the algae species composition in the pond (Charrette and Derry, 2016) Water temperatures are also important for supporting fish in ponds as fish, such as cyprinids, prefer cooler temperatures. This is also in line with the WFD requirements.

Shaded areas are generally cooler, for example shade from walls and buildings (some of SUDS inlets). The spread of the values suggests that there is seasonal variability in the observed water temperature, but there is very little difference observed between the inlet and outlet. Pond depth is also important here with deeper ponds taking a longer time to heat, so ponds with shallower inlets (SUDS ponds by CIRIA 2015 design standards) than outlets could have a reduction in water temperature observed, e.g July 2015. SUDS ponds are designed with shallower inlets to allow easier access for inspection of inlets.

In relation to water temperature, there is a seasonal variation in measurements taken. There is no clear difference between the SUDS ponds and non-SUDS ponds with respect to this variable. There is no statistically significant difference between median inlet ($p > 0.05$) and outlet ($p > 0.05$) for SUDS and non SUDS ponds.

Correlation tests reveal that there is a statistically significant association between water temperature for SUDS and non SUDS ponds inlets ($p < 0.05$) and (Tau =0.81) and outlets ($p < 0.05$) and (Tau=0.8). This highlights that there is a strong association between SUDS and non SUDS ponds in relation to water temperature.

4.7 Dissolved Oxygen

This section will present the results for Dissolved Oxygen observations taken at SUDS ponds and Non-SUDS ponds.

4.7.1 Pond Inlets

This section will compare SUDS and non SUDS ponds in relation to median Dissolved Oxygen. Figure 4-17 shows that the highest median Dissolved Oxygen value is 70% in April 2015, and the lowest observed values are April, May and June 2016, with 0%. This may be instrument error, as there were technical issues with the probe after winter. Issues are discussed more fully in Chapter 3.

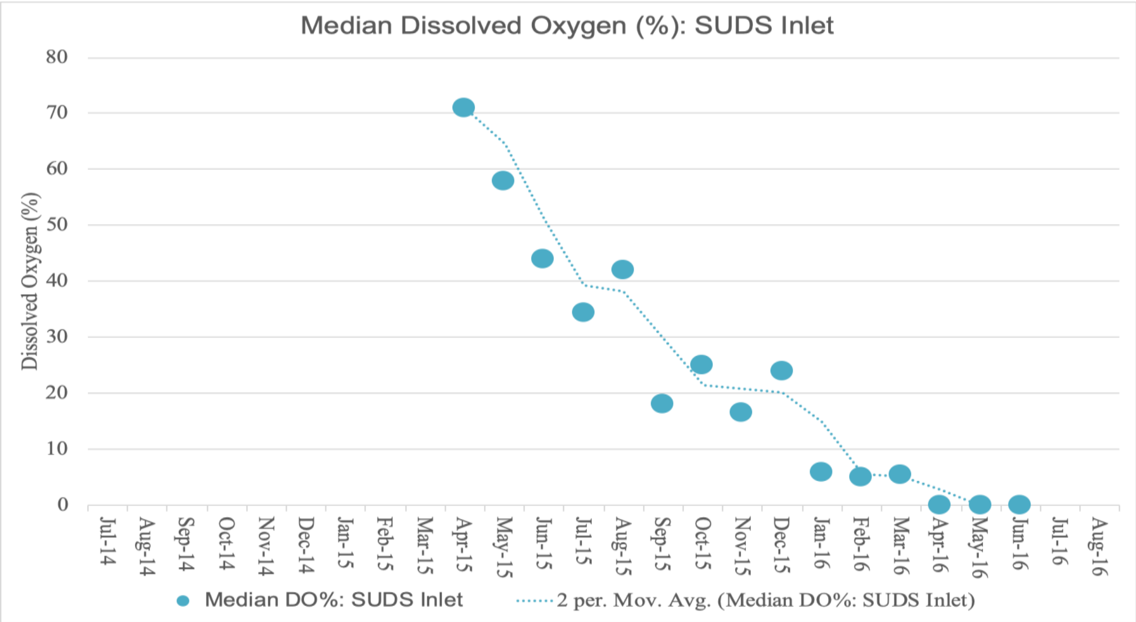

Figure 4-17 Median Dissolved Oxygen (%) for inlets of SUDS ponds

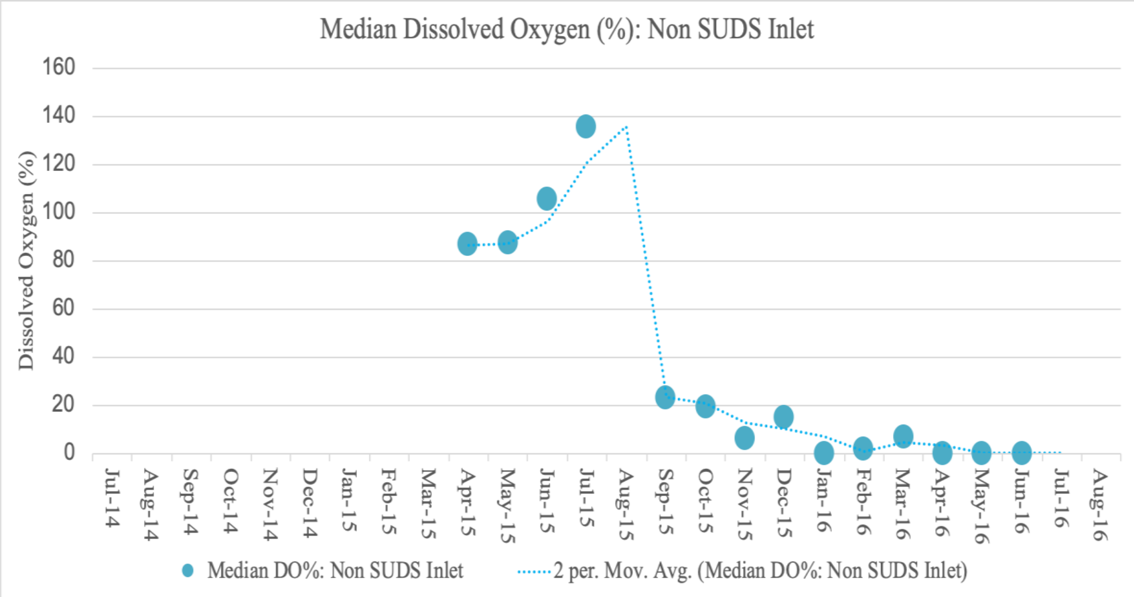

Figure 4-18 Median Dissolved Oxygen (%) for inlets of Non SUDS ponds

4.7.2 Pond Outlets

This section will compare SUDS and non SUDS ponds in relation to their median Dissolved Oxygen values. With the exception of July 2015, the SUDS pond outlets have median values less than 100% saturation (Figure 4-19).

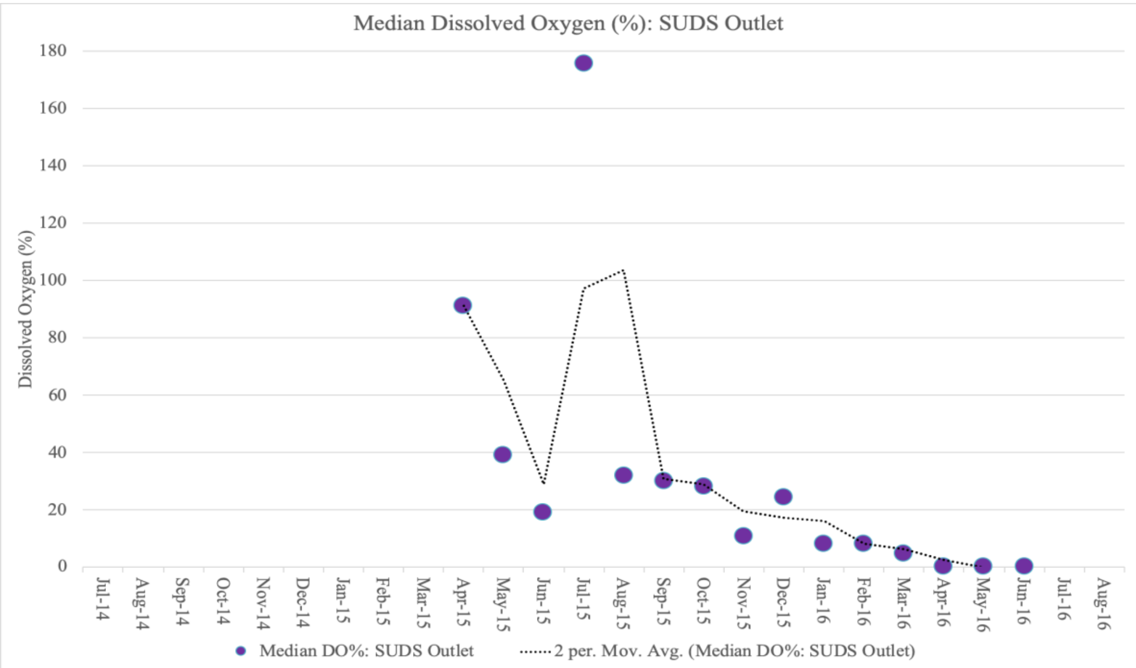

Figure 4-19 Median Dissolved Oxygen (%) for outlets of SUDS ponds

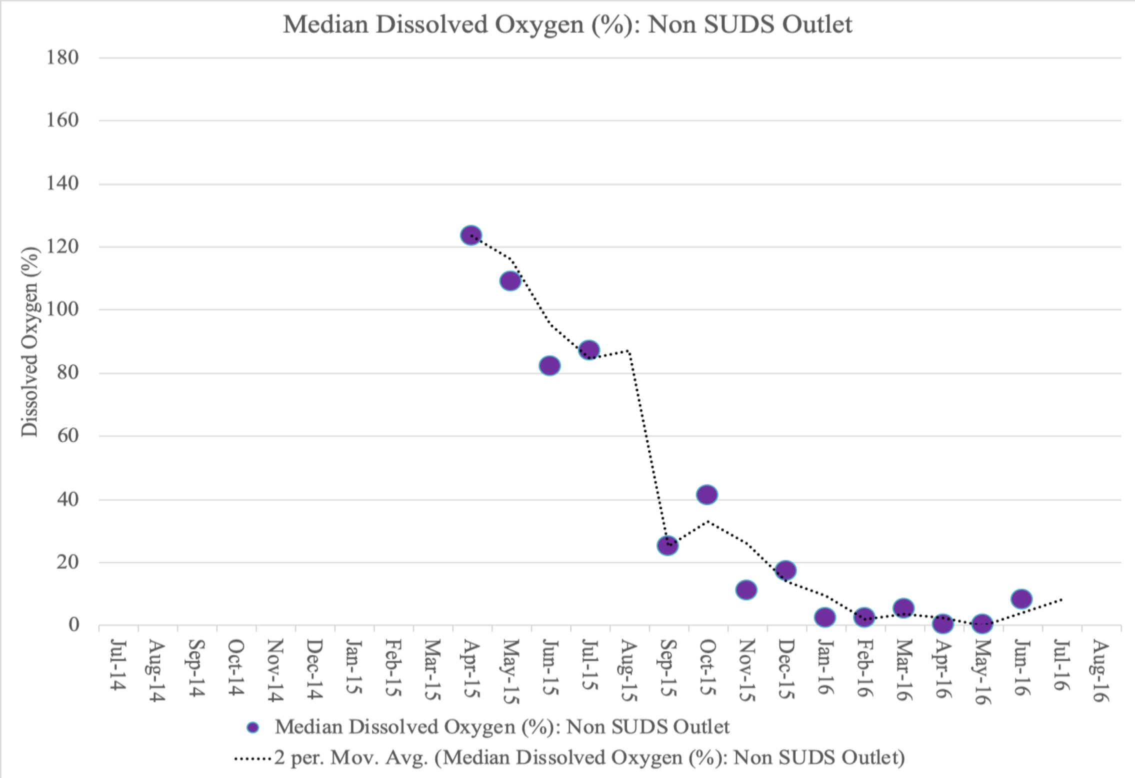

Figure 4-20 Median Dissolved Oxygen (%) for outlets of Non SUDS ponds

Figure 4-20 shows some super saturation for non SUDS ponds outlets in relation to the variable Dissolved Oxygen. Between summer and autumn 2015, the dissolved Oxygen values are between 120% and 20%.

4.7.3 Comparing Ponds

The saturated dissolved oxygen values reported in this chapter show periods of super-saturation which may be in relation to changes in water temperature (Figure 4-13- Figure 4-16), or relative to the nutrient loading of the pond (Table 4-2; Table 4-3; Table 4-4) where some ponds have net nutrient export in the summer months due to natural diatom cycles. A decrease in water temperature corresponds with an increase in saturated Dissolved Oxygen.

Values are similar to some of those reported in the literature, with values less than 40% corresponding with the lower end of values in a previous SUDS pond study (Briers, 2014). Outlier median values for SUDS and non SUDS ponds may be in relation to the diversity of diatoms and algae observed at ponds in summer months, and the seasonal cycle of photosynthesising algae/ diatoms. pH values (Section 4.4) indicate that there are eutrophic conditions in some ponds; specifically, the non SUDS ponds. More details are provided in the appendix which shows each pond in more detail.

Measuring Dissolved Oxygen is an important parameter and provides information about the issues within the ponds. SUDS ponds have more stressed conditions in relation to saturated Dissolved Oxygen than the non-SUDS ponds do. Ecosystem Service potential is lower for the proxy of macroinvertebrates where Oxygen levels exceed 100% which is the case for some ponds.

For non-SUDS ponds, there are stressed conditions with reference to high levels of saturated Dissolved Oxygen. However, there are also periods with very low Oxygen conditions which could influence the median ASPT values observed (Section 4.3).

Statistical tests reveal that there is a statistically significant association between inlet Dissolved Oxygen for SUDS and non SUDS ponds ($p<0.05$) and (Tau =0.77). There is also a statistically significant association between outlet Dissolved Oxygen for SUDS and non SUDS ponds ($p<0.05$) and (Tau=0.83). There is not, however, a significant difference between median populations for inlet or outlet Dissolved Oxygen in the ponds studied; showing that the Dissolved Oxygen samples are unlikely to be from two distinctive statistical samples. This may also suggest that there are similarities in relation to stressed or disturbed water quality regulation.

4.8 Turbidity

This section will present the turbidity results for the SUDS ponds, and non-SUDS ponds.

4.8.1 Pond Inlets

This section will compare the median turbidity values for the inlets of SUDS and non SUDS ponds. Median turbidity values are generally lower for non SUDS ponds (Figure 4-22) than SUDS ponds (Figure 4-21). This implies that the inflow into the non SUDS ponds is less impaired than SUDS ponds. There is an outlier measurement in August 2015 which could be due to human error or an increase in leaf litter as a result of heavy rainfall before the site visit.

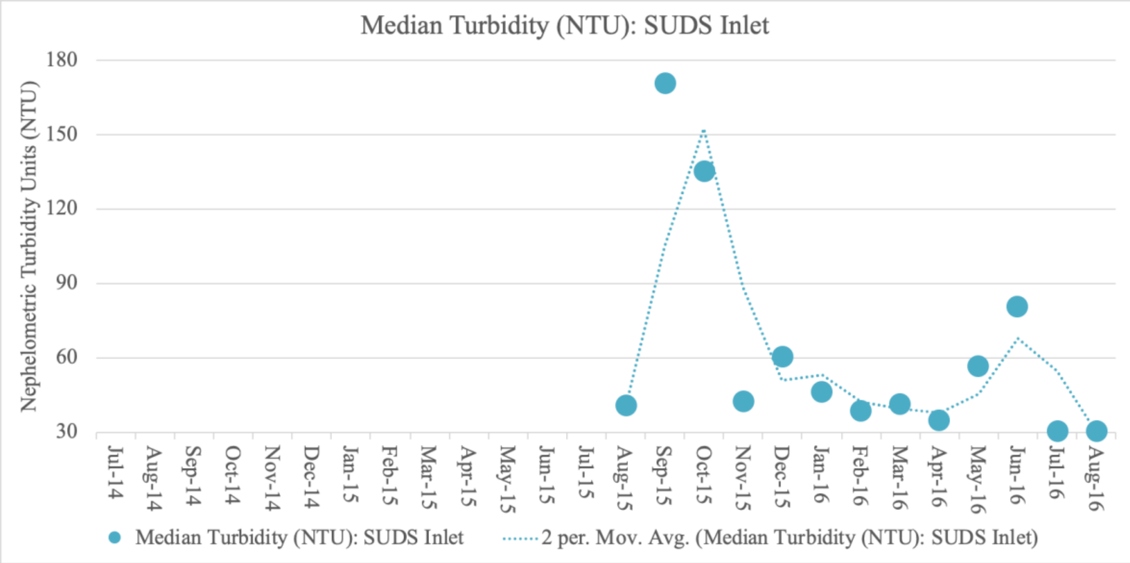

Figure 4-21 Median Turbidity (NTU) values for inlets of SUDS ponds

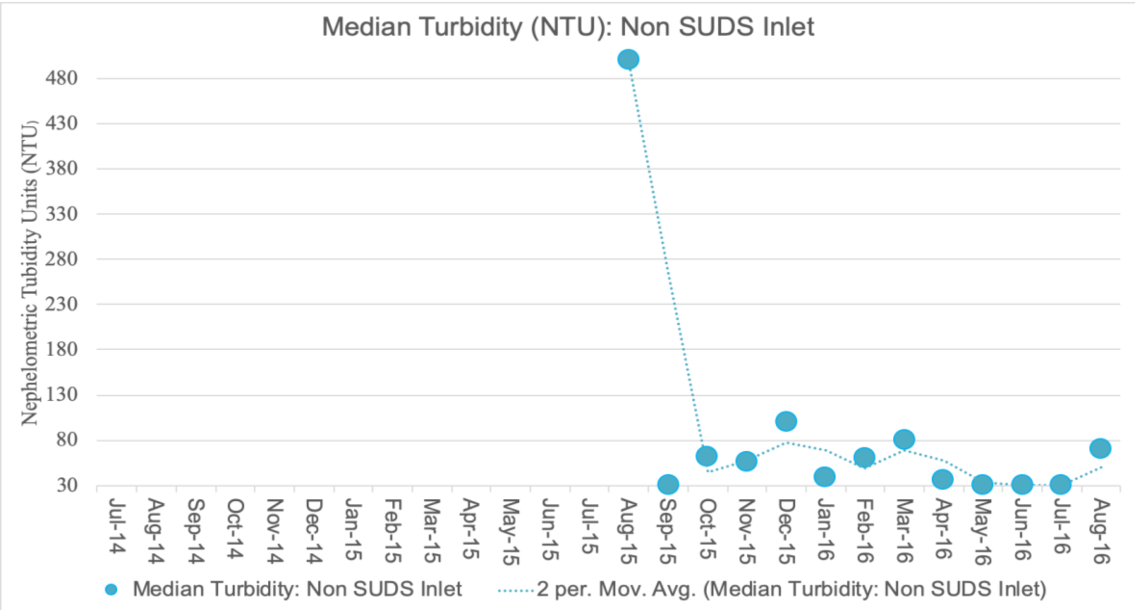

Figure 4-22 Median Turbidity (NTU) values for inlets of Non SUDS ponds

4.8.2 Pond Outlets

This section will compare the SUDS and non SUDS ponds in relation to the median turbidity values at outlets.

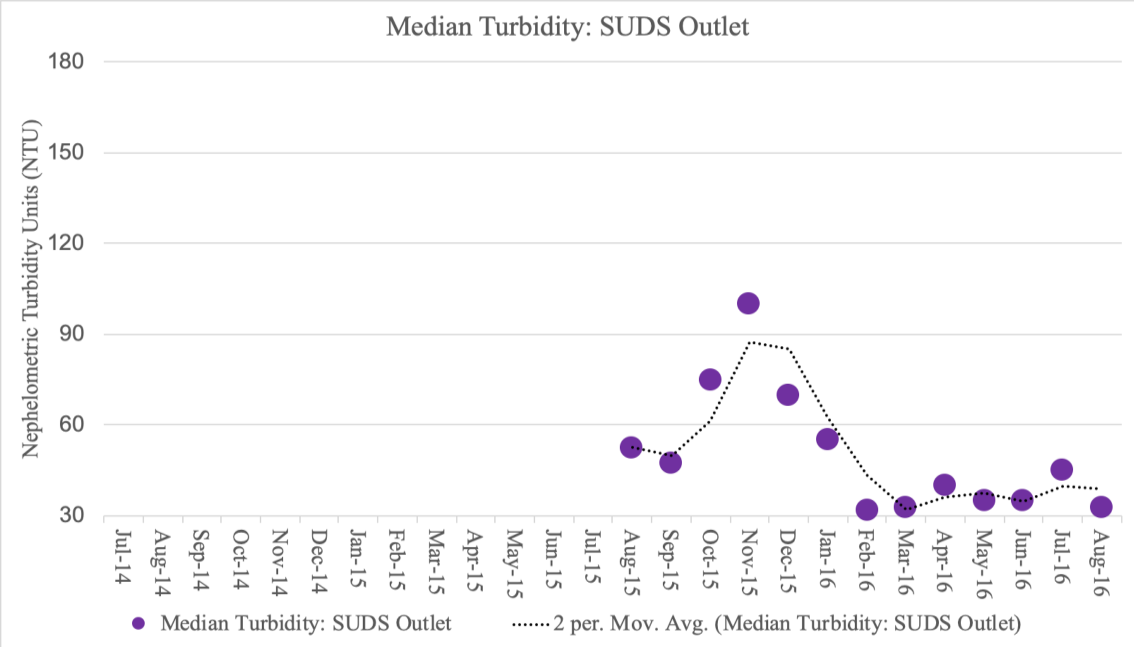

Figure 4-23 Median Turbidity values (NTU) for outlets of SUDS ponds

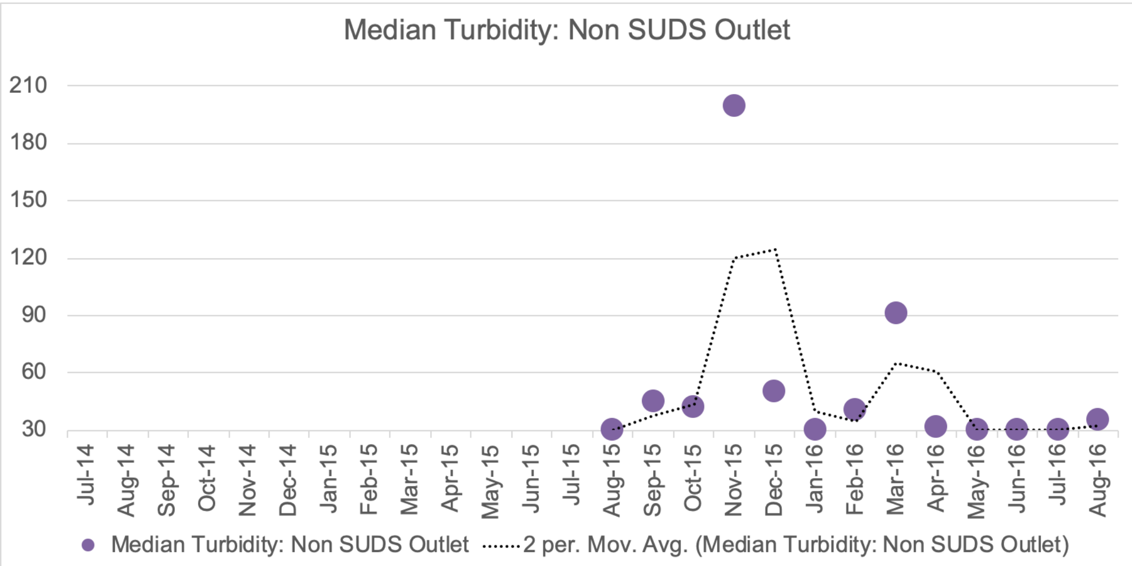

Figure 4-24 Median Turbidity (NTU) values for Non SUDS ponds

4.8.3 Comparing Ponds

Turbidity measurements for SUDS and non SUDS ponds are within the range of 30 to 500 NTU, where a previous study observed turbidity in the region of 0 to 419 NTU (Tu Nyugen *et al.*, 2014), and ponds within mine drainage have values of 100 to 500 NTU. Most values reported for SUDS and non SUDS ponds are less than 100 nephelometric turbidity units- with occasional values reported above 100, 300 and max 500- which means turbidity as an indicator of water purification is useful. However, there may be some bias in the values reported or possible links with antecedent rainfall which may erode or destabilise soil and sediment from nearby slopes.

Non SUDS ponds have median turbidity values between 30 and 100 NTU, with one value at 500 NTU. These values correspond with the values reported in the synthetic waste water and mine drainage (for outliers), but the main set of values align with a fish monitoring study in Auburn, Illinois (where max = 132.3 NTU; Xu and Boyd, 2016).

There is an overall improvement observed between the inlet and outlet for the ponds. Grass slopes near inlets of some SUDS ponds (Oxgangs and Eliburn) may result in antecedent rainfall washing excess soil and sediment into the pond which adds to the suspended matter in the pond, and hence increases turbidity values (Boyd, 2015). The spread of the values suggests the clarity of the water, in terms of turbidity values, is mis-matched between the inlet and outlet for SUDS ponds. This may be in relation to the dense cover of leaf litter at the outlet of the pond (e.g. Juniper Green), or it could be bioturbation where larvae are stirring up silt and sediment (Covich *et al.,* 1999). Differences in pond substrates may also influence the median turbidity values.

Statistical tests reveal that there is not a statistically significant association between ponds for inlet ($p > 0.05$) or outlet ($p > 0.05$) measurements. There is no significant difference between sample medians for SUDS or non SUDS ponds in relation to inlets and outlets ($p>0.05$). This highlights that the turbidity values for non SUDS ponds are influenced by the outlier (n=190) for November 2015 which resulted in a less smooth trend of values. Overall, however, the non SUDS outlets have lower median values for turbidity than the SUDS pond outlets; indicating that the non SUDS ponds may have better water quality in relation to turbidity.

4.9 Nutrient loading

Nutrient data will be presented for the spring-summer 2015 field season for SUDS and non SUDS ponds. Data are adapted from the field findings of another SUDS pond study undertaken in 2015 (source: Crimmins, 2015). The data are analysed in terms of net retention and export of ammonia, nitrates and phosphates. Retention is where nutrients are retained within the pond and in these cases are less likely to cause issues with water purification. Ponds with net exports of nutrients are likely to have prolific algal growth in spring and summer. Results are presented in Table 4-2; Table 4-3; and Table 4-4. Further details are provided in the Appendix (A.4) and Chapter 5 will focus on the proxy of diatoms in relation to algal removal processes.

4.9.1 Ammonia

This section will compare SUDS and non SUDS ponds in relation to ammonia net retention/ removal. SUDS ponds have higher net removal of ammonia (Table 4-2) than non SUDS ponds do. The highest value is 89% for June removal and 74% for June removal for SUDS and non SUDS, respectively.

4.9.2 Nitrate

This section will compare SUDS and non SUDS ponds in relation to nitrate net retention/ removal. SUDS ponds have greatest net retention in the month of April, and non SUDS ponds have greatest net retention in July. The pattern from the median data reveals that there is a nitrate issue with ponds studied, as net removal only occurs for non SUDS ponds in spring 2015 (April and May 2015).

4.9.3 Phosphate Ions

This section will compare SUDS and non SUDS ponds in relation to net retention/ removal of Phosphates. SUDS ponds have the greatest removal rate of Phosphates for the months of June and July 2015. With the exception of one month (July 2015), phosphates are retained in the non SUDS ponds; indicating there is nutrient pressures. The differences could be in relation to the SUDS pond design and flow to treatment pathway. Chapter 5 discusses this in more detail with reference to diatom proxies.

4.9.4 Comparing Ponds

Nutrient removal is an important aspect of the water quality regulation services provided by SUDS and non SUDS ponds. Background nitrate and phosphate levels are lower than those set by SEPA guidance (Crimmins, 2015), but there is evidence of net export of Nitrate from SUDS and non SUDS ponds. Phosphate improvement is evident in SUDS ponds more often than non SUDS ponds. Appendix A.4 provides a table which shows the patterns from each individual pond. Nutrient loading in larger ponds is less concerning (3 x Non SUDS) than smaller SUDS ponds. Low Oxygen conditions in non SUDS ponds (specifically Goreglen) produces more ammonia within the ponds (Boyd, 2015). When ammonia is not purified it become nitrite which is harmful to fish and macroinvertebrates. This may also explain some of the lower ASPT values in non SUDS ponds. Ponds with higher ammonia are not as likely to support fish within its pond ecosystem.

Table 4-2 Ammonia (NH^4) concentration recorded in the inlet and outlet of ponds between April and July 2015 (adapted from Crimmins, 2015). Nutrient balance data are presented according to the equation (Chapter 3) suggested by Fairchild et al., (2001). A negative value indicates an increase between the inlet and outlet.

Pond name	April Inlet	April Outlet	Net % removal/ retention	May Inlet	May Outlet	Net % removal/ retention	June Inlet	June Outlet	Net % removal/ retention	July Inlet	July Outlet	Net % removal/ retention
SUDS	0.143	0.078	72.45	0.024	0.025	0	0.483	0.024	89.43	0.205	0.038	86.85
Non SUDS	0.011	0.009	22.30	0.051	0.061	6.42	0.211	0.034	65.08	0.502	0.149	73.98

Table 4-3 Nitrate (NO_3) concentration recorded in the inlet and outlet of ponds between April and July 2015 (adapted from Crimmins, 2015). Nutrient balance data are presented according to the equation (Chapter 3) suggested by Fairchild et al., (2001). A negative value indicates an increase between the inlet and outlet.

Pond name	April Inlet	April Outlet	Net % removal/ retention	May Inlet	May Outlet	Net % removal/ retention	June Inlet	June Outlet	Net % removal/ retention	July Inlet	July Outlet	Net % removal/ retention
SUDS	0.284	0.4595	-1150.49	0.763	0.206	65	3.021	1.669	44.75	0.205	0.025	60.57
Non SUDS	2.0075	0.4395	77.41	2.37	0.3505	58.385	0.1855	0.344	-118.69	0.051	0.572	-1165.79

Table 4-4 Phosphate ion (PO^{3-}_4) concentration recorded in the inlet and outlet of ponds between April and July 2015 (adapted from Crimmins, 2015). Nutrient balance data are presented according to the equation (Chapter 3) suggested by Fairchild et al., (2001). A negative value indicates an increase between the inlet and outlet.

Pond name	April Inlet	April Outlet	Net % removal / retention	May Inlet	May Outlet	Net % removal/ retention	June Inlet	June Outlet	Net % removal/ retention	July Inlet	July Outlet	Net % removal/ Retention
SUDS	0.081	0.072	38.64	0	0	0	0.01	0	76.67	0.08	0.060	58.13
Non SUDS	0.025	0.023	0	0.01	0	0	0.045	0.05	-50	0.065	0.070	20.56

4.10 Antecedent Rainfall

This section will consider antecedent rainfall and antecedent dry weather period (ADWP) for SUDS and non SUDS ponds for the main field work season. The reason why data is from April 2015 to August 2016 being presented is that most of the data were collected in this period, and as explained earlier in the chapter, the statistics were based on the median values during this period.

Figure 4-25 shows that the median rainfall values are highest in January for SUDS ponds, and November for non SUDS ponds. Statistical tests show that there is a statistically significant association ($p < 0.05$; Tau= 0.74) between antecedent rainfall at SUDS and non SUDS ponds.

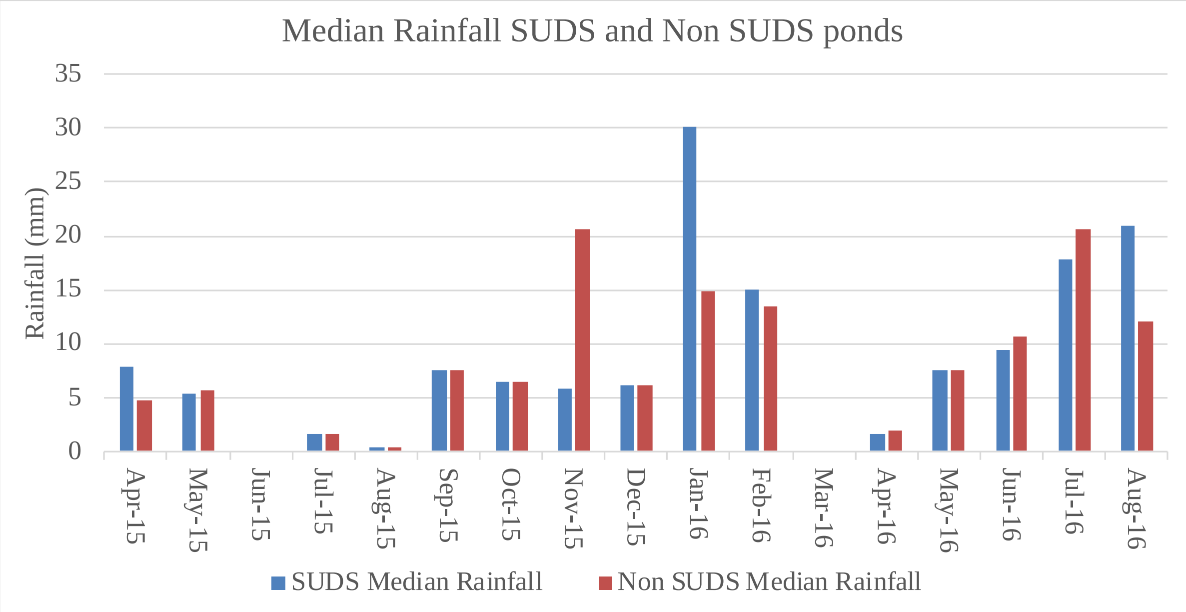

Figure 4-25: Total Rainfall (Median Values): SUDS and Non SUDS ponds

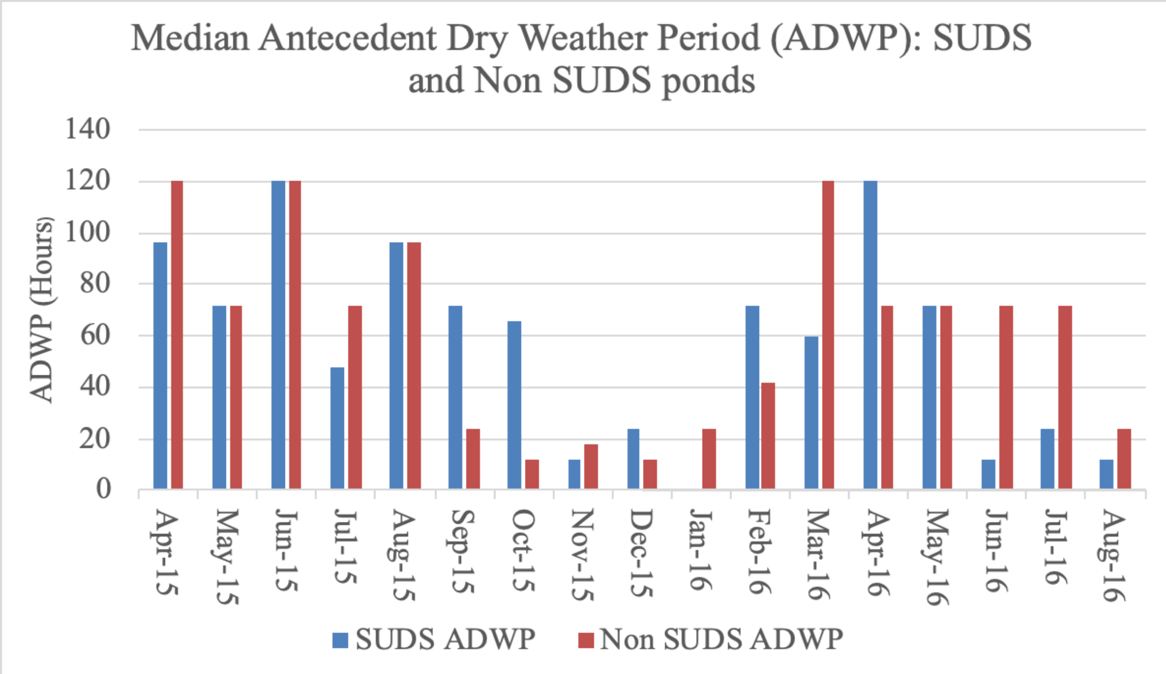

Figure 4-26: Median Antecedent Dry Weather Period (ADWP): SUDS and Non SUDS ponds

ADWP values are highest for SUDS and non SUDS ponds (120 hours) in June 2015. ADWP values are 120 hours for non SUDS ponds (April 2015; June 2015 and March 2016). This is only the case for two months (June 2015 and April 2016). Statistical tests reveal that there is a statistically significant association between ADWP of SUDS and non SUDS ponds ($p < 0.05$) and (Tau=0.43). There is a moderate positive correlation between antecedent conditions at SUDS and non SUDS ponds.

4.11 Chapter Summary

4.11.1 Research Questions addressed

1a: How effective is Water Quality Regulation in ponds between the inlet and outlet of SUDS and non-SUDS ponds, with respect to: -water chemistry, influence of rainfall, and nutrient loading?

Water quality regulation in ponds between the inlet and outlet of SUDS and non-SUDS ponds is effective for some ponds but not all. The main issues highlighted by the results in Section 4.3 are that non-SUDS ponds have lower biological quality in relation to macroinvertebrate proxies and associated ASPT values. This may be due to the flow to treatment path associated with SUDS ponds, and regular maintenance schedules.

Pressures exist in relation to conductivity for some of the SUDS ponds, but that is to be expected with seasonal changes in grit being washed into the pond from nearby roads and paths. However, this is not an issue for all SUDS ponds; for example, Juniper Green (Appendix A.4) has values of less than 500µ/s which is within the requirements for freshwater. Most of the SUDS ponds do have erratic conductivity values, and therefore lower potential to regulate water quality in relation to this parameter. Turbidity is another pressure which exists in the SUDS ponds which lowers the ponds potential to regulate water quality. However, the non-SUDS ponds have better potential to regulate water quality in relation to conductivity, turbidity and pH.

SUDS and non SUDS ponds have pressures in relation to nutrient removal which again reduces their potential to regulate water quality. Some of the issues are in relation to poor maintenance of vegetation and over-enrichment of the water column by nutrients from plants and birds.

1b: How do these ponds compare in relation to water quality regulation, and is there a statistically significant difference between SUDS and non SUDS ponds?

Some SUDS ponds perform satisfactorily in relation to regulating water quality which is suggested by the fact that the ASPT values are higher for SUDS ponds than for non-SUDS ponds. Water quality pressures do still exist in SUDS ponds which could limit the delivery of this service between the inlet and outlet. These pressures may not necessarily be an issue in some of the non SUDS ponds studied, with a greater flow path (e.g Blackford pond) to allow treatment processes to be carried out effectively. However, it should also be noted that while the ASPT is higher for SUDS ponds, the general water quality conditions are poorer than some of the other ponds; for example, Blackford pond which has lower conductivity and less variability in pH (see Appendix A.4).

Chapter 5- DIATOMS AS A PROXY FOR NUTRIENT REMOVAL IN PONDS (WATER QUALITY REGULATION)

5.0 Introduction

Costanza *et al.,* (1997) and Daily (1997) discussed the fundamental ecosystem benefits and how these related to society. The importance of supporting services and the importance of water quality regulation will be discussed in this chapter with reference to diatoms and nutrient enrichment. The findings of this chapter will be qualitatively related to Chapter 4, but with more emphasis of how the micro-organisms (diatoms) contribute to the understanding of regulating water quality within ponds.

Algae, which include diatoms and cyanobacteria, have differing optima for growth and development. Paerl and Otten (2012) suggested that the conditions for algal (and cyanobacteria) blooms differ according to seasonality and environmental conditions in each pond (Chapter 2 provides more details). Algal bloom conditions tend to be warmer and drier with high nutrient conditions (Nitrogen and Phosphorus). Low grazing rates from zoo-plankton and fish also contribute to the bloom forming conditions (Paerl and Otten, 2012). Sheltered areas of water bodies (e.g under bridges/ shrouded by vegetation and trees) may be less prone to blooms forming, as the light conditions are poor. In addition to this, ponds with dense vegetation cover (floating) are less likely to have blooms due to the light not being able to penetrate the cover which in turn influences the recycling of nutrients.

As Chapter 4 highlighted there is a growing demand and need to monitor and manage nutrients due to the implications of eutrophication and acidification. Nitrite is a harmful substance if not converted into ammonia (Boyd, 2015) which could result in detrimental effects within the pond ecosystem, for example limiting oxygen (Chapter 4) and promoting plant growth which acts as a nitrate store within the pond (Quilliam *et al.,* 2015). This may not be as applicable to smaller isolated ponds (n=1 SUDS ponds) or those within a forest setting (Camacho *et al.,* 2016), e.g. n=1, non SUDS ponds.

This chapter will focus on changes in diatom counts, with respect to the inlets and outlets; as well as the seasonality patterns observed. SUDS and non SUDS ponds will be considered with respect to the proxies of diatoms; where SUDS and non SUDS ponds will be compared with biotic and abiotic data from Chapter 4. Furthermore, there are data presented (Chapter 4) which indicates which ponds have nutrient enrichment as a problem for water quality, so it is important to investigate whether there are indicators of salinity, turbidity (low and high) identified. A full evaluation is provided in Chapter 8 where the following research questions will be addressed:

Research Question 2

Do SUDS ponds have more potential than non SUDS ponds for regulating Water Quality through algae removal processes (using diatoms as proxies)?

- Are the key functions (water quality regulation) performed better in SUDS or non SUDS ponds?
- What are the seasonal trends with diatoms and how does this influence the functioning of SUDS ponds?
- Are there challenging geo-chemical disturbances which could reduce the expected Ecosystem Service delivery; for example, conductivity levels.

Table 5-1 summarises the main indicators of freshwater diatoms observed in the field campaign in relation to water quality and their relative sensitivity to the nutrient Phosphorus; as documented in the Water Framework Directive and Trophic Diatom Index (Kelly *et al.*, 2001). It indicates the presence and absence of indicators observed at the inlets and outlet. This table will be used to highlight indicators of good water quality and regulating services within SUDS and non SUDS ponds; as well as providing an indication of stress or disturbance indicators. Furthermore Table 5-1 indicates the relative nutrient sensitivity scores for each diatom which will be explored in more detail within Section 5.4.3 in relation to testing whether statistically significant differences exist between median nutrient sensitivity scores for SUDS and non SUDS ponds using Mann-Whitney, Wilcoxon, test results from R. A seasonal comparison of medians is then presented in Section 5.3, and the reader is directed to Appendix A.5 for details of individual ponds- which is not provided within this chapter.

Table 5-1 Diatom water quality indicators. Nutrient sensitivity scores derived from Trophic Diatom Index (2001).Diatom water quality indicators. Nutrient sensitivity scores derived from Trophic Diatom Index (2001).

Indicators	Water Quality	Nutrient Sensitivity	SUDS Inlet	SUDS Outlet	Non SUDS Inlet	Non SUDS Outlet
Cymbella Sinuata	Excellent	1	√	√	√	X
Diploneis	Very good	1	√	√	X	√
Eunotia	Very good	1	√	√	√	√
Hannaea	Excellent	1	X	X	V	X
Neidium	Very good	1	X	X	X	X
Semiorbis	Excellent	1	X	X	V	X
Craticula	Good	2	√	√	√	√
Diatoma	Good	2	√	X	X	√
Fragilaria	Poor	2	√	√	√	√
Meridion	Very good	2	√	√	√	X
Pinnularia	Very good	2	√	√	√	√
Surillela	Good	2	X	X	√	X
Synedra	Good	2	√	√	√	X
Acnathes	Poor	3	√	√	X	X
Caloneis	Poor	3	X	X	X	√
Cocconeis	Poor	3	√	√	√	√
Rhoicosphenia	Poor	3	√	√	X	√
Gomphonema	Poor	3	√	√	√	√
Navicula	Poor	4	√	√	√	√
Reimeria	Poor	4	√	X	√	√
Bacillaria	Poor	5	√	X	X	X
Ellerbeckia	Poor/stressed	5	√	X	X	X
Hantschia	Poor	5	X	X	X	√
Amphora	Very poor	5	X	X	X	√
Actinoptychus	Good	None	√	X	X	X
Cyclotella	Poor	None	√	√	√	X
Stephanodiscus	Poor (turbid)	None	√	X	X	x

5.1 Water Quality Overview

This section will present the results for the diatoms present in SUDS and non SUDS ponds. The boxplots for the main water quality parameters are shown in Figure 5-1- Figure 5-4, and these are water temperature, conductivity (dissolved ions), turbidity and pH. The pH factor is important, as diatoms are particularly sensitive to changes in pH, and are useful indicators of increasing acidity (Bennion *et al.*, 2004). This section will also refer to the table (Table 5-1) which assesses the diatoms in terms of water quality.

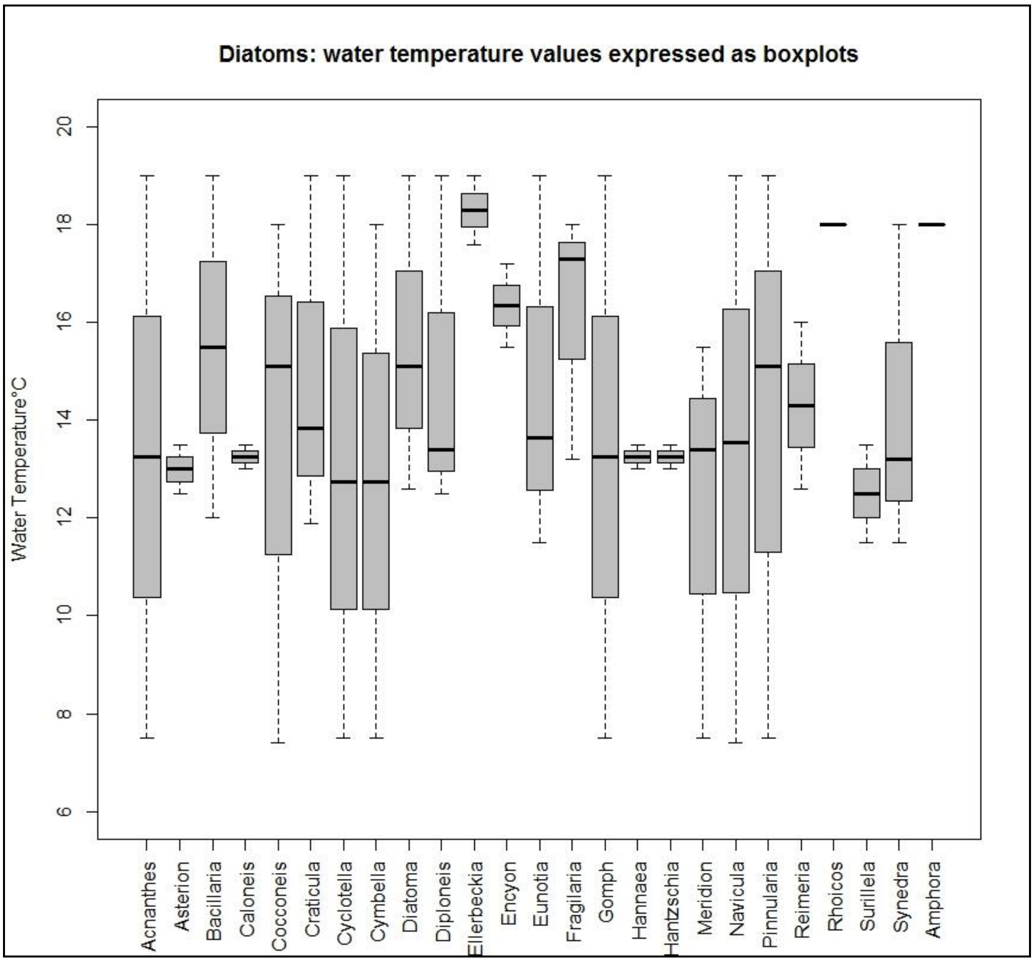

Figure 5-1 Minimum, maximum, and median values for individual diatom genera in the studied ponds. Thick black lines represent median values. The variable water temperature is considered.

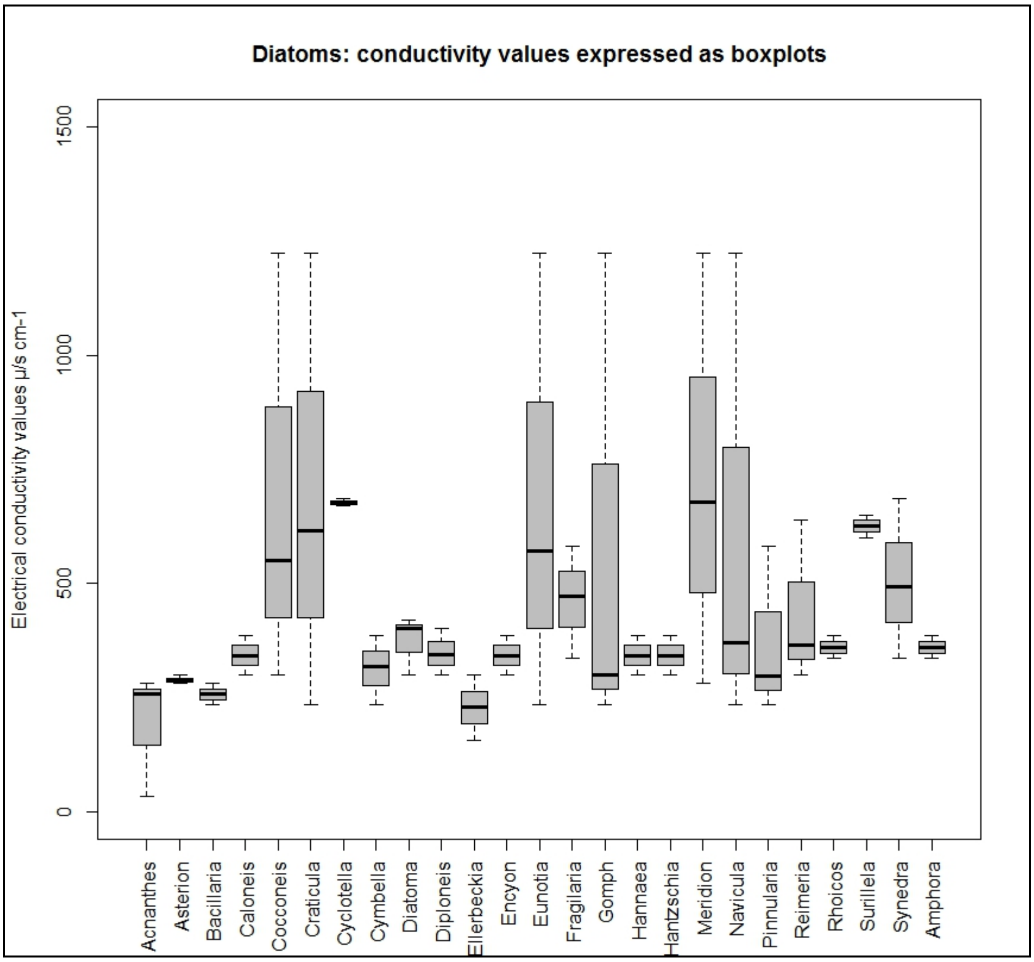

Figure 5-2 Minimum, maximum, and median values for individual diatom genera in the studied ponds. Thick black lines represent median values. The variable conductivity is considered. Asterion = Asterionella, Encyon = Encyonema, Gomph= Gomphonema, and Rhoicos= Rhoicosphenia.

Q1 (Quartile 1) values (Figure 5.2) are 100 to 700µ/s cm^{-1} for *Acnanthes* and *Surillela*, respectively. Median values are lowest for *Ellerbeckia* and highest for *Cyclotella* and *Navicula* genera. Upper whisker values are lowest for *Asterionella*, which was observed in (n=2) Blackford and Oxgangs ponds, and highest values for *Cocconeis*, *Craticula*, *Eunotia*, *Gomphonema*, *Meridion* and *Navicula*. Lower whiskers have highest values for *Surillela* (n=1), and lowest values for *Acnanthes*.

Q1 (Quartile 1) values for pH () are 7.6 (*Craticula* and *Eunotia*) to 8.5 (*Acnanthes* and *Bacillaria*). Median values are 7.7 (*Cyclotella*) to 8.8 (*Acnanthes* and *Bacillaria*). Lower whisker values are highest for *Acnanthes* and *Bacillaria*, and lowest for *Cyclotella*, *Fragilaria* and ***Gomphonema*.**

Q1 (Quartile 1) values (Figure 5.6) for water temperature are 10°C (*Cyclotella*) to 17°C (*Ellerbeckia*). Median values are 12.5°C (*Surillela*) to 18.5°C (*Ellerbeckia*). Lower whisker values are highest for *Ellerbeckia* (17.6°C) and lowest for *Cocconeis* (7.6°C). Upper whisker values are highest for *Acnanthes, Bacillaria, Craticula, Cyclotella Diatoma, Diploneis, Fragilaria, Gomphonema* and *Pinnularia* (19°C), and lowest for *Caloneis, Hantzschia, Hannaea*, and *Synedra* (13°C).

Q1 (Quartile 1) values (Figure 5.3) for turbidity are 30NTU (*Cocconeis*, *Diatoma*, *Fragilaria*, and *Pinnularia*) to 150NTU (*Reimeria*). Median values are 30NTU (*Rhoicosphenia*, *Amphora*, *Cocconeis*, *Diatoma*, *Fragilaria*, and *Pinnularia*) to 210NTU (*Reimeria*). Lower whisker values are highest for *Surrillela (*60NTU*)* and lowest for *Craticula, Cyclotella, Cymbella, Diploneis, Meridion*, and *Navicula (*30NTU*)*. Upper whisker values are highest for *Navicula*, *Diploneis*, *Reimeria* and *Synedra* (400NTU), and lowest for *Pinnularia* (40NTU).

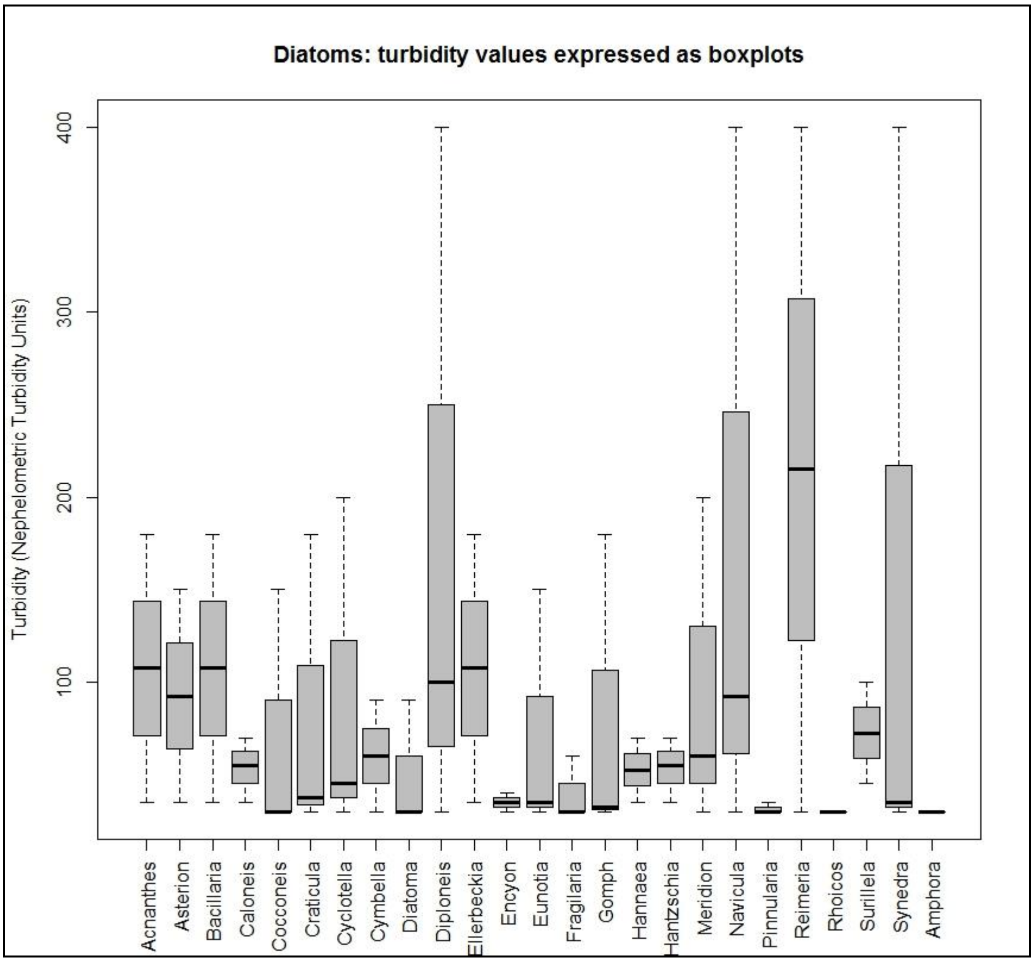

Figure 5-3 Minimum, maximum, and median values for individual diatom genera in the studied ponds. Thick black lines represent median values. The variable turbidity is considered. Asterion = Asterionella, Encyon = Encyonema, Gomph= Gomphonema, and Rhoicos= Rhoicosphenia

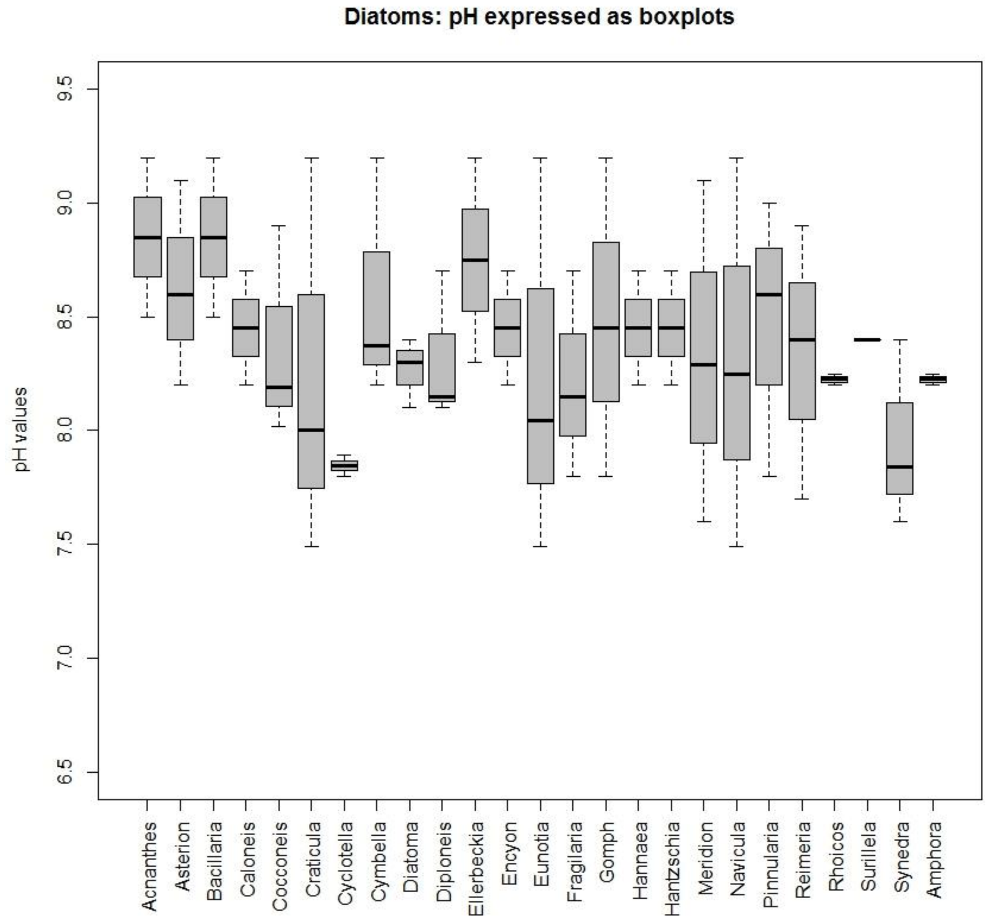

Figure 5-4 Minimum, maximum, and median values for individual diatom genera in the studied ponds. Thick black lines represent median values. The variable turbidity is considered. Asterion = Asterionella, Encyon = Encyonema, Gomph= Gomphonema, and Rhoicos= Rhoicosphenia.

5.2 Diatoms (inlet to outlet comparisons)

This section will provide an overview of the key differences between SUDS and non SUDS ponds in relation to the diatoms observed at inlets and outlets. Antecedent conditions are represented by plotting the antecedent rainfall (mm) for SUDS and non SUDS ponds to see whether months with more or less rainfall have an impact on diatom counts.

Statistical test results will be presented in Section 5.2.3 to highlight whether any key differences are of significance ($p<0.05$). This will be achieved by comparing median populations observed at inlet and outlets of ponds using the Mann Whitney-Wilcoxon test results from R.

5.2.1 SUDS

This section will present the results from SUDS ponds with the diatoms observed at the inlets and outlets. It will highlight the differences in median diatom counts for inlets and outlets. Individual ponds are considered in the appendix (A.5), and the reader is directed here for data from each sampled pond.

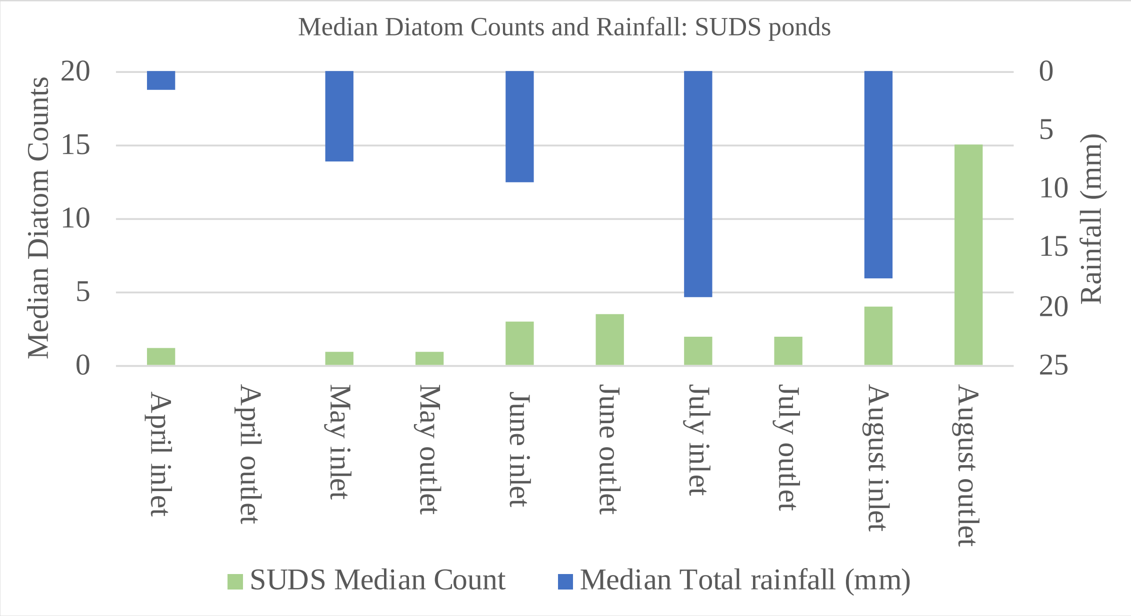

Figure 5-5 Diatom abundances, SUDS ponds, inlet and outlet, spring-summer 2016.

Figure 5-5 highlights that the median diatom counts decrease between the inlet and outlet of SUDS ponds during April 2016 (n=0). There are signs of nutrient retention in June (n=4) and August 2016 (n=15) with an increase in median diatom numbers observed at inlets and outlets. July and August have the highest level of antecedent rainfall with 20mm (appendix A.5). Excess rainfall may increase the diatom presence at the outlets of SUDS ponds with an increase in the level of sediment and soil being washed into the pond.

5.2.2 Non SUDS ponds

This section focuses on the median diatom counts for inlets and outlets of non SUDS ponds and compares these data to antecedent rainfall.

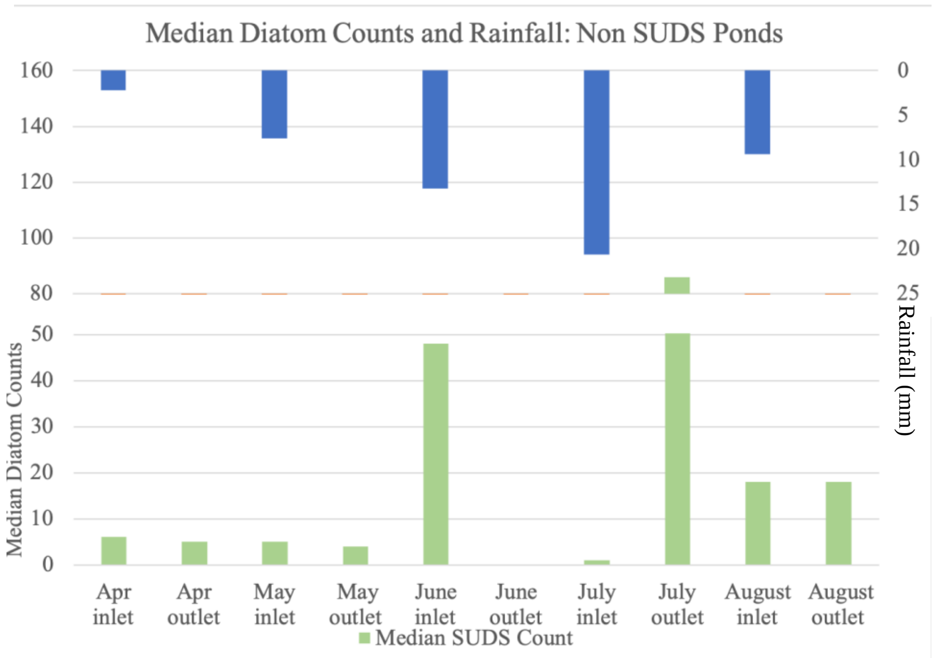

Figure 5-6 Diatom abundances, Non SUDS ponds, inlet and outlet, spring-summer 2016 (Graph split to show lower and high values).

Figure 5-6 highlights that there is a decrease in median diatom numbers observed between the inlet and outlet of non SUDS ponds in April (n=7), May (n=5) and June (n=0) 2016. There are signs of stress/ disturbance observed in July (median, n=84). This result is skewed by the presence of diatom *Fragilaria* during July 2016. Section 5.3 discusses this in more detail. July 2016 has the highest level of (median) antecedent rainfall for non SUDS ponds which could partly explain why there is an increase in diatom counts observed.

5.2.3 Comparing pond inlets and outlets

This section will discuss the differences between SUDS and non SUDS ponds, and observations at the inlets and outlets. Statistical results will be presented from correlation and Mann Whitney- Wilcoxon computed using R. This is with a view to highlight whether differences in median populations are statistically significant, and specifically whether the medians are significantly greater between ponds. Again, if the reader would like to see finer detail (individual ponds), these details are provided in Appendix A.5.

There is not a statistically significant association between pond inlets (p >0.05; Tau = 0.4) or outlets (P >0.05; Tau=0) for SUDS and non SUDS ponds in relation to median diatom observations. Comparing median populations, there is not a significant difference (increase) between the SUDS ponds and non SUDS ponds for inlets ($p > 0.05$; $W = 4.5$) and outlets ($p > 0.05$; $W = 6.5$). These results show that while there are differences in median observations between SUDS and non SUDS ponds that these are of no statistical significance. A longer duration study may change the outcome of these statistical findings.

5.3 Seasonal comparison of diatoms

This section will present the results for seasonal changes in diatoms. A comparison between observed diatoms at SUDS ponds and non SUDS ponds will be made with reference to statistical results from correlation and Mann Whitney Wilcoxon test results in Section 1.3.3.

5.3.1 SUDS ponds

This section will highlight the results for SUDS ponds in relation to diatom counts and spring and summer observations. Spring months are April and May 2016, and summer months are June-August 2016. A full breakdown is provided in Appendix A.5. Table 5-2 highlights the presence and absence of diatoms observed for spring and summer months. Indicators of good water quality are observed for spring and summer months, with the presence of *Eunotia* and *Pinnularia.* However, there are indicators of poorer water quality with the presence of *Navicula, Cyclotella, Gomphonema* and *Acnanthes. Navicula* is observed in spring and summer months at pond inlets and outlets. *Cyclotella* is only observed for summer months at the outlet.

Table 5-2 Presence and Absence of diatoms for SUDS ponds: Spring and Summer 2016

	Spring Inlet	**Summer Inlet**	**Spring Outlet**	**Summer Outlet**
pinnularia	√	X	X	√
synedra	X	X	X	√
eunotia	√	X	X	√
acnanthes	X	√	X	X
cymbella	X	√	X	X
craticula	√	X	X	X
diploneis	X	X	X	√
actinoptychus	X	√	X	X
navicula	√	√	√	√
fragillaria	X	X	X	√
cyclotella	X	X	X	√

	Spring Inlet	Summer Inlet	Spring Outlet	Summer Outlet
gomphonema	X	√	X	√
asterionella	X	X	X	√

5.3.2 Non SUDS ponds

This section will focus on the diatoms observed at inlets and outlets of non SUDS ponds. in spring and summer 2016. *Eunotia* is present at the inlet and outlet of non SUDS ponds for spring and summer months. *Navicula* is also present during spring and summer months. Table 5-1 refers to the water quality each indicator provides, and for non SUDS ponds, the presence of *Eunotia* is indicative of clearer water conditions. Chapter 4 revealed that there was not a statistically significant difference observed between median turbidity for pond outlets ($p>0.05$). Presence of *Hantschia* and *Amphora* are indicators of poorer water quality and suggest that the ponds could be stressed. Section 5.3.3 will discuss this in more detail.

Table 5-3 highlights the presence and absence of diatom indicators observed in spring and summer 2016. *Eunotia* is present at the inlet and outlet of non SUDS ponds for spring and summer months. *Navicula* is also present during spring and summer months. Table 5-1 refers to the water quality each indicator provides, and for non SUDS ponds, the presence of *Eunotia* is indicative of clearer water conditions. Chapter 4 revealed that there was not a statistically significant difference observed between median turbidity for pond outlets ($p>0.05$). Presence of *Hantschia* and *Amphora* are indicators of poorer water quality and suggest that the ponds could be stressed. Section 5.3.3 will discuss this in more detail.

Table 5-3 Presence and Absence of diatoms (April- August 2016, where Spring= April and May, and Summer= June-August)

	Spring inlet	Summer Inlet	Spring Outlet	Summer Outlet
pinnularia	√	√	√	X
synedra	√	√	X	√
eunotia	√	√	√	√
cymbella	X	√	X	X
craticula	√	X	√	X
diploneis	X	X	X	√
navicula	√	√	√	√
fragillaria	X	√	X	√
cyclotella	X	√	X	X
gomphonema	X	√	X	√
asterionella	X	X	X	√
meridion	√	X	X	X
diatoma	X	X	√	X
cocconeis	X	√	√	√
reimeria	X	X	X	√
encyonema	X	X	X	√
rhoicasphenia	X	√	X	X
semiorbis	X	√	X	X
hannaea	X	X	X	√
hantzschia	X	X	X	√
surillela	X	X	X	√
Amphora	X	X	X	√

5.3.3 Presence and absence of diatoms: comparing ponds

Acnanthes is a sediment-based diatom and is only observed in SUDS ponds (season = summer) and *Ellerbeckia* which is able to adapt to changes/ variability in salt and conductivity (season= summer). Chapter 4 revealed that the median conductivity of SUDS ponds was higher than non SUDS ponds ($p>0.05$)- which may be due to seasonal gritting near the ponds in urban areas and the influence of road runoff pollutants increasing the conductivity of the ponds.

Non SUDS ponds have *Hannaea* and *Hantzschia* diatoms present in summer 2016. *Hannaea* is an indicator associated with less phosphorus enrichment (Bixby and Jahn, 2011) whereas *Hantschia* is indicative of enriched conditions (Table 5-1). Changes in a pond community between the inlet and outlet suggest there is poorer water quality because of water birds; which adds to the nutrient enrichment through defecation. Some sources suggest that this could be 11% of Nitrate in a small lake, and 73% of Phosphate (Chiachana *et al.*, 2010). Restrictions in fauna could also result from enrichment. Decay and sinking of diatoms could temporarily increase the nutrient content; particularly phosphorus within the water. In 2015, the data from Chapter 4 suggests that there is a short period where phosphorus is retained. However, a seasonal release perhaps due to the presence of diatoms and other algae in the pond.

Craticula which is an indicator of clearer/ low turbidity conditions was present at SUDS ponds and non SUDS ponds indicating that non SUDS ponds have clearer or less turbid conditions. *Fragilaria* is present at SUDS and non SUDS ponds; suggesting there is disturbance in all ponds. Non SUDS ponds have a higher median of *Fragilaria* for summer months than non SUDS ponds have.

Nitzschia and *Pseudo-nitzschia* are not present in SUDS or non SUDS ponds, and these are toxic (harmful) diatom genera; which related to historical cases of shell-fish and mollusc poisoning- and this could then disrupt high trophic levels or humans with poisoned fish. This is due to the production of domoic acid (Tammilehto *et al.*, 2015). In contrast, *Peronia Fibula* and *Frustulia* are indicators of low nutrient conditions and these genera are very sensitive to pollution. Absence of these genera suggests that SUDS and non SUDS ponds do not meet reference conditions, and have impaired water quality. This results in less efficient water quality regulating services within the ponds.

The presence of *Amphora* in a non-SUDS pond (season = summer) is indicative of nutrient rich conditions and is also harmful to human health. Presence of this indicator is perhaps not surprising due to its eutrophic nature of the ponds studied (especially in the summer months). However, it is of concern at some ponds where the water is used for recreation purposes (e.g. feeding the birds or model boats).

5.4 Nutrient Sensitivity data

This section will present the results for SUDS and non SUDS ponds in relation to nutrient sensitivity scores based on the Diatom Trophic Index (Kelly *et al.*, 2001) and originally considered for river environments. However, to date, there is not a similar approach for smaller waterbodies, but this is in use for lake environments which have greater catchments than ponds. For the purpose of this assessment ponds are compared in relation to spring and summer observations to see whether differences exist between seasons for nutrient sensitivity.

5.4.1 SUDS

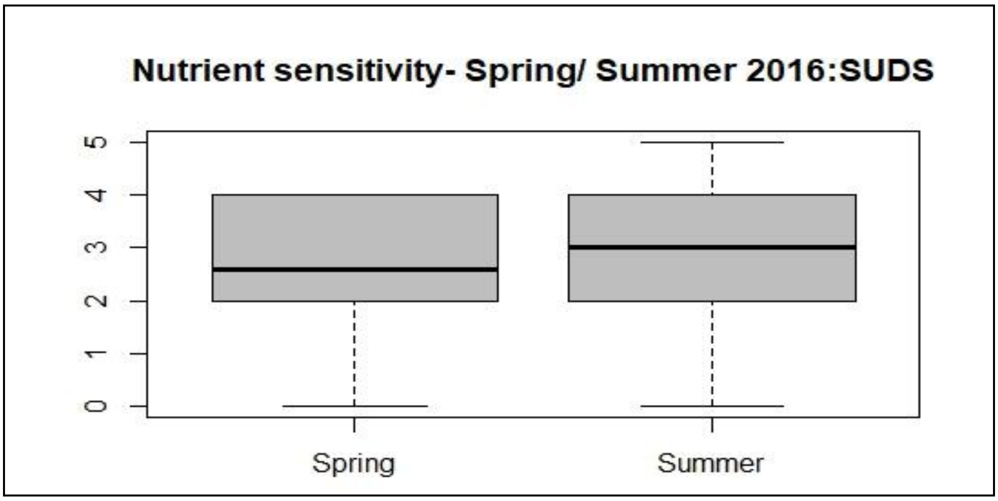

Figure 5-7 Boxplot highlighting nutrient sensitivity scores for SUDS ponds: Spring and Summer 2016

Figure 5-7 highlights the nutrient sensitivity scores for SUDS ponds in spring and summer. The highest value is 4 for spring, and 5 for spring. A value of 5 is indicative of nutrient stress, as taxa are tolerant to enrichment by Phosphorus; indicating poorer water quality conditions in summer for SUDS ponds. The median value indicated by the black line shows there is a marginal increase between spring and summer.

5.4.2 Non SUDS

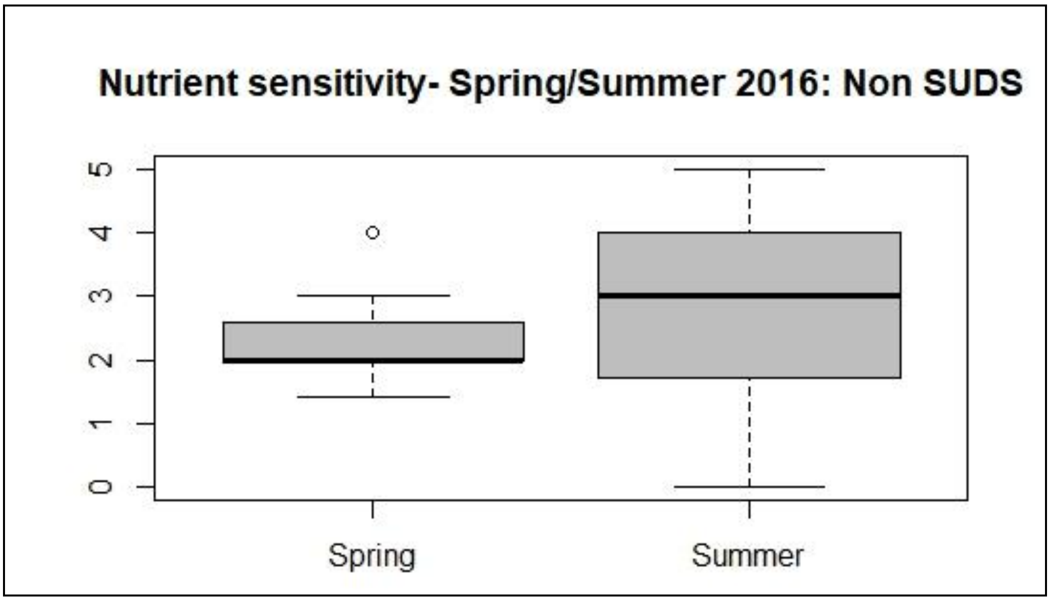

Figure 5-8 Boxplot highlighting nutrient sensitivity scores for Non SUDS ponds: Spring and Summer 2016

Figure 5-8 highlights the nutrient sensitivity scores for spring and summer at Non SUDS ponds. Spring months have lower nutrient sensitivity scores than summer months, with the main set of values between 1.4 and 3. Summer months have values between 0 and 5, indicating that there is more disturbance. As Section 5.3.3 indicated that there were presence of indicators associated with stressed conditions; e.g. *Hantzschia* and *Amphora*.

5.4.3 Nutrient Sensitivity Scores

This section will discuss the nutrient sensitivity scores and whether there are statistical differences between SUDS and non SUDS ponds. It should be noted that for the purpose of this assessment, the outlet conditions will be referred to; as these reveal the true water quality regulating ability of the ponds.

- Score 1: optimum occurs at or below 0.01mg/l filterable P
- Score 2: optimum occurs between 0.01 and 0.035mg/l filterable P
- Score 3: optimum occurs between 0.035 and 0.1mg/l filterable P
- Score 4: optimum occurs between 0.1 and 0.35mg/l filterable P
- Score 5: optimum occurs between 0.35 and 1mg/l filterable P
- 0 – ecological preferences are not well defined and planktonic (*Cyclotella*) which are excluded from assessment

Nutrient sensitivity values should reflect the median nutrient concentration for spring/ summer the previous year- e.g. eutrophic ponds (at outflow, see Chapter 4) are likely to have more taxa with a score above 2. This is expected with a decrease in nutrient concentration and thus the most sensitive taxa to Phosphate enrichment should be present. Also, the reduction in presence of taxa at the outlet (if NS value = 1 or 2, see above) is a useful indication of the treatment process and removal of Nitrate and Phosphate throughout the pond by adsorption through emergent vegetation and absorption in sediment or soil at the bottom of the pond. It is also likely that the SUDS ponds with surface vegetation (which is routinely managed/ maintained) improved water quality conditions due to the flow of Oxygen being in balance. However, this could not be the case for overgrown ponds or ponds without sufficient oxygen supply; for example, some SUDS ponds have spikes in Phosphorus, making the median value more variable ($p>0.05$). Ponds which treat road runoff (SUDS ponds) are most likely to have eutrophic conditions due to the excess minerals, soil, and pollutants being washed into the pond.

There is a statistically significant association for spring ($p <0.05$; Tau= 0.7) and summer ($p <0.05$; Tau=0.9) months in relation to nutrient sensitivity scores at SUDS and non SUDS ponds. This indicates that the two median populations are associated. However, the Mann Whitney tests revealed that there is no significant difference between median populations in spring and summer ($p >0.05$), and there is no significant increase in value between SUDS and non SUDS pond ($W=47.5$; $p >0.05$). This shows that while there may be a difference in median values the groups are not independent from each other. In reference to nutrient sensitivity scores, it highlights that both groups studied have a range of higher and lower values indicating variable water quality conditions.

5.5 Chapter Summary

Chapter 5 highlights the importance of using diatoms for bio assessment in freshwater environments: ponds, lakes, and rivers. This is important with respect to monitoring water quality and nutrient enrichment in water bodies; particularly ponds. This chapter has illustrated the need to monitor freshwater diatoms in SUDS ponds; especially with respect to the presence or absence of harmful genera, such as *Nitzschia*, *Pseudo-nitzschia* and *Amphora.* From the 2016 results, there are no harmful genera observed in SUDS ponds but there are in non SUDS ponds. However, this is not to say that these genera have not been captured, and long-term studies (out with the scope of this project) could highlight this. Rainfall has an effect if heavy rainfall (<20mm) has fallen less than 24 hours prior to data collection and could cause a disturbance in the pond. Therefore, disturbed indicators will be present as a result of this.

5.5.1 Research Questions addressed

Main: Do SUDS ponds have more potential for regulating Water Quality through algae removal processes (using diatoms as proxies)?

Algae (diatoms) traps nutrients which improves the water quality discharged into receiving water bodies. SUDS ponds have more potential for regulating water quality through algae removal processes, using diatoms as proxies. This is highlighted in Section 5.2 where the results revealed that the median diatom counts decrease between the inlet and outlet of the SUDS ponds. The seasonal distribution of diatoms also revealed a similar pattern with a general decreasing trend between the inlet and outlet. This pattern contrasts the situation with non SUDS ponds, where an increase in diatom counts was observed, with a dominance of *Fragilaria*; indicating that there was a disturbance at the outlet and a reduced ability to regulate water quality between the inlet and outlet.

Chapter 6 PLANT DIVERSITY IN PONDS (POLLINATION PROCESS)

6.1 Introduction

Species diversity, and richness, of flora and fauna is of increasing importance when studying pond ecosystems; particularly in relation to the provision of Ecosystem Services. Studying the interactions between urban landscapes and water has been well examined (Hill, 2015; 2016; Hassall *et al.*, 2016). Ecosystem assessment and monitoring is changing in relation to the ever- growing need for management of ponds at development and post development phases with an emphasis on multiple benefits (Chapter 2), and Ecosystem Services (Wade and McClean, 2014). It is recognised that the sampling effort is outwith the scope or capabilities for some projects, and that this gap needs to be filled to understand why the ecosystem diversity changes in relation to external and internal pressures. The research presented in this chapter focuses on pond diversity in relation to ecological and anthropogenic factors which shape the diversity scores within ponds.

This chapter will compare SUDS and non SUDS ponds in relation to flowering plants and the potential ponds have to support pollinators. Studying diversity of life within the pond environment is important and is an inexpensive way to sample (using DAFOR). DAFOR values (appendix A.6) were converted into the Shannon index values to see how diversity differs at ponds (Chapter 3). The approach is a well-tested method in ecology analysis employed by Claude Shannon in the 1950s for information technology- where letters and words were predicted in a line of communication (Spellerberg and Fedor, 2003). Shannon Wiener is the engineered approach for monitoring diversity in ecological systems (De Viol *et al.*, 2009).

Species richness and diversity are related to Ecosystem Services. Species richness and diversity is important for Ecosystem Services as it helps quantify the types and numbers of macrophytes at the studied ponds. Delivery of species diversity in ponds is important as some ponds may have direct problems with water chemistry (Chapter 4) and may not be suitable to support a wide diversity of species/ families. Maintenance regimes may reduce the wild plant species diversity by limiting the number of pollinating plants available.

Species diversity is an important consideration when building new ponds or maintaining older ponds, and it is an important consideration for developing a business case to promote the multiple benefits of ponds. Equally, the promotion of new ponds contributes towards local biodiversity targets. The main reason for studying species diversity is to investigate whether plant diversity is influenced by several anthropogenic and natural characteristics. Species diversity (and richness) is at threat from anthropogenic warming and pollution, as well as land use change and urbanisation (Vanbergen, 2013).

The current gap is quantifying Ecosystem Services within ponds and using these values to inform decision making at a local level. Species richness studies have been carried out in urban ponds (Hill *et al.,* 2015; 2016) and SUDS (Briers, 2014) but what these studies have not been able to achieve is relating this information to Ecosystem Services and decision-making policies.

Research Question:

3 a: Do SUDS ponds have more potential than non SUDS ponds for plant diversity to support flowering plants suitable for pollinators?

6.2 Field Results

The results section will focus on the data relating to Shannon Diversity indexes, where proportions are derived from the DAFOR field method (Chapter 3). The appendix conveys the graphical representation of this (A.6 for reference), but for the purpose of this chapter Shannon diversity values will be presented (Section 6.2.1). SUDS and non SUDS ponds will be compared and statistical results will be presented to see if there is a significant difference between ponds in relation to plants and pollination potential; specifically between insect and wind pollination processes.

6.2.1 Plant Diversity plots (SUDS Ponds)

This section will present the results for SUDS ponds. For statistical robustness, the data presented are from April 2015- August 2016 to ensure that all ponds are considered within the median values.

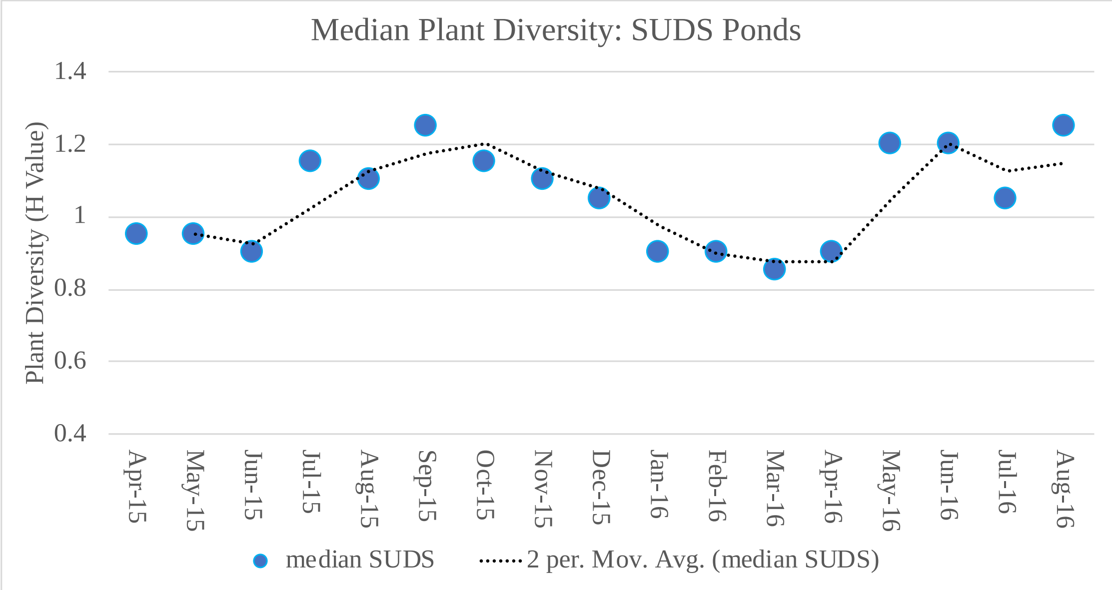

Figure 6-1: Median plant diversity for SUDS ponds using Shannon Indices

Figure 6-1 illustrates the results for plant diversity at SUDS ponds. Diversity at SUDS ponds varies between 0.9 and 1.3. The diversity is lower in winter and early spring- which is to be expected as colder weather limits plant growth. The lowest plant diversity is observed between January and March 2016.

<u>Non-SUDS ponds:</u>

This section will present the results for non SUDS ponds. For statistical robustness, the data presented are from April 2015- August 2016 to ensure that an optimum number of ponds are considered within the results.

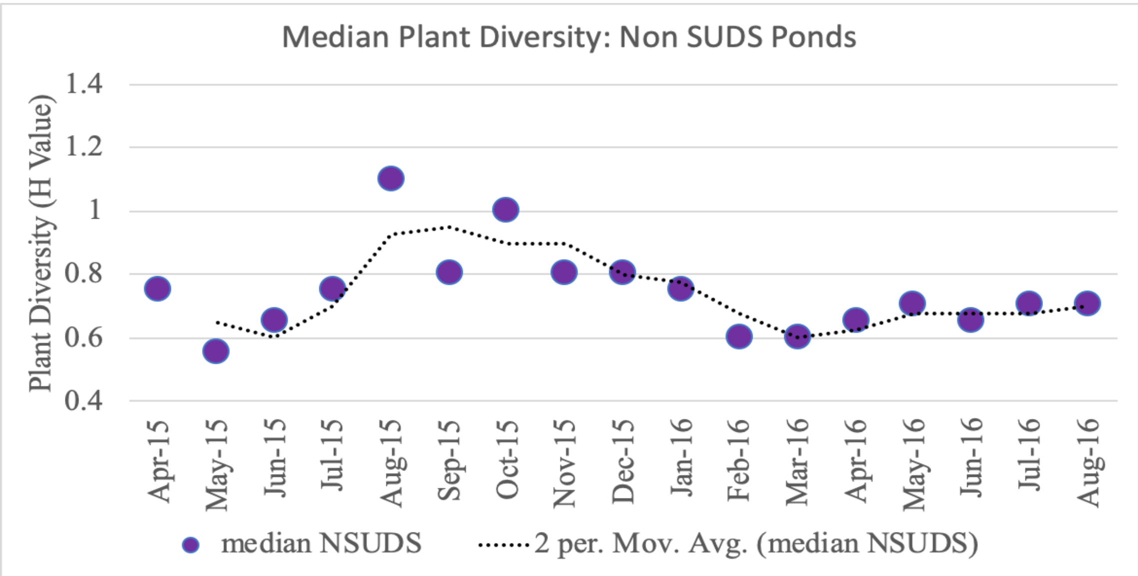

Figure 6-2: Pond plant diversity for non SUDS ponds using Shannon indices

Figure 6-2 reveals that the diversity non SUDS ponds have values between 0.5 and 1.1. The lowest values are observed in May 2015, February 2016 and March 2016. This could be expected autumn to winter as other flowering plants begin to drawback for winter. The pollination potential during autumn and winter is lower, as a result of seasonal change and the decrease in availability of bees to pollinate. Furthermore, there are fewer hours of sunlight available to promote plant growth and diversity (Appendix A.6).

6.2.2 Comparing diversity for SUDS and non-SUDS ponds

A comparison of plant diversity highlights there are differences between SUDS (Figure 6-1) and non SUDS ponds (Figure 6-2) , with SUDS ponds having a higher Shannon Index value than non SUDS ponds. This finding is of statistical significance, as there is a difference between median plant diversity observed at SUDS and non SUDS ponds ($p<0.005$; $W=276.5$). Table 6-1 summarises the plants observed at SUDS and non SUDS pond, this highlights that SUDS ponds have good potential to support plant diversity and have a range of plants suitable for animal and wind pollination (Section 6.3).

Table 6-1 Summary of plant families at SUDS and non SUDS ponds

Summary of plant families & species	**SUDS**	**Non SUDS**
Typha latifolia	√	√
Taraxacum offinale	√	√
Phragmites australis	√	√
Chamerion angustifolium	√	x
Urtica dioca	√	√
Carex acuta	√	x
Carex pendula	√	√
Carex limosa	√	x
Cirsium avense	√	√
Cirsium vulgare	√	x
Potamogeton natans	√	√
Iris pseudocorus	√	√
Pygmaea helvola	√	√
Primula vulgaris	√	√
Pea (vetch)	√	√
Holcus lanatus	√	√
Astragalus danicus	√	x

Summary of plant families & species	SUDS	Non SUDS
Trifolium repens	√	√
Carex hachijoensis	√	√
Carex elata aurea	√	x
Festuca ovina	√	√
Ranunculus flammula	√	x
Lythrum salicaria	x	√
Myositis scorpiodes	√	√
Lemna minor	x	√
Lysichiton americanus	x	√
Lysimachia nummularia	√	x
Anthriscus sylvestris	√	√

SUDS ponds are designed to treat water (stormwater runoff) and pollutants, to reduce the impact from flooding (through attenuation and interception) as well as promoting biodiversity.

Ponds have high conservation value – regional- and have a direct role in the provision of Ecosystem Services (Usio *et al.*, 2013). However, the way in which management and ownership is defined is a grey area, because there are disagreements on the way that ponds should be managed (Hassall 2016) and a lack of poor communication between ecologists and engineers in the early planning stages (D'Arcy, 2016).

An argument is that the current type of management of stormwater ponds (SUDS) with the removal of plants as part of decadal maintenance (CIRIA, 2015) is responsible for lowering macroinvertebrate diversity (Noble and Hassall, 2015). Although the Diversity of macroinvertebrates is promoted by balancing emergent, floating and submerged plants. Some ponds studied in the urban environment, do not have a high diversity of macroinvertebrates which may be related to the lower diversity of plants observed.

6.3 Plants and pollination

This section focuses on the pollinating plant potential at the ponds studied and highlights the potential for SUDS ponds to promote wild species diversity through the processes of wind and insect pollination.

6.3.1 Pollination process

This section will highlight the main plants observed at SUDS and non SUDS ponds in relation to pollination methods. Figure 6-3 compares plants observed at SUDS and non SUDS ponds The findings are that SUDS ponds have a higher observed median number of plants which are pollinated by wind (n=8) and animal (n=9) processes. No data were available for (n=7) plants for SUDS and (n=5) plants for non SUDS ponds; so there may be further potential for plants to provide pollination.

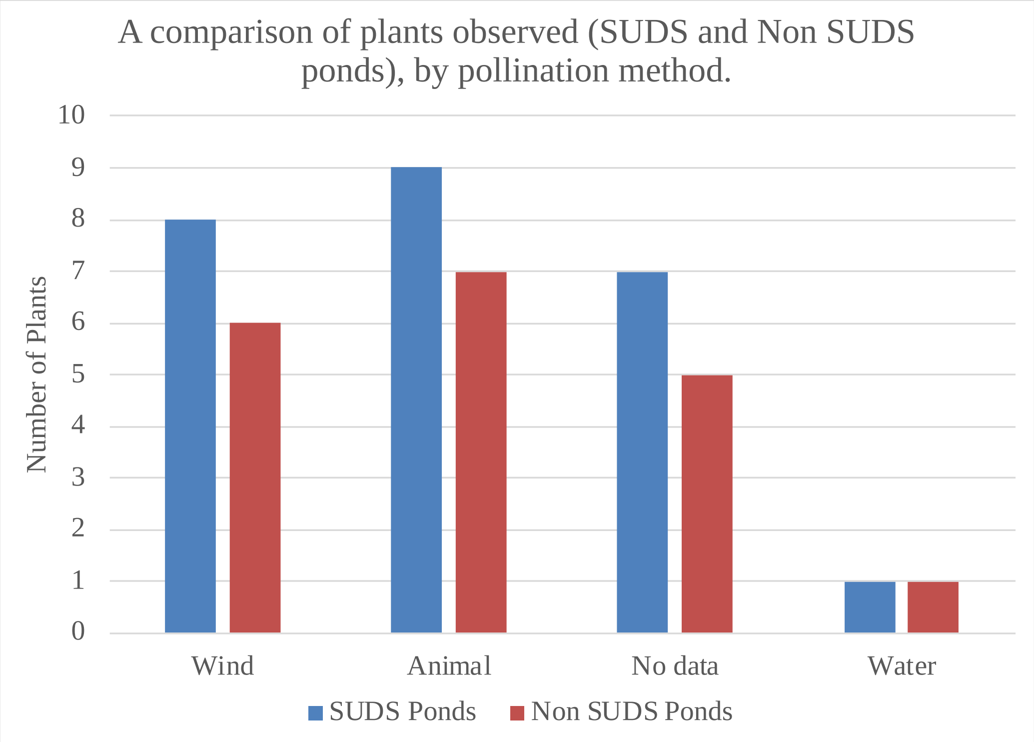

Figure 6-3 Summary of plants, ad pollination processes for SUDS and non SUDS

Animal (including insect) and wind pollination are the main methods of pollination at the SUDS and non SUDS ponds (Figure 6-3). Some of the species were excluded as there were no relevant data pertaining to pollination on the available databases (Ecoflora; Fitter and Peat, 1994). There is only one plant which is pollinated by the water, and this is *Potomageton Natans* (pond weed) which covers the surface of SUDS ponds in summer months, and is present at non SUDS ponds. Wind flowering species mainly include the sedge (*Carex spp.)* and *Typha Latifolia* species for SUDS and non SUDS ponds. SUDS ponds have more wind flowering plants present than non SUDS ponds.

Insect flowering plants include: *Iris Pseudocorus, Cirsium Vulgare, Trifolium Repens, Chamerion Angustifolium, Lysimachia Nummularia,* and *Ranunculus Flammula*, with a few other species. Three species of *Carex spp.* are exclusively found in the SUDS ponds, and these include the species: *Carex Acuta*, *Carex Elata* and *Carex Limosa.*

6.4 Comparing ponds and statistical outcomes

This section will compare ponds in relation to the plants observed; specifically, insect and wind flowering plants. Insect flowering plants have the potential to be pollinated by insects, and there are marginal differences between pond median populations ($p < 0.05$; $W=93$). There are, however, similar differences for median observations of wind flowering plants between SUDS and non SUDS ponds with no statistical significance ($p > 0.05$; $W=37$). Plants pollinated by the water are the same for SUDS and non SUDS ponds.

Ecosystem monitoring of pollinators is important for preserving diversity of wild plant species (Frund *et al.*, 2013) but also from an economic perspective, with increasing demand for food crops, in agriculture and the added stress that this places on pollinators, with three times more demand since 1961 (Vanbergen *et al.*, 2013). The economic value of bees is under appreciated (Senepathi *et al.*, 2015). Flowering plants and the pollinators which they attract provide an important ecosystem service, but there are concerns that the provision of wild species diversity is under threat, with stress conditions for honeybees to pollinate the flowering plants (Garantonakis *et al.*, 2016). Declining plant diversity could impair ecosystem processes (Venjakob *et al.*, 2016), such as pollination, which are fundamental to preserving wild species diversity; especially for green infrastructure (Tzoulas *et al.*, 2012). Furthermore, the pollinators depend on a diversity of plants; as this process leads to production of fruit and seeds for animals and humans (Senepathi *et al.*, 2015). Equally, flowering plant species depend on animals for pollination which is estimated to be 90% of species (Burkle *et al.*, 2013). There is a positive correlation observed between fruit set and the number of flower visitors (Garibaldi *et al.*, 2013), but this is not to say that all visitors benefit the flowering plants, for example some destroy the flowers or eat the parts necessary for pollination (Kevan, 1999).

6.4.1 Wind and animal pollination

SUDS ponds have more wind pollinating potential than non SUDS ponds. For example, SUDS ponds have multiple species of sedge grass (*Carex. spp*), which require wind pollination services, with fewer insect pollinated plants. However, the presence of a diversity of wild plants promotes the idea that insect and wind pollination processes play an important role in delivery of wild species diversity at ponds. Purple loose strife (*Lythrum Salicaria*) provides purple, pink, coloured flowers in the summer and attracts insects to promote pollination. Wind pollinator services may be an evolutionary response to animal pollination, where pollination by insects and birds is no longer an option (Friedmann and Barrett, 2009). This may also be a response to seasonality, as bees may not be available at certain times of the year, for example spring, due to changes in weather- which could reduce pollination efficiency (Hayter and Cresswell, 2006). However, it could also be argued that the rate of efficiency is also dependent on the morphology of the plants (Friedmann and Barrett, 2009).

While flowers of wind pollinating plants could appear less attractive, for example small black and brown flowers present on some *Carex.spp*, the morphology of these plants are more efficient at capturing pollen grains, due to their feather like appearance (Friedmann and Barrett, 2009). However, the main attraction to insect pollinators is the presence of the scented flowers, provision of pollen, and nectar (Flacher *et al.*, 2015), which is less likely to be observed in wind pollinating plants. Sedges do not produce nectar (Wragg and Johnson, 2011). However, it is important to study the whole plant community when evaluating the potential for pollination (Flacher *et al.*, 2015). Environmental changes to the field site may also impact the potential for pollination; for example, regular maintenance at SUDS ponds could reduce the diversity from the wild plant species. While, ponds are not considered for the provision of food, such as seeds, and fruit sets from wild plants, the process of pollination is important to maintain the plant diversity. Furthermore, by promoting the diversity of wild plant species, it also emphasises the value that insects have in an urban setting (Tzoulas et al., 2012) for pollination (Bolund and Hunhammer, 1999; Vanbergen *et al.,* 2013).

6.5 Summary

This chapter focused on the provision of plants to promote pollination for wild species diversity at the ponds. Diversity is greatest in SUDS ponds especially for flowering plants which attract insect pollinators. Pollination is important for creation of habitat and to protect bees from extinction. The results showed there was a statistical significant difference between the insect flowering plants at SUDS ponds and non-SUDS ponds. This suggests that the sample medians are different between the ponds; although on close inspection this difference is marginal- as there are fewer insect and wind flowering plants observed at non SUDS ponds.

6.5.1 Research Questions answered

Do SUDS ponds have more potential than non SUDS ponds for plant diversity to support flowering plants suitable for pollinators?

SUDS ponds have more potential for species diversity than non SUDS do in relation to the available data. This does vary from pond to pond (see Appendix A.6). In this study, SUDS ponds have more insect and wind flowering plants, and potential pollination than non SUDS ponds. For example, at SUDS ponds, there are multiple species of sedge grass (*Carex. spp*), which require wind pollination services. However, wild plant diversity promotes the idea that insect and wind pollination processes play an important role in delivery of wild species diversity at ponds.

Chapter 7- VALUING THE MULTIPLE BENEFITS FROM SUDS PONDS.

7.1 Introduction to Valuation

Chapter 7 presents the results for the Contingent Valuation analysis, and Whole Life Cost Assessment (Chapter 3).

1. What is the public perception of the potential benefits and disadvantages of living near a pond?
2. How much value is placed on supporting multiple benefits at their local pond (their Willingness to Pay for benefits), and are these values capable of offsetting costs?

The Contingent Valuation analysis is based on a survey which was undertaken to understand how the public perceive multiple benefits so that these principles may be incorporated into the future design of SUDS ponds. Studying urban ponds in a UK context is not new (Briers, 2014; Hassall, 2014; Hill *et al.*, 2015). Urban pond research has historically played a fundamental role in developing planning policy and, with this in mind; the following questions guided the development of the research:

7.2 Multiple benefits approach

Blue Green infrastructure (including SUDS), is designed with water quality (treatment) and water quantity (flood risk management) principles; as well as incorporating biodiversity and amenity to a lesser extent. Multiple benefits incorporate functions which provide sustainable conditions within the urban environment (Wade and McClean, 2014). The role of SUDS facilitates this process through ingenious design and engineering while making efficient use of parks and urban areas for health and well-being in addition to the main functions of SUDS.

Incorporating multiple benefits within planning will support best practice in designing new developments. An example of this is that a SUDS pond provides the basic water quality and quantity demands, as well as a suitable habitat for wildlife; while offering education opportunities and a place for meditation and relaxation. Within the context of multiple benefits, it is therefore important to look at services delivered by SUDS ponds, and the greenspace surrounding these, out with traditional design principles, and compare these with non SUDS ponds to see how the public view and value these benefits.

The multiple benefits of SUDS are assessed with economic and spatial analysis. The Benefit of SUDS Tool (BeST) highlighted the Whole Life Cost, and associated benefits, for SUDS uptake in London (Ossa-Moreno *et al.,* 2016). Monetary valuation is a well-known and accepted method for evaluating the costs and benefits of a project but using Whole Life Cost approaches has limitations too. For example, the cost benefit analysis is dependent on having accurate maintenance cost data (which is variable from site to site, e.g. Wolf *et al.,* 2014). Another chosen approach was Public Participatory Geographic Information Systems (PPGIS), which was used to define the multiple benefits from SUDS by involving the local community in the assessment process. This approach is positive as it is important to involve local communities in the development and post-development phases; as the former allows future residents to engage with the planning process, and the latter how effective the SUDS are functioning. Spatial analysis using non-monetary valuation could introduce subjective bias when characterising the multiple benefits by use of qualitative design (Keleman *et al.,* 2016)

In this chapter, Contingent Valuation was adopted to assess the multiple benefits associated with ponds. Contingent valuation is inexpensive, requires no market data, and is useful for decision making at a local scale (Whitehead, 2016) but there could be bias involved with some participants providing unrealistic ('pleasing') responses to valuation questions (Hausman, 2012). Therefore, it is important to compare the habitat benefits with costs in a Whole Life Cost analysis- as this validates the use of Contingent Valuation for planning policy and minimises some of the uncertainty associated with unrealistic responses. Applying a multiple benefit approach is a useful way to quantify the benefits from ponds (as it captures the multiple benefits associated with habitat) in relation to the perceived value from habitat potential, and to investigate whether the benefits exceed the Capital (CAPEX) and Operation/ maintenance (OPEX) costs for SUDS ponds. It is also important to assess the value of replacing a non SUDS pond, and to see whether these current benefits (NPV) exceed future costs for a pond of a similar catchment size. This is a novel approach as previous work has not compared the benefits of SUDS and non SUDS ponds in relation to the multiple benefits.

Table 7-1: Describes the setting of each pond, ownership, and the known uses. The main purpose of each pond is described, and some additional notes about amenity and biodiversity. This also highlights why the ponds were chosen (with SUDS ponds being compared to non SUDS ponds. Scottish Index of Multiple Deprivation (SIMD, hereafter) scores for each case study are presented.

Case Study	Setting of Pond	Use of Pond	Surface Area (m^2)	Date Established	Ownership	Population within 500 m Radius	SIMD Decile Score
Granton Pond, Edinburgh	In a park. Near a supermarket and college.	Drainage (SUDS) pond. Provides amenity and biodiversity.	12,000	2005	Private—Capita Symonds/National Grid	2315	3
Juniper Green Pond, Edinburgh	Residential area. Near the Water of Leith footpath.	Drainage (SUDS) pond, focal point from flats.	240	2005	Private—James Gibb	1459	10
Oxgangs, Edinburgh	Residential area.	Drainage (SUDS) pond and amenity	8099	2007–2010	Private—Dunedin Canmore	3796	2
Eliburn, Livingston	Residential area. Near light industrial units	Drainage pond (SUDS)—not accessible to public	1675	2007–2011	Private-Gladmans	364	9
Blackford, Edinburgh	Local Nature Reserve	Biodiversity and amenity (Non SUDS)	13,500	1800–1900	Public—Edinburgh Local authority	847	9
Goreglen, Mid Lothian	Woodland setting. Near main road.	No use currently. Flood plain (Non SUDS)	500	1794–1861	Public—Midlothian Ranger Service	39	4
Royal Botanic Gardens, Edinburgh	Former estate. Near residential area.	Amenity and education. Outflow pipe to Water of Leith. Feeding wildfowl. (Non SUDS)	4560	1880	Private	2312	10
Inverleith Pond, Edinburgh	Park setting. Near residential area.	Model boat activities, recreation, and feeding wild fowl (Non SUDS)	43,554	1870	Public—Edinburgh Local authority	804	10

7.3 Results

Of the 810 door to door (postal) surveys issued, 144 were returned with completed responses (2 were returned uncompleted). The response rate of 17.5% was calculating using AAPOR, and this was lower than Bastien *et al.*, 2012 (27%) but exceeded other surveys, such as Jose *et al.*, 2015 (8%). It is in line (17%) with an urban flooding CVM study (Owusu *et al.*, 2015). Furthermore, the online survey added a further 140 responses with a completion rate of 84% (n=238).

The data were all collated to include responses from both modes of the survey. Figure 7-1 illustrates that for the surveyed population, there are more responses from non SUDS ponds (n=205) than SUDS ponds (n=77). Responses for each pond are highlighted in the published article (Jarvie et al., 2017) and the data within Appendix A.7.

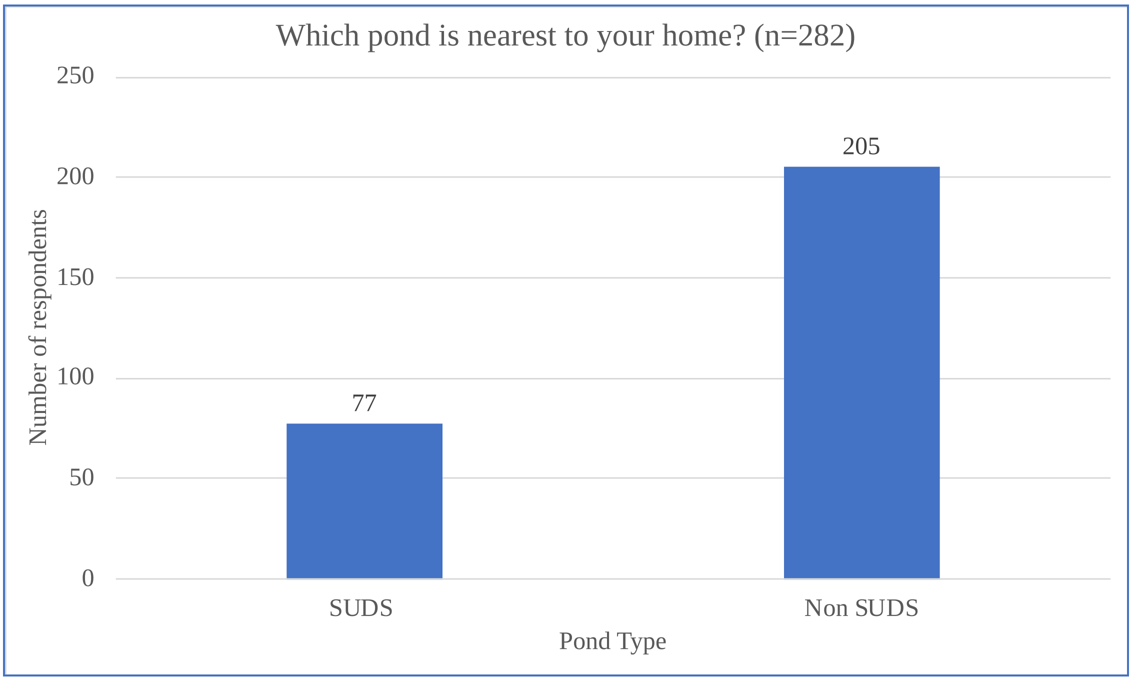

Figure 7-1: Which pond is nearest to their home, numbers at the top of the column indicate the number of responses for that sample group

The responses for some areas are relatively modest in number and, as such, may not produce results which are statistically significant. However, the total number of responses is sufficient to draw conclusions and support comparisons with other studies.

Respondents rated factors which influenced their decision to move (1 = most important and 5= least important) to their current home. A total of 80% stated that the accommodation size and condition influenced their decision to move to their home by giving it a score of 1 or 2 (Figure 7-2). A total of 66% of the sample viewed their natural environment and surroundings as an important factor- which may be related to choosing to live near open spaces and ponds. Price and rental cost were also important, with 67% citing this as the main reason they chose their current home. The least popular decision for choosing their current home was the nearby schools. Participants were able to choose more than one factor- as some did regard two or three factors of similar importance. The survey highlighted that over 90% of residents stated the pond was in place prior to moving to the area.

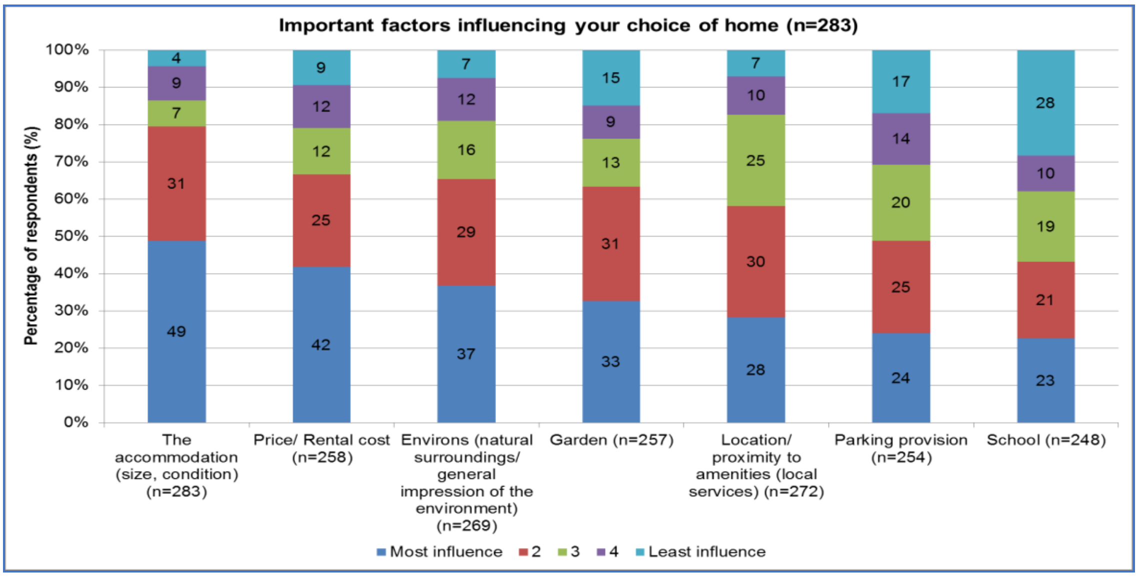

Figure 7-2: Important factors influencing a resident's choice of home, rated 1: greatest influential factor to 5: least influential factor

The perceived benefits of living next to a pond include the provision of biodiversity with 77% rating it as highly beneficial (Figure 7-3, n=277). Pet walking was viewed by 32% as most beneficial, with an additional 32% of respondents viewing it of benefit with a score of two or three. Aesthetics is viewed as most beneficial by 28%, with a further 31% viewing it as of secondary importance. Education purposes for children are viewed as most beneficial by 28% of respondents with 30% viewing this benefit as the second most important.

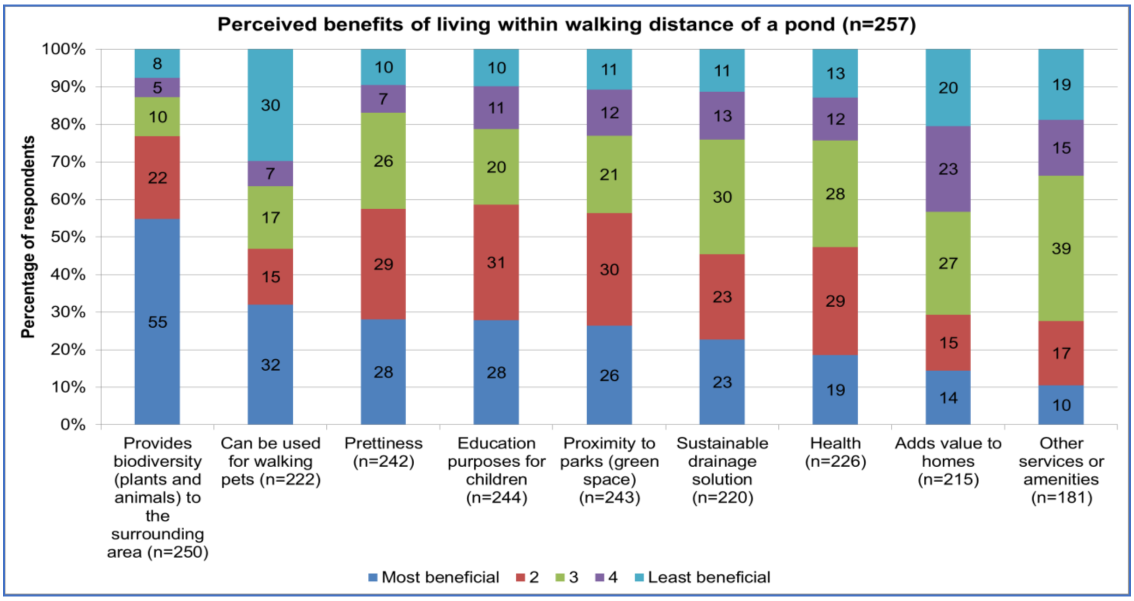

Figure 7-3: perceived benefits of living next to a pond, rated 1: Greatest benefit to 5: Least benefit

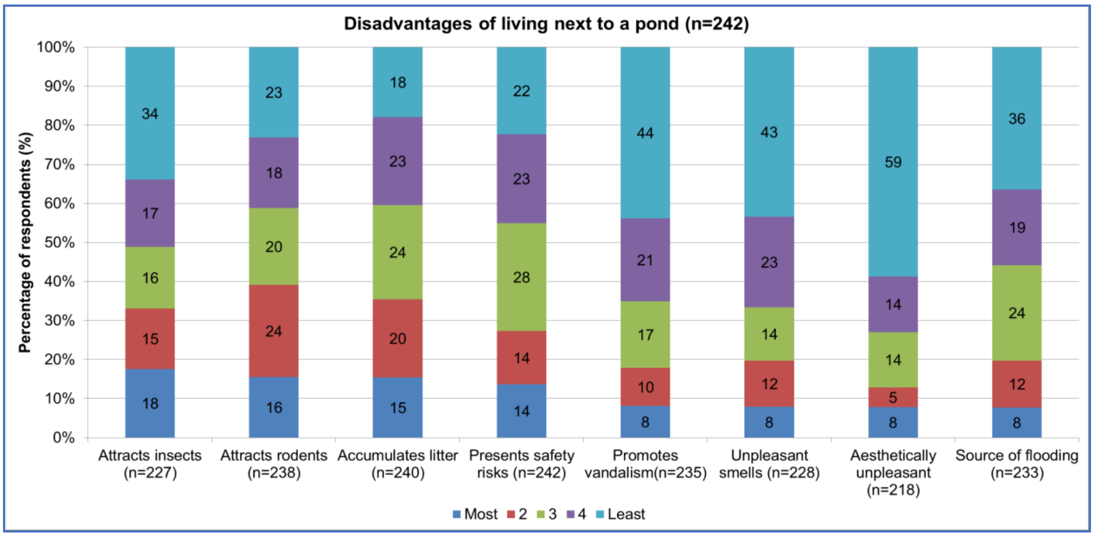

Figure 7-4: disadvantages to living next to a pond, rated 1: Greatest disadvantage to 5: Least disadvantage

The perceived disadvantages (Figure 7-4) of living next to a pond include: attracts insects with 18% of respondents viewing this as more of a disadvantage than rodents (16%). Safety risks were viewed as similar disadvantage (14%) as that associated with litter (15%).

7.3.1 Safety concerns

Safety of the area is the most important factor when choosing a neighbourhood to live, especially for those with families (Figure 7-5, n=67). Open space is another factor with high importance, which relates to the importance of SUDS greenery and, providing safe, open, spaces for children to play in. Low crime rates are another important factor which is re-emphasised by high levels of crime being the second highest perceived danger within this study.

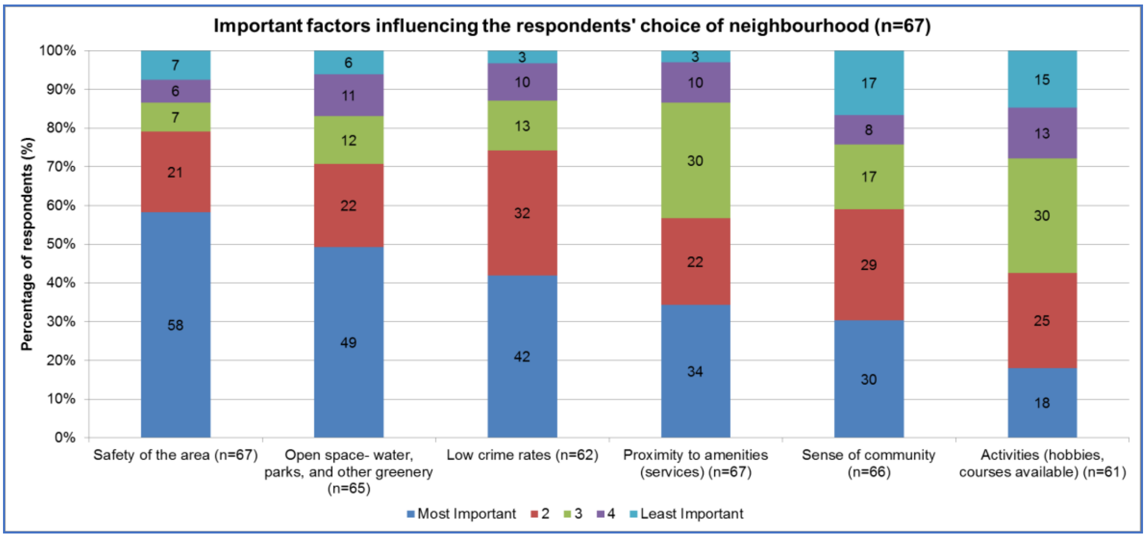

Figure 7-5: Which factors are important when choosing a neighbourhood (families- single parents and co-habiting)

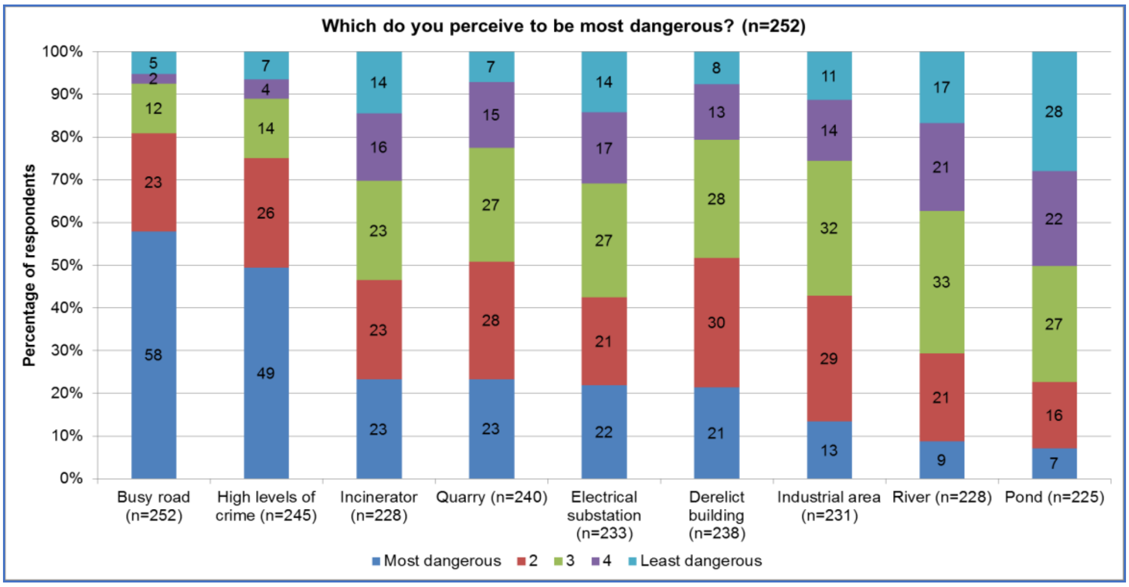

Figure 7-6: Which do you perceive to be the most dangerous, rated 1: Most dangerous to 5: Least dangerous

The lowest perceived dangers (Figure 7-6) in both modes of survey were ponds and rivers, with each having less than 10% of first preferences. Busy roads were the highest perceived danger with 58% of the sample population having significant concerns about busy roads, which also relates to the importance of safety in a neighbourhood and having park environments with open spaces nearby (Bastien *et al.*, 2012). However, this has its disadvantages too with safety perceptions in sparsely populated (Finlay *et al.*, 2015) or less affluent areas with the increased chance of anti-social behaviour due to boredom or inadequate facilities (Teedon *et al.*, 2014).

7.3.2 Biodiversity and observations of fauna and flora at their local pond

In total 63% of the respondents from the survey answered the question on biodiversity (n=177) and observed that their local pond provided a habitat. However, there were more responses for the questions about fauna (n= 228, 81%) and flora (n=203, 72%), with only one survey response stating that they were not clear what “biodiversity” meant.

In terms of SUDS ponds, the water birds and frogs were observed more frequently than water bugs, small fish and newts. However, the participants near non SUDS ponds observed water birds, frogs and water bugs more often. Fish were identified by participants living near SUDS and non SUDS ponds. Additional observations for fauna included: heron (*ardeidae*), geese (a*nserini*) water hens (a*mauramis*) and coots (f*ulica*), rats (*rattus*), grebes (*podicipedidae*), tern (*sternidae*), damselflies (*zygoptera*), dragonflies (*anisoptera*) and eels (a*nguilliformes*). Some participants also commented on issues at their local pond such as “rats were eating bird eggs” and birds being fed bread encouraged more pests. One participant said that they had never seen any wildlife at their local pond about Goreglen!

Bulrush (t*ypha*) and sedge (*carex*) plants were observed by residents near SUDS and non SUDS ponds. Bog bean (m*enyanthes trifoliata*) was observed in the fewest ponds. Other flora that was observed included: mint (*mentha*), iris (i*ris pseudocorus*), pondweed (p*otamogeton*) and duckweed (*lemnoideae*). In addition to this; herbs and an array of wild flowers (thistles (*carduus*), forget me not (*myosotis*), and daisies (*bellis perennis*)) were identified. A few respondents were not sure of the plants in their local pond, and stated: “(I am) aware, but not sure of plant type and unsure of their names”, “not noticed” and “sorry I am not good at plants”. Conversely, two responses stated that their pond was rich in flora with “A HUGE number of species, wildflowers, trees, ferns” and “loads of others (park setting)”

7.4 Value for supporting benefits

The following multiple benefit categories will be presented: habitat provision, education, recreation, spiritual, flood risk reduction and nutrient cycling. The total and media values will be presented for SUDS and non SUDS ponds with the intent to compare the benefits provided by ponds in relation to Contingent Valuation and Whole

Life Cost analysis. If the reader, would like more detail on individual ponds and values then these are provided in Appendix A.7.

7.4.1 Habitat provision

Before evaluating whether habitat benefits will offset CAPEX and OPEX costs (WLC) for SUDS ponds, it is important to consider each benefit individually. An additional part of the analysis will be to present the findings of the Contingent Valuation analysis in relation to the number of residents within a 500m radius of the pond, which is approximately a 5-minute walk from their home and aligns with a previous amenity study or ponds (Bastien *et al.*, 2012).

Table 7-2:Habitat benefits according to the residents in the survey: where the monthly total value is divided by the number living near each pond Total n= 233.

Pond name	Number of households	Total Population	Monthly value (£)	Annual value (£)
Total SUDS	3570	7934	£78,144	£937,756
Median SUDS	811	1887	8602.5	£103,246
Total Non SUDS	2421	5143	£69,775	£837,299
Median Non SUDS	623	1396	17367.5	£208,410
Totals (£)	5991	13077	£147,919	£1,775,028

The values for Willingness to Pay (per person) for habitat benefits are highlighted (Table 7-2). Total values and median values are presented for SUDS and non SUDS ponds. For SUDS ponds, the median annual value for SUDS ponds is less than (£103,246) that observed at non SUDS ponds (£208,410).

Pond characteristics may influence the perceived value from the residents living within close proximity. If a pond is further from housing in the case of n=2 SUDS ponds, and n=1 Non SUDS ponds then this could influence the participants willingness to pay for benefits (Appendix A.7). It also depends on the suitability of the pond for habitat and whether the respondents felt that the pond was diverse in life. For example, n=1 Non SUDS ponds (Goreglen) had poorer diversity scores for plants (Appendix A.6) than other ponds, and supported few invertebrates (Appendix A.4).

Table 7-3: Monthly and annual values (Willingness to Pay) for habitat benefits according to the number of residents in a household (Census, 2011; 2013).
Where: Number of residents in households (total n= 13077). Total value is calculated using the total benefits per person multiplied by the total population living within a 500m radius of their local pond.

Pond name	**Supports plants (£pp)**	**Supports mammals (£pp)**	**Supports fish (£pp)**	**Creates habitat for birds (£pp)**	**Supports Invertebrates (£pp)**	**Total (£pp)**
Total SUDS	9.99	7.40	7.81	10.13	11.92	47.24
Median SUDS	1.98	1.94	2.14	2.03	2.00	10.08
Total Non SUDS	10.24	9.42	9.57	11.15	8.62	49.01
Median Non SUDS	2.40	2.40	2.48	2.84	2.21	12.39
Totals (£):	20.23	16.82	17.38	21.28	20.54	96.25

7.4.2 Education benefits

This section presents the results for education benefits in relation to total and median values. This is to highlight the difference between SUDS and non SUDS ponds in relation to education benefits.

Table 7-4 shows the valued benefits in relation to the population living within a 500m radius from their local pond. The potential median annual value for SUDS ponds in the survey is £224,157, which is more than double the value from habitat benefits. Median values from non SUDS ponds is slightly higher with a value of £313,766. One non SUDS pond (Blackford) offers multiple educational benefits with the local authority ranger service and Hermitage of Braid visitor centre supporting the upkeep of the pond.

Table 7-4: Education benefits according to the residents in the survey: where the monthly total value is divided by the number living near each pond Total n= 233.

Pond name	Number of households	Total Population	Monthly value (£)	Annual value (£)
Median SUDS	811	1887	£18,680	£224,157
SUDS	3570	7934	£159,508	£1,914,102
Median Non SUDS	623	1396	£26,148	£313,766
Non SUDS	2421	5143	£97,908	£1,174,879
Totals (£):	5991	13077	£257,416	£3,088,992

Ecology courses have the highest total perceived value with a total value of £21.74. The lowest valued benefit is geography lessons with a total value of £14.80, and this may suggest that this is expected to be freely available within local schools. Median SUDS values are lower than median non SUDS ponds in relation to education benefits. However, pond dipping has more value at SUDS ponds (£2.16) than non SUDS ponds (£1.40), and this could be in relation to the design and purpose of the SUDS ponds studied offering more potential to support this benefit. An example of a non SUDS pond with community support for education at their local pond is Inverleith. Inverleith has a community which supports education at the local pond with Friends of Inverleith Park (pers, comm, Friends of Inverleith) supporting pond dipping activities for young children and families in the summer months.

Table 7-5: Monthly and annual values (Willingness to Pay) for education benefits according to the number of residents in a household (Census, 2011; 2013).
Where: Number of residents in households (total n= 13077). Total value is calculated using the total benefits per person multiplied by the total population living within a 500m radius of their local pond.

Pond name	**Conservation**	**Pond dipping**	**Nature walks**	**Tours around nature reserve**	**Formal training/ management**	**Ecology**	**Geography lessons**	**Biology field work**	**Total (£)**
Median SUDS	1.68	2.16	1.82	1.30	1.75	2.30	1.47	1.47	12.91
SUDS	7.48	9.91	7.98	7.05	8.07	10.21	7.21	7.97	65.88
Median Non SUDS	2.27	1.40	2.81	2.02	2.19	2.60	1.60	1.90	17.47
Non SUDS	8.65	6.17	9.94	7.81	10.13	11.52	7.60	8.28	70.07
Totals (£):	16.14	16.07	17.92	14.85	18.19	21.74	14.80	16.24	135.94

7.4.3 Recreation benefits

Median and total recreation benefits are highlighted in Table 7-6. It was decided to remove some of the benefits which related more to the greenspace around the pond, so a revised valuation is presented below which incorporates the benefits of direct use from the pond. Appendix A.7 provides more details on the data for individual ponds. Table 7-6 reveals that recreation benefits are lower for SUDS ponds than non SUDS pond, with median values of £2,658 and £6,864, respectively. This may show that recreation benefits are favoured by those living at non SUDS ponds in relation to direct use of the pond. However, the greenspace surrounding the pond also offers multiple benefits which may be considered in future studies.

Table 7-6:Recreation benefits according to the residents in the survey: where the monthly total value is divided by the number living near each pond Total n= 233.

Pond name	Number of households	Total Population	Monthly value (£)	Annual value (£)
Median SUDS	811	1887	£58	£586
SUDS	3570	7934	£314	£2,658
Median Non SUDS	623	1396	£253	£2,112
Non SUDS	2421	5143	£902	£6,864
Totals (£):	5991	13077	£1,216	£9,522

Table 7-7 highlights that that median values for SUDS ponds are marginally higher than non SUDS ponds. Boating is valued higher for non SUDS ponds than SUDS ponds as a recreational benefit. This is because of the size and nature of the ponds valued, as it is less likely that SUDS ponds could provide this benefit. Respondents at SUDS ponds value the pond more in relation to relaxation and meditation than respondents from non SUDS ponds.

Table 7-7: Monthly and annual values (Willingness to Pay) for recreation benefits according to the number of residents in a household (Census, 2011; 2013).
Where: Number of residents in households (total n= 13077). Total value is calculated using the total benefits per person multiplied by the total population living within a 500m radius of their local pond.

Pond name	Boating (£pp)	Model boats (£pp)	Relax/meditate (£pp)	Total (£pp)
Median SUDS	0.88	0.43	2.38	3.68
SUDS	5.15	1.72	9.91	16.78
Median Non SUDS	1.29	0.68	2.15	4.16
Non SUDS	5.59	2.58	8.23	16.40
Totals (£):	10.74	4.29	18.14	33.17

7.4.4 Spiritual benefits

Median and total values for spiritual benefits are presented for SUDS and non SUDS ponds (Table 7-8; Table 7-9). The spiritual benefits in relation to the population (Table 7-8) have a total of £579,720. Median SUDS pond values are higher (£363,251) than median non SUDS pond values (£216,470). Some of the ponds studied are less suited to church gatherings than others; for example, the isolated SUDS ponds (n=2; Eliburn and Juniper Green). This would make it more difficult to value this benefit in relation to the pond design and purpose.

Table 7-8:Spiritual benefits according to the residents in the survey: where the monthly total value is divided by the number living near each pond Total n= 233.

Pond name	Number of households	Total Population	Monthly value (£)	Annual value (£)
Median SUDS	811	1887	2082	24,982
SUDS	502.5	7934	30271	363,251
Median Non SUDS	623	1396	4092.5	49,107
Non SUDS	2421	5143	18039	216,470
Totals (£):	5991	13077	£48,310	579,720

Table 7-9 shows that the highest value is sense of place with a total value of £11.66. The median values reveal that there is a marginal difference in respondents at SUDS (£1.59) and non SUDS ponds (£1.30) in relation to sense of place. As discussed above, this my be in relation to the nature of some SUDS ponds being inaccessible to the public (Eliburn) / only for certain residents (Juniper Green). However, only the ponds within park or public garden environments are likely to host church gatherings.

Table 7-9: Monthly and annual values (Willingness to Pay) for spiritual benefits according to the number of residents in a household (Census, 2011; 2013).
Where: Number of residents in households (total n= 13077). Total value is calculated using the total benefits per person multiplied by the total population living within a 500m radius of their local pond.

Pond name	Place for reflection	Church gatherings	Sense of place	Total (£pp)
Median SUDS	0.47	0.35	1.59	2.37
SUDS	3.8	1.43	6.45	11.67
Non SUDS	4.01	2.2	5.21	11.42
Median Non SUDS	0.96	0.57	1.30	2.93
Totals (£):	7.81	3.62	11.66	23.09

7.4.5 Flood risk mitigation benefits

Flood risk mitigation benefits are presented as median and total value for SUDS and non SUDS ponds in Table 7-10 and Table 7-11. Considering the median values, non SUDS ponds have a higher annual total than non SUDS ponds have. This is surprising as one of the functions for SUDS is to reduce flood risk. However, one SUDS pond of note (see Appendix A.7) is Oxgangs which was constructed to reduce flood risk associated with the Braid Burn; as communities opted for this solution when the former high-density flats were demolished in the noughties (Dunedin, Canmore, 2015). Other SUDS ponds, however, were constructed with a vision to enhance biodiversity in the local area, as well as providing a haven for birds and amphibians (Bastien *et al.*, 2012). Flood risk reduction may not be a priority as some of the survey participants live further away from the park and pond setting.

Table 7-10:Flood Risk reduction benefits according to the residents in the survey: where the monthly total value is divided by the number living near each pond Total n= 233.

Pond name	Number of households	Total Population	Monthly value (£)	Annual value (£)
Median SUDS	811	1887	2,740	32,881
SUDS	3570	7934	32,240	386,881
Median Non SUDS	623	1396	4,799	57,587
Non SUDS	2421	5143	22,974	275,690
Totals	5991	13077	55,214	662,571

Table 7-11: Monthly and annual values (Willingness to Pay) for flood risk reduction benefits according to the number of residents in a household (Census, 2011; 2013). Where: Number of residents in households (total n= 13077). Total value is calculated using the total benefits per person multiplied by the total population living within a 500m radius of their local pond.

Pond name	Reduction in runoff	Reduces pressure on sewers and drains	Total (pp £)
Median SUDS	1.80	1.75	3.55
SUDS	7.42	7.29	14.71
Median Non SUDS	1.51	1.71	3.22
Non SUDS	6.97	6.74	13.71
Totals (£):	14.39	14.04	28.42

Table 7-11 highlights that is a marginal difference in median values for flood risk reduction benefits, with a higher value for reduction in runoff (£1.80) for SUDS ponds than non SUDS ponds (£1.51). There is a marginal increase in the median value for the benefit of reducing pressure on sewers and drains (£1.75) for SUDS ponds.

7.4.6 Nutrient Cycle benefits

This section will highlight the nutrient benefits valued by SUDS and non SUDS ponds. Table 7-12 and Table 7-13 highlight median and total values in relation to the benefits. Median SUDS pond annual values are lower (£32,070) than non SUDS ponds (£34,880).

Table 7-12:Nutrient benefits according to the residents in the survey: where the monthly total value is divided by the number living near each pond Total n= 233.

Pond name	Number of households	Total Population	Monthly value (£)	Annual value(£)
Median SUDS	811	1887	£2,673	£32,070
SUDS	3570	7934	£28,802	£345,626
Median Non SUDS	623	1396	£2,907	£34,880
Non SUDS	2421	5143	£15,680	£188,164
Totals (£):	5991	13077	£44,482	£553,784

Table 7-13 highlights that median values for SUDS ponds are higher than non SUDS ponds in relation to nutrient benefits. Pet safety benefits are higher for non SUDS ponds than SUDS ponds. This observation may be in relation to the wider open spaces available at the non SUDS ponds and accessibility to the ponds. As discussed previously, two of the SUDS ponds are less accessible to the public and therefore, pet safety is less of a priority in relation to these ponds This is true for Blackford and Goreglen ponds (see Appendix A.7 for individual values) which are situated in areas with accessible pathways for walking pets; so the health and safety concern is more relevant.

Participants from SUDS pond areas show that being aware of algal blooms is of more importance to them- perhaps this is in relation to pet and child safety- as some algae contain cyanobacteria strains which are hazardous to human health (Svirčev *et al.,* 2014). This may also be in connection with the disbenefit of odour- as algal blooms cause noxious odours.

Table 7-13:Monthly and annual values (Willingness to Pay) for nutrient benefits according to the number of residents in a household (Census, 2011; 2013).
Where: Number of residents in households (total n= 13077). Total value is calculated using the total benefits per person multiplied by the total population living within a 500m radius of their local pond.

Pond name	Being aware of the signs of algal blooms	Pet safety	Total (£pp)
Median SUDS	2.07	0.78	2.85
SUDS	9.51	4.39	13.90
Median Non SUDS	1.08	1.11	2.19
Non SUDS	4.96	5.26	10.22
Totals (£):	14.47	9.65	34.12

7.5 Offsetting replacement costs

The capital costs (CAPEX) are calculated according to surface area and pond volume (UKWIR, 2005; Royal Haskoning, 2012). In addition to capital costs, maintenance costs (OPEX) were calculated for each pond using the recommended 3.5%, followed by 20 years at 3%, discount when calculating Net Present Value (NPV) for projects with a life of 30–50 years. This process was undertaken for each benefit discussed in Section 7.4.

Table 7-14 summarises the main operation and maintenance costs for Whole Life Cost analysis. These include a cost for inspection of the pond following construction in line with CIRIA (2015) and UKWIR guidance. Regular maintenance costs are provided for grass cutting, barrier vegetation pruning and weeding in relation to the pond's catchment area. One of the ponds (see Appendix A.7) has no cost for grass cutting- as there is no grass surrounding the pond. Irregular maintenance costs include: the management of aquatic vegetation, desilting (decadal), mobilisation and removal of sediment, and vegetation replacement. Sediment mobilisation and removal has a lower median cost for SUDS ponds than non SUDS ponds, but the logistics of removing sediment from a larger catchment size (e.g. Blackford) are less realistic. Equally median values for vegetation replacement are greater at non SUDS ponds, and this is also in relation to the pond size.

Table 7-14: Costs derived from UKWIR, represented as median and total values for SUDS and non-SUDS ponds, in relation to typical operation costs. Appendix A.7 provides a fuller breakdown of costs for each pond.

	Inspection	**Litter and debris removal**	**Grass cutting**	**Barrier vegetation /pruning**	**Barrier vegetation weeding**	**Aquatic vegetation management**	**Desilting**	**Mobilisation-sediment removal**	**Disposal of sediment**	**Vegetation Replacement**
Total SUDS	£7,819	£21,804	£41,997	£189,349	£137,708	£195,086	£895,211	£74,816	£284,545	£1,184,353
Total Non SUDS	£7,819	£61,521	£119,804	£534,260	£388,553	£550,450	£2,679,411	£74,816	£851,656	£3,341,733
Median SUDS	£7,819	£4,840	£9,426	£42,034	£30,571	£43,308	£196,258	£18,704	£62,381	£262,921
Median Non SUDS	£7,819	£8,944	£17,417	£77,670	£56,487	£80,023	£429,109	£18,704	£136,393	£485,814

7.5.1 Habitat provision benefits

Table 7-15 highlights that benefits outweigh the costs for SUDS and non SUDS ponds; showing that habitat provision benefits are of importance to both surveyed populations. Median values highlight that there is nearly three times more value placed on habitat provision benefits from non SUDS ponds than SUDS ponds. However, the total values show that habitat provision is favoured more by SUDS than non SUDS ponds. Individual values are presented in Appendix A.7 which reveal that Oxgangs pond values habitat most of all SUDS and non SUDS ponds. This result is encouraging as it demonstrates the importance and value that residents place on living near SUDS ponds in relation to the habitat benefits and supports findings from previous pond research where biodiversity benefits were highly favoured (Bastien et al., 2012; Jose et al., 2015).

Table 7-15: Capital and maintenance costs for ponds, calculated following the guidance (surface area and pond volume for treatment) from UKWIR (2005) and Royal Haskoning (2012). The Net Present Value (NPV) habitat benefits refer to the total benefits over 50 years with a discount of 3.5% (30 years) the 3% (20 years) (HM Treasury Green book). The balance is calculated by subtracting the NPV maintenance and initial capital for the pond from the perceived NPV benefits.

Pond Name	NPV Benefits	NPV OPEX Costs	CAPEX Costs	Balance
Median SUDS	£2,478,810	£667,366	£391,662	£2,322,086
SUDS	£22,514,480	£3,007,432	£1,786,523	£18,609,462
Median Non SUDS	£5,003,681	£1,298,793	£856,350	£6,423,222
Non SUDS	£20,102,619	£8,500,122	£5,347,155	£12,846,443
Total	£42,617,101	£11,507,564	£7,133,678	£23,975,859
Per Population	£3,258.94	£879.99	£545.51	£1,833.44

7.5.2 Education benefits

Table 7-16 highlights that median non SUDS values are negative in relation to education benefits. Replacing these ponds using education benefits as an economic assessment would not be feasible. Median SUDS values, however, are positive, with a balance of £4,737,079. This could suggest that residents living in close proximity to the pond value the potential education opportunities available at their local pond.

Provision of access to green space has important implications for mental health and wellbeing (Mantaay, 2013). For SUDS ponds, Oxgangs, is a good example where construction of a pond provided access to previously inaccessible space (Wendel *et al.*, 2011) as tower blocks reduced access to green space and community cohesion.

Table 7-16: Capital and maintenance costs for ponds, calculated following the guidance (surface area and pond volume for treatment) from UKWIR (2005) and Royal Haskoning (2012). The Net Present Value (NPV) education benefits refer to the total benefits over 50 years with a discount of 3.5% (30 years) the 3% (20 years) (HM Treasury Green book). The balance is calculated by subtracting the NPV maintenance and initial capital for the pond from the perceived NPV benefits.

Pond name	NPV benefits	NPV OPEX Costs	CAPEX costs	Balance
Median SUDS	£5,381,761	£667,379	£391,662	£4,737,079
SUDS	£45,955,466	£3,007,468	£1,786,523	£36,970,555
Median Non SUDS	£7,533,162	£1,298,793	£856,350	(£858,501)
Non SUDS	£28,207,541	£8,500,532	£5,347,155	£8,662,485
Total	£74,163,007	£11,508,000	£7,133,678	£67,028,449
Per population	£5,671.26	£880.02	£545.51	£5,125.67

7.5.3 Recreation benefits

Table 7-17 highlights that median SUDS values have negative balances in relation to recreation benefits; suggesting that this benefit would not provide a feasible business case when designing a new pond. It also shows that the recreation benefits provided by direct use of the pond are limited for SUDS ponds. Median non SUDS pond values, however, are positive in relation to recreation benefits but the overall total value is negative. So, while the non SUDS ponds have more potential to provide recreational opportunities, the value placed on these is lower than habitat or education benefits, for example.

Table 7-17: Capital and maintenance costs for ponds, calculated following the guidance (surface area and pond volume for treatment) from UKWIR (2005) and Royal Haskoning (2012). The Net Present Value (NPV) recreation benefits refer to the total benefits over 50 years with a discount of 3.5% (30 years) the 3% (20 years) (HM Treasury Green book). The balance is calculated by subtracting the NPV maintenance and initial capital for the pond from the perceived NPV benefits.

Pond name	**NPV benefits**	**NPV OPEX costs**	**CAPEX costs**	**Balance**
Median SUDS	£266,499	£667,366	£391,662	-£792,528.
SUDS	£3,900,965	£3,007,442	£1,786,523	-£893,000
Median Non SUDS	£3,033,763	£1,298,793	£856,350	£878,620.71
Non SUDS	£10,965,340	£8,500,122	£5,347,155	-£2,881,936
Total	*£1,457,820*	*£723,868*	*£417,450*	*£316,502*
Per Population	*£111.48*	*£55.35*	*£31.92*	*£24.20*

7.5.4 Spiritual benefits

Table 7-18 highlights that median values for spiritual benefits are less favoured by respondents from non SUDS ponds than SUDS ponds. Median SUDS values highlight that benefits outweigh the costs (£363,507). However, overall, there is a deficit for this benefit; so future ponds are unlikely to be replaced (non SUDS) using only spiritual benefits.

Table 7-18: Capital and maintenance costs for ponds, calculated following the guidance Capital and maintenance costs for ponds, calculated following the guidance (surface area and pond volume for treatment) from UKWIR (2005) and Royal Haskoning (2012). The Net Present Value (NPV) spiritual benefits refer to the total benefits over 50 years with a discount of 3.5% (30 years) the 3% (20 years) (HM Treasury Green book). The balance is calculated by subtracting the NPV maintenance and initial capital for the pond from the perceived NPV benefits.

Pond name	NPV benefits	NPV OPEX Costs	CAPEX costs	Balance
Median SUDS	£585,273	£681,885	£391,662	£363,507
SUDS	£8,692,243	£3,036,479	£1,786,523	£5,435,955
Median Non SUDS	£1,178,993	£1,298,793	£856,350	(£868,627)
Non SUDS	£5,197,206	£8,500,523	£5,347,155	(£8,650,474)
Total	£13,889,447	£11,537,002	£7,133,678	(£3,214,519)
Per population	£1,062	£882	£546	(£246)

7.5.5 Flood Risk reduction benefits

Flood risk reduction benefits (Table 7-19) are a convincing argument for the residents living near each SUDS pond. This relates to the argument that good design of SUDS ponds makes the project more feasible and the residents are less likely to have high insurance premiums when living near a SUDS pond (Houston *et al.*, 2011). Replacing non SUDS ponds based on flood risk reduction benefits is not feasible in the future (based on the current assessment). Median values for SUDS ponds are greater (£494,184) than non SUDS ponds (-£638,466) suggesting there is a difference between median observed values.

Flood risk reduction and multiple deprivation could be linked, e.g. if the housing quality is poor, or residents live further away from the pond, they are less likely to value the flood risk benefits. Health and deprivation are well established as are the implications from social deprivation as a consequence from flooding (e.g. Tapsell *et al.*, 2002; Houston *et al.*, 2011).

Table 7-19: Capital and maintenance costs for ponds, calculated following the guidance (surface area and pond volume for treatment) from UKWIR (2005) and Royal Haskoning (2012). The Net Present Value (NPV) flood risk reduction benefits refer to the total benefits over 50 years with a discount of 3.5% (30 years) the 3% (20 years) (HM Treasury Green book). The balance is calculated by subtracting the NPV maintenance and initial capital for the pond from the perceived NPV benefits.

Pond name	NPV benefits	NPV OPEX Costs	CAPEX costs	Balance
Median SUDS	£789,424	£667,379	£391,662	£494,184
SUDS	£9,288,583	£3,007,465	£1,786,523	£4,494,595
Median Non SUDS	£1,382,600	£1,298,793	£856,350	(£638,466)
Non SUDS	£6,619,011	£8,500,523	£5,347,155	(£7,228,667)
Total	£15,907,595	£11,507,988	£7,133,678	£36,083,603
Per population	£1,216.46	£880.02	£545.51	£2,759.32

7.5.6 Nutrient Cycling benefits

Nutrient Cycling (Table 7-20) benefits and values associated with this benefit are unlikely to provide a feasible business case for replacing ponds. Median SUDS ponds have positive balances in relation to this benefit, but non SUDS ponds have a negative balance. When examining the individual ponds (Appendix A.7), Granton is the only SUDS pond with a negative balance for this multiple benefit, but this may be a reflection on the perceived purpose (and function) of the pond. Previous studies indicated that Granton pond was primarily built for enhancing biodiversity (Bastien *et al.*, 2012). It is encouraging to note that median SUDS pond values have a positive balance for whole life cost (based on nutrient cycling benefits alone). Nutrient enrichment leading to algal blooms is an issue at SUDS and non SUDS ponds (Chapter 4/5) - so it is useful for the residents to be made aware of this.

Table 7-20: Capital and maintenance costs for ponds, calculated following the guidance (surface area and pond volume for treatment) from UKWIR (2005) and Royal Haskoning (2012). The Net Present Value (NPV) nutrient cycling benefits refer to the total benefits over 50 years with a discount of 3.5% (30 years) the 3% (20 years) (HM Treasury Green book). The balance is calculated by subtracting the NPV maintenance and initial capital for the pond from the perceived NPV benefits.

Pond name	NPV benefits	NPV OPEX Costs	CAPEX costs	Balance
Median SUDS	£769,965	£667,379	£391,662	£561,433
SUDS	£8,298,096	£3,007,468	£1,786,523	£5,070,819
Median Non SUDS	£837,430	£1,298,793	£856,350	(£1,138,799)
Non SUDS	£4,517,609	£8,500,523	£5,347,155	(£9,330,069)
Total	£12,815,706	£11,485,976	£7,133,678	(£5,803,948)
Per population	£980.02	£878	£546	£2,759

7.5.7 Scottish Index of Multiple Deprivation for survey areas

Table 7-21 highlights the Scottish Index of Multiple Deprivation (SIMD) deciles for the areas closest to the ponds studied. It was useful to compare the least deprived areas in the study with those with most deprivation. SIMD is based on multiple factors and the ones of more importance to this study are probably income (median SUDS= 6, median non SUDS= 9), employment (median SUDS=6, median non SUDS=8.5), health (median SUDS=6; median non SUDS =8.5), housing (median SUDS= 6, median non SUDS= 8.5), and education (median SUDS= 6, median non SUDS=10). For Individual ponds see Appendix A.7.

The SUDS ponds have values of up to £24.50 per person, which is similar to the results from a previous amenity study (Bastien et al., 2012)—with the exception that Granton has a lower perceived value than suggested previously. This is, however, a true reflection of the high-density areas in Granton and Oxgangs with council and privately-owned flats; as accessibility to green spaces is limited in high density areas (Wade and McClean, 2014). It may also be in relation to the SIMD, as Granton has a decile score of 2 for housing (see Appendix A.7)—which indicates deprivation from overcrowding or poor-quality housing (SIMD, 2016). In addition to this, the latest SIMD revealed that the surrounding areas (within a 500 m radius) had low scores for crime and employment deprivation—which may suggest that this area have higher crime incidents, and some are unable to work or are unemployed.

Table 7-21:Scottish Index of Multiple Deprivation characteristics: Income, Health, Employment, Geographical access and crime decile scores, ranked by overall Decile (Most deprived to Least deprived). Descriptive statistics are added for each characteristic (mean, median, mode, maximum and minimum)

Pond name	SIMD decile	Income	Employment	Health	Education	Housing	Geographical access	Crime
Median	9	9	8	9	10	8	7	6
Median SUDS	6	6	6	6	6	6	4	3.5
Median Non SUDS	9.5	8.5	8.5	8.5	10	7.5	9	7

7.6 Discussion

Detailed environmental assessments should be carried out within a multiple benefits context prior to planning and developing homes (Wade and McClean, 2014), as this would encourage developers and local authorities to work closer with ecologists and engineers to optimise the multiple benefits from ponds. This is important because of the increasing need to co-design housing developments.

7.6.1 Public Perception

Biodiversity is of high importance when considering the benefits of living within walking distance to a pond. This result is in line with previous studies where biodiversity benefits were of high regard from the public (Bastien *et al.,* 2012; Wolf *et al.,* 2014). The habitat potential is enhanced where a well-maintained pond is found.

Safety is less of a concern now than in previous studies (Apostolaki, 2006; Bastien *et al.,* 2012). Insects, rodents and litter are the greatest perceived disadvantages, which is to be expected if poor maintenance takes place. Crime is another factor of concern to residents (especially vandalism). This issue may be magnified in sparsely populated (Finlay *et al.,* 2015) or less affluent areas with the increased chance of anti-social behaviour due to boredom or inadequate facilities (Teedon *et al.,* 2014). The area near Goreglen pond has a decile score of 4 for multiple deprivation (Table 7-21) which is attributed to the remote location making it difficult to access education and employment opportunities (with respective scores of 2 and 4). Crime for this area is lower, with a score of 9, which contrasts with other areas such as Granton and Oxgangs with higher crime levels and a decile score of 1.

7.6.2 Valuation Discussion

Previous Contingent Valuation studies have lower reported estimates for Willingness to Pay (WTP) (Bastien *et al.,* 2012; Chui and Ngai, 2016). One study (Bastien *et al.,* 2012) suggested that those with higher incomes are more likely to pay more for benefits relating to SUDS. However, they also acknowledge that lower income groups may be likely to pay more due to socio-economic factors; such as less deprived students living near the SUDS of concern, or retired residents with lifetime investments and savings. In this chapter, the highest willingness to pay is from a more deprived area in terms of housing, income, and employment; which may be subjected to some criticism from associated bias, for example valuing the habitat benefits at a higher value than they can reasonably afford (Arrow *et al.,* 1993; Hausman, 2012). Table 7-21 revealed that SUDS ponds have the lowest median decile score in terms of deprivation; as the deprivation is ranked 1 to 10 (where 1 is the lowest possible score) which suggests there may be some respondent bias (Arrow et al., 1993) at Oxgangs pond. The respondent bias could be in relation to perception of wealth or forecasted estimates of affordability (Chui and Ngai, 2016). However, in the case of (Chui and Ngai, 2016), this was discussed in relation to the demography of the community within Hong Kong, with a densely populated city, whereas Edinburgh is smaller and is surrounded by blue green infrastructure. Furthermore, the willingness to pay for habitat benefits could be in relation to the perception that living within walking distance to a pond, and nearby green areas, provides better social conditions (for example health benefits, Wade and McClean,2014). This supports previous work (e.g., Bastien *et al.,* 2012; Jose *et al.,* 2015) where biodiversity was favoured at well-maintained ponds, and provision of suitable open space is part of this argument.

From whole life cost (NPV) calculations of benefits and costs (Table 7-15-Table 7-20), it is apparent that median SUDS values are higher than median non SUDS pond values. SUDS ponds did not favour recreation benefits in relation to whole life cost. However, it is encouraging that habitat provision, education, flood risk reduction, nutrient cycling, and spiritual benefits would offset capital and maintenance costs. This demonstrates the importance of SUDS ponds and the multiple benefits provided.

The median values from non SUDS ponds highlight that habitat benefits are the only category of multiple benefits which offset costs. Values for non SUDS ponds are calculated assuming that these ponds may need to be replaced in the future or adapted to suit current legislative requirements (WFD 2001, Hill *et al.*, 2016), without compromising on the ecology and natural functionality of the ponds.

However, as stated previously, there are uncertainties with the data, as a true value from contingent valuation is difficult to estimate (Arrow *et al.,* 1993; Hausman, 2012). Furthermore, using whole life cost is difficult if maintenance data are not available (Duffy *et al.,* 2008; Wolf *et al.,* 2014; Wolf *et al.,* 2015) and if ponds are not perceived as well-maintained by the public. A limitation in the analysis of Contingent Valuation for this chapter was that data were estimated using secondary sources (UKWIR; Table 7-14) and not directly from maintenance schedules. At the time, of analysis, these data were not available; because of mixed ownership at ponds, and most SUDS ponds were owned by private factors.

Future studies may implement BeST which has the potential to override some of the issues relating to uncertainty—as overstated values (Hausman, 2012), and protest zeros (Arrow *et al.,* 1993) reduce the reliability of assessing multiple benefits in an economic context. Despite, the limitations of the approach, the data could be beneficial for the future design of SUDS ponds, and if replacement of existing non SUDS ponds.

7.7 Chapter Summary

Ponds offer multiple benefits and from the results of this chapter, it is possible to draw the following conclusions with reference to the key questions: 1. What is the public perception of the potential benefits, and disadvantages of living near a pond?; 2. How much value is placed on supporting multiple benefits at their local pond (Willingness to Pay for habitat provision benefits), and are these values capable of offsetting costs?

Biodiversity, an area for walking pets and being close to parks (green spaces) are three benefits of living within a close (walking) distance to a pond. This is like other studies where biodiversity was an important component of SUDS ponds (*Bastien et al.,* 2012; Wolf *et al.,* 2014), and of non SUDS ponds. Biodiversity was regarded as being of high importance to the public. The disadvantages of living next to a pond include insects, rodents, and litter. Whilst biodiversity is cited as the greatest advantage to living within walking distance to a pond, some of the public perceive insects as being a disadvantage too—for example, midges and wasps in summer months may be nuisances. Safety is still regarded as important but is less of a concern than previously considered (Apostolaki, 2006; Bastien *et al.,* 2012).

Median SUDS values reveal that habitat provision benefits provide the most value in offsetting costs. It is apparent that, with the exception of recreation, the respondents from SUDS ponds favour the multiple benefits associated with living near ponds. However, there is recognition that the values may be skewed by response bias (Arrow *et al.,* 1993). This is likely to be the case for some SUDS ponds (see Appendix A.7-Oxgangs) with inflated values. Median values represent a sensible approach and reduce the uncertainty with skewed data distributions.

For non SUDS ponds, habitat provision is of importance to each pond, with a positive whole life cost in relation to this benefit. This is due to the aesthetics and setting of some of the ponds, which are set in managed environments with an abundance of wildlife and wildflowers in the surrounding gardens (e.g. Royal Botanic Gardens, and Blackford- see Appendix A.7). However, one of the key results from this chapter analysis is that median non SUDS ponds have negative balances in relation to the whole life cost for each other multiple benefit category. This suggests respondents' value nature-based provisioning benefits more than other culturally based services. In addition, the bigger picture here is that ponds designed for flood risk reduction are less likely to be valued by those designed for habitat and biodiversity services.

Moving forward, one of the recommendations is that maintenance data for SUDS ponds should be made available for planning purposes (prior to development) and for monitoring the multiple benefits provided by ponds, thereby enabling a better assessment of whole life costs.

Chapter 8 considers the ecosystem disservices which could influence the willingness to pay for multiple benefits at their local pond. These were considered within the survey in terms of disadvantages of living close to a pond but were not the main focus of the survey which was to highlight the importance of valuing multiple benefits from SUDS ponds, but future studies may wish to focus on this within valuation.

Chapter 8- DISCUSSION & FRAMEWORK

8.1 Overview

This chapter will present a framework underpinned by the thesis. This is a novel approach as there are no studies which suggest or adopt a similar framework. The framework (Figure 8-1) is divided into five stages and each stage will be discussed in full. While, the previous section discussed the importance of multiple benefits and evaluating ponds (Chapter 7), this chapter will focus on an Ecosystem Service context. Ecosystem Services is a niche in local planning and environmental management, and the latest CIRIA guidance (2015) supports the idea that pond design should incorporate either multiple benefits (Chapter 7) in relation to whole life cost or provide a robust business case for delivery of Ecosystem Services.

Design of Sustainable Urban Drainage systems (SUDS) ponds involves co-design between engineers, ecologists, landscape architects, developers and planners. The wider benefits that ponds offer have been discussed and evaluated both conceptually (Scholz and Mak, 2015; Jose *et al.,* 2015) and by monetising the whole life cost (Bastien *et al.,* 2012; Ossa-Moreno *et al.,* 2017), but as discussed previously no one has compared SUDS ponds and non SUDS ponds using an Ecosystem Service approach. It was, therefore, the main objective of the PhD thesis to monitor ponds and compare SUDS and non-SUDS ponds in relation to the multiple benefits/ ecosystem services provided. This will be discussed in Stage one (Section 8.2).

The discussion chapter is split into five sections which correspond to a proposed framework which aims to evaluate Ecosystem Services of ponds. Stage one established the environmental standards (Chapter 3) and objectives for the thesis. Stage two focused on the field studies and collecting the data to support the research aim and questions/ hypotheses. The third stage evaluated the ponds in relation to the environmental standards and comparing the ponds in relation to water quality. Stage four focused on evaluating the ponds in relation to their Ecosystem Service potential, and this is the novelty in this thesis as this has not been achieved previously. The final stage assessed the ponds in relation to current design criteria (in the SUDS manual, 2015) to see whether this enhances their delivery of key Ecosystem Services.

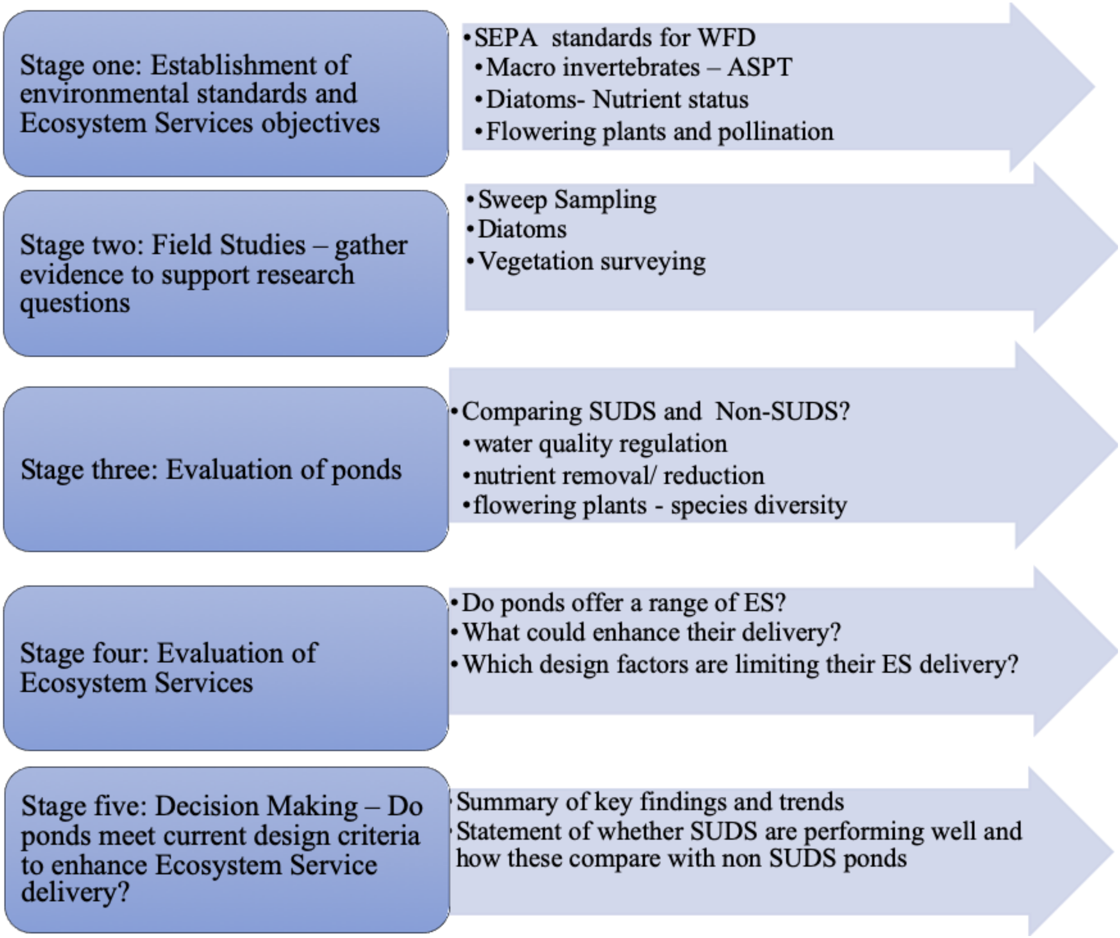

Figure 8-1 Framework for a field study of the Ecosystem Services of ponds.

8.2 Stage one:

Stage one involved the preparatory work for the thesis by identifying the main study aim, objectives, and related questions. The broad theme of Ecosystem Services for SUDS was discussed but it was not until later that the main idea of evaluating ponds came into being. This idea developed from the gaps in the literature in that very few studies focused on the ecology and water quality of urban ponds (Heal *et al.*, 2006; Hassall *et al.*, 2014), and even fewer had focused on SUDS (Briers,2014) or stormwater management facilities (Hassall and Anderson, 2015). However, the main gap is that no study has compared the benefits of SUDS and non SUDS ponds using field methods and whole life cost analysis to develop a framework to compare the benefits of ponds. This is discussed in Chapter 1 more fully.

SEPA (Scottish Environment Protection Agency) have existing water quality standards which were used to compare ponds across Edinburgh and the Lothians. The water quality/ environmental standards are in relation to the Water Framework Directive and the objective of meeting ‘good’ status in all water bodies by 2015. It should be noted that the next cycle is ongoing 2015-2021, so the parameters are likely to be updated/ reviewed later.

8.3 Stage two:

All methods chosen for this framework followed the BS Library of standards and conventions for establishing good practice in the field and laboratory (Chapter 3).

An overall assessment of the ponds will be discussed in Section 8.4, but it is important to discuss the novelty of this approach. While Chapter 4, 5, and 6 identified the issues with field monitoring, this chapter will now demonstrate the value in using a framework to test the Ecosystem Services from ponds, particularly SUDS ponds- as this will assist with future developments and also policy relating to Ecosystem Services.

8.4 Stage three:

The next question to consider is whether the ponds studied meet the current requirements for the Water Framework Directive and SEPA assessment of freshwater bodies. As discussed previously, there are currently no standards defined for ponds (Hassall *et al.,* 2016; Hill *et al.,* 2016), so the assessment is based on river standards with the possibility that the pond water will discharge into a receiving body, such as a stream or river. The framework will be applied to each case study to see which ponds meet ‘good’ ecological status or are closer to meeting these requirements. It is also important to establish whether SUDS ponds currently have higher water quality than non SUDS ponds, and whether there are reasons for this in relation to the main design criteria.

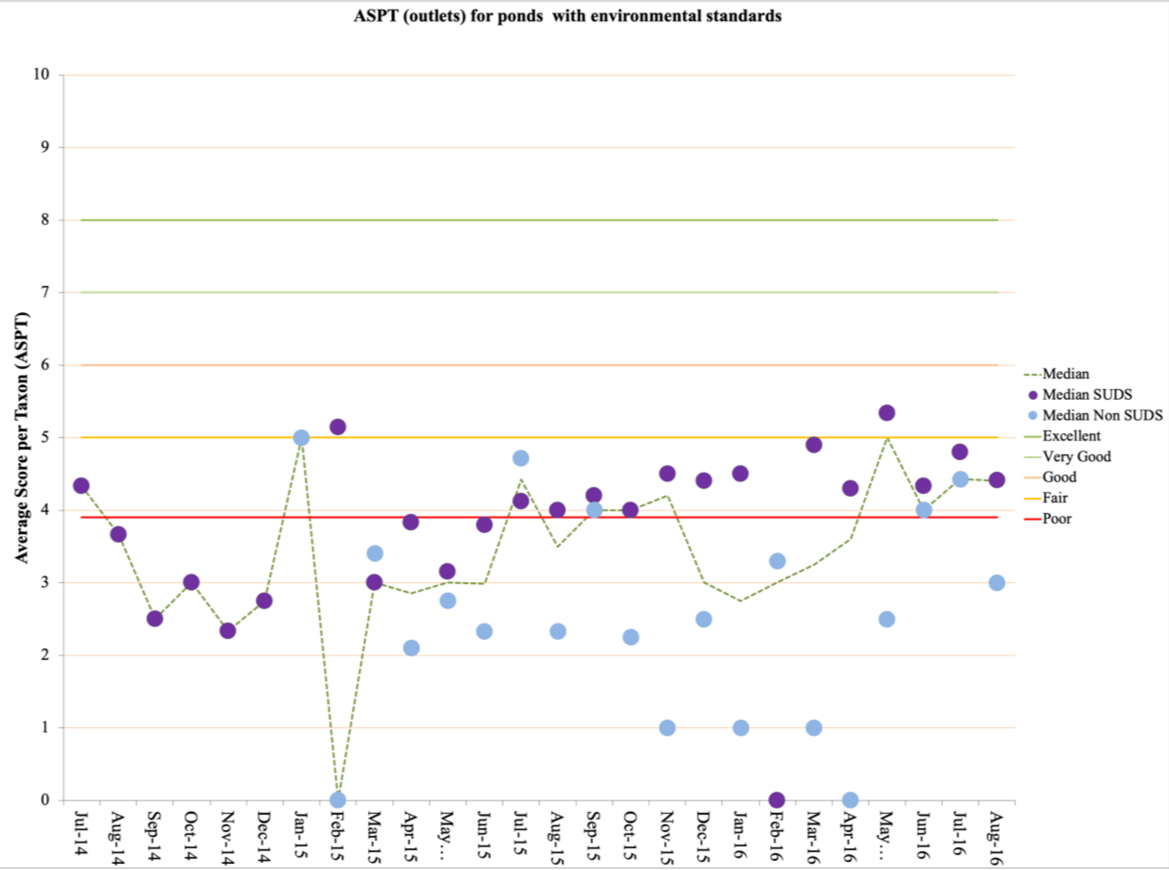

Figure 8-2 ASPT for each pond in relation to the monitoring period. The red line indicates poor status, the yellow is fair status. Amber is good status. Light green is very good status and dark green is excellent status.

8.4.1 ASPT

Median values for ASPT (Figure 8-2) indicate that none of the ponds reach good status in relation to water quality. Median SUDS values are between poor and fair status in relation to water quality. Most values (n=13) are between poor and fair status for SUDS ponds which aligns with previous studies for urban ponds where poor water quality was observed (e.g. Hassall and Anderson, 2015). Interestingly, the non SUDS ponds have lower median values than the SUDS ponds indicating that there may be more stressed/ disturbed conditions within these ponds.

This could suggest that the studied ponds are subjected to anthropogenic pressure from external sources of pollution (diffuse pollutants). SUDS ponds are situated near road verges or within urban settlements where salt bin use and gritting (Figure 8-3) could (Viol *et al.*, 2009) lower the expected water quality. Presence of domestic and construction-based litter is also likely to influence the water quality. There are also several ponds with water quality issues in relation to poor management of dog waste, and dog owners not cleaning up after their pets. Furthermore, as expected there are oil sheens present on some ponds- where car oil has been deposited in the ponds from nearby road drainage.

In relation to the SUDS ponds, it is likely that the ponds in urban settlements have poorer water quality in relation to the surrounding land-use, and anthropogenic pressures adding nutrients (***) to the watercourses.

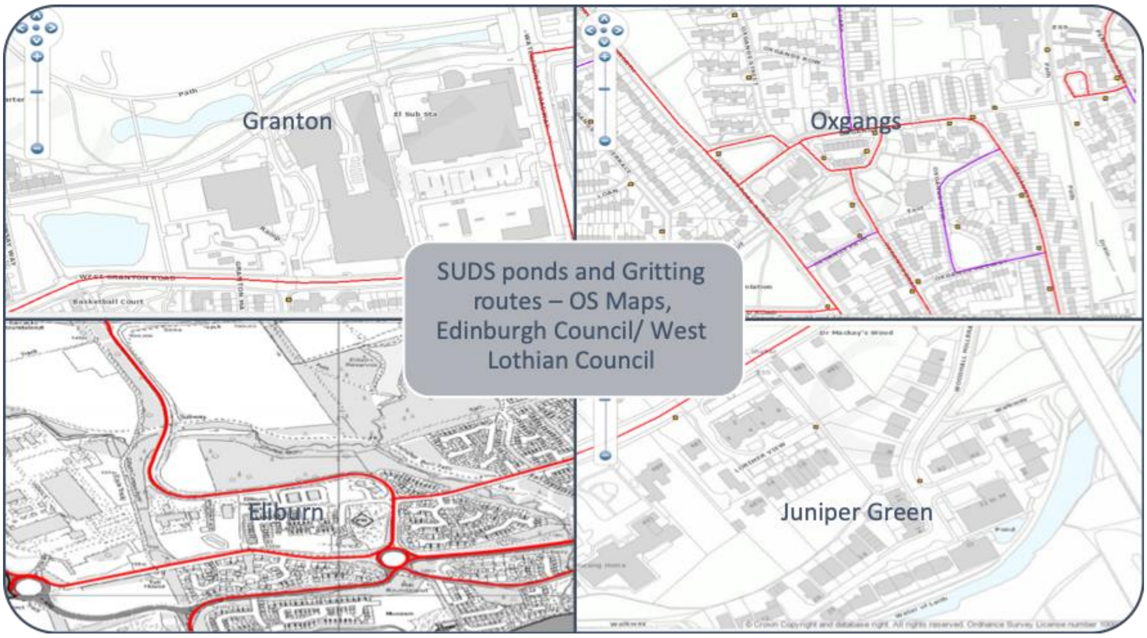

Figure 8-3 Gritting routes, Edinburgh Council and West Lothian Council. Eliburn is the only pond in West Lothian.

It was not expected that the SUDS ponds would provide higher ecological status in relation to macroinvertebrates and calculated ASPT (Figure 8-2;Figure 8-4). This finding was a little surprising, but encouraging, as it shows that pond design is operating to include a broad diversity of species. The latest CIRIA (2015) pond and wetland guidelines discussed the importance of ensuring that ponds meet biodiversity and water quality standards.

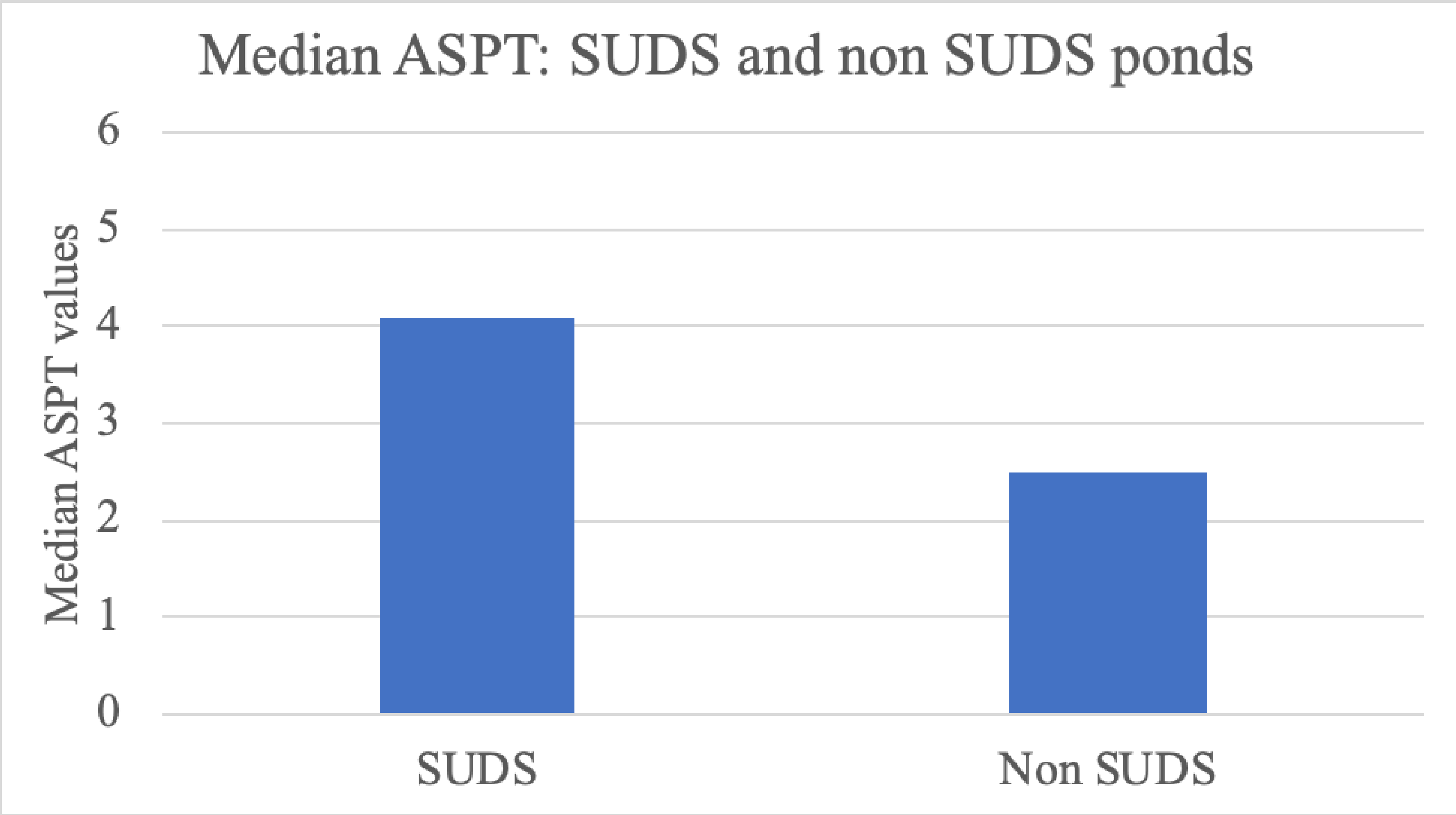

Figure 8-4 Median ASPT for outlets of SUDS and non SUDS ponds are highlighted.

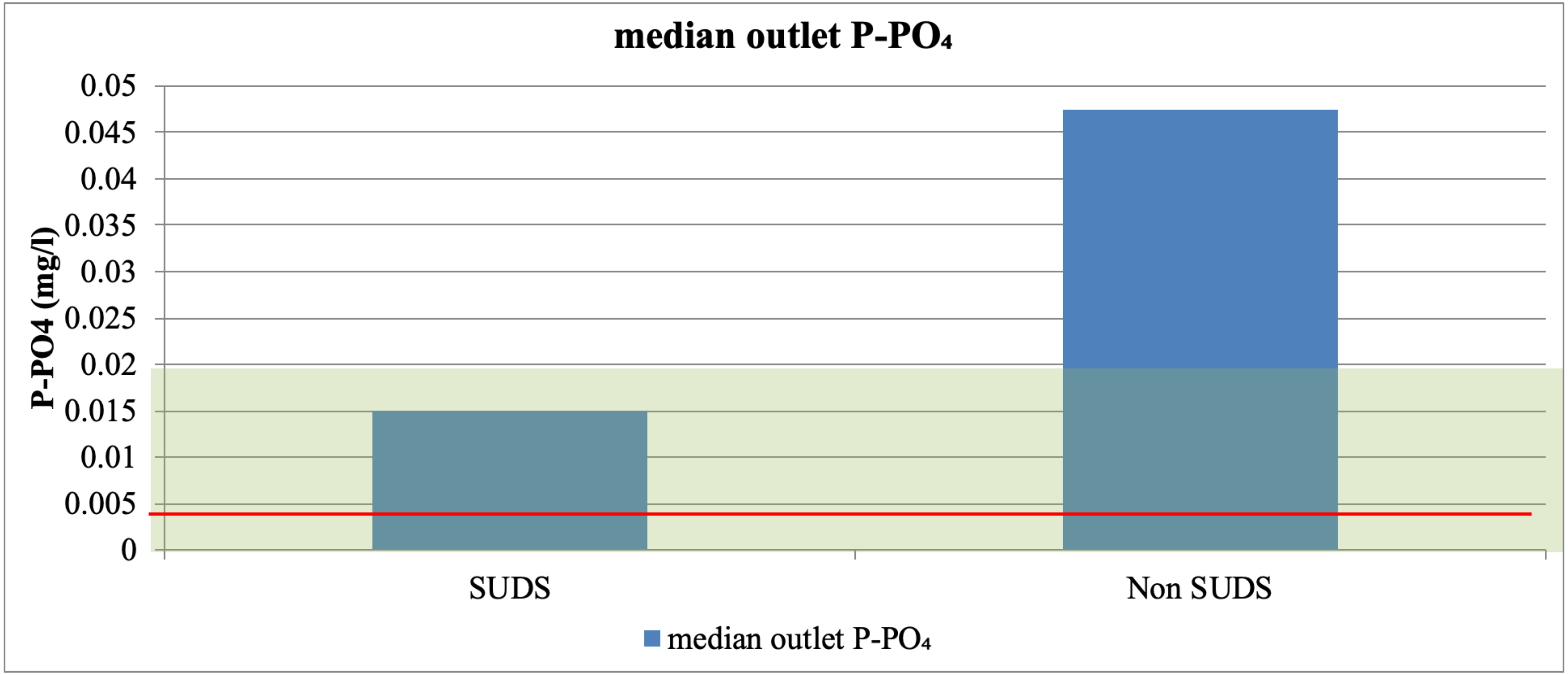

Figure 8-5 Median Phosphate at outlets for SUDS and non SUDS ponds. Red line is where the sensitive diatoms are found. Green shading indicates where the pond is not eutrophic (<0.035mg/l)

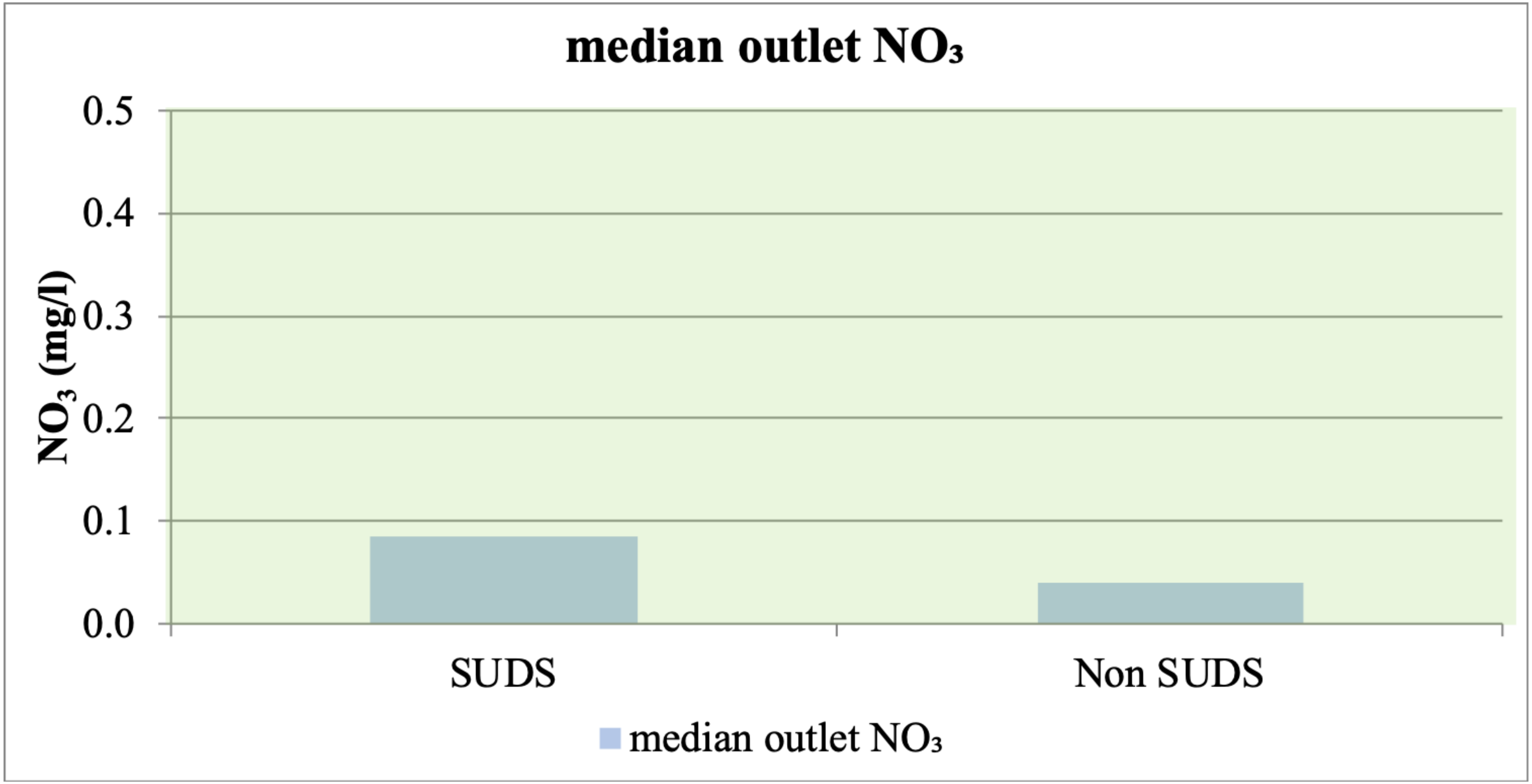

Figure 8-6 Median Nitrate concentrations for SUDS and non SUDS ponds. Green shading indicates the level where the pond is not eutrophic (< 0.5 mg/l)

8.4.2 Nutrients

The main trends emerging from Chapter 5 suggest that the ponds are of poor or disturbed water quality, so this will limit the regulation of water quality (as an Ecosystem Service). SUDS (n=3) and non SUDS (n=4) are represented in Figure 8-5 and Figure 8-6, and the threshold for poor water quality is illustrated- as this implies the water quality has nutrient pressure. The green shaded section of the figures represents the threshold where the pond becomes eutrophic in relation to phosphorus and nitrate pressure. In the Water Framework Directive, there are stringent legislative measures for rivers and lakes but none for smaller water bodies, such as ponds or wetlands. So, for the purpose of this assessment, the focus was on the river standards as a pond may discharge into a receiving water body – stream or river, so should be compliant with the discharge standards for nutrients into fresh water.

In 2016, the ponds were compared in terms of their nutrient sensitivities for diatoms. Diatoms are unicellular algae and are bioindicators of water quality, and form part of the requirements for the Water Framework Directive (EC, 2001) and WEWS Act in Scotland (2003). There was a decrease in abundance observed between the inlet and outlet for the SUDS ponds. This was not as evident in the non SUDS ponds; where a higher median value of Fragilaria *was observed (n=68)* in July 2016- which is an indicator of disturbed conditions (Round, 1993). Evidence of disturbed indicators was observed at SUDS and non SUDS ponds, but there was no significant difference observed between the samples in relation to nutrient sensitivity ($p>0.05$).

With respect to the design guidelines set out by CIRIA (2015), the factors in charge of maintenance could add barley or straw to the water where an algal bloom is observed. Additionally, the pond is overgrown, so this could amplify the nutrient issues. However, in the case of this study, the plants were not monitored in relation to nutrients or standards.

8.5 Stage four: Evaluation of ponds

The novelty in this research lies in comparison of SUDS ponds with non SUDS ponds. The proposed framework compared these ponds in relation to the main design criteria as outlined in the CIRIA SUDS manual. The main criteria were amenity, water quality regulation, flowering plants for pollination, and nutrient removal. Chapter 7 focused on the multiple benefits of ponds by comparing SUDS ponds with non SUDS ponds, and from the questionnaire benefits and disadvantages were chosen to assist with the final evaluation of the studied ponds. The idea is that a pond offers multiple benefits (Chapter 7) and Ecosystem Services (Chapter 4,5,6) but the delivery of these benefits could be hindered or promoted by several factors (Table 8-2); for example, the issues of litter, vandalism, and odours would reduce the appeal of the ponds, but an added flood benefit could increase the scores assigned. Furthermore, it was important to consider the population in relation to the pond (within a 500m radius) as this could influence the overall perception of the importance of the pond, and the number of people directly benefitting from the pond.

The chosen approach includes quantitative and qualitative measures to evaluate the overall potential of each pond to provide multiple benefits, and Ecosystem Services. Quantitative measurements include the count of flowering plants (for pollinators) at each pond which is an important consideration in design of ponds and is regarded as an important benefit of living near ponds. An additional quantitative approach is the Average Score per Taxon (ASPT) values associated with the ponds, in relation to the collected macroinvertebrates at each pond. This approach is a British Standard (BS EN ISO 10870 (2012)) for ponds (Chapter 3) and is widely incorporated into hydrology and ecology; making the data collection process more affordable and user friendly- which is arguably an important facet of monitoring and evaluating Ecosystem Services, and multiple benefits; especially in relation to frameworks and tools (e.g. Vortius and Spray, 2015).

A limit of the research framework suggested is the nutrient sensitivity scores as diatom identification requires more expertise and is therefore more research specific- which makes this aspect of the framework less user friendly, and perhaps an obstacle to wider implementation in decision making. Furthermore, there are possible issues with defining the scale to which the research should be applied. The affordability and time limits of a project should be managed sensibly.

The factors in Table 8-1 were chosen to represent the variables studied in relation to Ecosystem Services and multiple benefits. This table will be used to compare SUDS ponds and non SUDS ponds in relation to the benefits provided.

Divisions in the scoring matrix were developed using existing quantitative and qualitative data from the previous results chapters (Chapter 4-7). Flowering plants (for pollinators) were judged based on the difference across the ponds studied results showing that plants at SUDS ponds have more potential to support pollinators. Amenity was assessed in relation to the net present value benefits with most ponds scoring very good in relation to the population near the pond. Population was assessed based on living within 500m of the pond and derived from Address Based Premium GIS (Chapter 7). Macroinvertebrate proxies were used to assess water quality improvement with scoring based on Average Score per Taxon (Chapter 4), and supporting literature (Clarke and Bowker, 1999). Similarly, nutrient removal is based on existing Nutrient Sensitivity Scores with a score of 5 being very poor, and tolerant to nutrient enrichment from Phosphorus (Chapter 5).

Table 8-1 considers the main factors and measurements from the four results chapters, which include the counts of flowering plants suitable for pollinators, (Chapter 6), Annual Net Present Value Benefits (Chapter 7), Average Score per Taxon (ASPT) values using macroinvertebrate proxies (Chapter 4), and Nutrient Sensitivity Scores using diatoms as proxies (Chapter 5). This was with a view to compare the ponds in relation to their Ecosystem Service potential.

It is widely acknowledged in the literature (Chapter 2) that there are discrepancies within Ecosystem Service assessment, and sometimes the disbenefits are not considered in evaluation. To account for this, the scoring matrix provides an additional table with factors which could improve or reduce a pond’s score based on whether it adds to the potential delivery of the pond.

8.5.1 Rationale for factors chosen

This section will highlight the reasons for the factors adopted within Table 8-1 and document the scoring strategy chosen. Following on from stage three, it is important to present the evaluation of SUDS and non SUDS pond benefits, and relate this back to the main findings in the results chapters .It is hoped that the scoring strategy presented will be of use to stakeholders and practitioners as an alternative method to evaluate the multiple benefits from SUDS and non SUDS ponds.

The main factors chosen are based on the Contingent Valuation survey (Appendix A.7) and also from the guidelines in the recent CIRIA manual (2015), and these are summarised below:

- accessibility
    - Whether the public can freely access the pond/ within gated community

- ownership
    - Private ownership – more funding and investment into the pond is likely where contracted factors are responsible for maintaining the pond.

- population
    - This factor is in relation to the population living near the pond and those who are likely to directly use/ benefit from it.

- flood risk reduction
    - If an attenuation feature (such as a wetland) is present to provide some flood risk reduction benefits.
    - Whether the pond is designed for flood risk management and is a Sustainable Urban Drainage pond.

- park setting
    - Additional value/ benefits from the greenspace- making the pond more appealing to the public

- odour (survey disadvantage)
    - Detracts from benefits

- Nuisance to homeowners
- Issue with health/ air pollution

- - litter (survey disadvantage)
  - Common issue at ponds
  - Influences Aesthetics
  - Could influence pond functions (blockages of inlets and outlets- litter)

- - attracts pests (survey disadvantage)
  - Local residents may view as unsafe- e.g. rats and vermin

- - vandalism (survey disadvantage)
  - Reduces aesthetics
  - Could influence pond functionality if vital parts are destroyed.

- Scoring system adopted
  - The scoring system was chosen to show whether a pond was disadvantaged by a given factor. A score of 0 is for ponds which have the perceived disadvantage. A score of 0.5 is awarded to those ponds where the factors sometimes influence the overall perception of the benefits. Finally, a score of 1 is awarded to ponds where either there is no disadvantage perceived by a given factor (e.g. no litter issues) or it has the additional benefits (park setting).
  - This system is designed to be user friendly and to not bias the overall scores given to ponds. However, for the purpose of this analysis, individual ponds were assigned a score (see Appendix A.8) then the median scores were presented in this chapter. This is so that the median scores of ponds may be directly compared to show whether SUDS ponds have higher median values/ scores than non SUDS ponds, or vice versa. Additionally, this is with a view to evaluate the benefits of ponds in a simple and consistent way using novel data acquired from field observations (Chapter 4, 5, 6) and from the contingent valuation results (Chapter 7) and associated metadata.

Table 8-1 The following table and scoring matrix are the output of the framework and are used to evaluate the ponds in relation to benefits.

Factors based on CIRIA SUDS manual	**Pond**		
	Measurement	**Median SUDS Score**	**Median Non SUDS Score**
Plant Diversity	Counts of flowering plants suitable for pollinators	4	3
Amenity	Annual NPV Benefits (£)	5	5
Water Quality Improvement	Macroinvertebrate proxies, using Average Score per Taxon (median)	2	2
Nutrient Removal	Nutrient Sensitivity Scores using diatom proxies (median)	4	3
Sub Total / 20		15	11
	Additional Factors (See Table 8.2)	5	6
Total Score		20	17

Table 8-2 Summary of median scores for additional factors. Appendix A.8 provides a full breakdown for individual ponds

Pond Type	*Accessible*	*Population (within 500m radius)*	*Ownership*	*Reduces flooding*	*Park setting*	*Odour issues*	*Vandalism*	*Attracts Pests*	*Litter issue*
Median SUDS	0.25	1	1	1	0.5	0.25	0.25	0.25	0.5
Median Non SUDS	1	0.75	0.75	0.5	1	0.25	0.5	0.5	1

Table 8-1 summarises the median scores for SUDS and non SUDS ponds. The reader is directed to Appendix A.8 for a breakdown of scores for individual ponds. Median scores reveal that plant diversity is slightly higher at SUDS ponds than non SUDS ponds, with scores of 4 and 3, respectively. In relation to amenity benefits, SUDS and non SUDS ponds have very good scores in relation to this factor- highlighting that both sample groups highly value amenity benefits at their local pond. SUDS and non SUDS ponds have the same median score of 2 for APST- highlighting that ponds have poor potential in relation to water quality regulation. This highlights that while some of the individual ponds (see Appendix A.4) have good water quality potential (e.g. Juniper Green), the samples overall indicate that there are stressed conditions. Finally, SUDS ponds have higher median scores in relation to nutrient removal processes, with indicator values for nutrient sensitivity having lower median scores than non SUDS ponds. This also highlights that the SUDS ponds function better to remove algae than non SUDS ponds.

Table 8-2 highlights the extra scores assigned to ponds in relation to the factors chosen from the benefits of living near ponds, and some of the main disadvantages. Median values highlight that scores are more for Non SUDS ponds than SUDS ponds. Non SUDS ponds have more ponds within a park setting; which contributes to the overall appeal of the pond, and a key benefit of living near one.

Median values are higher for SUDS ponds in relation to population, ownership and reducing flooding. SUDS ponds studied are mainly within urban areas with higher population values than one of the non SUDS ponds. This could explain the marginal difference in median score. The SUDS ponds are in the main privately owned whereas the non SUDS ponds are public spaces and maintained by the Local Authorities. Privately owned ponds have factors and residents are required to pay for the upkeep of the pond by contributing towards an annual fee. This should assist with regular maintenance and allows ponds to function more efficiently without overgrown plants. However, this is not always the case with median values for litter, pests and vandalism indicating that some of the SUDS ponds have other issues that most of the non SUDS ponds have less often. Litter was highlighted as a disadvantage within the Contingent Valuation survey (Chapter 7).

8.6 Stage five

The proposed framework has the potential to evaluate existing "established" ponds and offer some guidance on how to improve the delivery of multiple benefits. The results from this matrix highlights that water quality is impaired in the studied ponds, as none of the ponds achieve good potential in relation to the macroinvertebrate proxies. SUDS ponds have good potential in relation to nutrient removal processes. However, as Chapter 5 highlighted there was no significant difference observed between SUDS and non SUDS ponds in relation to nutrient sensitivity scores. This indicates that some of the SUDS ponds have less potential than others and Appendix A.5 highlights this with more evidence of diatoms with scores greater than 4. This factor could be used to improve the ponds; as local authorities and factors could invest more capital into planting flowering plants suitable for pollinators and for maintenance of existing plants. By doing so, this will escalate amenity value; as the pond will have good habitat potential for birds, mammals, and small insects.

However, this proposed framework is not without its disadvantages. It is important to refer the reader to Chapter 3, where double counting was first referred to. There are potential overlaps between the factors of algae removal and water quality. Intrinsically, regulation of water quality and purification as its sometimes referred to is difficult to disentangle because proxies in the freshwater environment, (Macroinvertebrates and diatoms), could be used to monitor several Ecosystem Services. Diatoms which have been monitored (Chapter 5) in relation to nutrient enrichment may also be used for photosynthesis and carbon capture. Equally, macroinvertebrates are used in detoxification studies as indicators of water quality improvement. Both proxies allow an evaluation of pond ecology and water quality to be made.

Another potential limit of the framework is the overlap between plants and water quality. For the thesis, plants were only considered in relation to species diversity for pollination. The diversity was assessed for plants only to avoid the potential of double counting with diatom and macroinvertebrate proxies. The proposed framework requires ecology or engineering expertise to understand and fully interpret the results. However, the scoring matrix is user friendly and could be adopted on a larger scale if time and resources allowed. If the correct level of training and guidance was provided, then the ecology part of the framework could be adopted easily.

The main criticism and limit of the proposed framework is that the time and expertise needed for the amenity section could limit its use to academics; as the postal and online survey was a time intensive and data extensive process. A shorter survey could be used to get around this issue which would increase its usability. However, the level of detail needed for the Net Present Value benefits might be lost by shortening the survey.

Chapter 9- CONCLUSIONS

9.1 Introduction

The research problem that this thesis addressed was evaluating the Ecosystem Services, and multiple benefits provided by SUDS ponds. Until this study, there were very few field-based evaluation studies relating to the Water Quality regulation services comparing SUDS and non SUDS ponds. This was undertaken by monitoring macroinvertebrates for Average Score Per Taxon and assessing diatom counts for the purpose of nutrient sensitivity scores. The importance of studying macroinvertebrates and diatoms in relation to water quality should not be underestimated, as well as their importance for the functioning of ponds. Additionally, it is of importance within current design to incorporate flowering plants suitable for pollinators within new and retrofitted SUDS ponds, and it was important to study the plants at the ponds in relation to this potential benefit.

RQ 1: MACROINVERTEBRATES

How effective is Water Quality Regulation in ponds between the inlet and outlet, with respect to: -water chemistry, influence of rainfall, and nutrient loading?

Water Quality regulation potential is limited by nutrients (Chapter 4, 5) but this could be a response of the changing seasons rather than a function of the pond's ability to regulate water quality.

Chapter 4 revealed that median SUDS pond values for ASPT were higher than non SUDS ponds. There was, however, no statistically significant difference observed between pond samples for inlets or outlets ($p>0.05$). This highlights that while these are from two different sample groups, these are more likely to be from the same statistical group. SUDS ponds have higher ASPT (Average Score per Taxon) scores, in relation to the families of macroinvertebrates, than non SUDS ponds have. This is an interesting result as it shows SUDS ponds are functioning well due to less impaired water quality conditions (Chapter 4).

RQ 2: DIATOMS

Do SUDS ponds have more potential than non SUDS ponds for regulating Water Quality through algae removal processes (using diatoms as proxies)?

In terms of diatoms, there is a general decrease in abundance between the inlet and outlet which suggests that water quality regulation and nutrient removal potential is good, with respect to this biological proxy. Comparing median populations, there is not a significant difference (increase) between the SUDS ponds and non SUDS ponds for inlets ($p > 0.05$; W=4.5) and outlets ($p > 0.05$; W=6.5). This highlights that sample medians are only marginally different and that with the exception of summer months the results are broadly similar. There is no significant difference between observed median value at SUDS and non SUDS ponds for nutrient sensitivity values in spring ($p>0.05$) or summer months ($p>0.05$).

However, further evaluation reveals that there are disturbed indicators present (Chapter 5). Disturbed conditions could be reduced by seasonal monitoring or algal treatments (CIRIA, 2015). The only issue is that the treatment could reduce the biological potential within the ponds. *Neidium* was absent from all ponds but has been previously observed in Edinburgh ponds (Jahn *et al.,* 2008). However, this could be due to chance that these were not included in the samples or outwith the season. Diatom assessment in 2016 had a coarse time step (n=5 months) so a longer duration of study is advised in future monitoring. The evaluation (Chapter 8) also reveals the only pond with toxic indicators is a non SUDS pond, with a low abundance of *Amphora* (n=1) in August, which reduces the potential of the pond to regulate water quality at the outlet. Chapter 8 also revealed that median phosphorus (PO_4) was higher for non SUDS ponds with SUDS ponds having lower values. This could show that SUDS ponds have a better design to cope with nutrient removal than non SUDS ponds have. However, future studies should incorporate a greater number of ponds and more seasonal data to verify this.

RQ 3: PLANTS

Do SUDS ponds have more potential than non SUDS ponds to support flowering plants suitable for pollinators?

Insect flowering plants have the potential to be pollinated by insects, and there are marginal differences between pond median populations ($p < 0.05$; W=93). There are, however, similar differences for median observations of wind flowering plants between SUDS and non SUDS ponds with no statistical significance ($p > 0.05$; W=37). A recent study assessed farm ponds for pollination potential (Stewart *et al.*, 2017) but it did not compare flowering plants between SUDS and non SUDS ponds. Access to bees or syrphids, and the ability to quantify these was outwith the scope of the project, so evaluation was based on observed species and available secondary data (Eco-Flora, 1994; Fitter and Peat, 1994). Future studies could incorporate the use of bees and other insects into ecosystem assessment.

RQ 4: SURVEY RESULTS

1. What is the public perception of the potential benefits and disadvantages of living near a pond?

2. How much value is placed on supporting multiple benefits at their local pond (their Willingness to Pay for benefits), and are these values capable of offsetting costs?

Multiple benefits and evaluation of these in terms of whole life cost assessment, for SUDS ponds, had not been done in relation to public perception and qualitative data collection (Contingent Valuation based postal and online surveys). The work extended from a previous amenity study which assessed Whole Life Cost (WLC) for ponds within Edinburgh (Bastien *et al.,* 2012) but did not contextualise the results in a multiple benefits approach. However, there was a reference to biodiversity related benefits, but not a specification of habitat potential, nor a reference to the individual components relating to biodiversity.

Monetary assessment using Whole Life Cost analysis is an effective way to assess the multiple benefits associated with SUDS ponds, as this reduces some of the uncertainty associated with willingness to pay estimates (Arrow *et al.*, 1993). The results of this part of the thesis reveal that median Net Present Value (NPV) benefits outweigh costs for SUDS ponds in relation to habitat provision, education, flood risk and spiritual benefits. However, for non SUDS ponds, habitat provision is the only benefit which offsets costs. This demonstrates the importance of habitat provision benefits for SUDS and non SUDS ponds. Furthermore, this links with previous research where biodiversity was viewed as an important benefit of living near ponds (Bastien *et al.,* 2012; Jose *et al.,* 2015).

9.2 Knowledge contributions and implications

The following contributions to knowledge are provided from the findings of the research:

1. An assessment of the Water Quality Regulation potential from ponds. Making a comparison of SUDS ponds with non SUDS ponds. (RQ 1 / 2)
2. Comparing plant diversity and the potential for flowering plants to attract pollinators. (RQ3)
3. Whole life assessment of the multiple benefits from SUDS ponds (ecosystem-based assessment) and replacement costs for non SUDS ponds. (RQ 4)

4. Creating an evaluation framework for assessing ponds with Ecosystem Services in relation to the field-based monitoring which incorporates benefits and disadvantages into the overall assessment (RQ 1-3).

The implications for policy or practice could be:

- Current design standards enhance Ecosystem Service delivery of ponds.
- Improving knowledge of the public perception and multiple benefits offered by ponds.
- It is important to consider a variety of flowering plants- which may attract a variety of animal pollinators and facilitate wind-based pollination.

9.3 The unanswered questions:

One of the unanswered questions relating to the thesis results is: are the results representative of climate change and could long term monitoring reveal that drier years (with limited rainfall) reduce the potential for these ponds to function (reducing water purification potential, e.g Paerl and Otten,2012), but equally would heavy storm events improve functionality? Hydrology and flow (velocity) could be assessed in future projects to see whether this has a bearing on operation. A field based Acoustic Doppler Velocity profiler would assist with objective in future projects. Unfortunately, this was outwith the budget for this project.

Would increasing the number of ponds monitored reveal more about how the SUDS ponds are managed, and whether these results are circumstantial? Ideally, more ponds would be beneficial in future studies and certainly this is the case for other research in urban ponds (Hill *et al.,* 2016) where larger samples allowed more rigorous statistical tests to be performed – for example Principal Components Analysis and Canonical Analysis. This form of linear analysis would certainly be an advantage for future work. Unfortunately, due to the nature of the data and missing values or removed cases in some situations (diatoms) then this form of analysis would have led to misleading conclusions or unnecessary analysis.

Are there regional or national differences in the way that SUDS are managed, and why is this?

This argument relates back to the idea first proposed by Apostolaki *et al.,* (2006) that public perception varies on a national scale in relation to their national SUDS study. It is important to consider the results of the survey in a wider context, for example would ponds in London (Ossa-Moreno *et al.,* 2017) offer the same benefits as a smaller city such as Dundee (Jose *et al.*, 2015). While we have established that biodiversity is of importance to all sample groups within this study, this may not be the case in different settings. Public perception does vary, and some respondents still have concerns about mismanagement and ponds attracting crime (e.g. Teedon et al., 2014) and unwanted pests- which was the case for some in this study too, with pests being a key disadvantage of living close to ponds.

Studying regional differences in SUDS management would be an interesting study to take forward in relation to multiple benefits. However, this would require extensive social and physical science methods to be employed. This may also need a collaborative research approach with other universities with expertise in social science methodology and also within economic appraisal.

Could Ecosystem assessment be improved if Ecosystem Dis-services are valued and the associated values are removed from the multiple benefit assessment during the Whole Life Cost analysis?

The scoring strategy presented in Chapter 8 attempted to evaluate some of the ecosystem dis-services which is an important component of holistic ecosystem service assessment (see Uzomah *et al.,* 2014). The current data could be analysed in a different way to filter out the ecosystem dis-services- for example if the public viewed pests as the main disadvantage then how did this affect their valuation. However, a more rigorous approach is to change the valuation matrix at the end of the Contingent

Valuation survey to allow respondents to select the multiple benefits/ Ecosystem Services they favour and also select those dis-services which change their perceived value. The analyst would then deduct the selected dis-services values from the benefit matrix allowing a more realistic assessment of ponds.

Would implementing BeST (Benefit of SUDS tool) in wider practice be more efficient in monetary valuation?

The Benefit of SUDS (BeST) tool developed in 2016 is more routinely applied in industry and academic settings. O'Donnell *et al.,* (2017) applied BeST to a SUDS case study in Newcastle. Chapter 2 highlighted some of the issues with applying this tool in wider practice. BeST was in its early stages when the valuation for this thesis took place, so it was decided not to apply it. Future studies will benefit from adopting this tool now that more training and updates have been included allowing it to function more successfully. One of the key advantages of this tool is that it does not require. One of the gaps that remains is the ability to value some of the multiple benefits and Ecosystem Services discussed within this work; as the key ecosystem services do not include supporting services- for example the habitat provision benefits would be excluded from assessment. However, it does have a water quality section (regulating services) which aligns with the requirements of the Water Framework Directive (EC/2001). This also fits in with the thesis results in relation to research question 1 and 2.

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Chapter 11- APPENDIX

Chapter 1- Paper appendix (A.1)
MDPI- water journal

Article

1. Valuing Multiple Benefits, and the Public Perception of SUDS Ponds

Joy Jarvie *, Scott Arthur and Lindsay Beevers

1.1.1 School of Energy, Geoscience, Infrastructure and Society, Heriot Watt University, Edinburgh, EH14 4AS, UK; s.arthur@hw.ac.uk (S.A.); l.c.beevers@hw.ac.uk (L.B.)
1. ***** Correspondence: jaj31@hw.ac.uk

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Abstract: Understanding how the public perceive and value ponds is fundamental to appreciate the synergy between Sustainable urban Drainage (SUDS) ponds and the multiple benefits they provide. This paper investigates this, through the application of a structured postal and online survey, for a case study area of Edinburgh, in the UK. It compares man-made ponds (including SUDS), and ponds with natural origins. The results from Whole Life Cost show that the benefits (based on Contingent Valuation) exceed the CAPEX and OPEX costs for three of five artificial ponds studied. Benefits from natural (reference) ponds exceed the replacement costs for a pond with the same surface area/catchment. This paper highlights the importance of monetising the multiple benefits from ponds.

Keywords: contingent valuation; whole life cost; SUDS; public perception; multiple benefits; ponds

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1. 1. Introduction

Ponds are temporary or permanent water features that have a surface area between 1 m^2 and 2 ha (20,000 m^2), and may be artificial or natural in origin [1,2]. Existing literature on urban ponds refers to poor habitat and water quality due to nutrient enrichment [2]. However, there is an increasing awareness of the benefits associated with ponds and the need to preserve these small water bodies and create new ponds [2]. This may be hindered by a lack of a clear management framework [3] and only limited freshwater legislation for small water bodies in the United Kingdom and within Europe [2]. Ponds can be both naturally occurring and artificial in nature, which influences their characteristics.

1.1. Artificial Ponds (Including SUDS)

Artificial ponds are those which are man-made, and include recreation ponds, mill ponds, distillery (waste water), conservation, and Sustainable Urban Drainage (SUDS) ponds. Sustainable Urban Drainage (SUDS) ponds are designed to treat stormwater pollutants, attenuate runoff, and promote biodiversity and amenity wherever possible [4]. SUDS features mimic ecological systems as well as creating space for biodiversity to flourish.

1.2. Natural (Natural Origin) Ponds

Natural ponds are ecological features which may exist naturally in depressions or glacial features such as kettle holes [5], or adjacent to flood plains [6]. Natural ponds may be filled by an underground spring or with rainfall, and in this paper they are regarded as 'reference' conditions because they ideally have minimal human disturbance. However, it is recognised that natural ponds in or near urban areas are influenced by enhanced runoff as a consequence of urbanisation.

1.3. Multiple Benefits Approach

Blue Green infrastructure (including SUDS [7]), is designed with water quality (treatment) and water quantity (flood risk management) principles; as well as incorporating biodiversity and amenity to a lesser extent. Construction Industry Research and Information Association (CIRIA) [4] describe the multiple benefits from SUDS as having opportunities, in addition to the main design functions, which enhance local health and wellbeing through optimising green spaces. Designing for multiple benefits incorporates functions which provide sustainable conditions within the urban environment [8]. The role of SUDS facilitates this process through ingenious design and engineering while making efficient use of parks and urban areas for health and well-being in addition to the main functions of SUDS.

Incorporating multiple benefits within planning will support best practice in designing new developments. Well-designed SUDS ponds provide the basic water quality and quantity demands, as well as a suitable habitat for wildlife, while offering education opportunities and a place for meditation and relaxation. Within the context of multiple benefits, it is therefore important to look at opportunities provided by SUDS ponds, and compare these with natural ponds to see how the public view and value these benefits.

The multiple benefits of SUDS are routinely assessed with economic and spatial analysis. The Benefit of SUDS Tool (BeST) highlights the costs and benefits. Monetary valuation is a well-known and accepted method for evaluating the costs and benefits of a project, but using Whole Life Cost approaches has limitations too. For example, the cost benefit analysis is dependent on having accurate maintenance cost data (which is variable from site to site, e.g., [9, 10]). Other approaches include Public Participatory Geographic Information Systems (PPGIS), which has been used to define the multiple benefits from SUDS by involving the local community in the assessment process [11]. The participatory approach is positive as it is important to involve local communities in the development and post-development phases; as the early interaction allows future residents to engage with the planning process, and then comment on the effectiveness of the SUDS once they have been constructed. However, spatial analysis using non-monetary valuation may introduce subjective bias when characterising the multiple benefits by use of qualitative design [12].

In this paper, Contingent Valuation was adopted to assess the multiple benefits associated with ponds in relation to habitat provision. Contingent valuation is usually used in local planning policy and provides respondents with a hypothetical scenario where they are asked to state their willingness to pay for an improvement to an environmental issue or programme [13] with an appropriate payment vehicle (e.g., taxation, annual or monthly payments). Contingent valuation is inexpensive, requires no market data, and is thus useful for decision making at a local scale [14] but there could be bias involved with some participants providing unrealistic ('pleasing') responses to valuation questions [15]. Furthermore, there may be issues with response and non-response bias which may produce unreliable surveys [13, 15]. This is why it is important to compare the habitat benefits with costs in a Whole Life Cost (WLC) analysis as this validates the use of Contingent Valuation for planning policy and minimises some of the uncertainty associated with unrealistic responses [13]. Applying a multiple benefit approach is a useful way to quantify the benefits from ponds (as it captures the multiple benefits associated with habitat) in relation to the perceived value from habitat potential, and to investigate whether or not the benefits exceed the Capital (CAPEX) and Operation/maintenance (OPEX) costs for SUDS ponds. It is also important to assess the value of replacing a natural pond, and to see whether these current benefits (Net Present Value (NPV)) exceed future costs for a pond of a similar catchment size. Existing work quantifies and values the amenity [9,10,16] and biodiversity of ponds [16]. Other studies have monitored the biodiversity of SUDS ponds [17] and urban ponds [18, 19]. However, the previous work has not placed a monetary value on the benefits from natural and artificial ponds in relation to habitat provision (as a multiple benefit), and hence this paper sets out to do this.

1.4. Current Research

The Contingent Valuation analysis is based on a survey which was undertaken to understand how the public perceive multiple benefits so that these principles may be incorporated into the future design of SUDS ponds. Studying urban ponds in a UK context is not new [17–19]. Urban pond research has historically played a fundamental role in developing planning policy and, with this in mind; the following questions guided the development of the research:

2. 1. What is the public perception of the potential benefits and disadvantages of living near a pond?
3. 2. How much value is placed on supporting habitat at their local pond (their Willingness to Pay for benefits), and are these values capable of offsetting costs?

4. 2. Materials and Methods

Data collection, the design, and dissemination of surveys via the postal system and online to the survey areas are presented. Ponds within Edinburgh and the Lothians (UK) were chosen as these also formed the case studies for the doctoral field work between 2014 and 2016 (Table 1). Artificial ponds (including SUDS) and reference ponds (natural origins) were considered and the analysis section discusses the method of calculating the values from each individual in the survey, and the population values extracted from the statistical bulletin of the Census [20].

2.1. Postal Survey Format

Surveys focused on the multiple benefits of ponds within an ecosystem context. The reason for this was to highlight the existing gap in knowledge with respect to the management and delivery of the multiple benefits within the public domain, in relation to habitat provision.

The main focus was on the ecosystem benefits and underlying issues associated with living near a pond. Participants selected the benefits that they valued most and how much they were willing to pay to receive similar benefits elsewhere. The valuation was carried out using a matrix with multiple values for each assigned benefit [16, 21, 22]. This proved to be invaluable as it provided more detail with respect to the individual perceived benefits and provided some context for the respondents [21].

Incorporation of images allowed the participant to identify key benefits of the pond (for example, the addition of animals and plant life at your local pond). However, the length of the survey was somewhat longer than other authors [16, 23] which may have hindered the response.

2.2. Postal Survey Pilot

The survey was tested on individuals living close to a pond. Furthermore, the survey was tested on a local resident and NHS development officer within Edinburgh. Comments were taken into consideration and minor revisions were made prior to the surveys being issued to the public. Some of the language was altered to make these surveys more accessible.

2.3. Survey Administration

Each survey area was assigned a code so that the returned surveys could be tracked and included a business reply envelope to encourage a higher response rate. Whilst attempts were made to retrieve surveys in areas with lower response rates, it is unethical to pester participants to return surveys [24]. Reminder slips with instructions to leave completed surveys in their local library were the chosen solution for this. A potential problem with this approach is that a participant may provide more than one response, which results in multiple responses from the participant and yields unrealistic data in the results. In addition, all of the libraries in the survey areas were contacted and library staff arranged sessions where the research could be explained, and surveys were handed out where appropriate. Views and comments from the public at these sessions were welcomed and provided some invaluable feedback. Engagement at morning library classes was useful as some parents with young children completed the survey online during the morning session.

2.4. Development of an Online Survey

The online survey encouraged more participation from areas with a lower response rate by targeting local libraries and community centres (where access was permitted). Participants were asked to select their nearest pond (within walking distance). This approach was facilitated through social media and contacting local council representatives. Social media included local nature and conservation groups; as well as university and schools near the chosen ponds. Over 100 people were contacted by email or telephone to encourage wider participation in the survey. A map was included in social media adverts to allow participants to identify their closest pond more easily.

2.5. Post-Processing

Postal survey responses were integrated into the online survey sites (E-Survey) for comparability reasons, and to ensure that all survey responses were processed in the same way. Critically, the main section of benefit valuation remained the same. Comments from respondents were added, and these related to questions where an additional benefit was possible; for example are there other habitat benefits available at your local pond?

Within this paper, the survey responses are compiled for each individual assessing their willingness to pay for the multiple benefits pertaining to habitat provision, and these include sustaining suitable habitat conditions for: birds, fish, macroinvertebrates, macrophytes (plants), and mammals. The individual ponds are considered, too, to see if there are clear differences in the way that the public perceive artificial (including SUDS) ponds when compared with reference ponds (ponds with natural origins). As suggested in the literature, the valuation of the ponds was based on annual or monthly payments [25].

2.6. Analytical Techniques

Economic values were calculated by summing the values associated with each benefit type. Values ranged from £0 to >£25 (with a selection of £0, £1, £2, £5, £10, £15, £25 and >£25) as a monthly payment, as supported by [16]. The values were sorted into tables with the habitat provision benefits. To prevent the risk of double counting, whole life cost [26] was implemented to add more certainty to the contingent valuation estimates. It should be noted that only the multiple benefits are calculated but there is associated uncertainty as willingness to pay may be influenced by protest zeros [13] which may be in relation to maintenance issues [16,26].

Capital and maintenance costs were calculated according to surface area and pond volume, as suggested by the United Kingdom Water Industry Research, cited in [27]. Whole life maintenance costs were calculated using a discount rate of 3.5% for the first 30 years, and 3% for the remaining 20 years, as recommended by the HM Treasury Green book for projects of 30–50 years [28], and supported by other studies [16]. This was to investigate whether current benefits outweigh the replacement and maintenance costs for ponds.

Address-based information was acquired from the 2011 Census relating to the number of residents within close proximity to the pond (assumed by a 500 m radius from each pond). This process was facilitated by e-spatial [29], which produces maps for user defined places or postcodes. The street names were then noted and the corresponding postcodes were found. The address source data were then analysed using the Census bulletin [20] to investigate the total population living within a 500 m radius for each pond. This is consistent with a previous study which used a walking distance of 5 min, which is approximated by field evaluation [16]. Furthermore, the Scottish Index of Multiple Deprivation (SIMD) [30] was consulted to place values into a meaningful social context: where a decile score of 1 is most deprived and 10 is least deprived.

Table 1. Describes the setting of each pond, ownership, and the known uses. The main purpose of each pond is described, and some additional notes about amenity and biodiversity. This also highlights why the ponds were chosen (with SUDS ponds being compared to those with natural origins). Scottish Index of Multiple Deprivation (SIMD, hereafter) scores for each case study are presented.

Case Study	Setting of Pond	Use of Pond	Surface Area (m^2)	Date Established	Ownership	Population within 500 m Radius	SIMD Decile Score
Granton Pond, Edinburgh	In a park. Near a supermarket and college.	Drainage (SUDS) pond. Provides amenity and biodiversity.	12,000	2005	Private—Capita Symonds/National Grid	2315	3
Juniper Green Pond, Edinburgh	Residential area. Near the Water of Leith footpath.	Drainage (SUDS) pond, focal point from flats.	240	2005	Private—James Gibb	1459	10
Oxgangs, Edinburgh	Residential area.	Drainage (SUDS) pond and amenity	8099	2007–2010	Private—Dunedin Canmore	3796	2
Eliburn, Livingston	Residential area. Near light industrial units	Drainage pond (SUDS)—not accessible to public	1675	2007–2011	Private- Gladmans	364	9
Blackford, Edinburgh	Local Nature Reserve	Biodiversity and amenity	13,500	1800–1900	Public—Edinburgh Local authority	847	9
Goreglen, Mid Lothian	Woodland setting. Near main road.	No use currently. Flood plain	500	1794–1861	Public—Midlothian Ranger Service	39	4
Royal Botanic Gardens, Edinburgh	Former estate. Near residential area.	Amenity and education. Outflow pipe to Water of Leith. Feeding wildfowl.	4560	1880	Private	2312	10
Inverleith Pond, Edinburgh	Park setting. Near residential area.	Model boat activities, recreation, and feeding wild fowl	43,554	1870	Public—Edinburgh Local authority	804	10

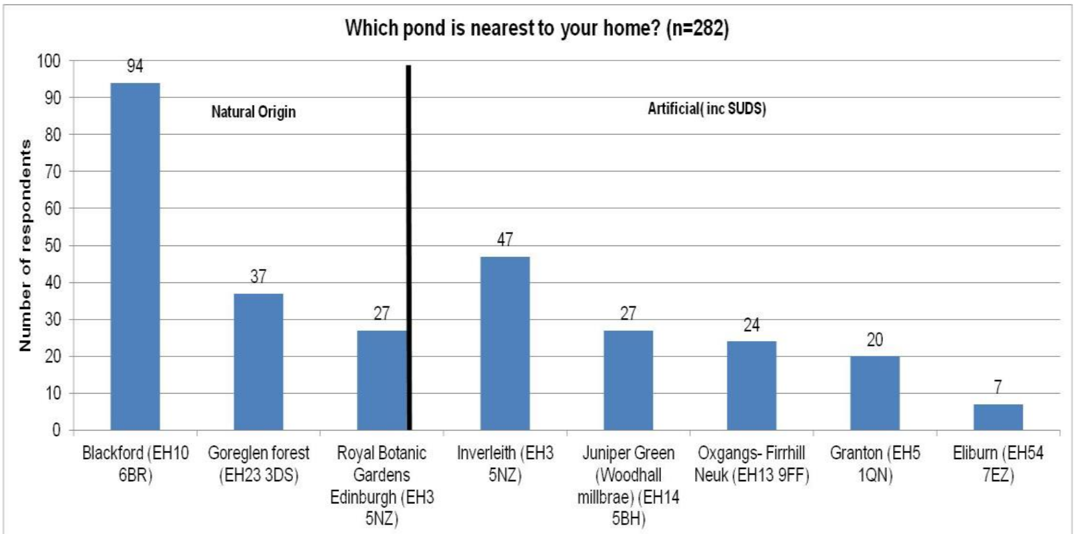
5. 3. Results

Of the 810 door-to-door (postal) surveys issued, 144 were returned with completed responses (an additional two were returned uncompleted). The response rate of 17.5% was calculated using guidelines from the American Association for Public Opinion Research (AAPOR) [31], and this was lower than [16] (27%) but exceeded other surveys, such as [11] (8%). It is in line (17%) with an urban flooding Contingent Valuation study [32]. Furthermore, the online survey added a further 140 responses with a completion rate of 84% (n = 238).

The data were all collated to include responses from both modes of the survey (see Supplementary Materials). Some questions have lower responses than others, but from 282 responses, 83% (n = 233) were assigned a value, including zero, for willingness to pay for habitat provision, which was the main focus of this paper. The data presented include location of each respondent (in terms of their closest pond), factors influencing their choice of home, and the perceived benefits and disadvantages associated with living next to a pond.

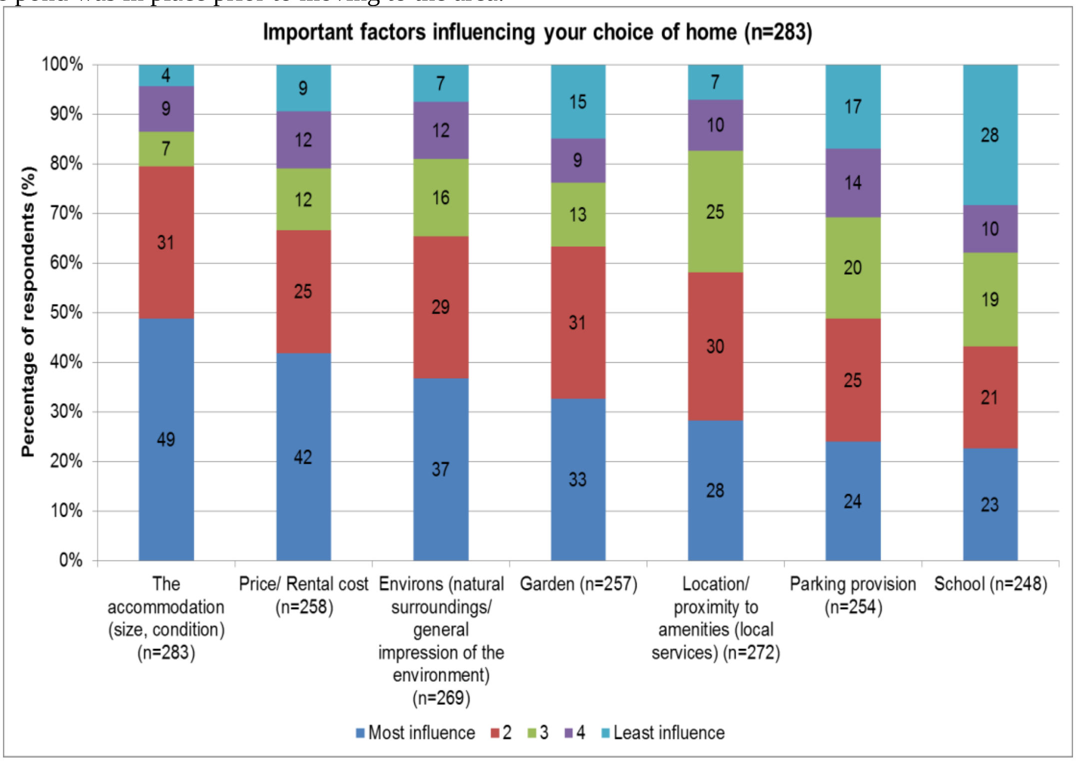
3.1. Perceptions of Ponds and Characteristics Influencing Choice of Home

Blackford pond has the highest number of survey responses (n = 94, Figure 1), and more than double the responses of Goreglen (n = 37), which may be due to the attraction of the local nature reserve as the pond has an abundance of water birds and insects in spring and summer. Juniper Green and the Royal Botanic gardens have the same number of responses. Juniper Green has the greatest number of responses from the SUDS ponds chosen, with the least recorded at the Livingston ponds. The responses for some areas are relatively modest in number and, as such, may not produce results which are statistically significant. However, the total number of responses may be sufficient to draw conclusions and support comparisons with other studies.

- 

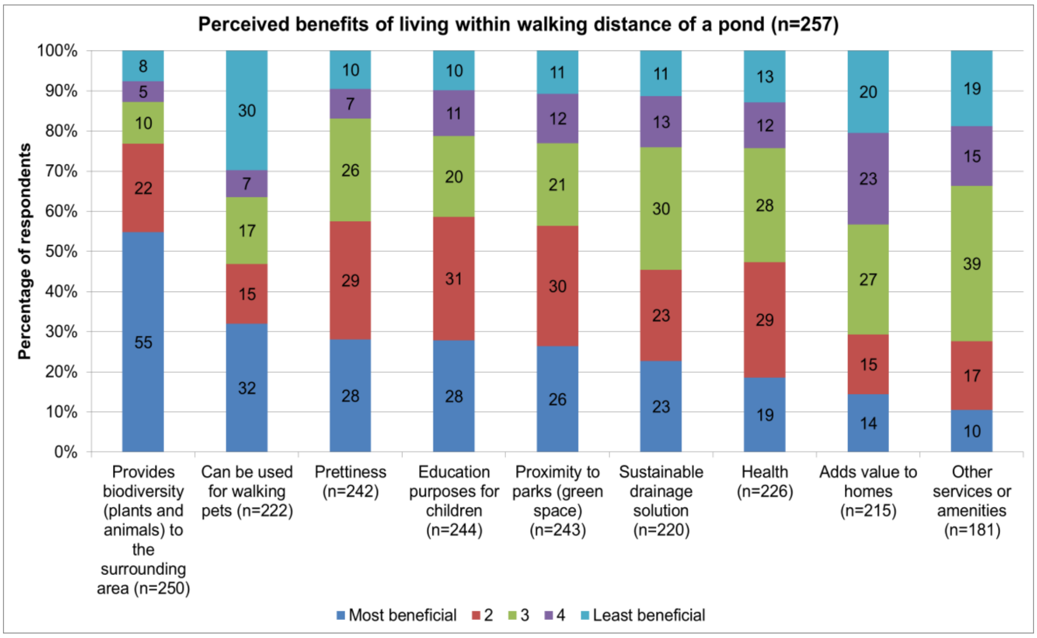
1. **Figure 1.** Which pond is nearest to their home, numbers at the top of the column indicate the number of responses for that sample group, SUDS = Juniper Green, Oxgangs, Granton and 2 × Livingston ponds.

Respondents rated factors which influenced their decision to move (1 = most important and 5 = least important) to their current home. A total of 80% stated that the accommodation size and condition influenced their decision to move to their home by giving it a score of 1 or 2 (Figure 2). A total of 66% viewed their natural environment and surroundings as an important factor—which may be related to choosing to live near open spaces and ponds. Price and rental cost was also important, with 67% citing this as the main reason they chose their current home. The least popular decision for choosing their current home was the nearby schools. Participants were able to choose more than 1 factor—as some did regard two or three factors of similar importance. The survey highlighted that over 90% of residents stated the pond was in place prior to moving to the area.



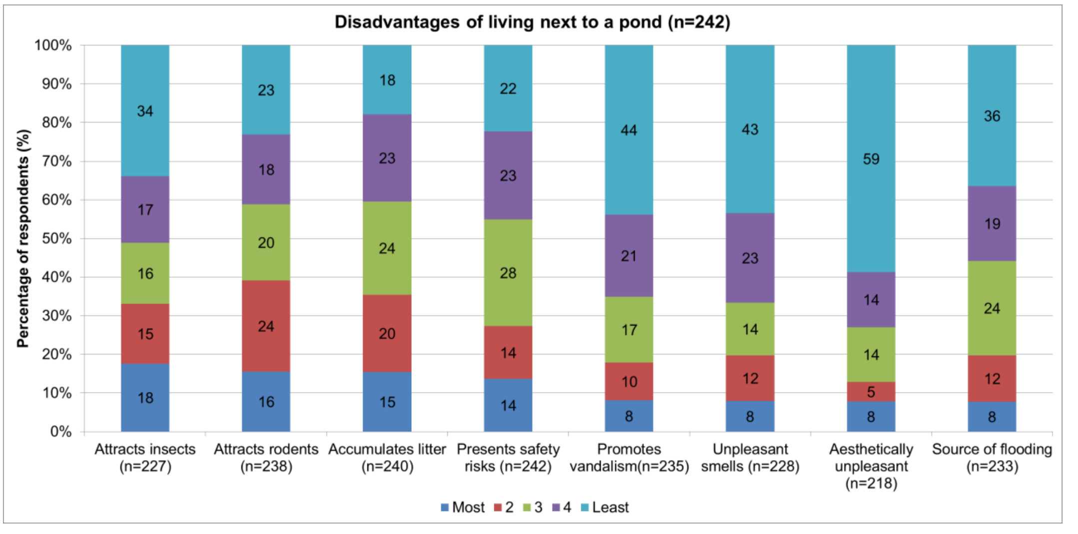
2. **Figure 2.** Important factors influencing a resident's choice of home, rated 1: greatest influential factor to 5: least influential factor.

The perceived benefits of living within a short walking distance (500 m) include the provision of biodiversity, with 77% rating it as highly beneficial (Figure 3, n = 257). Pet walking was viewed by 32% as most beneficial, with an additional 32% of respondents viewing it of benefit with a score of two or three. Aesthetics is viewed as most beneficial by 28%, with a further 31% viewing it as of secondary importance. Education purposes for children are viewed as most beneficial by 28% of respondents, with 30% viewing this benefit as the second most important.



3. **Figure 3.** Perceived benefits of living next to a pond (within walking distance), rated 1: Greatest benefit to 5: Least benefit.

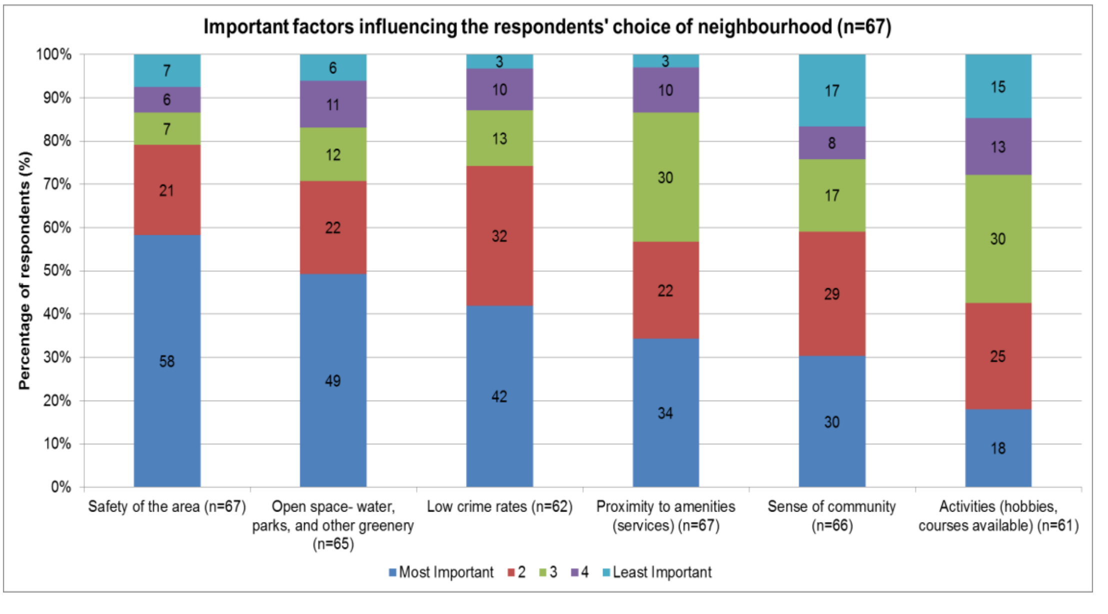
The perceived disadvantages (Figure 4) of living within a short walking distance from a pond include, attracts insects, with 18% of respondents viewing this as more of a disadvantage than rodents (16%). Safety risks were viewed as a similar disadvantage (14%) as that associated with litter (15%).



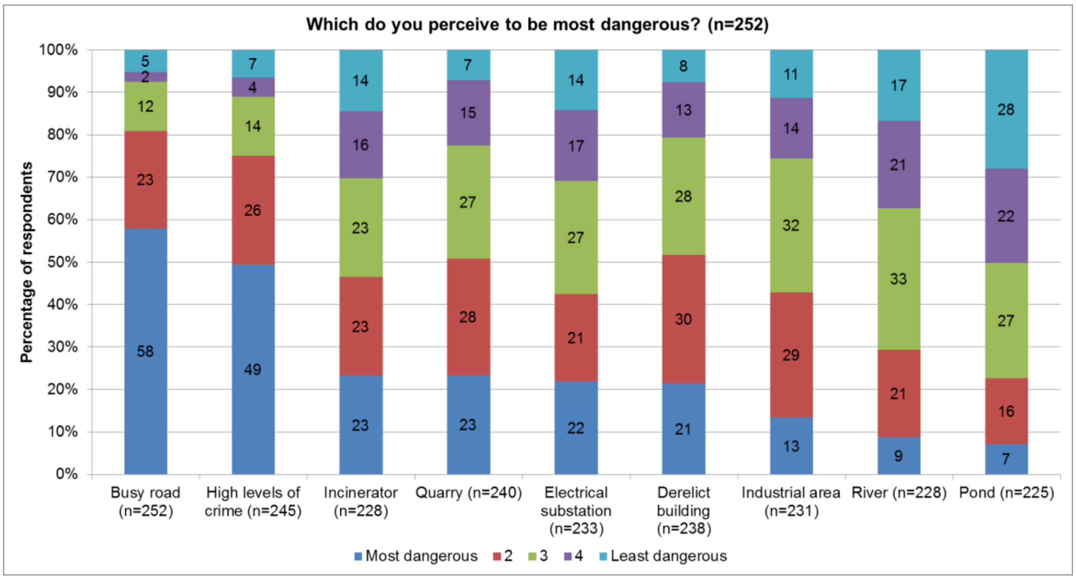
4. **Figure 4.** Disadvantages of living next to a pond (within walking distance), rated 1: Greatest disadvantage to 5: Lowest disadvantage.

3.2. Safety Concerns

Safety of the area is the most important factor when choosing a neighbourhood to live, especially for those with families (Figure 5, n = 67). Open space is another factor with high importance, which relates to the importance of SUDS greenery and, providing safe, open, spaces for children to play in. Low crime rates are another important factor which is re-emphasised by high levels of crime being the second highest perceived danger (Figure 6).



5. **Figure 5.** Which factors are important when choosing a neighbourhood (families—single parents and co-habiting).

- 

6. **Figure 6.** Which do you perceive to be the most dangerous, rated 1: Most dangerous to 5: Least dangerous.

The lowest perceived dangers in both modes of survey were ponds and rivers, with each having less than 10% of first preferences. Busy roads were the highest perceived danger, with 58% of the sample population having significant concerns about busy roads, which also relates to the importance of safety in a neighbourhood and having park environments with open spaces nearby [16].

3.3. Biodiversity and Observations of Fauna and Flora at Their Local Pond

In total, 63% of the respondents from the survey answered the question on biodiversity (n = 177) and observed that their local pond provided a habitat. However, there were more responses for the questions about fauna (n = 228, 81%) and flora (n = 203, 72%), with only one survey response stating that they were not clear what "biodiversity" meant.

In terms of SUDS ponds, the water birds (ducks, n = 35, swans, n = 24) and frogs (n = 23) were observed more frequently than water bugs (n = 15), small fish (n = 9) and newts (n = 4). Inverleith also observed frogs (n = 6), water birds (ducks, n = 15, swans, n = 11) with water bugs (n = 7). However, the participants near ponds with natural origins observed water birds (ducks, n = 81, swans, n = 72), frogs (n = 70) and water bugs (n = 62) more often. Both groups identified small fish, with Granton (n = 4) and Blackford (n = 15) having the highest number of observations. Additional observations for fauna included heron, geese, water hens and coots, rats, grebes, tern, damsel flies, dragonflies and eels. Some participants also commented on issues at their local pond such as "rats were eating bird eggs" and birds being fed bread encouraged more pests. One participant said that they had never seen any wildlife at their local pond in reference to Goreglen.

Bulrushes and sedge were observed by residents near SUDS (bulrush n = 19, sedge, n = 8) and reference ponds (natural origins, bulrush n = 28, sedge n = 8) and by those near Inverleith (bulrush n = 6, sedge n = 3). Bog bean was observed in the fewest ponds. Other flora that was observed included mint, iris, pond and duck weed. In addition to this, herbs and an array of wild flowers (thistles, forget me not, and daisies) were identified. A few respondents were not sure of the plants in their local pond, and stated: "(I am) aware, but not sure of plant type and unsure of their names", "not noticed" and "sorry I am not good at plants". Conversely, two responses stated that their pond was rich in flora with "A HUGE number of species, wildflowers, trees, ferns" and "loads of others (park setting)".

3.4. Value for Supporting Habitat

Before evaluating whether habitat benefits will offset CAPEX and OPEX costs for SUDS ponds, it is important to consider each benefit individually. An additional part of the analysis was to present the findings of the Contingent Valuation analysis in relation to the number of residents within a 500 m radius of the pond, which is approximately a 5 min walk from their home and aligns with a previous amenity study for ponds [16].

The values for Willingness to Pay (per person) for habitat benefits are highlighted in Table 2. For SUDS ponds, Granton has the lowest value with £2.58 (n = 19) on a monthly basis per person, and Eliburn has the highest value of £25 per person (but is disproportionate due to a small sample size, n = 2). Oxgangs has the second highest valuation of £14.48 per person (n = 23). The Royal Botanic gardens pond has a value of £15 (n = 21), and Blackford has a value of £12.21 (n = 78). Blackford has a rich biodiversity of plants (sedges, purple loosestrife, reeds and rushes, and a variety of small flowering plants) and fauna (water birds, water bugs and larvae, small fish and amphibians). Goreglen had the lowest valuation for the ponds with natural origins with a value of £9.23 (n = 22) per person.

Pond characteristics may influence the perceived value from the residents living within a close proximity. For example, Granton pond is located in a park which is further from housing than Blackford pond. Goreglen pond is located in woodland which is further from housing than other survey sites chosen for this analysis. In addition to this, the woodland pond has a covering of duckweed and poor diversity—no water birds and very few species of invertebrates.

Table 2. Habitat benefits according to the residents in the survey: where the monthly total value is divided by the number living near each pond (SUDS = Granton, Juniper Green, Oxgangs and Eliburn). Total n = 233.

Pond Name	Supports Plants (£)	Supports Mammals (£)	Supports fish (£)	Creates Habitat for Birds (£)	Supports Invertebrates (£)	Total (£)
Granton (n = 19)	0.53	0.53	0.53	0.58	0.42	2.58
Juniper Green (n =22)	1.09	1.09	1.32	1.09	1.09	5.68
Oxgangs (n = 23)	2.87	2.78	2.96	2.96	2.91	14.48
Eliburn (n = 2)	5.50	3.00	3.00	5.50	7.50	24.50
Blackford (n = 78)	2.40	2.47	2.53	3.03	2.09	12.51
Goreglen (n = 22)	1.73	1.86	1.91	2.00	1.73	9.23
Royal Botanic (n = 21)	3.71	2.76	2.71	3.48	2.33	15.00
Inverleith (n = 45)	2.40	2.33	2.42	2.64	2.47	12.27
Totals (£):	20.23	16.82	17.38	21.28	20.54	96.25

In relation to SIMD, Oxgangs has the highest level of housing deprivation (1) compared with Blackford and Inverleith with a decile score of 8 or 9 [30] (Table 1).

Table 3 outlines the number of households, and the total population, within a 500 m radius from each pond. Some surveys had lower populations, for example the postcodes near the ponds in Livingston and Goreglen. Granton pond and Oxgangs ponds are located near high density residential areas, with flats and semi-detached houses. Oxgangs has the highest contingent valuation, in relation to the total population, for SUDS and pond with natural origins with a monthly total of £54,966 (annual £659,593), and Granton has the lowest valuation for SUDS ponds with £5973 (annual £71,672). Goreglen has the lowest valuation for all ponds with a monthly total of £360 (£4320).

Table 3. Monthly and annual values (Willingness to Pay) for habitat benefits according to the number of residents in a household [20]. Where: Number of residents in households (total n = 13,077). Total value is calculated using the total benefits per person multiplied by the total population living within a 500 m radius of their local pond (Table 1).

Pond Name	Number of Households	Total Population	Monthly Value (£)	Annual Value (£)
Granton	1016	2315	£5973	£71,672
Juniper Green	606	1459	£8290	£99,475
Oxgangs	1840	3796	£54,966	£659,593
Eliburn	108	364	£8918	£107,016
Blackford	847	1988	£24,870	£298,439
Goreglen	14	39	£360	£4320
Royal Botanic	1161	2312	£34,680	£416,160
Inverleith	399	804	£9865	£118,380
Total	5991	13,077	£148,921	£1,775,055

3.5. Offsetting Replacement Costs

The capital costs (CAPEX) are calculated according to surface area and pond volume [27, 28]. In addition to capital costs, maintenance costs (OPEX) were calculated for each pond using the recommended 3.5%, followed by 20 years at 3%, discount when calculating Net Present Value (NPV) for projects with a life of 30–50 years. Table 4 highlights that benefits outweigh the costs for Juniper Green, Oxgangs, and Eliburn. The calculated costs at Granton pond outweigh the benefits due to the size of the pond catchment and the same may be true for Inverleith—as both of the ponds have larger surface areas, and the value placed on habitat is lower in relation to the population. This may also be because the ponds are artificial and perhaps the presence of litter and pollution detracts from the value. Blackford and Royal Botanic Gardens ponds exceed the replacement cost for a new pond with a similar surface area, but this is not the case for Goreglen. This may be because Goreglen is isolated and covered in duckweed—which makes it less attractive to value—with a poor habitat.

Table 4. Capital and maintenance costs for ponds, calculated following the guidance (surface area and pond volume for treatment) from [27]. The Net Present Value (NPV) benefits refer to the total benefits over 50 years with a discount of 3.5% (30 years) then 3% (20 years) [28]. Maintenance costs (see Table A1) are calculated with a discount of 3.5%. The balance is calculated by subtracting the NPV maintenance and initial capital for the pond from the perceived NPV benefits.

Pond Name	NPV Benefits	NPV OPEX Costs	CAPEX Costs	Balance
Granton	£1,720,765	£1,619,712	£990,000	−£888,946
Juniper Green	£2,388,284	£52,988	£13,200	£2,322,086
Oxgangs	£15,836,096	£1,101,592	£668,167	£14,066,337
Eliburn	£2,569,335	£233,140	£115,156	£2,221,039
Blackford	£7,165,189	£1,966,033	£1,336,500	£3,862,656
Goreglen	£103,718	£92,315	£41,250	−£29,847
Royal Botanic Gardens	£9,991,540	£631,553	£376,200	£8,983,787
Inverleith	£2,842,172	£5,810,221	£3,593,205	−£6,561,254
Total	£42,617,101	£11,507,564	£7,133,678	£23,975,859
Per Population	£3,258.94	£879.99	£545.51	£1833.44

6. 4. Discussion

Detailed environmental assessments should be carried out within a multiple benefits context prior to planning and developing homes [8], as this would encourage developers and local authorities to work closer with ecologists and engineers to optimise the multiple benefits from ponds. This is important because of the increasing need to co-design housing developments.

1. Public Perception

Biodiversity is of high importance when considering the benefits of living within walking distance to a pond. This result is in line with previous studies where biodiversity benefits were of high regard from the public [10, 16]. The habitat potential is enhanced where a well-maintained pond is found; for example Juniper Green and Blackford ponds.

Safety is less of a concern now than in previous studies [16, 23] but as expected this remains a concern for those respondents with families (Figure 5). Insects, rodents and litter are the greatest perceived disadvantages, which is to be expected if poor maintenance takes place. Crime is another factor of concern to residents (especially vandalism). This issue may be magnified in sparsely populated [33] or less affluent areas with the increased chance of anti-social behaviour due to boredom or inadequate facilities. [34] The area near Goreglen pond has a decile score of 4 for multiple deprivation (Table 1) which could be attributed to the remote location making it difficult to access education and employment opportunities (with respective scores of 2 and 4). Crime for this area is less deprived, with a score of 9, which contrasts with other areas such as Granton and Oxgangs with a decile score of 1 for crime.

2. Valuation Discussion

Goreglen has the lowest monthly valuation per person for the reference ponds (£9.23), and Royal Botanic Gardens has the highest (£15). However, the SUDS ponds have values of up to £24.50 per person, which is similar to the results from a previous amenity study [16]—with the exception that Granton has a lower perceived value than suggested previously. This is, however, a true reflection of the high density areas in Granton and Oxgangs with council and privately owned flats; as accessibility to green spaces is limited in high density areas [8]. It may also be in relation to the SIMD, as Granton has a decile score of 2 for housing—which indicates deprivation from overcrowding or poor quality housing [30]. In addition to this, the latest SIMD revealed that the surrounding areas (within a 500 m radius) had low scores for crime and employment deprivation—which may suggest that this area has a high level of crime and many are unable to work or are unemployed.

Previous Contingent Valuation studies have lower reported estimates for Willingness to Pay (WTP) [16, 21]. One study [16] suggested that those with higher incomes are more likely to pay more for benefits relating to SUDS. However, they also acknowledge that lower income groups may be likely to pay more due to socio-economic factors; such as less deprived students living near the SUDS of concern, or retired residents with life time investments and savings. In this paper, the highest willingness to pay is from a more deprived area in terms of housing, income, and employment; which may be subjected to some criticism from associated bias, for example valuing the habitat benefits at a higher value than they can reasonably afford [13,15]. Table 1 revealed that Oxgangs and Granton have the lowest decile score in terms of deprivation; as the deprivation is ranked 1 to 10 (where 1 is the lowest possible score) which suggests there may be some respondent bias [13] at Oxgangs pond. The respondent bias could be in relation to perception of wealth or forecasted estimates of affordability [21]. However, in the case of [21], this was discussed in relation to the demography of the community within Hong Kong, with a densely-populated city, whereas Edinburgh is smaller and is surrounded by blue green infrastructure. Furthermore, the willingness to pay for habitat benefits could be in relation to the perception that living within walking distance to a pond, and nearby green areas, provides better social conditions (for example health benefits, [8]). This supports previous work (e.g., [11,16]) where biodiversity was favoured at well-maintained ponds, and provision of suitable open space is part of this argument.

From whole life cost (NPV) calculations of benefits and costs (Table 4), it is apparent that the communities of Juniper Green and Oxgangs appreciate living close to a pond. The benefits outweigh the costs for these ponds, and it should be noted that Oxgangs has the highest perceived benefits during the project life (50 years) with a total of £15,836,096. For the Royal Botanic Gardens pond, the total benefits (£9,991,540) acquired over a 50 year time-scale would exceed the initial outlay for a pond of a similar size. Values are calculated assuming that these ponds may need to be replaced in the future or adapted to suit current legislative requirements (WFD, [2]), without compromising on the ecology and natural functionality of the ponds. However, as stated previously, there are uncertainties with the data, as a true value from contingent valuation is difficult to estimate [13,15]. Furthermore, using whole life cost is difficult if (up to date) maintenance data are not available [9,10,26], and if ponds are not perceived as well-maintained by the public. Future studies may implement BeST (Company, City, State, Country) which has the potential to override some of the issues relating to uncertainty—as over stated values [15], and protest zeros [13] reduce the reliability of assessing multiple benefits in an economic context. Despite, the limitations of the approach, the data could be beneficial for the future design of SUDS ponds, and if new ponds are formed to replace or restore former natural ponds.

7. 5. Conclusions

Ponds offer multiple benefits and from the results of this paper, it is possible to draw the following conclusions with reference to the key questions: 1. What is the public perception of the potential benefits, and disadvantages of living near a pond?; 2. How much value is placed on supporting habitat at their local pond (Willingness to Pay for habitat provision benefits), and are these values capable of offsetting costs?

Public perceived biodiversity, an area for walking pets and being close to parks (green spaces) are three benefits of living within a close (walking) distance to a pond. This is similar to other studies where biodiversity was an important component of SUDS ponds [10,16], and of natural ponds [16], and was regarded as being of high importance to the public. The disadvantages of living next to a pond include insects, rodents, and litter. Whilst biodiversity is cited as the greatest advantage to living within walking distance to a pond, some of the public perceive insects as being a disadvantage too—for example, midges and wasps in summer months may be nuisances. Safety is still regarded as important but is less of a concern than previously considered [16,23].

Pond benefits for three of the five artificial ponds (Oxgangs, Eliburn, and Juniper Green) exceed the construction and maintenance costs. However, the Eliburn sample (n = 2) is too small to determine how accurate this result is. For Oxgangs and Juniper Green, it is evident that the communities appreciate their local pond (typically for those living within a short walking distance). Oxgangs has more deprivation in terms of employment than at Juniper Green. Although the community is deprived, they seem to value nature and the multiple benefits of the pond. However, there is recognition that the values may be skewed. The pond at Juniper Green is valued highly by the population living there, as the pond provides amenity for home owners overlooking the pond.

In terms of natural ponds, with the exception of Goreglen, the benefits outweighed the replacement costs for a pond of a similar size. The pond at Goreglen is isolated in a forest and covered in duckweed which reduces the value placed of this pond. Blackford and the Royal Botanic Gardens have higher perceived monetary value which is due to the aesthetics and setting of these ponds, as both are set in managed environments with an abundance of wildlife and wildflowers in the surrounding gardens. Furthermore, both of these areas have high decile scores for employment and education, which could influence their willingness to pay for habitat benefits. Moving forward, the recommendation of this paper is that maintenance data for SUDS ponds should be made available for planning purposes (prior to development) and for monitoring the multiple benefits provided by ponds, thereby enabling a better assessment of whole life costs.

Supplementary Materials: The following are available online at www.mdpi.com/link. Attached in an excel spreadsheet. Further details may be provided through email communication.

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Conflicts of Interest: The authors declare no conflict of interest.

8. Appendix A

Table A1. Outlining costs for Whole Life Cost (WLC) analysis (based on UK Water Industry Research {UKWIR) 2005 & cited in [16, 27]). Costs are grouped together for barrier vegetation, aquatic vegetation and Desilting (which includes silt mobilisation and removal) OPEX outlines the total cost for operation and maintenance during the project life (50 years).

Pond	Inspection	Litter/Debris	Grass	Barrier Vegetation	Aquatic Vegetation	Desilting	OPEX
Juniper	£7203	£219	£0	£3284	£14,871	£27,421	£52,998
Granton	£7203	£10,948	£21,320	£164,221	£743,556	£672,464	£1,619,712
Eliburn	£7203	£1528	£2976	£22,912	£103,773	£94,749	£233,140
Oxgangs	£7203	£7389	£14,389	£110,835	£501,839	£459,938	£1,101,592
Inverleith	£7203	£39,736	£77,381	£596,039	£2,698,337	£2,391,526	£5,810,221
Blackford	£7203	£12,316	£23,985	£184,748	£836,501	£901,280	£1,966,033
Goreglen	£7203	£456	£888	£6843	£282,551	£267,133	£565,074
Royal Botanics	£7203	£4160	£8102	£62,404	£30,982	£45,944	£158,794

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A field approach for comparing the Ecosystem Services from SUDS and non-SUDS Ponds: preliminary results

J.A.JARVIE[(1)], DR S.ARTHUR[(1)] & DR L.BEEVERS[(1)]

[(1)] Heriot Watt University 1 , Edinburgh, United Kingdom,
jaj31@hw.ac.uk

ABSTRACT

Sustainable Urban Drainage systems (SUDS) are engineering solutions with the intention to mimic natural systems. SUDS were introduced to Scotland in the early 1990s with the establishment of the Forth Purification Board, latterly known as SEPA, in 1994. Their design is based on the SUDS triangle which incorporates water quality, water quantity, and amenity drivers. Until recently, the main focus was diffuse pollution and how SUDS offered a unique opportunity for pollutant removal from urban and peri-urban water courses. Climate change has increased the awareness for SUDS in terms of the benefits for pluvial flood risk management. Very little, however, has been done to quantify the benefits from SUDS in terms of the three main pillars of sustainability: social, economic and environmental factors. The often overlooked component of the SUDS triangle is the amenity component, especially with respect to habitat. It is therefore the focus of this paper to make the connection between aquatic habitats (ponds and wetlands) and the amenity and biodiversity functions offered. Habitat is fundamentally important to SUDS and assessment of Ecosystem Services. Ecosystem Services refer to the end user benefits obtained from the environment. Very few studies, to date, assess the Ecosystem Services from SUDS- although attempts have been made from the social science studies in terms of conceptualising SUDS and Ecosystem Services (Lundy and Wade, 2011; Scholz and Uzomah, 2013) none have assigned a monetary value to these services. The main focus of this paper, therefore, is to highlight the importance of Ecosystem Services as part of the valuing process in SUDS. It will align well established techniques in hydro-ecology with monetary valuation using Contingent Valuation Methods (CVM). Methods and some preliminary results will be presented, as well as the key lessons discovered during the experimental and field season phases. It is hoped that the study will allow for inter site comparisons to inform the environmental management and planning decisions- as well as providing a benchmark for future studies.

Keywords: SUDS, Ponds, Ecology, Management, Ecosystem Services

2. INTRODUCTION

2.1 Sustainable Urban Drainage (SUDS)

Sustainable Urban Drainage Systems (SUDS) are engineering solutions which mimic natural systems. Their design is based on the SUDS triangle which incorporates water quality, water quantity and amenity drivers (CIRIA, 2007; 2013).

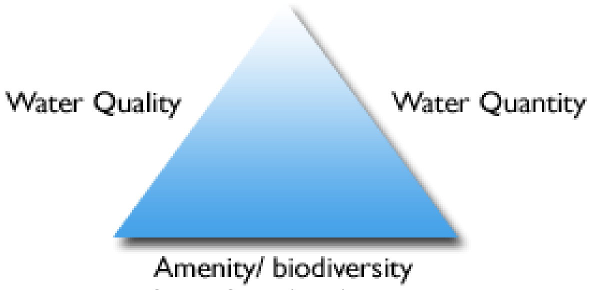

Figure 1: SUDS Triangle, after D'Arcy 1998, Source SEPA (2013)

Until recently, the main focus of SUDS research was diffuse pollution (D'Arcy and Frost, 2001; Duffy *et al.,* 2013) and how SUDS offered a unique opportunity for pollutant removal from urban and peri-urban water courses- via the treatment train (Jefferies *et al.,* 2009). Climate change has also increased the awareness for SUDS in terms of the benefits for pluvial flood risk management; following the Pitt Review in 2007. Very little, however, has been done to quantify the benefits from SUDS in terms of the three main pillars of sustainability: social, economic and environmental factors (Ashley *et al.,* 2013). A feasible option is to consider these features in the context of Ecosystem Services. Ecosystem Services is a relatively new notion in the context of SUDS, and refers to the multiple benefits- typically the end user benefits. The aim of the paper is to place SUDS into an Ecosystem Assessment framework and suggest that it is possible to test the wider benefits.

2.2 Ecosystem Services

Costanza *et al.,* (1997) discuss the importance of nature and placing a value on 'services', The term Ecosystem Services refers to the benefits that the environment provides- in terms of social, cultural, economic and environmental benefits. Provisioning services refer to the products derived from ecosystems, for example freshwater supplies provide fish and meat (Lundy and Wade, 2011). Regulating services relate to the benefits derived from regulating ecosystem processes, and an example of this is flowering plants for pollination (Liss *et al.,* 2013). Supporting services are critical for successful operation of other services. Cultural services refer to the products with no material benefit, and should thus be quantified in non-monetary terms (Bateman *et al.,* 2011).

2.3 Ecosystem Services in terms of SUDS

Ecosystem Services refer to the end user benefits obtained from the environment under scrutiny (MA, 2005). In the context of this paper, however, the Ecosystem Assessment will refer to the interpretation of the wider benefits from SUDS and Non-SUDS Ponds. This section will focus on the Ecosystem Services provided by SUDS ponds in terms of: provisioning, regulating, supporting and cultural services. Figure 2 illustrates the available Ecosystem Services from SUDS. Some of these services are less viable than others to quantify in a wider assessment, but the main services of importance to SUDS are supporting, regulating and cultural based.

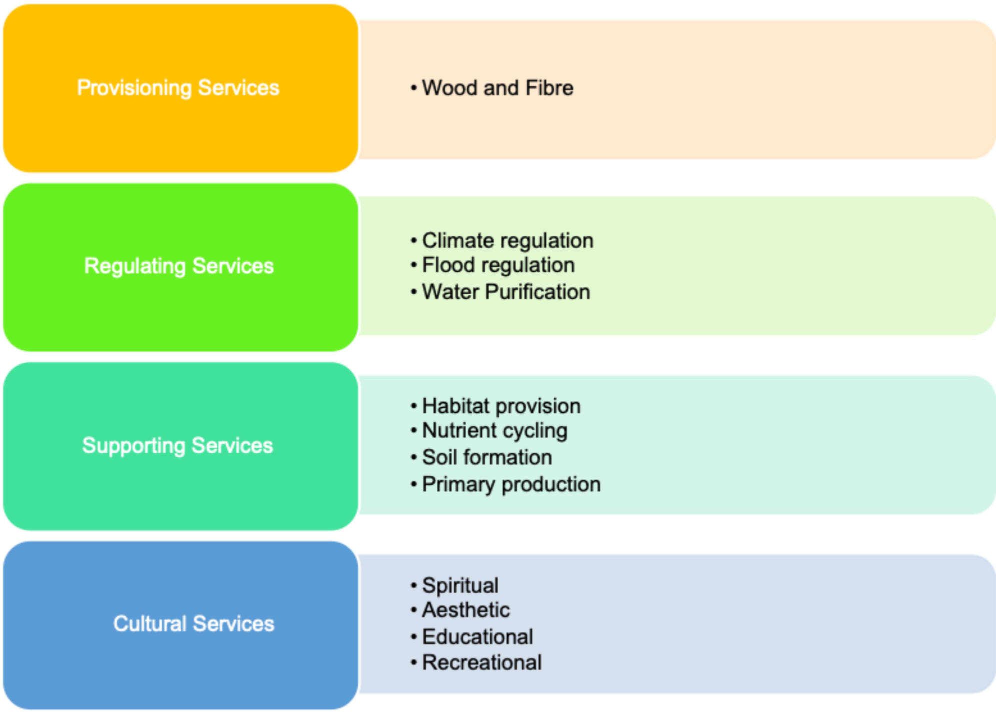

Figure 2: Summary of the key Ecosystem Services associated with SUDS

It is important to highlight the main services associated with SUDS, and why these are relevant to the proposed framework in this paper.

Cultural services are important as these underpin the social aspects of Ecosystem Assessment- in terms of providing some qualitative information and public opinion with respect to key issues in management. Previous studies in SUDS and Ecosystem Services focus on the social science aspects and provide an overview of the available Ecosystem Services (e.g. Wade *et al.,* 2012) without suggesting standardised methods for their framework. Some of their Ecosystem Assessment centres on the ability to place SUDS in a meaningful, and manageable, context; rather than underpinning the key variables needed to provide a useful and worthwhile assessment. However, a recent contribution assessing the value of public opinion for SUDS with respect to retrofitting permeable paving systems includes habitat provision in their Ecosystem Services variables. The key gap in review of recent contributions to SUDS and Ecosystem Services literature includes quantifying the habitat; especially with consideration to provision and suitability of habitat. Furthermore, the aspects of nutrient cycling and flood regulation, within the context of Ecosystem Assessment, have not been considered.

2.4 Ecosystem Services for SUDS Ponds

In the context of the paper, it is important to introduce the main Ecosystem Services for ponds (Figure 3) according to the Millennium Ecosystem Assessment. By doing this, it will provide some insight into the justification for the project framework chosen- as well as illuminating the key services found in SUDS ponds. Figure 3 also highlights where in the pond environment these services occur; as well as the processes involved. Furthermore, this will be applicable to the preliminary results within the paper.

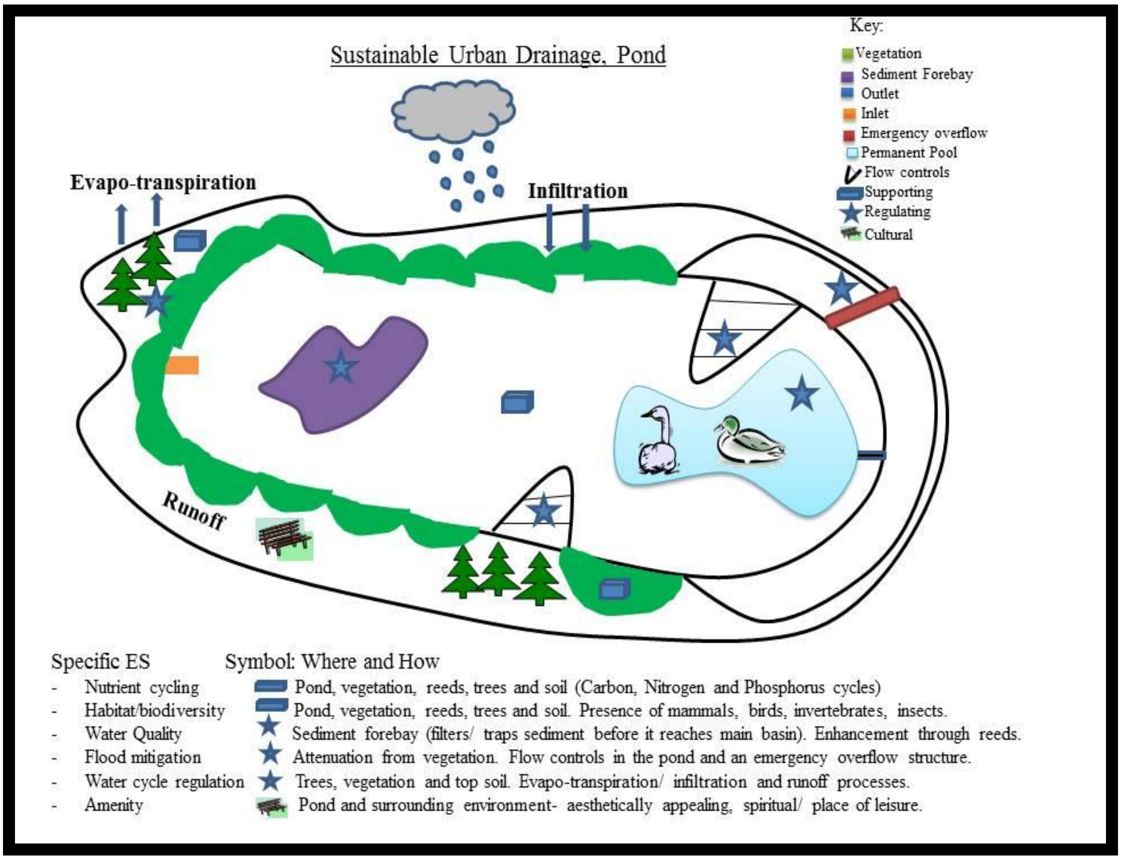

Figure 3: Summary of the key Ecosystem Services associated with a SUDS Pond

3. PROJECT FRAMEWORK

The project framework will outline the key variables needed to provide a suitable assessment for the Ecosystem Services of SUDS features (Table 1). The purpose of Table 1 is to highlight the suggested methods, hypotheses and the relation of those hypotheses to Ecosystem Services. The framework builds on existing frameworks (Lundy and Wade, 2011; Scholz and Uzomah, 2013) which conceptualise SUDS and Ecosystem Services; none have placed a monetary value on these services. The framework combines Ecosystem Services and SUDS with the hope to fill these key gaps.

This will facilitate the understanding of the contribution SUDS features make to the sustainability agenda. The three underpinning pillars of sustainability: social, economic, and environmental factors are considered.

Table 1 Project framework comparing SUDS and Non-SUDS Ponds

Possible Ecosystem Services	**Natural or man made Ponds**			**SUDS Ponds**			**Ecosystem Services that will**			**Expected results/ observations** ***Hypotheses***	**How to measure those Ecosystem Services** ***Suggested Methods***	**How it relates to Ecosystem Services** ***Relationships***
Category of Ecosystem Service	Yes	Maybe	No	Yes	Maybe	No	Yes	Maybe	No			
Cultural												
Spiritual	☺				😐				☹			
Aesthetic	☺			☺			☺			People will be more willing to pay for services associated with natural looking ponds	Contingent Valuation responses and house price data	Placing a monetary value on cultural services of ponds- aesthetic appeal
Educational	☺			☺			☺			Lower socio-economic groups are less likely to value the education benefits of the ponds	Contingent Valuation responses and Census data	Placing a monetary value on cultural services of ponds- educational provision and resources
Recreational	☺				😐		☺			Recreation services will be favoured by the younger demographic (16-25)	Contingent Valuation responses and visual observation of use	Placing a monetary value on cultural services of ponds
Regulating												
Climate Regulation		😐			😐				☹			
Flood Regulation			☹	☺				😐		Well maintained ponds provide better opportunities for habitat but not for flood protection benefits	Hydrology loggers- look at water levels and compare with insitu depth measurements	Water level will be linked to flood benefits and can inform of regulations
WaterPurification			☹	☺					☹			
Supporting												
Nutrient Cycling	☺			☺			☺			Ponds with higher eutrophic values (high Nitrogen and Phosphorus) will have less benefits for habitat provision	Inferences will be made from physiology of plants in terms of Nitrogen and Phosphorus properties	Nitrogen and phosphorus links with vegetation and habitat provision
Soil Formation					😐				☹			
Primary Production	☺			☺					☹			
Habitat Provision	☺			☺			☺			1) Natural ponds will have better biological quality and are likely to have more communities of macro-invertebrates. 2) Vegetation at SUDS Ponds will be less diverse than the natural ponds. 3)Sediment will be finer with distance from the inlet of the pond, and habitat will be richer.	1) Sweep sampling (BS EN 10870,2012), Identification of macro-invertebrates to family level (BMWP/ ASPT) 2)Vegetation surveys- look at seasonal change in riparian and in stream vegetation. 3) Mapping spatial distribution of sediment and vegetation across the pond (using field maps, GPS, and GIS and possibly remote sensing techniques)	Higher ASPT scores indicate better habitat. More diverse vegetation is evidence of healthy ponds, and no invasive species is of importance.
Provisioning												
Food production						☹			☹			
Water						☹			☹			
Wood and Fibre					😐				☹			
Fuel						☹			☹			

4. METHODS

The main methods will be highlighted with respect to British standards (where applicable). Methods are expanded from Table 1, and refer to the key Ecosystem Services highlighted in the framework.

4.1 Habitat Provision services

Habitat provision services have not been quantified in previous studies in relation to SUDS Ponds; thus, it is the intention of this project to gather monthly vegetation and macro-invertebrate data with a view to fill this important gap in knowledge. Furthermore, as the framework (Table 1) indicates there is novelty in comparing SUDS and Non-SUDS ponds to assess the differences in habitat provision. In terms of wider Ecosystem Assessment, standard methods allow the habitat provision to be assessed fairly and without compromising results. The nature of the methods for this form of Ecosystem Assessment includes:

- Sweep samples- covering open water and vegetated areas
- Vegetation transects and maps
- Sediment maps (samples of sediment type and detailed GPS coordinates)
- Turbidity and light measurements
- General pH, Electrical Conductivity, and Temperature readings along vegetation transects (near pond margin)

Sweep sampling and vegetation transects form the two main components of the ecology field work and will be discussed in detail.

3.1.1 Sweep Sampling

The standard approach is BS EN 10870:2012 and this refers to sweep sampling methods and other freshwater methods for still water. There are various steps involved in this method. One of the steps is bankside preparation and this involves ensuring the net is clean and free of debris from the previous sample site. Then sweeping begins where the net is swept through the surface of the water to catch surface. The substrate is gently agitated for the first minute, from a total of three minutes in the water, on the base of the pond- as this encourages benthic macro-invertebrates into the net. This compensates for the low or no flow conditions within the pond environment.
Sample points are chosen to capture micro-habitats (Pond Action, 1998; BS EN 10870, 2012).

The samples are then sorted and preserved. This involves using water (from the sample site) to wash the contents through the net, and then macro-invertebrates are stored in jars with ethanol (70%). Analysis of samples is undertaken using a high powered microscope and field identification guides (Croft, 1986). All species are then identified to family level and compared with ASPT (Average Score per Taxon) and BMWP (Biological Monitoring Working Party) scores. The former refers to the BMWP score divided by the number of families present. BMWP scores show the biological quality of the water and compare the macro-invertebrates to a matrix of pollution tolerance. Higher scores indicate better water and biological quality and lower scores indicate there may be a pollution incident.

3.1.2 Vegetation transects

Figure 4 summarises the approach taken to record vegetation in still water environments in relation to the standard method BS EN 15460:2007.

Step 1 Recording vegetation along 100m transects

- Tapes (2 x 50m) are set out along the margins of the pond to monitor changes in riparian and instream vegetation.
- Observations (and photographs) are taken at each 10m interval
- The percentage of species type is recorded- according to pictorial guides (e.g. Haslam *et al,* 2013)

Step 2 Assessing the % of floating, submerged and emergent vegetation

- Instream vegetation is monitored and recorded.
- Percentage of Emergent (e.g cattails or reeds)
- Percentage of Floating (e.g water lillies or duck weed)
- Percentage of submerged vegetation (e.g water weed)

Step 3 Comparing with DAFOR (abundance scale)

- DAFOR is an approved measure used to semi-quantify the plant species in a pond (BS EN 15460:2007)
- An abundance scale with assigned values based on percentages.
- Differs from flowing water techniques (e.g Clarke *et al.*, 2002)

Figure 4 Summary of methods to record vegetation in still water environments

4.2 Cultural Services

Cultural services will be assessed in relation to SUDS and Non-SUDS using Contingent Valuation methods.

3.2.1 Contingent valuation

Contingent valuation will be the main method applied to test the public perception of the Ecosystem Services provided by SUDS and Non-SUDS Ponds (Table 1). This method is sometimes scrutinized as being over used and inexact because it does not take market preferences into consideration (Bateman *et al.,* 2001**),** but it is well established and requires minimal economic expertise to carry out.

It is important to see whether perceptions change with respect to the age of ponds. Equally, it is important to assess the Ecosystem Services and see how much the respondents, to the surveys, are willing to pay for the same services in a different location. This component of the research project builds on existing where the amenity value of SUDS and wider benefits of ponds were tested (Bastien *et al.,* 2012). Some of the chosen survey sites (Table 2) were used in those particular studies, but it is useful to compare the findings with respect to Ecosystem Services and see whether a certain pond has changed (improved or deteriorated).

Table 2 Summary of surveys sites and observed use

Case Study	Setting of pond	Use of Pond
Blackford Pond, Edinburgh	Local Nature Reserve. Near housing in Morningside.	Walking nearby, view point from Blackford hill, feeding wild fowl.
Granton Pond, Edinburgh	In a park. Near a supermarket and college.	Drainage pond, feeding wild fowl, admiring green space
Juniper Green Pond, Edinburgh	At the foot of Woodhall Mill Brae flats. Near the Water of Leith footpath.	Drainage pond, focal point from flats.
Livingston x1 Livingston x2	Residential area Near light industrial units	Drainage pond (new build) Drainage pond
Inverleith Pond, Edinburgh	Park setting. Near residential area.	Model boat activities, recreation, and feeding wild fowl
Royal Botanic Gardens, Edinburgh	Former estate. Near residential area.	View point from houses, educational resource, and focal point of gardens.
Gorebridge (Goreglen), Mid Lothian	Local Nature Reserve. Woodland setting. Near main road.	No use currently.

5. PRELIMINARY RESULTS

Preliminary results for habitat provision at Granton Pond are presented (Figure 5a- 5f). These results cover July 2014 to January 2015. Unfortunately, there are no sampling data for January due to adverse weather conditions freezing the pond. The results will be followed by analysis by comparing the findings to existing literature studies for ponds.

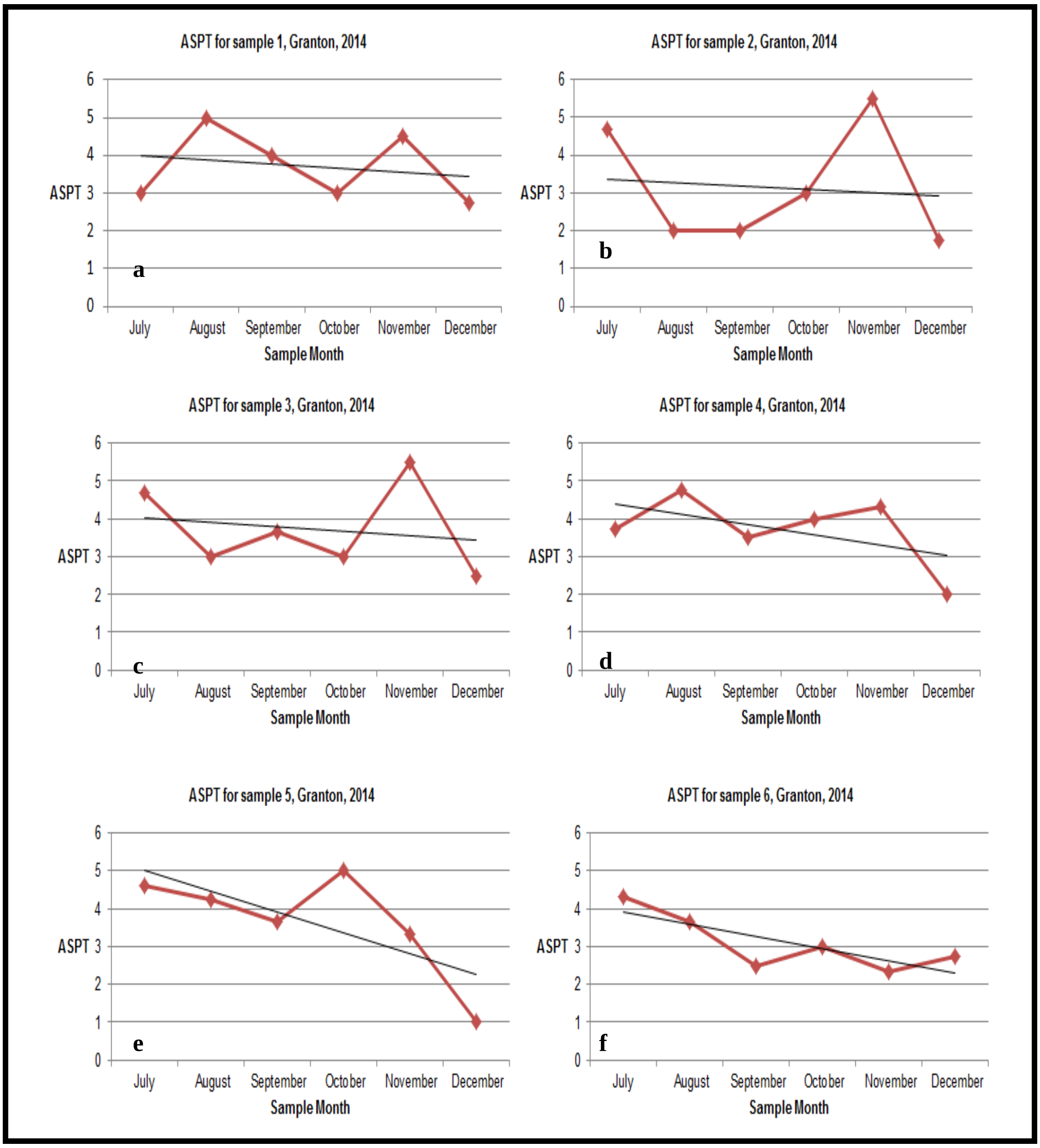

Figure 5a-f ASPT results for Granton, Macro-invertebrate samples 1-6

According to the fresh water guidance, the BMWP (biological method working party) scores reveal the biological quality of the water environment. Figure 5a-f highlight the ASPT (average score per taxon). More diversity provides higher scores- as it is calculated based on the number of families within the BMWP score. At Granton, the preliminary results indicate that July ASPT averages between 3 and 4.5 with 5 the highest recorded in November for sample 2 and 3. In these samples, water bugs and shrimp are found- but in previous months fewer families are discovered.

Table 3 Summary of macro-invertebrate families, found at Granton, and respective BMWP Scores

Latin name	**Common name**	**BMWP Score**	**What it means in terms of pollution tolerance**
Gammaridae	Shrimp	6	Less tolerant- pollution can cause damage
Notonectidae	Great water boatman	5	Moderately Tolerant
Gerridae	Skaters	5	Moderately tolerant
Corixidae	Lesser water boatman	5	Moderately tolerant
Simuliidae	Black flies	5	Moderately tolerant
Dytiscidae	Diving beetles	5	Moderately tolerant
Sialidae	Alder fly	4	Moderately tolerant
Lymnaeidae	Pond snails	3	Very Tolerant
Planorbidae	Ramshorn snails	3	Very Tolerant
Sphaeriidae	Small bivalve molluscs	3	Very tolerant
Hirudinidae	Leeches	3	Very Tolerant
Asellidae	Hog lice	3	Very tolerant
Chironomidae	Midges	2	Very tolerant
Oligochaeta	Worms	1	Very tolerant
Chaoboridae	Ghost larva- phantom midge	No score	Very tolerant

Table 3 summarises the macro-invertebrates discovered in Granton Pond. In terms of the BMWP score, the highest matrix score is 6 for the family of shrimp found in sample 1-6. The lowest score is worms with a score of 1, and in certain samples these are abundant- particularly in sample 6. Equally, at sample 6 backswimmers known as lesser water boatmen are found on the surface of the water in each sample month. Sample 1 is situated in vegetated debris and a miniature wetland is nearby. The samples from this site usually contain shrimp, and hog lice, but on one occasion a large diving beetle larva was found. In terms of pollution tolerance, eight families are very tolerant to organic pollution and are more likely to be found in poorer water quality ponds. Six families are moderately tolerant to impacted water and one family is less tolerant.

In terms of habitat provision, the preliminary results indicate that the biological quality of the pond varies from poor to very poor depending on the time of the year when the sampled was taken. This is apparent from the sparse findings in the literature where ponds are in a setting which may be subjected to potential pollution issues (table 4). Heal *et al*.,(2006) have the highest BMWP range with 24-37 which is the higher end of poor in terms of biological quality and therefore provides more habitat provision.

Table 4 Preliminary results from Granton compared with the literature

Study author(s)	Type of Pond	BMWP range	ASPT range	Case Study area
Sriyajarav and Shutes (2001)	Urban- constructed wetland/ pond	11-24	3-4	Turkey brook. Pond, London
Heal (2006)	SUDS	24-37	4-4.63	Cessnock, Ayrshire
Batty *et al.,* (2010)	Urban	5-25	2.5-6.5	Various in England
Noble and Hassall (2014)	Urban	None reported	2.3-4.3	Bradford
Preliminary results	SUDS	2-26	2-5	Granton Pond, Edinburgh

6. CONCLUSIONS

The Ecosystem Services approach offers an opportunity to optimise the multiple benefits of SUDS and thereby enhance the value of green space in urban areas. The SUDS Ecosystem Services framework outlined in this paper has been designed to be used flexibly in a way which takes account of uncertainty.
Preliminary results indicate that the SUDS pond tested is poor in terms of biological and water quality in most parts. This is only one of four SUDS ponds, however, so no firm conclusions can be made at this stage. Notwithstanding, undertaking Ecosystem Assessments for local ponds will be a useful exercise – particularly linking habitat provision and cultural based Ecosystem Services.
Future research will compare the habitat provision of SUDS and Non-SUDS Ponds, and provide a benchmark for other Ecosystem Assessments within ponds. Furthermore, the cultural Ecosystem Services will be assessed by using Contingent Valuation methods to place a monetary value on wider benefits of the ponds examined.

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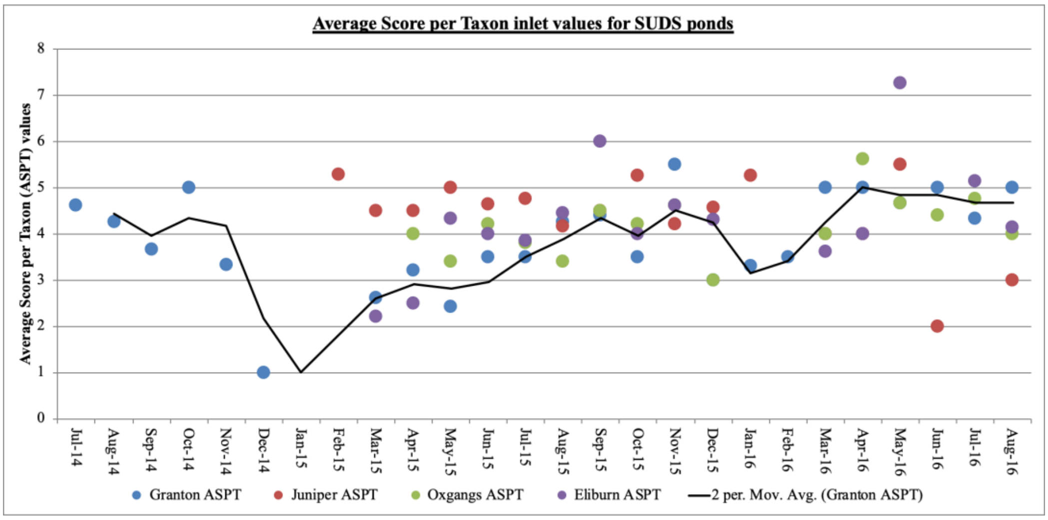
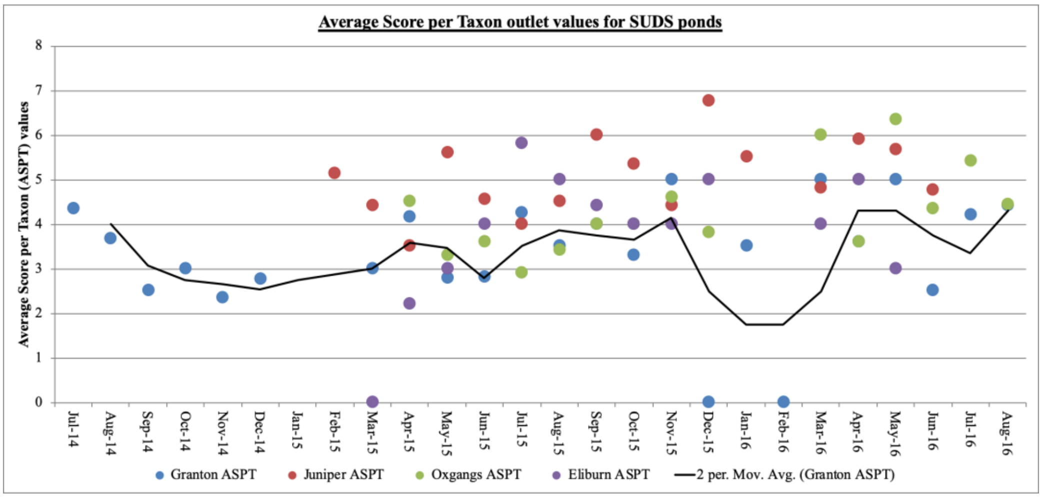
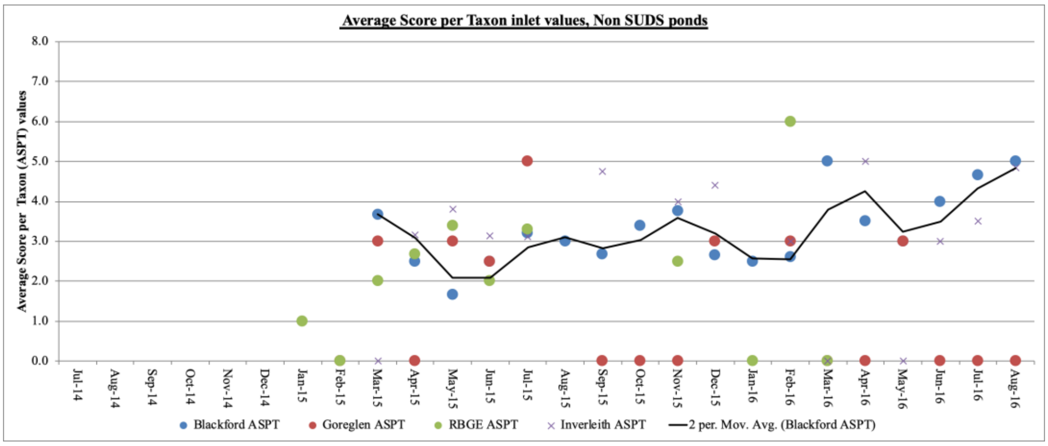
Chapter 4- Macroinvertebrates/ Water Quality measurements appendix

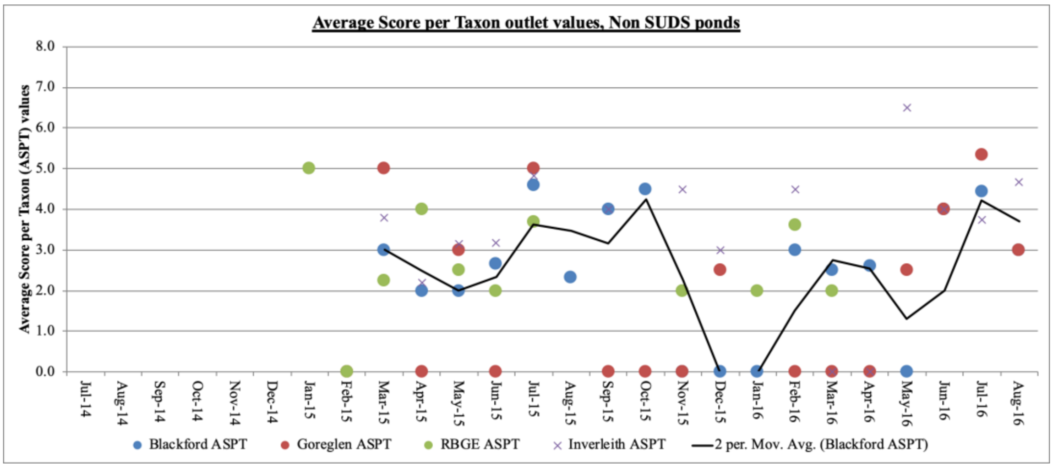
Appendix A.4: ASPT Graphs

A.4 1 ASPT SUDS and non SUDS ponds

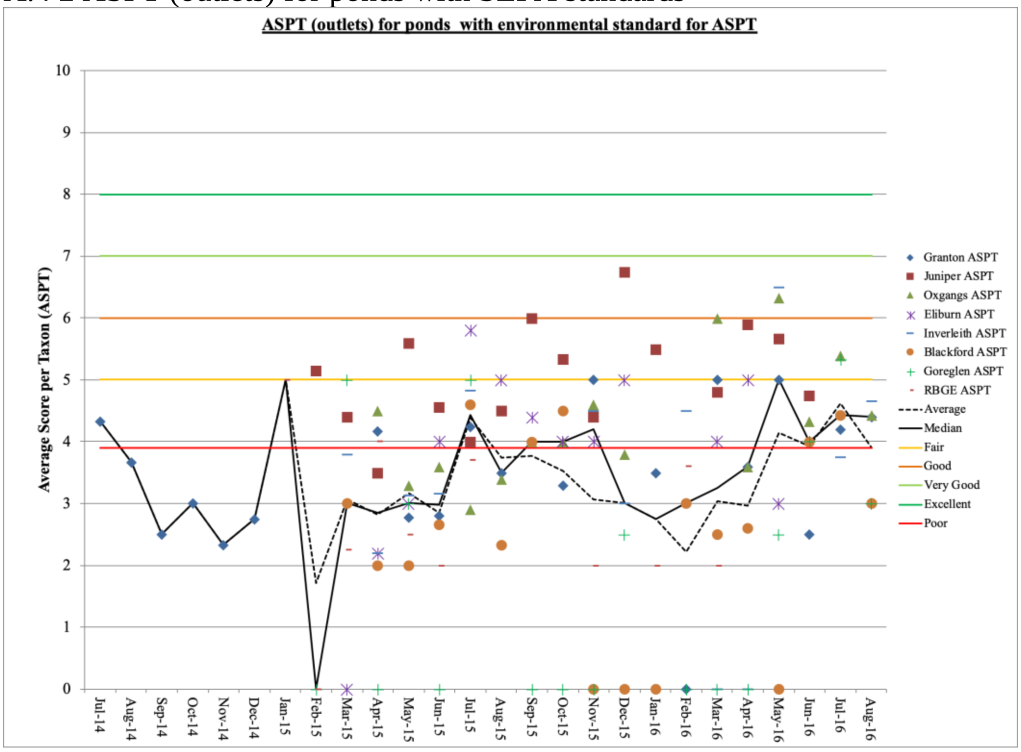




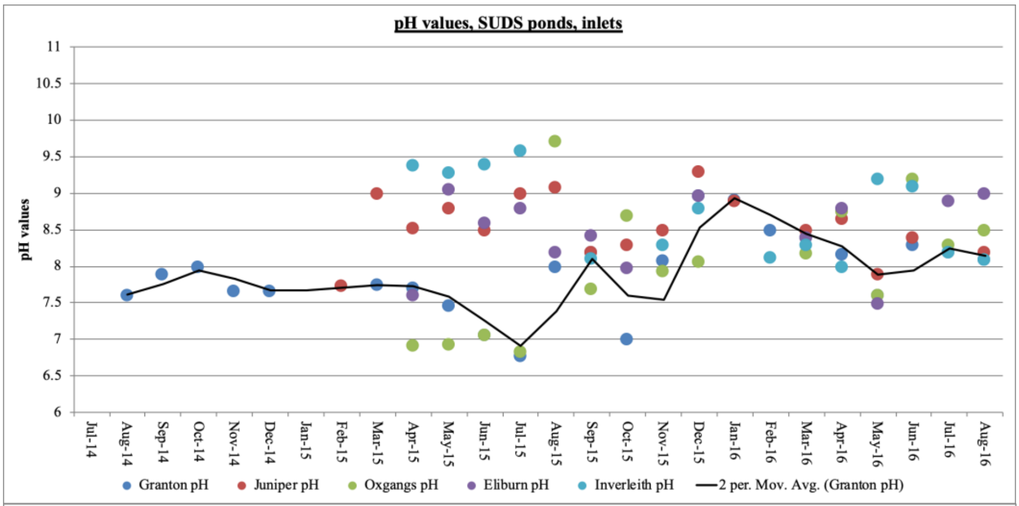


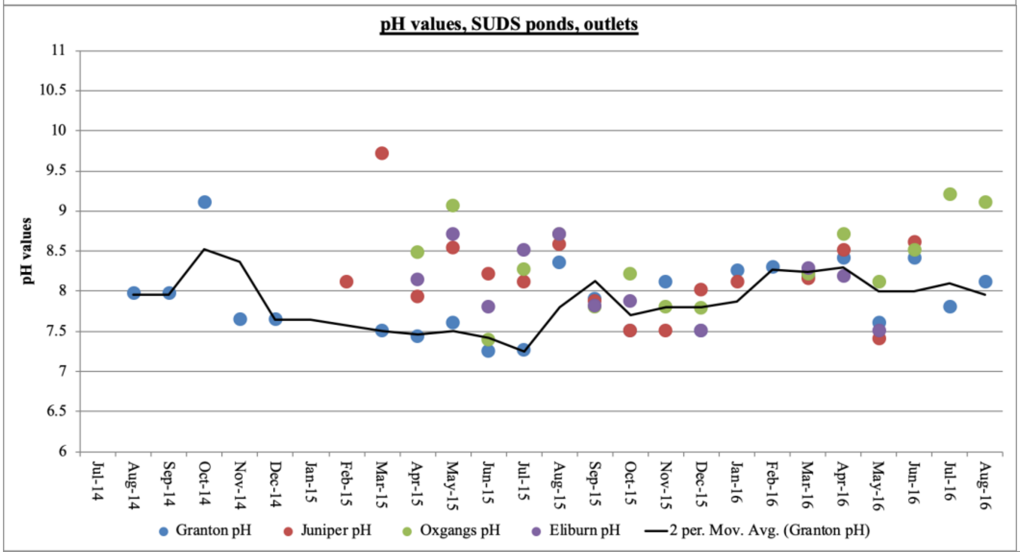


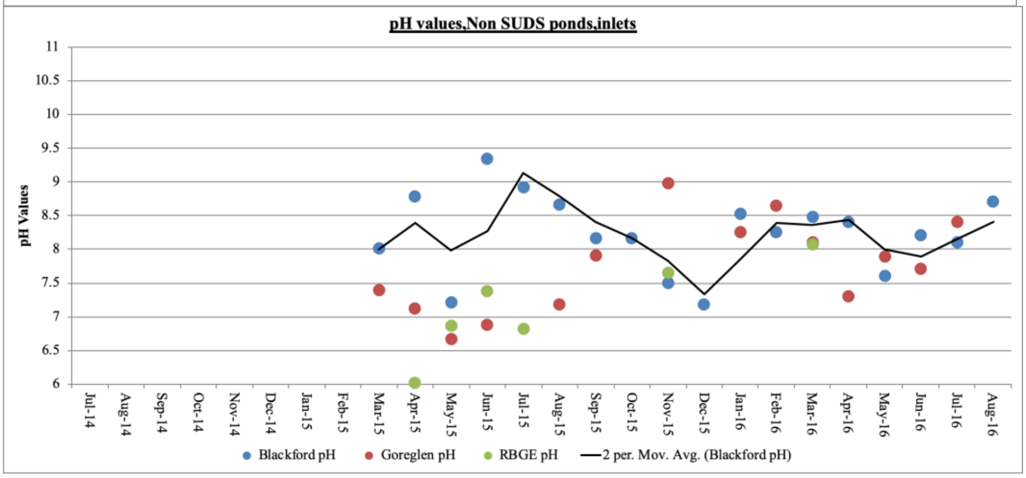
A.4 2 ASPT (outlets) for ponds with SEPA standards

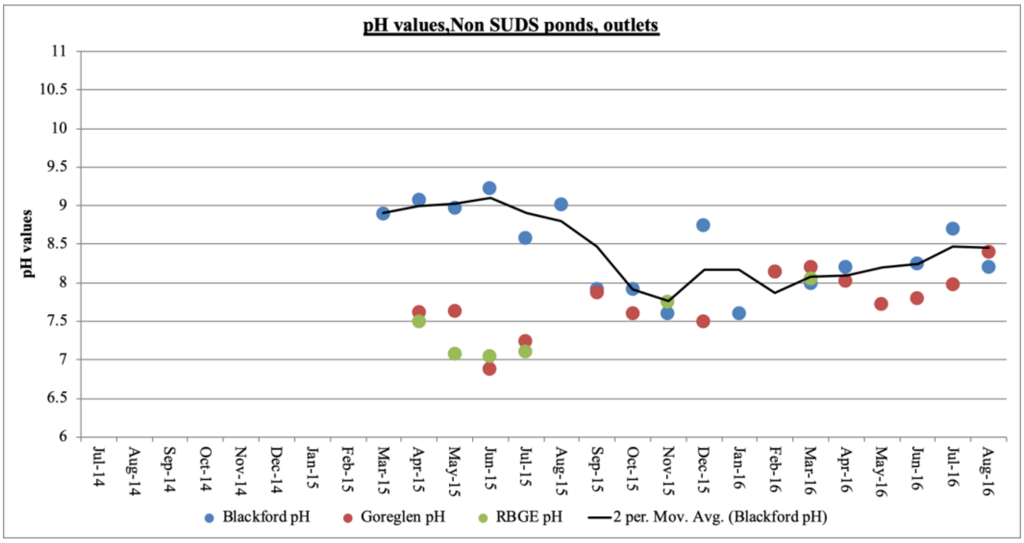


A.4 3 pH values: SUDS and non SUDS ponds

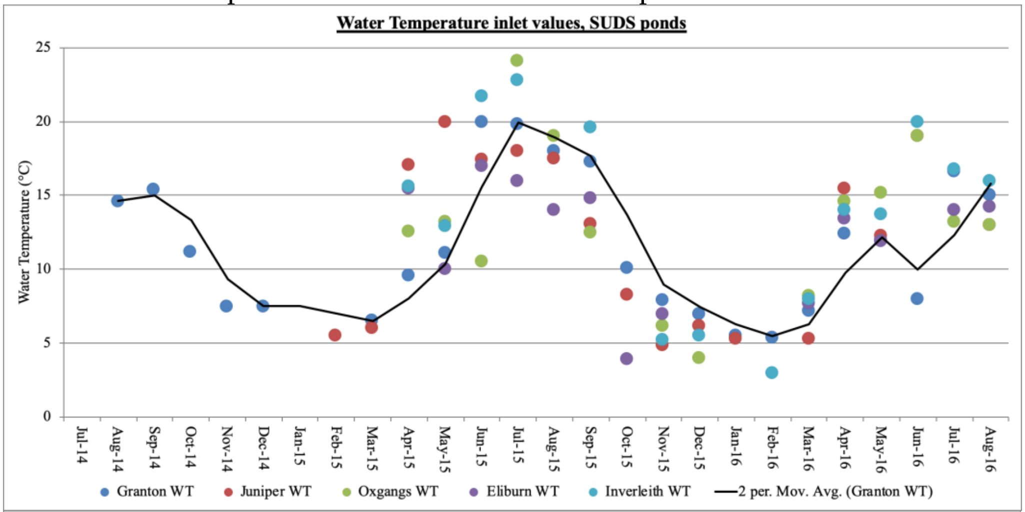


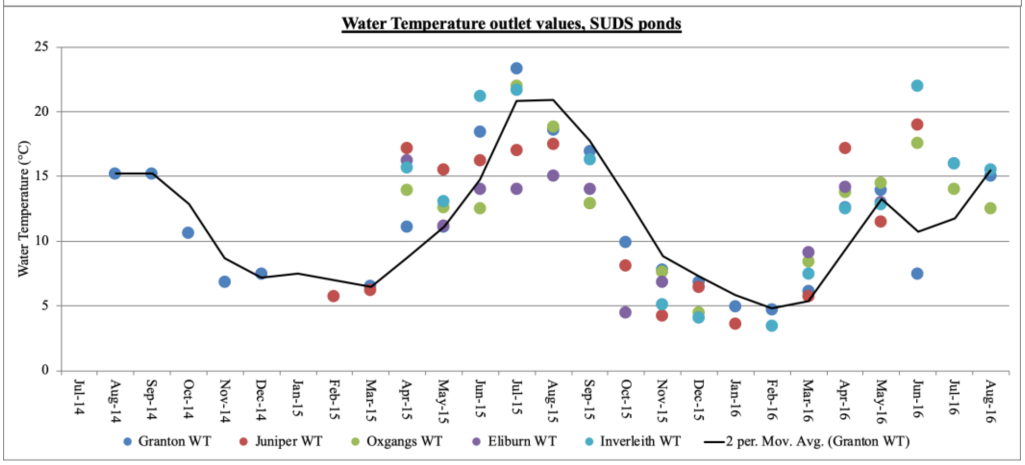


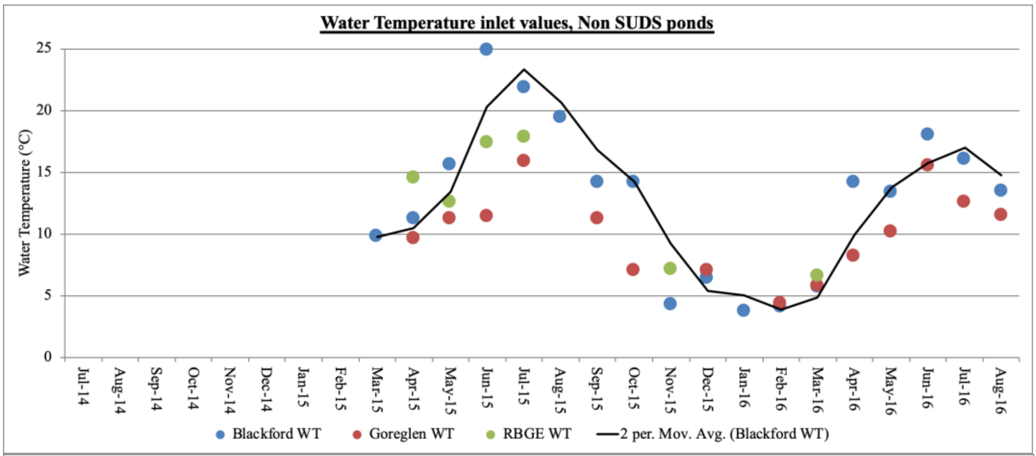


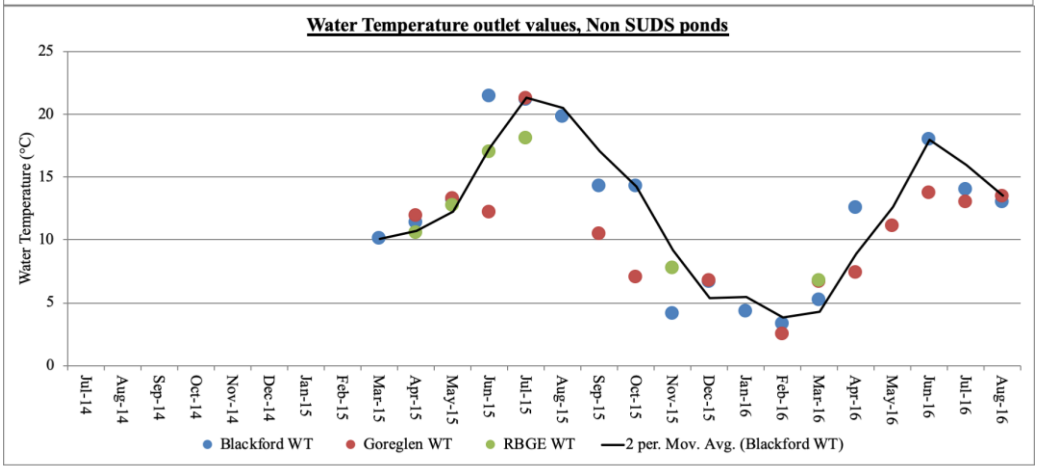


A.4 4 Water Temperature: SUDS and non SUDS ponds

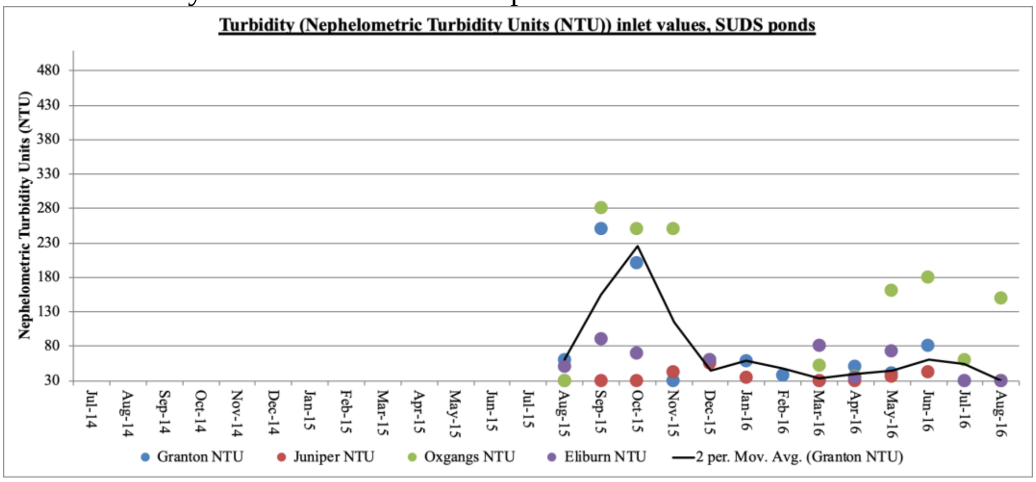




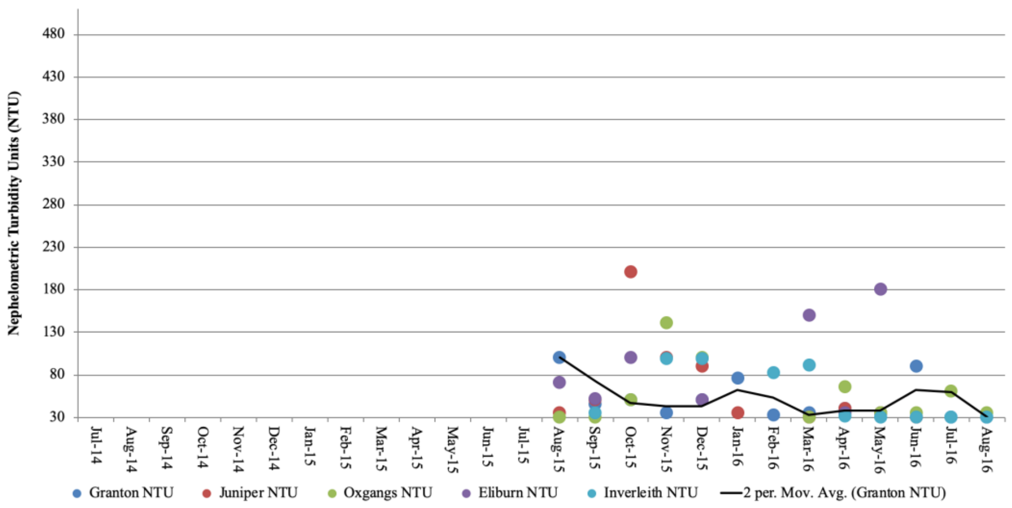




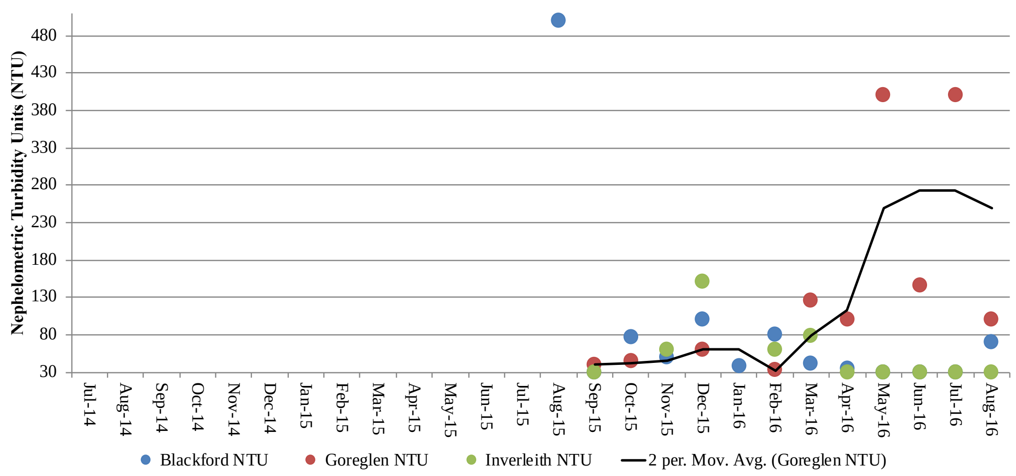
A.4 5 Turbidity: SUDS and non SUDS ponds



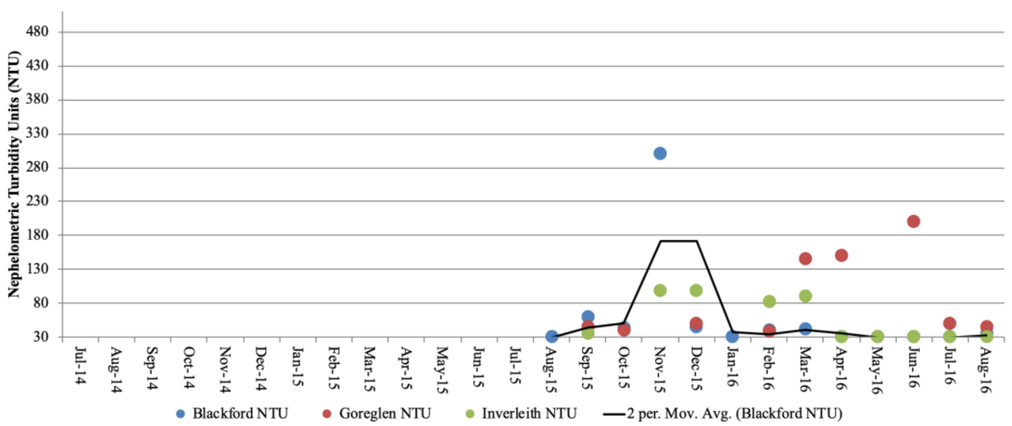
Turbidity (Nephelometric Turbidity Units (NTU)), outlet values, artificial ponds



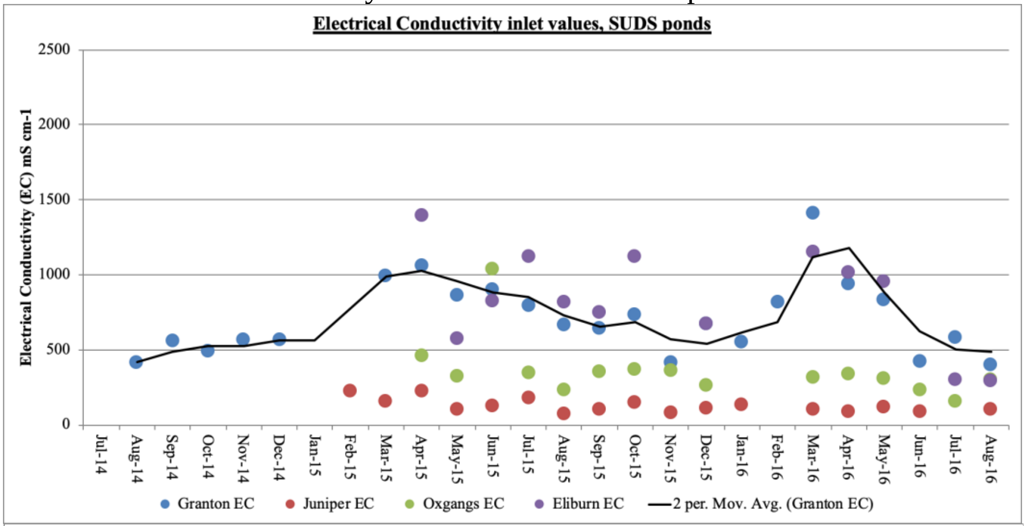
Turbidity (Nephelometric Turbidity Units (NTU)), inlet values, Non SUDS ponds

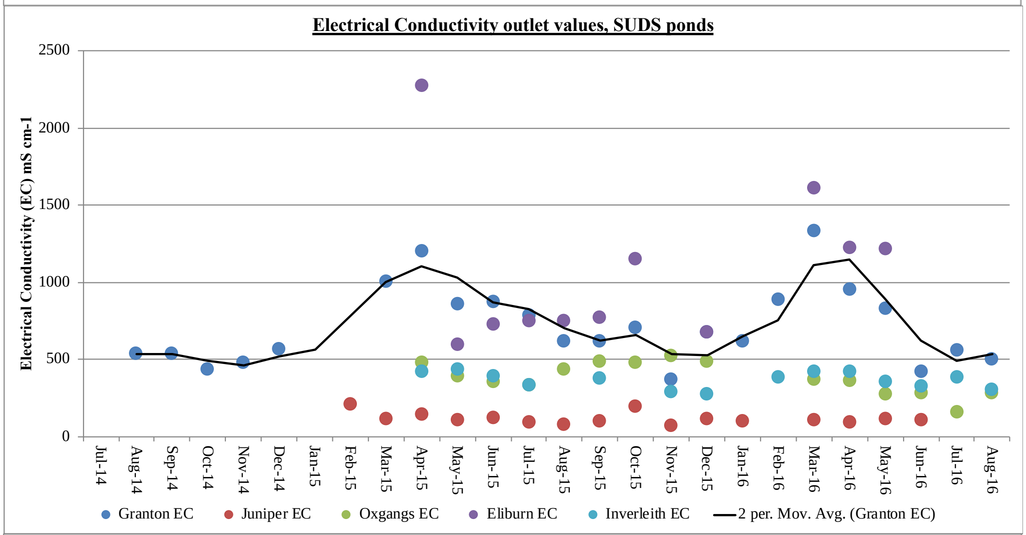


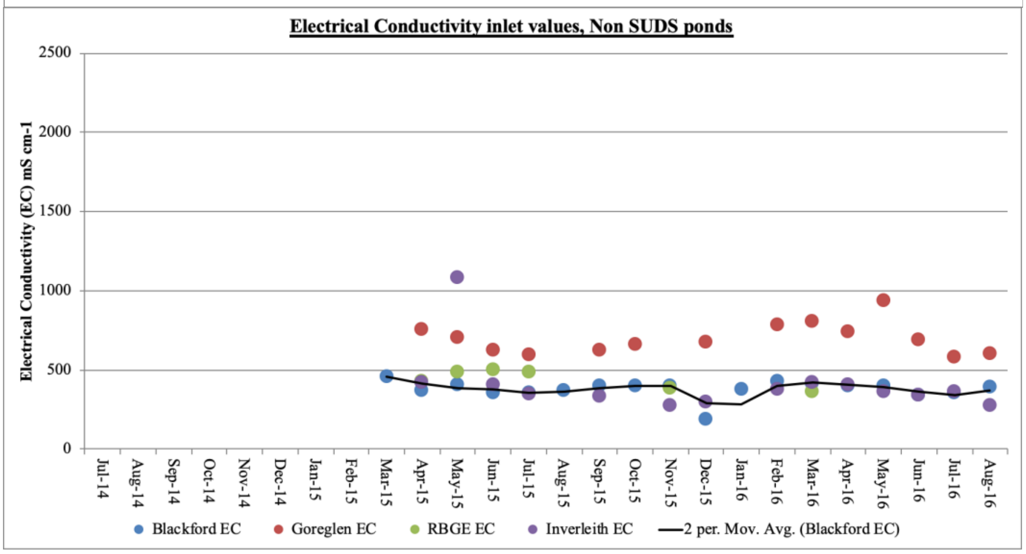
Turbidity (Nephelometric Turbidity Units (NTU)), outlet values, Non SUDS ponds

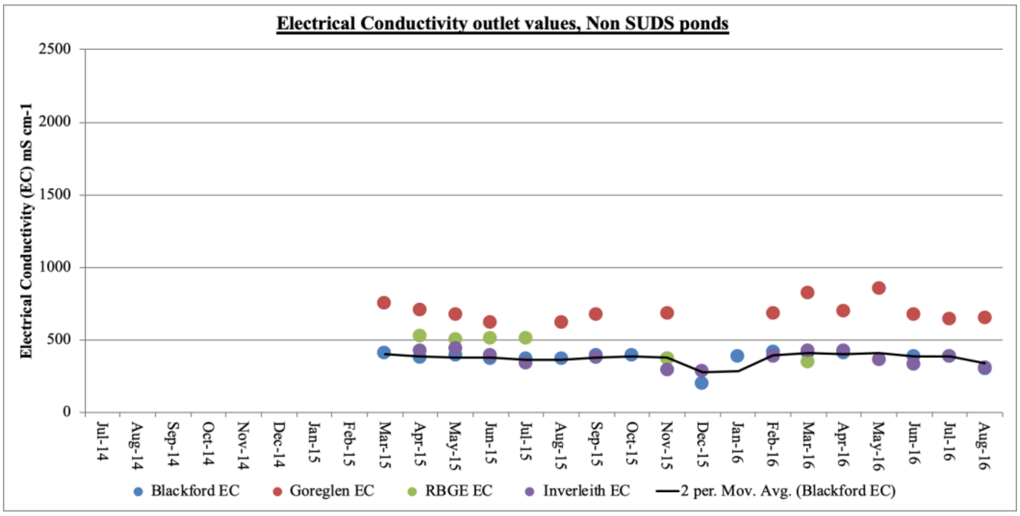


A.4 6 Electrical Conductivity: SUDS and non SUDS ponds









A.4 7 ASPT monthly mean values for each pond

Date	Granton ASPT	Juniper ASPT	Inverleith ASPT	Blackford ASPT	Goreglen ASPT	RBGE ASPT	Oxgangs ASPT	Eliburn ASPT	Average
Jul-14	4.3								4.3
Aug-14	3.7								3.7
Sep-14	2.5								2.5
Oct-14	3.0								3.0
Nov-14	2.3								2.3
Dec-14	2.8								2.8
Jan-15						5.0			5.0
Feb-15		5.1			0.0	0.0			1.7
Mar-15	3.0	4.4	3.8	3.0	5.0	2.3		0.0	3.1
Apr-15	4.2	3.5	2.2	2.0	0.0	4.0	4.5	2.2	2.8
May-15	2.8	5.6	3.1	2.0	3.0	2.5	3.3	3.0	3.2
Jun-15	2.8	4.6	3.2	2.7	0.0	2.0	3.6	4.0	2.8
Jul-15	4.3	4.0	4.8	4.6	5.0	3.7	2.9	5.8	4.4
Aug-15	3.5	4.5		2.3			3.4	5.0	3.7
Sep-15	4.0	6.0	4.0	4.0	0.0		4.0	4.4	3.8
Oct-15	3.3	5.3		4.5	0.0		4.0	4.0	3.5
Nov-15	5.0	4.4	4.5	0.0	0.0	2.0	4.6	4.0	3.1
Dec-15	0.0	6.8	3.0	0.0	2.5		3.8	5.0	3.0
Jan-16	3.5	5.5		0.0		2.0			2.8
Feb-16	0.0		4.5	3.0	0.0	3.6			2.2
Mar-16	5.0	4.8	0.0	2.5	0.0	2.0	6.0	4.0	3.0
Apr-16	3.6	5.9	0.0	2.6	0.0		3.6	5.0	3.0
May-16	5.0	5.7	6.5	0.0	2.5		6.3	3.0	4.1
Jun-16	2.5	4.8	4.0	4.0	4.0		4.3		3.9
Jul-16	4.2		3.8	4.4	5.3		5.4		4.6
Aug-16	4.4		4.7	3.0	3.0		4.4		3.9
Mean	3.3	5.0	3.5	2.5	1.8	2.6	4.3	3.8	3.3
median	3.5	5.0	3.8	2.6	0.0	2.3	4.0	4.0	3.1

A.4 8:DO% mean values, monthly observations

	Granton DO%	Juniper DO%	Eliburn DO%	Goreglen DO%	RBGE DO%	Blackford DO%	Oxgangs DO%	Inverleith DO%
Apr-15	89		71	35	101	100	57	163
May-15	27		93	27	123	70	58	105
Jun-15	34		51	9	62.5	226	44	138
Jul-15	33			10	127	112	36	173
Aug-15			42					
Sep-15	75		18	10		23	15	55
Oct-15	25	70		15		23	17	
Nov-15	25	9.3	15		4	6	18	40
Dec-15	25	17		0		14.6	24	29
Jan-16	8	6				0	4	
Feb-16	5		15	0	5.5	4	4	2
Mar-16	8	8.5	3	1		5.1	0	8
Apr-16	0	6	0	0		7.98		0
May-16	0	0		0		0		0
Jun-16		0		0				
Jul-16								
Aug-16								

A.4 9 mean Electrical Conductivity Values, monthly observations

	Granton EC	Juniper Green EC	Eliburn EC	Goreglen EC	Oxgangs EC	RBGE EC	Inverleith EC	Blackford EC
Jul-14								
Aug-14	418							
Sep-14	557							
Oct-14	492							
Nov-14	564							
Dec-14	564							
Jan-15								
Feb-15		226						
Mar-15	990	153						454
Apr-15	1057	223	1394	752	458	475	420	368
May-15	866	101	573	700	324	493	1082	405
Jun-15	900	128	824	622	1039	502	402	352
Jul-15	797	179	1124	589	346	493.5	344	355
Aug-15	662	75	820		235			370
Sep-15	642	102	751	618	354		330	398
Oct-15	731	150	1119	656	370			398
Nov-15	412	78			360	373	275	399
Dec-15	675	110	675	675	264		291	188
Jan-16	550	135						377
Feb-16	820			780			377	428
Mar-16	1410	106	1155	800	313	351	420	411
Apr-16	940	89	1012	735	335		406	395

May-16	830	115	951	930	305		358	395
Jun-16	420	90		685	234		335	335
Jul-16	580		300	580	156		360	350
Aug-16	400	103	295	600	300		275	385

A.4 10:Mean pH values, monthly observations

	Granton pH	Juniper pH	Eliburn pH	Oxgangs pH	Inverleith pH	RBGE pH	Goreglen pH	Blackford pH
Jul-14								
Aug-14	7.61							
Sep-14	7.9							
Oct-14	8							
Nov-14	7.67							
Dec-14	7.67							
Jan-15								
Feb-15		7.73						
Mar-15	7.75	9					7.39	8
Apr-15	7.71	8.52	7.6	6.92	9.38	6.76	7.12	8.77
May-15	7.46	8.8	9.05	6.93	9.28	6.97	6.66	7.2
Jun-15	7.06	8.5	8.6	7.06	9.4	7.21	6.87	9.34
Jul-15	6.77	9	8.8	6.83	9.59	6.96		8.91
Aug-15	8	9.09	8.2	9.72			7.18	8.65
Sep-15	8.2	8.2	8.42	7.7	8.11		7.9	8.16
Oct-15	7	8.3	7.98	8.7				8.16
Nov-15	8.08	8.5		7.93	8.3	7.7	8.97	7.5
Dec-15	8.97	9.3	8.97	8.07	8.8			7.18
Jan-16	8.91	8.9					8.25	8.52
Feb-16	8.5				8.12		8.64	8.25
Mar-16	8.4	8.5	8.4	8.18	8.3	8.06	8.1	8.47
Apr-16	8.16	8.65	8.8	8.75	8		7.3	8.4
May-16	7.6	7.9	7.49	7.6	9.2		7.89	7.6
Jun-16	8.3	8.4		9.2	9.1		7.7	8.2
Jul-16	8.2		8.9	8.3	8.2		8.4	8.1
Aug-16	8.1	8.2	9	8.5	8.1		8.4	8.7

A.4 11: Turbidity measurements, monthly observations

	Granton NTU	Juniper NTU	Eliburn NTU	Oxgangs NTU	Inverleith NTU	Blackford NTU	Goreglen NTU
Aug-15	60	30	50	30		500	
Sep-15	250	30	90	280	30	30	42.5
Oct-15	200	30	70	250		76	42.5
Nov-15	30	42		250	60	50	
Dec-15	60	55	60	60	150	100	55
Jan-16	58	34				38	
Feb-16	38				60	80	35
Mar-16	30	30	80	52	79	42	135
Apr-16	50	30	34	35	30	35	125

	Granton NTU	Juniper NTU	Eliburn NTU	Oxgangs NTU	Inverleith NTU	Blackford NTU	Goreglen NTU
May-16	40	35	72	160	30	30	215
Jun-16	80	42		180	30	30	172.5
Jul-16	30		30	60	30	30	225
Aug-16	30	30	30	150	30	70	72.5

A.4 12:Water Temperature (mean values) monthly observations

	Granton WT	Juniper WT	Eliburn WT	Oxgangs WT	Inverleith WT	RBGE WT	Blackford WT	Goreglen WT
Jul-14								
Aug-14	14.6							
Sep-14	15.4							
Oct-14	11.2							
Nov-14	7.5							
Dec-14	7.5							
Jan-15								
Feb-15		5.5						
Mar-15	6.5	6					9.8	
Apr-15	9.6	17.1	15.5	12.6	15.6	12.55	11.2	11.9
May-15	11.1	20	10	13.2	12.9	12.7	15.6	13.3
Jun-15	20	17.4	17	10.5	21.7	17.2	24.9	12.2
Jul-15	19.8	18	16	24.1	22.8	17.95	21.8	21.3
Aug-15	18	17.5	14	19			19.4	
Sep-15	17.3	13.1	14.8	12.5	19.6		14.2	10.5
Oct-15	10.1	8.3	3.9				14.2	7
Nov-15	7.9	4.9	7	6.2	5.2	7.45	4.3	
Dec-15	7	6.2		4	5.5		6.4	6.8
Jan-16	5.5	5.3					3.7	
Feb-16	5.4				3		4.1	2.5
Mar-16	7.2	5.3	7.7	8.2	8	6.7	5.7	6.7
Apr-16	12.4	15.5	13.4	14.6	14		14.2	7.4
May-16	12	12.3	11.9	15.2	13.7		13.4	11.1
Jun-16	8	19		19	20		18	13.8
Jul-16	16.6		14	13.2	16.8		16	13
Aug-16	15	13	14.2	13	16		13.5	13.5

Chapter 5- Diatoms appendix

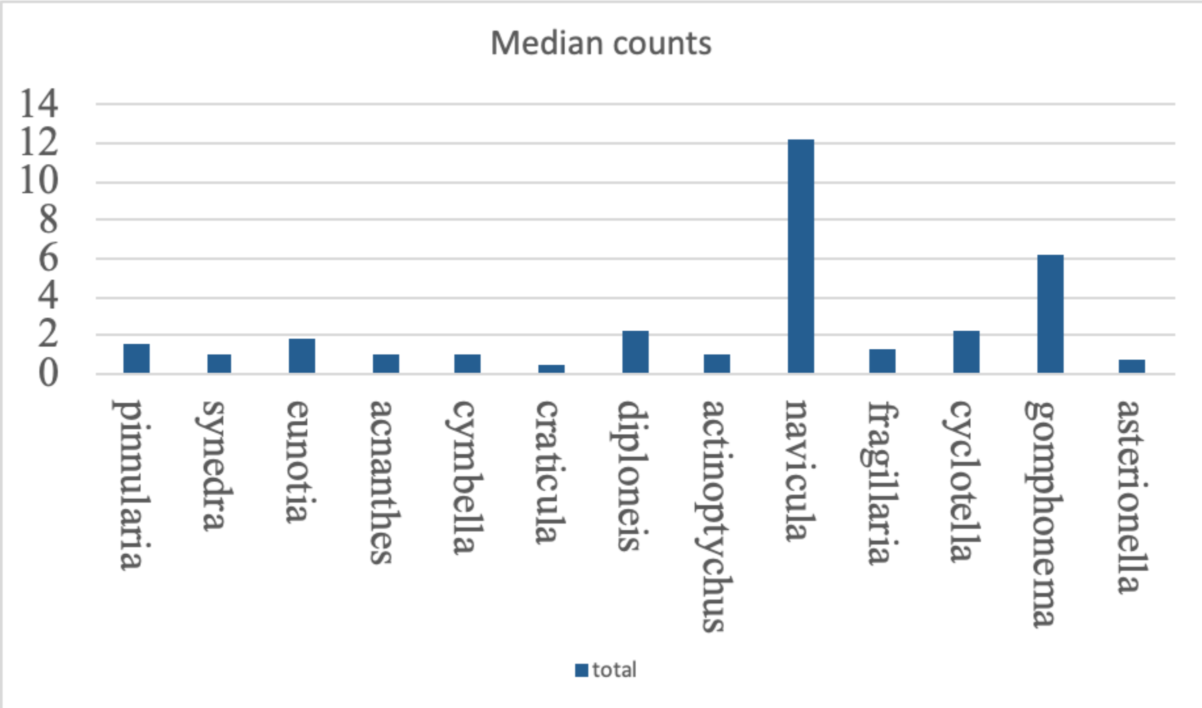
A.5.1:Diatom Species, number of taxa, monthly observations during April- August 2016

Month	Pond	Oxgangs				Granton				Eliburn				Juniper Green				Blackford				Goreglen			
April		*Inlet*	*N Taxa*	*Outlet*	*N Taxa*	*Inlet*	*N Taxa*	*Outlet*	*N Taxa*	*Inlet*	*N Taxa*	*Outlet*	*N Taxa*	*Inlet*	*N Taxa*	*Outlet*	*N Taxa*	*Inlet*	*N taxa*	*Outlet*	*N taxa*	*Inlet*	*N taxa*	*Outlet*	*N taxa*
		Pinnularia	2	Synedra	1	Cyclotella	2	None	0	Eunotia	1	Cocconeis	1	Craticula	1	None	0	Eunotia	1	Pinnularia	1	Synedra	1	Cocconeis	1
		Synedra	1	Pinnularia	1					Navicula	1	Meridion	1	Eunotia	1			Craticula	1	Diatoma	1	Pinnularia	1		
		Eunotia	1							Meridion	1	Eunotia	1	Meridion	1			Synedra	1	Navicula	1	Navicula	1		
												Craticula	1	Encyonema	1					Craticula	1				
												Gomphomena	1	Gomphonema	1										
														Pinnularia	1										
May		None	0	None	0	None	0	Meridion	1	None	0	Navicula	1	None	0	Eunotia	1	Eunotia	1	None	0	None	0	None	0
								Craticula	1			Synedra	1			Gomphomena	1	Craticula	1						
								Navicula	1			Craticula	1			Navicula	1	Synedra	1						
												Eunotia	1			Synedra	1	Navicula	1						
																		Meridion	1						
June		Acnanthes	11	Gomphonema	2	Gomphonema	2	Navicula	1	No access	n/a	No access	n/a	Cyclotella	8	Pinnularia	1	Navicula	2	None	0	None	0	None	
		Cymbella	2	Navicula	2	Cyclotella	8	Pinnularia	2					Actinoptychus	2	Gomphonema	1	Cyclotella	7						
		Craticula	1			Meridion	1	Cymbella	1									Eunotia	4						0
		Bacillaria	5			Diatoma	1	Acnanthes	1									Rhoicasphenia	2						
		Eunotia	1			Navicula	4											Fragillaria	14						
		Ellerbeckia	3			Pinnularia	1											Gomphonema	10						
		Diploneis	1															Synedra	1						
		Actinoptychus	1															Cocconeis	6						
																		Cymbella	1						
																		Semiorbis	1						
July		Navicula	1	Fragillaria	1	Pinnularia	23	Navicula	1	Gomphonema	1	No access	n/a	No access	n/a	No access	n/a	Gomphonema	1	Fragillaria	70	None	0	Synedra	1
		Fragillaria	1			Navicula	1			Navicula	5									Navicula	5			Navicula	1
						Eunotia	1			Cocconeis	5									Reimeria	1			Reimeria	1
						Gomphonema	2			Reimeria	1													Diploneis	7
						Fragilaria	1			Unknown	3													Unknown	1
August		Navicula	3	Navicula	4	Navicula	1	Navicula	6	Gomphonema	2	No access	n/a	Diatoma	4	No access	n/a	Navicula	5	Diploneis	5		Surillela	1	
				Gomphonema	3	Gomphonema	5	Fragillaria	2	Navicula	1			Diploneis	3			Gomphonema	8	Cocconeis	1				
				Asterionella	1	Diploneis	2	Synedra	4	Pinnularia	1			Gomphonema	5			Pinnularia	5	Gomphonema	3				
				Pinnularia	1	Stephanodiscus	1	Gomphonema	2					Encyonema	5					Asterionella	1				
				Diploneis	3									Fragilaria	2					Eunotia	2				
				Cyclotella	3									Synedra	7					Hannaea	1				
				Eunotia	1									Navicula	1					Encyonema	1				
																				Navicula	1				
																				hantzschia	1				

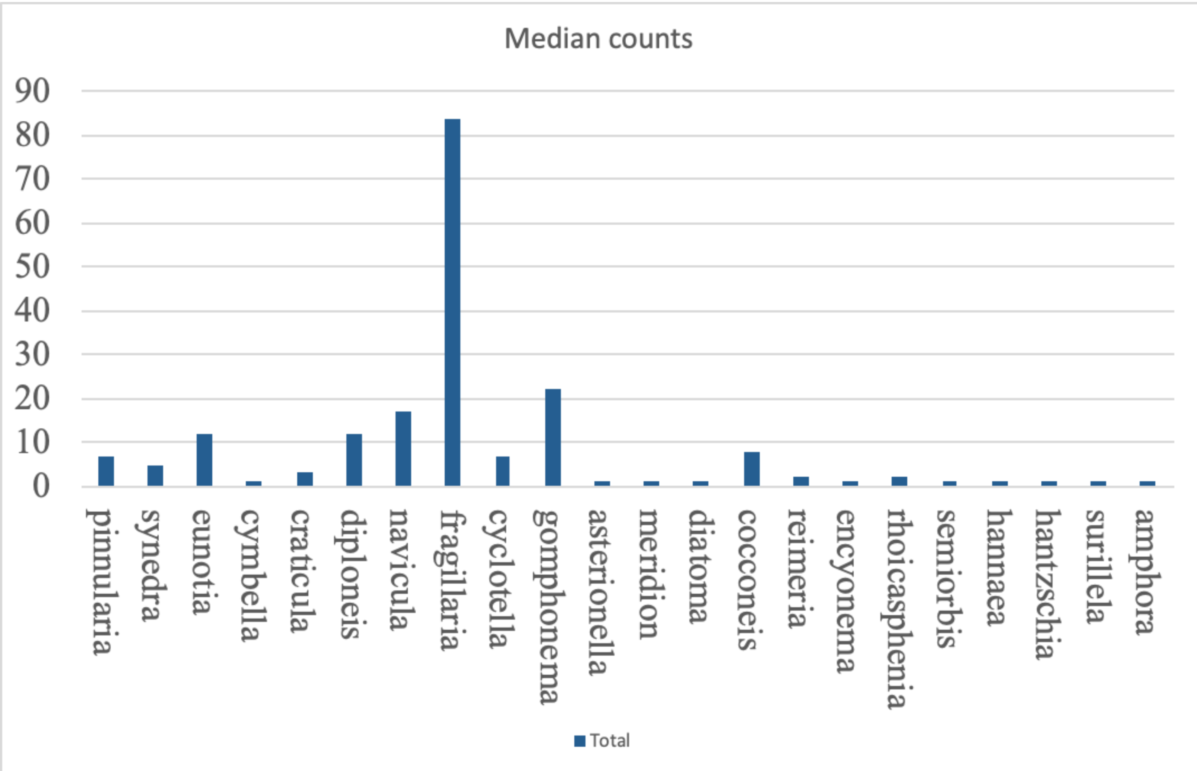
A5.2 Antecedent Dry Weather Period April 2015-Aug2016: RGBE (Royal Botanic Gardens), Blk (Blackford), GG (Goreglen), Gr (Granton), JG(Juniper Green), Ox (Oxgangs), Inv (Inverleith), and Eli (Eliburn).

Variables	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16
RBGE ADWP (hours)	120	120	120	120	NA	NA	NA	24	NA	120	12	12	NA	NA	NA	NA	NA
RBGE total rainfall (mm)	1.8	5.4	0	1.2	NA	NA	NA	60.8	NA	6.2	13.4	8	NA	NA	NA	NA	NA
Blk ADWP (hours)	120	120	120	120	120	120	120	24	120	24	12	120	72	72	72	72	24
Blk total rainfall (mm)	7.8	7.8	0	1.6	0.4	7.6	2	60.8	5.2	43	13.4	0	2.2	7.6	13.2	20.6	9.4
GG ADWP (hours)	72	24	24	24	72	24	12	0	12	0	72	120	72	72	72	72	24
GG total rainfall (mm)	0.2	8	0.6	1.6	0.4	7.6	6.4	3.2	6.2	11.8	15	0	2.2	7.6	15	20.8	9.8
Gr ADWP (hours)	120	120	120	120	120	120	120	24	120	24	72	120	120	12	12	24	12
Gr total rainfall (mm)	7.8	4.4	0	1.4	0.4	7.6	6.4	20.6	5.2	42.2	13.4	0	0.2	8.6	9.4	21.4	21
JG ADWP (hours)	120	120	120	72	120	120	120	12	24	0	72	120	120	72	12	12	12
JG total rainfall (mm)	8.2	0.6	0.2	10.8	0.4	7.6	2	20.6	56	18	13.4	0	1.6	7.6	9.2	17.8	14.2
Ox ADWP (hours)	72	24	12	24	72	24	12	0	12	0	72	0	72	72	72	72	24
Ox total rainfall (mm)	0.2	7.8	0.6	1.6	0.4	7.6	6.4	3.2	6.2	11.8	15	0	2.2	7.6	12	20.6	5.6
Inv ADWP (hours)	120	0	120	24	NA	24	0	12	0	NA	72	120	120	12	12	24	0
Inv total rainfall(mm)	4.8	5.6	0	4.8	NA	7.6	6.4	5.8	6.2	NA	15	0	1.6	8.6	9.4	17	21.2
Eli ADWP (hours)	12	12	120	24	72	24	12	12	24	0	72	0	120	72	0	24	12
Eli total rainfall (mm)	21	5.4	0	0	0.4	7.6	6.4	5.8	5	42.2	15	0	1.6	7.6	9.4	17.8	21

A.5.3: SUDS Ponds: median diatom counts



A.5. 4 Non SUDS Ponds: median counts

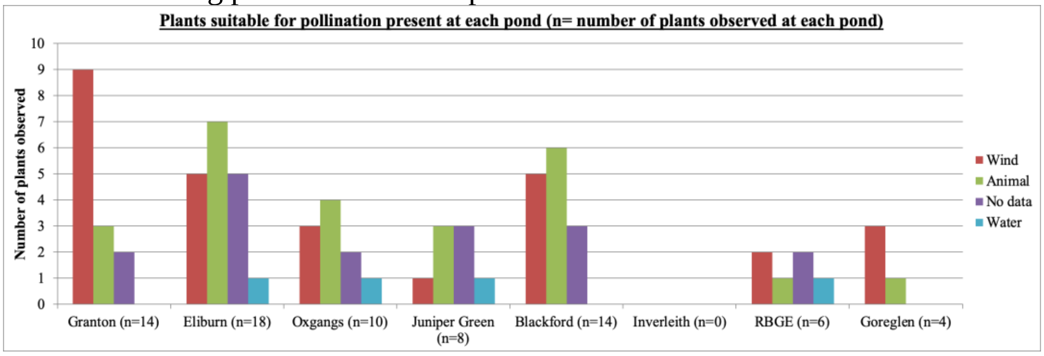


Diatom Family	Nutrient Sensitivity	SUDS inlet	SUDS outlet	Non SUDS Inlet	Non SUDS Outlet	Total
Acnanthes	3	3	1	0	0	4
Actinoptychus	0	1	1	0	0	2
Asterionella	0	1	1	0	1	3
Bacillaria	5	5	0	0	0	5
Caloneis	3	0	0	0	1	1
Cocconeis	3	5	1	6	2	14
Craticula	4	6	3	2	1	12
Cyclotella	0	18	3	7	0	28
Cymbella	3	1	1	1	0	3
Diatoma	2	5	0	0	1	6
Diploneis	5	6	3	0	12	21
Ellerbeckia	4	3	0	0	0	3
Encyonema	4	6	0	0	1	7
Eunotia	1.4	1	2	6	2	11
Fragillaria	2	0	4	14	70	88
Gomphonema	3	9	9	19	3	40
Hannaea	1	0	0	0	1	1
Hantzschia	5	0	0	0	1	1
Meridion	2	10	2	1	0	13
Navicula	4	3	1	9	8	21
Pinnularia	2.2	28	3	6	1	38
Reimeria	3	1	0	0	2	3
Rhoicasphenia	4	0	0	2	0	2
Semiorbis	0	0	0	1	0	1
Stephanodiscus	0	1	0	0	0	1
Surillela	2	0	0	1	0	1
Synedra	2	8	7	4	1	20
Amphora	5	0	0	0	1	1
Total		113	35	75	107	330

Chapter 6- Plant diversity appendix

Appendix A.6

A.6 1: Flowering plants suitable for pollination



A.6 2: Shannon Index (Diversity scores derived from plants at ponds)

	Granton MP	Juniper Green MP	Oxgangs MP	Eliburn MP	Blackford MP	Goreglen MP
Apr-15	1.2	0.9	1	0.8	0.9	0.6
May-15	1.3	1	0.9	0.9	0.8	0.3
Jun-15	1.3	0.8	1	0.8	1	0.3
Jul-15	1.4	1	1	1.3	1	0.5
Aug-15	1.3	1	1.2	0.9	1.1	
Sep-15	1.2	1.4	1.1	1.3	1.1	0.5
Oct-15	1.2	1	1.1	1.2	1	
Nov-15	1.1	0.8	1.1	1.2	1	0.6
Dec-15	1	0.8	1.1	1.2	0.9	0.7
Jan-16	0.8	0.9	0.9		0.8	0.7
Feb-16	0.7	0.9	0.9		0.5	0.7
Mar-16	0.7	0.7	1	1.2	0.5	0.7
Apr-16	0.7	0.8	1	1.1	0.7	0.6
May-16	0.9	1.3	1.1	1.3	0.8	0.6
Jun-16	1	1.3	1.2		0.9	0.4
Jul-16	1	0.9	1.1	1.3	0.9	0.5
Aug-16	1	1.3	1.2	1.3	0.9	0.5

Chapter 7- Valuing the multiple benefits from SUDS ponds Appendix

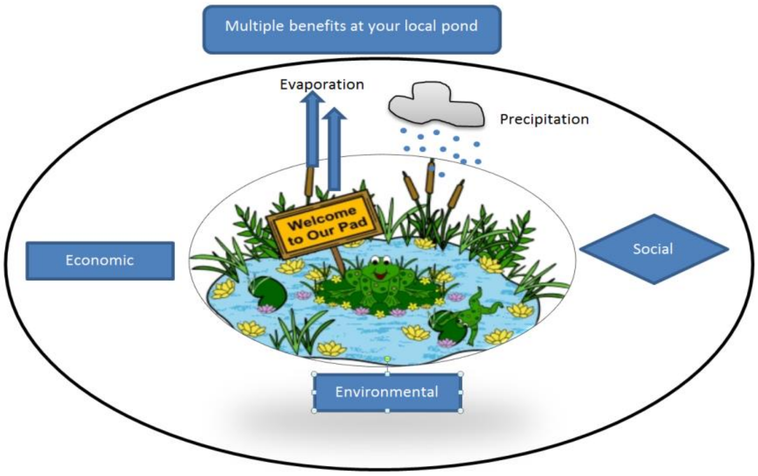
A.7 1: Contingent Valuation Survey

15 Minute Pond Survey

Hello, my name is Joy Jarvie and I am a PhD student at Heriot Watt University. As part of my research, I am trying to understand how the public view the potential benefits of local ponds.

The aim of this survey, therefore, is to introduce the wider benefits of ponds and see how much the general public value. The value you place on the benefits is hypothetical (not real) and will not be communicated to anyone else.

I would appreciate if you could fill out this questionnaire and send it back to the address on the self-addressed envelope (free of charge). The survey results are anonymous.



A) Home and aesthetics

Q1) Please rank from 1 to 5 the factors you see as important to the neighbourhood:-
(with 1 as the most important and 5 as the least important)

	1	2	3	4	5
Safety of the area					
Proximity to amenities (services)					
Low crime rates					
Open space- water, parks, and other greenery					
Sense of community					
Activities (hobbies, courses available)					
Other (please specify):……………					

Q2) Please rank from 1 to 5 the factors that influenced your choice of home:-
(*with 1 as the most important and 5 as the least important)*

	1	2	3	4	5
The accommodation (size, condition)					
Location/ proximity to amenities (local services)					
Environs (natural surroundings/ general impression of the environment)					
Parking provision					
Price/ Rental Cost					
School					
Garden					
Other (please specify):……………					

Q3) Please select which pond you live closest to:
- ☐ Blackford (EH10 6BR)
- ☐ Gorebridge- Goreglen forest (EH4 3DS)
- ☐ Granton (EH5 1QN)
- ☐ Inverleith (EH3 5NZ)
- ☐ Juniper Green (Woodhall mill) (EH14 5BH)
- ☐ Livingston- Appleton parkway (EH54 7EZ)
- ☐ Livingston – Old Cousland Road (EH54 7EZ)
- ☐ Oxgangs- Firrhill Neuk (EH13 9FF)
- ☐ Royal Botanic Gardens Edinburgh (EH3 5NZ)

Q4) Was the pond in place when you moved to this area?
Yes No

Q5) Would you say that the presence of the pond effected your decision to move to this area in a positive way?
Yes No

Q6) Is the pond visible from your home?
Yes No

Q7) Overall, do you think that your pond is appropriately maintained?
Yes No

If no, which measures do you think should be taken to improve this?

……..
……..

Q8) Is your local pond within walking distance?
Yes No

If yes, is it accessible?
Yes No

Q9) Please rank from 1 to 5 what you perceive the benefits of living close to a pond to be:-
(*with 1 as the most important and 5 as the least important*)

	1	2	3	4	5
Can be used for walking pets					
Provides biodiversity (plants and animals) to the surrounding area					
Sustainable drainage solution					
Educational purposes for children					
Adds to the value of homes					
Proximity to parks					
Prettiness					
Health					
Other services/ amenities					
Other (please specify):…..					

Q10) Please rank from 1 to 5 what you perceive to be dangerous:-
(*with 1 as the most dangerous and 5 as the least dangerous*)

	1	2	3	4	5
Electrical substation					
Incinerator					
Busy Road					
Pond					
River					
Quarry					
High levels of crime					
Derelict building					
Industrial area					

Q11) Where on the following scale would you consider your local pond?

- ☐ Very natural looking
- ☐ Somewhat natural looking
- ☐ Man-made looking

Q12) Please rank from 1 to 5 what you perceive to be the potential disadvantages of living in close proximity of a pond:-
(*with 1 as the most important and 5 as the least important)*

	1	2	3	4	5
Promotes vandalism					
Presents safety risks					
Source of flooding					
Accumulates litter					
Attracts insects					
Attracts rodents					
Aesthetically unpleasant					
Unpleasant smells					
Other (please specify):………					

B) Recreation

Q1) Are any of the following recreation benefits available at your local pond?

Possible Activities	Yes	No	Maybe
Boating			
Model boats			
Walking			
Relaxation/ meditation			
Reading			
Dog walking			
Family picnics			
Exercise classes			
BBQ			
Other, please specify:……			

C) Education

Q1) Are any of the following education benefits available at your local pond?

Educational opportunities	Yes	No	Not sure
Conservation groups			
Pond dipping activities			
Nature walks			
Tours around pond- nature reserve			
Formal training/ management			
Ecology courses			
Geography lessons			
Biology field work			

D) Spiritual

Q1) Are any of the following spiritual benefits available at your local pond?

	Yes	No	Maybe
Place for reflection			
Meditation			
Church gatherings			
Sense of place and belonging			

E) Habitat Provision

Q1) Does your local pond support habitat (where creatures live) and biodiversity (a range of plants and animals).

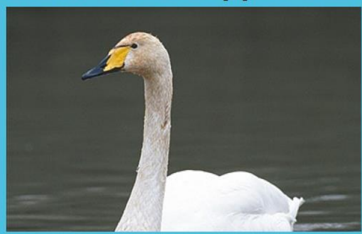
Yes No

Q1a) Tick if you have seen these species may be present in your local pond (images from RSPB).

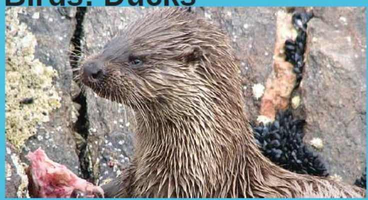
Amphibians: Frogs

Birds: Grasshopper warbler

Birds: Ducks



Birds: Swans



Mammals: Otters

Amphibians: Newts

Water bugs: water boatmen

Small fish: stickleback

Other, please specify:

Animals in your pond

Plants in your pond


Bulrushes


Pond water crowfoot


Rosebay Willow herb


Yellow lillies


Purple loosestrife


Bogbean


Sedge

Other, please specify:

F) Flood Regulation

Q1) Are you aware that your local pond may help reduce flooding?

Yes No Maybe

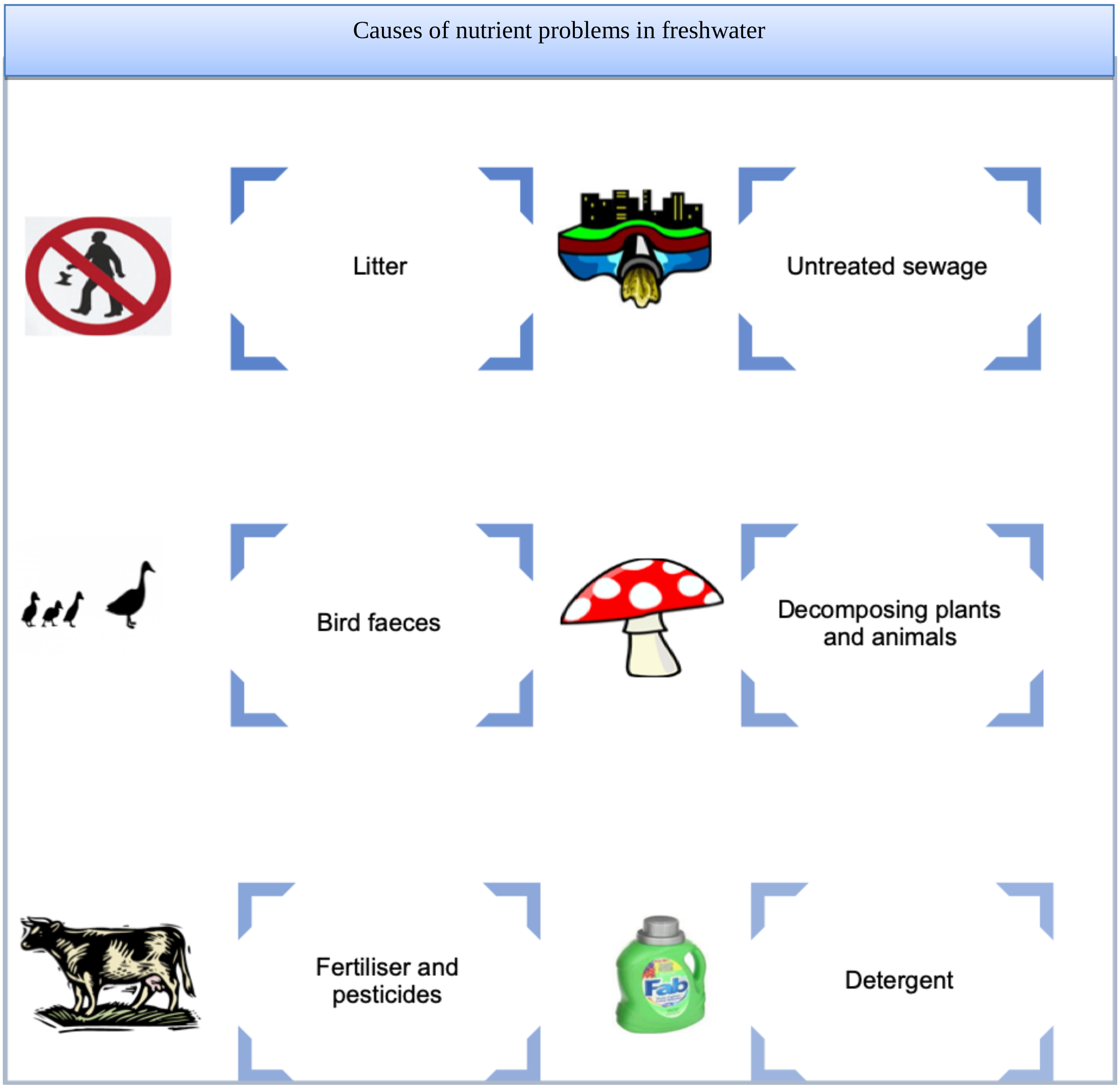
Q2) Are you aware of the following benefits with respect to flood regulation?

	Yes	No	Maybe
Evapotranspiration from plants and trees			
Wetland plants act as a “sponge” and reduce runoff			
Reduces pressure on sewers and drains			

G) Nutrient Problems

The nutrient cycle transfers nutrients from the air, water and land.

Nutrient overloading has implications for human and animal health.



Q1) Are you aware of the term Eutrophication?
Yes No

Picture of a Eutrophic pond and algal blooms (source:EPA)

Q2) Have you noticed any of these signs in your local pond?

	Yes	No	Maybe
Presence of algae			
Cannot see the bottom of the pond easily			
Decrease in species diversity			
An increase in sediment			
Dominance by certain species			

Q3) Are you aware of the following impacts that algal blooms/ cyanobacteria have on pet health?

	Yes	No	Maybe
Liver toxins (disease)			
Brain defects			
Stomach cramps/ gastroenteritis			
Kidney disease			
Joint pain			
Skin irritation			

H) Willingness to pay summary

Q1) If you were to move elsewhere, how much would you be willing to pay, on a monthly basis, for similar benefits?
Please fill out the following grid to indicate which benefits you favour at your local pond.

Benefits Category	£0	£1	£2	£5	£10	£15	£25	>£25
B Recreation								
Boating								
Model boats								
Walking								
Relaxation/ meditation								
Reading								
Dog walking								
Family picnics								
Exercise classes								
BBQ								
C Education								
Conservation groups								
Pond dipping activities								
Nature walks								
Tours around pond-nature reserve								
Formal training/ management								
Ecology courses								
Geography lessons								
Biology field work								
D Spiritual								
Place for reflection								
Church gatherings								
Sense of place and belonging								
E Habitat Provision								
Supports plants								
Supports mammals								
Supports fish								
Creates habitat for birds								
Supports invertebrates								
F Flood Regulation								
Reduction in runoff								
Reduces pressure on sewers and drains								
G Protection against Eutrophication								
Being aware of the signs of algal blooms								
Keeping pets safe								

I) Demographic Questions

Q1) Are you… male ☐ female☐ prefer not to disclose☐

Q2) Who lives in your home, please select all which apply?

	Number of people	Number of children (if relevant)
Living alone		n/a
Living with partner		
Single with children		
Lives with other adults/ family members		

Q3) How long have you been living in your home, please select which applies?

- ☐ Less than 1 year
- ☐ 1- 5 years
- ☐ 5-10 years
- ☐ 11-20 years
- ☐ More than 20 years

Q4) How do you class your employment?

- ☐ Full time
- ☐ Part time
- ☐ Self-employed
- ☐ Retired
- ☐ Unemployed
- ☐ Student
- ☐ Unable to work
- ☐ Full time carer
- ☐ Stay at home parent/ guardian

Q5) What is your annual household income, please select which applies?

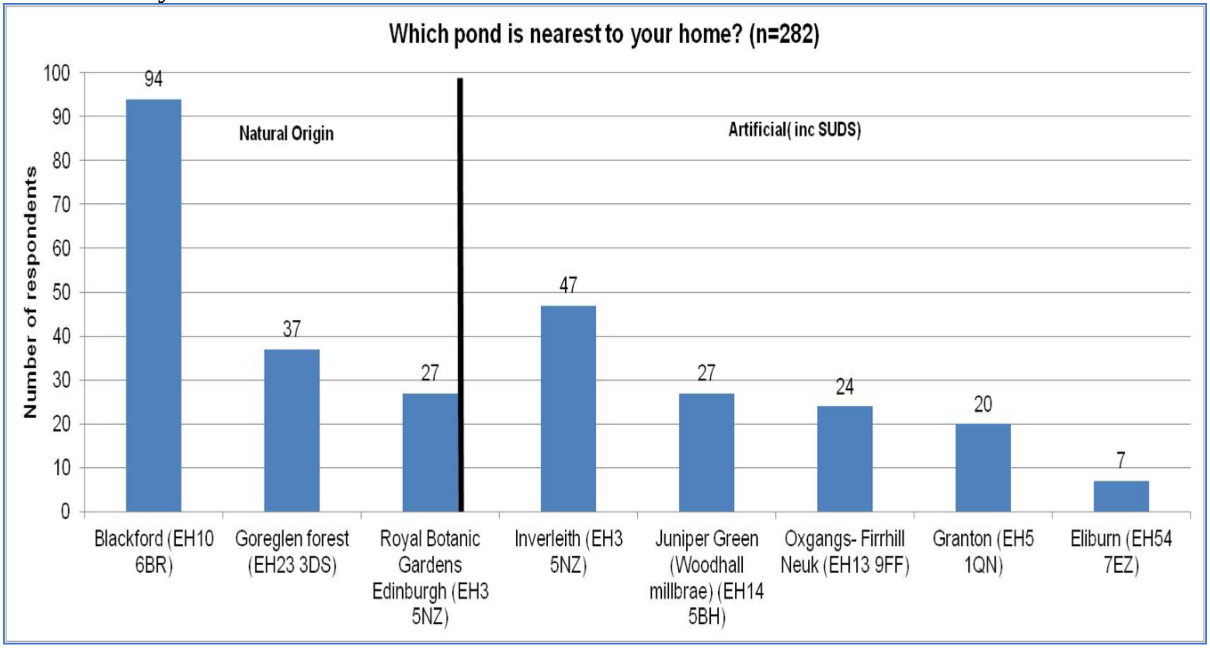
- ☐ Less than £10k
- ☐ £10-20k
- ☐ £20-30k
- ☐ £30-50k
- ☐ £50-75k
- ☐ More than £75k

……
………

Thank you for participating in our questionnaire.

Please note that your answers and views will remain confidential, and the research is not intended for commercial purposes.

A.7 2 Survey Results



A.7 3 Whole Life Cost Analysis: Habitat

Pond Name	NPV Benefits	NPV OPEX Costs	CAPEX Costs	Balance
Granton	£1,720,765	£1,619,712	£990,000	−£888,946
Juniper Green	£2,388,284	£52,988	£13,200	£2,322,086
Oxgangs	£15,836,096	£1,101,592	£668,167	£14,066,337
Eliburn	£2,569,335	£233,140	£115,156	£2,221,039
Blackford	£7,165,189	£1,966,033	£1,336,500	£3,862,656
Goreglen	£103,718	£92,315	£41,250	−£29,847
Royal Botanic Gardens	£9,991,540	£631,553	£376,200	£8,983,787
Inverleith	£2,842,172	£5,810,221	£3,593,205	−£6,561,254
Total	£42,617,101	£11,507,564	£7,133,678	£23,975,859
Per Population	£3,258.94	£879.99	£545.51	£1,833.44

A.7 4 Whole Life Cost Analysis: Recreation

Pond name	NPV benefits	NPV OPEX costs	CAPEX costs	Balance
Juniper Green	£69,146	£52,998	£13,200	£2,948
Granton	£388,944	£1,619,712	£990,000	-£2,220,768
Eliburn	£144,053	£233,140	£115,156	£2,221,039
Oxgangs	£3,298,822	£1,101,592	£668,167	£1,529,062
Inverleith	£4,753,760	£5,810,221	£3,593,205	-£4,649,666
Blackford	£4,753,760	£1,966,033	£1,336,500	£1,451,228
Goreglen	£144,053	£92,315	£41,250	£10,488
Royal Botanic Gardens	£1,313,766	£631,553	£376,200	£306,014
Total	*£1,457,820*	*£723,868*	*£417,450*	*£316,502*
Per Population	*£111.48*	*£55.35*	*£31.92*	*£24.20*

A.7 5: Whole Life Cost: Education

Pond name	NPV benefits	NPV OPEX Costs	CAPEX costs	Balance
Granton	£6,216,118	£1,619,712	£990,000	£5,173,120
Juniper Green	£4,547,404	£52,998	£13,200	£4,301,038
Eliburn	£1,573,063	£233,166	£115,156	£356,314
Oxgangs	£33,618,881	£1,101,592	£668,167	£27,140,083
Inverleith	£4,375,380	£5,810,631	£3,593,205	(£1,183,858)
Blackford	£13,001,558	£1,966,033	£1,336,500	£11,572,743
Goreglen	£139,660	£92,315	£41,250	(£533,143)
Royal Botanics	£10,690,943	£631,553	£376,200	(£1,193,257)
Total	£74,163,007	£11,508,000	£7,133,678	£67,028,449
Per population	£5,671.26	£880.02	£545.51	£5,125.67

A.7 6: Whole Life Cost: Spiritual

Pond name	NPV benefits	NPV OPEX Costs	CAPEX costs	Balance
Granton	£106,720	£1,619,712	£990,000	(£936,278)
Juniper Green	£937,379	£52,998	£13,200	£871,181
Eliburn	£233,166	£262,177	£115,156	(£144,167)
Oxgangs	£7,414,978	£1,101,592	£668,167	£5,645,219
Inverleith	£674,074	£5,810,622	£3,593,205	(£8,729,753)
Blackford	£1,683,912	£1,966,033	£1,336,500	(£1,618,622)
Goreglen	£14,934	£92,315	£41,250	(£118,632)
Royal Botanics	£2,824,286	£631,553	£376,200	£1,816,533
Total	£13,889,447	£11,537,002	£7,133,678	(£3,214,519)
Per population	£1,062	£882	£546	(£246)

A.7 7: Whole Life Cost: Flood Risk Reduction

Pond name	NPV benefits	NPV OPEX Costs	CAPEX costs	Balance
Granton	£700,315	£1,619,709	£990,000	(£1,909,394)
Juniper Green	£878,533	£52,998	£13,200	£812,335
Eliburn	£524,354	£233,166	£115,156	£176,032
Oxgangs	£7,185,381	£1,101,592	£668,167	£5,415,622
Inverleith	£623,103	£5,810,622	£3,593,205	(£8,780,724)
Blackford	£2,142,097	£1,966,033	£1,336,500	(£1,160,436)
Goreglen	£17,070	£92,315	£41,250	(£116,495)
Royal Botanics	£3,836,741	£631,553	£376,200	£2,828,988
Total	£15,907,595	£11,507,988	£7,133,678	£36,083,603
Per population	£1,216.46	£880.02	£545.51	£2,759.32

A.7 8: Whole Life Cost: Nutrient Cycling

Pond name	NPV benefits	NPV OPEX Costs	CAPEX costs	Balance
Granton	£526,899	£1,619,712	£990,000	(£516,099)
Juniper Green	£1,013,031	£52,998	£13,200	£946,833
Eliburn	£524,354	£233,166	£115,156	£176,032
Oxgangs	£6,233,812	£1,101,592	£668,167	£4,464,053
Inverleith	£535,086	£5,810,622	£3,593,205	(£8,868,741)

Blackford	£1,139,774	£1,966,033	£1,336,500	(£2,162,759)
Goreglen	£18,727	£92,315	£41,250	(£114,838)
Royal Botanics	£2,824,022	£631,553	£376,200	£1,816,269
Total	£12,815,706	£11,485,976	£7,133,678	(£5,803,948)
Per population	£980.02	£878	£546	£2,759

A.7 9: SIMD (Deciles)

Pond name	SIMD decile	Income	Employment	Health	Education	Housing	Geographical access	Crime
Granton	3	3	4	2	2	2	7	1
Goreglen	4	5	4	4	2	6	8	9
Blackford	9	9	8	10	10	9	6	2
Eliburn	9	9	10	9	9	10	2	6
Royal Botanics	10	10	9	9	10	8	10	5
Inverleith	10	8	10	8	10	7	10	9
Juniper Green	10	9	8	9	10	10	5	7
Median	9	9	8	9	10	8	7	6
Median SUDS	6	6	6	6	6	6	4	3.5
Median Non SUDS	9.5	8.5	8.5	8.5	10	7.5	9	7

A.7 10: Costs (Capital and O&M)

Pond name	**Capital(upper cost- Stovin and Swan, 2007)**	**Inspection**	**Litter and debris removal**	**Grass cutting**	**Barrier vegetation/ pruning**	**Barrier vegetation weeding**	**Aquatic vegetation management**	**Desilting**	**Mobilisation-sediment removal**	**Disposal of sediment**	**Vegetation replacement**
Juniper Green	£13,200	£300	£9.12	n/a	£79.20	£57.60	£81.60	£1,653.60	£4,676	£526	£3,228.00
Granton	£990,000	£300	£456.00	888	£3,960.00	£2,880.00	£4,080.00	£124,020	£4,676	£39,420	£161,400.0
Eliburn	£115,156	£300	£63.65	123.95	£552.75	£402.00	£569.50	£14,425.94	£4,676	£4,585	£22,528.8
Oxgangs	£668,168	£300	£307.76	599.326	£2,672.67	£1,943.76	£2,753.66	£83,703	£4,676	£26,605	£108,931.6
Blackford	£1,336,500	*£300*	£513.00	999	£4,455.00	£3,240.00	£4,590.00	*£167,427*	£4,676	£53,217	£181,575.0
Inverleith	£3,593,205	*£300*	£1,655.05	3222.996	£14,372.82	£10,452.96	£14,808.36	£450,131	£4,676	*£143,075*	£585,801.3
Royal Botanics	£376,200	*£300*	£173.28	337.44	£1,504.80	£1,094.40	£1,550.40	47127.6	£4,676	14979.6	£61,332.0
Goreglen	£41,250	*£300*	£19.00	37	£165.00	£120.00	£170.00	5167.5	£4,676	1642.5	£6,725.0
Median SUDS	£391,662	£300	£186	£599	£1,613	£1,173	£1,662	£49,065	£4,676	£15,595	£65,730
Median Non SUDS	£856,350	£300	£343	£668	£2,980	£2,167	£3,070	£107,277	£4,676	£34,098	£121,454
Total SUDS	£1,786,524	£1,200	£837	£1,611	£7,265	£5,283	£7,485	£223,803	£18,704	£71,136	£296,088
Total Non SUDS	£5,347,155	£1,200	£2,360	£4,596	£20,498	£14,907	£21,119	£669,853	£18,704	£212,914	£835,433

Regular maintenance
Irregular maintenance