Combined Permeable Pavement and Ground Source Heat Pump Systems

Assessment of their Design Impact on Water Treatment Performance

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Declaration

I hereby declare that the following research work has been completed independently by myself (Piotr Grabowiecki) and its parts were neither published nor presented elsewhere except as in referenced text.

~ Piotr Grabowiecki

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Dziękuję za Twój śmiech i łzy
i za nadanie życiu nowego sensu istnienia.

Byłaś bardzo cierpliwa...

Nie ma jak uśmiech Ninkensa...

Gutta cavat lapidem, non vi, sed saepe cadendo.

~Ovid, Epistles

Abstract

The PhD thesis focuses on the performance assessment of permeable pavement systems incorporating ground source heat pumps (GSHP). The relatively high variability of temperature in these systems allows for the survival of pathogenic organisms within the sub-base. Salmonella sp, Escherichia coli, Enterococci and total heterotrophic bacteria were analysed in order to assess potential risk to health. Supplementary carbon dioxide monitoring indicated relatively high microbial activity on the geotextile and within the lower parts of the sub-base. Anaerobic processes were concentrated in the space around the geotextile, where carbon dioxide concentrations reached up to 2000 ppm. The overall water treatment potential was high, with up to 99% biochemical oxygen demand removal. Variable removal efficiencies have been calculated for nutrients such as ortho-phosphate-phosphorus, ammonia and nitrates/nitrites. Calculated Coefficients of Performance and Energy Efficiency Rates provided evidence on correctness of GSHP design. Collected data was analysed with non-parametrical statistics and a self-organizing map model was used to assess relationships between variables. Findings present correlations considered as low and insignificant between temperature fluctuations and pathogen numbers. Highly significant correlations ($p<0.01$) were calculated for influent-effluent relationships. Air and water temperatures and water quality data variability within the systems provided evidence for the high level of biological processes leading to a low risk of pathogen transition to human.

Publications

Co-authorship in publications (by the year of publication):

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List of used abbreviations:

AN	Ammonia (NH_4)
ANN	Artificial Neural Networks
ANOVA	Analysis of Variance
BMP	Best management Practices
BOD_5	5-day Biological Oxygen Demand
CFU	Colony Forming Units
COND	Conductivity
COP	Coefficient of Performance
DO	Dissolved Oxygen
EC	*Escherichia coli sp*
EER	Energy Efficiency Ratio
EN	*Enterococci sp*
GSHP	Ground Source Heat Pumps
H/C	Heating / Cooling
HGV	Heavy Goods Vehicles
NN	Nitrates/nitrites (NO_{2+3})
ORP	Oxidation Reduction Potential
PICP	Permeable Interlocking Concrete Pavers
PO	Ortho-phosphate-phosphorus PO_4
PPS	Permeable Pavement Systems
RSD	Relative Standard Deviation
SA	*Salmonella sp*
SS	Suspended Solids
SOM	Self Organising Maps

SUDS	Sustainable Urban Drainage Systems
TDS	Total Dissolved Solids
THB	Total Heterotrophic Bacteria
TIN	Total Inorganic Nitrate
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen

r_s	Spearman's correlation
$\tilde{x}$	Median
p	Probability

1 Introduction

This chapter examines the background of the project and research questions raised by this examination. It explains the structure of the document in different chapters as well as the objectives of the experiment.

1.1 Background to the project

The modern world of environmental protection is full of challenges and techniques trying to provide solutions to problems such as water shortages, glacial meltdown, tornados, hurricanes, flooding, torrential rain, forest fires, atmospheric pollution and many more.

Among many initiatives such as green campaigns to 'save the world', mainly concentrating on public awareness, scientists have also started to develop new techniques for the most efficient usage of natural resources.

While wind, solar or wave farms are tremendous projects in terms of scale, design, technology, and knowledge resources (constructed by large corporations, very often with governmental involvement), it is important to recognise the need for project design on a much smaller scale.

Starting from 'one's own back yard' is one of the most important educational paths for present and future generations. Once achieved, it is possible to implement environmentally (and cost) friendly tools in real-life applications.

Concerning water protection and re-use, the European Union has created various regulations, the most recent of which is the Water Framework Directive.

The EU Water Framework Directive (The Council of The European Communities, 2007) requires EU members states to achieve 'good surface water status' by 2015. As defined by the Directive, 'good status' means good ecological and chemical status.

Regional governments also announced their own policies, such as The Code for Sustainable Homes in the United Kingdom, as of 1st May 2008 (Department for Communities and Local Government, 2008). It obliges new housing developments to produce zero carbon dioxide (code level 6) buildings by 2016. This policy is a response to demands for action on climate change and the overall CO_2 emissions reduction of 60% by 2050 in the UK.

For energy saving, designs such as wind turbines, solar panels, ground source heat pumps, insulation or natural air circulation systems can be found.

For water recycling, water storage ponds, attic water tanks or rainwater barrels are some of the basic techniques currently used.

One of the techniques used to recycle and treat water is Permeable Pavement Systems (PPS).

As PPS fulfils the requirements of the Directive and has been used for several years, Ground Source Heat Pumps (GSHP) may help in meeting other sustainable requirements.

Permeable Pavement Systems (PPS), are one of Sustainable Urban Drainage Systems' (SUDS) techniques. Their construction is based on paved blocks overlaid on mineral aggregates (depth depends on local conditions; Formpave, 2004). As blocks are permeable, they allow water to percolate into the sub-base (aggregates) where it is either stored for recycling or released into groundwater (Pratt, 1989).

The PPS sub-base design potential can be used for installation of Ground Source Heat Pumps (GSHP), which provide a mixture of eco-efficient installations for private households or commercial applications.

Geothermal (ground-source) heat pumps (GSHP) are one of the best applications of renewable energy around the globe today (Kavanaugh and Rafferty, 1997; Lund *et al.*, 2004).

By combining other techniques such as solar panels or small wind turbines a new opportunity arises for providing tools to build and design joint eco-houses, such as the ones researched at the British Research Establishment, Watford, UK.

In 2003 the PPS systems manufacturer Formpave Ltd. proposed a PhD project on PPS water quality assessment with GSHP installation at The University of Edinburgh, Scotland, UK. The project was supervised by Dr Miklas Scholz (Edinburgh) and Dr Stephen Coupe (Coventry University, Formpave).

GSHP is manufactured by Water Furnace Plc., Europe, a company registered in the US.

The combination of both commercially available techniques brings the advanced engineering tool described and researched in the following thesis.

In 2004, Formpave Ltd. merged with Hanson Ltd., which became a part of Heidelberg Cement Group in 2007. Formpave has been awarded BS EN ISO 9001:2000 Quality Assurance accreditation and is a British Standard Institution registered company.
Currently, it remains the sponsor of the project under the name of Hanson Formpave.

1.2 Rationale, aims and objectives

The aim of the research is to assess water quality and health safety risks related to the GSHP within PPS sub-base.

The main objectives can be classified as follows:

- to provide PPS and GSHP design and construction for academic research purposes, allowing for reliable simulation of both systems;
- to assess the PPS design and its performance by pollutant removal rates determinations;
- to assess the combined PPS and GSHP systems' performance and potential influences on each other
- to characterize microbial activities under different temperature patterns

Depending on the numerical analysis, the answers to the above can be provided with various accuracies.

1.3 Thesis outline

The thesis discusses techniques used in the project (GSHP and PPS), their design and efficiency in Chapters 2-4. Chapter 2 concentrate on the literary presentation of the specific SUDS techniques, the existing application and up-to-date research conclusions. It concentrates on current findings on PPS and GSHP, which provides useful information on the systems, their construction and ability to provide expected outcomes.
Chapter 3 describes the design, various types and workability of PPS, such as pollutants removal rates or expected problems and errors during PPS research. It also explains what other pollutants were used to assess the above systems and the knowledge on the removal efficiencies gathered so far.

The GSHP system description compares this tool to other energy saving tools such as air heat pumps or photo voltaic cells used for air and water heating.
Chapter 4 describes the designs and possible applications of the system.

In Chapter 5, analysis techniques (materials and methods) are described. The descriptions focus on chosen equipment for the analysis such as pH,

DO, and ORP meters, as well as materials used for systems construction. It also provides information on quality assessment (QA) and frequency of sample collection. It provides the reader with information on microbiological techniques used for bacteria determination as well as water quality sampling and analyses.

At the end of Chapter 5 the Health and Safety (H&S) assessment is described. This part of the thesis is of high importance because of human health and safety, and risks involved during laboratory analysis. The COSHH and RA forms prepared are attached as appendices at the end of the thesis.

Chapter 6 presents the temperature fluctuations according to seasonality in both rigs and possible impact on nutrients, water physical properties and microbial quantities. It compares the most important measures such as median and standard deviations.

Chapter 7 presents the measured removal rates for chosen parameters such as nutrients or BOD.

Chapter 8 analyses data using Self-Organising Maps (neural networks modelling) in Matlab Software and statistical methods (non-parametrical tests) where appropriate.

The thesis is concluded with findings and future work proposals.

2 Sustainable Urban Drainage Systems

SUDS are well recognised techniques amongst civil engineers and environmentalist. This chapter examines SUDS techniques, types and design in more detail.

2.1 Development and design

Sustainable Urban Drainage Systems (SUDS), or Best Management Practices (BMPs) have been recognised since 1972 in the USA, following the introduction of the Clean Water Act (EPA, 1999).

The traditional method of storm runoff capture depended on piped sewer systems. Most of today's cities depend on 19th century pipe network systems, which have become insufficient and inefficient over time and expensive to maintain (Schlűter and Jefferies, 2002).

In contrast to 'end-of-pipe' treatment, SUDS provide pollution source control and precipitation management (Balkema *et al.*, 2002; Scholz, 2006a).

The SUDS approach is beneficial as it deals with water quality, quantity, and amenity holistically. The SUDS triangle is presented in **Figure 2-1**.

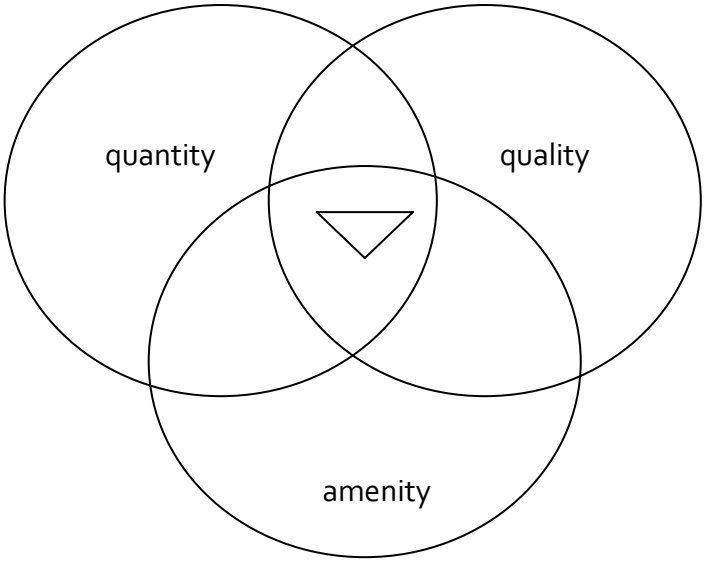


Figure 2-1 The SUDS triangle

(after SUDS design manual for Scotland (2000)).

These systems are sympathetic to local communities and needs, as they protect or even upgrade water quality and provide wildlife habitats in heavily urbanised areas (CIRIA, 2000b).

SUDS provide water reclamation, recycling and reuse. **Figure 2-2** presents the SUDS treatment train.

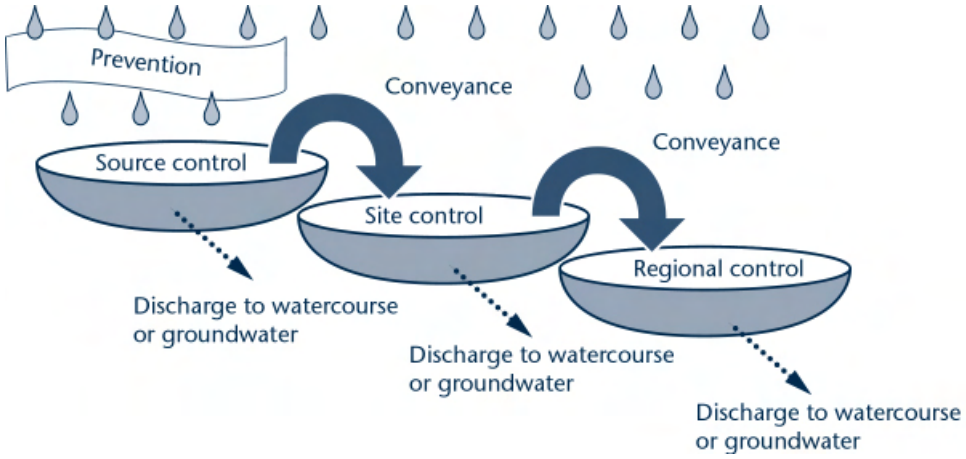


Figure 2-2 SUDS treatment train.

(Source: UK Environment Agency: http://www.environment-agency.gov.uk/commondata/103196/472738?referrer=/business/444304/502508/464710/)

The above figure presents the SUDS treatment train, providing information on how a water droplet would travel through the treatment process. The source control allows for pollutant removal in the area of contamination, whether the pollution is atmospheric or if it occurred during surface contaminant wash out. Systems such as permavoid boxes, PPS and filter strips start treating water the moment it reaches the ground surface. The next stage is site control and regional control. It is not necessary for water to travel through all stages of the treatment train, and the greatest efficiency is obtained on the local level.

The idea of the SUDS train is to divide catchment areas into smaller sub-catchments with different drainage techniques depending on land use and land characteristics (CIRIA, 2000a).

From the hydrological point of view SUDS try to mimic flow patterns that occur naturally. They reduce peak flow by infiltration and ground water recharge (Pratt, 1995; Pratt, 2001).

According to Astebol *et al.* (2004), a central element of sustainable storm water management is the utilisation of storm water as a resource. In countries such as Norway, Sweden and Denmark, water in open systems is used recreationally and in ecosystem and landscape development.

2.2 Types of SUDS

A basic classification divides SUDS into two groups of hard SUDS, with hard surfaces such as PPS, and soft SUDS such as constructed wetlands or retention ponds. The first category is easier to maintain and can be used in

highly urbanised areas, while the second category needs more space and is not usually designed for areas of high density, e.g. city centres.

The Environment Agency for England and Wales (EA, 2000) distinguishes SUDS techniques as follows:

Source control and prevention techniques

- Green roofs
- Permeable Pavement Systems
- Rainwater harvesting
- Infiltration trenches
- Infiltration basins

Permeable Conveyance Systems

- Filter (French) Basins
- Swales

Passive Treatment Systems

- Filter strips
- Detention Basins
- Retention Ponds
- Wetlands

The US EPA (EPA, 1999) categorises BMPs as follows:

Infiltration Systems:

- Infiltration Basins
- Porous Pavement Systems
- Infiltration Trenches and Wells

Detention Systems:

- Detention Basins

- Underground Vaults, Pipes and Tanks

Retention Systems:

- Retention Ponds
- Retention Tanks, Tunnels, Vaults and Pipes

Constructed Wetlands Systems:

- Wetland Basin and Wetland Channels

Filtration Systems:

- Surface Sand Filters
- Underground Vault Sand Filters
- Biofiltration/Bioretention Filters

2.3 Pollutant removal mechanisms

Despite categorisation differences and various names for specific techniques, the main tasks of SUDS can be summarised as follows (EPA, 1999):

- To control the flow - volume and intensity - of urban water discharges.
- To remove pollutants:
    - ~ To remove suspended particulates from the water column by gravitational settling.
    - ~ To remove low-density particulates such as paper or foamed polystyrene in the process of flotation.
    - ~ To remove particles by filtration through porous media.

  - ~ To infiltrate water - to reduce the volume of runoff and remove pollutants.
  - ~ To adsorb specific elements such as dissolved metals and incorporate them into underlying soils, such as clay.
  - ~ To remove nutrients by biological uptake.
  - ~ To convert organic contaminants in biological processes by microorganisms.
  - ~ To degrade organic compounds such as pesticides or herbicides by the processes of hydrolysis, volatilization and photolysis.
- To control pollution at source and control the amount of pollutants entering storm water runoff.

In the UK, the Environment Agency prepared an Interim Code of Practice for SUDS to help local authorities and developers implement SUDS (EA, 2004).

It describes the preparation and planning route, as well as current legislation and industry requirements for SUDS. The popularity of SUDS has resulted in the CIRIA Design Manual for England and Wales (CIRIA, 2000a), Sustainable Urban Drainage systems - design manual for Scotland and Northern Ireland (CIRIA, 2000b) and The SUDS Manual (Woods Ballard and Kellagher, 2007); this now replaces the previous manuals.

In 2005 a Drainage Assessment Guide for Scotland was created explaining the changes in the Water Environment and Water Services Act 2003 (SEPA, 2005), which introduces SUDS usage in Scotland.

As a detailed description of SUDS is beyond the scope of the thesis, further information will focus on PPS, GSHP and the experiment itself.

3 Permeable Pavement Systems

In this chapter PPS will be described in detail. Design types, lifespan, maintenance, current research and hydraulics assessed previously are described providing a broad picture of the systems.

Permeable pavement systems (PPS) **(Figure 3-1)** are suitable for a wide variety of residential, commercial and industrial applications; however they are confined to light duty and infrequent usage, even though the capabilities of these systems allow for such uses as Heavy Goods Vehicles (HGVs) parking space provision.

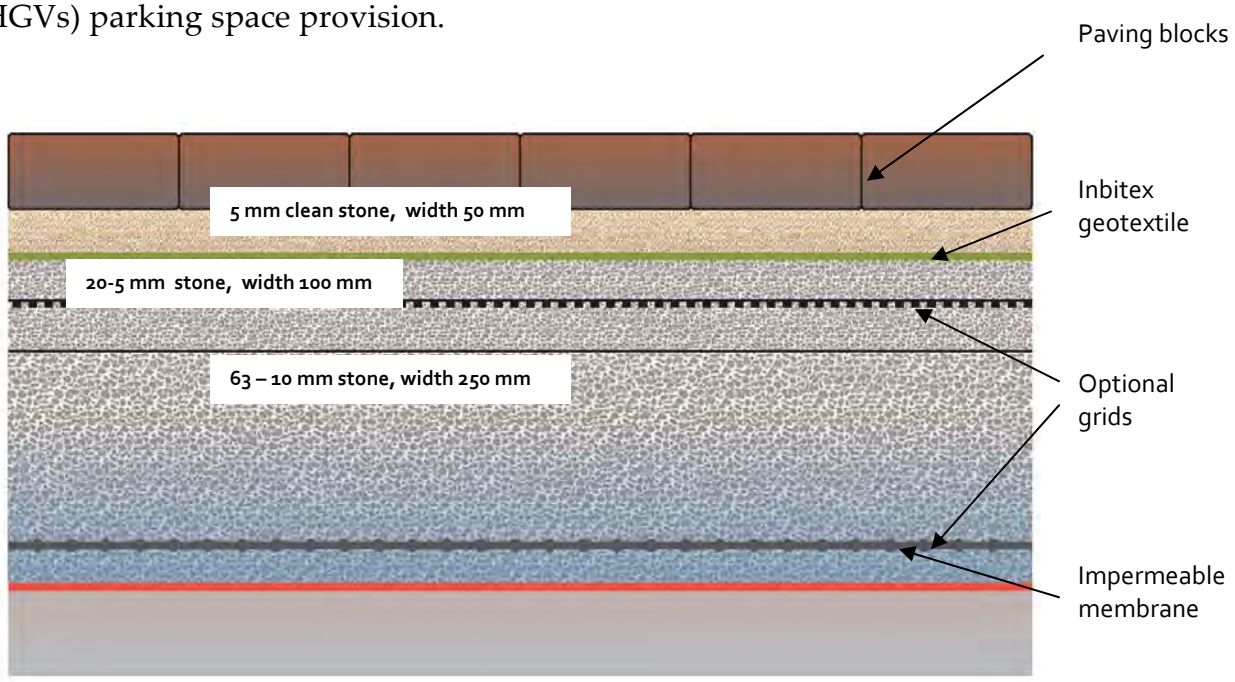


Figure 3-1 Detention sub-base structure with permeable geotextile
(Source: Formpave, 2004 - changed).

Where there is any concern about the possible migration of pollutants into the groundwater, PPS should be constructed with an impermeable

membrane, and the treated storm water should subsequently be discharged into a suitable drainage system (Wilson, 2003).

The current maintenance recommendation for PPS is machine swapping after the first 12 months and every 6 months thereafter (Formpave, 2004).

Common applications of PPS can be summarised as follows:

- Vehicle access: residential driveways, service and access driveways, roadway shoulders, crossovers, fire lanes, and utility access;
- Slope stabilization and erosion control;
- Golf courses (cart paths and parking);
- Parking (church, employee, overflow, airport and event);
- Pedestrian access;
- Bicycle and equestrian trails; and
- Land irrigation.

Some of the examples are presented in **Figure 3-2.** The first part of the figure presents the application in a garden centre where water is being collected in a tanked system and recycled for plant watering and landscaping (fountains). The second example presents a typical PPS application - car parking spaces.

Figure 3-2 Two examples of PPS applications in UK
(courtesy of Formpave Limited).

The general principle of PPS is to collect, treat and infiltrate free surface runoff to support groundwater recharge or direct treated runoff to open water streams. In comparison to traditional drainage systems, storm water retention and infiltration is a sustainable and cost effective process, which is suitable for urban areas (Andersen *et al.*, 1999; Dierkes *et al.*, 2002). PPS has many potential benefits such as reduction of runoff, recharging of

groundwater, saving water by recycling and pollution prevention (Pratt *et al.*, 1999).

Permeable pavement systems have not only been established as a solution for controlling flow, but also as a tool for control, concerning surface runoff from roads or parking spaces, where contaminated water may infiltrate into the soil. Harmful pollutants, such as hydrocarbons and heavy metals in surface runoff, have the potential to endanger soil and groundwater resources when they are not sufficiently biodegraded and/or removed during infiltration (Dierkes *et al.*, 2002; Brattebo and Booth, 2003).

Reductions in suspended solids, biochemical oxygen demand, chemical oxygen demand and ammonia levels in comparison to highway gullies not only demonstrate the high treatment efficiency of PPS, but also that there is no need for frequent maintenance, unlike with gully pots (Pratt, 1999).

Hydrocarbon pollution and mineral oil deposition onto urban surfaces have been effectively addressed by PPS. Research has also shown that the structure itself is an effective in-situ aerobic bioreactor (Pinado *et al.*, 1999).

3.1 Pollutant removal efficiencies

Impervious surfaces have a high potential for introducing pollution to watercourses. Possible water quality variables of concern include the following (D'Arcy *et al.*, 1998; NCDENR, 2005):

- Sediment and suspended solids (including phosphorus and some metals);
- Organic waste with high biochemical oxygen demand;

- Dissolved nutrients and pollutants (including nitrogen, heavy metals, solvents, herbicides and pesticides);
- Oil and grease;
- Faecal pathogens.

Permeable pavements have a good track record of removing suspended solids and nitrogen. However, PPS, which do not rely on below ground infiltration and the use of an underdrain system, will not be successful in the removal of nitrogen. When an underdrain system is incorporated into the pavement design, storm water tends not to infiltrate into the soil, but into the underdrain, where it can be denitrified or removed by plant uptake (NCDENR, 2005).

Along with atmospheric contaminants, harmful pollutants can also be emitted by roof materials and road surfaces. Hydrocarbons, lead and copper show the highest pollutant concentrations. Rainwater gutters and associated pipes often consist of zinc-coated sheets or copper. Metal roofs usually show high concentrations of heavy metals in the corresponding runoff, if not cleaned prior to discharge (Dierkes *et al.*, 2000).

Dierkes *et al.* (2000) summarized possible ranges of pollutant concentrations in rain as well as roof and road runoff, taken from more than 60 sites throughout Europe. Rain may contain sulphate, chloride, ammonia and phosphate. Phosphorous and inorganic nitrogen concentrations are generally lower than those of organic substances. These pollutants are potentially harmful to receiving waters. Runoff from roads usually contains higher pollutant concentrations than roof runoff (Dierkes *et al.*, 2000).

The Waste Water Treatment EU Directive 91/271/EEC (EU, 2008) set the requirements of BOD concentrations in waste water discharges from water treatment plants of 25 mg/l, less then 1 mg/l of total phosphorus and less then 10 mg/l of total nitrogen (for communities of more then 100,000 residents). It will be proven that the above requirements are fulfilled by PPS.

3.1.1 Hydrology and hydraulics

Tests have shown that evaporation, drainage and retention within the permeable structures were mainly influenced by the particle size distribution of the bedding material, and by the retention of water in the surface blocks (Andersen *et al.*, 1999).

Movement of water through the porous permeable installation is controlled by surface runoff, infiltration through the pavement stones, percolation through the unsaturated zone, lateral drainage at the base and deep percolation through the sub-grade. There are three possible outcomes for precipitation reaching the surface of a PPS installation (James and von Langsdorff, 2003):

- Infiltration to the base material;
- Evaporation;
- Runoff (overland flow).

In designing a permeable pavement installation, it is important to provide and maintain surface infiltration and storage capacity to allow an adequate volume of storm water to be captured and treated by the facility. James and von Langsdorff (2003) describe the underlying method and function of a computer program, which uses the United States Environmental Protection Agency Storm Water Management Model (SWWM) for the hydraulic design of permeable pavement installations.

In comparison to conventional asphalts, permeable and porous pavements provide more effective peak flow reductions (up to 42%) and longer discharging times. There is also a significant reduction of evaporation and surface water splashing (Booth and Leavitt, 1999; Pagotto *et al.*, 2000; Abbot *et al.*, 2003).

It is important to highlight the difference between porous and permeable types of blocks. The first technique allows water percolation through the paving block, as it is porous, and the second technique does not allow for such water movement. Permeable blocks are not porous and water infiltration occurs 'between' the blocks using specially designed cuts.

Infiltration through the permeable pavement stones and the bedding layer is usually modelled using the Green-Ampt equation, which has physically-based parameters that can be predicted. Infiltration is related to the volume of water infiltrated, and to the moisture conditions in the pavers and bedding layer (James and von Langsdorf 2003).

Percolation represents the vertical flow of water from the unsaturated to the saturated zone of the base layer, and is the only inflow source to the

saturated zone. If system is not lined, lateral inflow can be introduced from surrounding area. This is not the case in the experiment.

Base layer discharge represents lateral flow from the saturated zone of the base to the receiving water. Deep percolation represents a lumped sink term for not quantified losses from the saturated zone of the base. Two primary losses are assumed to be percolation through the confining layer and lateral outflow to somewhere other than the receiving water (James and von Langsdorff, 2003).

Concrete grid pavers and permeable interlocking concrete pavers were tested for infiltration at North Carolina State University, USA, with pavement ages ranging between 0.5 and 20 years. Analysis of the data showed that appropriate maintenance improved permeability on 13 out of 14 sites at a confidence level of 99.8%. Sites built in close proximity to loose fine particles had infiltration rates significantly less than sites free of loose fine particles. Even the minimum existing infiltration rates were comparable to those of a grassed sandy loam soil (Bean *et al.*, 2004).

In addition, the surface infiltration rates of 48 PPS sites were tested in North Carolina, Maryland, Virginia and Delaware (Bean *et al.*, 2004). Maintenance consisted of removing the top layer (13-19 mm) of residual material. The location of PPS and their maintenance were critical to maintaining high surface infiltration rates

In tanked systems maintenance, water quality and water level control can be performed using manholes - **Figure 3-3**.

Figure 3-3 Collection chamber in tanked system provides sub-base water level control and appropriate maintenance
(courtesy of Formpave Limited).

Caoi *et al*. (1998) provided a method to determine the amount of infiltration, and the storage capacity of a permeable base relative to the time of retention and degree of saturation associated with the characteristics of the base. Their guidelines contain a step by step process for engineers to select the best pavement option in terms of base materials and gradients for given drainage, sub-grade strength conditions, and the criteria for maximum allowable rutting (wheel deformation).

Infiltration supports groundwater recharge, decreases groundwater salinity, allows smaller diameters for sewers (resulting in cost reduction) and improves the water quality of receiving waters, because pollutants and high peak flow are effectively controlled. On the other hand, pollutants in

runoff originating from domestic and industrial emissions and traffic threaten soil and groundwater, if they are not removed from runoff before it infiltrates into the ground (Dierkes *et al.*, 2002).

3.1.2 Metal removal in PPS

Studies have shown an improvement of water quality by filtration through PPS, which work well in removing suspended solids and particularly heavy metals from runoff. For example, Legret *et al.* (1996) have shown that suspended solids and lead can be reduced by PPS up to 64% and 79%, respectively. Similar findings were reported by Pratt *et al.* (1995).
PPS research findings summary is presented in **Table 3-1**.

Table 3-1 Selected PPS research findings in literature.

Authors	Duration	Sample number (n)	Removal efficiency
Legret *et al.* (1996)	4 years	30 rain events	64% and 79% SS
Pratt *et al.* (1995)	300 days	300	97% Motor oil reduction
Brattebo and Booth (2003)	5 years	12 storm simulations	Motor oil not detected in 89% of samples
Bean (2007)	26 months	15	86% NH_4, 88% Zn, -48% NO_{2+3}, 65%
Kadurupokune and Jayasuriya (2009)	17 years	-	63% TN, 53% TP, 95% SS, 85% Oil, 94% Cu

Kellems *et al.* (2003) showed that BMPs enhanced filtration on industrial sites was an effective treatment to chemical precipitation for the treatment of storm water. Filtration through a specific adsorbent organic medium, for example, can remove about 95 percent of dissolved copper and zinc.

In comparison to pavements made of asphalt, outflow concentrations of zinc, copper and lead were significantly lower on permeable structures (Brattebo and Booth, 2003). Lead concentrations were in fact undetectable. A PPS should be cleaned regularly to prevent clogging.

PPS are efficient in trapping dissolved heavy metals in surface runoff (Dierkes *et al.*, 2002), but not all pavers and joint fillings have the ability to trap dissolved heavy metals. Pavements with large joints for infiltration must have a suitable joint filling. Otherwise, metals will pass through them, and may subsequently enter groundwater.

Particles usually accumulate in geotextiles and on pavement surfaces. Geotextiles usually separate micro-pollutants such as cadmium, zinc and copper from the underlying soil, thereby preventing groundwater contamination (Legret *et al.*, 1996).

Geotextiles are one of the most important components within PPS (Newman, 2003; Omoto *et al.*, 2003; Spicer *et al.*, 2006). Geotextiles extend the durability and structural performance of the sub-base (Omoto *et al.*, 2003), enhancing microbial growth and providing increased pollutant removal efficiency (Coupe, 2004a).

3.1.3 Hydrocarbon removal in PPS

Oil and diesel fuel contamination on asphalt is found in almost 90% of road runoff samples. In comparison, these contaminants were not detected on PPS surfaces assessed by Booth and Brattebo (2004). Hydrocarbons can endanger soil and groundwater, if they are not removed sufficiently during infiltration through the surface layer (Dierkes *et al.*, 2002). Many pollutants such as polycyclic aromatic hydrocarbons, metals, phosphorous and organic compounds are absorbed into suspended solids; therefore their seizure on PPS filter or retention at the sub-base would eliminate harmful pollutants and store them as sediments, which would be treated further in biochemical processes.

For various PPS types, Booth *et al.* (1998) showed that infiltrated water had significantly lower levels of copper and zinc in comparison to the direct surface runoff from the asphalt area. Motor oil was detected in 89% of samples from the asphalt runoff, but not in any outflow water samples from the PPS. Diesel fuel was not detected in any samples.

PPS infiltrate measured five years earlier displayed significantly higher concentrations of zinc, and significantly lower concentrations of copper and lead (Booth *et al.*, 1998), which could be caused by introduction of roof runoff containing increased levels of zinc from metal tiles or external zinc polluting source.

Permeable pavements can operate as efficient hydrocarbon traps and powerful in-situ bioreactors. Coupe *et al.* (2003) showed that a PPS specifically inoculated with hydrocarbon-degrading micro-organisms does

not successfully retain a viable population of organisms for the purpose of increased hydrocarbon degradation over many years. This concludes that there is no need for additional inoculation and the biochemical processes occurring naturally would allow for adequate pollutant removal.

For the successful biodegradation of polycyclic aromatic hydrocarbons, certain environmental conditions need to be met. Degradation takes place when prolonged anaerobic, sulphate reducing and denitrifying conditions occur (Lei *et al.*, 2005). Very large hydrocarbon spills can be contained due to absorption processes within the pavement (Newman *et al.*, 2004).

Wilson *et al.* (2003) incorporated an oil interceptor into a porous surface construction. Tests were carried out for worst-case scenarios such as the worst possible combined pollution and rainfall event to assess how the system retains pollutants within its structure. The results demonstrated that the system can contain hydrocarbons, and can offer improved water quality outflow. Where certain detergents are present in the pavement system, they can cause contamination of the outflow water, which may require secondary treatment to improve its water quality.

3.2 Microbial processes in PPS

Permeable pavement systems are powerful in-situ bioreactors, which can reduce hydrocarbon contamination by 98.7%. Biodegradation in PPS is enhanced by bacteria and fungi (Coupe *et al.*, 2003; Coupe, 2004b). When inoculated with microorganisms, the protozoan population diversity increases more rapidly than in similar non-inoculated systems. This lead to

the conclusion that inoculated rigs would provide enhanced pollutant removal efficiencies. Further research had proven the above statement as false (Coupe *et al.*, 2003). Pavements also contain protozoan communities such as testate amoebae, ciliates, flagellates and gymnamoebae. The understanding of microbial biodiversity helps to interpret biodegradation mechanisms (Coupe *et al.*, 2003).

Permeable pavement systems have the capacity to degrade large quantities of clean motor oil. Bio-treat HD, a commercially available oil degrading microbial mixture, will not degrade oil any better that the local microbial biomass established within the pavement over a long period of time. The local microbial biomass can only achieve high degradation rates if there is an adequate supply of nutrients (e.g., nitrogen and phosphorous) in the feed. Monitoring of biofilm development through scanning electron microscopy has revealed that a PPS can obtain a high degree of biodiversity due to the development of complex microbial compositions (Newman *et al.*, 2002).

The assessment of the microbiological water quality has been an important process in preventing waterborne diseases. The two most common tests carried out are for coliforms and *Escherichia coli*, or faecal coliforms (Barrell *et al.*, 2000).

Microbiological analysis in the research is conducted in order to identify pathogenic organisms that may be transferred from the sub-base to end

user. This could be a potential public health risk especially when PPS-GSHP installations in open access spaces, such as airports or shopping malls.

Total coliforms, faecal coliforms, faecal *Streptococci*, heterotrophs, fungi, *Pseudomonas aeruginosa*, *Leptospira*, *Salmonella sp* and viruses are often analysed in an attempt to determine the temporal distribution of bacterial pathogens and viruses in storm water runoff. However, findings usually show that it is not possible to accurately predict the time when peak microbial populations including human pathogens occur in runoff waters (Sato *et al.*, 1995).

Some pathogenic organisms found in wastewaters are (Gerardi and Zimmerman, 2005):

Actinomyces israelii, *Clostridium perfringens*, *Clostridium tetani*, *Escherichia coli*—Enteroinvasive, *Escherichia coli*—Enteropathogenic (ETEC), *Escherichia coli*—Enterotoxigenic, *Escherichia coli*—enterohemorrhagic O157:H7, *Mycobacterium tuberculosis*, *Nocardia sp*, including *N. asteroides*, *N. caviae*, and *N. brasiliensis*, *Salmonella sp*, *Salmonella paratyphi*, *Salmonella typhi*, *Shigella sp, Vibrio cholerae, Vibrio parahaemolyticus, Yersina enterocolitica*.

Microbes assessed in this research were limited to the following organisms: *Salmonella sp* and *Shigella sp, Escherichia coli* and *Enterococcus faecalis* (group D Streptococcus).

The World Heath Organization's Water Quality Standards and Health Guidelines recognize three groups of indicator organisms (World Health Organisation, 2001):

- process indicators - represent the quality and efficiency of water disinfection;
- fecal indicators – infer the presence of pathogens resulting from fecal contamination;
- index and model indicators – groups of species indicating the presence of pathogens presence e.g. *Escherichia coli* as indicator of *Salmonella sp* presence.

Bacterial numbers and characteristics will be described in the next chapters.

Two types of pathogenic bacteria have been distinguished (Gerardi and Zimmerman, 2005): true pathogens (e.g. *Shigella sp, Vibrio cholerae*) and opportunistic pathogens (e.g. *Aeromonas hydrophilia, Escherichia coli, Mycobacterium avium,* and *Pseudomonas aeruginosa*). The main difference between them is that the first type of bacteria is aggressive and transmitted from human to human, animal to human or animal waste to human. The opportunistic type of pathogens are usually found in human organisms and the outbreak of the disease is caused by an increase of their numbers in the body or by weakening of the immune system.

Generally speaking Minimal Infective Dose (MID) varies greatly between pathogenic species, usually more than 10,000 cells is needed, in order to cause disease, although Bitton (2005) determines minimal infective doses for some pathogens in much lower levels, i.e.: *Shigella sp* 10^1 – 10^2, Escherichia coli O157:H7 <100, *Vibrio cholerae* 10^3, *Campylobacter jejuni* – 500).

Species chosen for this PhD occur naturally and may be found in waters such as lakes, rivers or ponds. As it is impossible to mention all species, only the most important for human health prevention have been described.

The main diseases caused by the examined microbes are as follows:

- *Salmonella sp* is classified as a hazard group 3 organism, according to the Advisory Committee on Dangerous Pathogens (ACDP) (Health and Safety Executive, 2004). Usually infection with the organism causes abdominal pain, fever, vomiting, nausea and fluid loss. In the case of typhoid malaise, aches and pains and maculopapular spots can occur in addition to the above. It should be treated with antibiotics. Lack of treatment can lead to delirium and death (Hunter, 1997).
- *Shigella sp*, an ACDP group 2 organism, causes various diseases depending on the strain. Usual symptoms include diarrhoea, vomiting, fever, abdominal pain, meningitis (very rare), headache, and dehydration. In hard cases bleeding and mucus formation can occur. As a result, post–infection may lead to hemorrhoids and Reiter's syndrome. Severe diseases are usually associated with Shigella dysenteriae and may cause gangrenous cholera-type form and lead to death. (Hunter, 1997).
- *Esherichia coli* (an ACDP group 2 organism) can cause dehydrating diarrhoea in children and fever and persistent diarrhoea for up to 14 days in developing countries depending on the strain. Diarrhoea can cause bloody stools and abdominal pain. In extreme cases rising

levels of serum urea and creatinine can occur, leading to anemia or thrombocytopenia (Varnam and Evans, 1996; Hunter, 1997)

- *Enterococcus faecalis* (group D Streptococcus) can cause symptoms such as diarrhoea, dehydration and fever. It can also cause bladder, prostate and epididymal infections, but very rarely causes Central Nervous Sysytem infections (Hunter, 1997).

Legionella pneumophila presence was not assessed in the research, but as concerns regarding the organism grow, future research might include it in further analyses. This organism is extremely important as it occurs in cooling towers and AC systems, and there is a possibility of finding it at the bottom of PPS sub-base during cooling. The bacteria are the cause of legionnaire's disease, causing pneumonia with a high death rate. It is usually transmitted via aerosols and vapors distributed within the active area of infection (Bitton, 2005).

In addition to the occurrence of bacterial communities, Coupe (2004a) identified the protozoan communities found in PPS, such as flagellates, gymnamoebae, ciliates and amoebae. Some of these organisms are pathogenic, but they also play a role as predators within the water community, as they feed on bacteria and fungi. The diversity within PPS protozoan organisms included *Monosiga*, *Colpoda*, *Acanthamoeba* and *Euglypha rotunda*, which were present on the geotextile (Coupe, 2004b). The same studies also identified the following organisms in PPS sub-base:

- Geotextile: *Heteromita globosa, Acanthamoeba sp, Colpoda sp*
- Gravel: *Bodo saltans*

- Concrete: *Heteromita globosa*
- Granite: *Heteromita globosa, Monosiga, sp, Salpingocea sp, Amoeba sp, Acanthamoeba sp, Cntopyxis aerophila, Euglypha rotunda, Colpoda sp, Lembadion sp, Vorticella sp*
- All components: *Heteromita globosa, Acanthamoeba sp.*

Flagellates were the organisms most commonly found within the PPS profiles in all levels. The next in numbers found, were ciliates and amoebae.

The above chapter provided evidence of a good record on PPS in removing pollutants from urban runoff. It described a wide variety of PPS usage as well its complicated environment, being a combination of sub-surface, saturated and un-saturated conditions, allowing for rich and diverse microbial communities.

4 Ground Source Heat Pumps (GSHP)

The second technique used in PPS-GSHP research is of a different matter, designed for energy saving and heat storage. The following section describes types and designs in detail, explaining these types and methods for GSGP efficiency calculations.

GSHP are established technologies, capable of providing high efficiencies for heating and cooling, employing the renewable storage capacity of the ground (Curtis *et al*., 2005).

It has been widely recognized as an alternative to fossil fuel systems as it offers a very significant reduction in CO_2 emissions related to the cooling and heating of buildings (Healy and Ugursal, 1997; Esen *et al*., 2006).

Recent estimates and forecasts for energy consumption in developing countries are expected to increase exponentially by the year 2020 as a result of set economic development targets (Lior, 2008).

This shows the urgency for developing more sustainable and renewable technologies such as GSHP.

GSHPs use the constant temperature of the earth to provide heating, cooling and domestic hot water for homes, schools, government and commercial buildings. It transforms the earth's energy into useful energy by providing low temperatures of heat extracted from the ground for heating purposes or a body of water for reversing the process of cooling (Healy and Ugursal, 1997; Hepbasli, 2005). In short, stable temperatures of

the ground provide constant source for air and water heating or cooling in different seasons.

A GSHP system consists of three major components (Kavanaugh and Rafferty, 1997):

- a heat pump,
- an earth connection and
- an interior heating or cooling distribution system.

The basics of GSHP workability is presented in **Figure 4-1**.

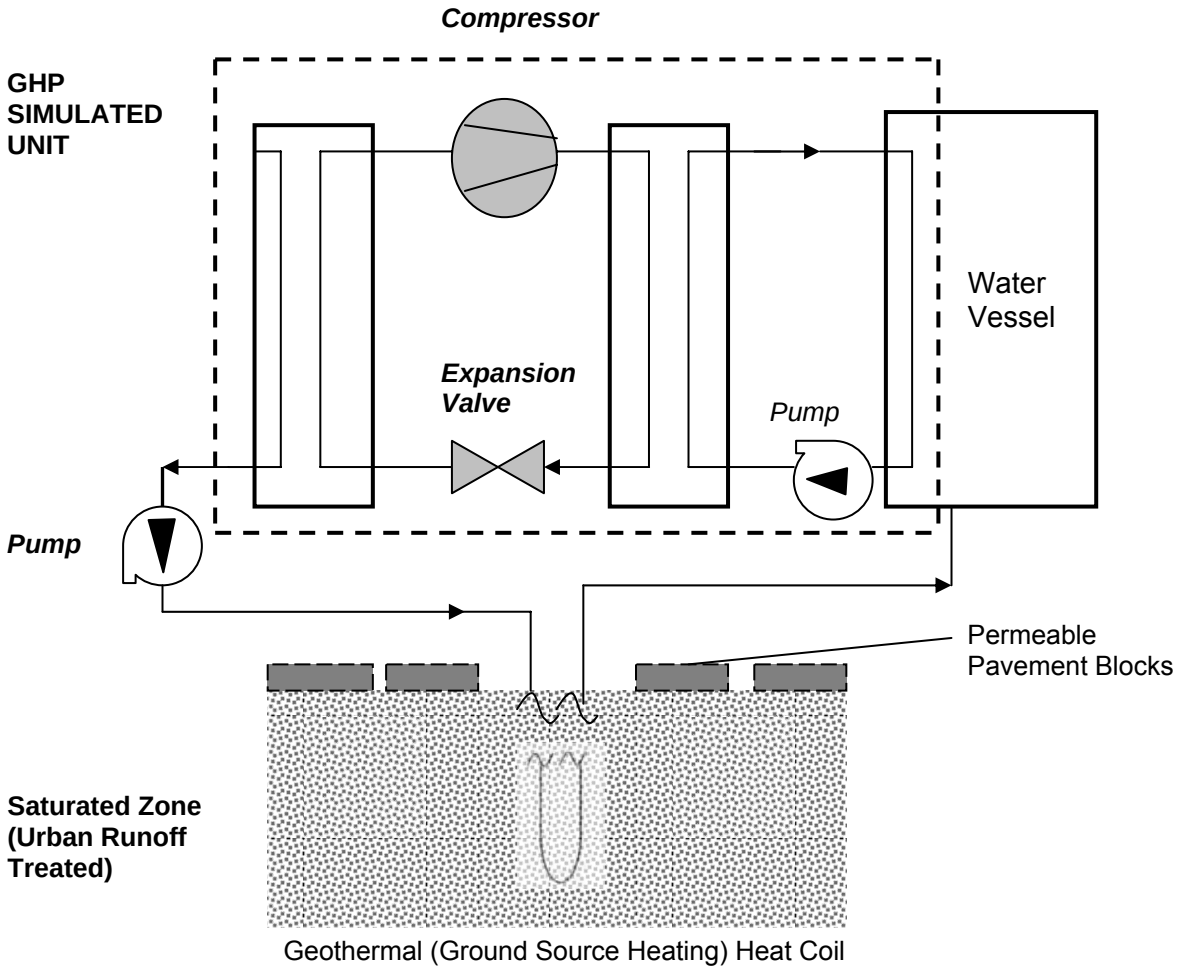


Figure 4-1 Basic rule of GSHP workability.

In conventional GSHP installations, coils are buried in the ground or placed under water (pond-type installation). The more moisture in the surrounding environment, the better conductivity of the system is; hence, saturated or water environments are preferred. Tanked PPS provide these conditions despite the surrounding types of soil, allowing for combined usage of PPS and GSHP.

The earth connection is where heat transfer between the GSHP system and the soil occurs and the heating/cooling distribution system delivers heating or cooling from the heat pump to the building (**Figure 4-2**).

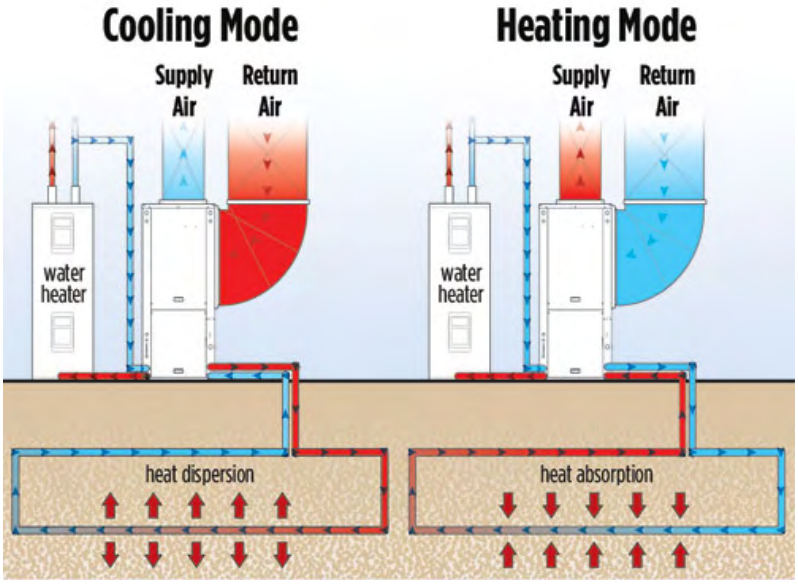


Figure 4-2 Heating and cooling mode using GSHP.
(Source: http://www.waterfurnace.com/popups/heat_transfer.aspx)

For ground connections, plastic pipes are installed within the soil or underground water reservoir. In PPS-GSHP applications the coils are kept within PPS sub-base in saturated environment because of increased conductivity and improved performance of GSHP.

The main thermal carrier within the coils is a mixture of water and antifreeze. The length and width of the loops is determined by the ground conductivity properties. The most important variables are the type of soil, geology and area of available land for such installations.

In heating mode, the water temperature of the coil (soil temperature) is higher than in-building air temperature and in cooling mode the cycle is reversed – water temperature carried from the ground is lower than the air temperature.

Applying GSHP can lead to 54% reductions in CO2 emission in comparison to air-source heating pumps (Genchi *et al.*, 2002). Energy bills for domestic applications can be reduced between 30% and 70% during the heating mode and between 20% and 50% during the cooling mode (Bose, 2005). GSHP reduce gas emissions by 66%. They also use 75% less electricity than conventional AC systems (Omer, 2008).

4.1 Types of GSHP

GSHP systems can be grouped into two types: closed-loop and open systems. The closed-loop systems circulate a fluid through a subsurface loop of pipe and then to the heat pump (Kavanaugh and Rafferty, 1997; Lund *et al.*, 2004)

Open systems (groundwater heat pump systems) circulate groundwater to the heat pump and then discharge it (Curtis *et al.*, 2005).

The most usual applications can be classified as follows (Sanner *et al.*, 2003; Omer, 2008):

- **Horizontal heat exchangers** are usually used in closed loop systems. Because of the area availability, these are usually packed in coils. They are usually laid in the excavation after previous top soil removal (**Figure 4-3**) and then buried in the ground. As the main source of energy in these systems is the sun, it is important to keep the area clear of any obstacles. The main advantage of this system is greater efficiency and flexibility. The disadvantage is that seasonal variance has a large impact on ground, temperature although it is much less expensive than borehole drilling. However, weather parameters such as precipitation events or soil dryness might have direct impacts on the system's workability
- **Spiral loops** are a modification of the horizontal type called 'slinkies'. The pipes are laid in the trench as rolled coils. This type of layout is the most common in PPS. One variation is to place the coils in vertical trenches in the upright position. These require more piping, and pumping energy but less space. It is also easier to damage the piping during trench re-filling.
- **Vertical loops** are installed in very deep boreholes which are either filled with a pumpable material or are left open so the underground water acts as a heat exchanger between pipes and the soil/rock. The bore holes are usually filled with a pair of U-pipes. This type of installation is used when there is a very limited area although the costs of borehole drilling make it very expensive. Seasonal

temperature changes are not an issue as the boreholes are usually drilled to a depth of 23-92 m.

- **Submerged loops** are possible for an installation if a lake, pond or any other large water reservoir is available. The pipes are submerged and fitted to large concrete anchors, which keep the pipes below the water surface. The main advantage is the reduction of installation costs when using this type of application.
- **Open loop systems** use local surface or ground water as the heat-transferring fluid. Pumped water is being re-injected into the well or surface water reservoir, recycling water and lowering the costs of the installation. Water quality and water availability are the major considerations for decision-makers in the application of these systems. The first will determine clogging and corrosion of pipes and equipment and the second determines the flow rates that can be used. An additional factor impacting the feasibility of such installations is local water regulations because of water discharges.

  The main technical disadvantage of the application is the need for two wells – one for water collection and another for water injection ('doublette').

All of the above GSHP types are subject to local environmental conditions, installation costs and conductivity of local soils.

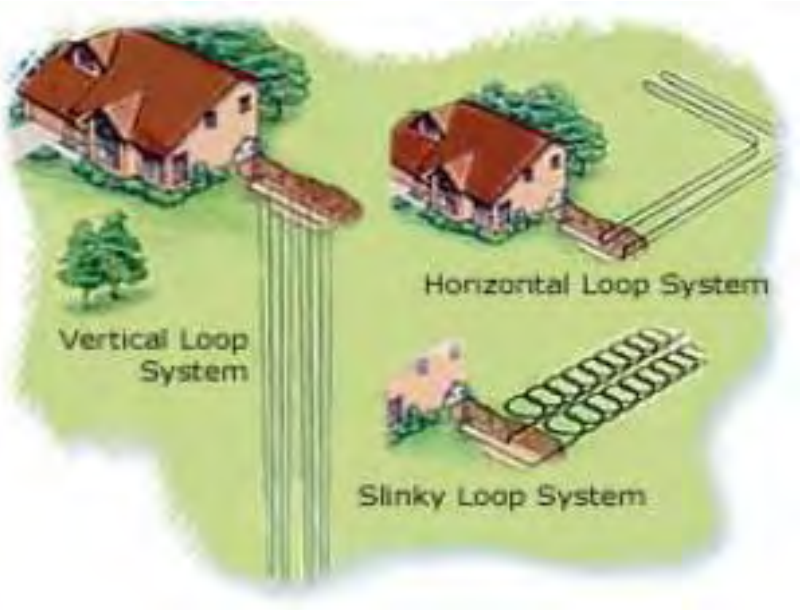


Figure 4-3 Different GSHP designs existing in practise
(Source: http://www.devondare.org/geothe15.jpg)

4.2 The energy efficiency of GSHP

To assess the energetic efficiency of the geothermal heat pump process, the ratio of the available useful heat produced by the system is compared to the energy that must be fed into the system (Wark, 1999).

The efficiency of GSHP units is described by the Coefficient of Performance ($COP_{heating}$) in the heating mode and the Energy Efficiency Ratio ($EER/COP_{cooling}$) in the cooling mode, which is the ratio of the output energy divided by the input energy (work done by compressor and pumps) and varies from 3 to 6 with present equipment (the higher the number, the better the efficiency) (Healy and Ugursal, 1997; Hepbasli, 2005).

COP and EER, in essence, depend on the difference in temperatures between the source of heat and the heating system, which needs to be overcome (Hepbasli and Akdemir, 2004).

GSHP Energy Efficiency Ratings EER differ depending on the individual application but usually heating COP (Coefficient of Performance) applications range from 3.0 to 4.0 and cooling EER between 11.0 and 17.0, although the closed-loop applications have COP of 2.5-4.0 and EER of 10.5-20.0 (Omer, 2008).

According to the first law of classical thermodynamics in a reversible system (Cengel and Boles, 2007):

$$Q_{(\text{Heat Supplied})} = Q_{(\text{Heat Rejected})} + W_{(\text{Net Work Input})} \quad (1)$$

Here Q is the useful heat supplied by the condenser and W is the work consumed by the compressor and pumps. The amount of work is always less than the heat supplied or heat rejected, and COP or EER is thus always greater than unity. The smaller difference in temperatures between the heat source and the heating system, the better the COP or EER (Hepbasli *et al.*, 2003; Inalli and Esen, 2004).

GSHP in the constructed system can be assumed to follow a reversed cycle (Carnot) to supply heat at an elevated temperature at the expense of work done on the working fluid (Cengel and Boles, 2007).

In a reversed Carnot cycle, a wet vapour is compressed isentropically and passed to the condenser. Then the fluid is expanded to its original pressure and evaporated at constant pressure to the initial state (Cengel and Boles, 2007).

The Coefficient of Performance COP in a heating mode for a reversible inverse Carnot Cycle and the Energy Efficiency Ratio EER (Wark, 1999; Cengel and Boles, 2007) for the cooling mode is given by

$$COP_{heating} = \frac{Q_{HeatSupplied}}{W_{NetWorkInput}} \tag{2}$$

$$The\ Energy\ Efficiency\ Ratio\ EER\ or\ COP_{cooling} = \frac{Q_{Heat\,\mathrm{Re}\,jected}}{W_{NetWorkInput}} \tag{3}$$

By substituting the Work done, $W_{\text{Net Work Input}}$ into equations (3) and (4),

$$COP_{heating} = \frac{Q_{HeatSupplied}}{Q_{HeatSupplied} - Q_{Heat\,\mathrm{Re}\,jected}} \tag{4}$$

In addition,

$$EER\ or\ COP_{cooling} = \frac{Q_{HeatSupplied}}{Q_{HeatSupplied} - Q_{Heat\,\mathrm{Re}\,jected}} \tag{5}$$

When the GSHP is operating at a maximum theoretical efficiency (i.e. Carnot efficiency) (Hepbasli *et al.*, 2003; Hepbasli and Akdemir, 2004; Inalli and Esen, 2004; Hepbasli, 2005)

$$\frac{Q_{HeatSupplied}}{T_{Max}} = \frac{Q_{Heat\,Re\,jected}}{T_{Min}}, \tag{6}$$

Where T_{Max} is the maximum temperature of the hot reservoir (Heat Supplied) and T_{Min} is the minimum temperature of the cold reservoir (Heat Rejected).

By substituting $\frac{Q_{HeatSupplied}}{Q_{Heat\,Re\,jected}} = \frac{T_{Max}}{T_{Min}}$ we get:

$$COP_{heating} = \frac{T_{Max}}{T_{Max} - T_{Min}} \tag{7}$$

and similarly

$$EER\ or\ COP_{cooling} = \frac{T_{Min}}{T_{Max} - T_{Min}} \tag{8}$$

4.3 Coefficient of Performance in heating and cooling (EER) mode

As the main characterisation of heat pumps is their Coefficient of Performance (COP) (Michopoulos *et al.*, 2007), using the maximum and minimum temperatures measured from the experimental rigs, the overall Coefficient of Performance for the heating cycle and Energy Efficiency Ratio for the cooling cycle were plotted against time and are presented here in **Figures 4-4 to 4-7**.

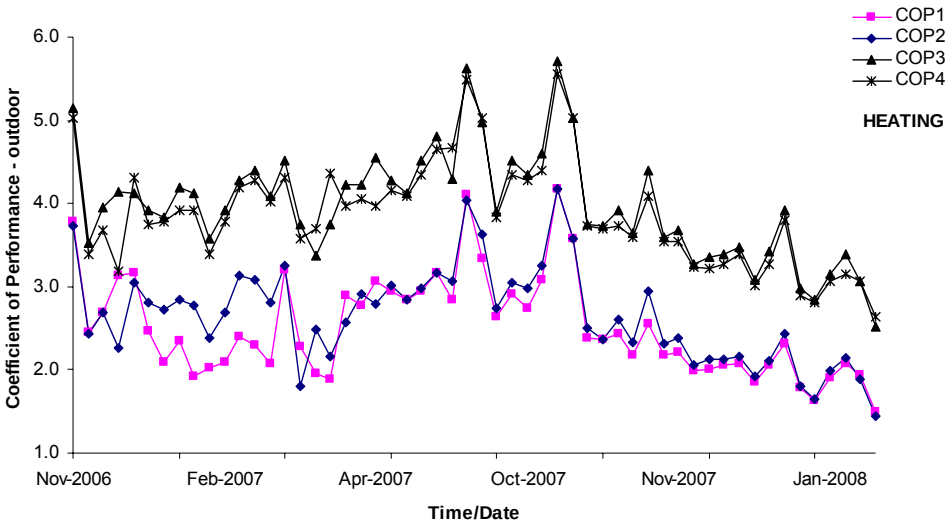


Figure 4-4 Coefficient of Performance – outdoor rig.

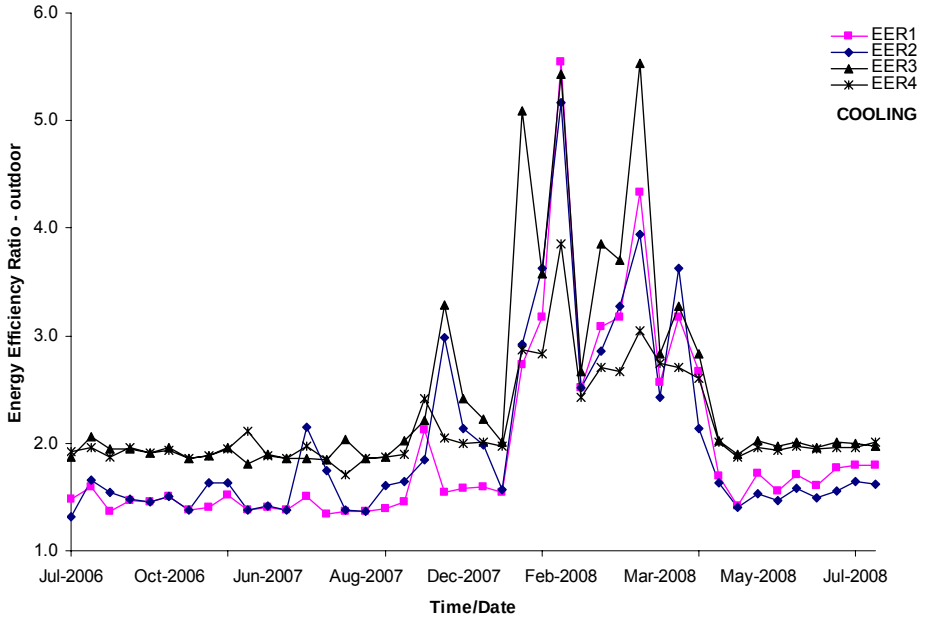


Figure 4-5 Energy Efficiency Ratio – outdoor rig.

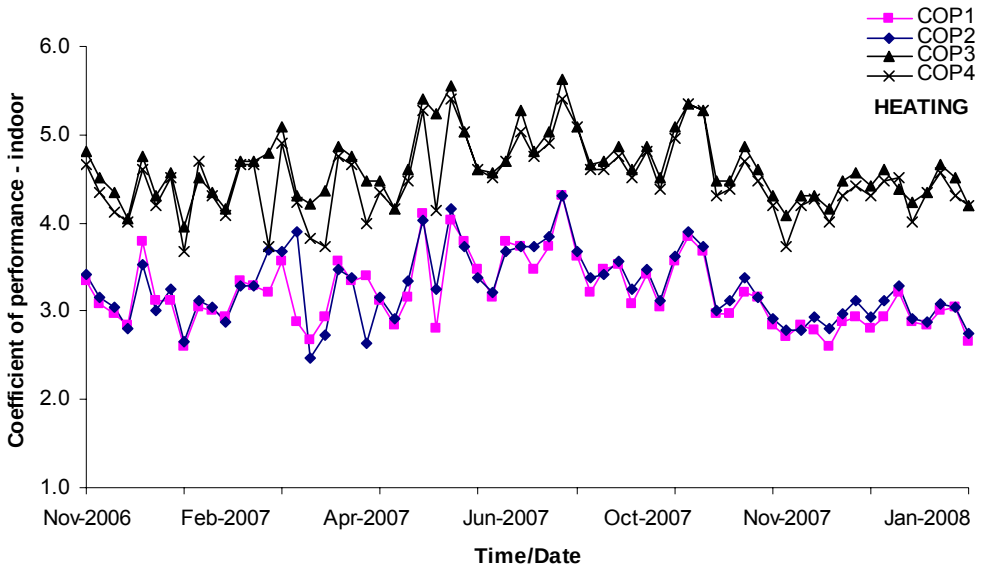


Figure 4-6 Coefficient of Performance – indoor rig.

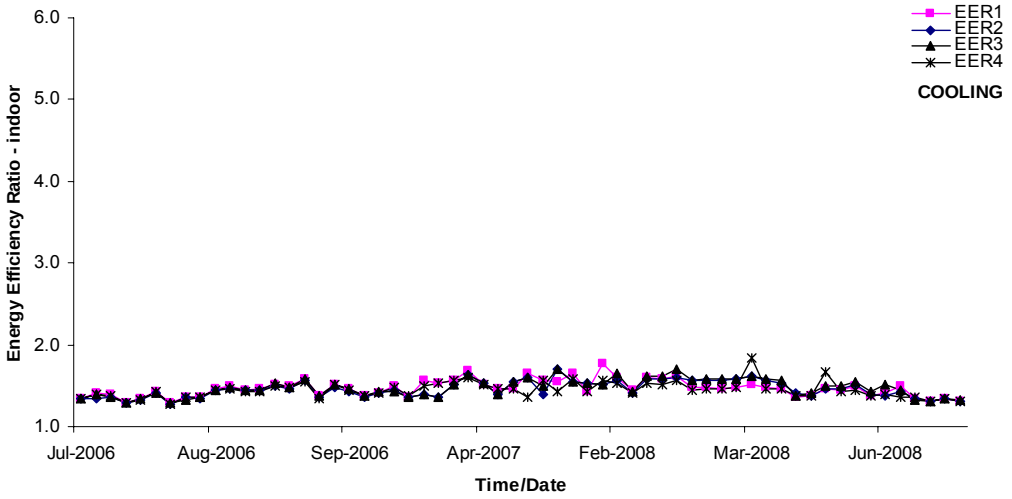


Figure 4-7 Energy Efficiency Ratio – indoor rig.

To further investigate the performance of the GSHP, the heating operation modes were used for different seasons throughout the year. The ground

source heat pump outdoor and indoor rigs were designed to follow the same pattern of temperature rise as in the case of the cooling mode.
More variability is found in outdoor rigs than in those indoors, as expected. The evidence for strong seasonal influence on system is found by high heating efficiency during the summer and more efficient cooling in the winter.

The values of COP (heating) were found to be 2.3-4.6 for the indoor rigs and 1.5-4.4 for the outdoor rigs, respectively.

The EER values for both indoor and outdoor experimental rigs were in the range of 1.3-1.8 for indoor bins and 1.5-5.5 for outdoor bins, lower than US values which range from 3-5 for heat pumps in a cooling cycle (United States Department of Energy, 2001).

Although the values are smaller than the ones reported in large scale applications they provide evidence of the realism of both systems because of their overall stability.

The above chapter provided information on current designs and complexity of GSHP. Different types of the systems are used depending on the local requirements as well as underlying geology and morphology. In order to achieve best results, soil conductivity is the most crucial parameter needed for a site assessment.

The correctness of experimental (small scale) design was proven by COP and EER calculations; however, these are not appropriate for industrial applications, though they are appropriate for laboratory scale work.

5 Materials and methods

In order to assess combined GSHP-PPS, these had to be built in a small scale, allowing for laboratory workability. Before setting the design, the researcher had to determine which of the parameters should be treated as the most important. At the same time, the research was designed to be novel and unique; therefore, one of the aims was not to repeat any previous research works (e.g., nutrient pollutants instead of hydrocarbons).

This chapter examines system design and workability, as well as techniques used to assess water quality (pollutant removals).

5.1 Experimental design and set-up

Because of the complexity of both systems their design and installation was planned based on previous experiments reported in the literature and also incorporated some new features.

The main features of the experimental systems were:

- two types of chosen pollutants (*Canis lupus familiaris* excrements and gully pot liquor);
- type of systems (tanked);
- integration of energy systems (GSHP systems) with existing water saving tools.

The timescale of the experiment was to cover at least 1 hydrological year, which was more than 2 years in practice.

Six indoor and six outdoor rigs were constructed at the university premises, with indoor rigs in a temperature controlled room with a constant temperature of 15^{o}C, and outdoor rigs exposed to strong temperature variability and unpredictable weather conditions.
The setup was designed for the similarity of procedures and mirroring sampling cells (bins) for statistical comparison at the end of the experiment.

At one rig, four bins were receiving a mixture of water and gully pot liquor. The remaining two were receiving water, gully pot liquor and animal faeces as a source for high levels of pathogenic organisms such as *Salmonella* and *Shigella.* Four bins were constructed with GSHP simulations and the remaining two were treated as control bins. None of the control bins received faeces.
Two bins in a rig with H/C coils were constructed with CO_2 sampling points – one with an additional pollutant and one without it, which contained only water and gully pot liquor.

Each bin was filled with different layers of PPS aggregates as per PPS construction design, including geotextile, and paving blocks. For the ease of sampling, a square pipe was installed perpendicularly to the layer of paving blocks, cutting through all aggregate layers, to the bottom of the bin. It was placed in the centre of the bin. **Figure 5-1** shows the basic experimental design.
Because of animal excrement additions in large quantities, at the end of the experiment the paving blocks began to clog with debris and other organic matter. In this instance, the debris acted as clay, decreasing the permeability

of the PPS structure. Formpave Ltd. advises for pavement machine swapping every 6 months for basic maintenance. In the experiment, the bins were overloaded with the organic matter and the author is convinced that this situation would not occur in full scale applications.

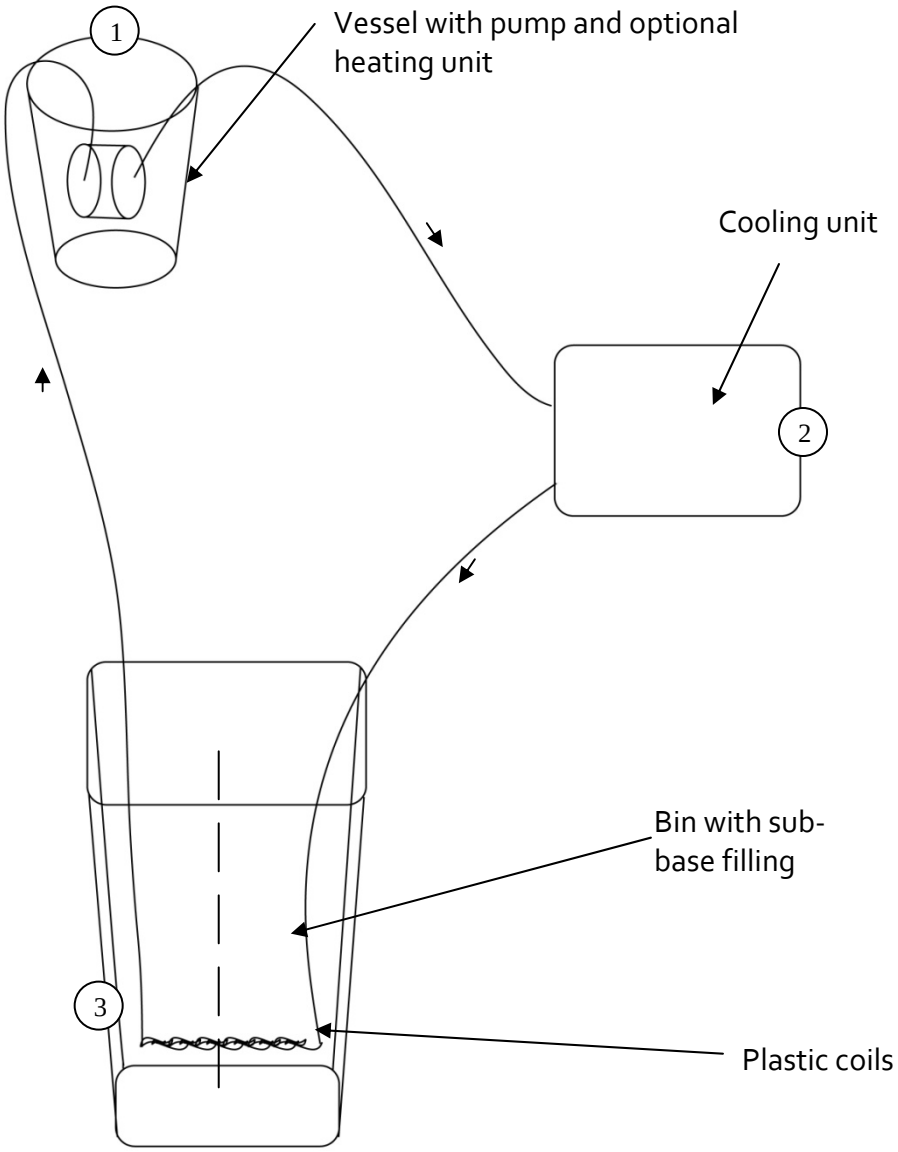


Figure 5-1 Basic construction layout of PPS with GSHP installation.

The starting point for the system workability is to provide water in the vessel (1) (**Figure 5-1**) where the pump directs water into the cooler (2). It then circulates through the coils situated at the bottom of the bin (3) and comes back into the vessel (1).
This type of water circulation provides closed cycle without a need to provide water from external sources (except the heating cycle or during the summer season where evaporation occurs). Water circulation was forced by constantly running the vessel pump.
The dashed line represents the position of the square collection pipe; short arrows represent the direction of water circulation.

It is worth noting that, in heating mode (modes described in 5.2.1), the heater would be switched on and placed in the vessel (1). In the cooling mode, the heater would be removed and the cooler (2) switched on. In both cycles, water circulates through the cooler, although it will work depending on the switching pattern.
Water analysed later did not have contact with coil water at any point.

Temperature measurements were taken by placing thermal electrodes near the coils (submerged in water). The display was installed on the top of the paving block, allowing for block level air temperatures monitoring. Reference air temperature thermometer was installed on the top of the vessel, providing vessel water temperature at the same time (electrode submerged). Temperature readings were also taken from the cooler (in coil water temperature during cooling). During heating mode, heaters were set

up in order not to exceed 22°C, although actual temperatures could be higher in the outdoor rig because of the surrounding air temperatures.
Temperature recording times varied during the experiment, depending on day-to-day laboratory analyses and its timing, but in order to keep the consistency, readings were taken in the morning, between 8:00 and 10:00 and in the afternoon between 15:00 and 17:00.
The same conditions were created for indoor rig, where the air temperature was constant through the year.

The content of each experimental system was based on field PPS apart from the depth of the lower sub-base which was extended to 500 mm as shown in **Table 5-1**. The reason for the extension was to provide a more stable environment around the coils and to increase conductivity. The researcher was also convinced that this kind of arrangement will decrease water level changes due to evaporation allowing for better development of indicator microorganisms.

Table 5-1 PPS sub-base components and their characteristics used in the experiment.

Depth (mm)	Type	Thickness (mm)	Aggregate diameter (mm)
80	paving block	80	
>130	clean stone	50	5
>132	geotextile	2	
>232	upper sub-base	100	5-20
>735	lower sub-base (presence of **water** in lower part)	500	10-63

It was the researcher's decision to provide controlled and uncontrolled rigs. In the controlled rig, the set up and environmental conditions should be stable while in the outdoor rig there is no control over changing temperatures of the air and soil. It is expected that, in the outdoor rig, data variability is higher than in the indoor rig and that microbial numbers will be better controlled in the indoor rig, as opposed to the outside.

To provide replication, two experimental rigs composed of six High Density Polyethylene (HDPE) bins (**Figures 5-2 and 5-3**) each, were constructed.

One rig was in a temperature controlled room. The set air temperature was 15^{o}C, but because of external interferences the calculated average air temperature from readings was 15.6^{o}C.

Figure 5-2 Indoor rig layout

The second rig was placed outside at the Kings Buildings campus, University of Edinburgh, in ambient weather conditions. The bins were insulated with soil, up to the pavement blocks level, to simulate the natural (in soil) conditions as shown in **Figure 5-3**.

Figure 5-3 Outdoor rig layout

5.1.1 Experimental design

Three parameters varied in the experimental rigs: geotextile type, pollutant added and cooling or heating. The application of these parameters and monitoring setup is show in **Table 5-2**.

One of the most important constituents of Formpave PP System is a geotextile, specially designed for microbial development, composed of Polypropylene (PP) and Polyethylene (PE) fibres, which is manufactured by Terram, UK. Two types of geotextile are used in practice, Inbitex™ and Inbitex™ composite. The main difference between the two types is the presence of the impermeable layer and the reinforcing grid, both made of plastic.

The geotextile remains flexible in both forms, although as the composite is impermeable, it has to be cut into smaller pieces and overlapped with other parts, so that water can reach lower levels in the PPS.

Table 5-2 Experimental design and monitoring of the rigs.

	Inside rig						*Outside rig*					
Feature	1	2	3	4	5	6	1	2	3	4	5	6
Inbitex composite	●	●	●				●	●	●			
Inbitex geotextile				●	●	●				●	●	●
Cooling or heating	●	●		●	●		●	●		●	●	
Additional pollutant	●			●			●			●		
Air thermometers	●				●	●	●				●	●
Vessel thermometers	●				●		●				●	
Carbon dioxide sampling	●				●		●				●	

This experimental design was chosen to provide replicate systems of the indoor and outdoor rigs, for later statistical analysis.

5.1.2 Operational conditions

The heating and cooling periods of the experimental rigs were controlled by the timers which switch the required elements on or off to heat up or cool down the water within the coils. The pumps ran continuously. The coolers prevent the temperature falling below 5^{o}C and thermostats prevent overheating by switching the heaters off at 22^{o}C.

Two main switching patterns exist in practice: domestic and commercial. Commercial sites such as large supermarkets prefer to have the devices off as long as possible or have as few switches as possible to save energy. This type of running pattern was chosen for the experiment as it is the most likely application for the combined PPS-GSHP design. The on or off switching modules can be programmed up to six times within 24 h.

The heating and cooling cycles were set as follows:

- Heating during winter was switched on between these hours: 04:00-08:00, 09:00-11:00, 12:00-15:00, 16:00-18:00 and 19:00-23:00.
- Cooling during summer was switched on between these hours: 11:00-12:00, 13:00-14:00, 15:00-18:00 and 19:00-20:00.

The heating and cooling were chosen to take account of equipment safety concerns such as overheating and economical constrains such as electricity supply costs, which are particularly high if the switching frequency is high.

Water-gully pot liquor-faeces mixture was evenly distributed over the PPS blocks. Water residence in bins was estimated to between 3-4 days, as sampling was done twice per week.
Before new influent induction, effluent samples were collected in order to prevent the collection of fresh mixture.
For percentage removal calculations, effluent results were compared with an influent from a week before.

5.1.3 Chosen pollutants

One of the main concerns about PPS-GSHP combination identified by Formpave Ltd. was the health and safety issues in hot countries, such as Australia or Spain, as changing temperatures might have influence on numbers of pathogenic organisms.

In Australia, for example, it is not possible to re-use water which has been in contact with animal excrement. Experiment results could provide the assessment on microbial levels and potential health risks to the public.

The other issue is the effectiveness of treatment of pollutants, such as PAHs (polycyclic aromatic hydrocarbons), which have been discussed previously (Pratt *et al.*, 1999; Batt, 2001; Newman *et al.*, 2002; Coupe, 2004b; Puehmeier, 2004). In order not to duplicate current research findings on PPS and focus on unknown pollutant levels, PAHs analysis was not conducted in the experiment. The type of analyses was also determined by used pollutants (e.g. PAHs would rather be found in engine oil droppings rather than faeces).

Therefore, in these experiments the polluting mixture chosen was dog faeces and gully pot liquor mixed with tap water.

A gully pot is a chamber which collects the runoff from roads and pavements and where the first treatment of runoff water occurs. It is situated at the edge of a pathway or road with a protective cast iron grating on top. When water is introduced into the chamber it fills up and the overflow is directed into the traditional sewage system. This kind of set-up

allows the sedimentation of heavier particles, as well as the first occurrence of anaerobic processes. Because of its specific role and placement it is often full of organic matter such as vegetation debris or the corpses of small animals. Asphalt washout is also introduced into the chamber including PAHs, which also originate from engine oil spillages, as well as metals from corroded car chassis. The sediment, including various pollutants, is stored in the chamber and forms a primary sludge which, because of turbulence during precipitation events, is released from the chamber and introduced into the sewage system (Memon and Butler, 2002).

Ongoing chemical reactions in the gully pot chamber, especially changes of forms of metals, COD transformation (reduction) or ammonia nitrogen transformation, from the beginning of pollution treatment (Butler and Memon, 1999).

Gully pots need to be cleaned on a regular basis to maintain their functioning (Butler *et al.*, 1995).

The design of gully pots means that they have a direct impact on water introduced into the sewers, as well as receiving watercourses, as the biochemical processes increase the amount of dissolved pollutants in the liquor which is washed out during storm events (Memon and Butler, 2002).

Because of the complex nature of the gully pot liquor it was decided that it would be an excellent pollution source to use in these experiments, although because of its density and its chemical characteristics, it was decided to dilute it with tap water (1:10 ratio).

As mentioned above, dog excrement was chosen to be investigated because of the particular concerns with animal pathogens in PPS, as well as the lack of previous studies of this type of pollutant.

Animal faeces from dogs, birds and horses are not commonly studied pollutants in experimental sustainable (urban) drainage system research, because of their nature. However they may cause serious health concerns if PPS water is contaminated with faecal matter if recycled within buildings for toilet flushing, watering of lawns and other applications (Scholz, 2006a; Scholz, 2006b; Scholz and Grabowiecki, 2007).

95% of faecal coli forms found in urban storm water originates from non-urban areas (e.g. parks, loans) where the most important contributors are dogs and cats (Alderiso *et al.*, 1996).

One gram of dog faeces may contain 23,000,000 faecal coli forms (van der Wel, 1995).

Studies in the USA by Olivieri *et al.* (1977) found that dogs were the single most important source of faecal coli forms and faecal *Streptococci* bacteria in urban storm water from a highly urbanised area of Baltimore. In a more recent study it was shown that residential lawns, driveways and streets were the main sources of pathogenic bacteria in the areas of Crane Creek, Florida. Assuming that 40% of the 11,084 households in the study have one dog and that 40% of dog owners do not pick up their dogs' droppings, it was calculated that the total waste produced by the animals accounted for 798,300 grams daily giving 1.76×10^{12} faecal coli forms counts per day deposited on the area (Brevard County, 2007). Researchers were using Washington, D.C., study findings (Thorpe, 2003), assuming that dogs produce 190.5 g per day.

In the UK the dog population was estimated to be 7.3 million in 2008, which produce 1,000 tonnes of droppings daily (Environmental Campaigns, 2003). The main concern is that these faeces contain pathogenic organisms

Toxocara canis, a roundworm leading to the infection named as Toxocariasis, which may cause blindness. Another issue is the collection and disposal costs of dog faeces paid by local authorities which amounted to £62,000 per annum between 2002 and 2003 (Environmental Campaigns, 2003).

Milkovič *et al.* (2009) conducted a spatial distribution experiment on canine faecal contamination in Buenos Aires. The research conclusion stated that it was really difficult to find spatial connection between the amount of faecal contamination and grassed and non –grassed areas; low income and middle income neighbourhoods; number of trees or number of standing objects. Favourable conditions for parasite eggs (helminth infections) development were found in grassed or porous areas rather than in impermeable surfaces, although faeces found on pavements represented an increased health risk to children playing on them.

A survey conducted in the Edinburgh area found that deposition rate of dog faeces was 3.32 g/m^2. Because of designed over-pollution, it was decided that the amount of addition per bin would vary between 6.4 to 6.8 g per week. Since sampling water was conducted twice per week, the amount of added pollutant was 3.2 – 3.4 g per bin per sampling occasion. This additional rate of faeces was extremely high as it is highly improbable that faeces are deposited every day in exactly the same place. As a result the experimental bins were overloaded with pollutants, causing clogging after 1.5 years of the experiment, as described previously.

Clogging could become a serious issue in removal efficiencies and can decrease removal efficiency of total nitrogen from 62% to 12% or total

phosphorus from 52% to 22% as described by Kadurupokune and Jayasuriya (2009) over 17 years of simulation.

The amount of measured *Canis lupus familiaris* excrements additions by number of recorded samplings is accounted for 544 – 578 g (n=85) for outdoor rig and 704 – 748 g/l (n=110) for indoor rig.
In the research, the outdoor rig was operational for 24 months and 14 days and the indoor rig for 26 months and 21 days, i.e., for 98 and 107 weeks respectively.
Because of gaps in data records, the overall amount of added pollutant is calculated by multiplying the amount of faeces added weekly (6.4 – 6.8 g) by the number of weeks in a year (52). The overall additions were 627.2 – 666.4 g into the outdoor rig and 684.8 – 727.6 g into the indoor rig.

The input mixture was prepared as follows:
Gully pot liquor was collected from various gullies at the King's Buildings campus. 0.2l liquor was mixed with tap water in a 1:10 ratio in 2l plastic beakers. 3.2 – 3.4 g dogs' faeces samples were weighed on the balance and then stirred into the water-liquor mixture. Fresh faeces were collected from various parks, loans and pavements on the day of analysis.
The mixture was evenly distributed over the pavement rigs.

5.2 Physical and chemical analysis of water samples

All water sample analysis was conducted according to the American Health Public Association (APHA) Standard Methods For the Examination of Water and Wastewater (Clesceri *et al., 1998*). The analyses were conducted in Ecological Engineering and Public Health Laboratories at The University of Edinburgh Institute for Infrastructure and Environment by and under the supervision of the author. Main contributors to the project were either University of Edinburgh final year students or visiting students from other EU universities (primarily France and Germany).

The analysis of nutrients was conducted in Crew Labs, School of GeoSciences, by Andy Gray and John Morman.

5.2.1 Sample collection and preparation

Water samples (2.2 litres) were collected from the bottom of the bins with a hand pump and placed into plastic beakers. Immediately after collection, its temperature was measured.

As it was not possible to prevent sediments from entering the pump, the sample consisted of PPS water and sediments. This sample was used for further analyses, except nutrients' analyses, where it was filtered on a glass fibre paper.

Samples were pumped out twice a week and influent for treatment was introduced on the same occasion.

Occasional breaks in data collection occurred when the author was not present due to training or because of technical difficulties. This is clearly identified at a later stage in presented figures (e.g. Autumn 2006 or Summer

2007). In order to keep microbes which already developed in the rigs, pollutants' additions and water pump-outs were continued. Where it was impossible to keep this arrangement, i.e. pollutants added once a week only, their amount was doubled to 6 g per bin per week (during gaps in data collection only).

During analysis for suspended solids (SS), samples were filtered through glass fibre filtering paper. Approximately 20 ml of filtered sample was stored in plastic containers and frozen for storage (Clesceri *et al.*, 1998), prior to analysis.

Discussed sample data numbers (n) are counted as follows:

pH, EC,TDS, SS, DO, ORP, NO_{2+3}, PO_4, NO_{2+3}, sample temperature:

- indoor rig n=110
- outdoor rig n=85

BOD

- indoor rig n=34
- outdoor rig n=32; total n=68

Microbiological assessment:

Salmonella sp and *Shigella sp; Enterococcus faecalis* (group D *Streptococcus*); Total Heterotrophic Bacteria:

- indoor n=35
- outdoor n=25; total n=60

Escherichia coli:

- indoor n=24
- outdoor n=19; total n=43

5.2.1.1 BOD determination

BOD_5 was measured with WTW OxiTop vessels. The measurement is done according to European Norms EN 1899-1 and EN 1899-2 (WTW, 2008). The determination uses a respirometric method based on carbon dioxide production and pressure changes within the bottle. Adding nutrient inhibitor to the sample suppresses the oxidation of ammonia to nitrates/nitrites. The pressure changes when sodium hydroxide transforms into sodium carbonate. Carbon dioxide is then removed by sodium hydroxide tablets (WTW, 2008). The pressure change is recorded by an electronic data logger and measured over five days at constant temperature of 20^{o}C. The BOD values are recorded in mg/l and the usual sample volume is 432 ml. For samples with high BOD values, a smaller sample volume is diluted, although with a wider ranges of errors.

The assumptions made in the calculations assume zero values '0' to be recorded as <0-5 mg/l. This is because of the Oxi Top™ method level of accuracy, where units are displayed in the nearest whole number in milligrams per litre.

The alternative method was to use DO meters measuring values of dissolved oxygen before sample incubation and after 5 day incubation, although it was not used because of limited time and resources.

5.2.1.2 pH , TDS and conductivity

A Hanna HI-991300 combined meter was used to take readings of pH, total dissolved solids, sample temperature and conductivity. During the measurements, the electrode was gently stirred in the sample. The probe was washed with deionised water between sample measurements.

Electrodes were calibrated according to manufacturer's instructions using special calibration buffers. For pH electrode these were pH 7 and pH 10 buffers. The electrodes were soaked in the solution for 20 minutes. When temperature changes, pH values change as well, but as the samples were measured in the laboratory environment (approx. 20^{o}C), temperature compensation was done automatically on the electrode. The usage of buffers also eliminates this error.

5.2.1.3 Dissolved oxygen and redox potential determinations

Dissolved oxygen content was measured with a WTW Oxi 315i meter. Redox potential (ORP) reading was taken with a Hanna HI 98201 meter.

The instruments were calibrated on a monthly basis or more often if required, using solutions supplied by the manufacturers (OxiCal air calibration vessel for DO and Hanna REDOX solution for platinum and gold ORP electrodes).

5.2.1.4 Suspended solids

Suspended solids levels were determined by total filterable residue dried at 103-105^{o}C method (Clesceri *et al.*, 1998). The procedure involves filtration of a 100 ml sample on glass fibre filter. After filtration, the residue is transferred to a weighted dish and left for at least 1 hour in the oven at 103-105^{o}C. After drying, the filter was cooled in the fume cupboard and weighted. The research samples were left in the oven for 24 hours.

The difference in weight of the clean filter and a dried filter with a residue was reported as total suspended solids.

5.2.1.5 Nutrient determinations

PO_4, NH_4 and NO_{2+3} concentrations were conducted in the School of GeoSciences laboratories.

Nutrients were using automated colorimetric methods. Nitrate was reduced to nitrite by hydrazine in alkaline solution and absorption measured at 550 nm using a Bran Luebbe AA3 flow injection analyzer.

In the ortho-phosphate-phosphorus determination, ammonium molybdate, ascorbic acid, sulfuric acid, ammonium molybdate and 0.5 mol bicarbonate of soda were used in the analyses performed by automated AA3 at the wavelength of 660nm (Clesceri *et al.*, 1998). Ortho-phosphate reacts with molybdate and ascorbic acid to form a blue compound. Antimony potassium tartrate is a catalyst.

Ammonia coloured blue compounds were measured at the 660nm wavelength on Bran Luebbe autoanalyser (model AA3).
For the determination of ammonia, the following chemical reagents were used: ammonium molybdate, ammonium fluoride, antimony potassium tartrate, ascorbic acid, calcium chloride, hydrochloric acid, potassium dihydrogen phosphate, sodium dodecyl sulfate, sodium hydrogen carbonate, sulfuric acid. (Bran and Luebbe, 1999).

In samples from the first five months of the experiment nutrients were determined using Palintest Kits and a Palintest Photometer 5000 (Palintest, 2000). This method is usually used for in-field measurements and its accuracy is much lower than the automated colorimetric analyser. It is also very time consuming as some of the samples involve 4 to 5 step treatment for single parameter determination. Also if the concentration is high, the sample needs to be diluted with deionised water and 5-step test repeated.
Some of the data outliers arising from this method were omitted from the data analysis as explained in Chapter 6.

5.3 Microbiological analysis

5.3.1 Sample preparation

For microbiological testing of water samples agar media had were prepared.

Most media are grown on plates using selective plating techniques. The agars are mixtures of sugars, proteins and fats which contain inhibitors to prevent competitor growth and also nutrients to promote growth of the desired species (Varnam and Evans, 1996).

The agars used in this research were made by Oxoid Ltd, Bagingstoke and are shown in **Table 5-3**.

Table 5-3. Agars used for bacteria species isolation according to manufacturer product information (Oxoid Ltd., 2008)

Agar name	**Grown organism**	**Agar composition**
MacConkey Agar No.3	*Salmonella* and *Shigella*	Peptone, lactose, bile salts no. 3, sodium chloride, neutral red, crystal violet, agar
Slanetz and Bartley Medium	*Enterococci*	Tryptose, yeast extract, glucose, di-potassium hydrogen phosphate, sodium azide, tetrazolium chloride, agar
Eosin Methylene Blue Agar (modified) Levine	Different Enterobacteriaceae (*Escherichia coli* as purple coloured colonies with green metallic sheen)	Peptone, lactose, dipotassium hydrogen phosphate, eosin Y, methylene blue, agar

For Total heterotrophic bacteria Nutrient Agar no. 2 was used. It is composed of peptone (vegetable), vegetable extract and agar (Atlas, 2006), and was obtained in a ready-made form from The School of Biological Sciences, while the rest of the media was obtained in a dehydrated form. For agar preparation, 1000 ml of deionised water was added to the weighed culture media. Once mixed it was heated to boiling point. The hot liquid was divided into 4 bottles sterilised in an autoclave at 120°C. Once sterilised, the medium was reheated and divided into Petri dishes.

After medium coagulation in the Petri dishes, 100 μl of water sample was evenly spread over the agar surface and the dishes were inoculated for 24-48 hours at constant temperature of 37°C.

5.3.2 Plate counts

Counting was done by the naked eye in a fume cupboard in order to prevent pathogenic organism transmission on the researchers.

Colonies were recorded as Colony Forming Units (CFU) per 100 ml. Depending on the samples, the number of colonies varied from zero to a few thousand. Where growth was so high that it was not possible to count colonies on the whole plate, APHA methods for counting were implemented. Four lines were drawn on the plate dividing its area into eight independent areas. The number of CFUs in one area was counted and then multiplied by eight, giving a total number for the plate.

5.3.3 Dilution

When samples overgrew the dishes (usually for total heterotrophs), water samples were diluted with sterile water at 1:10, 1:100 and 1:1000 ratios as appropriate.

5.3.4 Filtering

Where low numbers of colonies were found (usually for *Salmonella sp* and *Shigella sp*), 20 ml water sample was passed through glass fibre filter. The filtered paper was placed on the agar and incubated in the same way as spread samples. After incubation, the numbers of colonies were counted on the filter using a magnifying glass. The results were multiplied by 5 in order to give the number of CFUs per 100 ml.

5.3.5 CO_2 measurements

An indirect assessment of microbial activity within the systems was CO_2 measurement. In order to do this, four vertical tubes were installed in selected bins from both the outdoor and indoor bins. The first tube, which is the shallowest, samples carbon dioxide just above the geotextile where the highest activity is expected. The second tube was installed in the mid-point of the upper sub-base. The third tube samples carbon dioxide in the mid-point of the upper part of the lower sub base (first 250 mm). The final

tube samples CO_2 from the bottom of the bin – partly submerged in stored water as in **Figure 5-5**.

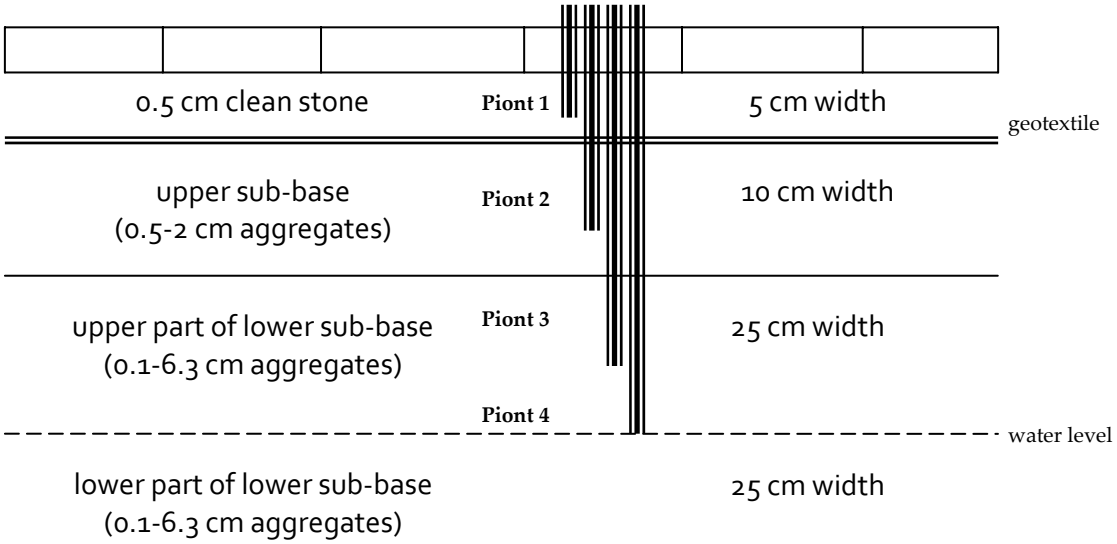


Figure 5-5 Carbon dioxide sampling points installed in the experimental rigs (not to scale)

Sampling tubes were open at the bottom and sealed with black silicone rubber on the top. To the top of the silicone, a flexible tube was jointed, which formed a valve - opened only during sample collection by the automated reader. CO_2 concentrations were determined using automated portable IRGA - Infra Red Gas Analyser (PP Systems Hitchin, UK).

5.3.6 Industrial H&S guidance

In Summer 2008 an Industrial Health and Safety form was prepared that could be used with PPS products. The document (see Appendix 1) was

prepared on the basis of information from the following organisations: DEFRA (Department for Environment, Food and Rural Affairs), OPSI (Office of Public Safety Information), SEERAD (Scottish Executive Environment and Rural Affairs Department), HSE (Health and Safety Executive). Additional information was collected from previous H&S forms as well as available literature (Bitton, 1994; Varnam and Evans, 1996; Hunter, 1997).

The form describes all PPS components and the risks involved with its usage. These include tripping, falling, oil and faecal contamination. It provides information on organisms that are the most likely to occur in the system's sub-base. One of the most dangerous organisms belongs to the protozoan community, *Naegleria fowleri* or *Acanthamoeba sp* which have serious consequences if left untreated, leading to death. Although it is very unlikely that such central nervous system invasions (i.e. amoebic meningoencephalitis) will occur, it has to be mentioned in such a summary.

This chapter assessed types of analysis, experimental design and research assumptions. As the laboratory-scale system design was novel, it led to several unpredicted technical difficulties, such as issues of sample collection or problems with choosing PPS sub-base containers.

Because of existing water and wastewater quality testing standards, sample analyses were prepared according to specifications recognised worldwide. Ready-made, commercially available agars for the growth of microorganisms allowed for conducting standardised microorganism determination procedures as well as assessing for health and safety risks.

6 Water sample results

The chapter present levels of nutrients found in systems as well as numbers of microbes and their activity in combined PPS-GSHP. Figures and tables were prepared for nutrients, TDS, CO_2 and BOD_5, while microbial findings are presented in tabular form only. Data is presented according to seasonal changes which occurred during the experimental period.

Since air temperature can influence numbers of microbes within systems all data for the outdoor rig were split according to the seasons of the hydrological year.

Although there were no temperature fluctuations for indoor rigs, data from these were split in the same way, for the ease of comparison.

The hydrological year (or water year) in the northern hemisphere starts on 1st October and ends on the 30th September the following year, due to the timing of soil moisture recharge and maximum evapotranspiration (AMS, 2008).

The seasonal categorisation is shown in **Figure 6-1**.

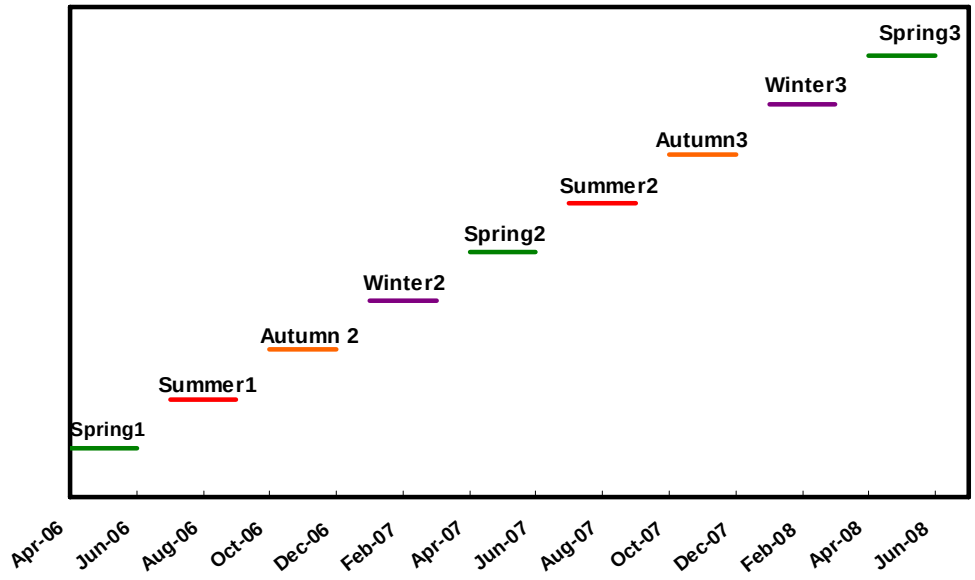


Figure 6- 1 Seasonal categorisation of PPS rigs, according to hydrological cycle.

It was decided to categorise the data into heating or cooling cycles, as well; this is shown in **Table 6-1**.

Table 6-1 Heating and cooling cycles during the experiment.

From	**To**	**Cycles**	**Duration (months, days)**
5th June 2006 (inside rig)	6th November 2006	Cooling1	5m
14th August 2006 (outside rig)	6th November 2006	Cooling1	2m23d
7th November 2006	11th June 2007	Heating 1	8m 4d
12th June 2007	25 July 2007	Cooling 2	1m 13d
26 July 2007	4th February 2008	Heating 2	6m 10d
5th February 2008	31st July 2008	Cooling 3	5m 24d

For better understanding of selected patterns, **Figure 6-2** had been prepared. The monthly break in the heating cycle occurred because of technical issues outdoors.

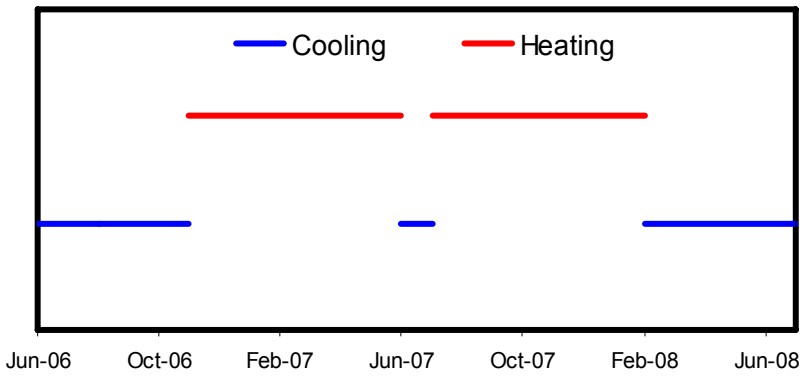


Figure 6-2 Graphical representation of experimental heating and cooling cycles.

It was aimed to run the cycles for about 6 months, but because of technical difficulties (e.g., problems with heating elements at the outdoor rig during June and July 2007), both rigs were operated in the cooling cycle for the period.

To simplify data calculations and results interpretation, data was merged for two cycles only:

- Heating (the sum of Heating 1 and Heating 2), a total of 14 months and 14 days.
- Cooling (the sum of Cooling 1, Cooling 2 and Cooling 3), a total of 12 months and 7 days (indoor rig) and 10 months (outdoor rig).

Some of the dataset outliers were removed when they were very unique and it was not possible to explain why the particular value occurred.

The data was also removed when it was contrasting with the rest of data in the dataset. This kind of outliers occur when data variability is extremely high such as in microbiological tests where standard deviation (STDEV) reached up to 277,316,477 Colony Forming Units (CFU) for inflow or 757,974 for outflow maximum values.

This kind of practice is common in sciences and provides better understanding of data by eliminating extreme values. Osborne and Overbay (2004) claim that:

> 'We argue that what to do depends in large part on why an outlier is in the data in the first place ; [...]Where outliers are illegitimately included in the data, it is only common sense that those data points should be removed; [...]When the outlier is either a legitimate part of the data or the cause is unclear, the issue becomes murkier [...] This is a case where researchers must use their training, intuition, reasoned argument, and thoughtful consideration in making decisions.'

Taking the above under consideration, outliers were removed when errors were identified. In all other cases, data removals were discussed with more experienced academic researchers and laboratory technicians.

6.1 Temperature results

Indoor rig temperatures (**Figure 6-3**) were relatively stable and varied between 13.8°C – 17.8°C. Small fluctuations were caused by different cooling unit temperatures during the cooling cycle.

Other factors affecting the temperature could be radiators unintentionally switched on or heated offices on the other side of walls or temperature changes caused by staff entering the room.

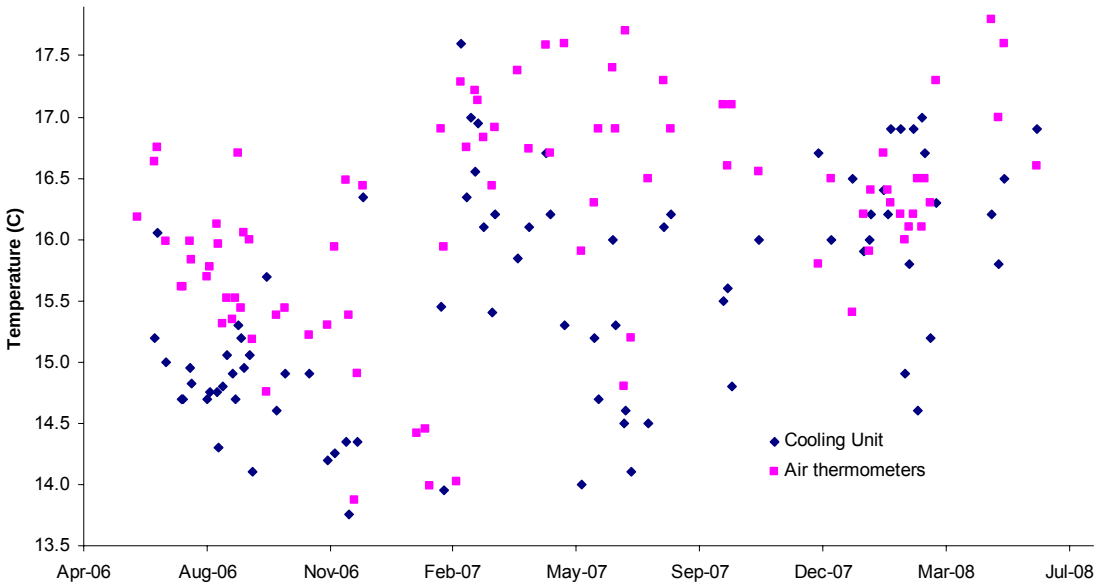


Figure 6-3 Indoor rig air temperatures (°C).

Figure 6-4 presents air temperature measured at the outdoor rig during the experiment. The temperatures show annual patterns with maximum values in summers and measured minimum values in winters. Maximum temperatures of 20.3°C were measured in July and September 2007.

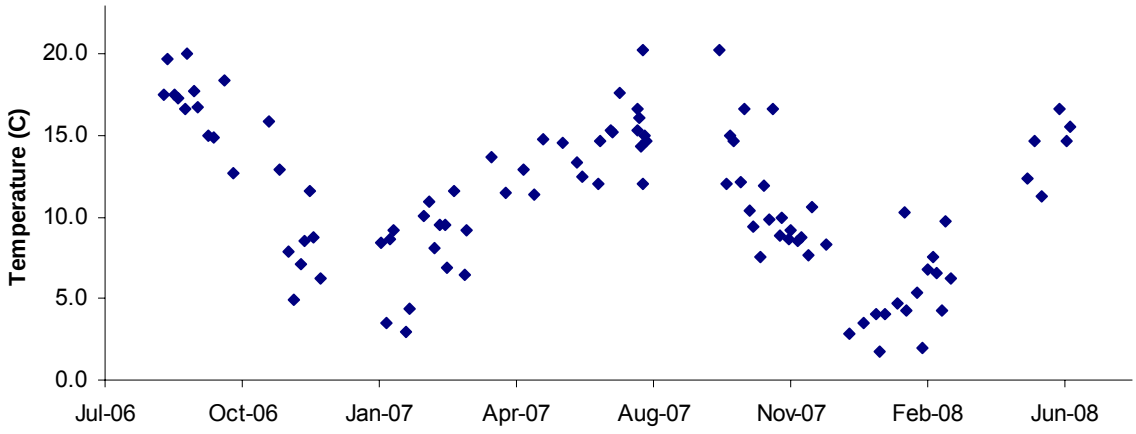


Figure 6-4 Outdoor rig air temperatures (°C).

As temperature was one of the most important factors in the experiment, it was measured at various points in the rig. **Figure 6-5** presents different temperatures recorded at the outdoor rig during the experiment. Temperatures at the top of the bin (average of 9.9°C) followed the seasonal temperature patterns and cold periods and mirror the air temperatures. Bins with coils temperatures follow the same pattern as vessel water temperature, with the averages 15.5°C and 14.9°C respectively.

Water temperature in bins with H/C coils installed follow vessel water temperature patterns providing evidence on design correctness – confirmation on actual temperature changes caused by coil presence.

Non-coiled bins follow the air temperature patterns. Although being covered with soil (isolation), air temperatures had strongest impact on bin water temperatures.

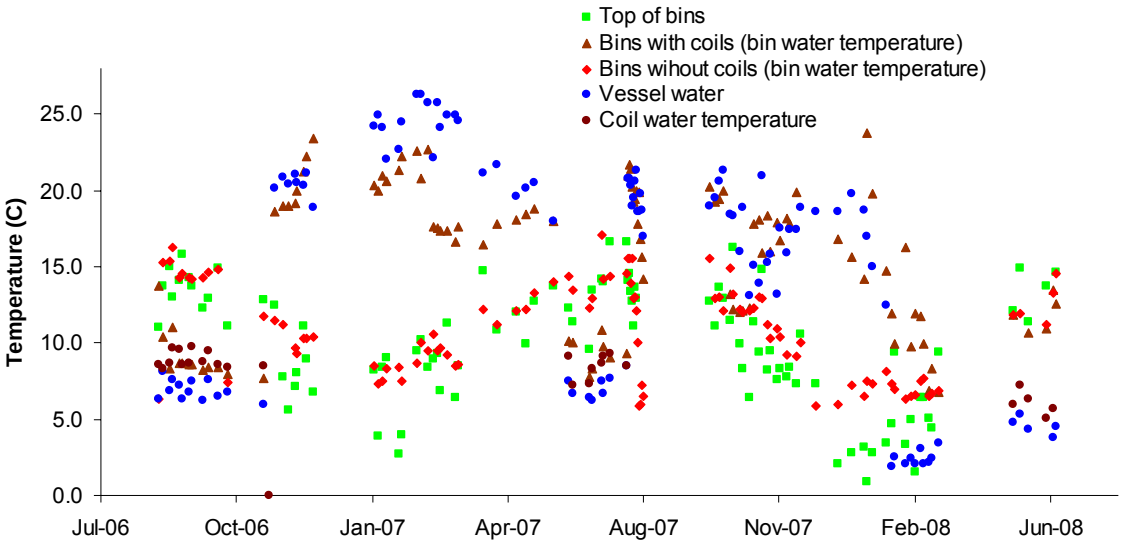


Figure 6-5 Various temperatures (°C) measured at the outdoor rig.

6.1.1 Water sample temperatures

Water sample temperatures are one of the most important ones, describing environmental conditions in the sub-base. Cooling water distributed energy along the piping system and the temperature of water entering the vessel was almost the same as it was at the exit. The temperature difference between water entering and exiting the vessel was measured to be 0.9°C in the indoor (n=110) rig and 1.4°C in the outdoor (n=97) rig (mean values). These small measured temperature differences showed the pipe material being a good isolator and that the flow created by the pump was high enough to transport the fluid without high energy loss.

Figure 6-6 shows how water sample temperatures were influenced during the heating and cooling cycles in the indoor rig.

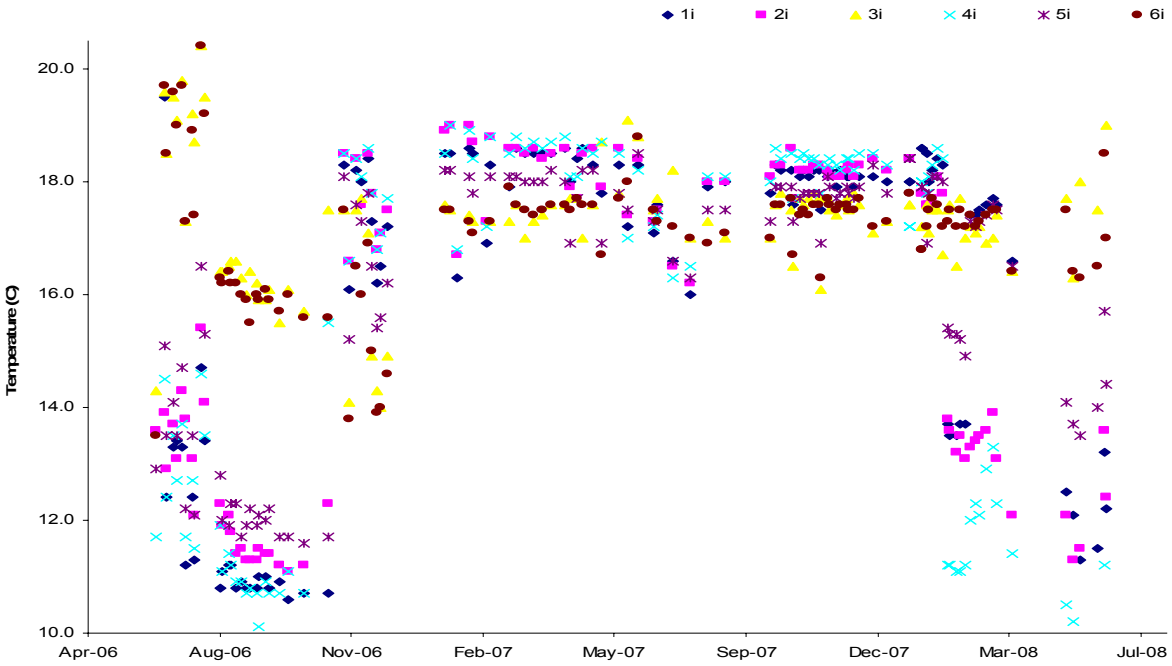


Figure 6-6 Indoor rig water sample temperatures at collection (°C).

Because of the stable air temperature, with an average of 15.9°C, the H/C coils had a much stronger impact on the water sample temperatures and the environment, where the microbiological processes took place. Bins 3i and 6i with no H/C coils followed the average air temperature in the room – with higher temperatures in the summer and cooler temperatures in winter. During heating seasons the temperature differences between bins with and without coils were less visible, with differences of only 1.5°C to 2.0°C on average. This indicates that the heaters were not powerful enough to warm up water to achieve significant temperature differences. One of the other factors decreasing the heaters' efficiency might be poor insulation of vessels, so that lower air temperature was neutralising the higher temperature produced by heaters.

Figure 6-7 shows water sample temperatures measured immediately after collection at the outdoor rig. The seasonal pattern of temperature is similar to vessel temperatures (**Figure 6-5**) and the air temperatures (**Figure 6-4**).

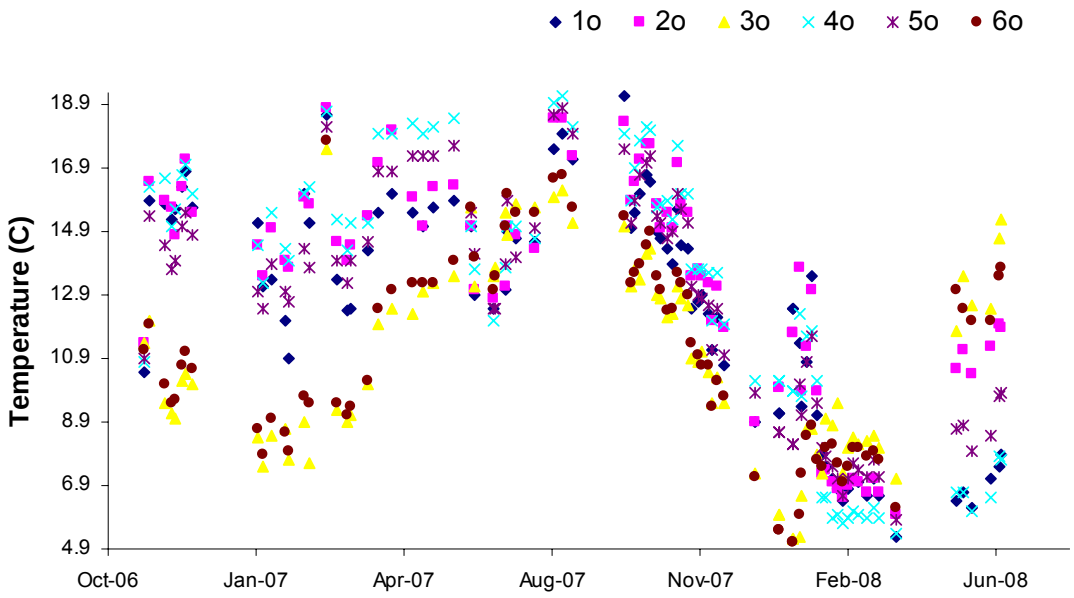


Figure 6-7 Outdoor rig water sample temperatures at collection (°C).

To conclude, outside air temperatures had a big impact on water stored in the tanked system which was prone to changing external conditions.

6.2 Water sample physico-chemical results

Means, standard deviations and relative standard deviations (RSD) of the water sample analyses were calculated for each set up and the results are presented in **Tables 6-2, 6-3 and 6-4.**

Standard deviations were calculated using the following formulas:

- mean standard deviation (σ):

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}, \tag{9}$$

- sample standard deviation (s):

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2}, \tag{10}$$

- relative standard deviation (RSD):

$$RSD = S / \overline{x} \tag{11}$$

where:

σ - mean standard deviation

s - sample standard deviation

RSD - relative standard deviation

N – number of observations in the sample

The reason for RSD calculation was to obtain an expression in % in order to compare the variability between different bin s in the system i.e. bin 1o and 2o for pH.

In **Table 6-2** values are divided into IN and IN+P with the second mixture including dog excrements.

The greatest differences between the two mixtures were for ammonia, ortho-phosphate-phosphorus 5-day BOD and SS which were higher in the mixture containing faeces. pH values were similar and constant for the two types of inflows, due to sample dilutions and constant pH values for the materials used.

Variability is the highest for SS resulting from variable gully pot liquor properties during the year. Other variable parameters were BOD, conductivity and ORP, due to changing liquor and faeces properties over the course of the experiment.

As number of records is different for indoor (n=110) and outdoor (n=85) rigs, **Table 6-2** present mean values of the calculated averages.

Table 6-2 Mean influent concentrations for tested physical and chemical water quality parameters in both rigs.

	Data from direct observations			
	Input	Input with faeces	Input	Input with faeces
	means		standard deviations	
pH	6.9	7.0	0.50	0.48
Conductivity (μS * cm^{-1})	116.3	174.5	59.63	55.96
Total Dissolved Solids (ppm)	58.4	87.8	30.87	28.13
Suspended solids (mg/l)	116.9	233.9	121.86	174.67
Dissolved Oxygen (mg/l)	8.8	8.3	1.06	1.19
Redox (mV)	177.9	149.2	64.68	50.33
NO_{2+3} (mg/l)	1.2	1.3	0.77	1.2
PO_4 (mg/l)	0.6	4.2	0.54	3.78
NH_4 (mg/l)	0.3	1.7	0.46	1.44
BOD_5 (mg/l)	42.4	90.1	22.33	50.42

Outflows for both rigs are presented in **Table 6-3**. Average sample temperatures during the experiment were higher at the indoor rig than at the outdoor rig, with values of 17.1°C as the maximum indoors and 13.3°C outdoors.

As outdoor air temperatures had a stronger impact on stored bin water temperatures, more extreme values and outliers were found outdoors.

TDS, SS, pH, conductivity and ORP concentrations were relatively similar across bins indicating that the physical and some chemical outflow properties were similar in all the bins. Slightly lower DO values were observed probably due to higher sample temperatures.

The biggest differences in mean values were for nutrients.

NO_{2+3} concentrations were highest for both rigs in bins 1 and 4 (but not 4o) for both rigs. This is because dog excrement addition with high ammonia nitrogen concentrations which were nitrified releasing NO_{2+3} into the system. The highest nitrate concentrations were recorded indoors resulting in negative removals in bins. According to the EU Waste Water Directive the concentration of total nitrogen discharged into the receiving water should be less than 10 mg/l (EU, 2008). This indicates that although ammonia removal efficiencies are high as 100% the amount of 0.3 - 0.35 kg annual faeces additions were too high for the system to reduce NO_{2+3} produced.

It is also possible that designed system was not effective for NO_{2+3} removal as longer contact time was needed.

The presence of geotextile effect SS in a way that bins 1-3 (geotextile present) SS concentrations are higher than in bins 4-6 (geotextile not present). The researcher is not aware of the reasons for this occurrence.

Seasonal RSD of parameters in the bins are shown in Table **6-4**. The parameter within the highest variability was SS. Other high standard deviations were recorded for COND, TDS and ORP. The reason for these

high values is variable liquor properties depending on the season and rainfall conditions. For nutrients the highest standard deviations were for NO_{2+3} in bin1 and 4, both inside and outside due to faeces additions into the bins.

Table 6-3 Mean effluent concentrations for tested physical and chemical water quality parameters in both rigs.

	1o	2o	3o	4o	5o	6o	1i	2i	3i	4i	5i	6i
Sample temperature (^{o}C)	12.5	13.3	10.9	13.1	12.7	11.0	15.9	15.8	17.3	15.5	16.1	17.1
pH	7.1	7.3	7.3	7.1	7.4	7.4	7.2	7.5	7.5	7.4	7.4	7.5
Conductivity ($\mu S*cm^{-1}$)	424	333	315	384	330	308	366	361	308	396	354	334
Total Dissolved Solids (ppm)	212	167	156	187	165	153	183	180	152	198	176	167
Suspended solids (mg/l)	170	101	94	100	88	67	145	139	173	120	133	115
Dissolved Oxygen (mg/l)	6.3	7.9	7.6	5.8	8.2	8.3	6.5	7.3	7.7	7.0	6.4	7.2
Redox (mV)	166	165	171	171	173	175	163	159	156	161	157	157
NO_{2+3} (mg/l)	8.05	3.80	5.47	4.67	4.26	5.05	18.44	5.88	4.52	17.06	3.23	4.67
PO_4 (mg/l)	0.93	0.32	0.19	1.46	0.15	0.20	1.39	0.41	0.28	1.28	0.29	0.29
NH_4 (mg/l)	0.06	0.03	0.03	0.03	0.03	0.03	0.05	0.06	0.07	0.07	0.06	0.07
BOD_5 (mg/l)	2.3	0.4	0.3	0.9	0.6	0.7	0.5	1.0	0.9	0.6	0.7	0.5

Table 6-4 RSD (%) effluent concentrations for tested physical and chemical water quality parameters in both rigs.

	1o	2o	3o	4o	5o	6o	1i	2i	3i	4i	5i	6i
Sample temperature (^{o}C)	4.28	4.09	3.54	5.03	4.15	3.66	2.96	2.57	1.01	3.03	2.06	1.03
pH	0.26	0.43	0.22	0.30	0.21	0.22	0.26	0.19	0.21	0.24	0.18	0.18
Conductivity (µS)	94.54	55.71	38.78	79.79	51.82	39.18	42.72	60.72	64.49	37.97	49.12	63.25
Total Dissolved Solids (ppm)	47.05	27.92	19.34	17.83	25.99	19.04	20.80	30.22	31.56	19.15	24.68	32.06
Suspended solids (mg/l)	186.54	128.43	119.57	118.15	117.33	70.83	129.41	142.39	158.43	107.52	106.96	113.99
Dissolved Oxygen (mg/l)	15.24	16.59	14.06	14.04	16.80	13.09	15.53	18.94	22.71	15.91	16.81	18.56
Redox (mV)	68.97	66.49	67.51	66.49	63.43	66.46	60.27	57.28	55.97	58.08	54.78	55.51
NO_{2+3} (mg/l)	10.06	3.61	2.97	6.24	3.68	2.83	15.14	4.54	2.91	15.71	2.76	3.68
PO_4 (mg/l)	0.86	0.24	0.15	0.89	0.12	0.20	0.60	0.31	0.33	0.62	0.35	0.33
NH_4 (mg/l)	0.07	0.03	0.03	0.03	0.03	0.03	0.07	0.07	0.08	0.09	0.07	0.08
BOD_5 (mg/l)	1.79	0.90	0.53	1.39	1.05	1.20	1.36	3.81	1.82	1.40	2.00	1.33

6.2.1 Nutrients seasonal variability

Total average values, standard deviations and RDS do not provide enough information on impact of external factors. Therefore it has been decided to compare the values according to year seasons. These were categorised as explained on pages 103-104. Additionally, seasons were categorised according to heating cooling seasons. Data layout is composed as follows: means and RSD for year seasons; means and RSD for heating/cooling seasons. Indoor rigs are discussed first.

Extensive research on nutrients removal had been prepared through the years in various disciplines of science. The most adequate for PPS comparisons are constructed wetlands (Bastian *et al.*, 1993; Chung *et al.*, 2008; Yeh *et al.,* 2010), soils or groundwater (Magmedov, 1987; Riaz *et al.*, 2009; Sonneveld *et al.*, 2010).

Because of the specific nature of PPS, the literature is limited and avaliable results in literature are very difficult to compare with other experiments, not only on nitrogen cycle but all other parameters.
Results are compared on the basis of PPS publications accessible to the author – in general already cited in the literature review – including unpublished BSc, MSc and PhD theses. Some comparisons were made with BMP removal efficiencies. This approach allows for trustworthy analysis and clear understanding of results.

6.2.1.1 Nitrogen mass balance

As sample concentrations were obtained as the sum of NO_3 and NO_2 and NH_4, in order to compare nitrogen mass entering and exiting the system, these should be converted to NO_{2+3}-N and NH_4-N. The calculation can be made by using multiplication factors taken from atomic weight of nitrogen N=14 and formula weights for NO_{2+3} = 62 and NH_4=18 (Ryan *et al*, 2001), giving multiplication factors:

14/62=0.226

14/18=0.778

NO_{2+3} is usually reported as nitrates only (NO_{2+3}) due to analytical assumption that NO_2 constitute to less than 10% of NO_{2+3} value (verbal communication with Senior GeoSciences Laboratory Technician, Mr Andy Gray).

Such arrangement allowed for Total Inorganic Nitrogen calculation which is the sum of NO_2-N, NO_3-N (or NO_{2+3}) and NH_4.

Calculation results are presented in **Table 6-5**

Table 6-5. Total Inorganic Nitrogen concentrations in both rigs.

Outdoor rig	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
NO_{2+3} – N (mg/l)	1.82	0.86	1.24	1.06	0.96	1.14	0.29	0.32
NH_4 – N (mg/l)	0.05	0.02	0.02	0.03	0.02	0.02	0.25	1.53
Total Inorganic Nitrogen	1.87	0.88	1.26	1.08	0.99	1.17	0.54	1.85
Indoor rig	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
NO_{2+3} – N (mg/l)	4.17	1.33	1.02	3.86	0.73	1.06	0.23	0.25
NH_4 – N (mg/l)	0.04	0.05	0.05	0.05	0.05	0.05	0.29	1.17
Total Inorganic Nitrogen	4.21	1.37	1.07	3.91	0.78	1.11	0.52	1.42

The above results confirm aerobic conditions in the PPS sub-base enhancing nitrification (aerobic oxidation) due to Total Inorganic Nitrogen (TIN) presence in the effluent, based on nitrates and nitrites concentrations. On the contrary highest TIN presence in IN+Po and IN+Pi is the result of high loads of ammonia in the influent. These statements are valid for both experimental rigs.

6.2.1.2 Nitrates/nitrites

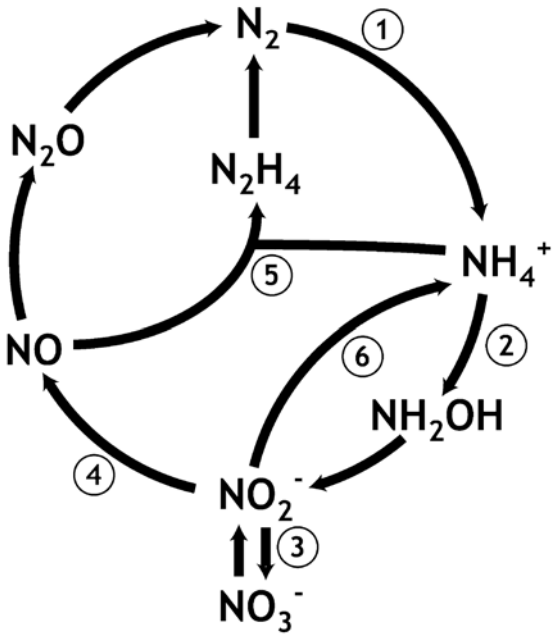


Figure 6-8. Nitrogen cycle in environment: 1-gas fixation, 2-ammonium oxidation by bacteria, 3-aerobic nitrite oxidation, 4-denitrification , 5-anaerobic ammonium oxidation, 6-nitrate and nitrite reduction to ammonium (Mike, 2008).

Nitrification is the conversion of ammonium to nitrate ions as in the following equations (O'Neill, 1998):

$$4NH_4 + 6O_2 \rightarrow 4NO_2 + 8H + 4H_2O \quad (12)$$

$$4NO_2 + 2O_2 \rightarrow 4NO_3 \quad (13)$$

This might be one of the reasons why negative removals of NO_3-N were calculated. The construction of systems provides constant additional O_2 introduction into the system, therefore enhances the NO_2 to NO_3 as well as oxidation microbial growth. This activity was not intentional during vertical collection piping installation. Consequently high concentrations of NO_{2+3} were found in the samples. Dissolved oxygen values are discussed later in the chapter.

Nitrogen aerobic oxidation and reduction can be written as follows:

$$NH_4 \rightarrow NO_2^- \rightarrow NO_3^- \quad \textit{nitrification} \quad (14)$$

$$NO_3^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \quad \textit{denitrification} \quad (15)$$

If present in the human body, nitrate can be broken down to NO_2 and come into contact with human blood causing methaemoglobinaemia (O'Neill, 1998).

In the aquatic environment, high concentrations of NO_3 can cause eutrophication, and cyanotic blooms.

For the analysed systems one of the additional sources of nitrates might be fine material between the aggregates (filters not washed) - building material for PPS sub-base - as in natural environments high nitrate levels in soil can contaminate groundwater by leaching into the saturated zone (Weiner, 2008).

Denitrification is one of the crucial processes in nitrogen cycle and is performed by various organisms which reduce nitrate to nitrite-nitrogen and then to nitric oxide, nitrous oxide and at the end to di-nitrogen gas.
The nitrogen cycle is presented in **Figure 6-8** and denitrification process expressed by equation (15).

As piping introduces more O_2 into the substrate, NO_2 is being converted to NO_3 in nitrification process, but because of high oxygen levels and little organic matter, environmental conditions are less favourable for denitrification processes, hence conversion of NO_3 to N_2.

For indoor rigs (**Table 6-6**) recorded concentrations are higher than outdoor rigs. NO_{2+3} levels are the highest in bin 1i and 4i. Maximum mean values for the indoor rig reached 21.14 mg/l for Autumns and 20.19 mg/l for Winters (both bin 1i).
The highest variability was RSD 20.19% in bin 1i in Winters. The lowest outflow variability was in bin 5i (RSD 2.76%) in Springs.

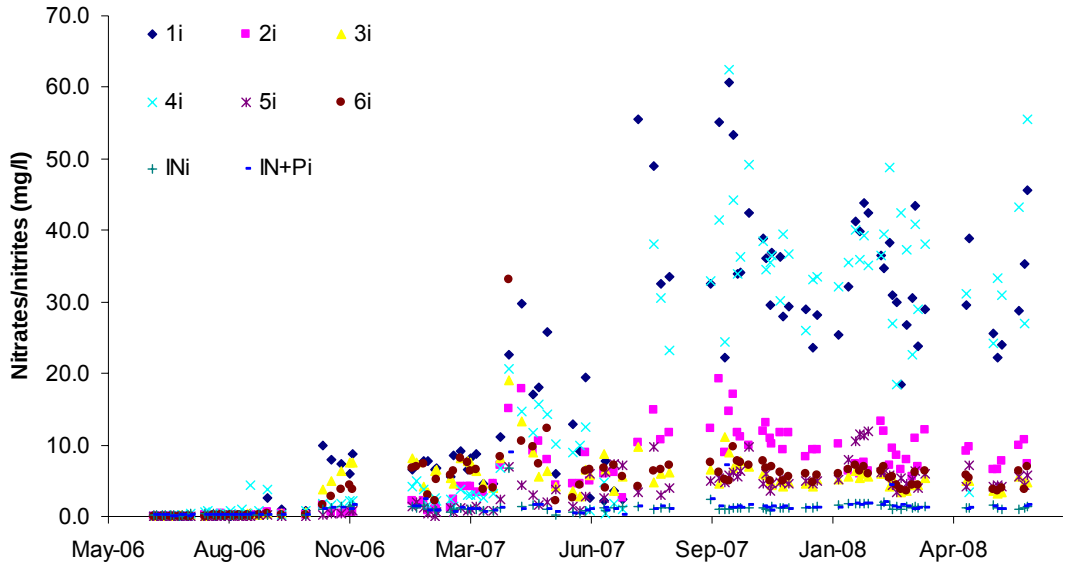


Figure 6-9 Indoor NO_{2+3} concentrations during experimental period (mg/l).

Comparing H/C mean values (**Table 6-7**), maximum NO_{2+3} concentrations occurred during the heating seasons for all bins. Also inflow values are higher in polluting mixture added into the bin in heating seasons. In the result, during heating cycle, denitrification inhibited reduction of nitrate, although higher levels of NO_{2+3} during could be the result of cooler temperatures.

The interesting fact is that, if calculating removals taking H/C mean values instead of seasonal averages, the removal rates would be positive for both rigs, in contrast to outdoor rigs. The temperature was high enough in indoor rigs for some denitrification occurrence during winter.

Looking at the NO_{2+3} levels (**Figure 6-9**) it is clear that NO_{2+3} levels in the indoor rig are relatively stable over time for bins 2i, 3i, 5i, 6i but the concentrations increase in bins 1i and 4i.

Jenkins (2002), after Bond (1999), reports that before application of NPK fertiliser (not used in The University of Edinburgh research), nitrate-nitrite concentrations ranged between 1.3 mg/l and 6.7 mg/l, mean of 2.5 mg/l at the top of examined PPS car park section and 0.44-2.8 mg/l, mean 1.5 mg/l respectively at the bottom section of the PPS car park.

Table 6-6 Seasonal means and RSD effluent and influent concentrations for tested NO_{2+3} in indoor rig (n=110).

	means (mg/l)								relative standard deviations (%)							
	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
Spring 1	0.02	0.03	0.03	0.04	0.02	0.02	0.20	0.18	0.01	0.01	0.02	0.01	0.00	0.01	0.07	0.07
Summer 1	0.25	0.14	0.21	0.75	0.05	0.11	0.25	0.19	0.49	0.12	0.10	1.04	0.04	0.08	0.07	0.07
Autumn 2	5.96	0.63	4.45	1.50	0.37	2.37	1.00	0.88	3.37	0.41	2.76	0.66	0.27	1.60	0.49	0.47
Winter 2	7.02	2.60	6.03	2.96	0.95	5.69	1.01	1.06	1.32	1.22	1.54	0.87	0.42	1.67	0.22	0.41
Spring 2	14.21	8.24	7.65	10.07	3.34	8.77	1.44	1.59	7.97	3.79	3.95	5.31	1.77	7.18	1.49	2.03
Summer 2	29.88	9.79	6.03	21.25	5.60	6.36	1.37	1.20	18.50	3.77	1.75	14.67	2.28	1.05	0.40	0.58
Autumn 3	36.32	11.67	6.01	37.40	5.35	6.35	1.14	1.58	10.02	2.66	1.74	8.02	1.18	1.20	0.13	1.32
Winter 3	33.35	8.47	5.01	35.20	6.81	5.64	1.51	1.61	6.83	2.20	0.80	6.80	2.54	1.02	0.25	0.70
Spring 3	31.24	8.42	4.40	31.07	4.92	4.93	1.19	1.21	7.30	1.47	0.77	13.65	0.99	1.20	0.17	0.22
Springs	**15.16**	**5.56**	**4.03**	**13.73**	**2.76**	**4.57**	**0.94**	**0.99**	**5.09**	**1.76**	**1.58**	**6.33**	**0.92**	**2.80**	**0.57**	**0.77**
Summers	**15.06**	**4.97**	**3.12**	**11.00**	**2.83**	**3.23**	**0.81**	**0.70**	**9.50**	**1.95**	**0.93**	**7.85**	**1.16**	**0.56**	**0.24**	**0.32**
Autumns	**21.14**	**6.15**	**5.23**	**19.45**	**2.86**	**4.36**	**1.07**	**1.23**	**6.70**	**1.54**	**2.25**	**4.34**	**0.72**	**1.40**	**0.31**	**0.90**
Winters	**20.19**	**5.53**	**5.52**	**19.08**	**3.88**	**5.66**	**1.26**	**1.33**	**4.07**	**1.71**	**1.17**	**3.84**	**1.48**	**1.35**	**0.24**	**0.56**

Table 6-7 H/C means and RSD effluent and influent concentrations for tested NO_{2+3} in indoor rig (n=110).

	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
NO_3	**means (mg/l)**								**relative standard deviations (%)**							
heating	23.3	7.5	6.3	20.8	3.9	6.6	1.3	1.5	14.11	4.53	2.35	15.14	2.92	3.81	0.75	1.24
cooling	13.3	4.2	2.7	13.1	2.6	2.7	0.8	0.7	14.92	4.02	2.46	15.65	2.46	2.50	0.49	0.69

Figure 6-10 shows the rise in outdoor rig mean concentrations in bins 1o and 4o, especially during Spring 2007 and Winter 2008. The overall increase in concentrations over time falls in Summer and Autumn 2007, probably due to the unplanned cooling in Summer 2007.

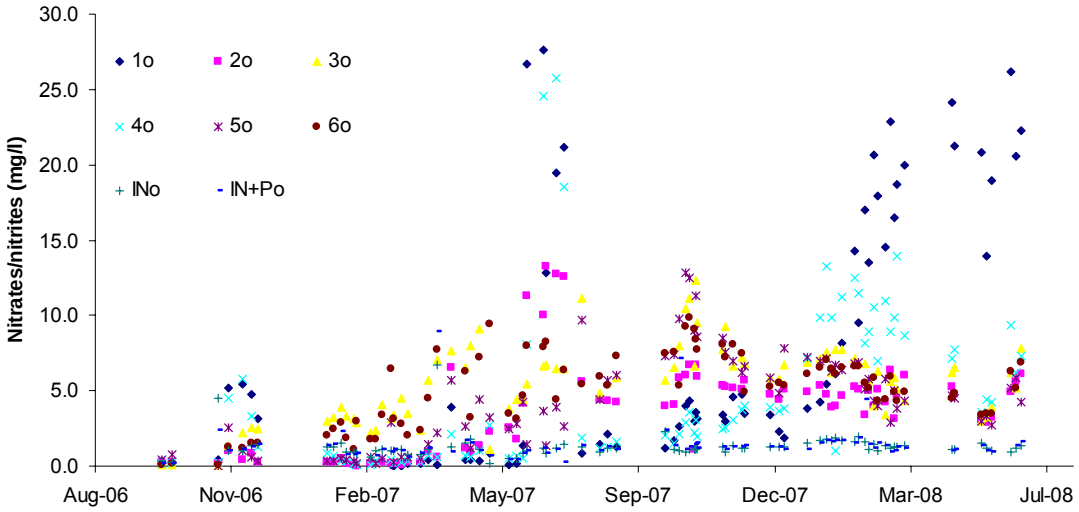


Figure 6-10 Outdoor rig NO_{2+3} water sample concentrations during experimental period (mg/l).

Seasonal variability presented in **Table 6-8** indicates that the highest levels at the outdoor rig were achieved during Spring 3 - 21 mg/l . The mean of 13.4 mg/l for Springs is considered as the maximum value of nitrates/nitrites.

The difference between average Springs' values for bins 1o and 4o equals 8.5 mg/l.

For Summers, Autumns and Winters the differences between the above bins were 0.4, 0.5, 1.5 mg/l respectively. Because bin 1o failure occurred in

January and February 2007, the data gap is accounted in the calculations in Winter 2. The highest seasonal mean occurred in Spring 3 when bin1 had been operational for 12 months, therefore the cause of higher concentrations is likely to be denitrification of NH_4 added in dog faeces rather than bin failure.

The highest mean NO_{2+3} concentrations during other seasons is found in bin 1o, 2o and 4o (Summers), 3o and 5o (Autumns), 1o and 4o (Winters).
The highest inflow variability was recorded for Springs with RSD of 1.39 and 1.81%. The highest outflow variability is recorded in bins 1o and 4o during Springs and Summers reaching 8.85% in bin 1o.

Bean (2005) reports mean concentrations of total nitrogen (TN) in Swansboro and Goldsboro study sites (Permeable Interlocking Concrete Pavers – PICP) between March and November 2004 for 0.36 mg/l; NO_{2+3} – N 0.17 mg/l and total Kjeldahl nitrogen (TKN) 0.13 mg/l. Samples were collected as PICP exfiltrate. In the same study PICP Cary, run between February and December 2004, recorded TN, NO_{2+3} - N and TKN mean concentrations were equal to 2.77 mg/l, 1.66 mg/l and 1.11 mg/l respectively.

Table 6-9 shows mean nitrate concentrations in the heating and cooling phases. Values were higher during cooling in bins 1o, 2o and 4o and higher during heating in bins 3o, 5o and 6o. Except bin 5o the explanation for these patterns is the presence of H/C coils in bins 1o, 2o, 4o and 5o. Coils were not installed in bins 3o and 6o.

Consequently, in bins with no coils, more NO_{2+3} was released during the heating season than in bins with coils. In bins with coils, more NO_{2+3} was released during the cooling season. This provides the evidence on systems' dependency on temperature. The reason for the occurrence might be increased oxygen levels introduced via piping in higher temperatures, hence better O_2 solubility in water providing favourable nitrification conditions, less favourable denitrification conditions in bins with no coils.

The maximum mean value during heating was in bin6 (5.13 mg/l) and was 16.09 mg/l, during cooling in bin1.

The highest variability was recorded in bin1 (RSD 9.91%) during cooling season and bin5 during heating season (RSD 4.22%).

Concentrations in both H/C seasons were relatively stable and similar for both inflows.

Table 6-8 Seasonal means and RSD outflow and inflow concentrations for tested NO_{2+3} in outdoor rig (n=85).

	means (mg/l)								relative standard deviations (%)							
	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
Summer 1	0.28	0.24	0.11	0.24	0.60	0.13	0.29	0.19	0.10	0.02	0.02	0.07	0.25	0.07	0.07	0.02
Autumn 2	3.80	0.54	1.73	3.01	0.91	1.11	1.89	1.46	2.44	0.44	1.26	2.68	1.18	0.72	1.73	0.65
Winter 2	0.07	0.20	3.21	0.34	0.59	2.65	1.01	1.06	0.09	0.14	0.77	0.26	0.80	1.49	0.29	0.54
Spring 2	5.79	4.38	5.89	3.57	2.83	6.15	1.44	1.59	11.87	5.21	2.46	8.18	1.63	2.63	1.92	2.62
Summer 2	6.77	6.84	6.57	7.47	5.67	6.03	1.37	1.20	10.87	4.71	2.46	12.05	2.75	1.31	0.52	0.75
Autumn 3	3.28	5.15	8.03	2.98	8.39	7.27	1.16	1.67	1.07	1.58	2.38	0.93	2.77	1.90	0.15	1.80
Winter 3	12.93	4.71	6.14	9.61	5.62	5.74	1.51	1.61	7.42	1.01	1.55	3.48	1.61	1.05	0.32	0.91
Spring 3	21.01	4.48	5.26	6.25	4.18	4.75	1.19	1.21	5.84	2.62	1.07	5.28	0.95	0.95	0.86	0.99
Springs	13.40	4.43	5.57	4.91	3.51	5.45	1.31	1.40	8.85	3.91	1.76	6.73	1.29	1.79	1.39	1.81
Summers	3.53	3.54	3.34	3.86	3.14	3.08	0.83	0.70	5.49	2.37	1.24	6.06	1.50	0.69	0.30	0.38
Autumns	3.54	2.85	4.88	2.99	4.65	4.19	1.52	1.56	1.76	1.01	1.82	1.81	1.98	1.31	0.94	1.22
Winters	6.50	2.46	4.68	4.98	3.10	4.20	1.26	1.33	3.76	0.58	1.16	1.87	1.20	1.27	0.30	0.72

Table 6-9 H/C means and RSD outflow and inflow concentrations for tested NO_{2+3} in outdoor rig (n=85).

	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
NO_{2+3}	means (mg/l)								relative standard deviations (%)							
heating	2.68	2.85	5.63	2.55	4.41	5.13	1.29	1.48	2.49	2.77	3.07	3.48	4.22	3.03	1.00	1.65
cooling	16.09	5.48	5.12	8.46	3.91	4.84	1.29	1.26	9.91	4.16	2.83	7.62	2.42	2.48	0.84	0.93

6.2.1.3 Ammonia (NH_4)

Tables 6-10 and 6-11 present the seasonal changes in the indoor rig. The effluent values are as stable as in the outdoor rig varying between 0.02 – 0.14 mg/l, in both rigs and the RSD 0.02-0.08% as maximum values in the indoor rig. Mean influent values were the highest for the IN+P reaching a mean of 1.78 mg/l in Summers.

Higher values were recorded for cooling cycle.

Higher outflow concentrations are recorded in the indoor rig at the beginning – similar to PO_4 indoor patterns (**Figure 6-11**) (double Y-axis).

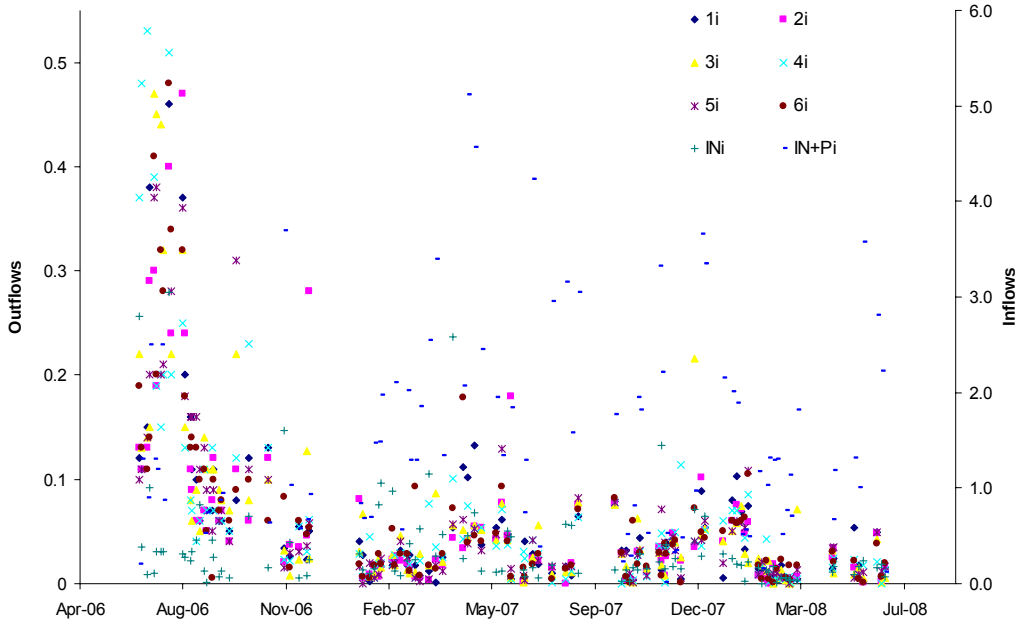


Figure 6-11 Indoor ammonia concentrations during experimental period (mg/l). Second Y-axis represents influent concentrations.

Table 6-10 Seasonal means and RSD outflow and inflow concentrations for tested ammonia in indoor rig (n=110).

	means (mg/l)								relative standard deviations (%)							
	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
Spring 1	0.19	0.17	0.16	0.46	0.14	0.14	1.07	1.23	0.01	0.01	0.06	0.07	0.01	0.04	1.56	0.71
Summer 1	0.14	0.15	0.19	0.15	0.18	0.18	0.43	1.12	0.11	0.12	0.13	0.11	0.10	0.12	0.62	0.55
Autumn 2	0.06	0.09	0.06	0.08	0.05	0.06	0.47	1.26	0.04	0.08	0.04	0.07	0.03	0.02	0.50	1.10
Winter 2	0.02	0.02	0.02	0.03	0.01	0.03	0.46	1.45	0.01	0.02	0.02	0.02	0.01	0.02	0.35	0.57
Spring 2	0.05	0.05	0.04	0.05	0.04	0.05	0.50	2.37	0.04	0.04	0.02	0.02	0.03	0.04	0.60	1.28
Summer 2	0.03	0.03	0.04	0.03	0.04	0.03	0.27	2.45	0.03	0.03	0.03	0.03	0.03	0.03	0.22	1.16
Autumn 3	0.03	0.03	0.04	0.03	0.03	0.03	0.33	1.25	0.02	0.02	0.04	0.03	0.02	0.02	0.32	1.11
Winter 3	0.03	0.03	0.03	0.03	0.03	0.03	0.12	1.11	0.03	0.02	0.02	0.03	0.03	0.03	0.09	0.54
Spring 3	0.02	0.02	0.02	0.02	0.02	0.02	0.16	1.61	0.02	0.01	0.01	0.01	0.01	0.01	0.05	1.05
Springs	**0.09**	**0.08**	**0.07**	**0.17**	**0.07**	**0.07**	**0.58**	**1.74**	**0.02**	**0.02**	**0.03**	**0.03**	**0.02**	**0.03**	**0.74**	**1.01**
Summers	**0.08**	**0.09**	**0.11**	**0.09**	**0.11**	**0.11**	**0.35**	**1.78**	**0.07**	**0.07**	**0.08**	**0.07**	**0.06**	**0.07**	**0.42**	**0.86**
Autumns	**0.05**	**0.06**	**0.05**	**0.05**	**0.04**	**0.04**	**0.40**	**1.25**	**0.03**	**0.05**	**0.04**	**0.05**	**0.03**	**0.02**	**0.41**	**1.11**
Winters	**0.02**	**0.02**	**0.02**	**0.03**	**0.02**	**0.03**	**0.29**	**1.28**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.22**	**0.56**

Table 6-11 H/C means and RSD outflow and inflow concentrations for tested ammonia in indoor rig (n=110).

	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
NH_4	means (mg/l)								relative standard deviations (%)							
heating	0.04	0.04	0.04	0.04	0.03	0.04	0.41	1.63	0.03	0.04	0.03	0.02	0.02	0.03	0.42	1.07
cooling	0.07	0.08	0.09	0.10	0.09	0.09	0.33	1.32	0.09	0.10	0.11	0.12	0.09	0.10	0.52	0.85

Ammonia outdoor values are presented in **Tables 6-12 and 6-13**. The data means vary from 0.02 mg/l (bin3) during Winters with the maximum of 0.14 mg/l (bin1) for the effluents during the same season. RSD are relatively stable throughout the year for effluents. The influent values reached the maximum mean of 2.77 mg/l during Springs for the IN+P type. The highest variability was recorded for the same parameter during Summers. Higher mean effluent concentrations occurred during heating.

Figure 6-12 (double Y-axis) analysis provides information on NH_4 fluctuations during the experiment.

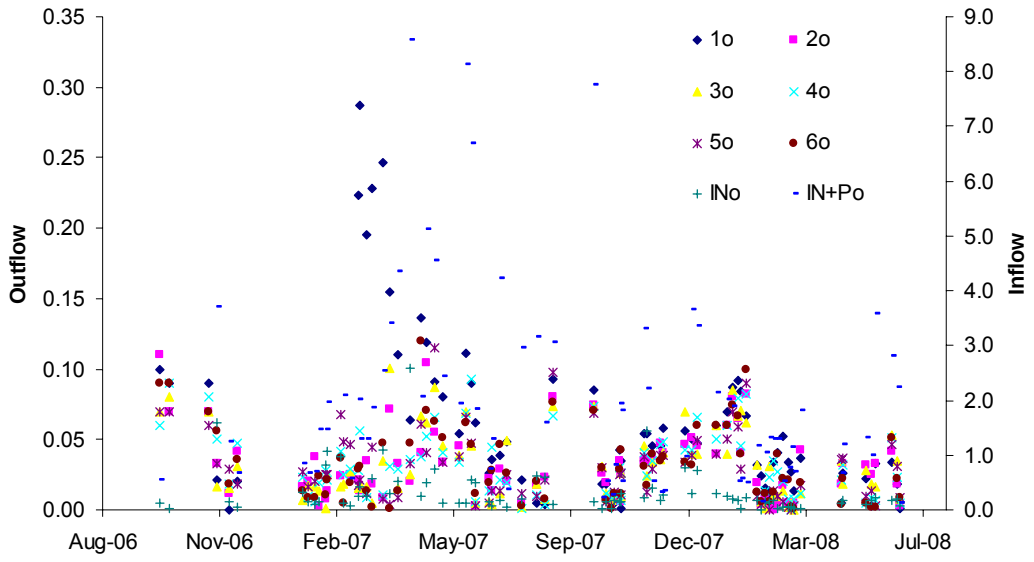


Figure 6-12 Outdoor ammonia concentrations during experimental period (mg/l). Second Y-axis represents influent concentrations.

Maximum mean effluent records are found for Spring 2007 and Winter 2008.

Bin1 NH_4 concentrations are higher than in the other bins, because of the bin failure, described in previous chapters. Increase in data levels seen in September 2007 is attributed to temporary cooling in the Summer 2007.

In the Summary of Hollywood branch Peat/Sand filter sampling data US EPA (1999) reports that ammonia-N concentrations were non-detectable for the baseflows (n=3) and mean AN concentrations of 2.95 mg/l during storm events (n=5), with three samplings out of five as <1 mg/l.

In Prince William Parkway Regional wet pond (EPA, 1999) during October 1998, sampling data (n=9) US EPA reports ammonia-N concentrations as not detected during the first four sampling days in four effluent sampling points. For the next five sampling days mean concentrations were as follows:

n_5= 4.48 mg/l; n_6= 0.06 mg/l; n_7= 0.19 mg/l; n_8= 0.29 mg/l; n_9= 0.62 mg/l. It is worth noting that wet pond concentrations are much lower due to a higher volume of water in the aquifer, hence better dilution of the sample.

Bean (2004) reports mean concentrations for PIPC exfiltrate at Cary and Swansboro as 0.06 mg/l and 0.05 mg/l respectively in after treatment samples.

Table 6-12 Seasonal means and RSD outflow and inflow values for tested ammonia in outdoor rig (n=85).

	means (mg/l)								relative standard deviations (%)							
	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
Summer 1	0.10	0.09	0.08	0.08	0.07	0.09	0.07	0.55	0.01	0.03	0.01	0.02	0.00	0.00	0.08	-
Autumn 2	0.03	0.04	0.03	0.05	0.04	0.05	0.60	1.87	0.05	0.03	0.03	0.03	0.02	0.03	1.02	1.90
Winter 2	0.24	0.02	0.02	0.02	0.03	0.02	0.45	1.45	0.04	0.01	0.01	0.02	0.02	0.02	0.44	0.74
Spring 2	0.09	0.04	0.04	0.04	0.04	0.04	0.50	3.93	0.05	0.03	0.04	0.03	0.04	0.04	0.78	3.04
Summer 2	0.04	0.04	0.03	0.03	0.04	0.04	0.27	3.30	0.04	0.03	0.04	0.03	0.04	0.03	0.28	2.74
Autumn 3	0.04	0.03	0.03	0.03	0.03	0.03	0.35	1.39	0.02	0.02	0.02	0.02	0.02	0.02	0.44	1.46
Winter 3	0.05	0.03	0.03	0.03	0.02	0.03	0.12	1.11	0.03	0.03	0.03	0.03	0.03	0.03	0.11	0.70
Spring 3	0.02	0.03	0.03	0.02	0.02	0.01	0.16	1.61	0.02	0.01	0.01	0.01	0.02	0.02	0.38	1.03
Springs	**0.05**	**0.03**	**0.04**	**0.03**	**0.03**	**0.03**	**0.33**	**2.77**	**0.03**	**0.02**	**0.03**	**0.02**	**0.03**	**0.03**	**0.58**	**2.03**
Summers	**0.07**	**0.06**	**0.05**	**0.05**	**0.05**	**0.06**	**0.17**	**1.93**	**0.03**	**0.03**	**0.02**	**0.03**	**0.02**	**0.02**	**0.18**	**2.74**
Autumns	**0.03**	**0.03**	**0.03**	**0.04**	**0.03**	**0.04**	**0.47**	**1.63**	**0.04**	**0.02**	**0.02**	**0.03**	**0.02**	**0.02**	**0.73**	**1.68**
Winters	**0.14**	**0.02**	**0.02**	**0.03**	**0.03**	**0.03**	**0.29**	**1.28**	**0.04**	**0.02**	**0.02**	**0.02**	**0.03**	**0.03**	**0.28**	**0.72**

Table 6-13 H/C means and RSD outflow and inflow values for tested ammonia in outdoor rig (n=85).

	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
NH_4	**means (mg/l)**								**relative standard deviations (%)**							
heating	0.08	0.04	0.04	0.04	0.04	0.04	0.42	2.18	0.08	0.03	0.03	0.02	0.03	0.03	0.56	2.29
cooling	0.04	0.02	0.02	0.03	0.02	0.02	0.14	1.60	0.03	0.03	0.03	0.03	0.02	0.03	0.15	1.71

6.2.1.4 Ortho-phosphate-phosphorus

Phosphorus concentrations are usually very low in waters ranging from 0.01 – 0.1 mg/l. The reason for this is that PO_4 is relatively hard to dissolve in waters. If too much phosphate is introduced into surface waters it enhances algal blooms and eutrophication (Weiner, 2008), causing accelerated plant growth and death of fish and other aquatic organisms vulnerable to rapid water quality changes.

Sources of phosphates are different including agriculture (fertilisers), faecal runoff from livestock farms and pigsties, failing septic systems (Spellman, 2008), usually large quantities of phosphates are found in industrial sewage. In domestic discharge is mainly introduced by detergents containing polyphosphates.

Most often, an inorganic form of phosphate is suspended in water and the organic form is being used by live organisms.
Organic phosphorus is decomposed by living organisms into inorganic form. Usually plants uptake inorganic phosphorus feeding on it.

Zhang *et al.* (2010) reports average concentrations of total phosphorus inflows in domestic waters between 2006-2007 for 8.4±0.9 mg/l.

Tables 6-14 and **6-15** and **Figure 6-13** show the indoor ortho-phosphate-phosphorus values.

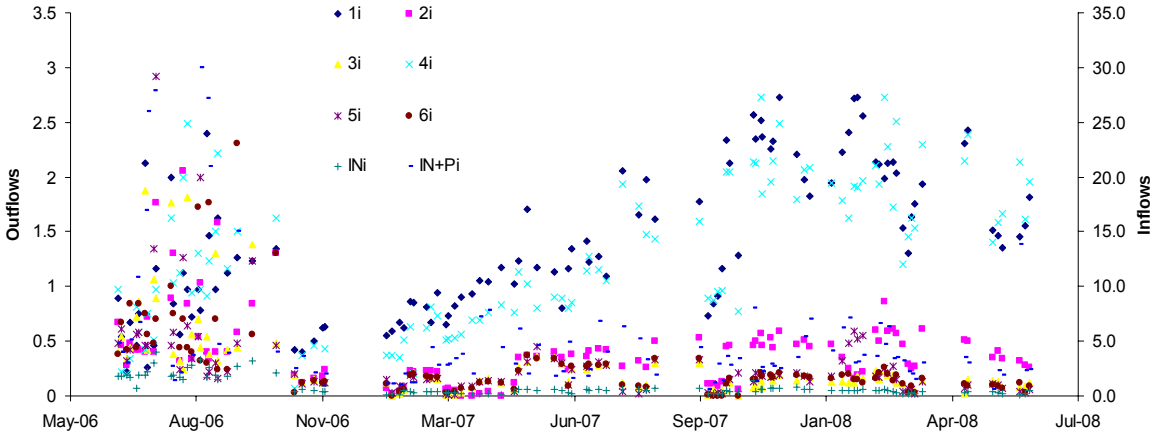


Figure 6-13 Indoor ortho-phosphate-phosphorus concentrations during experimental period (mg/l). Second Y-axis represents influent concentrations.

Until the Autumn of 2006, values are higher and more variable compared to later data.

Causes of this are:

- washing of P from the unwashed aggregates introduced in the sub-base;
- interference on H/C cycle on 6th November 2006 due to technical difficulties, resulting in rapid changes of concentrations – possible devastation of current (at the time) environmental conditions

The lowest values in the influent (**Table 6-14**) are recorded for Winters (values of 0.1 mg/l), although it might be argued that while considering indoor rig it should not be analysed for seasonal changes (because of stable and controlled temperatures).

H/C higher mean concentrations are recorded during cooling cycle (**Table 6-15**).

RSD records fall into IN+Pi influent values with the maximum of 7.04%.

Influent concentrations are 10 times higher than effluent concentrations (**Figure 6-13**) (double Y-axis) which can explain extremely high removal rates, as described previously.

Past the initial stage, the indoor data cloud took the shape of outdoor data cloud with the slight decrease in both types of values in Spring 2008.

Table 6-14 Seasonal means and RSD effluent and influent concentrations for tested ortho-phosphate phosphorus in indoor rig (n=110).

	means (mg/l)								relative standard deviations (%)							
	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
Spring 1	0.58	0.47	0.43	0.43	0.46	0.58	1.80	4.24	0.22	0.13	0.09	0.48	0.08	0.19	0.00	0.51
Summer 1	1.10	0.76	0.77	1.20	0.70	0.76	2.19	13.34	0.52	0.48	0.48	0.50	0.63	0.51	0.70	9.73
Autumn 2	0.74	0.43	0.37	0.51	0.34	0.34	1.10	2.55	0.35	0.41	0.42	0.52	0.37	0.41	1.02	1.02
Winter 2	0.76	0.11	0.09	0.53	0.10	0.10	0.30	2.29	0.12	0.09	0.07	0.15	0.06	0.07	0.10	1.05
Spring 2	1.19	0.26	0.23	0.91	0.23	0.23	0.40	3.83	0.20	0.14	0.09	0.16	0.10	0.10	0.18	1.98
Summer 2	1.63	0.39	0.21	1.48	0.20	0.22	0.59	4.56	0.32	0.10	0.09	0.28	0.14	0.11	0.08	1.55
Autumn 3	1.91	0.38	0.10	1.76	0.14	0.12	0.56	3.19	0.60	0.17	0.06	0.56	0.06	0.08	0.27	1.80
Winter 3	2.07	0.43	0.14	1.91	0.25	0.15	0.42	3.97	0.36	0.18	0.05	0.35	0.17	0.06	0.13	1.54
Spring 3	1.74	0.37	0.10	1.86	0.07	0.09	0.31	3.74	0.37	0.09	0.04	0.31	0.03	0.02	0.12	3.81
Springs	**1.17**	**0.37**	**0.25**	**1.07**	**0.25**	**0.30**	**0.83**	**3.94**	**0.27**	**0.12**	**0.07**	**0.32**	**0.07**	**0.10**	**0.10**	**2.10**
Summers	**1.37**	**0.57**	**0.49**	**1.34**	**0.45**	**0.49**	**1.39**	**8.95**	**0.42**	**0.29**	**0.29**	**0.39**	**0.38**	**0.31**	**0.39**	**5.64**
Autumns	**1.32**	**0.40**	**0.23**	**1.14**	**0.24**	**0.23**	**0.83**	**2.87**	**0.48**	**0.29**	**0.24**	**0.54**	**0.22**	**0.24**	**0.65**	**1.41**
Winters	**1.42**	**0.27**	**0.12**	**1.22**	**0.17**	**0.13**	**0.36**	**3.13**	**0.24**	**0.13**	**0.06**	**0.25**	**0.11**	**0.06**	**0.11**	**1.30**

Table 6-15 H/C means and RSD effluent and influent concentrations for tested ortho-phosphate phosphorus in indoor rig (n=110).

	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
PO_4	**means (mg/l)**								**relative standard deviations (%)**							
heating	1.41	0.26	0.13	1.16	0.18	0.14	0.46	3.27	0.68	0.16	0.08	0.64	0.13	0.09	0.21	1.70
cooling	1.37	0.58	0.44	1.41	0.41	0.45	1.25	6.93	0.53	0.36	0.42	0.58	0.47	0.43	0.94	7.04

Looking at **Figure 6-14** there is a clear difference in values between outflow and inflow – the former reached higher concentrations. It is also noticeable that bins 1 and 4 have higher values of the compound. The concentrations are stable through the year, although concentrations decrease is recorded in Spring 2008 for both influent and effluent values.

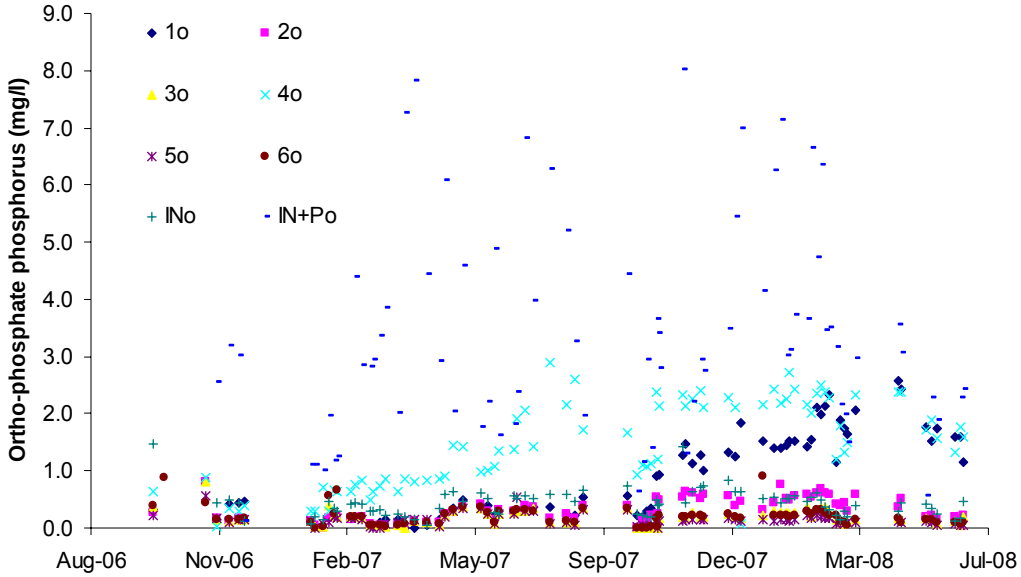


Figure 6-14 Outdoor ortho-phosphate-phosphorus concentrations during experimental period (mg/l). Second Y-axis represents influent concentrations.

Outdoor rig mean PO_4 concentrations in outflow samples were highest at 1.48 mg/l in bin 4o (**Tables 6-16 and 6-17**). The lowest mean value was 0.12 mg/l. The maximum mean values for seasons (not in all bins) are recorded for Springs with the mean of 0.54 mg/l. The highest mean variability is recorded for bin4 during Summers with the RSD of 0.63%. As for the inflows, the highest mean values are recorded for IN+Po (4.56 mg/l) in Summers. This type of inflow had the highest RSD of 2.08% for Autumns.

Looking at the H/C seasons ortho-phosphate phosphorus was at higher concentrations in bins 1 and 4, during cooling seasons.
Inflow values were similar - for both types INo = 0.44 and 0.42 mg/l; INPo = 3.32 and 3.34 mg/l.

For Swansboro site, Bean (2005) reported mean Total Phosphorus (TP) exfiltrate concentrations as 0.057 (range of 0.005 - 0.140 mg/l). In Goldsboro site, TP mean concentrations were 0.048 mg/l (range of 0.025 – 0.28 mg/l) n his laboratory experiment Jenkins (2002) reported minimum PO_4 concentrations as 0.02 mg/l and maximum as 0.18 mg/l over 10 days of the study.

Table 6-16 Seasonal means and RSD effluent and influent concentrations for tested ortho-phosphate phosphorus in outdoor rig (n=85).

	means (mg/l)								relative standard deviations (%)							
	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
Summer 1	0.32	0.28	0.36	0.64	0.22	0.65	1.46	-	-	-	-	-	-	-	-	-
Autumn 2	0.37	0.29	0.28	0.39	0.22	0.21	0.37	2.23	0.18	0.35	0.35	0.37	0.22	0.15	0.20	1.68
Winter 2	0.09	0.10	0.13	0.61	0.10	0.17	0.30	2.29	0.07	0.08	0.13	0.23	0.08	0.24	0.13	1.36
Spring 2	0.24	0.23	0.20	1.14	0.23	0.22	0.40	3.83	0.18	0.14	0.14	0.39	0.15	0.14	0.23	2.56
Summer 2	0.39	0.30	0.23	2.07	0.21	0.23	0.59	4.56	0.15	0.13	0.14	0.63	0.15	0.15	0.10	2.00
Autumn 3	0.91	0.41	0.13	1.71	0.10	0.14	0.55	3.27	0.62	0.24	0.11	0.84	0.07	0.11	0.38	2.48
Winter 3	1.70	0.52	0.23	2.12	0.14	0.25	0.42	3.97	0.39	0.15	0.11	0.50	0.05	0.22	0.16	1.99
Spring 3	1.79	0.25	0.14	1.82	0.08	0.12	0.31	2.29	0.56	0.15	0.06	0.45	0.04	0.04	0.15	1.11
Springs	**1.02**	**0.24**	**0.17**	**1.48**	**0.15**	**0.17**	**0.35**	**3.06**	**0.37**	**0.14**	**0.10**	**0.42**	**0.10**	**0.09**	**0.19**	**1.84**
Summers	**0.35**	**0.29**	**0.29**	**1.36**	**0.21**	**0.44**	**1.03**	**4.56**	**0.15**	**0.13**	**0.14**	**0.63**	**0.15**	**0.15**	**0.10**	**2.00**
Autumns	**0.64**	**0.35**	**0.21**	**1.05**	**0.16**	**0.17**	**0.46**	**2.75**	**0.40**	**0.29**	**0.23**	**0.61**	**0.14**	**0.13**	**0.29**	**2.08**
Winters	**0.89**	**0.31**	**0.18**	**1.36**	**0.12**	**0.21**	**0.36**	**3.13**	**0.23**	**0.11**	**0.12**	**0.36**	**0.07**	**0.23**	**0.15**	**1.68**

Table 6-17 H/C means and RSD effluent and influent concentrations for tested ortho-phosphate phosphorus in outdoor rig (n=85).

	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
PO_4	**means (mg/l)**								**relative standard deviations (%)**							
heating	0.65	0.28	0.17	1.28	0.13	0.19	0.44	3.32	0.66	0.24	0.13	0.94	0.10	0.20	0.27	2.27
cooling	1.37	0.38	0.22	1.77	0.17	0.23	0.42	3.34	0.92	0.22	0.18	0.65	0.16	0.20	0.30	2.08

6.2.2 pH seasonal variability

Indoor effluent pH (**Tables 6-18** and **6-19**) values range from 7.2 – 7.6 with the highest values recorded in bin 6i. **Figure 6-15** provides flat, close to sinusoidal, shape with it maximums in Summer of 2006 and Winter of 2008.

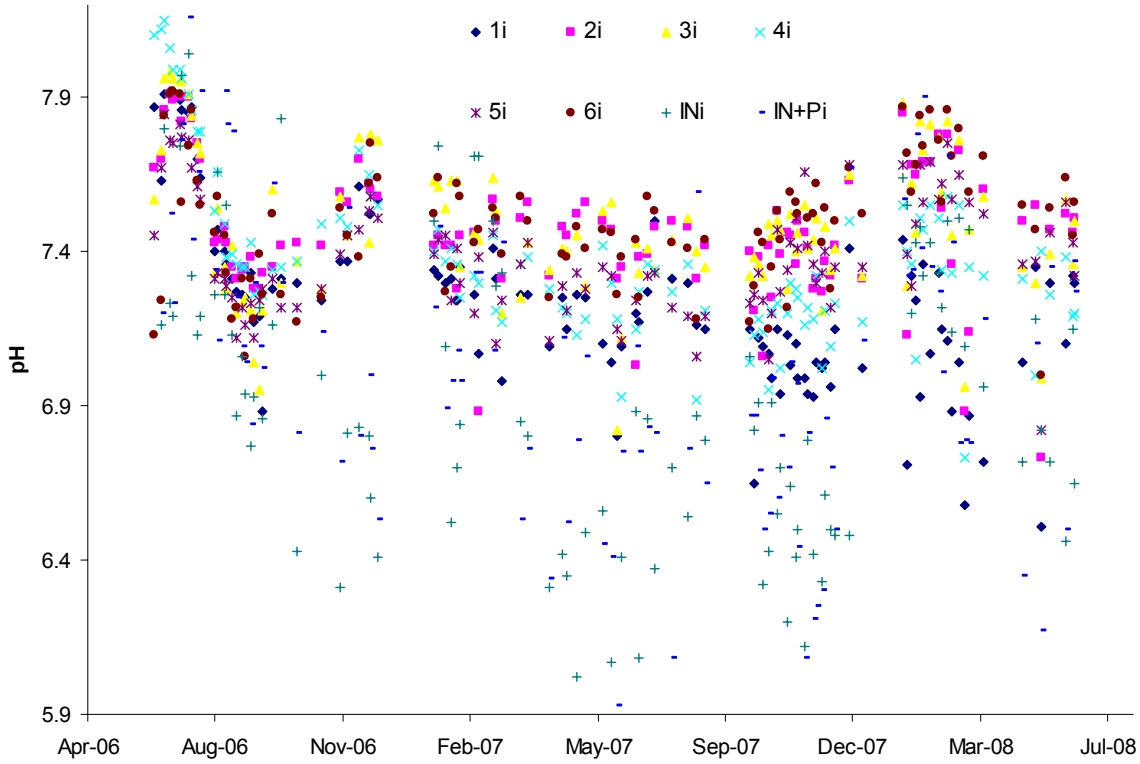


Figure 6-15 Indoor pH concentrations during experimental period.

Similar conclusions can be drawn regarding influent values as for the outdoor rig, because the same type of polluting mixture had been added into both rigs. The highest RSD values were recorded for IN+Pi type of inflow during Summers 0.36%. IN inflow RSD maximum values are

recorded for Winters. There is no clear difference between values when taking H/C seasons under consideration.

Alkaline pH can provide stable conditions for partial nitrification and autotrophic nitrogen removal over nitrate (Guo *et al., 2006*).

Table 6-18 Seasonal means and RSD effluent and influent concentrations for tested pH in indoor rig (n=110).

	means (mg/l)								relative standard deviations (%)							
	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
Spring 1	7.9	7.8	7.8	8.1	7.7	7.6	7.3	7.3	0.11	0.10	0.17	0.06	0.14	0.35	0.28	0.16
Summer 1	7.4	7.5	7.5	7.5	7.4	7.4	7.3	7.5	0.25	0.20	0.28	0.23	0.21	0.21	0.35	0.34
Autumn 2	7.4	7.6	7.6	7.5	7.4	7.5	6.6	6.9	0.12	0.09	0.18	0.10	0.11	0.18	0.22	0.28
Winter 2	7.3	7.4	7.5	7.3	7.3	7.5	7.2	7.1	0.11	0.16	0.14	0.08	0.10	0.10	0.39	0.25
Spring 2	7.1	7.4	7.3	7.2	7.3	7.4	6.4	6.7	0.12	0.13	0.18	0.12	0.09	0.08	0.26	0.32
Summer 2	7.2	7.4	7.4	7.2	7.2	7.4	6.8	6.8	0.22	0.09	0.06	0.15	0.08	0.14	0.19	0.37
Autumn 3	7.1	7.4	7.4	7.2	7.4	7.5	6.5	6.7	0.10	0.11	0.09	0.11	0.13	0.12	0.20	0.34
Winter 3	7.1	7.5	7.6	7.4	7.6	7.7	7.4	7.3	0.24	0.26	0.22	0.20	0.11	0.10	0.18	0.32
Spring 3	7.1	7.4	7.4	7.2	7.3	7.5	6.8	6.9	0.27	0.27	0.17	0.12	0.22	0.19	0.24	0.47
Springs	**7.4**	**7.5**	**7.5**	**7.5**	**7.4**	**7.5**	**6.9**	**7.0**	**0.17**	**0.17**	**0.17**	**0.10**	**0.15**	**0.21**	**0.26**	**0.32**
Summers	**7.3**	**7.5**	**7.4**	**7.4**	**7.3**	**7.4**	**7.0**	**7.1**	**0.24**	**0.14**	**0.17**	**0.19**	**0.14**	**0.17**	**0.27**	**0.36**
Autumns	**7.2**	**7.5**	**7.5**	**7.4**	**7.4**	**7.5**	**6.6**	**6.8**	**0.11**	**0.10**	**0.14**	**0.10**	**0.12**	**0.15**	**0.21**	**0.31**
Winters	**7.2**	**7.5**	**7.5**	**7.4**	**7.5**	**7.6**	**7.3**	**7.2**	**0.17**	**0.21**	**0.18**	**0.14**	**0.11**	**0.10**	**0.28**	**0.29**

Table 6-19 H/C means and RSD effluent and influent concentrations for tested pH in indoor rig (n=110).

	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
pH	**means (mg/l)**								**relative standard deviations %**							
heating	7.1	7.4	7.5	7.3	7.4	7.5	6.7	6.9	0.18	0.15	0.13	0.15	0.13	0.14	0.39	0.38
cooling	7.3	7.5	7.5	7.5	7.4	7.5	7.1	7.2	0.31	0.23	0.27	0.28	0.21	0.22	0.38	0.44

Regarding pH values for outdoor rig (**Table 6-20 and 6-21**), the minimum mean levels were recorded for IN inflow in autumn and spring reaching the values of 6.6. The values were stable as seen in RSD columns. During H/C seasons there is no clear difference between mean values.

During the experimental period, there is no visible difference in pH values (**Figure 6-15**). Recorded influent levels were lower than effluent because of the influent reaction with PPS aggregates leading to its increase in values.

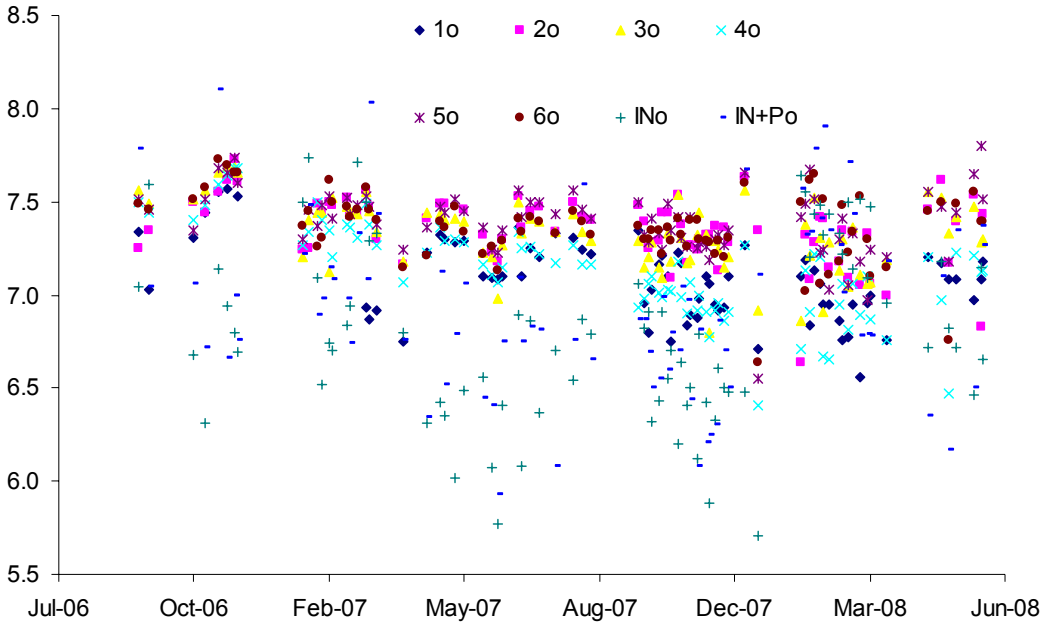


Figure 6-16 Outdoor pH effluent during experimental period.

pH values can indicate processes affecting sample composition as well as water corrosivity and conductance or contaminant solubility (Weiner, 2008). pH above 7.0 is considered as alkaline, below 7.0 as acidic. Water corrosivity increases in more acidic conditions. Looking at indoor/outdoor results, all seasonal means in effluents are more alkaline (still close to neutral) than acidic except bin 1o during Winters. This is mainly because of

alkaline properties of PPS sub-base – granite, which is composed of magnesium and quartz ($3MgO*4SiO_2*H_2O$) (Albertus, 1967).

Inflow values tend to be more acidic with the reason being gully pot liquor presence.

Pratt *et al.* (1989) reported pH levels of the PPS effluent above 7.0 in experimental systems assessed.

Table 6-20 Seasonal means and RSD effluent and influent concentrations for tested pH in outdoor rig (n=85).

	means (mg/l)								relative standard deviations (%)							
	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
Summer 1	7.2	7.3	7.5	7.5	7.5	7.5	7.3	7.4	0.26	0.08	0.06	0.05	0.04	0.02	0.46	0.62
Autumn 2	7.5	7.6	7.6	7.6	7.6	7.6	6.8	7.1	0.14	0.12	0.09	0.14	0.17	0.10	0.33	0.63
Winter 2	6.9	7.4	7.4	7.4	7.4	7.4	7.2	7.2	0.04	0.12	0.15	0.10	0.08	0.12	0.48	0.40
Spring 2	7.2	7.1	7.3	7.2	7.4	7.3	6.3	6.7	0.20	0.98	0.17	0.12	0.13	0.12	0.38	0.41
Summer 2	7.2	7.4	7.3	7.1	7.5	7.4	6.8	6.8	0.14	0.06	0.11	0.15	0.09	0.06	0.25	0.48
Autumn 3	7.0	7.3	7.2	7.0	7.3	7.3	6.4	6.7	0.19	0.15	0.21	0.20	0.24	0.21	0.36	0.43
Winter 3	6.9	7.2	7.2	6.9	7.3	7.3	7.4	7.3	0.20	0.24	0.21	0.22	0.23	0.25	0.23	0.42
Spring 3	7.1	7.3	7.4	7.0	7.5	7.4	6.8	6.9	0.09	0.32	0.13	0.32	0.23	0.32	0.31	0.61
Springs	**7.1**	**7.2**	**7.4**	**7.1**	**7.5**	**7.3**	**6.6**	**6.8**	**0.15**	**0.65**	**0.15**	**0.22**	**0.18**	**0.22**	**0.35**	**0.51**
Summers	**7.2**	**7.4**	**7.4**	**7.3**	**7.5**	**7.4**	**7.0**	**7.1**	**0.20**	**0.07**	**0.08**	**0.10**	**0.06**	**0.04**	**0.35**	**0.55**
Autumns	**7.3**	**7.4**	**7.4**	**7.3**	**7.4**	**7.5**	**6.6**	**6.9**	**0.16**	**0.14**	**0.15**	**0.17**	**0.20**	**0.15**	**0.34**	**0.53**
Winters	**6.9**	**7.3**	**7.3**	**7.1**	**7.4**	**7.4**	**7.3**	**7.3**	**0.12**	**0.18**	**0.18**	**0.16**	**0.16**	**0.19**	**0.36**	**0.41**

Table 6-21 H/C means and RSD effluent and influent concentrations for tested pH in outdoor rig (n=85).

	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
pH	means (mg/l)								relative standard deviations (%)							
heating	7.1	7.3	7.3	7.2	7.4	7.4	6.7	6.9	0.27	0.51	0.23	0.30	0.21	0.22	0.56	0.53
cooling	7.1	7.3	7.3	7.1	7.4	7.3	6.9	7.0	0.23	0.22	0.21	0.29	0.23	0.22	0.54	0.58

6.2.3 TDS seasonal variability

The amount of total residue is dependent on weather characteristics and geological conditions as well as anthropogenic pollution (Faust and Aly, 1981).

Because of various layers composing PPS sub-base, TDS effluent contained washout from those layers.

Indoor data experimental period is presented on **Figure 6-17**.

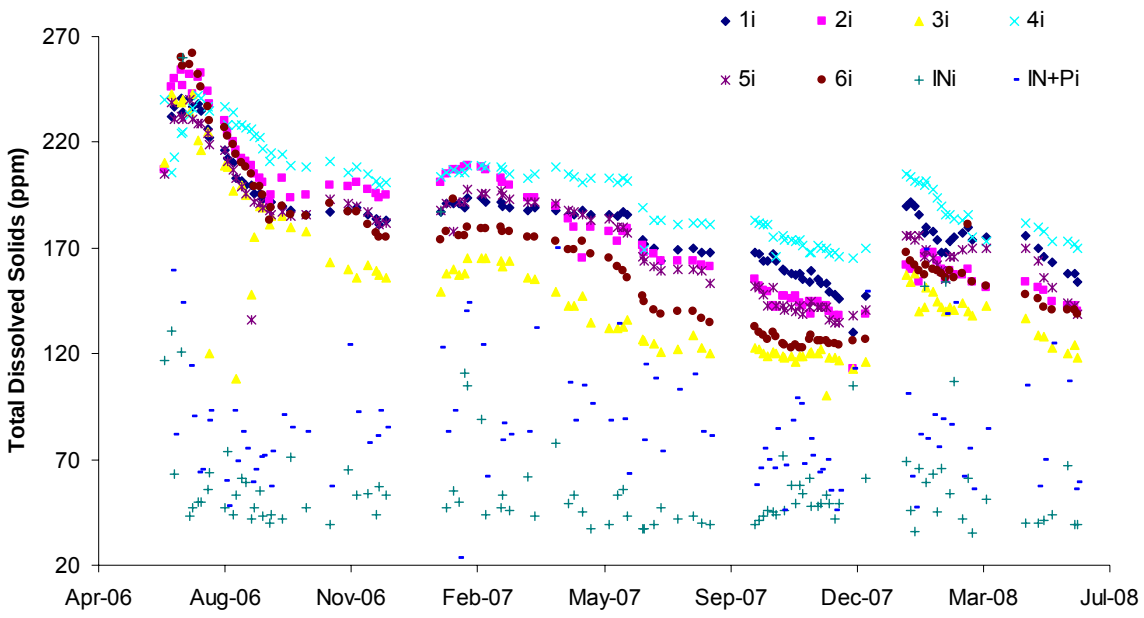


Figure 6-17 Indoor Total Dissolved Solids concentrations during experimental period (ppm).

Initial stage data levels can be seen on the graphs until August 2006, when values are much higher, and then they stabilise and decrease continuously

until the Winter 2007. Rise in levels is noted in Winter 2007 after switching into cooling cycle from heating.

Table 6-22 provides information on indoor systems' stability, although found RSD values are higher in the effluents than in the outdoor system. As an example, bins 2i and 3i reach RSD values of 11.7% and 16.8% respectively. In general summer RSD values are higher than in the rest of the seasons as seen in **Table 6-22**. During H/C seasons (in **Table 6-23**), much higher mean effluent values were recorded during cooling seasons. Mean values during heating ranged between 133 to 186 ppm and during heating 364 – 410 ppm. This provides the conclusion that temperature control over the systems can be beneficial. If high temperatures are present in the sub-base, TDS removal increases, due to improved solubility of particles in water.

Table 6-22 Seasonal means and RSD effluent and influent concentrations for tested TDS in indoor rig (n=110).

	means (ppm)								relative standard deviations (%)							
	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
Spring 1	236	241	234	222	228	258	138	128	3.6	17.4	12.5	11.8	11.9	2.6	66.3	37.1
Summer 1	209	220	190	227	203	217	52	76	16.4	18.8	31.1	9.1	21.4	22.3	9.0	14.6
Autumn 2	186	197	161	205	187	182	52	87	2.4	2.4	6.6	3.5	4.0	5.6	7.3	17.1
Winter 2	191	204	160	207	192	179	75	94	2.0	4.1	4.4	1.7	4.9	4.4	38.7	31.3
Spring 2	184	178	138	199	182	163	48	105	5.0	7.7	8.3	9.7	8.1	9.0	10.7	26.4
Summer 2	168	161	123	182	157	137	41	85	1.8	4.6	2.5	0.8	3.7	3.6	2.5	17.9
Autumn 3	155	142	118	171	142	126	54	76	7.6	7.0	4.2	4.2	3.6	1.9	12.9	22.0
Winter 3	179	160	145	192	168	160	69	90	6.8	4.7	5.8	9.4	5.7	6.1	33.5	30.5
Spring 3	164	147	126	175	152	143	44	83	7.0	4.7	5.8	4.1	10.5	2.9	9.2	26.2
Springs	**195**	**189**	**166**	**199**	**187**	**188**	**77**	**105**	**5.2**	**9.9**	**8.9**	**8.5**	**10.2**	**4.8**	**28.7**	**29.9**
Summers	**189**	**190**	**157**	**205**	**180**	**177**	**46**	**81**	**9.1**	**11.7**	**16.8**	**4.9**	**12.6**	**12.9**	**5.8**	**16.2**
Autumns	**170**	**170**	**140**	**188**	**164**	**154**	**53**	**82**	**5.0**	**4.7**	**5.4**	**3.8**	**3.8**	**3.7**	**10.1**	**19.5**
Winters	**185**	**182**	**153**	**199**	**180**	**170**	**72**	**92**	**4.4**	**4.4**	**5.1**	**5.6**	**5.3**	**5.3**	**36.1**	**30.9**

Table 6-23 H/C means and RSD effluent and influent concentrations for tested TDS in indoor rig (n=110).

	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
TDS	means (ppm)								relative standard deviations (%)							
heating	170	162	133	186	161	146	55	84	15.3	22.5	16.9	14.6	19.7	21.2	19.3	24.7
cooling	384	383	338	410	373	364	127	172	45.7	66.1	75.3	42.0	51.2	68.5	72.1	51.2

Outdoor TDS values (**Tables 6-24, 6-25**) are highly dependent on the amount of the material washed out and dissolved from the sub-base. This is clear when comparing the effluent values with the influent values which are much lower. This is because effluent values were affected by leaching from the sub-base. The first bin seasonal mean values are recorded in bin1o (184 - 271 ppm) and the second bin 4o ranging between 180 – 198 ppm in values. Inflow values are stable, although the highest RSD are recorded for IN inflows 50.9% for Winters' seasons, corresponding mean value of 75 ppm. The main cause of such concentrations and variability can be winter road salting, being introduced into the gully pot chamber as a part of road runoff. Slightly higher released values are recorded for four out of six bins during heating cycle, although the differences between H/C are not very high and the difference ranges between 1 – 11 ppm. **Figure 6-18** provides information on TDS records during the year in outdoor rig.

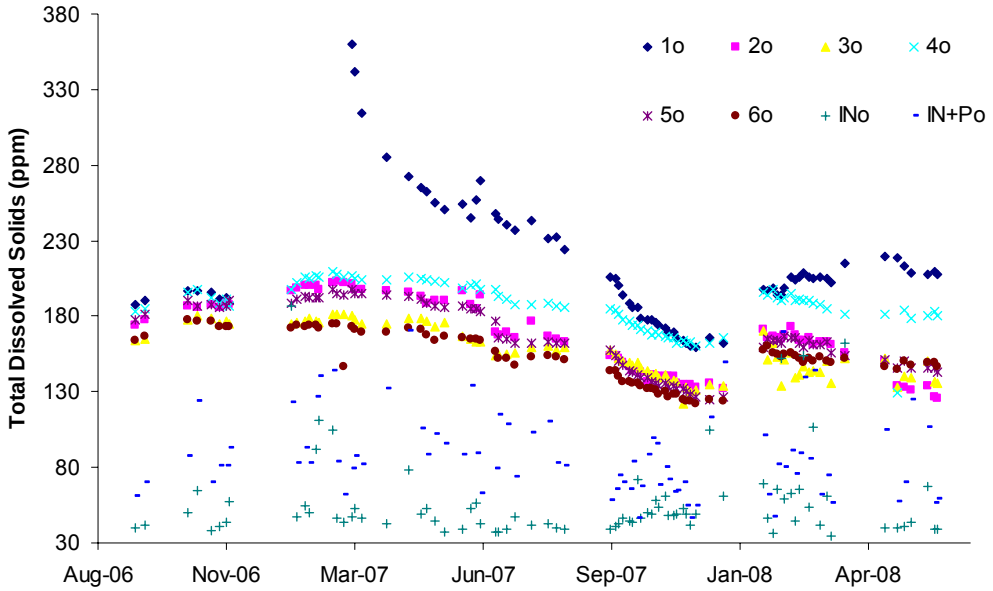


Figure 6-18 Outdoor Total Dissolved Solids concentrations during experimental period (ppm).

Stable outflow is being recorded during the years until Summer 2007. After a gap in data collection, data cloud continues previous pattern, although the data readings are raised slightly from before.

A very clear pattern of bin 1o raised data levels can be noticed on the graph. It is brought down to the similar levels as in bin 4o during the Summer of 2007. This is due to the re-installation of bin 1o – hence, new washout and initialization period, with raised values.

Table 6-24 Seasonal means and RSD effluent and influent concentrations for tested TDS in outdoor rig (n=85).

	means (mg/l)								relative standard deviations (%)							
	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
Summer 1	189	176	165	184	180	166	41	66	1.7	3.3	0.8	1.7	2.5	2.5	1.7	7.5
Autumn 2	194	187	177	192	188	175	49	89	4.1	1.4	2.4	4.9	2.0	2.8	12.1	21.9
Winter 2	339	200	178	205	194	171	74	99	27.3	2.2	2.7	3.6	3.2	9.0	51.1	31.8
Spring 2	259	188	169	201	185	165	48	105	14.5	11.6	10.5	4.4	8.9	6.6	13.8	34.1
Summer 2	227	164	158	187	161	150	41	85	17.4	9.0	2.3	2.6	4.0	4.8	3.3	23.1
Autumn 3	174	140	140	168	136	130	54	76	13.9	6.4	9.2	6.9	8.2	6.3	16.6	28.5
Winter 3	203	165	148	191	162	153	76	91	6.7	4.8	11.1	5.0	4.3	3.7	50.8	40.8
Spring 3	212	134	141	174	147	148	44	83	6.0	9.3	8.5	23.3	3.2	2.0	12.0	33.9
Springs	**236**	**161**	**155**	**187**	**166**	**156**	**46**	**94**	**10.2**	**10.5**	**9.5**	**13.8**	**6.1**	**4.3**	**12.9**	**34.0**
Summers	**208**	**170**	**161**	**186**	**170**	**158**	**41**	**75**	**9.5**	**6.2**	**1.5**	**2.2**	**3.3**	**3.6**	**2.5**	**15.3**
Autumns	**184**	**164**	**159**	**180**	**162**	**153**	**51**	**83**	**9.0**	**3.9**	**5.8**	**5.9**	**5.1**	**4.5**	**14.4**	**25.2**
Winters	**271**	**182**	**163**	**198**	**178**	**162**	**75**	**95**	**17.0**	**3.5**	**6.9**	**4.3**	**3.7**	**6.4**	**50.9**	**36.3**

Table 6-25 H/C means and RSD effluent and influent concentrations for tested TDS in outdoor rig (n=85).

TDS	means (mg/l)								relative standard deviations (%)							
heating	209	169	160	187	166	153	56	88	57.7	30.8	21.1	19.5	30.7	23.0	29.4	32.8
cooling	216	161	149	186	163	154	60	89	24.4	21.4	13.0	14.9	14.8	8.6	42.6	34.2

6.2.4 Conductivity seasonal variability

Figures 6-19 and 6-20 present the data distributed in a pattern that is mirroring TDS figures. The conductivity is higher with increased pollutant values in the sample.

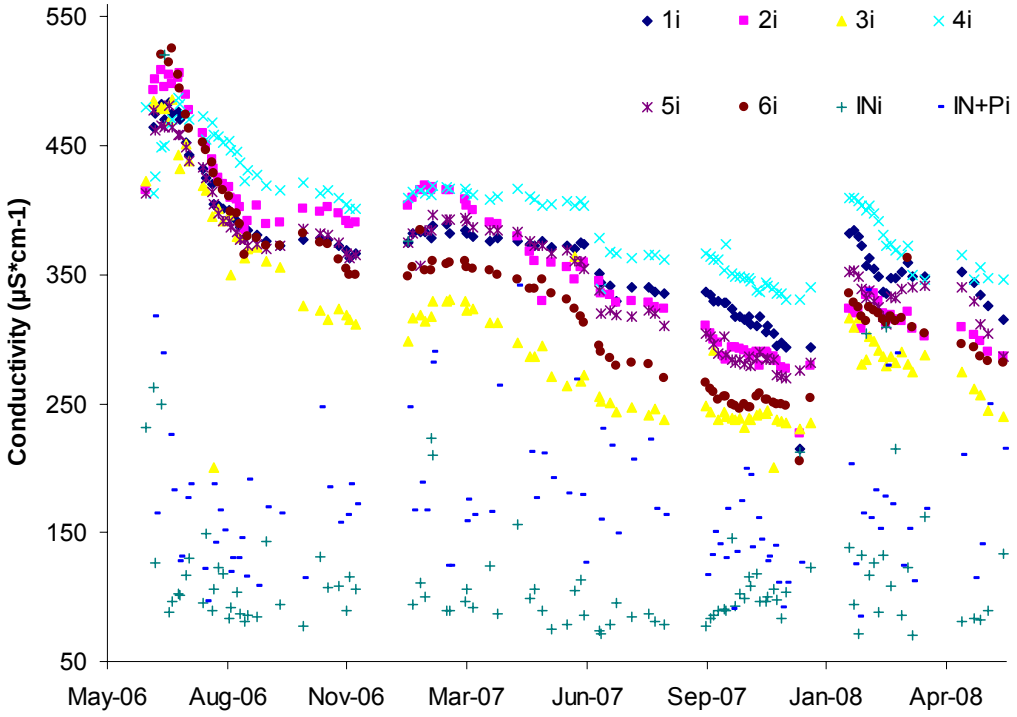


Figure 6-19 Indoor conductivity concentrations during experimental period (µS*cm^{-1}).

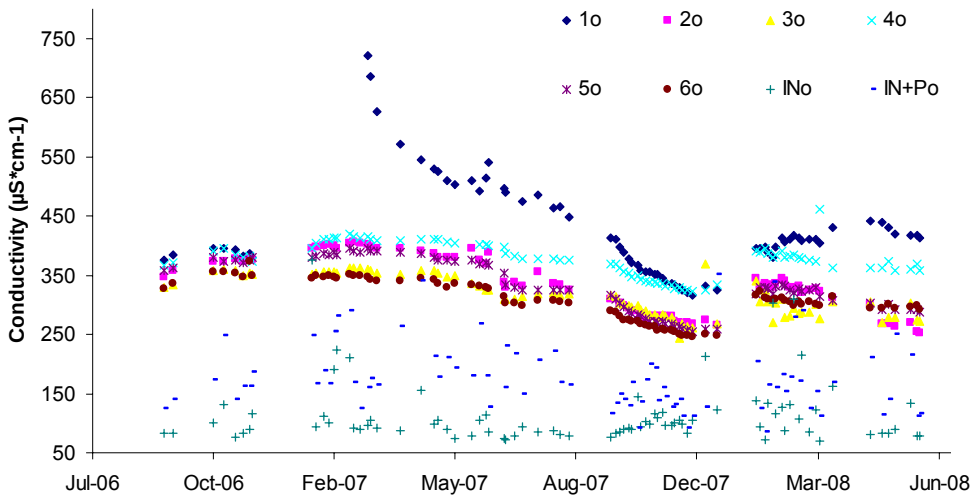


Figure 6-20 Outdoor conductivity concentrations during experimental period (µS*cm^{-1}).

In the case of analysed systems, TDS and conductivity are almost the same, when discussing concentrations over time (different units).

Indoor rig maximum mean values were recorded in Bin4i equalling 410 µS*cm^{-1}, during Summers and the lowest mean values were equal to 281 µS*cm^{-1} in bin3i during Autumns, when discussing effluent values. The least stable values were recorded in Bin3i again – RSD 29% - Autumns (**Table 6-26**).

Influent maximum mean values were 212 µS*cm^{-1} for INP type (Springs) and 94 µS*cm^{-1} (Summers) for IN type as a minimum mean.

For H/C cycles (**Table 6-27**) higher values were recorded for cooling cycle in all bins in the effluent.

By comparing indoor rigs with outdoor rigs they were similar in seasonal variability but higher values were recorded for indoor rig as a result of constant air temperature. Such relation originates in very close dependence of conductivity on total solids in the sample. With sub-base leaches of TSD, conductivity increased in parallel.

Table 6-26 Seasonal means and RSD effluent and influent concentrations for tested conductivity in indoor rig (n=110).

	means ($\mu S \cdot cm^{-1}$)								relative standard deviations (%)							
	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
Spring 1	473	483	470	444	457	520	278	257	7	35	24	23	23	0	133	74
Summer 1	419	441	396	455	412	434	104	150	33	39	54	18	32	45	18	31
Autumn 2	372	395	324	411	374	365	104	174	5	5	13	7	8	11	15	34
Winter 2	382	410	320	414	385	358	143	188	4	8	8	3	10	8	79	50
Spring 2	370	357	285	400	363	327	95	212	10	15	28	19	17	18	21	52
Summer 2	337	323	245	365	315	275	83	172	4	9	4	2	7	8	5	36
Autumn 3	308	285	239	346	283	249	108	140	23	14	14	10	7	10	26	27
Winter 3	357	320	291	384	335	321	142	180	14	9	12	19	11	12	67	62
Spring 3	328	293	252	350	305	286	90	166	15	10	12	8	21	6	18	53
Springs	**390**	**378**	**336**	**398**	**375**	**378**	**154**	**212**	**10**	**20**	**21**	**17**	**20**	**8**	**57**	**60**
Summers	**378**	**382**	**320**	**410**	**364**	**354**	**94**	**161**	**18**	**24**	**29**	**10**	**20**	**27**	**12**	**33**
Autumns	**340**	**340**	**281**	**378**	**329**	**307**	**106**	**157**	**14**	**9**	**13**	**8**	**7**	**11**	**21**	**30**
Winters	**370**	**365**	**306**	**399**	**360**	**340**	**142**	**184**	**9**	**9**	**10**	**11**	**10**	**10**	**73**	**56**

Table 6-27 H/C means and RSD effluent and influent concentrations for tested conductivity in indoor rig (n=110).

	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
conductivity	means ($\mu S \cdot cm^{-1}$)								relative standard deviations (%)							
heating	340	325	269	374	322	292	109	162	34	45	35	29	39	44	38	44
cooling	384	383	338	410	373	364	127	172	46	66	75	42	51	68	72	51

Influent water values are lower as a result of leaching from the sub-base. The highest recorded mean values account for Winters in bin1o (541 $\mu S*cm^{-1}$), with the least stable values in bin 4o (RSD 94%, Summers), when considering effluent values (**Table 6-28**).

For the influent values, the lowest recorded influent was IN type (83 $\mu S*cm^{-1}$) during Summers and the maximum recorded values were found for IN+P type during Springs and Winters 189 and 190 $\mu S*cm^{-1}$, respectively. Looking at the H/C (**Table 6-29**), higher mean concentrations were recorded during cooling in bins 1o and 6o and during heating in bins 2o – 5o.

Table 6-28 Seasonal means and RSD effluent and influent concentrations for tested conductivity in outdoor rig (n=85).

	means ($\mu S \cdot cm^{-1}$)								relative standard deviations (%)							
	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
Summer 1	380	353	331	369	360	332	84	132	7	7	3	4	5	6	1	13
Autumn 2	389	375	355	385	376	356	99	179	8	3	5	10	4	11	24	43
Winter 2	677	400	357	411	389	347	148	199	55	4	5	7	6	4	103	64
Spring 2	519	376	338	448	371	331	95	212	29	25	21	182	17	13	28	68
Summer 2	452	330	316	375	323	300	83	172	35	18	4	5	8	9	7	46
Autumn 3	349	280	286	338	272	260	108	151	27	13	29	13	16	12	34	65
Winter 3	405	331	297	387	324	308	142	180	14	10	22	25	8	8	86	80
Spring 3	426	268	283	364	294	296	90	166	13	19	17	7	6	3	24	68
Springs	**472**	**322**	**311**	**406**	**332**	**313**	**92**	**189**	**21**	**22**	**19**	**94**	**12**	**8**	**26**	**68**
Summers	**416**	**341**	**323**	**372**	**341**	**316**	**83**	**152**	**21**	**13**	**4**	**5**	**6**	**8**	**4**	**30**
Autumns	**369**	**328**	**321**	**361**	**324**	**308**	**104**	**165**	**17**	**8**	**17**	**12**	**10**	**12**	**29**	**54**
Winters	**541**	**365**	**327**	**399**	**356**	**327**	**145**	**190**	**35**	**7**	**13**	**16**	**7**	**6**	**95**	**72**

Table 6-29 H/C means and RSD effluent and influent concentrations for tested conductivity in outdoor rig (n=85).

	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
conductivity	means ($\mu S \cdot cm^{-1}$)								relative standard deviations (%)							
heating	419	339	323	386	332	307	113	176	116	62	42	99	61	48	59	69
cooling	430	323	300	380	326	308	115	178	49	43	26	23	30	17	72	67

6.2.5 Dissolved Oxygen seasonal variability

The indoor rig highest RSD effluent values were calculated for Bin3i - 7.4% (Springs) (**Table 6-30**).

H/C values (**Table 6-31**) provide information on higher DO values during heating cycles, leading to positive aerobic conditions.

Yearly graphical analysis (**Figure 6-21**) provides information on decreasing influent values during year one, until the Summer of 2007, with further decrease in values being equalled or even overtaken by effluent values.

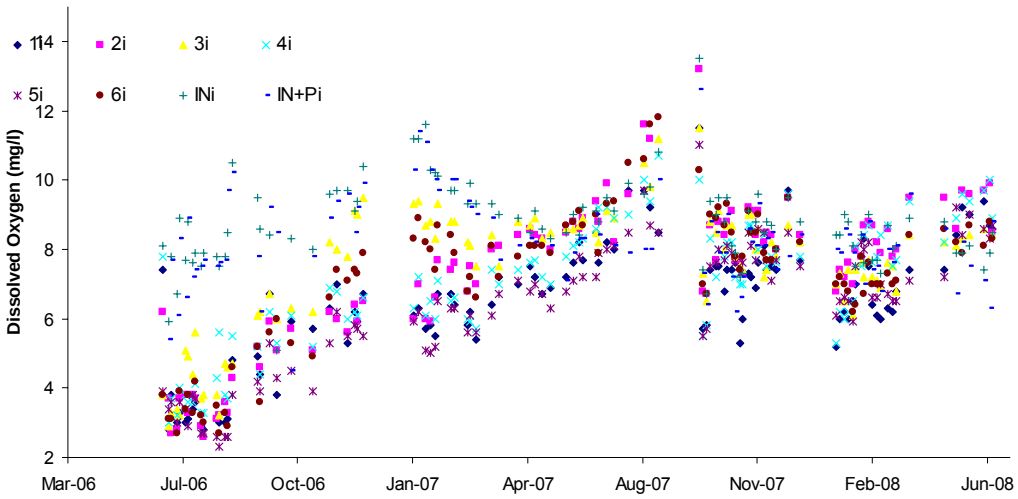


Figure 6-21 Indoor Dissolved Oxygen concentrations during experimental period (mg/l).

Looking at the seasonal averages this trend is less apparent, with all the effluent values being lower than the influent values.

The interference with anaerobic processes was caused by the construction of the bins, which allowed oxygen to be introduced to the bottom of the systems because of the collection pipe.

Large air voids in PPS could also be beneficial for introduction of oxygen, as a bin's water-free zone was equal to about 50-60% from the top; hence; there was good ventilation in the upper part of the PPS profile.

As for H/C cycles, raised DO concentrations were related to increased temperatures during heating cycle.

Table 6-31 H/C means and RSD effluent and influent concentrations for tested dissolved oxygen in indoor rig (n=110).

	means (ppm)								relative standard deviations (%)							
	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
Spring 1	236	241	234	222	228	258	138	128	3.6	17.4	12.5	11.8	11.9	2.6	66.3	37.1
Summer 1	209	220	190	227	203	217	52	76	16.4	18.8	31.1	9.1	21.4	22.3	9.0	14.6
Autumn 2	186	197	161	205	187	182	52	87	2.4	2.4	6.6	3.5	4.0	5.6	7.3	17.1
Winter 2	191	204	160	207	192	179	75	94	2.0	4.1	4.4	1.7	4.9	4.4	38.7	31.3
Spring 2	184	178	138	199	182	163	48	105	5.0	7.7	8.3	9.7	8.1	9.0	10.7	26.4
Summer 2	168	161	123	182	157	137	41	85	1.8	4.6	2.5	0.8	3.7	3.6	2.5	17.9
Autumn 3	155	142	118	171	142	126	54	76	7.6	7.0	4.2	4.2	3.6	1.9	12.9	22.0
Winter 3	179	160	145	192	168	160	69	90	6.8	4.7	5.8	9.4	5.7	6.1	33.5	30.5
Spring 3	164	147	126	175	152	143	44	83	7.0	4.7	5.8	4.1	10.5	2.9	9.2	26.2
Springs	**195**	**189**	**166**	**199**	**187**	**188**	**77**	**105**	**5.2**	**9.9**	**8.9**	**8.5**	**10.2**	**4.8**	**28.7**	**29.9**
Summers	**189**	**190**	**157**	**205**	**180**	**177**	**46**	**81**	**9.1**	**11.7**	**16.8**	**4.9**	**12.6**	**12.9**	**5.8**	**16.2**
Autumns	**170**	**170**	**140**	**188**	**164**	**154**	**53**	**82**	**5.0**	**4.7**	**5.4**	**3.8**	**3.8**	**3.7**	**10.1**	**19.5**
Winters	**185**	**182**	**153**	**199**	**180**	**170**	**72**	**92**	**4.4**	**4.4**	**5.1**	**5.6**	**5.3**	**5.3**	**36.1**	**30.9**

Table 6-32 Seasonal means and RSD effluent and influent concentrations for tested dissolved oxygen in outdoor rig (n=85).

	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
DO	means ($\mu S \cdot cm^{-1}$)								relative standard deviations (%)							
heating	7.1	8.1	8.4	7.5	7.2	8.3	9.1	8.5	1.2	1.3	1.0	1.2	1.1	1.1	1.1	1.1
cooling	6.0	6.6	6.7	6.7	5.7	6.1	8.2	7.8	2.0	2.3	2.8	2.1	2.0	2.1	0.8	1.0

Seasonal outdoor RSD ranged between 3.5% – 94.3% in the effluent (**Table 6-32**). Maximum mean effluent values equalled 8.7 mg/l in bin 5o during Springs as the result of increased precipitation during the season (bins only partly covered). There was no strong observed difference between H/C seasonal averages, where the highest difference of 1.2 mg/l was recorded in bin 5o (**Table 6-33**).

As standard, the temperature limits DO in water. The higher the temperature, the less oxygen dissolves in water. On the contrary, DO concentration in waters increases in lower temperatures (Spellman, 1999).
Maximum concentrations of DO in waters are limited by temperature, for example maximum DO concentrations at 20°C (maximum water temperature), 15 °C and 4 °C (minimum water temperature) are 9.07 mg/l, 10.07 mg/l, 13.09 mg/l, respectively (Spellman, 2008).

Expected occurrences of DO concentrations in relation to H/C seasons would confirm the relation of low temperature-high DO concentrations, and high temperature-low DO concentrations, which might not be the case in examined bins. For example, during the second heating cycle (Summer 2, Autumn 3), measured concentrations are relatively higher than expected at 20 °C, reaching values of e.g. 10-11 mg/l (**Figure 6-22**)
DO data runs show similar behaviour in the system indoors (**Figure 6-21**).

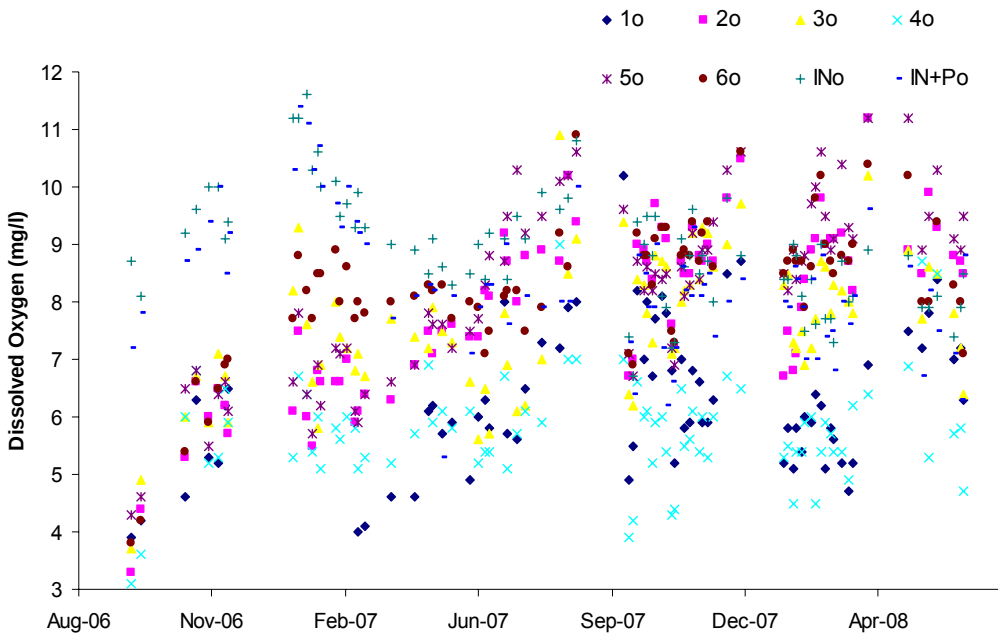


Figure 6-22 Outdoor Dissolved Oxygen concentrations during experimental period (mg/l).

The identified reason for this phenomenon was aeration of the sediments with a vertical water sample collection pipe. Also, by the end of year one, effluent values were stabilised enough in order to settle washed out sediments. By this time, influent samples diluted with tap water took over the water-sediment mixture properties, acting as a solvent to the sediments. This is also the most probable cause of negative NO_{2+3} removal, enhancing the nitrification process and ammonia to nitrates/nitrites transformation, due to increased aerobic condition in bins.

Additionally, effluent levels were increased by June 2007 from the start of the experiment to 8-9 mg/l and then stabilised. This is also the time when a short 1.5 months coiling period was enabled.

As explained previously, because of the outdoor systems failure (**Figure 6-4**), the system was switched to a cooling cycle for 1.5 months. This accounts for the raised DO for the time, i.e., corresponding DO maximum concentration sample temperatures of 11°C is 11.01 mg/l (Spellman, 1999). It is more difficult to explain values beyond the end of July 2007.

There are several possible reasons which could contribute to such concentrations:

- de-calibration of DO meter, though this is very unlikely as meters were calibrated on a regular basis;
- inappropriate identification of the outliers;
- errors while noting the reading from instruments;
- storing the sample in a temperature controlled room, before analysis by Public Health Labs and cooling it to 15°C or lower, which was possible while transferring samples between rig and laboratories and between laboratories – max DO concentration at 15°C – 10.07 mg/l;
- oversaturation of the sample during collection, which is very possible, as samples were collected with a hand pump, and air was introduced into the collection chamber together with a water-sediment mixture.

Table 6-32 Seasonal means and RSD effluent and influent concentrations for tested dissolved oxygen in outdoor rig (n=85).

	means (ppm)								relative standard deviations (%)							
	1i	2i	3i	4i	5i	6i	INi	IN+Pi	1i	2i	3i	4i	5i	6i	INi	IN+Pi
Summer 1	4.1	3.9	4.3	3.4	4.5	4.0	8.4	7.5	0.2	0.9	1.0	0.4	0.2	0.3	0.5	0.5
Autumn 2	5.7	6.1	6.4	6.0	6.3	6.4	9.6	9.1	0.9	0.6	0.6	0.7	0.5	0.7	0.5	0.6
Winter 2	4.1	6.4	7.3	5.7	6.6	8.2	10.2	10.0	0.1	0.6	1.1	0.6	0.7	0.5	0.9	0.9
Spring 2	5.8	7.7	7.0	5.8	7.9	8.0	8.8	7.8	1.1	0.9	0.9	0.7	1.0	0.4	0.4	1.1
Summer 2	7.2	8.7	8.0	6.5	9.6	8.5	9.4	8.2	1.9	1.3	2.1	1.7	1.3	1.5	1.2	1.1
Autumn 3	6.9	8.8	8.3	5.7	8.5	8.8	8.6	7.9	1.2	1.0	1.0	0.9	1.1	1.0	1.0	1.0
Winter 3	5.6	8.5	8.0	5.5	9.3	8.9	8.2	7.9	0.7	1.4	0.9	0.6	1.0	0.8	0.7	0.9
Spring 3	7.3	8.9	7.9	6.5	9.6	8.4	8.1	7.6	0.8	0.6	1.0	1.8	1.0	1.2	0.5	1.1
Springs	**6.6**	**8.3**	**7.4**	**6.2**	**8.7**	**8.2**	**8.4**	**7.7**	**0.9**	**0.8**	**1.0**	**1.3**	**1.0**	**0.8**	**0.5**	**1.1**
Summers	**5.6**	**6.3**	**6.1**	**4.9**	**7.0**	**6.2**	**8.9**	**7.9**	**1.1**	**1.1**	**1.5**	**1.1**	**0.8**	**0.9**	**0.9**	**0.8**
Autumns	**6.3**	**7.4**	**7.3**	**5.8**	**7.4**	**7.6**	**9.1**	**8.5**	**1.1**	**0.8**	**0.8**	**0.8**	**0.8**	**0.9**	**0.7**	**0.8**
Winters	**4.8**	**7.5**	**7.7**	**5.6**	**8.0**	**8.6**	**9.2**	**9.0**	**0.4**	**1.0**	**1.0**	**0.6**	**0.9**	**0.6**	**0.8**	**0.9**

Table 6-33 H/C means and RSD effluent and influent concentrations for tested dissolved oxygen in outdoor rig (n=85).

	1o	2o	3o	4o	5o	6o	INo	IN+Po	1o	2o	3o	4o	5o	6o	INo	IN+Po
DO				means (mg/l)							relative standard deviations (%)					
heating	6.3	7.6	7.7	5.7	7.8	8.3	9.1	8.5	1.6	1.5	1.2	0.9	1.5	1.1	1.2	1.4
cooling	6.1	8.4	7.3	5.7	9.0	8.1	8.4	7.9	1.3	1.9	1.6	1.3	1.8	1.8	0.8	0.9

6.2.6 ORP seasonal variability

Oxidation Reduction Potential measures the availability of electrons for exchange between chemical species. This is analogous to pH, which measures the presence of H^+ ions (Weiner, 2008). When electrons are exchanged, the alkaline and acid properties are changed resulting in oxidation-reduction properties change. For every electron donor (oxidation), there is an electron acceptor (reduction). In a natural, environment this is usually O_2. When REDOX potential is positive there is enough DO present in order to allow metals and any other organic matter to be oxidised (Weiner, 2008).

Indoor values (**Figure 6-23**) reflect indoor DO as well as outdoor ORP outdoor patterns.

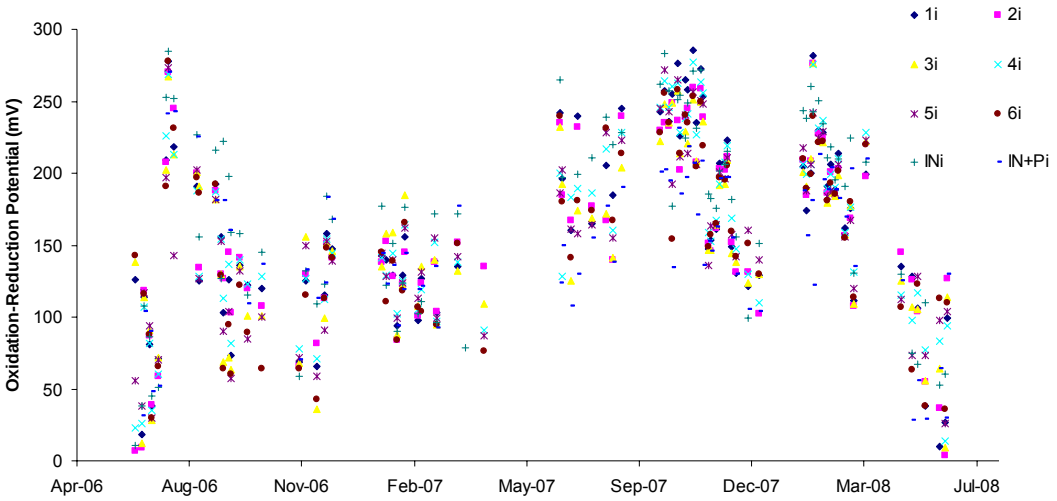


Figure 6-23 Indoor Oxidation-Reduction Potential values during experimental period (mV).

Maximum effluent values were obtained for bin 1i, 183 mV for Summers, while the minimum were equal to 93 mV in bin 4i during Springs. RSD minimum value was found to be 26% in bin 5i during Winters. The maximum RSD value was 51%, bin 6i during Springs (**Table 6-34**).

H/C values were also higher during heating than cooling as in outdoor bins (**Table 6-35**).

REDOX potential is an index used in a 'black box' approach in a specific environment, rather than an absolute indicator of a process (MEND, 2001).

In an examined environment, it can be a used as a descriptive state of a system, indicating which chemical processes can be occurring. In relation to DO in water, it justifies whether more aerobic or anaerobic processes take place in the system. By comparing ORP – DO figures it is clear that more oxidising processes occurred with increased DO concentrations, the maximums occurring during Summer 2 and Autumn 3.

Table 6-34 Seasonal means and RSD effluent and influent concentrations for tested ORP in indoor rig (n=110).

	means (mg/l)								relative standard deviations (%)							
	1i	2i	3i	4i	5i	6i	INi	IN+Pi	1i	2i	3i	4i	5i	6i	INi	IN+Pi
Spring1	75	52	77	55	67	94	58	68	43	45	50	34	34	44	35	31
Summer 1	154	159	146	155	140	146	186	185	55	54	61	54	56	64	60	64
Autumn 2	114	113	108	116	109	98	131	133	32	28	42	29	35	37	37	34
Winter 2	127	126	132	129	131	122	136	128	18	20	26	20	19	24	31	22
Spring 2	219	185	178	140	158	165	180	137	30	45	57	50	57	75	86	17
Summer 2	213	199	182	209	201	199	235	163	35	36	37	32	42	36	27	32
Autumn 3	210	198	197	208	200	196	207	171	51	44	41	46	38	38	42	34
Winter 3	198	195	195	203	196	194	218	181	35	35	35	32	30	29	30	25
Spring 3	78	85	83	85	88	84	83	66	47	49	38	32	31	34	28	40
Springs	124	107	112	93	104	115	107	90	40	46	48	39	40	51	50	29
Summers	183	179	164	182	170	173	210	174	45	45	49	43	49	50	43	48
Autumns	162	156	153	162	154	147	169	152	41	36	42	37	36	38	40	34
Winters	162	161	164	166	163	158	177	154	27	28	30	26	24	27	31	23

Table 6-35 H/C means and RSD effluent and influent concentrations for tested ORP in indoor rig (n=110).

	1i	2i	3i	4i	5i	6i	INi	IN+Pi	1i	2i	3i	4i	5i	6i	INi	IN+Pi
Redox	means (mg/l)								relative standard deviations (%)							
heating	190	180	179	188	184	179	195	163	54	48	47	52	48	48	52	34
cooling	150	148	144	147	141	147	166	142	63	64	61	61	56	59	68	61

As discussed before, DO values in the analysed systems were high enough in order to provide positive ORP values, as can be seen in **Figure 6-23**.

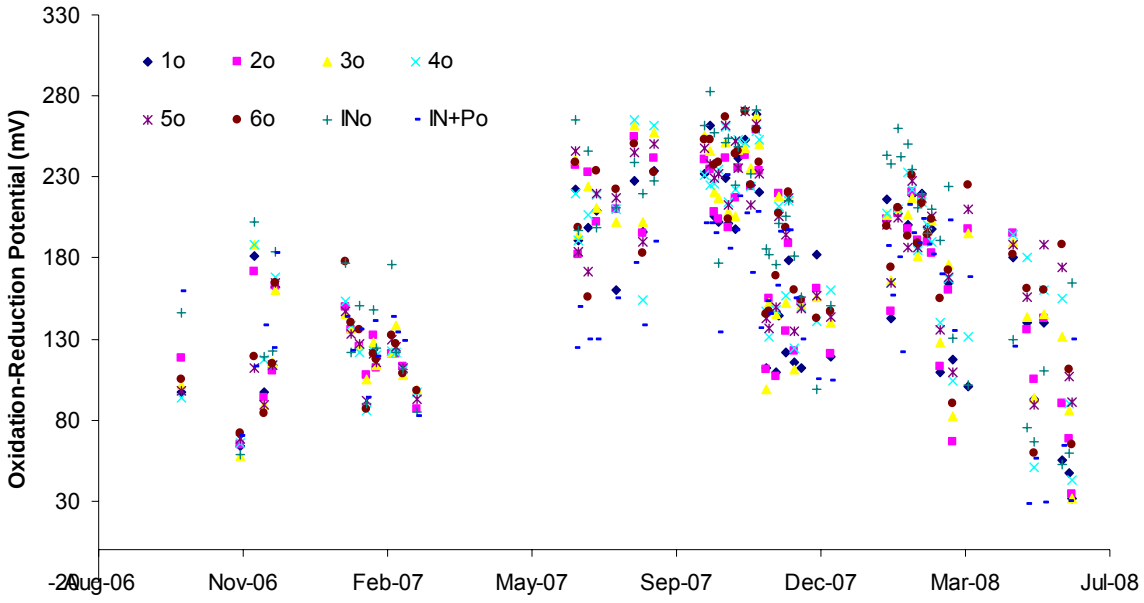


Figure 6-24 Outdoor Oxidation-Reduction Potential concentrations during experimental period (mV).

Looking at the outdoor mean effluent values in individual bins the seasonal averages are relatively similar, although when looking at the RSD values, these ranged between 30% - 59%. The highest recorded values were found to be equal to 178 mV during Springs in bin 5o. The minimum values found were found to be equal to 149 mV during Winters as in **Table 6-36** (bin 2o). For H/C seasons, ORP values were higher during heating seasons in all bins (**Table 6-37**). Generally, INo ORP is higher than effluent ORP although IN+Po ORP is lower than effluent ORP.

Table 6-36 Seasonal means and RSD effluent and influent concentrations for tested ORP in outdoor rig (n=85).

	means (mg/l)								relative standard deviations (%)							
	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
Summer 1	87	94	98	89	97	89	139	130	17	41	7	8	2	27	12	48
Autumn 2	124	121	122	131	110	111	137	126	56	54	62	57	43	43	67	48
Winter 2	-	121	122	120	120	125	131	125	-	20	18	22	20	30	38	25
Spring 2	207	210	218	206	215	219	231	137	26	46	39	24	52	33	57	22
Summer 2	215	227	233	222	223	223	236	165	36	25	30	41	34	42	32	36
Autumn 3	179	187	195	199	202	206	207	171	62	58	60	57	55	53	55	44
Winter 3	176	177	183	182	186	189	211	178	52	53	46	46	39	43	53	31
Spring 3	98	110	117	125	142	132	94	66	66	63	60	73	53	63	49	52
Springs	**152**	**160**	**167**	**165**	**178**	**176**	**163**	**102**	**46**	**54**	**50**	**49**	**52**	**48**	**53**	**37**
Summers	**151**	**160**	**165**	**155**	**160**	**156**	**188**	**148**	**27**	**33**	**19**	**25**	**18**	**35**	**22**	**42**
Autumns	**152**	**154**	**159**	**165**	**156**	**159**	**172**	**149**	**59**	**56**	**61**	**57**	**49**	**48**	**61**	**46**
Winters	**176**	**149**	**153**	**151**	**153**	**157**	**171**	**151**	**52**	**36**	**32**	**34**	**30**	**36**	**45**	**28**

Table 6-37 H/C means and RSD effluent and influent concentrations for tested ORP in outdoor rig (n=85).

	1o	2o	3o	4o	5o	6o	INo	IN+Po	1o	2o	3o	4o	5o	6o	INo	IN+Po
Redox	means (mV)								relative standard deviations (%)							
heating	177	166	172	173	172	176	185	156	65	63	68	65	68	67	70	47
cooling	151	159	164	164	171	169	174	137	71	70	66	67	56	65	78	66

6.2.7 BOD seasonal variability

As 5-day BOD reductions were very high, reaching levels of 90% - 100%, the mean values are not presented. Instead, the time series data are presented in **Figures 6-25 and 6-26**.

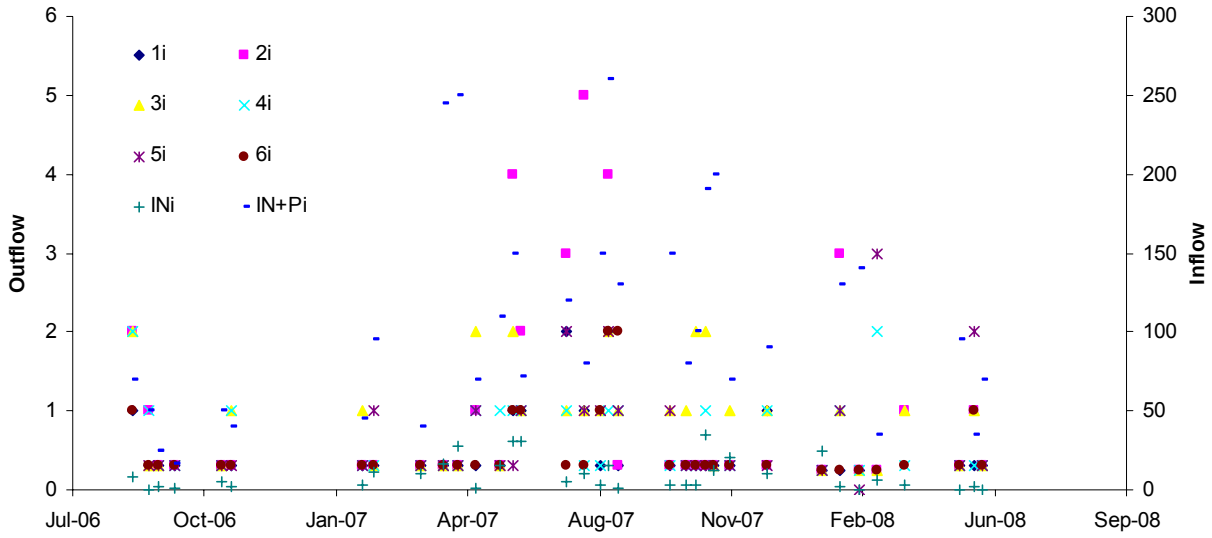


Figure 6-25 Indoor 5-day Biochemical Oxygen Demand values during experimental period (mg/l). Second Y-axis represents influent concentrations.

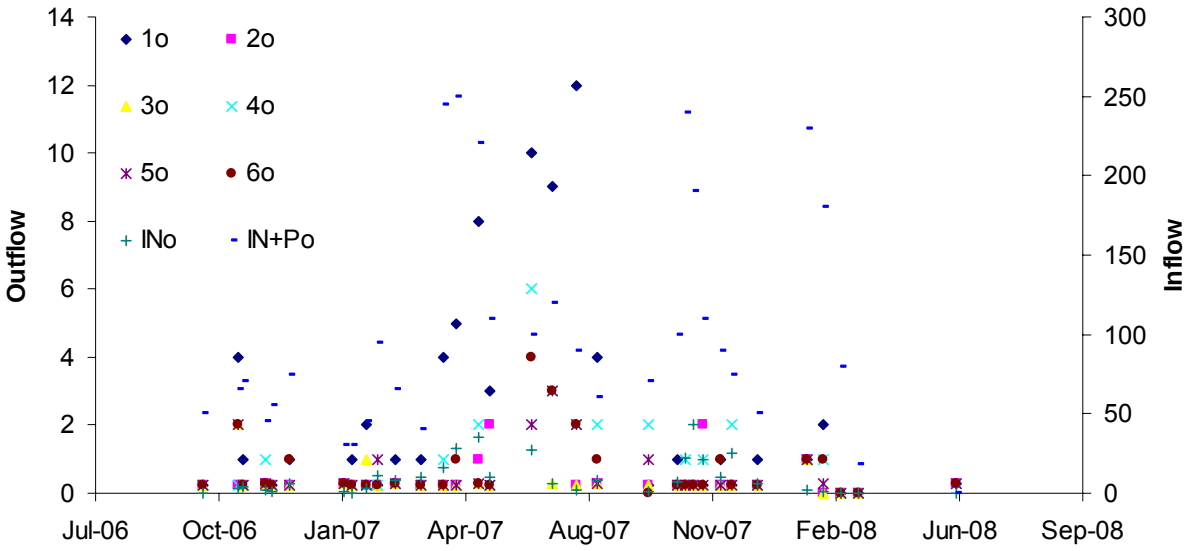


Figure 6-26 Outdoor **5-day** Biochemical Oxygen Demand concentrations during experimental period (mg/l). Second Y-axis represents influent concentrations.

The contrast in values is shown when looking at vertical axes values. In both rigs, inflow values are presented on the right OY_1 axis and outflow values on the left axis OY. The maximum outflow value reached 5mg/l in indoor rig (bin2) and 12 mg/l in outdoor rig (bin1). Inflow maximums reached values of approximately 250 mg/l.

Mean outflow values of 0.9 mg/l and 0.7 mg/l were recorded in outdoor and indoor rigs. 9.7, 99.8 mg/l and 9.2 and 104.6 mg/l were recorded for IN, IN+P for outdoor and indoor inflows, respectively.

Inflow values strongly depended on gully pot liquor characteristics. Maximum values were measured during Summer of 2007 for both inflow and outflow values. Jayasuriya *et al.* (2007) reports the world's mean BOD_5

in urban stormwaters as of 12 mg/l (range 5.6-25.7); therefore, in the PPS experiment, IN+Po concentrations exceeded the average of about 8.5 times BOD_5 than in the standard urban runoff.

By looking at BOD values in the figures above, it seems that low effluent values dictate that anaerobic conditions can be found in the PPS sub-base. In natural waters, for example, low BOD_5 values up to 5 mg/l in slow moving streams are capable of developing aerobic conditions (Weiner, 2008).

BOD:DO ratio = 30/32 (very close to 1/1 ratio) provides evidence that there was a very little organic matter to be removed by biological oxidation in the effluent, because of extremely high BOD removal values (99%). This is because of high microbial activity in the systems as indicated by CO_2 analysis.

6.2.8 Carbon dioxide variability

In soils, CO_2 originates from microbial activities and living roots and plant respiration. The assessment of CO_2 evolution from soil can be made by soil respiration measurements using infra red gas analysers (Koizumi *et al.*, 1991).

Carbon Dioxide values are presented in **Figures 6-27 and 6-28**

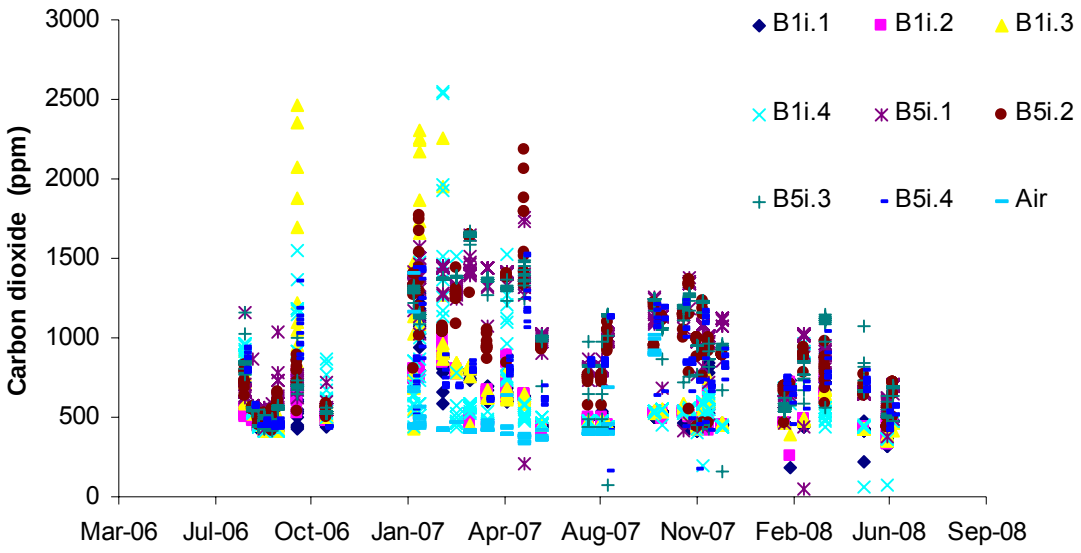


Figure 6-27 Indoor CO_2 concentrations during experimental period in bin1i and 5i (ppm).

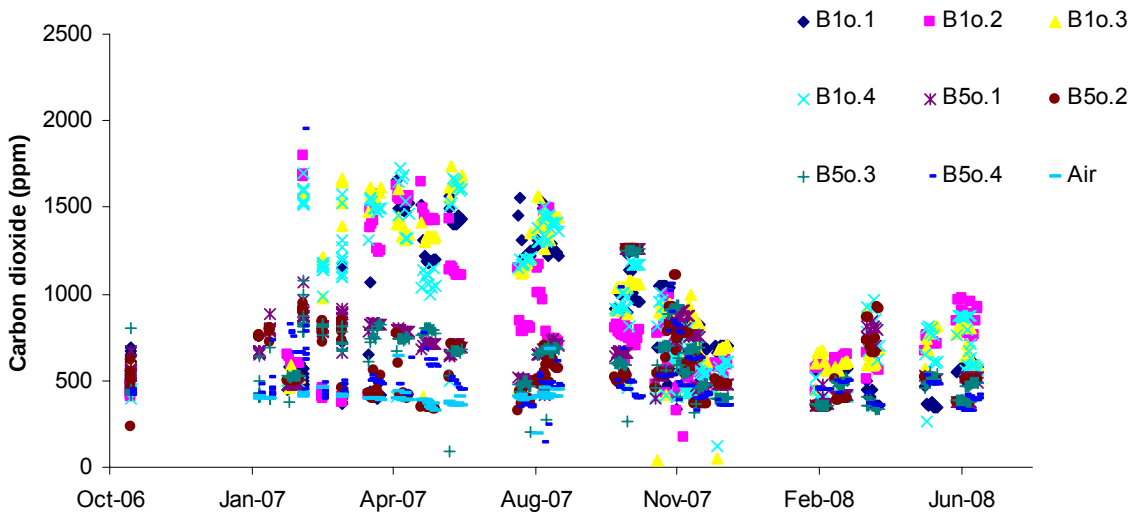


Figure 6-28 Outdoor CO_2 concentrations during experimental period in bin1o and bin 5o (ppm).

As described in Chapter 5 (**Figure 5-5**), in order to collect CO_2 samples with auto analyser, four vertical tubes were installed in bins 1i, 1o, 5i and 5o at different depths.

Points 1o.1 and 1i.1 provided collection of the samples from the shallowest points, just above the Inbitex™ geotextile. When numbering increases, the depth increases from the surface in order to reach the lower sub-base level. The bottom end of 4th collection point was periodically submerged in the stored water.

In large scale PPS CO_2 levels are the mirror of O_2 consumed by microbes in the biodegradation process (Coupe, 2004b).

In order to assess microbial activity in analysed systems it was decided to monitor CO_2 levels, as it is the product of the organisms' respiration.

For both rigs, the maximum values reached were between 2000-2500 ppm. For comparison, average indoor air concentration was recorded as 475 ppm, while outdoors it was 405 ppm. Also, in indoor rigs, CO_2 was decreasing in three steps during the whole experimental period.

Because of large dataset, the following **Table 6-38** summarises mean CO_2 concentrations in PPS profile

Table 6-38 Carbon Dioxide average concentrations in tested rings (ppm).

	Individual collection point			
Bin number	1	2	3	5
1i	552	535	550	561
5i	916	899	897	744

Inside average	734	717	723	652
1o	832	810	981	919
5o	673	599	602	489
outside average	752	704	792	704
Total average	741	712	751	673

Looking at the average values, it seems that the overall activity was highest in the upper part of the lower sub-base (point 3), but the geotextile level (point 1) had lower average values only by 10 ppm. Overall activity was higher in the outside rig with the exception of point 2 (upper sub-base). Therefore it seems that wider and more natural temperature fluctuation positively influences microbial development.

Indoor rig activity was highest at the geotextile level and the lowest was recorded at the very bottom of the unsaturated zone (top of the saturated zone): 652 ppm. The highest recorded average was for Bin1o at point 3.

The data occurrence clearly demonstrates increased microbial activity on the geotextile level, as without Inbitex or Inbitex composite it would not be possible to record increased CO_2 levels at the level of the profile; most likely, the biodegradation would be much lower and transferred deeper into the sub-base. Increased levels in point 3 mean that biodegradation does not stop at the geotextile, but also evolves deeper in the lower part of the sub-base. Lower concentrations of CO_2 at point 4 might be caused by the temporary immersion of the sampling tube or, more likely, by microbes which had a much better micro climate just above the water levels.

de Dreu (2004), in a conducted experiment on permeable pavement systems and floating mats, polluted boxes with car engine oils and additional nutrients for more effective development.

Recorded maximum average of CO_2 concentrations were: 16000 ppm in boxes with nutrient additions; 4000 ppm with nutrients and floating mat; <100 ppm with floating mat only; and less than <20 ppm in boxes with no additions.

Such high values were found because of the calorific properties of engine oils; hence, more rapid bacterial growth in the systems. This proves that microbial levels and efficiencies are dependent on the amount of introduced pollutants and their type, as differences between oil+nutrient fertiliser and dilluted gully pot liquor+animal feaces:

16,000-2,500 = 13,500 ppm - difference in CO_2 maximum measured concentrations.

One of the conclusions of the microbial activity assessment is that it was decreasing in outdoor rig until Winter of 2007, then after a gap in the data collection, it started to increase until the end of the experimental period.

6.3 Microbiology seasonal variability

Microbial variability was one of the hardest parameters to describe because of its high diversification in group organisms and particular species. Their numbers also vary greatly.

The expected outcome was that the organisms' numbers would vary depending on temperature seasonal changes in the outdoor rig and H/C cycles in the indoor rig.

Microbiology testing was less frequent than physico-chemical water parameters.

For *Salmonella sp, Shigella sp, Streptococcus* and THB number of analysed samples (n) equals:

- indoor rig n= 35
- outdoor rig n= 28

For *Escherichia coli:*

- indoor rig n= 23
- outdoor rig n = 20

Ideally, samples from the first rig were to be analysed fortnightly by turns with the second rig. The sum of sample numbers is equal to 63 and 43, just for *E. coli.*

The reason for this was the later start of microbial analysis as well as time constraints involving analysis – one system - six samples – four agars per sample – 2 replicators per agar – 48 Petri dishes were prepared for inoculation and incubation on day one – 48 Petri dishes were analysed on day three (24-48 hours incubation).

The percentage of presence of *Salmonella sp, Streptococcus and Escherichia coli* is presented in **Table 6-39.** The highest percentage of present pathogens accounts for *Escherichia coli* especially in the outdoor rig in bins 2, 3 and 4 (48, 79, 58 %). As bins 2o and 4o received faeces and had H/C installations,

bin3o received only gully pot liquor mixed with tap water and had no additional devices installed within the sub-base.

Indoor rig values are much lower for percents of total heterotrophic organisms.

The main conclusion of this occurrence is that *Escherichia coli* species could play a major part of all organisms available in the ecosystem and constitute a large part of the total numbers of all organisms, especially in the outdoor rig for more than 50% in the water sample.

Looking at the sample numbers (**Table 6-40**), it is noticed that the indoor numbers of the 3 analysed species (not *Salmonella spp.; Shigella spp*.) were higher in bins 1 and 4, although total numbers of microbes (total heterotrophs) were found in bin1 and bin5, 490,083 and 173,417 CFU/100 ml.

As for the indoor rig, the highest numbers for bins 1 and 4 are found for *Streptococcus* and *Escherichia coli* only 900 and 194 CFU/100 ml and 7,813 and 9,581, respectively. The highest total numbers of bacteria were found in bin3i and 6i - 78,076 and 96,147 CFU/100 ml. The conclusion is that there were more total microorganisms found in the uncontrolled bins, i.e., bin 3i and 6i, than in the ones with H/C installations.

Inflow values are presented in **Table 6-41.** It is clear that IN+P values are higher than IN. Maximum means are recorded for *Salmonella sp* and *Escherichia coli*, 423,718 and 1,735,250 CFU/100 ml, when discussing species tested.

Table 6-39 Percentage of pathogenic microbes as a part of THB.

	1o	2o	3o	4o	5o	6o	1i	2i	3i	4i	5i	6i
Salmonella spp.; Shigella spp.	0.1	0.3	0.5	0.4	0.1	0.5	1.0	0.4	0.3	0.4	0.8	0.2
Enterococcus faecalis (group D Streptococcus)	0.1	0.1	0.1	0.6	0.1	0.5	2.4	0.4	0.2	0.3	0.1	0.1
Escherichia Coli	31	48	79	58	3	14	21	3	4	15	11	3
Total Heterotrophs	100											

Table 6-40 Mean effluent concentrations for tested microbes found in samples - both rigs.

	1o	2o	3o	4o	5o	6o	1i	2i	3i	4i	5i	6i
Salmonella spp.; Shigella spp.	347	305	198	370	215	202	366	154	253	265	471	210
Enterococcus faecalis (group D Streptococcus)	497	130	54	596	162	220	900	158	177	194	55	138
Escherichia Coli	153,750	56,789	28,700	123,050	5,750	5,900	7,813	1,073	2,767	9,581	7,017	2,888
Total Heterotrophs	490,083	118,724	36,138	95,517	173,417	42,190	37,471	41,801	78,076	65,832	61,665	96,147

Table 6-41 Mean influent concentrations for tested microbes found in samples - both rigs.

	Data from direct observations			
	Input	**Input with faeces**	**Input**	**Input with faeces**
	means (CFU/100ml)		**standard deviations**	
Salmonella spp.; Shigella spp.	16,789	423,718	35,071	1,235,700
Enterococcus faecalis (group D Streptococcus)	212	32,655	460	169,525
Escherichia Coli	106,471	1,735,250	304,660	5,319,422
Total Heterotrophs	4,473,912	122,208,794	15,539,685	277,316,477

6.3.1 Total heterotrophs seasonal variability

In order to visualise the data, their log 10 values were presented on cumulative 100% stacked area graphs. The information shows the percentage of each value contributing over the time and categories. A stacked area graph presents the percentage of the whole data variation. It displays percents that the values represent of the total of all plotted data series (Harris, 1996).

Choosing this type of graphical representation helps to identify trends of data during the time, as well as its contribution into the whole dataset and whether it contributed to the microbial community.

The example of approach is presented in **Figure 6-29**, below.

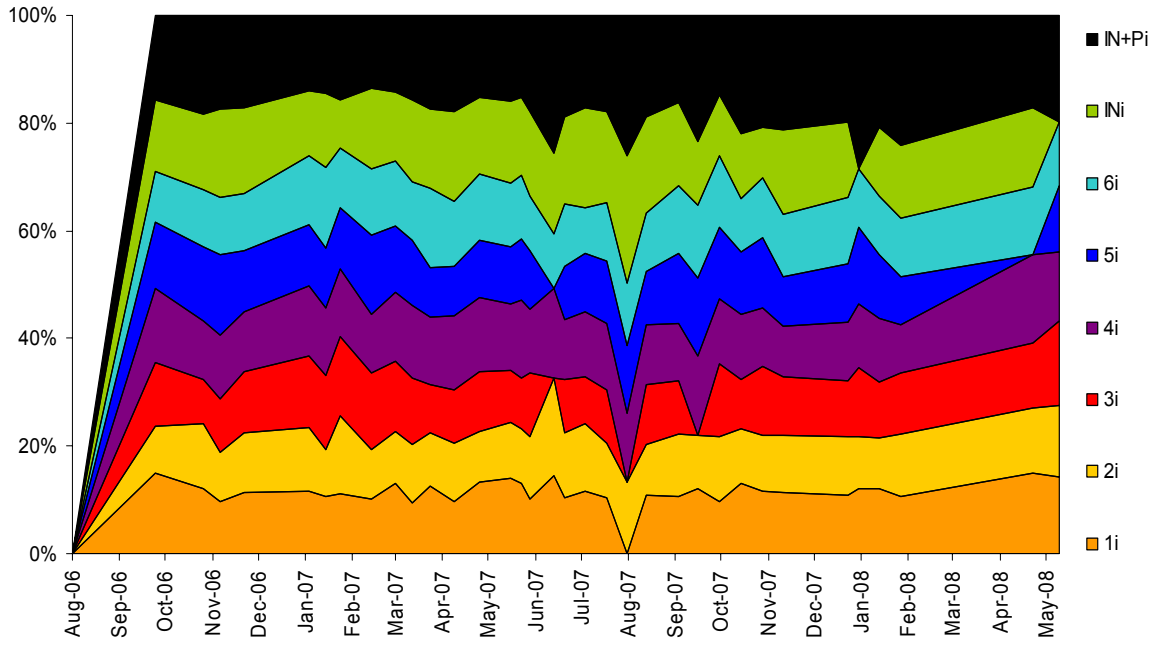


Figure 6-29 log 10 cumulative stacked area graph (100%) for THB concentrations in indoor rig. Presents the trend of the percentage each value contributes over time and categories.

At the indoor rig (**Table 6-42**), mean outflow microbial levels reached the maximum values of 143,987 CFU/100 ml in bin 5 (Autumns), while the lowest levels were recorded in bin 3 – 9,771 CFU/100 ml (Summers). This low value is because only one season (Summer) was taken for calculation. The next lowest values are recorded in bin 2 (24,263 CFU/100 ml) using two Autumn seasonal mean values for calculation.

Effluent values follow the influent in all of the bins. As IN+P values raise at the end of the experimental period (Autumn 3 and Winter 3), the effluent values increase too. Bin 1i and bin 4i (the only ones receiving faeces) show slightly higher values than other bins.

Highest inflow RSD values are recorded for Summer seasons reaching even up to 667,978,653% (IN+P inflow).

Heating seasons were influencing mainly bins 3i, 5i and 6i, although these did not have any H/C installations; therefore it is clear that cooling cycles had a strong impact on bacterial growth in all bins with those installations when discussing Total Heterotrophic Bacteria (THB) (**Table 6-43**).

Table 6-42 Seasonal means and RSD effluent and influent concentrations for tested THB numbers in indoor rig (n=35).

	means (CFU/100ml)							
	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
Autumn 2	49,500	7,125	6,625	22,200	58,875	4,375	240,000	1,570,000
Winter 2	52,400	65,400	242,600	122,600	81,160	123,600	120,800	452,200
Spring 2	45,571	7,821	9,814	104,571	9,271	221,286	651,000	3,608,571
Summer 2	20,286	107,714	9,771	54,714	24,714	38,929	20,364,286	151,190,000
Autumn 3	48,800	41,400	215,200	65,400	229,080	148,000	624,400	380,000,000
Winter 3	10,250	6,250	8,250	8,125	15,000	15,000	75,000	290,000,000
Spring 3	30,801	24,500	12,500	107,000	7,000	8,000	14,000	40,000
Springs	**38,186**	**16,161**	**11,157**	**105,786**	**8,136**	**114,643**	**332,500**	**1,824,286**
Summers	**20,286**	**107,714**	**9,771**	**54,714**	**24,714**	**38,929**	**20,364,286**	**151,190,000**
Autumns	**49,150**	**24,263**	**110,913**	**43,800**	**143,978**	**76,188**	**432,200**	**190,785,000**
Winters	**31,325**	**35,825**	**125,425**	**65,363**	**48,080**	**69,300**	**97,900**	**145,226,100**
	relative standard deviations (%)							
Autumn 2	221,442	23,915	17,197	74,402	155,386	4,862	582,278	5,162,766
Winter 2	181,160	244,862	615,549	531,496	242,918	456,565	298,482	1,335,188
Spring 2	170,233	14,278	29,794	239,523	23,998	1,548,459	2,376,494	16,189,998
Summer 2	55,616	397,495	40,530	128,335	61,228	194,874	88,293,407	672,573,658
Autumn 3	115,783	162,312	895,254	163,964	776,988	655,579	3,795,181	1,318,281,194
Winter 3	16,721	17,202	10,785	17,627	36,515	57,333	299,205	1,322,621,598
Spring 3	35,559	86,873	38,386	238,396	28,284	16,162	24,244	161,624
Springs	**102,896**	**50,576**	**34,090**	**238,959**	**26,141**	**782,311**	**1,200,369**	**8,175,811**
Summers	**55,616**	**397,495**	**40,530**	**128,335**	**61,228**	**194,874**	**88,293,407**	**672,573,658**
Autumns	**168,613**	**93,114**	**456,226**	**119,183**	**466,187**	**330,220**	**2,188,730**	**661,721,980**
Winters	**98,940**	**131,032**	**313,167**	**274,562**	**139,716**	**256,949**	**298,844**	**661,978,393**

Table 6-43 H/C means and RSD effluent and influent concentrations for THB numbers in indoor rig (n=35).

	1i	2i	3i	4i	5i	6i	INi	IN+Pi
THB	**means (CFU/100ml)**							
heating	35,040	30,810	96,224	65,812	79,824	121,160	4,899,520	139,120,840
cooling	44,222	72,333	27,667	65,889	11,222	26,667	3,291,667	75,230,889
	relative standard deviations (%)							
heating	132,646	142,527	545,397	272,275	408,651	873,041	49,515,314	886,715,643
cooling	143,561	379,040	152,161	205,746	31,712	175,743	27,545,852	450,866,949

The highest numbers of microorganisms in outdoor rig (**Table 6-44**) were recorded for Springs in bins 1o and 5o with means of 836,750 and 813,600 CFU/100 ml, respectively. Autumns and Winters values are calculated for approximately 30,000 CFU/100 ml.

During H/C cycles (**Table 6-45**), higher numbers of microbes were recorded during heating, except bin3 (no H/C installation).

The most interesting aspect of this is the extremely high variability in inflows, especially during Winters with values as high as RSD of 1,385,888,780,420%.

Also, microbial numbers in these inflows were the highest during the whole year, as opposed to previous assumptions or expectations. Such high values were recorded mainly during Winter 3, January – March 2008 (380,000,000 CFU/100 ml).

Figure 6-28 represents log 10 levels of THB in outdoor rig.

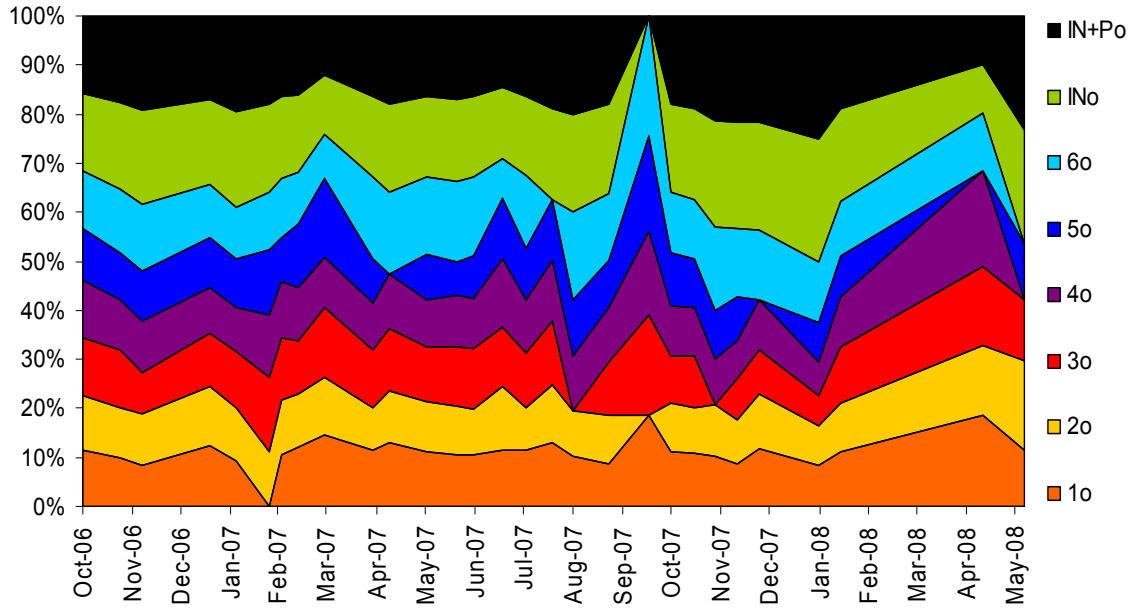


Figure 6-30 log 10 cumulative stacked area graph (100%) for THB concentrations in outdoor rig. Presents the trend of the percentage each value contributes over time and categories.

Looking at the figure it is clear that influent values accounted for about 30% of the whole microbial population being assessed. Secondly, microbial numbers and their distributions follow common trends, strongly impacted by introduced pollutants as clearly seen in IN values data configuration.

Three clear peaks in values are seen in March and September 2007 and April 2008. Also, contributions in individual bins are relatively equal, except in Autumn 2007, where bin 2o THB effluent was much lower than in bin 1o. At this point, systems were in heating cycle and it was the beginning of Autumn 2 season. This is the same time where the highest peak in outflow values was recorded as higher than the influent THB numbers.

It is important to remember that while discussing THB values the whole microbial community is being discussed, including organisms that were not identified by plate spreading.

All other pathogenic organisms analysed in the research are part of the THB community, and therefore included in the above calculations.

Table 6-44 Seasonal means and RSD effluent and influent concentrations for tested THB in outdoor rig (n=25).

	means (CFU/100ml)							
	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
Autumn 1	17,667	52,667	50,333	71,333	85,000	22,667	138,333	9,900,000
Winter 1	206,000	22,833	9,000	28,000	6,833	58,083	8,817	2,990,833
Spring 2	1,416,000	80,800	17,000	224,800	27,200	6,200	12,860,000	21,020,000
Summer 2	730,000	226,800	95,800	197,200	270,800	146,000	30,194,600	234,460,000
Autumn 2	36,333	12,167	7,000	4,500	4,850	6,000	965,667	181,150,000
Winter 2	20,000	17,500	9,500	19,000	7,000	4,000	365,000	490,018,500,000
Spring 3	257,500	751,000	109,000	106,500	1,600,000	1,000	3,500	2,251,000
Springs	**836,750**	**415,900**	**63,000**	**165,650**	**813,600**	**3,600**	**6,431,750**	**11,635,500**
Summers	**730,000**	**226,800**	**95,800**	**197,200**	**270,800**	**146,000**	**30,194,600**	**234,460,000**
Autumns	**27,000**	**32,417**	**28,667**	**37,917**	**44,925**	**14,333**	**552,000**	**95,525,000**
Winters	**113,000**	**20,167**	**9,250**	**23,500**	**6,917**	**31,042**	**186,908**	**245,010,745,417**
	relative standard deviations (%)							
	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
Autumn 1	63,791	337,386	290,168	375,709	537,029	122,464	250,067	18,255,958
Winter 1	-	119,235	16,781	80,598	23,244	372,405	33,885	23,610,392
Spring 2	2,391,752	115,772	36,000	716,544	65,446	21,429	23,185,513	42,368,290
Summer 2	4,288,021	1,153,823	511,565	751,294	928,424	340,599	207,290,825	1,330,631,778
Autumn 2	177,929	36,081	21,166	18,547	12,480	17,158	7,953,489	1,025,124,188
Winter 2	22,627	48,083	14,142	101,823	28,284	11,314	1,895,046	2,771,753,930,448
Spring 3	1,032,376	4,236,984	356,382	585,484	9,050,967	5,657	19,799	12,722,265
Springs	**1,712,064**	**2,176,378**	**196,191**	**651,014**	**4,558,206**	**13,543**	**11,602,656**	**27,545,278**
Summers	**4,288,021**	**1,153,823**	**511,565**	**751,294**	**928,424**	**340,599**	**207,290,825**	**1,330,631,778**
Autumns	**120,860**	**186,734**	**155,667**	**197,128**	**274,755**	**69,811**	**4,101,778**	**521,690,073**
Winters	**22,627**	**83,659**	**15,462**	**91,211**	**25,764**	**191,860**	**964,466**	**1,385,888,770,420**

Table 6-45 H/C means and RSD effluent and influent concentrations for THB numbers in outdoor rig (n=25).

	1o	2o	3o	4o	5o	6o	INo	IN+Po
THB	**means (CFU/100ml)**							
heating	448,000	72,409	15,364	64,773	38,141	44,114	8,519,632	44,651,429,318
cooling	137,699	47,449	28,579	42,617	4,636	4,305	40,824	2,400,951
	relative standatd deviations (%)							
heating	3,018,332	623,182	97,070	458,323	313,772	307,631	103,594,298	835,652,577,901
cooling	3,266,199	2,187,355	445,821	684,103	4,680,798	268,680	33,958,300	64,696,720

6.3.2 *Salmonella sp* seasonal variability

In 1979, Qureshi and Dutka were concluding that assessed storm sewer systems contained significant numbers of faecal pollution indicating bacteria. Salmonellae were indicated in very small quantities of waters - 10ml. Infiltrations waters were the source of low but continuous microbial contamination. Qureshi and Dutka (1979) also report that there was no effect of initial flushing during storm events ('first flush effect') and there was no possibility for providing control from separate storm sewers, polluting receiving waters and reservoirs with high numbers of pathogenic organisms. Roser *et al.* (2006) confirm that concentrations of faecal coliforms during first flush did not exceed 30% of the total bacterial population during the first 30% of runoff volume.

Above examples assured that *Salmonella sp* should not be prone to first flush effect and continuously constituted faecal pollution in urban storm runoff at least for the last 30 years. Ashbolt *et al.* (2001) classifies *Salmonella sp* as an index and model organism indication of pathogen presence.
As levels of microbial numbers contamination depend on local environment, type of carrier (water, soil), runoff velocity and depth, influent concentrations and other various factors only expected removal efficiencies are discussed in Chapter 7.

Figure 6-31 provides a picture of high variability in the dataset. What is noticeable is that after high pollutant introduction the response is seen later on as high peaks.

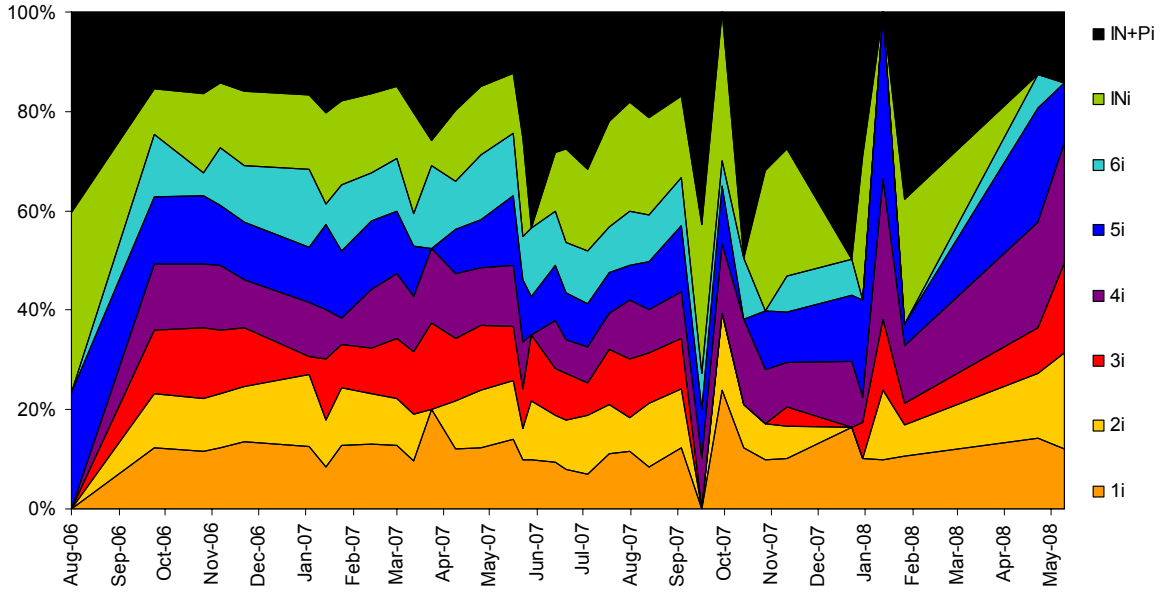


Figure 6-31 log 10 cumulative stacked area graph (100%) for *Salmonella sp* concentrations in indoor rig. Presents the trend of the percentage each value contributes over time and categories.

Indoor highest mean value was recorded for bin 5i = 1,001 CFU/100 ml during Springs and the lowest mean during the same season in bin 2i = 95 CFU/100 ml (**Table 6-44**). The least stable outflow of *Salmonella sp* was recorded in bin 1i. This is because it had been replaced due to its failure during the experiment, and therefore released TDS as well as other inorganic matter, fauna and flora in large quantities.

Because *Salmonella sp* was introduced in the filters it was present in the after-the-installation effluent as well.

Influent values were very high for both rigs, reaching the maximum value of 1,030,000 CFU/100ml, Autumn 3, (**Table 6-44**) through the year or 289,190 CFU/100 ml, Spring 2, indoors.

Once divided into H/C seasons, there were more organisms recorded during the heating cycle in the effluent in bins 1i, 3i and 6i. And during cooling, higher values were recorded in bins 4i and 5i (**Table 6-45)**.

Table 6-44 Seasonal means RSD effluent and influent concentrations for tested THB in outdoor rig (n=25).

	means (CFU/100ml)								relative standard deviations (%)							
	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
Summer 1					70		750	1,500	-	-	-	-	-	-	-	-
Autumn 2	805	286	840	630	741	405	1,778	3,438	1,755	261	467	958	616	803	4,171	5,571
Winter 2	707	345	198	352	996	636	4,659	7,428	1,600	876	719	1,280	2,111	2,091	16,979	28,347
Spring 2	367	137	450	307	402	201	35,238	388,475	738	357	1,762	745	1,516	472	184,184	2,151,201
Summer 2	211	182	180	112	233	155	24,256	827,619	552	401	423	367	943	339	106,079	5,577,826
Autumn 3	350	29	1	44	38	10	24,000	1,030,000	2,062	138	6	54	77	22	68,809	6,342,053
Winter 3	30	5	6	49	185	1	5,000	278,750	56	16	14	126	637	7	16,496	1,434,102
Spring 3	140	53	33	790	1,600	10		40	543	4	4	7	8	3	0	5
Springs	**254**	**95**	**241**	**549**	**1,001**	**106**	**35,238**	**194,258**	**640**	**181**	**883**	**376**	**762**	**238**	**92,092**	**1,075,603**
Summers	**211**	**182**	**180**	**112**	**151**	**155**	**12,503**	**414,559**	**552**	**401**	**423**	**367**	**943**	**339**	**106,079**	**5,577,826**
Autumns	**578**	**158**	**421**	**337**	**390**	**207**	**12,889**	**516,719**	**1,909**	**200**	**236**	**506**	**346**	**413**	**36,490**	**3,173,812**
Winters	**369**	**175**	**102**	**200**	**590**	**319**	**4,830**	**143,089**	**828**	**446**	**367**	**703**	**1,374**	**1,049**	**16,737**	**731,225**

Table 6-45 H/C means and RSD effluent and influent concentrations for THB numbers in outdoor rig (n=25).

	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
Salmonellae sp.	**means (CFU/100ml)**								**relative standard deviations (%)**							
heating	462	187	306	249	410	240	19,668	231,038	1,464	565	1,237	885	1,478	1,123	109,875	2,842,612
cooling	127	74	119	306	625	136	9,592	905,420	500	230	622	1,431	2,811	623	71,276	4,753,465

Outdoor *Salmonella sp* influent numbers account for about 40% of the total numbers of analysed *Salmonella sp* community (**Figure 6-30**).

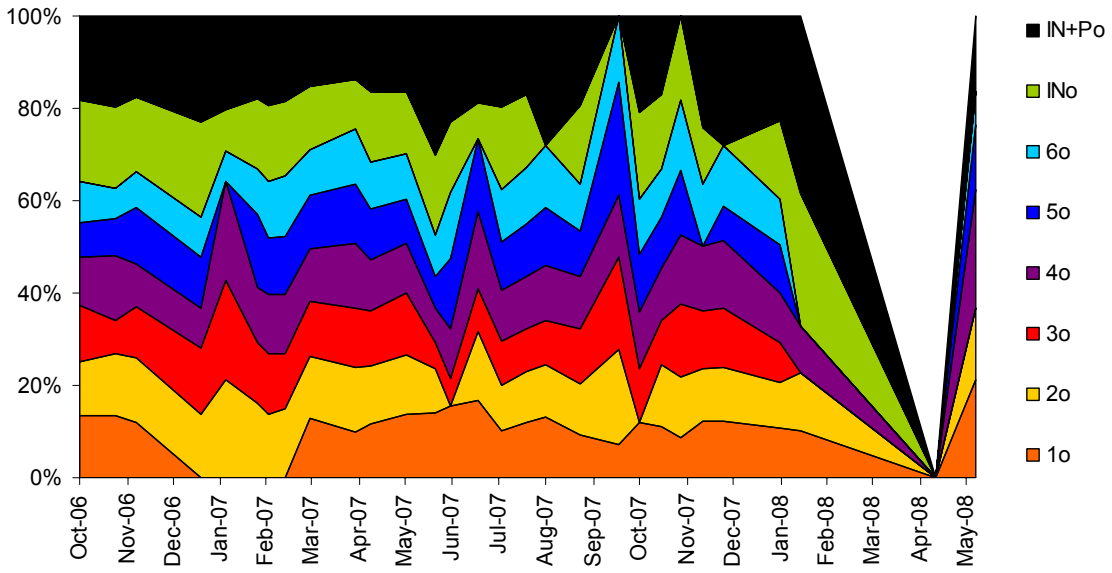


Figure 6-32 log 10 cumulative stacked area graph (100%) for *Salmonella sp* concentrations in outdoor rig. Presents the trend of the percentage each value contributes over time and categories.

Because a stacked area graph assumes data continuity, breaks in data collections are not represented well. Such occurrence takes place. for example, during August 2007 (**Figure 6-32**), when data values drop down to zero, while in reality there are no records for the above time slot.

Changes in microbial numbers for similar events follow similar patterns, except in January 2008, where a species' countable numbers were found only in bins 1o, 2o and 4o. This was the beginning of hydrological winter and the systems were set to heating cycle. This occurrence is linked to lowest air temperatures through the year (temperatures ranged between 0-

2°C). And only bins 1o, 2o and 4o had a *Salmonella sp* community strong enough to survive, even in heating cycle.

Values increase after low levels later on in the year, from February 2008, which is confirmed by CO_2 levels (**Figures 6-27 and 6-28**).

Microbial activity during experimental years assessed by CO_2 levels (**Figures 6-27 and 6-28**) does not necessary mean that it was caused by pathogenic organisms. Other organisms present in rigs could determine a systems' bio-activity, but not all of them were examined.

The white area in **Figure 6-32** is caused by a break in the observations and is represented as zero values, although the analysis was not carried out.

The highest effluent population number was recorded in bin 4o during Springs (**Table 6-48**) equalling to 1,073 CFU/100 ml.

RSD values ranged between 181 - 1,374% in seasonal effluent averages.

The cooling cycle (**Table 6-49**) had an impact on bins with additional pollutants (bins 1o and 4o), meaning that numbers of pathogenic organisms increased in lower temperature environment. It could also be caused by higher *Salmonella sp* numbers in inputs during Springs and Summer when the cooling cycle was started.

In all other bins, the reverse trend occurred – values increased during heating.

Statistical analysis in further chapters assesses for influences and relations between variables such as temperature and number of pathogens or influent-effluent relations.

Table 6-48 Seasonal means RSD effluent and influent concentrations for tested *Salmonella sp* numbers in outdoor rig (n=25).

	means (CFU/100ml)								relative standard deviations (%)							
	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
Autumn 2	245	240	108	153	68	32	1,492	2,483	370	271	383	552	283	83	2,868	3,523
Winter 2	660	480	240	227	197	138	773	2,384	-	1,393	530	582	595	586	2,268	8,236
Spring 2	624	458	359	358	395	292	1,760	289,190	1,377	1,767	1,264	1,729	1,431	1,054	6,454	2,484,486
Summer 2	471	316	271	492	404	524	12,303	215,930	1,000	419	1,169	698	610	1,549	69,812	1,540,769
Autumn 3	74	166	133	161	117	131	592	5,183	226	650	476	378	388	384	2,568	28,046
Winter 3	56	60	18	60	38	33	5,600	116,500	164	28	99	198	212	184	24,890	585,484
Spring 3	445	65	0	1,788	45	5	0	90	2,517	368	0	10,112	255	28	0	509
Springs	**535**	**262**	**180**	**1,073**	**220**	**149**	**880**	**144,640**	**1,947**	**1,067**	**632**	**5,920**	**843**	**541**	**3,227**	**1,242,497**
Summers	**471**	**316**	**271**	**492**	**404**	**524**	**12,303**	**215,930**	**1,000**	**419**	**1,169**	**698**	**610**	**1,549**	**69,812**	**1,540,769**
Autumns	**160**	**203**	**121**	**157**	**93**	**81**	**1,042**	**3,833**	**298**	**460**	**430**	**465**	**336**	**233**	**2,718**	**15,785**
Winters	**358**	**270**	**129**	**143**	**117**	**85**	**3,186**	**59,442**	**164**	**711**	**315**	**390**	**403**	**385**	**13,579**	**296,860**

Table 6-49 H/C means and RSD effluent and influent concentrations for *Salmonella sp* numbers in outdoor rig (n=25).

	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
Salmonellae sp.	**means (CFU/100ml)**								**relative standard deviations (%)**							
heating	290	378	249	297	226	228	3,519	52,389	1,052	1,176	875	1,026	733	1,031	36,294	764,421
cooling	483	89	38	599	182	120	2,395	237,011	1,703	295	306	5,266	1,316	1,046	14,437	2,076,181

6.3.3 *Enterococci sp* seasonal variability

Enterococci are classified as index and model organisms. Predominant intestinal enterococci are *E.faecalis, E.faecium, E.durans and E.hirae*. Enterococci are indicator organisms of faecal pollution in waters although they can originate from other sources (Ashbolt, 2001). Roser *et al.* (2001) concluded in their study of urban recreational lakes that pathogenic organism numbers are dependent on reservoir water levels as well as storm events and dry periods. In the study, wildfowl is identified as the main source of pollution, with the highest enterococci mean numbers of 19 MPN/100 ml, n = 50 during dry periods.

The above example provides evidence of the significance of the sample dilution on total numbers of organisms in the effluent.

Indoor data values (**Table 6-50**) were not as stable as expected. Highest seasonal microbial mean levels were recorded for bin 1i during Springs' reaching 9,952 CFU/100ml with a very high variability of 40,151%. Similar findings are also true for Bin 2i.

As these effluent levels are dependent on bacterial inflow levels, the impacting factor is clear. During Autumns, higher microbial numbers are found. During Winters and Springs, gully pot liquor is diluted by more intensive precipitation.

This occurrence is seen in **Figure 6-33**, where bins not receiving excrements have a lower percentage of concentrations than bins 1i and 4i. This trend changed with the beginning of Summer and continued until Autumn '07.

The interesting change occurred after a data collection break, where *Enterococci sp* species were found in only three out of six bins.

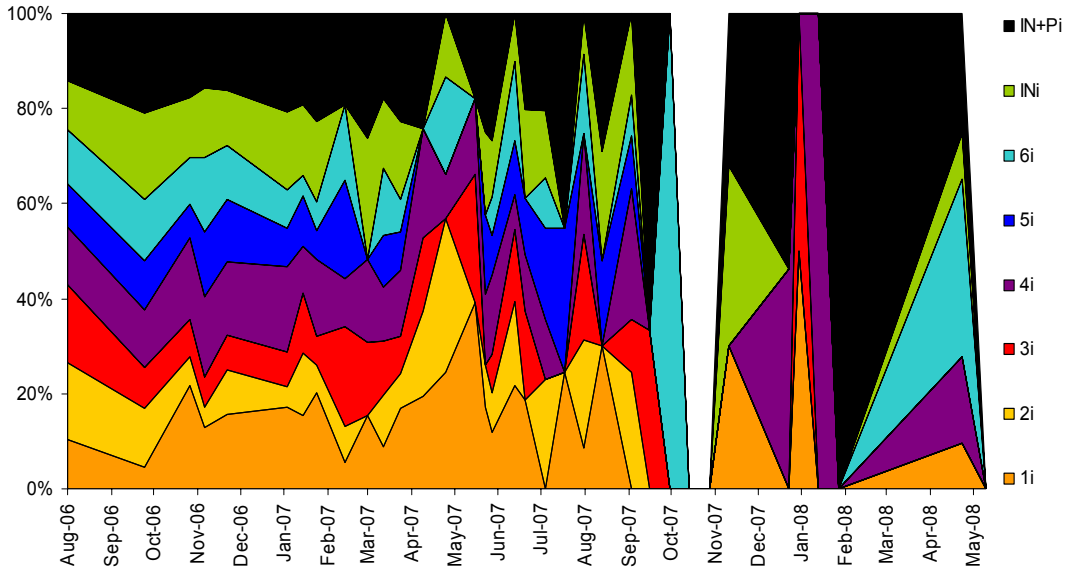


Figure 6-33 log 10 cumulative stacked area graph (100%) for *Enterococci sp* concentrations in indoor rig. Presents the trend of the percentage each value contributes over time and categories.

There are many possible reasons for this change, but the most likely is either that the system's removal efficiencies were extremely good or that the microbial population had changed and started to re-grow at a later stage, as seen in April 2008. Similar system's behaviour was found for ortho-phosphate-phosphorus removal rates increase after breaks. The bacteria were found in the effluent collected after November 2007 only in bins 1i and 4i, until January 2008 when the organisms were found in bin 3i. From then, almost none of the organisms were found until February 2008, when they occurred in bins 1i, 4i and 5i.

Surprisingly, a higher numerical count of organisms was recorded during the cooling cycle, as in **Table 6-51.**

Table 6-50 Seasonal means and RSD effluent and influent concentrations for tested *Enterococci sp* numbers in indoor rig (n=35).

	means (CFU/100ml)								relative standard deviations (%)							
	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
Summer 1	95	1,160	1,270	205	55	140	90	510	-	-	-	-	-	-	-	-
Autumn 2	1,135	33	17	430	91	141	261	809	5,479	92	14	770	213	401	690	1,444
Winter 2	224	34	129	188	130	35	280	942	645	155	563	869	611	144	750	2,063
Spring 2	100	59	20	59	52	45	119	797	307	276	85	129	196	279	422	2,701
Summer 2	3,365	562	296	69	81	291	223	726	21,125	3,418	1,375	314	181	2,153	1,059	2,550
Autumn 3	100	0	200	0	0	200	500	200,150	639	1	1,278	0	0	1,278	3,194	1,277,514
Winter 3	250	0	250	750	0	0	0	30,750	1,429	0	1,429	2,736	0	0	0	170,048
Spring 3	19,803	0	0	10	0	250	3	33	79,996	0	0	40	0	1,010	10	131
Springs	**9,952**	**29**	**10**	**35**	**26**	**148**	**61**	**415**	**40,151**	**138**	**42**	**85**	**98**	**645**	**216**	**1,416**
Summers	**1,730**	**861**	**783**	**137**	**68**	**216**	**156**	**618**	**21,125**	**3,418**	**1,375**	**314**	**181**	**2,153**	**1,059**	**2,550**
Autumns	**618**	**16**	**108**	**215**	**46**	**171**	**381**	**100,479**	**3,059**	**47**	**646**	**385**	**106**	**840**	**1,942**	**639,479**
Winters	**237**	**17**	**190**	**469**	**65**	**18**	**140**	**15,846**	**1,037**	**77**	**996**	**1,802**	**306**	**72**	**375**	**86,055**

Table 6-51 H/C means and RSD for effluent and influent concentrations for *Enterococci sp* numbers in indoor rig (n=35).

	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**	**1i**	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
Enterococci spp .	**means (CFU/100ml)**								**relative standard deviations (%)**							
heating	409	41	116	171	57	82	216	40,681	2613	197	807	803	293	612	1448	571,028
cooling	2,130	426	330	251	52	274	203	12,591	17,962	2783	1514	1764	192	1789	966	107,851

Enterococci sp numbers are greatly dependant on animals' intestinal flora. Surbeck *et al.* (2006) reported that faecal pollution in the Santa Ana River watershed, CA, was primarily of non-human waste origin. *E.coli* numbers ranged between four analysed storm events, from 1.87-8.06*10^4 MPN/100ml (MPN – most probable number), while for *Enterococi* and total coliforms these were found 1.35-4.70*10^4 and 3.59*10^4-2.29*10^5 MPN/100ml.

As excrements were collected randomly from various sites, their levels were very variable, as seen in **Table 6-52** (outdoors)**.** RSD values were reaching even up to 639,479% in the IN+P influent of Autumn periods.
Such high numbers resulted in raised effluent values where maximum seasonal RSD were equal to, e.g., 40,151% in bin 4o. Maximum seasonal recorded values were equal to 1,221 CFU/100 ml in bin 1o for Springs and 1,510 CFU/100 ml for Summers in bin 4o as the result of faeces additions.
H/C cycles favoured growth in bins 1o, 4o and 5o during cooling periods and favoured the above during heating in bins 2o, 3o and 6o, although the difference in numbers during H/C period can be within measured error. This indicates that *Enterococci sp* had more comfortable growing conditions during lower temperatures in the sub-base (**Table 6-53**) when compared with water sample temperatures and H/C introduced water temperature through coils (vessel water temperature).

Lowest effluent numbers were in Autumns and Winters, where the PPS environment did not allow for their survival. Influent concentrations remained very high, however. This is clearly presented in **Figure 6-32,** where reductions in effluent occurred during cooler seasons.

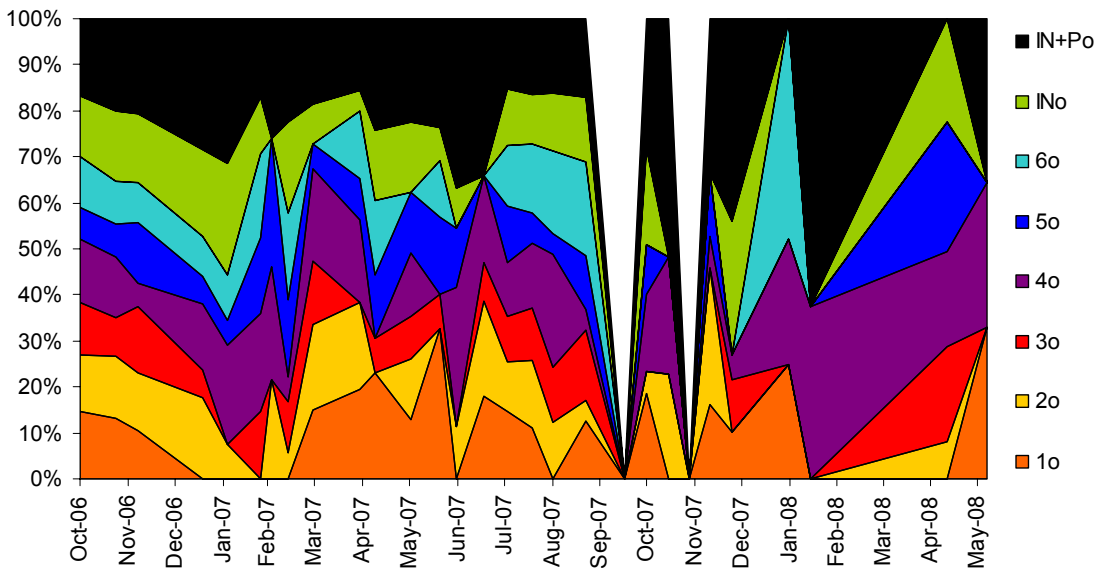


Figure 6-34 log 10 cumulative stacked area graph (100%) for *Enterococci sp* concentrations in outdoor rig. Presents the trend of the percentage each value contributes over time and categories.

By comparison of individual bins, it is seen that at the beginning of experiment their levels were following a similar pattern, although bins 1o and 4o took the greatest portion of total bacterial numbers. The relation of bins is changed after November 2007, when bins 3o, 4o, 5o and 6o are dominant with bin 4o as the greatest. It might be possible that during that period increased volume of faecal matter was introduced into gully pot liquor (INo – 1,400 CFU/100ml; IN+Po – 96,250 CFU/100ml).

Table 6-52 Seasonal means and RSD effluent and influent concentrations for tested *Enterococci sp* numbers in outdoor rig (n=25).

	means (CFU/100ml)								relative standard deviations (%)							
	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
Autumn 2	113	75	55	83	25	33	122	573	480	120	139	356	87	110	95	227
Winter 2	95	78	35	393	113	103	379	2,971	-	393	185	1,575	541	607	2,726	22,736
Spring 2	1,579	247	9	786	71	129	102	5,406	8,120	1,958	43	5,123	211	726	532	28,162
Summer 2	265	136	120	1,512	89	716	137	765	1,875	584	446	12,281	596	3,025	506	1,746
Autumn 3	86	193	8	83	10	0	1,400	96,250	717	1,600	60	496	63	0	10,431	763,459
Winter 3	18	0	0	525	0	500	0	53,500	99	0	0	2,687	0	2,828	0	302,642
Spring 3	863	5	200	818	1,550	0	330	1,600	4,879	28	1,131	2,503	8,768	0	1,867	9,051
Springs	**1,221**	**126**	**105**	**802**	**811**	**65**	**216**	**3,503**	**6,499**	**993**	**587**	**3,813**	**4,490**	**363**	**1,199**	**18,607**
Summers	**265**	**136**	**120**	**1,512**	**89**	**716**	**137**	**765**	**1,875**	**584**	**446**	**12,281**	**596**	**3,025**	**506**	**1,746**
Autumns	**100**	**134**	**31**	**83**	**18**	**17**	**761**	**48,412**	**599**	**860**	**99**	**426**	**75**	**55**	**5,263**	**381,843**
Winters	**56**	**39**	**18**	**459**	**56**	**301**	**189**	**28,235**	**99**	**197**	**93**	**2,131**	**271**	**1,718**	**1,363**	**162,689**

Table 6-53 H/C means and RSD effluent and influent concentrations for *Enterococci sp* numbers in outdoor rig (n=25).

	1o	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**	**1o**	**2o**	**3o**	**4o**	**5o**	**6o**	**INo**	**IN+Po**
***Enterococci spp*.**	**means (CFU/100ml)**								**relative standard deviations (%)**							
heating	496	163	48	519	69	293	508	27,703	4,896	1,225	292	5,899	417	1,953	5,296	410,455
cooling	501	26	69	836	456	11	116	18,376	3,070	156	593	4,281	4,665	97	980	158,200

6.3.4 *Escherichia coli* seasonal variability

Escherichia coli was not examined at the beginning of the experiment among other organisms, therefore the n value (indoors n=23; outdoors n=20) is lower than for other microorganisms as described at the beginning of the chapter.

Indoor average seasonal maximum levels were observed in Springs (21,984 CFU/100 ml, bin 1i) with minimums in Winters (calculated average of 0 CFU recorded in bin 2i) (**Table 6-54**). Increased levels were observed in bin 4i for Autumns and Winters.
The highest variability values were recorded for warm seasons.
Influent variability in organism levels in INi influent during Autumns was lower (2,787,334 %) than in IN+Pi during Summers: 39,105,409%, although the former was calculated for only one seasonal mean.
H/C effluent mean concentrations were recorded higher during cooling cycles in all analysed bins as in **Table 6-55.**

Escherichia coli levels usually followed the same patterns over examination seasons. In January 2008 no organisms appeared in bins 2i-6i as in **Figure 6-35**, caused by the start of the cooling cycle at the beginning of the calendar year. Then an *E.coli* microbial community was gradually rebuilt, but only in bins 1i, 3i and 4i. IN+P inflow type dominated over the examination period. The white area represents a break in data collection.

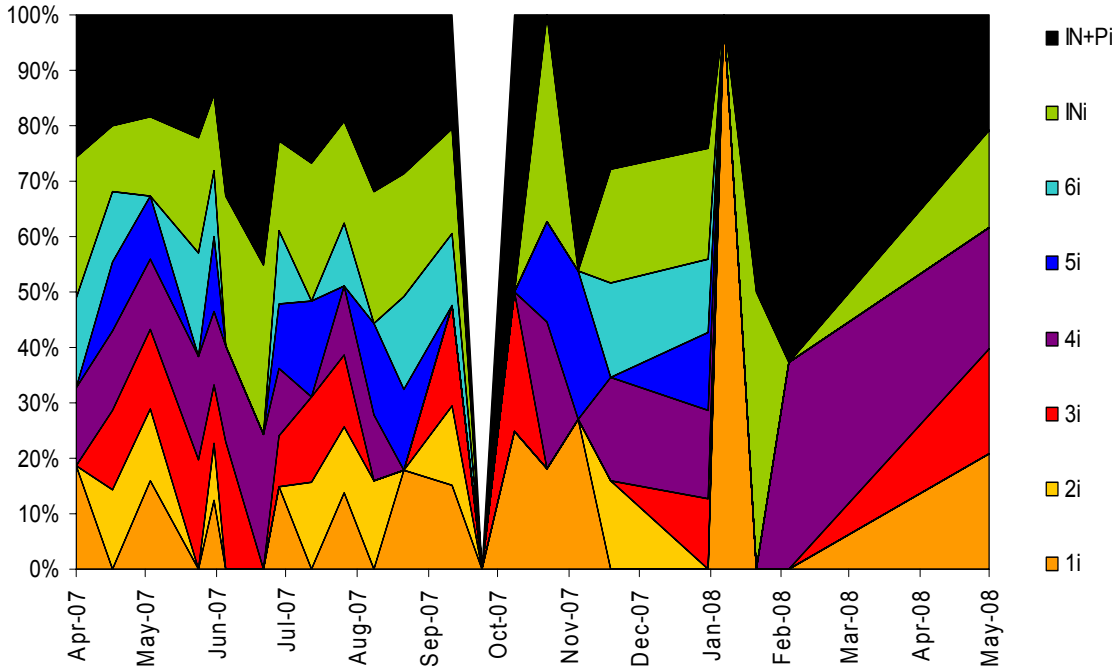


Figure 6-35 log 10 cumulative stacked area graph (100%) for *Escherichia coli* concentrations in indoor rig. Presents the trend of the percentage each value contributes over time and categories.

Table 6-54 Table 6-55 Seasonal means and RSD effluent and influent concentrations for measured *Escherichia coli* numbers in indoor rig (n=24).

	means (CFU/100ml)							
	1i	**2i**	**3i**	**4i**	**5i**	**6i**	**INi**	**IN+Pi**
Spring 2	13,167	3,083	5,750	22,967	25,500	7,000	82,883	231,333
Summer 2	11,786	750	2,843	2,307	1,600	3,286	68,000	5,209,286
Autumn 3	600	400	200	6,200	400	620	303,400	338,000
Winter 3	250	0	250	2,500	550	300	15,000	520,000
Spring 3	30,801	0	5,000	17,500	0	0	2,500	11,500
Springs	**21,984**	**1,542**	**5,375**	**20,233**	**12,750**	**3,500**	**42,692**	**121,417**
Summers	**11,786**	**750**	**2,843**	**2,307**	**1,600**	**3,286**	**68,000**	**5,209,286**
Autumns	**600**	**400**	**200**	**6,200**	**400**	**620**	**303,400**	**338,000**
Winters	**250**	**0**	**250**	**2,500**	**550**	**300**	**15,000**	**520,000**
	relative standard deviations (%)							
Spring 2	84,755	15,834	16,016	206,445	254,156	57,388	454,812	661,489
Summer 2	107,340	3,348	22,773	13,899	10,419	27,398	245,315	39,105,409
Autumn 3	2,282	3,727	1,863	43,341	2,282	5,777	2,787,334	1,805,278
Winter 3	2,083	0	2,083	12,028	4,583	2,500	99,187	3,199,573
Spring 3	51,857	0	29,463	103,120	0	0	14,731	67,764
Springs	**68,306**	**7,917**	**22,739**	**154,782**	**127,078**	**28,694**	**234,771**	**364,626**
Summers	**107,340**	**3,348**	**22,773**	**13,899**	**10,419**	**27,398**	**245,315**	**39,105,409**
Autumns	**2,282**	**3,727**	**1,863**	**43,341**	**2,282**	**5,777**	**2,787,334**	**1,805,278**
Winters	**2,083**	**0**	**2,083**	**12,028**	**4,583**	**2,500**	**99,187**	**3,199,573**

Table 6-55 H/C means and RSD outflow and inflow values for *Escherichia coli* numbers in indoor rig (n=24).

Escherichia coli	1i	2i	3i	4i	5i	6i	INi	IN+Pi	1i	2i	3i	4i	5i	6i	INi	IN+Pi
	means (CFU/100ml)								relative standard deviations (%)							
heating	2,719	1,047	2,275	3,184	713	1,019	129,706	288,875	19,982	7,016	16,848	25,322	3,429	5,153	1,546,293	1,374,661
cooling	18,000	1,125	3,750	22,375	19,625	6,625	60,000	4,628,000	116,752	13,258	20,503	177,630	219,735	54,506	326,758	36,892,060

Looking at the outdoor seasonal average values (**Table 6-56**) it is clear that bacterium numbers are decreasing from Spring to Autumn. The same pattern is being recorded for RSD values. Maximum average effluent Springs' value is recorded in bin 1o, while the minimum is recorded in bin 2o (500 CFU/100 ml) for Winters. The following pattern is echoing the inflow levels as a similar decrease in microbial presence was recorded.
Taking H/C (**Table 6-57**) seasons under consideration, *E.coli* levels were definitely higher in the cooling cycle, meaning that these were 1.4 – 11 times higher than during another cycle run. This can be an indication of favourable conditions for pathogenic organism development.

Escherichia coli numbers dominate in bins 1o-3o until January 2008 when the cooling cycle started and *E.coli* numbers become greater in the effluent than influent. Also, after starting the cooling cycle in 2008, there was no presence of the species in bin 5o, as in **Figure 6-36**.

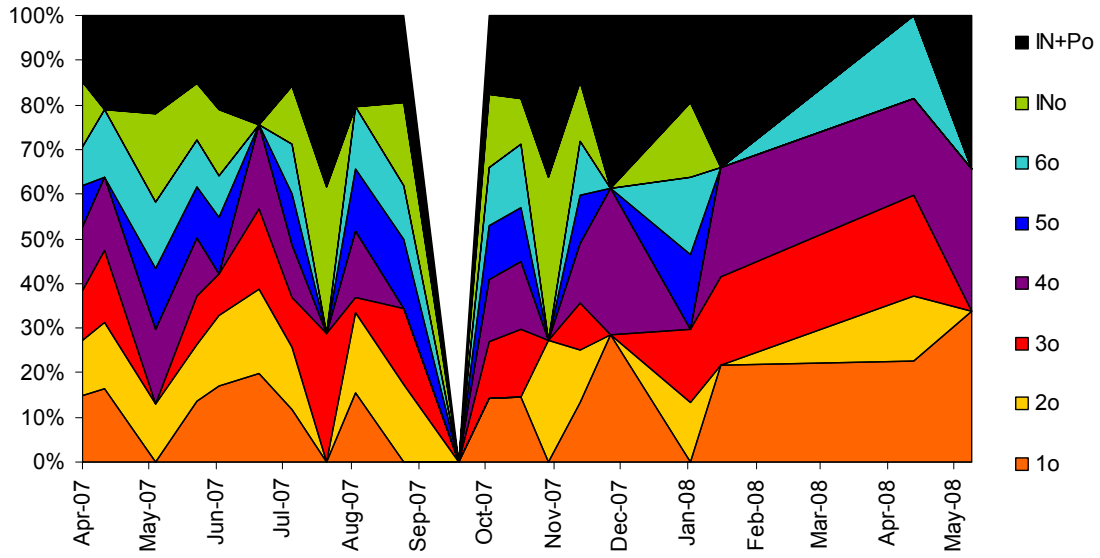


Figure 6-36 log 10 cumulative stacked area graph (100%) for *Escherichia coli* concentrations in outdoor rig. Presents the trend of the percentage each value contributes over time and categories.

The noticeable fact is that while comparing indoor and outdoor rigs for all types of microbes, indoor rigs were more stable, exhibiting lower fluctuations, but at the same time were more prone to the amount of pollutants introduced into the bins. In some cases, e.g. *Enterococci sp.*, microbes indoors were not present in all bins, as only the ones with the highest numbers of pollutants survived.

The main conclusion on microbiological assessment is that at the outdoor rig air temperatures were determining the microbial numbers and at the indoor rig, it was the number of introduced pollutants and systems' reaction on them, as air temperatures were stable, although this statement can only be rejected or proved true through a more detailed statistical analysis, which is described in Chapter 8.

Table 6-56 Seasonal means and RSD effluent and influent concentrations for measured *Escherichia coli* numbers in outdoor rig (n=19).

	1o	2o	3o	4o	5o	6o	INo	IN+Po
	means (CFU/100ml)							
Spring 2	460,800	150,600	9,400	143,000	12,800	4,200	204,000	8,478,000
Summer 2	16,200	62,400	10,602	12,000	6,800	4,800	33,400	411,200
Autumn 3	9,667	1,800	3,000	11,000	1,833	4,333	24,217	97,500
Winter 3	1,000	500	3,000	2,500	3,000	3,500	3,000	82,500
Spring 3	315,000	2,000	225,000	174,000	0	20,000	0	100,000
Springs	**387,900**	**76,300**	**117,200**	**158,500**	**6,400**	**12,100**	**102,000**	**4,289,000**
Summers	**16,200**	**62,400**	**10,602**	**12,000**	**6,800**	**4,800**	**33,400**	**411,200**
Autumns	**9,667**	**1,800**	**3,000**	**11,000**	**1,833**	**4,333**	**24,217**	**97,500**
Winters	**1,000**	**500**	**3,000**	**2,500**	**3,000**	**3,500**	**3,000**	**82,500**
	relative standard deviations (%)							
Spring 2	3,212,809	1,376,382	60,766	1,295,849	89,582	8,648	1,413,484	94,235,320
Summer 2	77,923	364,730	34,211	59,894	38,569	33,577	189,459	1,436,632
Autumn 3	61,977	18,383	19,972	53,259	13,487	28,570	237,792	662,353
Winter 3	7,443	3,722	14,886	18,608	22,330	26,051	22,330	427,986
Spring 3	1,168,587	14,886	1,674,727	640,118	0	148,865	0	744,323
Springs	**2,190,698**	**695,634**	**867,746**	**967,983**	**44,791**	**78,756**	**706,742**	**47,489,822**
Summers	**77,923**	**364,730**	**34,211**	**59,894**	**38,569**	**33,577**	**189,459**	**1,436,632**
Autumns	**61,977**	**18,383**	**19,972**	**53,259**	**13,487**	**28,570**	**237,792**	**662,353**
Winters	**7,443**	**3,722**	**14,886**	**18,608**	**22,330**	**26,051**	**22,330**	**427,986**

Table 6-57 H/C means and RSD effluent and influent concentrations for *Escherichia coli* numbers in outdoor rig (n=19).

	1o	2o	3o	4o	5o	6o	INo	IN+Po
Escherichia coli	**means (CFU/100ml)**							
heating	74,929	32,154	7,501	46,214	4,286	5,071	75,521	286,143
cooling	337,667	110,167	78,167	80,800	9,167	7,833	46,833	6,898,333
	relative standard deviations (%)							
heating	1,290,645	290,920	44,644	707,312	26,229	25,154	894,015	1,744,748
cooling	2,640,972	1,295,192	958,920	553,075	88,972	83,578	541,880	86,640,598

7 Pollutant removal efficiencies

Removal efficiency for all parameters in the experimental rigs was calculated using the following formula:

$$\%\ removal = 100 - (outflow\ concentration * 100 / inflow\ concentration) \quad (9)$$

Removal rates in bins receiving excrements (bins 1 and 4 in both rigs) were calculated with IN+P type of inflow and bins with a standard mixture of gully pot liquor and tap water were calculated with IN type of inflow.
Concentrations, microbial levels and removal efficiencies concern the bottom of sediment tank and would not normally reach the outflow in commercial applications, if not pumped out, as in the experiment.

7.1 Nutrients removal

7.1.1 Nitrates/nitrites removal

NO_{2+3} removal values were mostly negative, even up to 1500% in the outdoor rig and 3000% in the indoor rig.
Some fluctuations during the experimental period with smaller negative reductions took place until Winter 2 in both rigs. From then, removals become negative, as in **Figure 7-1** and **Figure 7-2.**

The highest negative removals are observed mainly during Summer 2 and Autumn 3 (2007) as well as Winter 3 (Spring 3 in outdoor rig).

The main reason for the negative removals of nitrates/nitrites is because of NH_4 transformations to NO_{2+3} in the process of nitrification. In soils, the organisms responsible for the transformation are bacteria from *Nitrosomas* and *Nitrobacter* families, which were not assessed in the experiment.

Kadurupokune and Jayasuriya (2009) report a decreasing trend in total nitrogen removal efficiencies during 17 years of simulation from 62.94% in year 1 and 22.74% in year 9 to 12.02% in year 17 due to clogging; thus, apart from increased oxidation, PPS performance could be affected by leaching of NO_{2+3} in the granular material used in the sub-base as well as decomposition of aggregates used for pavement structure. Therefore it is recommended to sweep the top of PPS at least four times a year in order to prevent clogging (EPA, 1999).

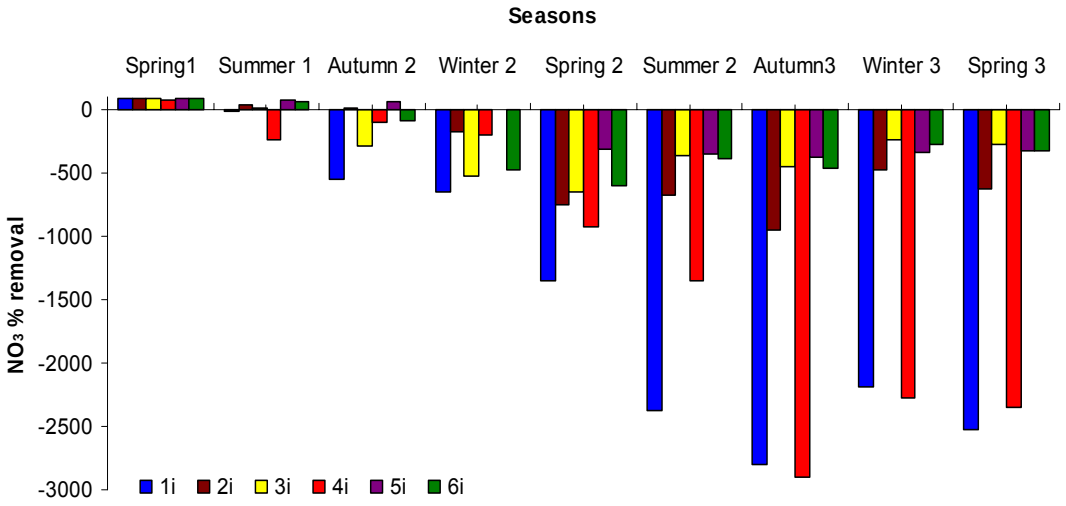


Figure 7-1 Percentage of NO_{2+3} removal in indoor rig.

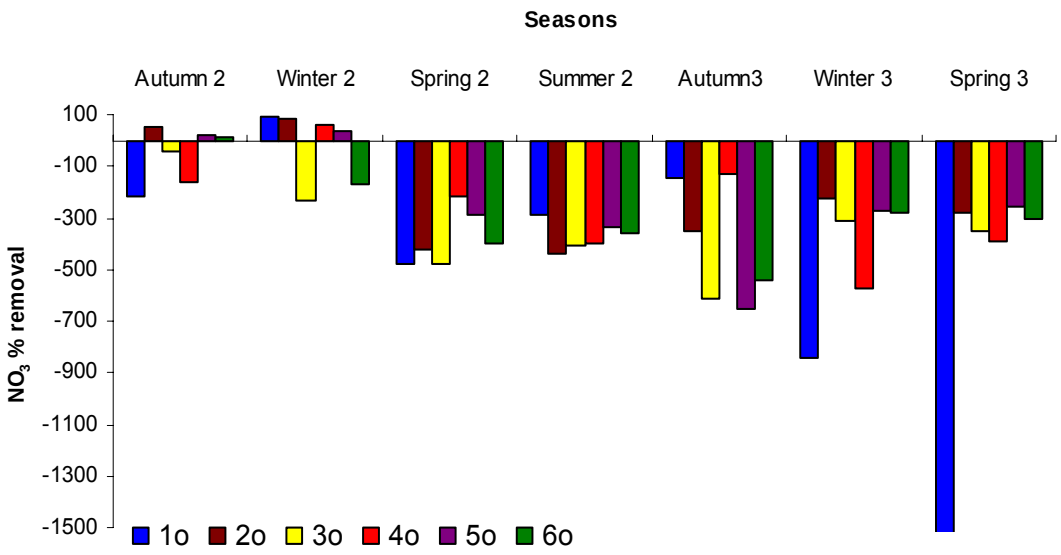


Figure 7-2 Percentage of NO_{2+3} removal in outdoor rig.

High concentrations of nitrogen in the effluent (constructed wetlands) can be explained by low microbial metabolic activity due to low temperatures as optimal nitrification is around 25-35^{o}C (Kadlec and Knight, 1996).

7.1.2 Ammonia removal

Figures 7-3 and **7-4** present ammonia removals. Removal efficiency is high through the year, usually ranging between 70% – 99%. The results are constant through both years of the experiment, with the highest removal efficiencies calculated for bins 1 and 4 in both rigs.

While looking at indoor removal for all bins except bins 1i and 4i (receiving faeces), the removal pattern is relatively stable, with maximum efficiency during Winter 2. In the outdoor rig for bins 2i, 3i, 5i and 6i, removal

efficiencies do not follow air temperature seasonal fluctuation, as increased removal efficiency is recorded during Winter 2, Spring 2 and Winter 3, while in the heating cycle. This allows for the conclusion of the existence of H/C relation to removal efficiencies in the outdoor rig. Such relations or their absence and statistical significance are discussed in Chapter 8.

Removal efficiencies in bins 1 and 4 are stable during the whole experimental period.

Chung *et al.* (2008) reports 92% removal efficiency of NH_4-N in planted constructed wetlands.

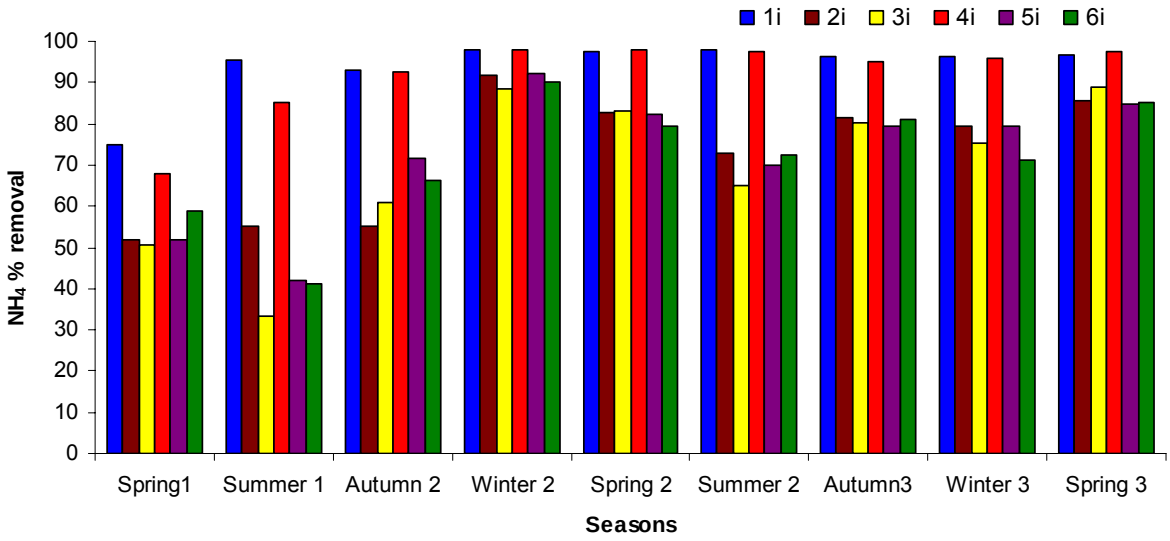


Figure 7-3 Percentage of ammonia removal in indoor rig.

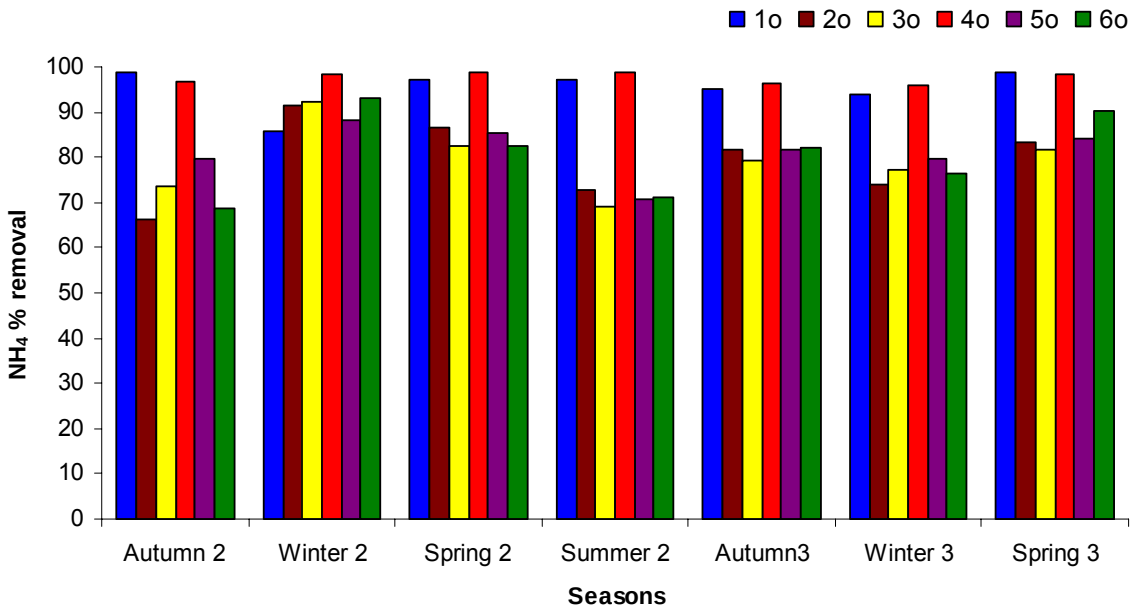


Figure 7-4 Percentage of ammonia removal in outdoor rig.

7.1.3 Ortho-phosphate-phosphorus removal

Ortho-phosphate-phosphorus removals are presented in **Figures 7-5 and 7-6**.

Indoor rig average reductions of PO_4 range between 60% and 80%. Each rig's negative removal efficiencies are recorded for Winter 3 and Spring 3 and the highest positive removal efficiencies in bin 1i during Spring 1.

Looking at **Figure 7-5,** removal efficiencies decline until Autumn 3 (bins 1i,2i and 4i), when levels become more stable.

Chung *et al.* (2008) defines PO_4-P removal efficiencies of 72% and 79% over a 10-day hydraulic retention time during a 160 day experiment on constructed wetlands.

In storm water filtration systems, US EPA (1999) reports pollutant removal efficiency of -31% for soluble phosphorus and 45% for total phosphorus in 2 and 15 observations respectively.

Lund *et al.* (2001) assessed constructed wetlands removal efficiency, with maximum removal of 12% for filterable reactive phosphorus over 2 years of study, describing it as very high. This proves that every system is different and will return different numbers of concentrations and removal efficiencies.

Comparison of various SUDS techniques is difficult, as every technique is designed independently to treat different types of urban runoff locally.

Negative removal efficiencies in PPS are recorded in the outdoor rig during similar seasons as indoor bins 1o, 2o and 4o. As removal efficiency varies greatly outdoors, it is not possible to comment on existing patterns without more sophisticated mathematical/statistical analyses.

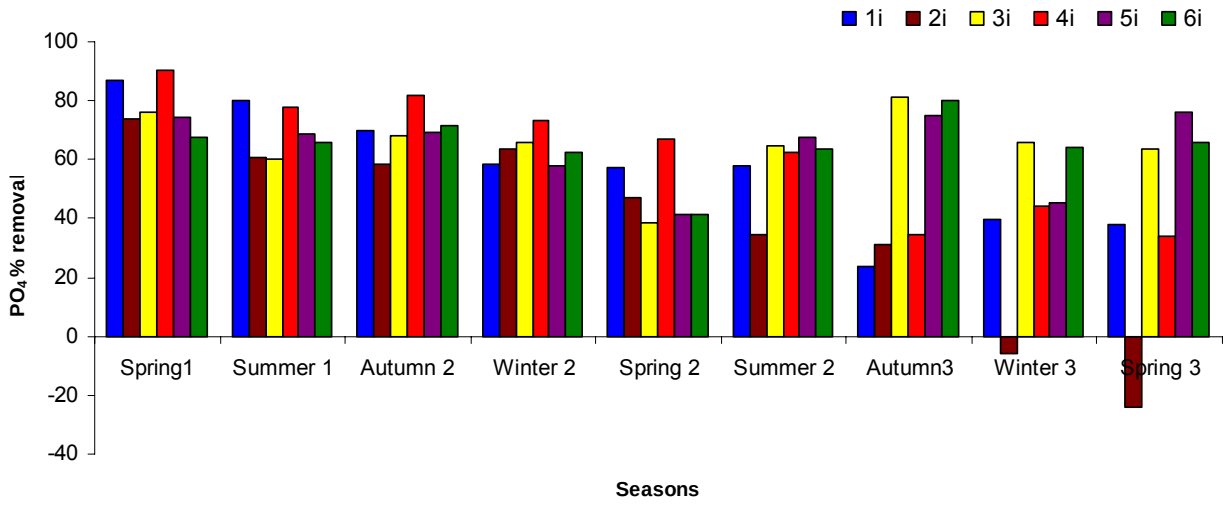


Figure 7-5 Percentage of ortho-phosphate-phosphorus removal in indoor rig.

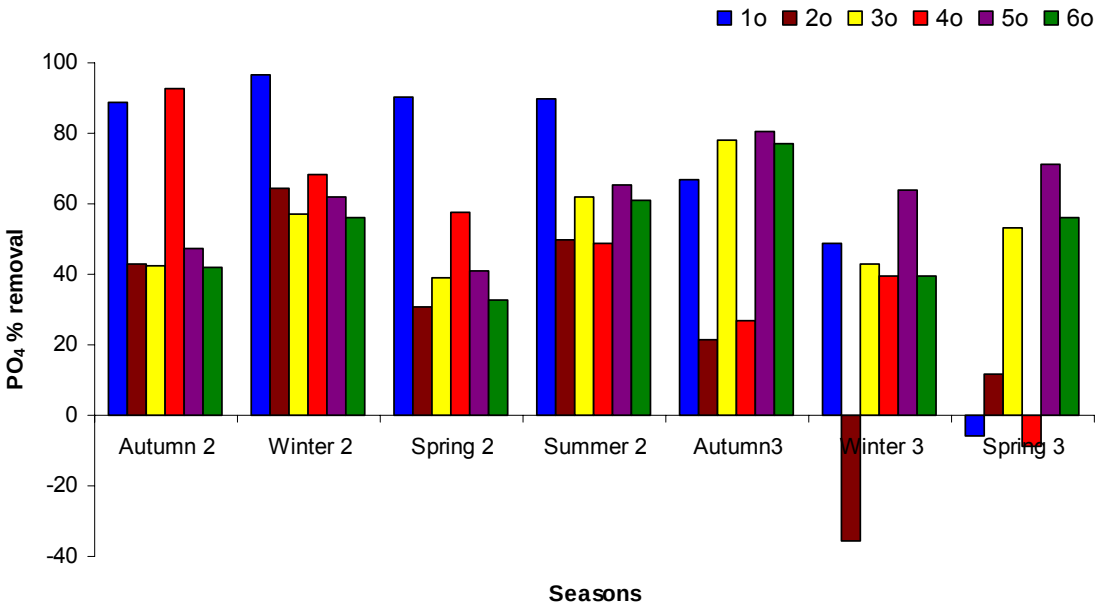


Figure 7-6 Percentage of ortho-phosphate-phosphorus removal in outdoor rig.

7.2 BOD_5 removal

5-day BOD high and stable removals through the experimental period reaching up to 100% in both rigs are presented in **Figures 7-7 and 7-8**. There was worse performance during Winter 2 in the outdoor rig, with only a 30% - 40% removal. There was decreased removal in bins 5o and 6o in Summer 2 and Winter 3 (20-60%), though this was still positive in both rigs.

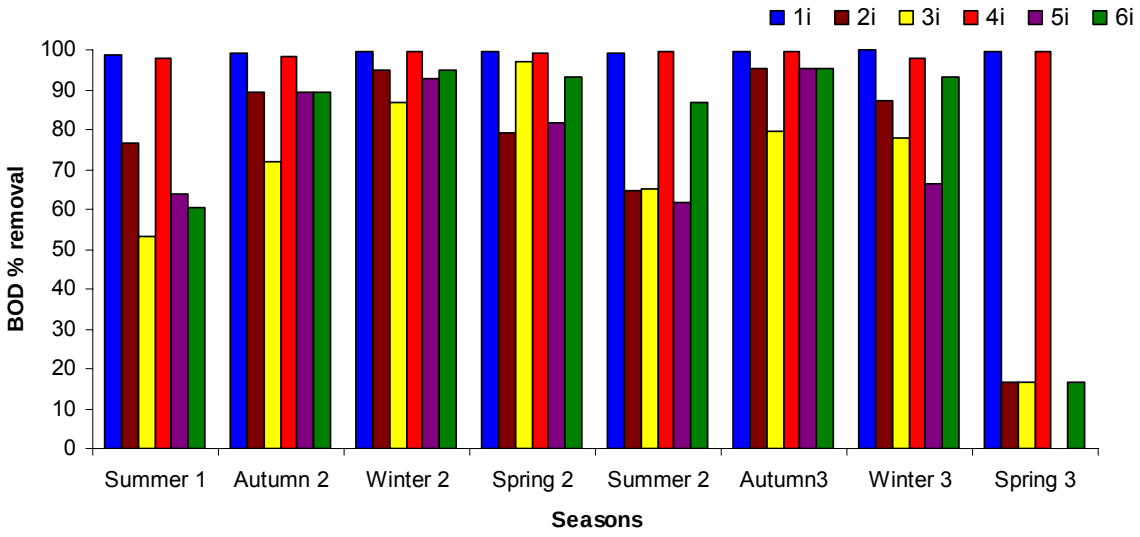


Figure 7-7 Percentage of Biological Oxygen Demand removal in indoor rig.

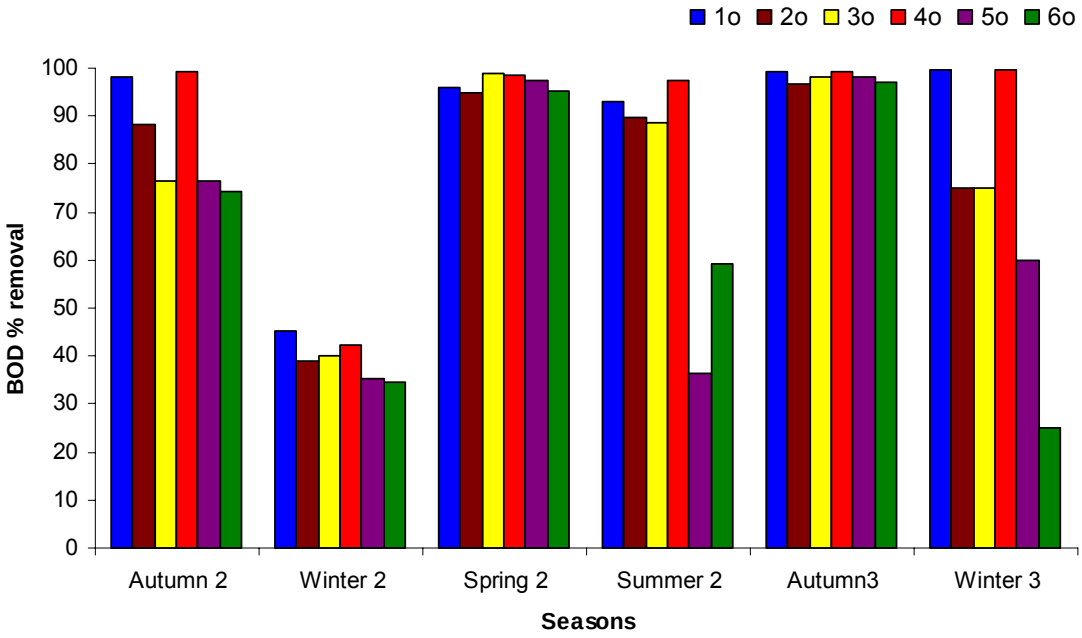


Figure 7-8 Percentage of Biological Oxygen Demand removal in outdoor rig.

Papadimitriou *et al.* (2010) reports high BOD_5 removals in constructed wetlands, reaching up to 85%, which were attributed to the consumption of the organic substances by microbes and their adsorption on the wetland substrate.

7.3 Total Dissolved Solids (TDS) removal

TDS removals were mainly negative. The lowest reduction was found in the outdoor rig, reaching the maximum negative value of -300% (Autumn 2 – Summer 2). Comparing **Figures 7-9 and 7-10,** it is clear that removal patterns are quite similar and mirror each other in both rigs.

The main source of TDS in the inflow was gully pot liquor which was later diluted in 1:10 ratio with tap water. The consequence of this treatment is lower TDS inflows (outdoor and indoor rig 57.3 and 88.6 mg/l and 59.5 and 86.9 mg/l for IN and INP respectively) than the outflows collected with a pump (e.g. 212.2 mg/l on average collected in bin 1 outdoors). This created conditions favourable for particle wash-outs from PPS

layers.

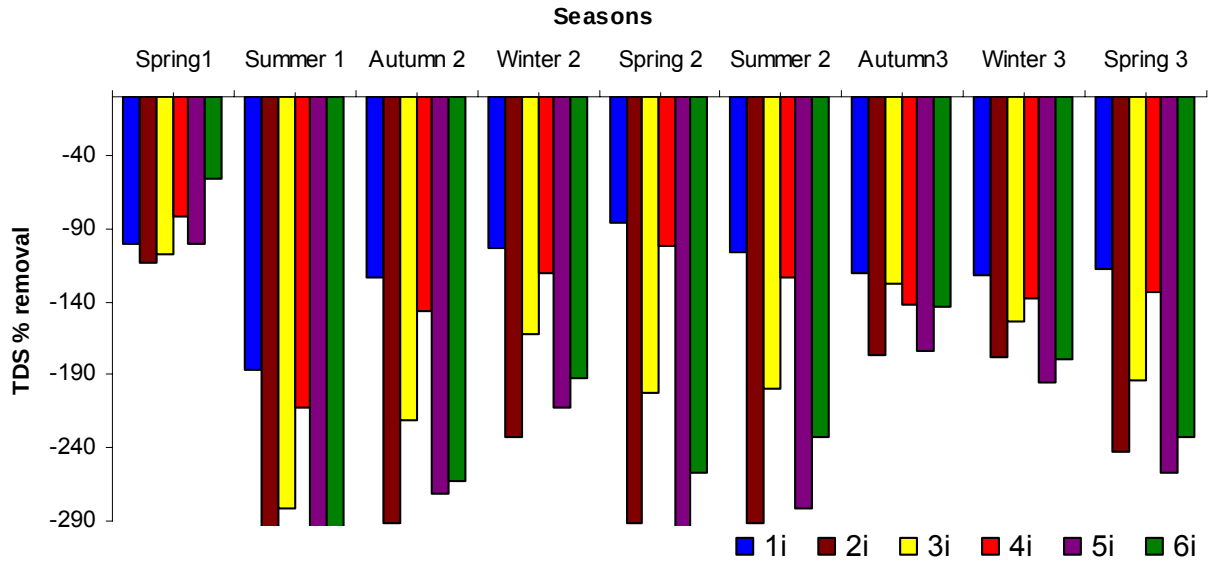


Figure 7-9 Percentage of Total Dissolved Solids removal in indoor rig.

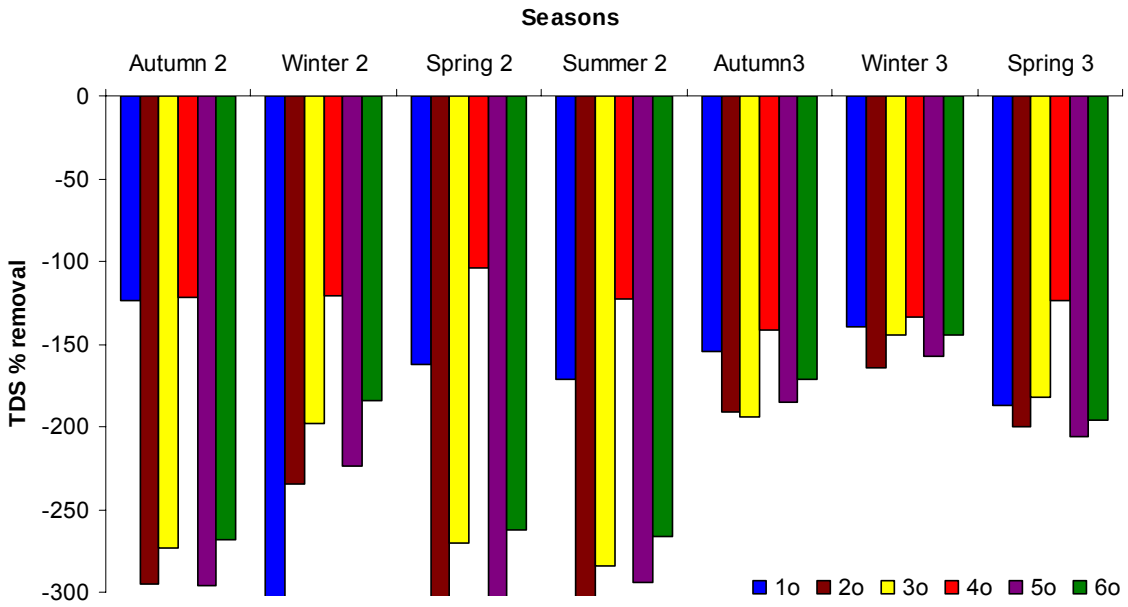


Figure 7-10 Percentage of Total Dissolved Solids removal in outdoor rig.

7.4 Total Heterotrophic Bacteria removal

Only a few of the indoor seasonal removal efficiencies were negative, as shown in **Figure 7-11**. During Winter 2 and Autumn 3, Bin 6 failed to reach the maximum negative removal of 40%. The lowest removal was recorded in bin 3, a value of -60%. Removal efficiencies in other bins and seasons were relatively stable and positive ranged between 80-100%.

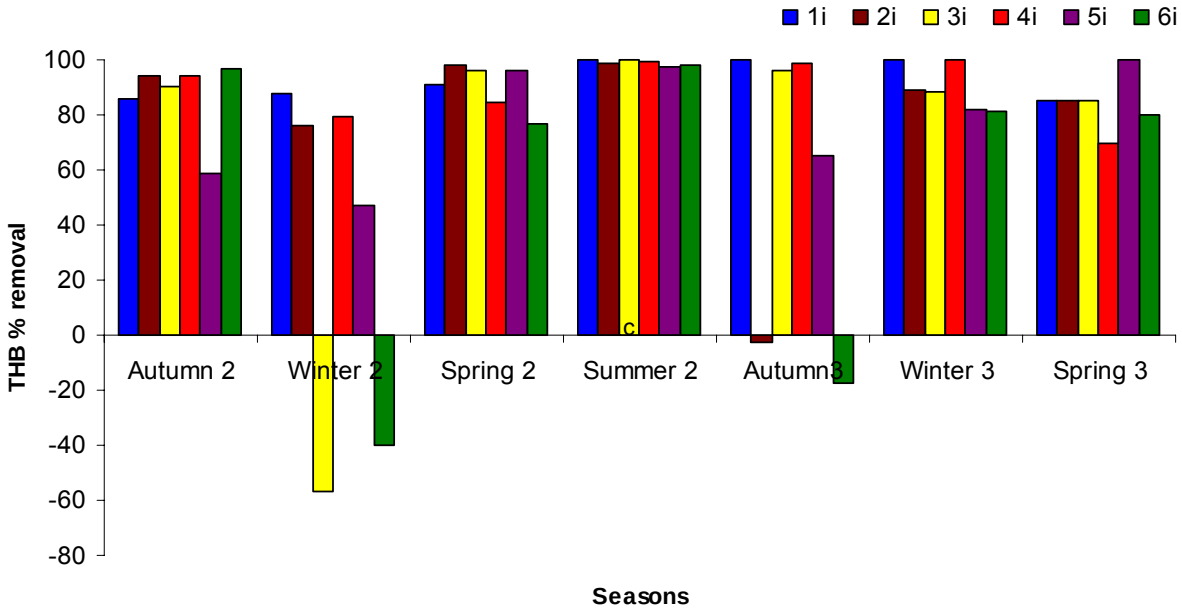


Figure 7-11 Percentage removal of Total Heterotrophic Bacteria in indoor rig.

THB removal values in the outdoor rig (**Figure 7-12**) were stable and ranged between 70% - 100%. Some initial, lower, average removal efficiencies can be found in bins 2o, 3o and 5o, ranging from 60% to 90% during Autumn 2 and Winter 2.

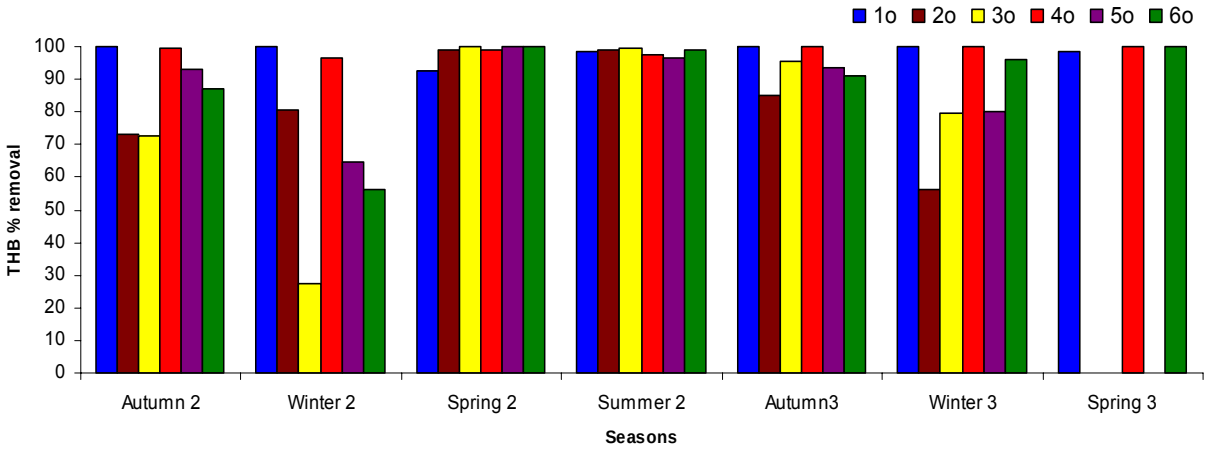


Figure 7-12 Percentage removal of Total Heterotrophic Bacteria in outdoor rig.

The results had shown stable environmental conditions during the experimental period, as THB levels are the indication of all heterotrophic bacterial organisms within PPS.

Despite high THB removal efficiencies, Hathaway *et al.* (2009) suggest that storm water BMPs can be sources of indicator bacteria because of animal activities and indicator bacteria (especially fecal coliform and *E.coli*) persistence in BMPs. Reported removal efficiencies were very low, reaching 0.89% (faecal cliform) and 0.92% (*E.coli*). Such low removal efficiencies were calculated depending on a small sized sample set and influent concentrations.

The above example suggests the need for long-term observations on BMPs as low numbers of datasets (n = 6-14 for *E.coli* and n = 6-19 for fecal coliforms) can provide abbreviated picture of SUDS efficiencies. Expected

bacteria removal efficiencies for constructed wetlands ranges between 55% - 97% (EPA, 1999)

7.5 *Salmonella sp* removal

Indoor rig removals efficiencies for *Salmonella sp* were extremely high, reaching 80% - 100% on average (**Figure 7-13**). Influent values were about 800 times higher than in the effluent (e.g. IN+P influent, bin 1).

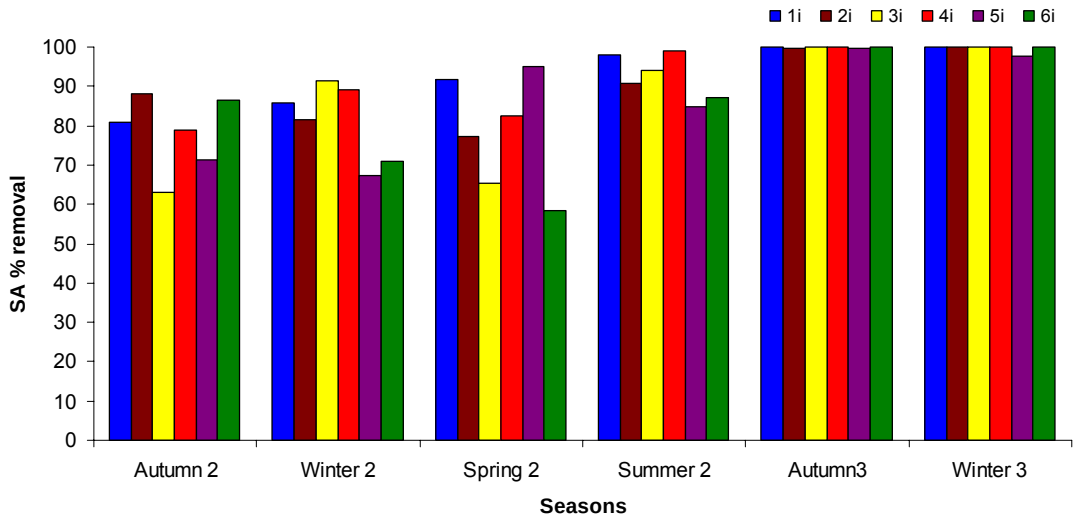


Figure 7-13 Percentage removal of *Salmonella sp* in indoor rig.

Outdoor *Salmonella sp* removal efficiencies (**Figure 7-14**) were high thought the experimental period, ranging between 30-100% in Year 2 and 50-100% in Year 3.

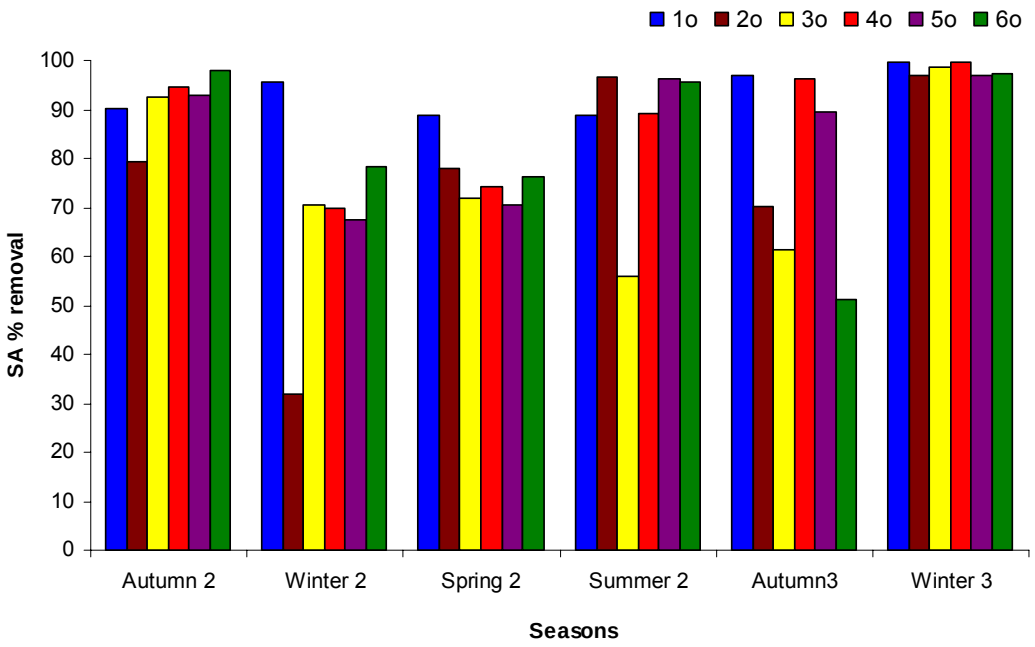


Figure 7-14 Percentage removal of *Salmonella sp* in outdoor rig.

7.6 *Enterococci sp.* removals

Indoor removal patterns (**Figure 7-15**) reached the lowest removal efficiencies in Autumn 2 and Summer 2, reaching -200%. Positive removal efficiencies ranged between 5% - 100%, depending on the amount of bacterium (faeces) in the influent through the years of the experimental period.

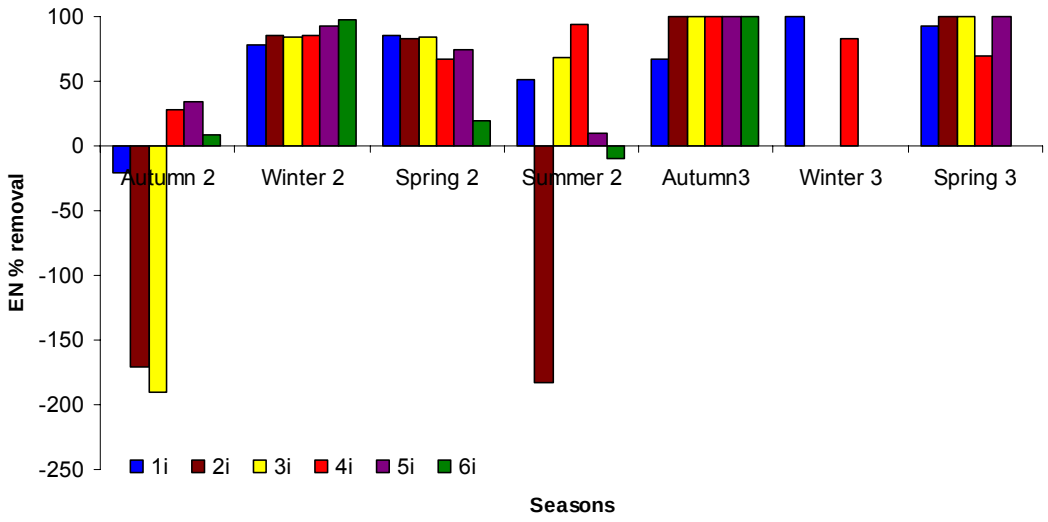


Figure 7-15 Percentage removal of *Enterococci sp* in indoor rig.

Enterococci sp outdoor average removals were relatively unstable through the years of research, ranging from 10% to 100% during positive removal periods and negative removal efficiencies of -350% during Summer 2 and Spring 3. This can be the result of switching H/C cycles from cooling to heating in 2007 and heating to cooling in 2008 (**Figure 7-16**).

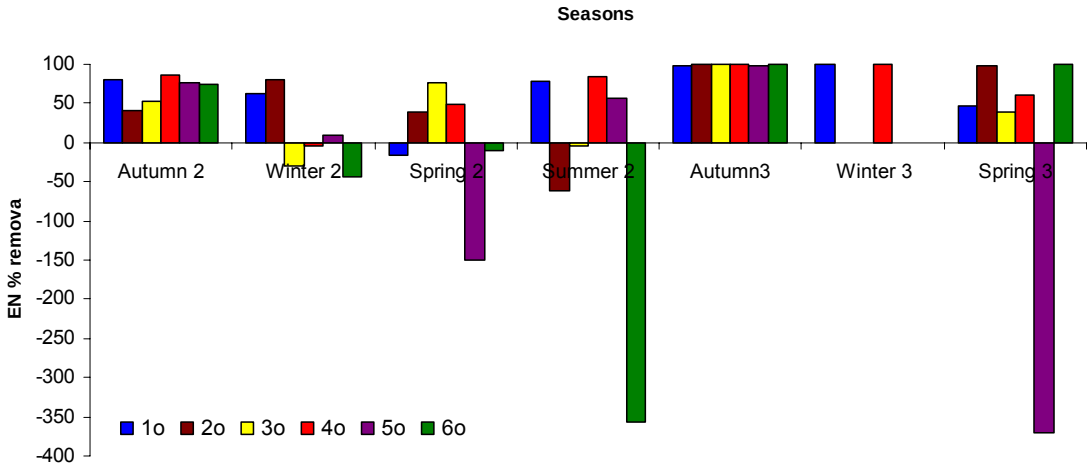


Figure 7-16 Percentage removal of *Enterococci sp* in outdoor rig.

7.7 *Escherichia coli* removal

The removal of indoor bacterium was stable and the influent organisms were removed at the level of 65% - 100% (**Figure 7-17**). Less data was recorded for Spring 3 because of lower numbers of organisms in the rig.

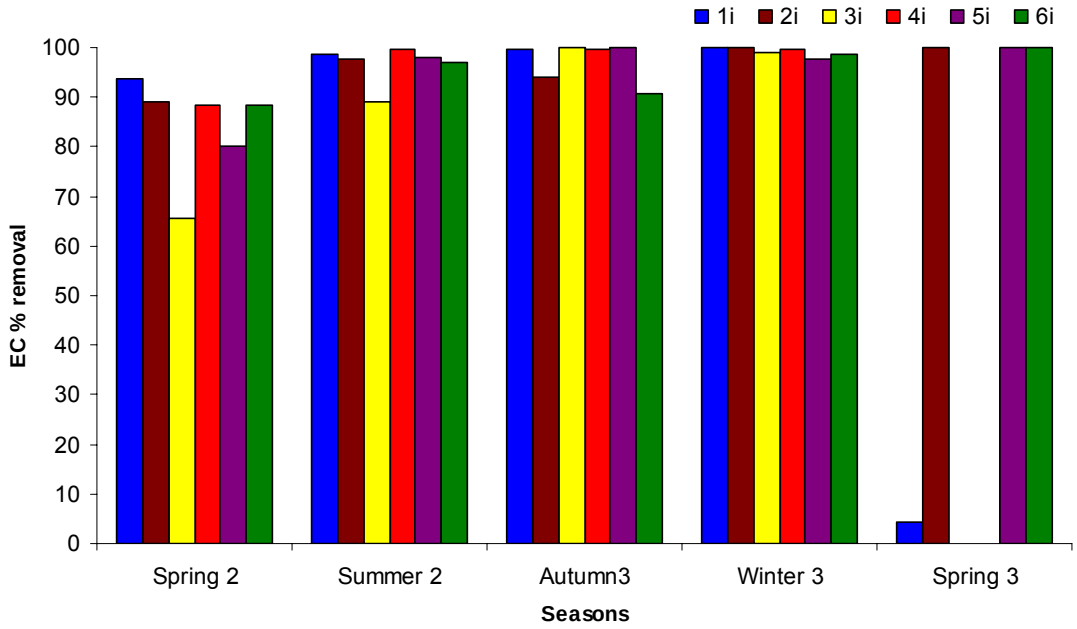


Figure 7-17 Percentage removal of *Escherichia coli* in indoor rig.

Outdoor rig for *Escherichia coli* removal was stable through the experimental period, varying from 20% (Winter 3) up to 90% (Summer 2, Winter 3) (**Figure 7-18**). Because most of the analysis returned zero values, they were not included in the analysis; hence, there is less data present in the figures for Winter 3 and Spring 3.

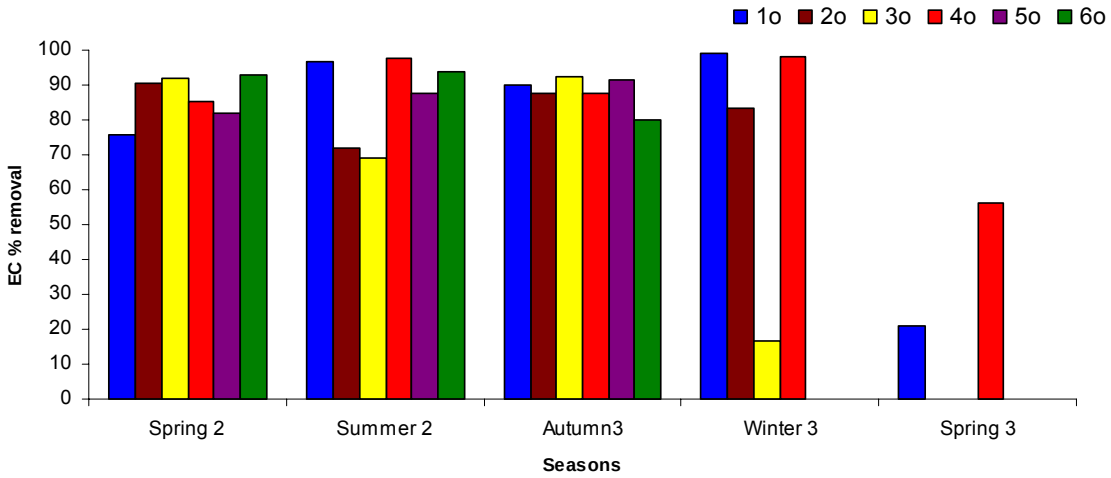


Figure 7-18 Percentage removal of *Escherichia coli* in outdoor rig.

Expected pathogens removal efficiency in structural BMPs is less than 30% for dry retention basins, retention basins, constructed wetlands, grassed swales, vegetated filter strips and surface sand filters. 65% - 100% removal efficiency is expected for infiltration basins dry wells and amongst them - porous pavements (EPA, 1999). This study confirms PPS removal efficiency in pathogenic removals.

Microbial removal efficiencies were stable during the experiment. The majority of pathogenic species were following overall THB patterns. *Enterococci sp* appeared to be the most 'fragile' bacterium, prone to temperature switching in the PPS sub-base. This provides evidence that some pathogenic organisms can be more temperature-dependant than the whole bacterial community.

The above statement can only be tested with statistical analyses and provides conclusions based on observed data patterns only, rather than analytical tests. More detailed analysis is provided in Chapter 8 and

includes non-parametrical testing for Spearman's correlations, Wilcoxon rank-sum test as well as artificial neural network modelling, i.e., self-organising maps.

8 Numerical analyses

8.1 Statistical (non parametric) analysis

The following tests were run using Statistica 9.0 by Stat Soft, Tulsa, OK, USA.

The most common and important approach in statistics is data normalisation in order to obtain normal distribution. Further analysis allows for data predictions by sampling existing data for future predictions. Normal distribution datasets are represented by a normal density curve or, in other words, a bell-shaped curve (Durham and Turner, 2008). This approach allows for the reliability and ease of data usage. In many cases, observed data does not allow for normal distribution and other tests must be used.

These tests are called non parametrical tests and very often are underestimated in the analyses as (depending on the dataset) the statistical power of the non parametrical tests can be higher than the parametrical ones. Non parametric procedures work with the median, which is less prone to outliers, extreme values and is not affected by skews in comparison to the median (Rumsey, 2007)

For data normalisation checks Shapiro – Wilk's W-test was used. If the statistic is significant, the null hypothesis of distribution normality has to be rejected (StatSoft, 2010), which was the case when analysing the PPS dataset. 'Using generalized least squares (the ordered varieties are correlated) linear and higher-order models can be fitted and an 3'-type ratio used to evaluate the adequacy of the linear fit' (Shapiro and Wilk, 1965). This approach makes the W-test the most powerful amongst all available statistical tests (StatSoft, 2010). Only a few of the data variables collected for PPS experiment were

normally distributed, and most of the data were not distributed normally. The in-depth testing for normality was made even more difficult because of different data collections for microbes and nutrients, and strong discrepancy in the number of samples (n-values) collected in both rigs. Also, microbial concentrations showed a strong variability in the observations. As a result, the decision of non parametrical statistics usage was made.

Relationships between influent (polluted) and effluent (treated) concentrations were calculated by Spearman's (non parametrical) correlations (r_s). The same type of analysis was used for the evaluation of the effect of sample temperature on nutrient and bacterial concentrations. Spearman's correlation test is an equivalent of Pearson's correlation for normalised data. The major difference is that Spearman's test ranks where variables were measured on at least ordinal (ranked) scale and direct observations can be ranked into ordered series (StatSoft, 2010).
The method was used to calculate influent (two types) - effluent relations for all nutrients and microbial populations examined in both rigs during the research.

The effect or lack of effect of temperature during H/C on microbial and nutrient concentrations was analysed using the Mann Whitney Wilcoxon rank sum statistic.
Effects of the presence or lack of presence of Inbitex geotextile and Inbitex composite; H/C cycles and type of influent (IN; IN+P) on nutrient and bacterial effluent concentrations were analysed using the Mann Whitney Wilcoxon rank sum statistic as well.

U-test is a non parametrical equivalent of a parametrical student t-test. It is used when observations from one sample are larger than in the other (Shier, 2004) or when comparing two populations using two independent random samples (Chang, 2010). It is worth noting that Mann-Whitney and Wilcoxon u-test is the same test.

For comparisons between nutrient and microbial removals depending on the type of influent and rig p values were calculated using Kurskal-Wallis test, which is a non-parametrical equivalent of one way ANOVA. It compares between the medians of two or more samples to determine if the samples were drawn from the same distributions or distributions with the same median (StatSoft, 2010).

Detailed description of the analyses used can be found in earlier publications by the tests' authors: Wilcoxon (1945), Mann and Whitney (1947), Kurskal and Wallis (1952) and Shapiro and Wilk (1965).

The probability of occurrence was considered as significant with $p \leq 0.05$ and highly significant at $p \leq 0.01$.
In the tables, significant correlations were marked with asterisk (*) and highly significant with double asterisk (**).
In descriptive statistics tables, values in rows have the following meanings: 1-mean, 2-standard deviation, 3-median, 4-lower/upper quartile.

8.1.1 Influent-effluent correlations

Correlation between influent concentrations for chosen parameters and their effluent equivalents are presented in **Tables 8-1 – 8-3.**
Correlations were calculated for the total number of bins; all bins in indoor rig and all bins in outdoor rig; bin type (as in **Table 5-2**, p. 84); individual bins in rigs.

In **Table 8-1,** highly significant ($p<0.01$) moderate correlations ($r_s = 0.4925$) were found between influent and effluent NO_{2+3} concentrations. The relation is higher in the system operating in a stable environmental conditions (indoor $r_s = 0.667$) than in the system with changing environmental conditions (outdoor $r_s = 0.2286$). This means that environmental conditions were influencing the system strongly enough to make the relationship much less bonded.
Correlations between indoor NO_{2+3} influent and effluent concentrations in all of the bins were highly significant ($p<0.01$) and considered high, ranging from $r_s = 0.6097$ to $r_s = 0.7735$, while in the outdoor system in all bins correlations were considered low, with r_s ranging from 0.1493 to 0.3495. It provides evidence on clear influence of the outdoor conditions on the processes of NO_{2+3} removals.

In the same table, highly significant ($p<0.01$), but low (0.1644) correlations were found between NH_4 influent and effluent concentrations. This dependence in individual bins is low, with r_s ranging from 0.0421 to 0.4058 and does not indicate any clear relationships with the type of bin.

High (r_s = 0.7757) and highly significant (p<0.01) correlation was found between PO_4 influent and effluent concentrations. The relationship is stronger in systems with stable environmental conditions (r_s = 0.8163) than outdoors, which was prone to changing environmental conditions (r_s = 0.6995). This demonstrates that changing environmental conditions influenced the outdoor system strongly, although the difference in values is relatively small. The above findings are presented in **Table 8-1.**

Correlations between influent and effluent PO_4 concentrations were highly significant (p<0.01), apart from bins 1 and 4 with IN+P type of influent. Apart from bin 4o, all other bins with IN+P influent had r_s ranging between 0.0205 to 0.1639 and no-significant (p>0.05) relationships between PO_4 influents and effluents. Bins 4i's correlation was considered low (r_s = 0.3483), although the significance was high (p<0.01). This means that additional portions of pollutant influence the relationship between PO_4 influent and effluent concentrations.

Table 8-1. Spearman's correlations (r_S) between influent concentrations for NO_{2+3}, NH_4 and PO_4 and their effluent equivalents (mg/l).

mg/l	**NO_{2+3}**	**NH_4**	**PO_4**
Total	0.4925 **	0.1644 **	0.7757 **
Indoor rig	0.6675 **	0.1063 **	0.8163 **
Outdoor rig	0.2286 **	0.2478 **	0.6995 **
Bin type 1	0.4878 **	0.2391 **	0.1174
Bin type 2	0.4561 **	0.2345 **	0.6261 **
Bin type 3	0.5111 **	0.1673 *	0.7284 **
Bin type 4	0.5211 **	0.1482	0.2205 **
Bin type 5	0.5610 **	0.2294 **	0.6858 **
Bin type 6	0.5087 **	0.2304 **	0.7395 **
Indoor bin 1	0.7574 **	0.0421	0.1537
Indoor bin 2	0.6385 **	0.2683	0.6348 **
Indoor bin 3	0.6097 **	0.1931 *	0.7780 **

Indoor bin 4	0.7735 **	0.0600	0.1639
Indoor bin 5	0.7041 **	0.2244 *	0.7429 **
Indoor bin 6	0.6906 **	0.2531 **	0.8118 **
Outdoor bin 1	0.1493	0.4058 **	0.0205
Outdoor bin 2	0.1885	0.1753	0.5844 **
Outdoor bin 3	0.3495 **	0.1275	0.6693 **
Outdoor bin 4	0.2719 *	0.2898 *	0.3483 **
Outdoor bin 5	0.2824 *	0.2305 *	0.5384 **
Outdoor bin 6	0.2132	0.2011	0.6414 **

p≤0.05; ** p≤0.01

In **Table 8-2**, highly significant ($p<0.01$) but low (0.1460) correlations were found for DO (%) influent-effluent concentrations relationships. This correlation was slightly lower in the indoor rig (r_s = 0.1094) than in the outdoor rig (r_s = 0.2151). Correlations calculated for bin types were highly significant only for bins 3 (r_s = 0.2738) and 6 (r_s = 0.2405).
Correlations for individual bins were mostly considered low, although for bins 3i (r_s = 0.4035) and 6i (r_s = 0.3138) these were highly significant ($p<0.01$). Outdoor system correlations for bins 1o (r_s = 0.2866) and 4o (r_s = 0.3116) were found to be significant ($p<0.05$) and highly significant ($p<0.01$), respectively.

For DO (mg/l), highly significant ($p<0.01$) but low correlations (r_s = 0.2092) were found between influent and effluent concentrations. These were considered higher indoors (r_s = 0.2151) than outdoors (r_s = 0.1236).
Bin type correlations were calculated as highly significant only in bin 3 (r_s = 0.3692) and 6 (r_s = 0.3214).
Correlations calculated for individual bins were usually low, although for bins 3i and 6i they were highly significant ($p<0.01$), r_s = 0.6357 and r_s = 0.5298, respectively. Outdoor significant correlations were found only for bins 2o and 5o r_s = -0.2643 and -0.2460, respectively.

ORP correlations were found as significant and highly significant ($p<0.05$ and $p<0.01$), which allows for a conclusion that strong relationships between influent and effluent values were found.

BOD_5 influent-effluent concentrations correlations were found as highly significant ($p<0.01$), although they were considered low ($r_s = 0.1867$). They were stronger outdoors ($r_s = 0.3070$) and close to zero indoors ($r_s = 0.0140$).

BOD_5 influent-effluent relationships were found to be low, as r_s ranges between -0.0083 and 0.3192. They were also insignificant and without any indication of relationships in individual bins.

Table 8-2. Spearman's correlations (r_s) between influent concentrations for DO (mg/l), DO (%), ORP (mV), BOD_5 (mg/l) and their effluent equivalents.

	DO (mg/l)	**DO (%)**	**ORP (mV)**	**BOD_5 (mg/l)**
Total	0.2092 **	0.1460 **	0.7672 **	0.1867 **
Indoor rig	0.2728 **	0.1094 **	0.8085 **	0.0140
Outdoor rig	0.1236 **	0.2151 **	0.7190 **	0.3070 **
Bin type 1	0.1205	0.1025	0.6953 **	0.1541
Bin type 2	0.0177	-0.0203	0.8640 **	0.1739
Bin type 3	0.3692 **	0.2738 **	0.8429 **	0.0677
Bin type 4	0.1132	0.0607	0.7302 **	0.2151
Bin type 5	0.0081	-0.0876	0.8247 **	0.0037
Bin type 6	0.3214 **	0.2405 **	0.8339 **	0.1202
Indoor bin 1	0.1039	-0.0255	0.7706 **	0.0679

Indoor bin 2	0.2045 *	0.0146	0.9006 **	0.0872
Indoor bin 3	0.6357 **	0.4035 **	0.8591 **	0.1077
Indoor bin 4	0.0553	-0.0624	0.8049 **	-0.0081
Indoor bin 5	0.1726	-0.0381	0.8743 **	-0.0083
Indoor bin 6	0.5298 **	0.3138 **	0.8823 **	0.1443
Outdoor bin 1	0.0877	0.2866 *	0.5960 **	0.3085
Outdoor bin 2	-0.2643 *	-0.0690	0.8172 **	0.2824
Outdoor bin 3	-0.0320	0.1338	0.8278 **	0.1211
Outdoor bin 4	0.1981	0.3116 **	0.6344 **	0.3192
Outdoor bin 5	-0.2460 *	-0.1583	0.7668 **	0.0172
Outdoor bin 6	-0.0151	0.1373	0.7727 **	0.1735

*p≤0.05; ** p≤0.01

Highly significant correlations ($p<0.01$) were found between influent and effluent conductivity concentrations (r_s = 0.3873). The above were considered weaker indoors (r_s = 0.3416) and considered stronger outdoors (r_s = 0.4346). When considering individual bins, most correlations were found to be insignificant, although in bins 1o and 4o with IN+P inflow, type r_s was calculated as 0.3384 and 0.3973 respectively, with a high significance of $p<0.01$.

For TDS ($p< 0,01$), total influent-effluent correlations were calculated for r_s = 0.3814. This relationship was considered slightly weaker indoors (r_s = 0.3438) and considered stronger outdoors (r_s = 0.4163). In individual bins, correlations were usually considered weak, although, again, in bins 1o and 4o these were still highly significant ($p>0.01$) and considered high (r_s = 0.3484 and 0.4124 respectively) in comparison to total correlations.

pH total correlations were found to be highly significant ($p<0.01$) although low with r_s = 0.1577. The correlation was slightly higher indoors (r_s = 0.2769), but equal to zero outdoors (r_s = -0.0257).

All indoor bins were characterised by significant ($p<0.05$) influent-effluent pH correlations, with some highly significant ($p<0.05$), equalling r_s = 0.2402 and 0.4702. In outdoor bins, they were insignificant ($p>0.05$) and considered low (r_s ranged from -0.1713 to 0.1835).

Table 8-3. Spearman's correlations (r_s) between influent concentrations for COND (µS*cm^{-1}), TDS (ppm) and pH and their effluent equivalents.

	Conductivity (µS*cm^{-1})	**TDS (ppm)**	**pH**
Total	0.3873 **	0.3814 **	0.1577 **
Indoor rig	0.3416 **	0.3438 **	0.2769 **
Outdoor rig	0.4346 **	0.4163 **	-0.0257
Bin type 1	0.2163 **	0.1709 *	0.2807 **
Bin type 2	0.1444 *	0.1620 *	0.0770
Bin type 3	0.1465 *	0.1324	0.1820 *
Bin type 4	0.2272 **	0.2044 **	0.3054 **
Bin type 5	0.1284	0.1576 *	0.1885 *
Bin type 6	0.1120	0.1505 *	0.2752 **
Indoor bin 1	0.1566	0.1113	0.4702 **
Indoor bin 2	0.1905 *	0.2165 *	0.2402 *

Indoor bin 3	0.2063 *	0.2074 *	0.2934 **
Indoor bin 4	0.1339	0.0879	0.4145 **
Indoor bin 5	0.1953 *	0.2453 *	0.3153 **
Indoor bin 6	0.1297	0.1810	0.3518 **
Outdoor bin 1	0.3384 **	0.3484 **	-0.0477
Outdoor bin 2	0.0746	0.0706	-0.1713
Outdoor bin 3	0.0629	0.0113	0.0168
Outdoor bin 4	0.3973 **	0.4124 **	0.1568
Outdoor bin 5	0.0151	0.0216	0.0590
Outdoor bin 6	0.0417	0.0483	0.1835

*p≤0.05; ** p≤0.01

Table 8-4. Spearman's correlations (r_s) between influent concentrations for THB, *Salmonella sp,* Enterococci and *Escherichia coli* and their effluent equivalents.

CFU/100ml	**THB**	***Salmonella sp*** ***Shigella sp***	**Enterococci**	***Escherichia coli***
Total	0.1631 **	0.1074	0.3604 **	0.3418 **
Indoor rig	0.1342	0.0066	0.3405 **	0.2967 **
Outdoor rig	0.1954 *	0.2958 **	0.3745 **	0.4691 **
Bin type 1	0.0943	-0.0164	0.2156	0.2391
Bin type 2	0.2257	0.1456	0.2268	0.2327
Bin type 3	-0.0507	0.1564	0.4081 **	0.2070
Bin type 4	-0.0390	-0.1762	0.2287	0.2580
Bin type 5	0.1657	0.2074	0.5001	0.5098
Bin type 6	0.1520	0.1462	0.3154 *	0.3488 *
Indoor bin 1	0.0182	-0.2205	0.2533	0.0415

Indoor bin 2	0.2356	0.1391	0.3402	0.1829
Indoor bin 3	-0.0909	0.1022	0.2646	0.1781
Indoor bin 4	-0.0452	-0.3791 *	0.2153	0.2638
Indoor bin 5	0.0443	0.1669	0.4975 **	0.3919
Indoor bin 6	0.2415	0.0590	0.3053	0.4443 *
Outdoor bin 1	0.1209	0.3504	0.0708	0.4976 *
Outdoor bin 2	0.2383	0.3037	0.0892	0.4744 *
Outdoor bin 3	0.0401	0.2148	0.6296	0.3214
Outdoor bin 4	0.0059	0.1623	0.2240	0.4436
Outdoor bin 5	0.3015	0.1971	0.4857 **	0.6493 **
Outdoor bin 6	0.0403	0.3474	0.3384	0.2727

*p≤0.05; ** p≤0.01

Highly significant correlations were found between THB in the influent and effluent concentrations ($p < 0.01$, $r_s = 0.1631$). The relationship became weaker indoors ($r_s = 0.1342$) and was considered stronger outdoors ($r_s = 0.1954$). Correlations calculated for individual bins were low and statistically insignificant. In general, this demonstrates a lack of relationship between THB influents and THB effluents.

Similar significance correlation of $p < 0.01$ was found between *Escherichia coli* influent concentrations and their equivalents in the effluents. The relationship is lower indoors ($r_s = 0.2967$) and higher outdoors ($r_s = 0.4691$). The highest correlation was found in bin 5o ($r_s = 0.6493$)

No significant relations were found between influents of *Salmonella sp* and *Shigella sp* and their effluents ($r_s = 0.1074$). None of the relations were found when considering indoor rig ($r_s = 0.0066$), although highly significant correlations ($p < 0.01$) were found outdoors ($r_s = 0.2958$).

Interestingly, in bin 4i (Inbitex geotextile, H/C coils, IN+P) significant negative ($p < 0.05$, $r_s = -0.3791$) correlations were found, meaning that in this bin, where more bacteria was introduced, less was found after PPS filtration.

Highly significant but considered low ($p < 0.010$, $r_s = 0.3604$) correlations were found between *Enterococcus faecalis* (group D Streptococcus) in influent-effluent concentrations relationships, which are present both indoors ($r_s = 0.3405$) and outdoors ($r_s = 0.3745$).

A highly significant relationship ($p < 0.01$, $r_s = 0.4081$) was found for type of bin 3 (Inbitex composite, no H/C coils, IN). Although, when comparing bins 3i ($r_s = 0.2646$) and 3o ($r_s = 0,6296$), the correlations became insignificant.

Highly significant correlations were found for bins 5 (Inbitex geotextile, H/C coils), where calculated r_s was equal to 0.4975 indoors and 0.4857 outdoors.

Highly significant ($p < 0.01$) but considered low correlations were found for *Escherichia coli* influent-effluent concentrations relationships, with $r_s = 0.2967$ indoors and 0.4691 outdoors. The strongest correlation was found in bin 5o, with $r_s = 0.6493$, although it was insignificant.

8.1.2 Nutrient and microbial removal correlations

The aim of the research was to answer the question of whether microbial numbers and nutrient removal rates were prone to Inbitex composite presence or absence; whether there were significant differences during H/C cycles; whether the sample temperatures had impact on microbial removal rates; and what were the differences in the above when considering two types of influents. The following sub-section presents further findings calculated for PPS experiment.

8.1.2.1 H/C cycles distributions

Removal distributions for PO_4 *Salmonella sp, Shigella sp* and *Escherichia coli* during heating or cooling cycle are presented in **Figures 8-1 – 8-3.**

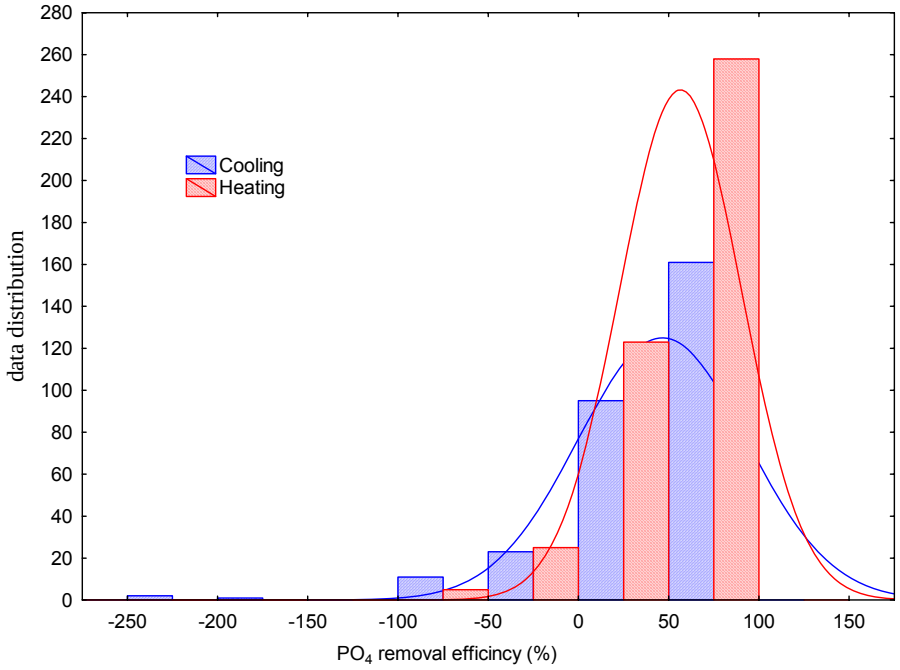


Figure 8-1 PO_4 removal distributions in heating or cooling cycle.

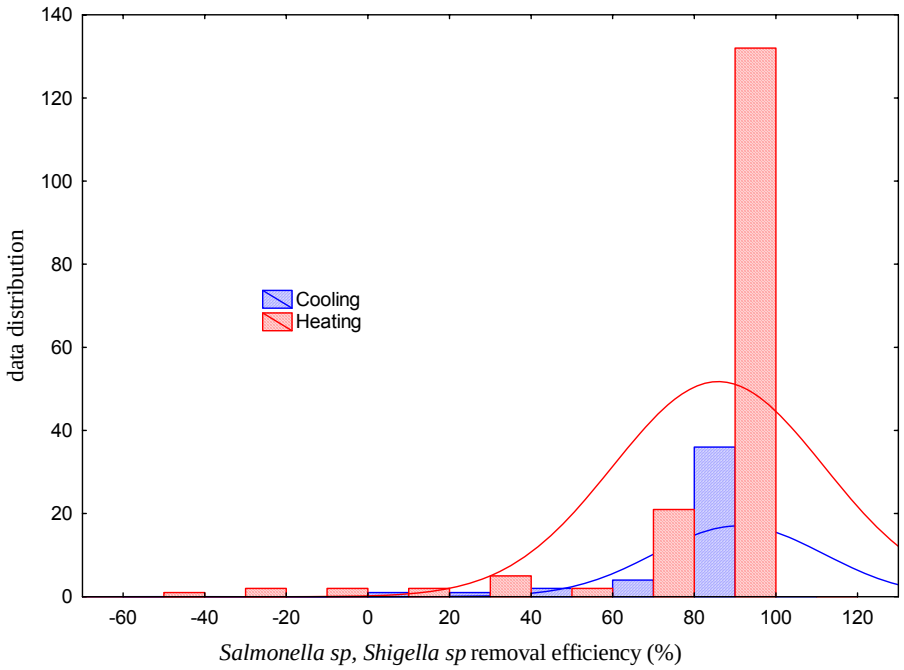


Figure 8-2 *Salmonella sp, Shigella sp* removal distributions in heating or cooling cycle.

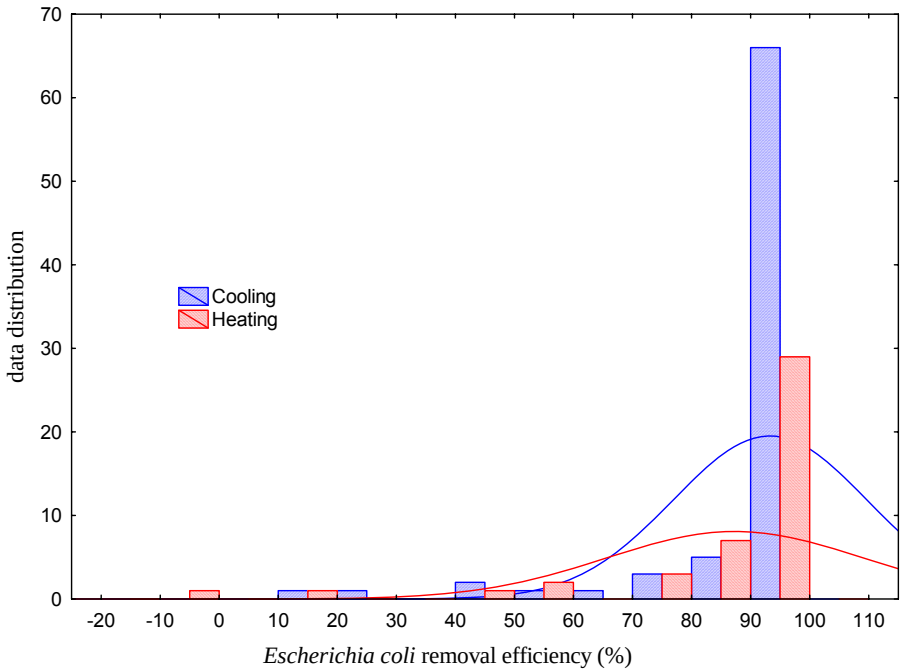


Figure 8-3 *Escherichia coli* distributions in heating or cooling cycle

Values calculated for nutrient/bacteria removals are presented in **Table 8-5.**

Table 8-5 Nutrients and bacteria removal in heating or cooling cycle.

Nutrients/bacteria removals	Cooling	Heating	p value (Mann-Whitney u-test)
NO_{2+3}	-579.4 (861.4) -267.2 (-749.8/9.5)	-625.5 (971.1) -265.0 (-687.0/-17.5)	0.4931
PO_4	44.7 (46.7) 54.6 (27.0/76.7)	54.9 (33.7) 63.6 (35.7/78.6)	0.0170
NH_4	83.2 (26.4) 93.8 (80.0/98.8)	88.1 (19.4) 95.6 (85.9/98.5)	0.2542
Salmonella sp	90.2 (20.6) 99.8 (92.4/100.0)	85.1 (25.7) 95.1 (83.3/99.7)	0.0008
Enterococci	33.2 (197.0) 89.3 (50.0/98.4)	42.1 (122.6) 90.0 (49.4/99.1)	0.8070
THB	87.3 (24.5) 98.8 (93.0/99.9)	89.6 (29.9) 99.2 (92.8/99.9)	0.6171
Escherichia coli	92.7 (16.4) 99.6 (95.3/100.0)	86.8 (21.7) 95.6 (82.8/100.0)	0.0265

Figures in columns 2 and 3, rows 1 to 4: 1-mean, 2-standard deviation, 3-median, 4-lower/upper quartile.

Insignificant correlations (p = 0.4931) were calculated for NO_{2+3} removals and used H/C cycle. This indicates the lack of the relationships between the level of NO_{2+3} removals and the heating or cooling cycle. In case of PO_4 removals, a significant difference (p = 0.0170) between the heating and cooling cycle was found. The distribution was skewed to the left for the heating cycle and with a higher median than for the cooling cycle. NH_4 removal distributions are not scientifically different (p = 0.2542) between the heating or cooling cycle. This means that there is no difference in NH_4 removals when considering H/C cycles.

A highly significant change in distributions was found for *Salmonella spp,* and *Shigella spp.* when considering H/C cycles (p = 0.0008). In the case of the heating cycle, the distribution is skewed to the left and is wider, which means that higher variability occurs.

No significant differences were found for *Enterococcus faecalis* (group D Streptococcus) (p = 0.8070) and THB (p = 0.6171) between H/C cycles, but for Escherichia *coli* this difference was significant (p = 0.0265), with wider distribution **Figure 8-3,** hence bigger variability during the cooling cycle. In the heating cycle, a higher median was calculated, which was close to upper quartile in value. This means that the character of the distribution is skewed towards maximum values.

It is a different issue when discussing the presence of heating or cooling cycles and when discussing the presence or lack thereof of the above cycles. The following analysis compares bins with H/C installations and the ones

without. The distributions are presented in **Figures 8-4 - 8-6,** while the summary of calculations is presented in **Table 8-6.**

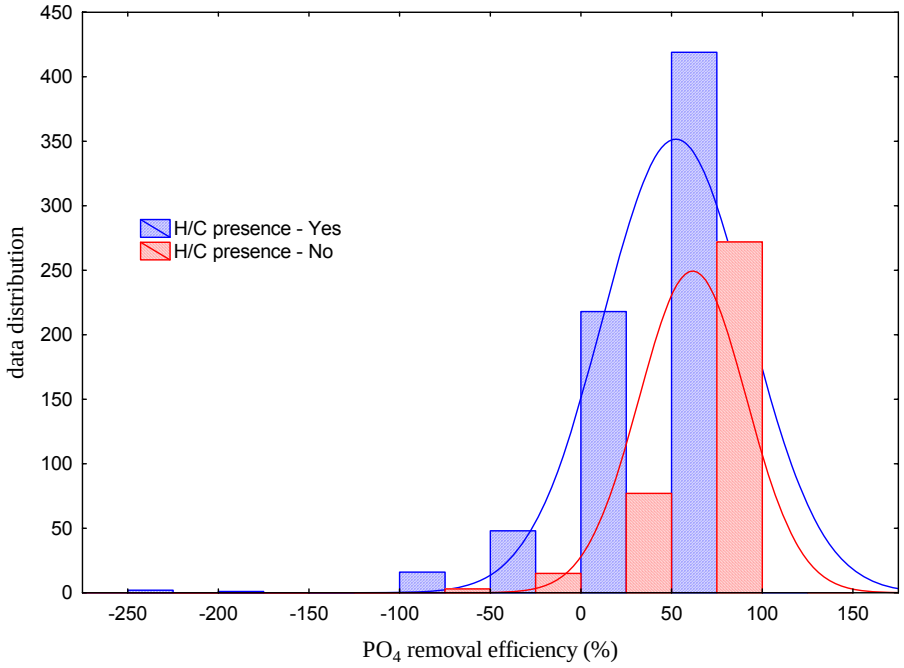


Figure 8-4 PO_4 removal distribution depending on the presence or no presence of H/C coils.

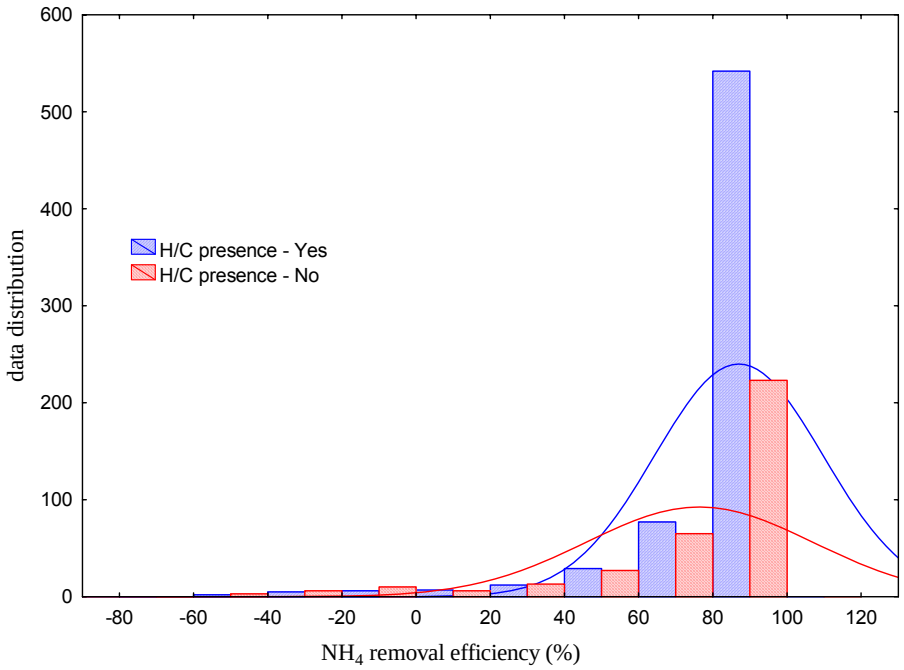


Figure 8-5 NH_4 removal distribution depending on the presence or no presence of H/C coils.

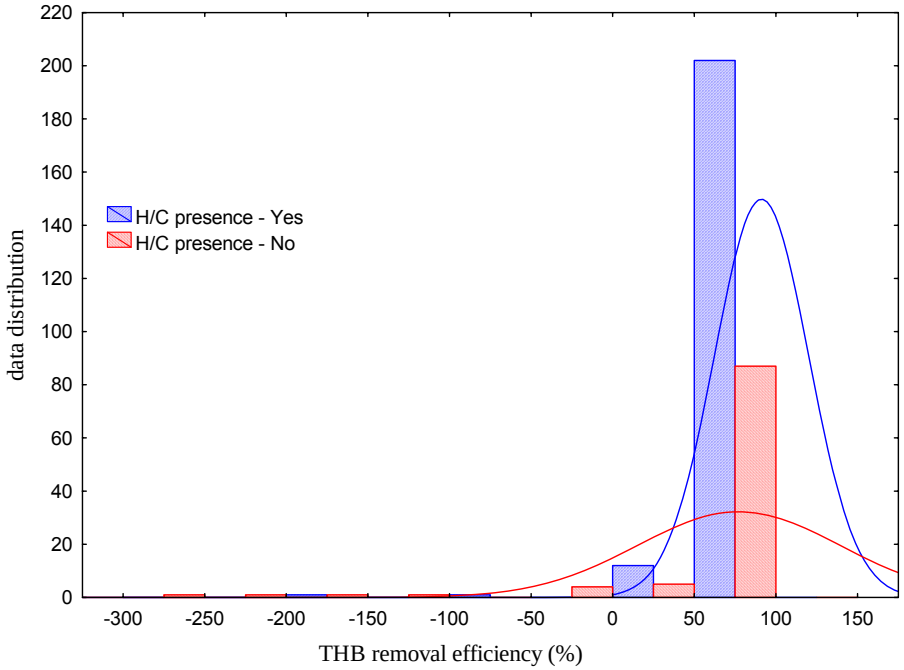


Figure 8-6 THB distribution depending on the presence or no presence of H/C coils.

Table 8-6. Nutrient and bacteria removal distribution depending on the presence or no presence of H/C coils.

Nutrients/bacteria removals	Yes	No	p value (Mann-Whitney u-test)
NO_{2+3}	-605.6 (925.0) -265.0 (-720.1/-7.4)	-320.9 (260.4) -303.1 (-479.7/-171.0)	0.6521
PO_4	50.7 (39.9) 61.2 (31.4/78.0)	60.0 (29.3) 65.6 (49.1/79.2)	0.0014
NH_4	86.1 (22.6) 95.0 (84.8/98.6)	75.6 (30.5) 88.0 (65.8/95.0)	< 0.0001
Salmonella sp	86.2 (24.8) 96.1 (85.1/99.9)	79.9 (33.7) 96.3 (80.0/99.5)	0.1639
Enterococci	39.6 (146.6) 89.8 (50.0/98.9)	11.1 (204.0) 85.2 (24.3/100.0)	0.6731
THB	89.1 (28.8) 99.1 (92.9/99.9)	75.3 (61.8) 97.9 (85.8/99.7)	0.0277
Escherichia coli	90.6 (18.6) 98.3 (91.2/100.0)	86.9 (21.8) 97.6 (82.6/100.0)	0.3497

Figures in columns 2 and 3, rows 1 to 4: 1-mean, 2-standard deviation, 3-median, 4-lower/upper quartile.

The presence of H/C coils did not have a significant impact on NO_{2+3} removals ($p = 0.6521$). This impact was seen for PO_4 and NH_4 removals. The former's p- value was calculated as highly significant (0.014). Quartile range for PO_4 removals was wider with H/C installations in comparison to those without. Also, the median was lower when coils were present. This allows for the conclusion of significant impact of H/C coils presence on PO_4 removals.

Their presence had a highly significant ($p < 0.0001$) impact on NH_4 removals. In bins with H/C coils, the quartile range was narrower and the median higher than in the bins without such installations. This results in significant impact of the presence of H/C coils on NH_4 removals. In general, the usage of H/C coils results in a narrower quartile range leading to a higher concentration of data around the median.

When discussing microbes, significant distribution variability was calculated only for THB ($p = 0.0277$), where narrower quartile range and higher median lead to the conclusion of significant impacts of H/C coils presence on THB removals.

8.1.2.2 Water sample temperature distribution

Calculated r_s between water sample temperatures and nutrients/bacteria removals and presence or no presence of H/C coils are presented in **Tables 8-7 and 8-8.**

Table 8-7 Spearman's correlations (r_s) between water sample temperature and nutrient and microbial removals.

Nutrients/bacteria removals	Water sample temperature (^oC)
NO_{2+3}	-0.2467 **
PO_4	-0.0455
NH_4	0.1459 **
Salmonella sp	0.1565
Enterococci	0.2204
THB	-0.1226
Escherichia coli	-0.1091

Highly significant negative and considered low ($p < 0.01$, $r_s = -0.2467$)) correlations were calculated between water sample temperatures and NO_{2+3} removals. This means that as the water sample temperature was rising, the NO_{2+3} removals were lower.

For NH_4 removals, highly significant ($p<0.01$) although considered low ($r_s = 0.1459$) correlations were calculated when considering water sample temperatures, meaning that if water sample temperature was rising, the NH_4 removals were increasing.

Table 8-8 Spearman's correlations (r_s) between water sample temperature with nutrients and bacteria removals and presence or no presence of H/C coils.

Nutrients/bacteria removals	H/C presence

	Yes	No
NO_{2+3}	-0.3512 **	-0.0436
PO_4	-0.1077 *	0.1482 *
NH_4	0.2429 **	-0.1014
Salmonella sp	0.0464	0.3293
Enterococci	0.1782	0.2085
THB	-0.2105	-0.1098
Escherichia coli	-0.1519	-0.0672

Highly significant, negative ($p < 0.01$, $r_s = -0.3512$) correlations were found between water sample temperature and NO_{2+3} removals in bins with H/C installations, meaning that if water sample temperature was rising the NO_{2+3} removals were decreasing in H/C bins. This kind of relationship was not found in bins without H/C installations

Correlations between water sample temperature and PO_4 removals were found to be significant ($p < 0.05$), but negative and considered low ($r_s = -0.1077$) in bins with H/C installations. Similarly significant ($p < 0.05$), and low but positive correlations were found in bins with no H/C coils ($r_s = 0.1482$) .
In case of NH_4 removals positive and highly significant ($p < 0.01$, $r_s = 0.2429$) correlations were calculated for bins with H/C installations. In bins without coils, the correlations were considered low ($r_s = -0.1014$).
For bacteria, only insignificant correlations were found (**Table 8-8**).

Table 8-9 presents relationships between water sample temperature with nutrients and bacteria removals depending on the type of inflow.

Table 8-9 Spearman's correlations (r_S) between water sample temperature with nutrients and bacteria removals and type of influent IN or IN+P.

Nutrients/bacteria removals	Inflow type	
	IN+P	IN
NO_{2+3}	-0.3324 **	-0.1797 **
PO_4	-0.1778 **	0.0163
NH_4	0.1803 **	0.0573
Salmonella sp	-0.0622	0.2208
Enterococci	0.1151	0.2894
THB	-0.1429	-0.1994
Escherichia coli	-0.1145	-0.0849

For bins with IN+P type of inflow (1 and 4), highly significant ($p<0.01$) correlations were found for water sample temperatures and:

NO_{2+3} removals (r_s = -0.3324), NH_4 removals (r_s = 0,1803) and PO_4 removals (r_s = -0,1778).

When no additional pollutant was used (IN inflow type), a highly significant ($p<0.01$) correlation was found only for NO_3 removals (r_s = -0.1797).

All other correlations were found to be insignificant and considered low.

8.1.2.3 Indoor/Outdoor distributions

Nutrient and bacterial removals were analysed depending on the location of the bins (indoors versus outdoors). Related distributions (**Figures 8-7 – 8-12**) and calculations (**Table 8-10**) are presented below.

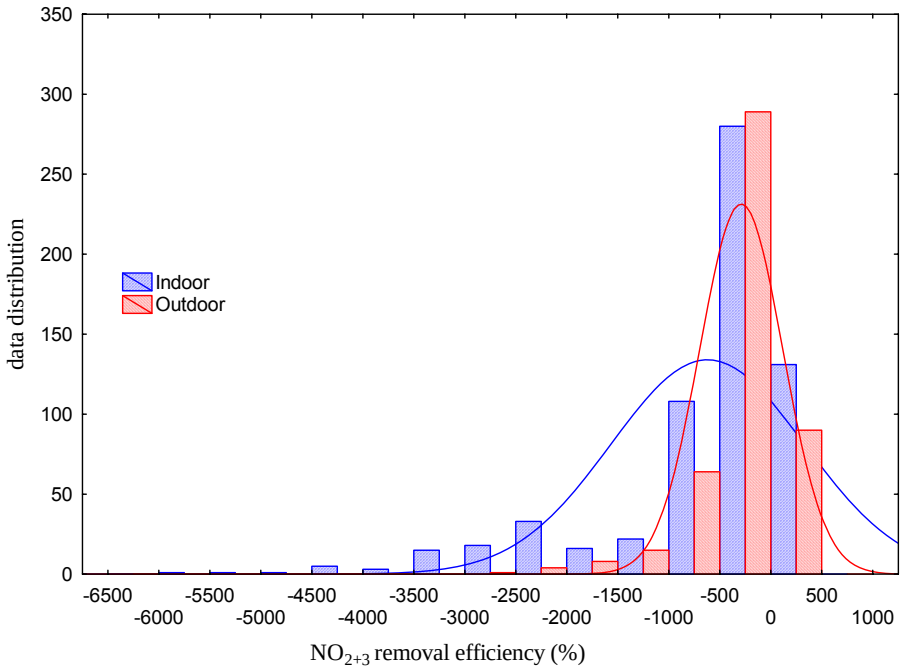


Figure 8-7 NO_{2+3} removal distributions depending on indoor or outdoor systems.

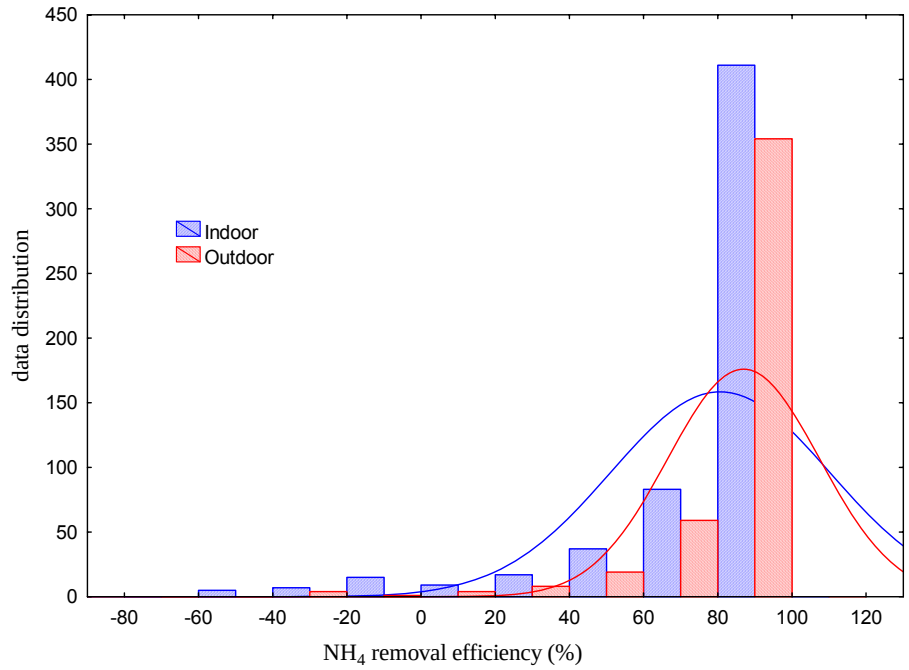


Figure 8-8 NH_4 removal distributions depending on indoor or outdoor systems.

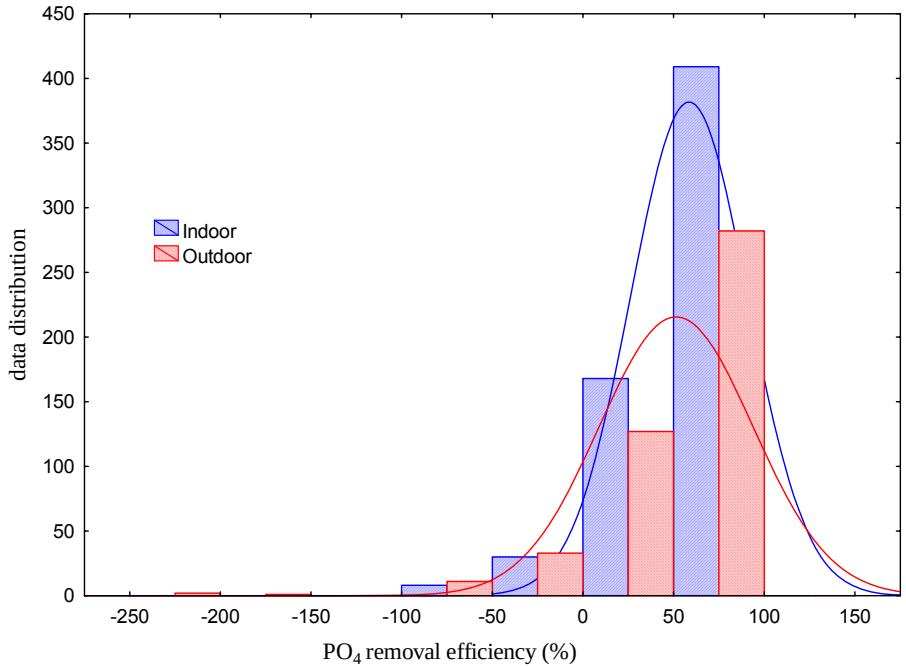


Figure 8-9PO_4 removal distributions depending on indoor or outdoor systems.

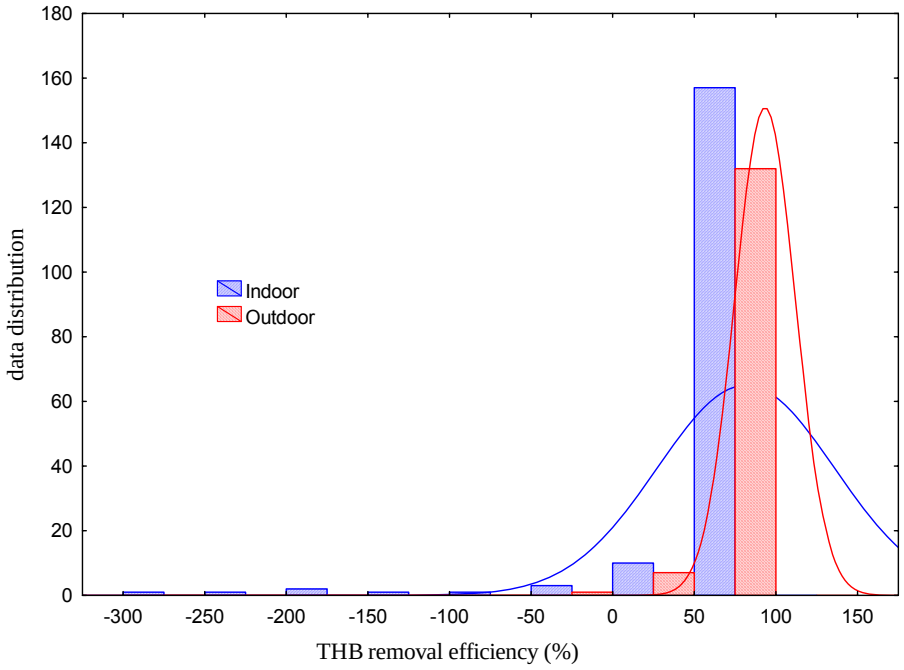


Figure 8-10 THB removal distributions depending on indoor or outdoor systems.

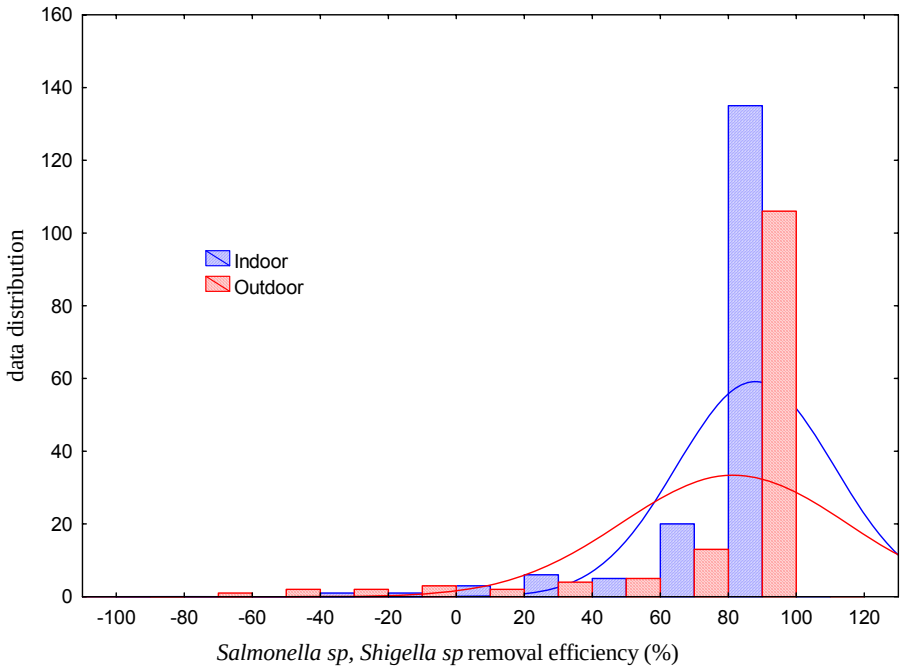


Figure 8-11 *Salmonella sp, Shigella sp* removal distributions depending on indoor or outdoor systems.

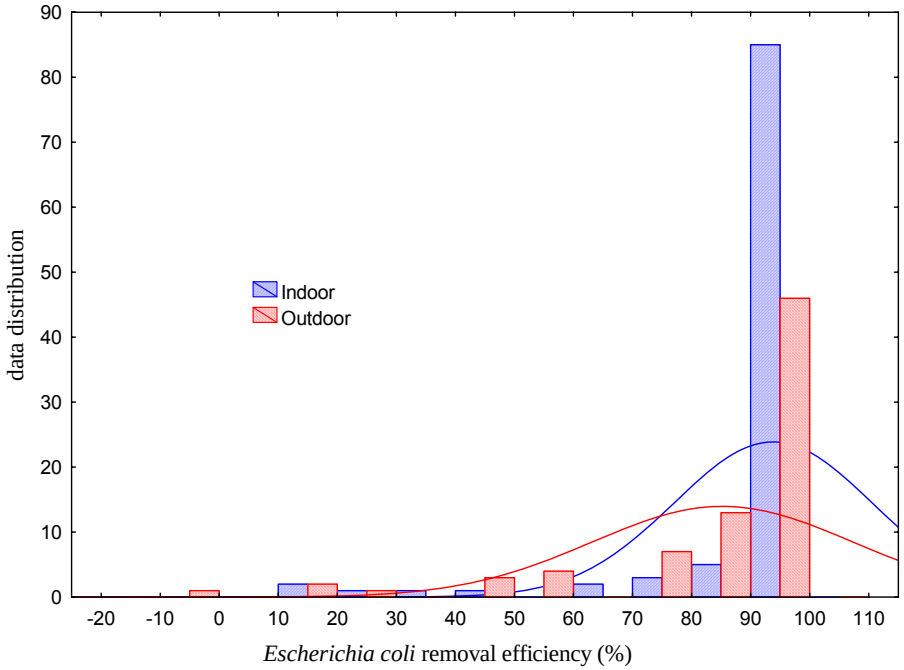


Figure 8-12 *Escherichia coli* removal distributions depending on indoor or outdoor systems.

Table 8-10 Nutrients and bacteria removal distributions depending on indoor or outdoor systems.

Nutrients/bacteria removals	Indoor	Outdoor	p value (Mann-Whitney u-test)
NO_{2+3}	-649.0 (944.2) -312.5 (-698.4/-45.4)	-321.7 (406.1) -259.8 (-420.4/-48.6)	0.0001
PO_4	56.9 (32.1) 65.6 (41.7/79.2)	49.8 (42.2) 59.3 (34.0/77.6)	0.0173
NH_4	79.8 (29.4) 92.3 (75.4/97.9)	86.1 (20.4) 93.5 (84.1/98.2)	0.0183
Salmonella sp	87.0 (23.1) 98.3 (84.0/99.9)	80.7 (33.0) 93.7 (82.5/98.9)	0.0021
Enterococci	36.9 (184.0) 89.0 (51.7/98.3)	23.0 145.0) 88.6 (28.6/99.2)	0.4258
THB	79.6 (54.1) 98.3 (87.1/99.8)	91.3 (18.5) 99.2 (93.2/99.9)	0.0238
Escherichia coli	93.2 (16.7) 99.9 (96.2/100.0)	84.7 (22.0) 93.8 (91.8/99.2)	< 0.0001

Figures in columns 2 and 3, rows 1 to 4: 1-mean, 2-standard deviation, 3-median, 4-lower/upper quartile.

Highly significant relationships ($p = 0.0001$) were found for NO_{2+3} removals. In the indoor system, the distribution was wider with a lower median than outdoors, with a narrower distribution and higher median.

Significant differences ($p = 0.0173$) were found for indoor-outdoor PO_4 removals. The distribution was narrower indoors and with a higher median than outdoors.

Similarly significant ($p = 0.0183$) and narrower distributions were calculated for NH_4 removals.

With *Salmonella sp* and *Shiglella sp,* highly significant distribution differences were found ($p = 0.0021$) when considering indoor or outdoor rigs. Indoor distribution of *Salmonella sp* was narrower, but with a higher median than outdoors.

In the case of Escherichia *coli,* highly significant relationships were found ($p< 0.0001$) depending on indoor-outdoor system. Indoor distributions were narrower and with a higher median; this is a distribution similar to upper quartile.

8.1.2.4 IN, IN+P distribution

Depending on the influent type, removal distributions were calculated as below in **Figures 8-13 – 8-16** and **Table 8-11**.

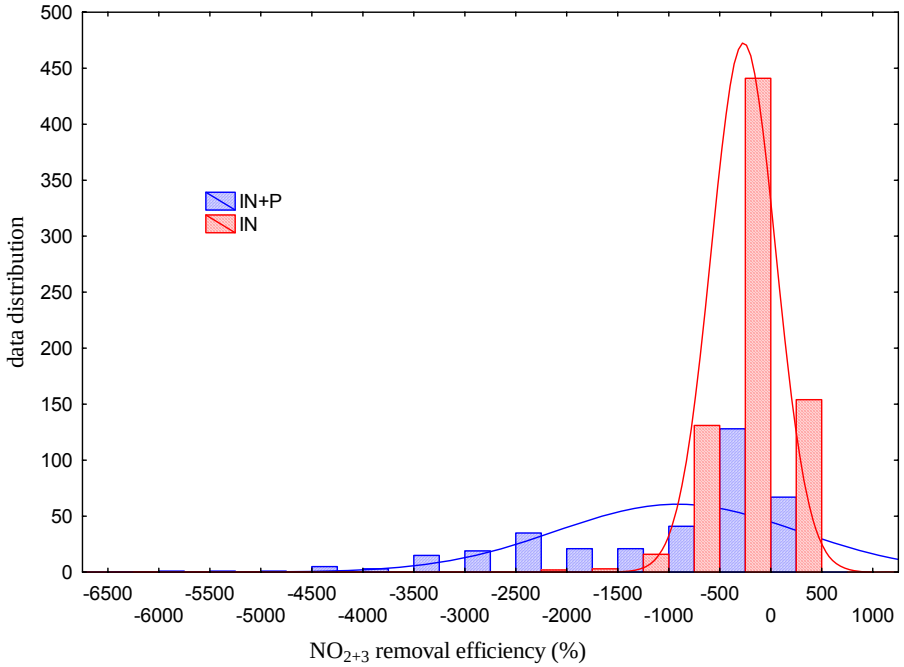


Figure 8-13 NO_{2+3} removal distribution depending on the type of influent.

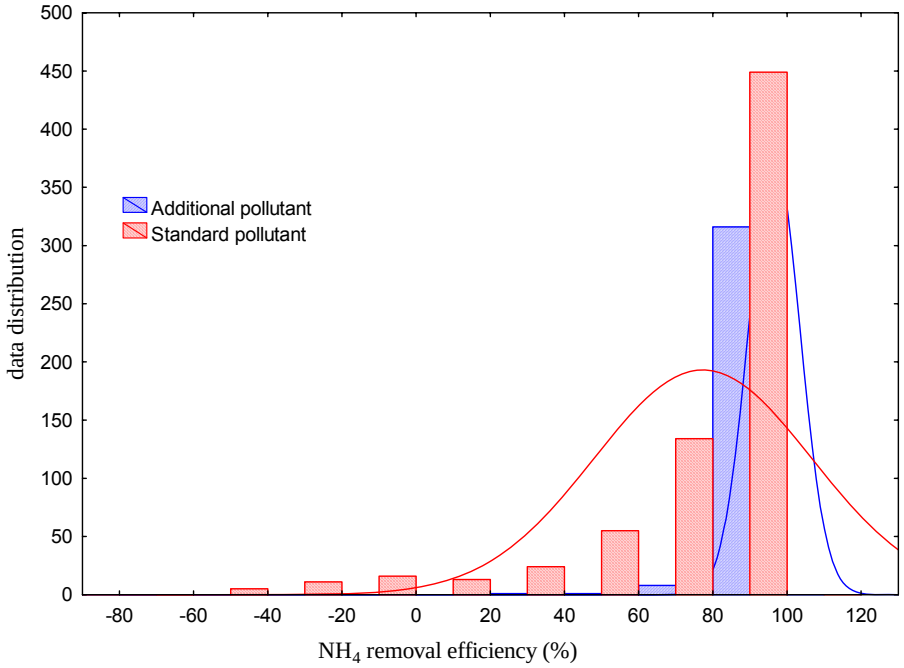


Figure 8-14 NH_4 removal distribution depending on the type of influent.

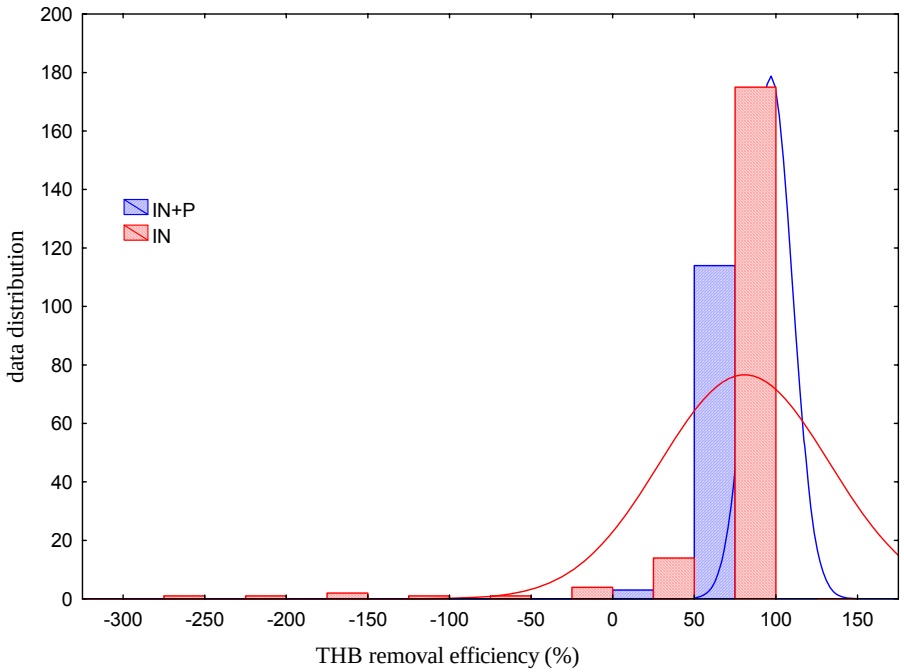


Figure 8-15 THB removal distribution depending on the type of influent.

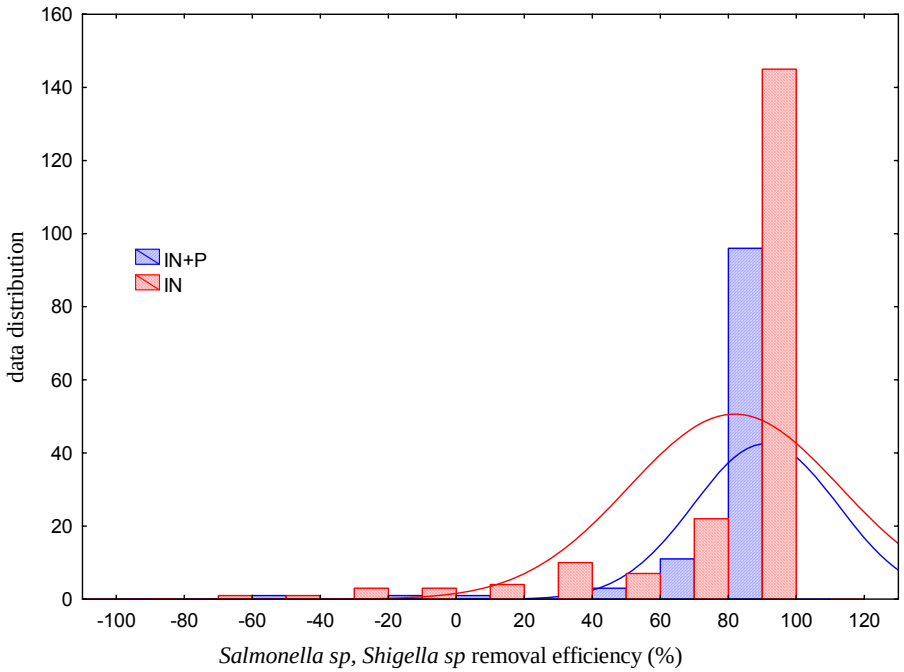


Figure 8-16 *Salmonella sp, Shigella sp* removal distribution depending on the type of influent.

Table 8-11 Nutrients and bacteria removal distribution depending on the type of influent.

Nutrients/bacteria removals	IN+P	IN	p value (Mann-Whitney u-test)
NO_{2+3}	-946.4 (1178.1) -345.8 (-1837.9/-45.4)	-300.1 (315.2) -275.3 (-460.9/-48.3)	< 0.0001
PO_4	55.1 (37.0) 64.1 (33.0/81.5)	53.3 (36.8) 62.2 (41.6/77.9)	0.6265
NH_4	95.6 (6.9) 98.1 (95.4/99.1)	76.5 (29.2) 87.9 (68.8/95.1)	< 0.0001
Salmonella sp	89.9 (21.2) 98.0 (90.4/99.9)	80.9 (30.9) 94.4 (78.5/99.5)	0.0019
Enterococci	61.8 (80.3) 92.7 (60.9/99.1)	12.6 (198.7) 85.2 (39.1/99.2)	0.2529
THB	94.8 (13.0) 99.7 (97.5/100.0)	78.8 (51.8) 97.6 (84.9/99.7)	< 0.0001
Escherichia coli	91.9 (16.2) 98.4 93.0/100.0)	87.9 (21.5) 97.7 (83.7/100.0)	0.5992

Figures in columns 2 and 3, rows 1 to 4: 1-mean, 2-standard deviation, 3-median, 4-lower/upper quartile.

Highly significant ($p < 0.0001$) differences in distributions were found for NO_{2+3} removals depending on the type of influent. The distribution was clearly narrower in case of IN type of influent.

NH_4 removal relationships were found to be highly significant ($p < 0.0001$) depending on the type of influent introduced into the system. The distribution was found much narrower when IN type of inflow was introduced to PPS.

In case of PO_4 removal distributions, relationships were found to be insignificant.

For THB removals ($p < 0.0001$), highly significant distribution variability was found in IN+P bins, with narrower distributions (1 and 4).

Similar findings were obtained for *Salmonella sp, Shigella sp* with $p = 0.0019$ and narrower distribution.

Enterococci and *Escherichia coli* relationships were found to be insignificant.

8.1.2.5 Inbitex geotextile (inbitex composite) presence distribution

Removals were compared and calculated based on the type of geotextile used. The findings are presented in **Figures 7-17 and 7-18 and Table 8-12.**

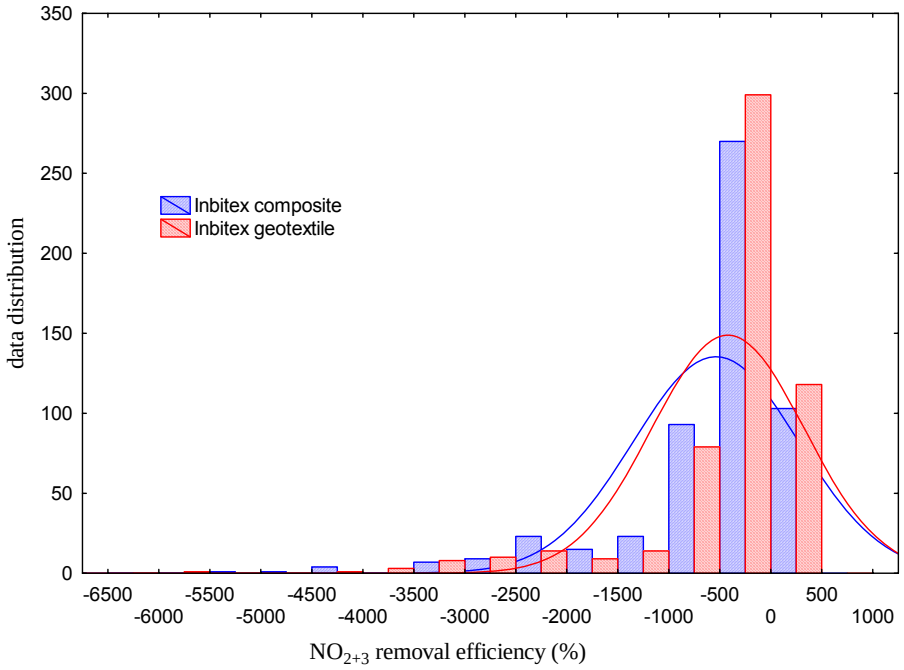


Figure 8-17 NO_{2+3} removal distribution depending on the type of Inbitex (geotextile/composite).

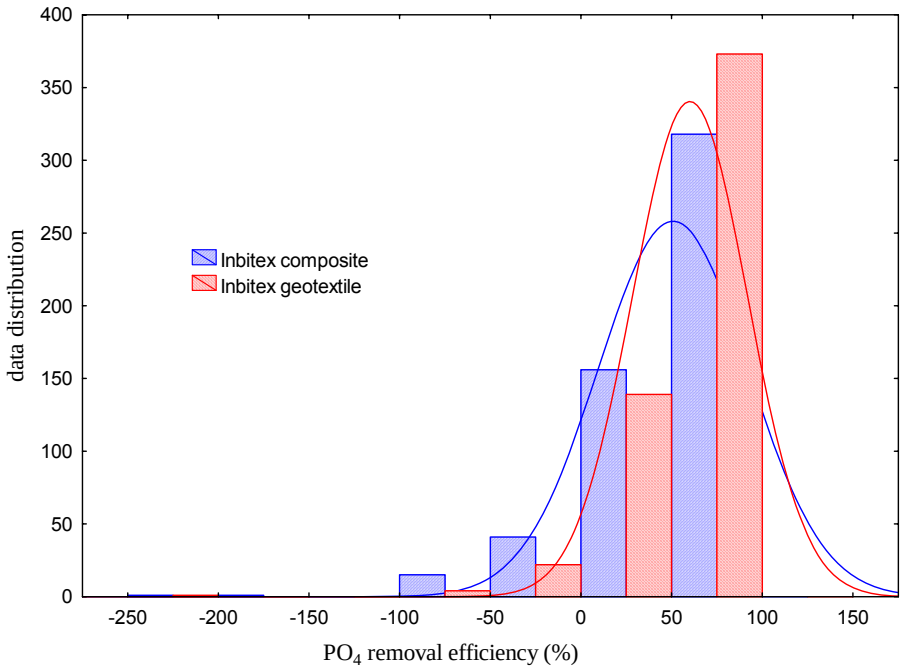


Figure 8-18 PO_4 removal distribution depending on the type of Inbitex (geotextile/composite).

Table 8-12 Nutrients and bacteria removals distribution depending on the type of Inbitex (geotextile/composite).

Nutrients/bacteria removals	Yes	No	p value (Mann-Whitney u-test)
NO_{2+3}	-451.4 (745.3) -257.0 (-500.0/-28.9)	-568.3 (809.0) -320.6 (-665.7/-70.0)	0.0010
PO_4	58.4 (31.6) 65.4 (44.9/78.9)	49.2 (41.1) 59.7 (31.1/77.9)	0.0014
NH_4	82.9 (24.7) 93.1 (79.1/98.1)	82.2 (27.3) 92.3 (79.7/97.9)	0.7380
Salmonella sp	84.0 (29.1) 96.4 (85.1/99.7)	84.3 (27.1) 96.1 (82.4/99.9)	0.7497
Enterococci	31.7 (134.2) 87.7 (40.0/99.1)	29.3 (197.2) 89.1 (49.7/99.1)	0.6030
THB	84.7 (41.7) 98.8 (88.3/99.9)	84.8 (43.4) 99.0 (91.8/99.9)	0.3965
Escherichia coli	90.6 (17.6) 97.3 (89.6/100.0)	88.4 (21.5) 98.3 (89.1/100.0)	0.8419

Figures in columns 2 and 3, rows 1 to 4: 1-mean, 2-standard deviation, 3-median, 4-lower/upper quartile.

Significant differences ($p = 0.0010$) in NO_{2+3} removal distributions were found as highly significant depending on the type of geotextile. The

quartile range was narrower and the median was higher in bins with IN type of influent.

While considering NH_4 and bacterial removals, no significant relationships were found with the presence of different types of geotextile. This means that the type of used geotextile did not have an impact on chosen parameters.

In PO_4 removals ($p=0.0014$), highly significant differences were found for bins with Inbitex geotextile, with data distributed mainly around narrower quartile with higher median values.

For comparison of removals in rigs, **Table 8-13** had been produced. The same letters represent a lack of difference in distributions; if the differences existed, the letters varied as well.

For NO_{2+3}, the IN+Pi distribution differed from other ones. And the others (INi, INo, IN+Po) did not vary between each other when considering influent concentrations impacts on nutrients and microbial removals in both rigs. In PO_4 removals, the distributions were different depending on INi or INo inflow type. Distributions of IN+Pi and IN+Po are not different between each other and are not different to other distributions.

For NH_4, BOD_5, and *Salmonella sp* removal distributions, there were no differences depending on IN and IN+P influents and between the indoor and outdoor rig. In all of the above, INi and INo and IN+Pi and IN+Po were not different between the same type of inflows (IN), but were different between 2 types of inflows (IN and IN+P). This means that there was no real impact of the type of the rig on NH_4, BOD_5, and *Salmonella sp* removals.

Enterococci removal distributions, depending on the type of inflow and rig, did not show any difference and were insignificant ($p = 0.2381$).

For the distributions of removals of THB IN+Pi and INi, there were significant differences calculated, but IN+Pi distribution was not different from INo and IN+Po, which were different from one another.

E.coli removal distributions were not different within the rigs with one exception: IN+Pi was similar to all of the bin types. This means that there was a difference between indoor and outdoor rigs when discussing *E.coli* removals.

Table 8-13 Comparison of indoor and outdoor rig removals depending on the type of inflow.

	Indoor		Outdoor		Significance - p (Kruskal-Wallis)
	IN+P	IN	IN+P	IN	
NO_{2+3} removal	-1345.7 (1314.8) -923.4 (-2338.8/-131.6) A	-303.9 (345.8) -268.6 (-489.4/-1.7) B	-379.9 (601.8) -159.8 (-513.2/33.5) B	-295.1 (270.4) -283.6 (-417.3/-110.4) B	< 0.0001
PO_4 removal	56.1 (30.2) 64.45 (35.0/80.8) AB	57.2 (33.0) 66.4 (44.3/79.1) A	53.6 (44.9) 63.4 (31.4/83.0) AB	48.0 (40.8) 57.5 (35.5/75.5) B	0.0160
NH_4 removal	95.1 (8.3) 98.1 (94.4/99.3) A	73.0 (32.7) 86.7 (63.5/94.8) B	96.3 (4.7) 98.1 (96.5/99.1) A	81.1 (23.0) 89.6 (74.0/95.9) B	< 0.0001
Salmonella removal	91.1 (16.0) 99.5 (90.0/100.0) A	84.6 (26.1) 97.7 (83.3/99.9) B	88.5 (26.4) 96.5 (91.8/99.6) A	76.3 (35.5) 90.7 (73.2/97.9) B	0.0001
Enterococcus removal	64.2 (71.9) 90.0 (59.8/98.2) A	21.3 (223.3) 88.0 (50.0/98.9) A	59.0 (89.9) 94.9 (63.3/99.2) A	2.3 (165.7) 66.7 (10.5/99.4) A	0.2381
THB removal	92.0 (16.8) 99.3 (92.4/100.0) AC	72.3 (65.9) 97.5 (81.0/99.5) B	98.4 (3.2) 99.9 (98.8/100.0) A	87.1 (22.2) 98.6 (85.5/99.8) C	< 0.0001
Escherichia coli removal	96.6 (8.2) 99.9 (97.7/100.0) A	91.3 (19.8) 99.7 (94.9/100.0) AB	87.1 (20.5) 95.6 (86.5/99.3) B	82.5 (23.3) 90.0 (80.0/99.2) B	0.0001

Figures in columns 2 and 3, rows 1 to 4: 1-mean, 2-standard deviation, 3-median, 4-lower/upper quartile.

The summary of calculated statistics for most important parameters is presented below.

NO_{2+3} effluents were found to be significantly correlated (total r_s = 0.4925, p<0.01) with influents and prone to outdoor (removal $\tilde{x}$ = -259.8 %, p = 0.0001) environmental conditions. A higher median ($\tilde{x}$ = -257.3%, p < 0.0001) was recorded for bins receiving IN-type of inflows. When discussing water sample temperatures, with temperatures increasing, the NO_{2+3} removal efficiency was dropping (removal r_s = -0.2467), especially in bins with H/C installations (r_s = -0.3512). Kurskal-Wallis analysis provided evidence on significant difference between indoor IN+P and outdoor inflows (p< 0.0001).

NH_4 effluent concentrations were weakly correlated (total r_s = 0.1644) with the influent concentrations. With the temperature increase in the outdoor rig, NH_4 removal efficiencies were increasing as well (r_s = 0.1459), which brings an evidence on higher temperatures enhancing nitrification. The above were also determined by the IN+P type of influent ($\tilde{x}$ = 98.1%, p<0.0001). As a result of this regularity, negative removal efficiencies of NO_{2+3} occurred. Kurskal-Wallis analysis provided evidence on the lack of differences between indoor and outdoor rigs (A-B, A-B, p<0.0001), which may suggest that it was the presence of H/C coils which determined the removal efficiencies, which is also supported by Mann Whitney Wilcoxon u-test (p<0.0001).

PO_4 concentrations provided evidence of strong correlations between influents and effluents (total r_s = 0.7757). The removals were prone to indoor environmental conditions (indoor $\tilde{x}$ = 65.6%, p=0.0173), and the effect of

using H/C coils was significant (p = 0.0014), but no significant evidence of using different influent types was detected. Temperature correlations provided evidence on significant temperature differences in PO_4 distributions in bins with no H/C devices (r_s = 0.1482), where removal efficiencies were increasing.

Total heterotrophic bacteria correlations were usually weak and insignificant. Distribution testing provided evidence of removals being influenced significantly by IN+P type of influent.

Salmonella sp and *Shigella sp* correlations were calculated as low (total r_s = 0.10747), but bins 1i and 4i correlations (r_s = -0.2205 and -0.3791, respectively) were negative, providing evidence on the dependency of effluent concentrations on the type of influent, which was also confirmed by u-tests (p = 0.0019). Higher data variability in *Salmonella sp* removals was caused by heating ($\tilde{x}$ = 95.1%, p = 0.0008), although the presence or lack thereof of H/C did not provide any significant evidence of parameter dependencies (p = 0.1639). It can also be concluded that the indoor system and IN+P type of influents were the cause of *Salmonella sp* removal's higher median ($\tilde{x}$ = 98%). Kurskal-Wallis testing did not provide evidence of significant dissimilarities between the indoor and outdoor rigs. Temperature and *Salmonella sp* correlations were considered weak and insignificant.

Escherichia coli influent-effluent correlations were considered weak in general (r_s = 0.3418), but highly significant (p<0.01). Outdoor rig correlations were considered stronger (r_s = 0.4691). Kurskal-Wallis test provided strong

evidence of significant differences between both rigs (p = 0.0001). *E.coli* removal variability was changing significantly during heating (lower and upper quartiles = 82.8/100), but higher median values were recorded for cooling periods ($\tilde{x}$ = 99.6%), meaning that lower temperatures could favour the pathogen's growth.

8.2 Self Organising Maps – the fuzzy modelling as data distribution visualisation tool.

In order to assess the systems' influent-effluent relations, it had been decided to use Self Organising Maps (SOM) modelling. As the dataset was disturbed and had a very high variability for some parameters – especially when considering microbial levels - alternative (i.e., more sophisticated) methods could provide an aid in data interpretation and finding relationships.

Also, because of non-normalized data, tests such as ANOVA or regression predictions were not performed in traditional statistical analysis.

SOM can compare highly variable datasets despite their distribution or normalisation. Output data and visualisations can be produced for non-normalized, normalized or for data that has been normalized and then de-normalized prior to output (de Smith *et al*, 2009).

Artificial neural networks (ANN) are part of artificial intelligence research. In principal, they mimic natural learning occurrences in the same way that the human brain does. The network is using nodes and neurons in the same way as a nervous system. Using mathematical algorithms, the output of the

data can be modelled and displayed in an understandable way for the researchers.

ANN use a 'black box' approach, which describes the mechanisms of input to output values transition.

The network model used in the analysis was Self Organising Maps (SOM), developed by Helsinki University, Finland (SOM toolbox). SOM exploits the model which is using unsupervised learning. SOM has proven its workability and optimal use for large databases in environmental research (López García and Machón González, 2004).

The basic principles of SOM toolbox workability is presented in **Figure 8-19.**

BMU and its neighbours are updated towards the input sample (x). The situation before and after the update is represented by solid and dashed lines, respectively (Kohonen *et al*, 1996).

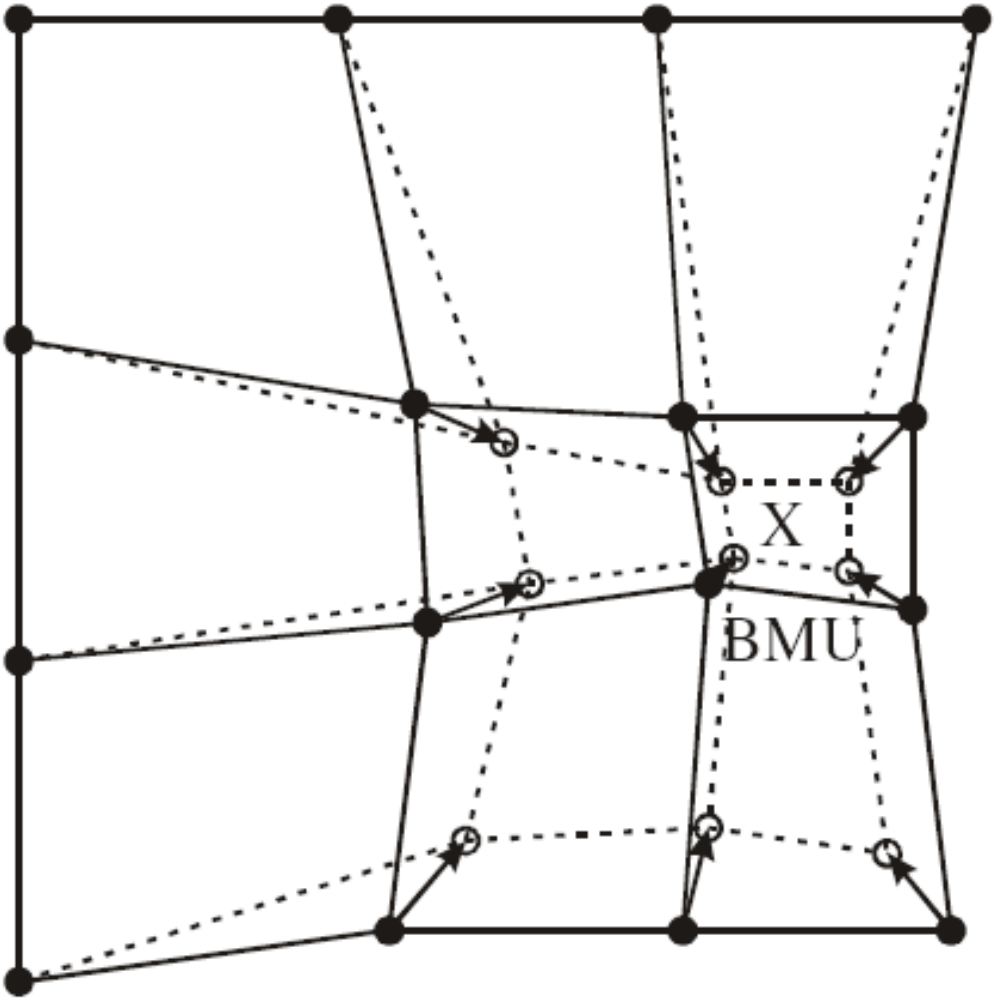


Figure 8-19 Distribution of data using Best Matching Unit method over the net fitted into displaying cell. x - is the input sample (from Vesanto *et al.*, 1999).

SOM consists of an input layer and output layer where neurons of both layers are connected. The input vector is normalised to unit length (x) (Lu and Lo, 2002):

$$x = X/|X|$$

, where x is the input vector.

Similar procedure applies to synaptic strength (w_i), which is normalised as input vectors:

$$w_i = W_i / |W_i|$$

, where W is synaptic weight vector for i-neuron in the output.

The output neuron is described as:

$$O_i = w_i * x = \cos è$$

, where O_i is the output vector, which is the cosine between the synaptic weight and input vector (è) (Lu and Lo, 2002).

The output is calculated with all output neurons on the basis of the strongest value, which in this case is called the Best Matching Unit (BMU) within the cell (**Figure 8-19**).

In the result the following equation is being used:

$$w_{i+1} = w_i + \alpha (x - w_i)$$

, where α is the learning rate.

The SOM is the net spread to data cloud and the training algorithm moves weighting vectors, spanning them over the data cloud, and neighbouring neurons on the grid get similar weight vectors (Vesanto *et al.*, 1999).

In the batch training used in the following analysis, the dataset is presented and new weight vectors are weighted averages of the data vectors.

The toolbox had been downloaded from: http://www.cis.hut.fi/projects/somtoolbox/, where instruction manuals and read me files were also found.

For SOM toolbox installation, Matlab™ and Simulink™. developed by The MathWorks™ software, have been used.

As Matlab is software using a programmers' commands, developers of SOM toolbox allowed for the usage of graphical user interface.

The maps were created using initialisation, hexagonal cells with the size of 15 x 10.

Also, batch training was used and the neighbouring BMU's were calculated. In order to load the data into the Matlab, it had been specially prepared for maps display. SOM toolbox requires filling the empty spaces with text data, either 'x' or 'NaN', standing for 'not a number'; therefore, the programme does not include them in the calculations, although 'zero' values are incorporated in the calculations.

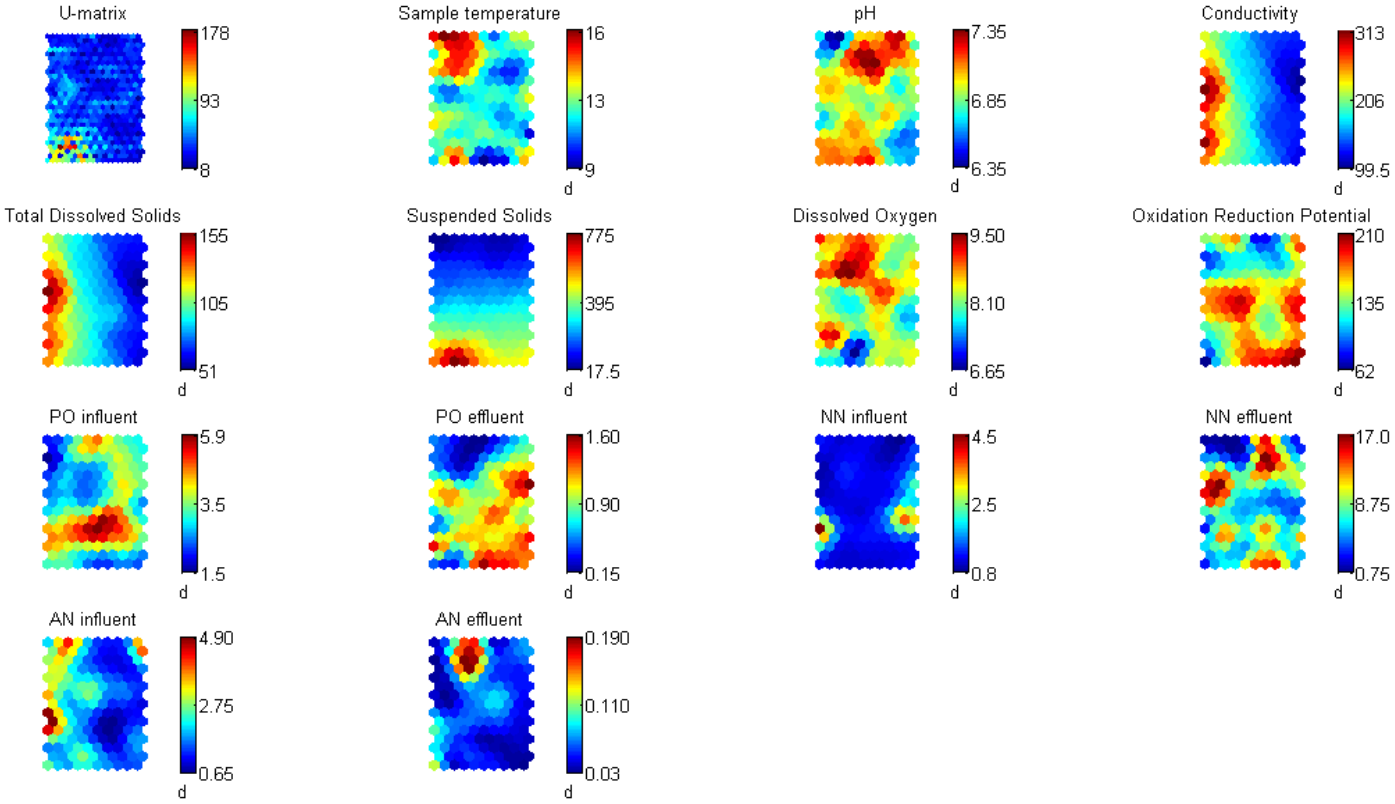
Bin 1 (H/C, IN+P), bin 2 (H/C, IN) and bin 3 (no H/C, IN) were chosen for indoor and outdoor comparisons.

Influent values of pH, conductivity, TDS, SS, DO, and ORP were compared with effluents of the PO_4, NO_{2+3}, NH_4 values as well as their influents. Because of the importance of the temperature, they have also been compared with water sample temperatures.

Prepared maps show influent values in comparison to nutrient and bacterial effluents in chosen bins. If effluent has been used, it is clearly marked above the calculated map.

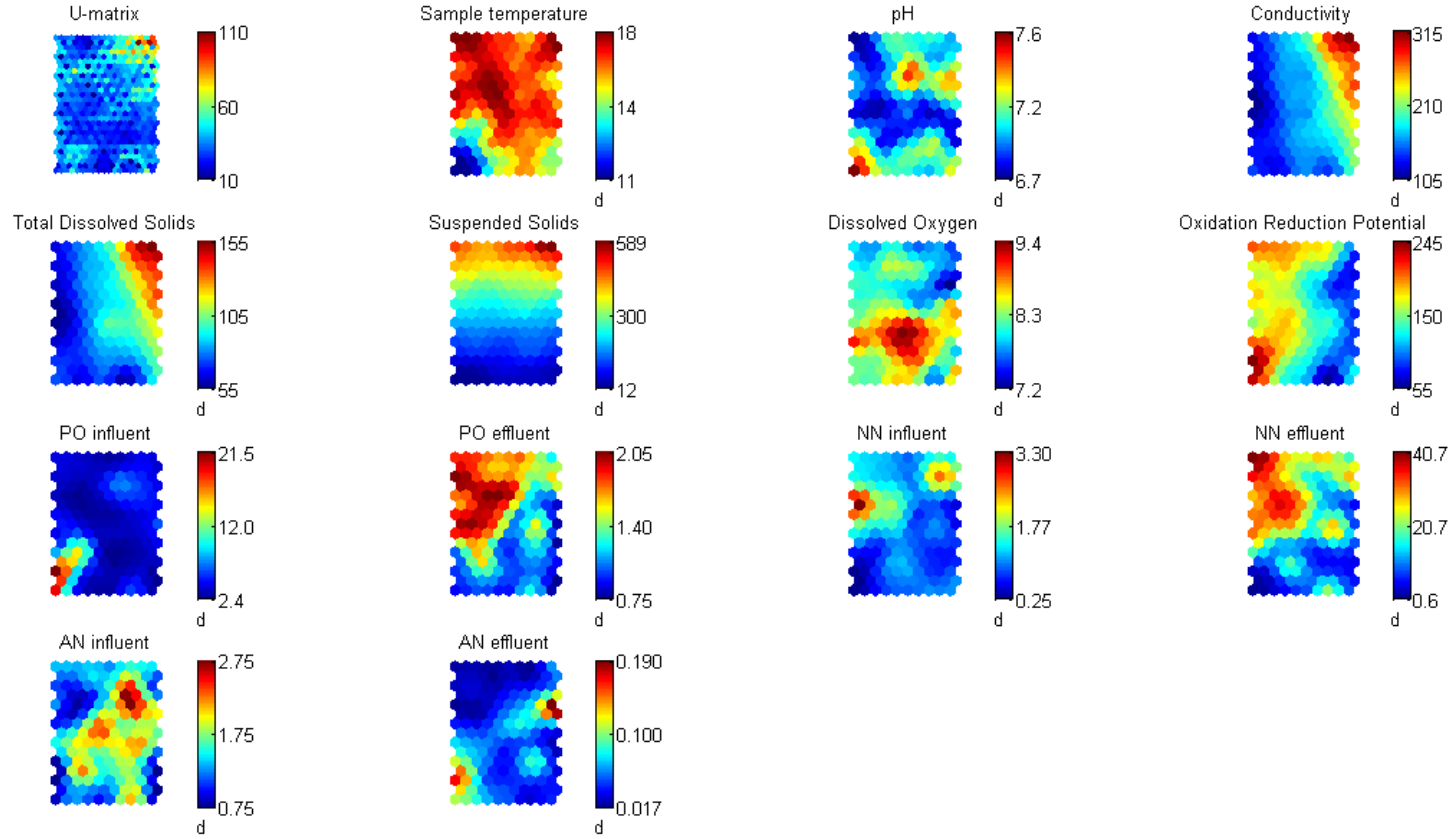
SOM outputs include U-matrix, which shows the clustering structure of the SOMs in the batch (figure), computing the unified distance matrix of SOM. It is calculated using all variables, where all component planes are shown. U-matrix is always calculated for a sheet-shaped map and the grids are always at least 2-dimensional (after SOM online documentation, http://www.cis.hut.fi/projects/somtoolbox/package/docs2/somtoolbox.html) .

8.2.1 SOM maps for chosen nutrients



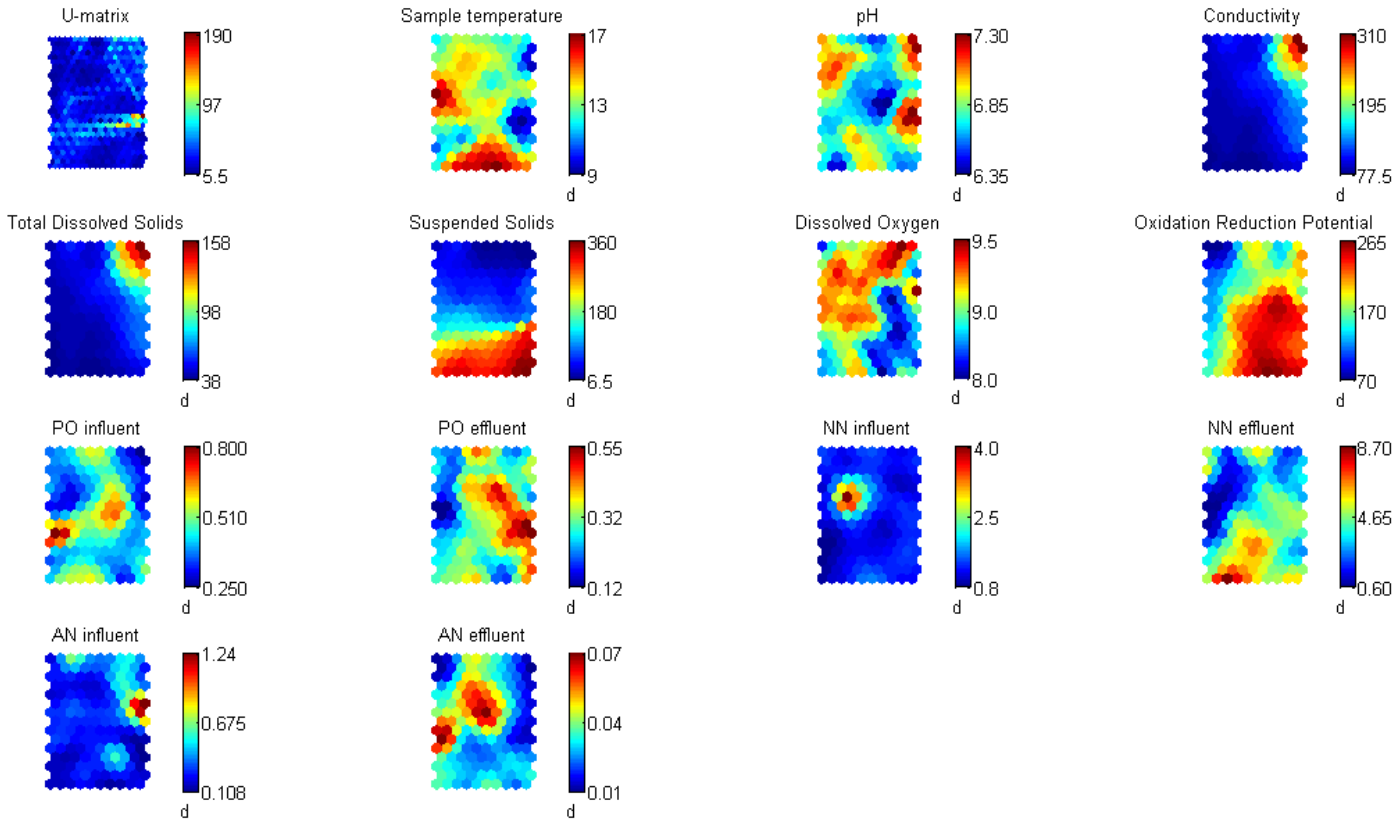
Units and abbreviation of displayed data: Temperature – ^{o}C; Conductivity - μS*cm^{-1}; TDS - ppm, SS, DO, ORP – mg/l; PO – ortho-phosphate phosphorus, NN – nitrates/nitrites, AN – ammonia – mg/l.

Figure 8-20 SOM maps relating influent physico-chemical parameters to nutrient influent and effluent levels. Bin 1o, with H/C installation and receiving faeces.



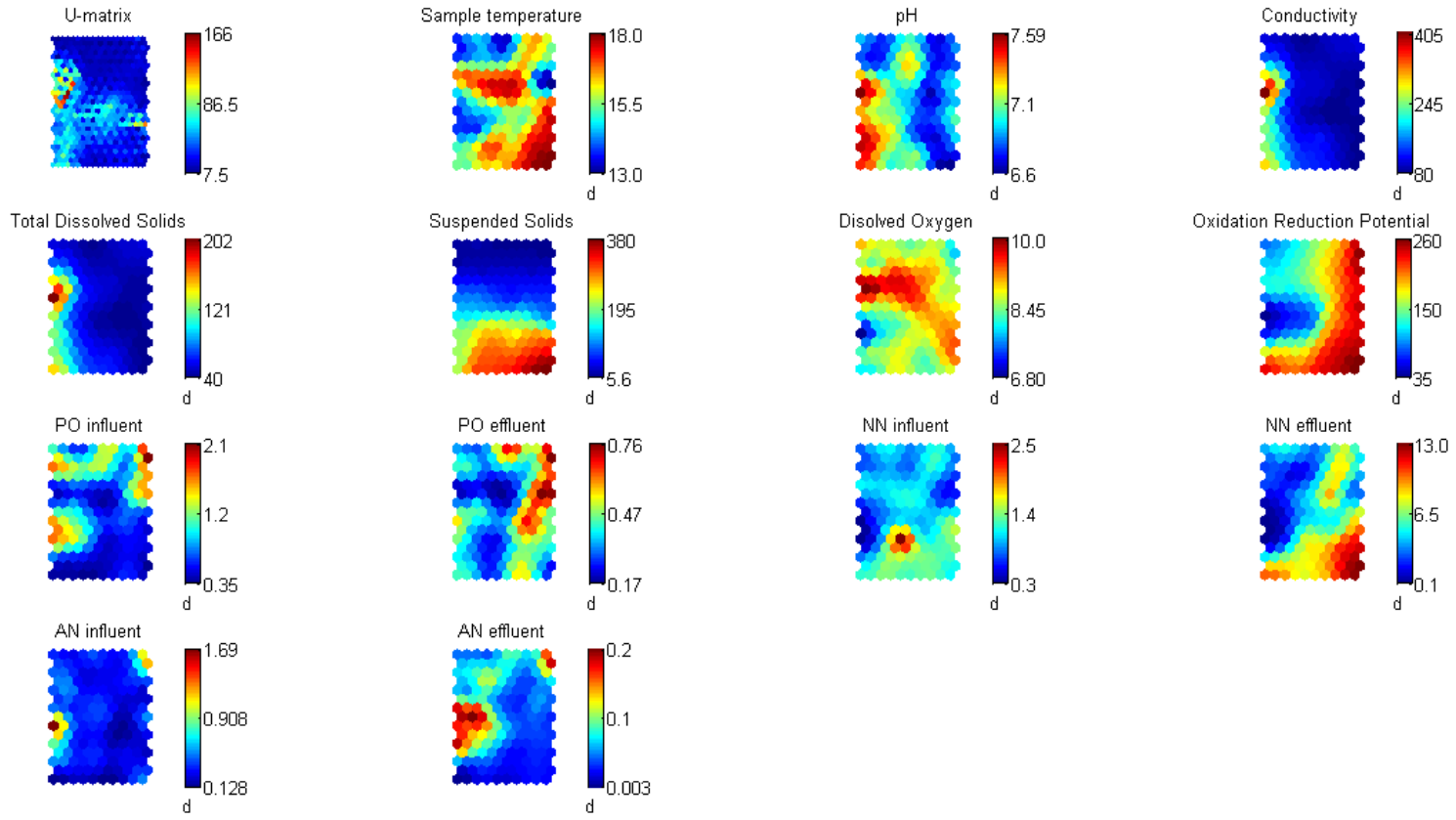
Units and abbreviation of displayed data: Temperature – ^{o}C; Conductivity - $\mu S*cm^{-1}$; TDS - ppm, SS, DO, ORP – mg/l; PO – ortho-phosphate phosphorus, NN – nitrates/nitrites, AN – ammonia – mg/l.

Figure 8-21 SOM maps relating influent physico-chemical parameters to nutrient influent and effluent levels. Bin1i, with H/C installation and receiving faeces.



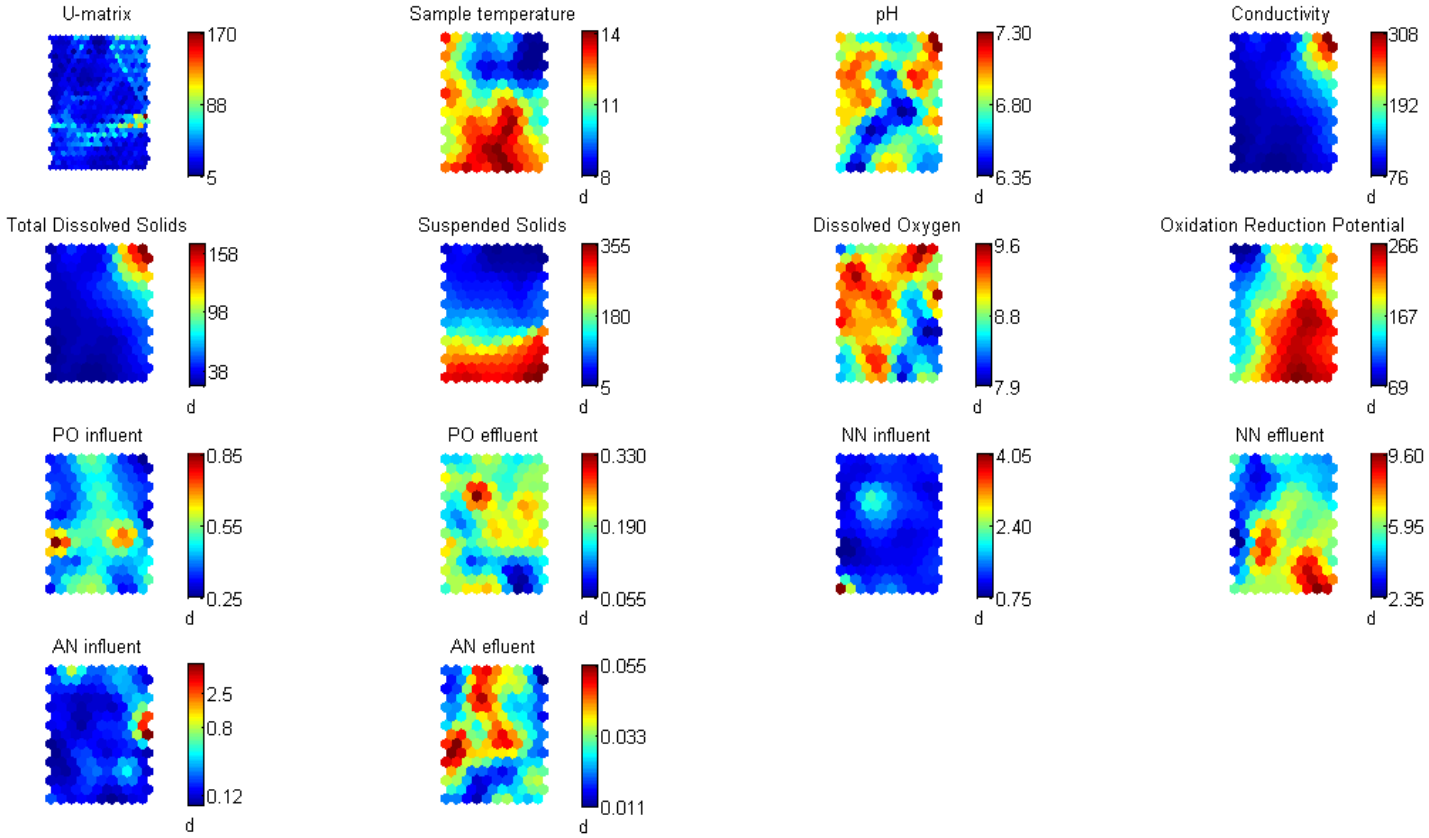
Units and abbreviation of displayed data: Temperature – ^{o}C; Conductivity - $\mu S*cm^{-1}$; TDS - ppm, SS, DO, ORP – mg/l; PO – ortho-phosphate phosphorus, NN – nitrates/nitrites, AN – ammonia – mg/l.

Figure 8-22 SOM maps relating influent physico-chemical parameters to nutrient influent and effluent levels. Bin2o, with H/C installation and not receiving faeces.



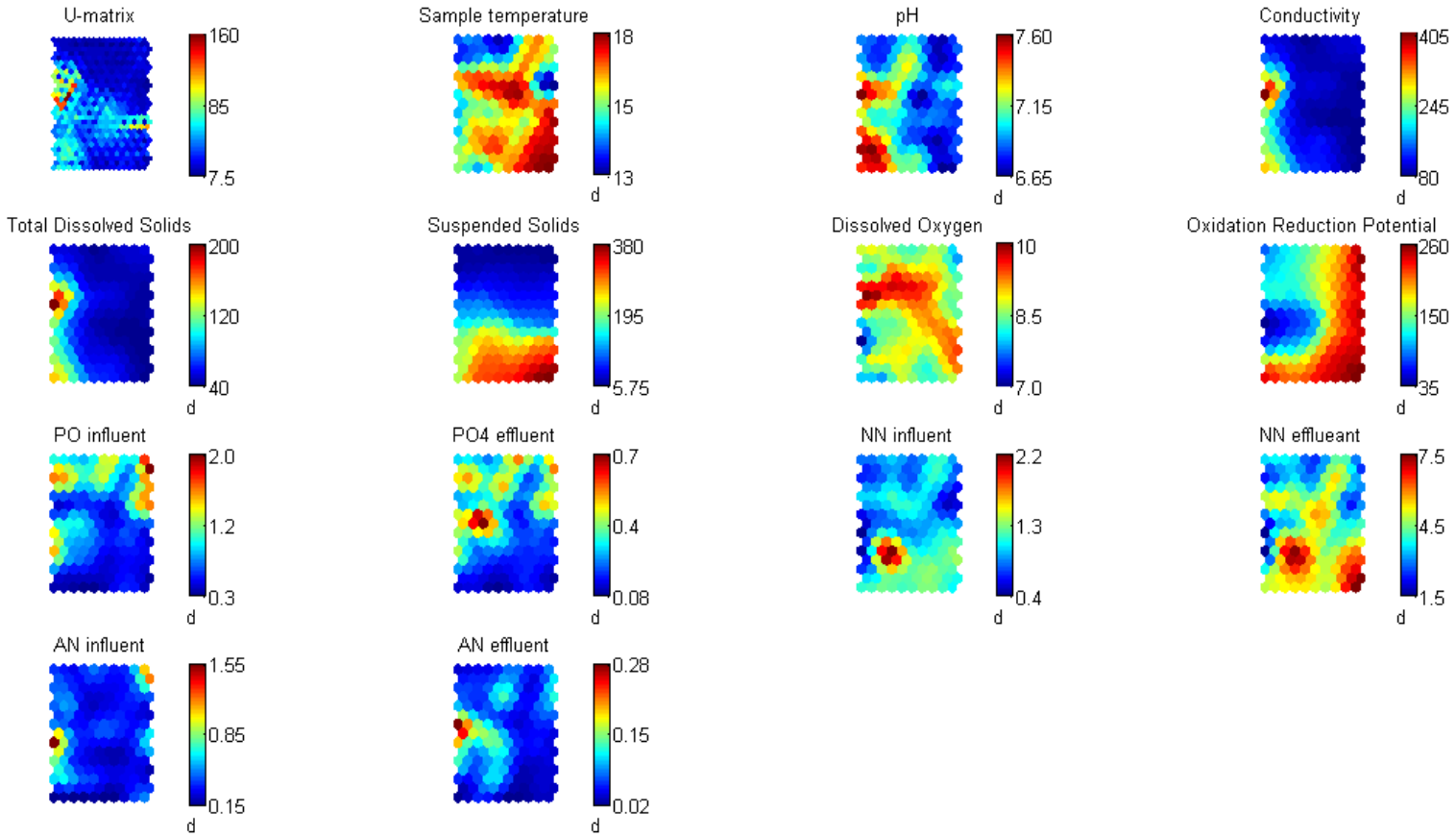
Units and abbreviation of displayed data: Temperature – ^{o}C; Conductivity - μS*cm^{-1}; TDS - ppm, SS, DO, ORP – mg/l; PO – ortho-phosphate phosphorus, NN – nitrates/nitrites, AN – ammonia– mg/l.

Figure 8-23 SOM maps relating influent physico-chemical parameters to nutrient influent and effluent levels. Bin2i, with H/C installation and not receiving faeces.



Units and abbreviation of displayed data: Temperature – ^{o}C; Conductivity - μS*cm^{-1}; TDS - ppm, SS, DO, ORP – mg/l; PO – ortho-phosphate phosphorus, NN – nitrates/nitrites, AN – ammonia – mg/l.

Figure 8-24 SOM maps relating influent physico-chemical parameters to nutrient influent and effluent levels. Bin3o, with no H/C installation and not receiving faeces.



Units and abbreviation of displayed data: Temperature – ^{o}C; Conductivity - μS*cm^{-1}; TDS - ppm, SS, DO, ORP – mg/l; PO – ortho-phosphate phosphorus, NN – nitrates/nitrites, AN – ammonia – mg/l.

Figure 8-25 SOM maps relating influent physico-chemical parameters to nutrient influent and effluent levels. Bin3i, with no H/C installation and not receiving faeces.

Relationships (correlations) found in SOMs were compared visually, allowing for a quick analysis by juxtaposing two or more maps.

The strongest relationships were found in bin 1o between PO_4 effluent and high ORP influent values. On NH_4 effluent concentrations, the highest impact on the sample was made by pH and temperature, meaning that the impact of GSHP on the stored sample was important when considering ammonia nitrate effluent, as seen in **Figure 8-20**. Visible correlations (i.e., inversely correlated) were also found between NO_{2+3} and NH_4 effluents. NO_{2+3} effluent values were strongly correlated with pH influent values and influent NH_4 concentrations.

In bin 1i (**Figure 8-21**), the most clear relationship is found between high values in PO_4 effluent and high sample temperatures, which also had an impact on high NO_{2+3} effluent and low values of NH_4 effluent. Low values of pH are found to be correlated with high NO_{2+3} and PO_4 effluents. Effluent NO_{2+3} was also dependent on its influent values.

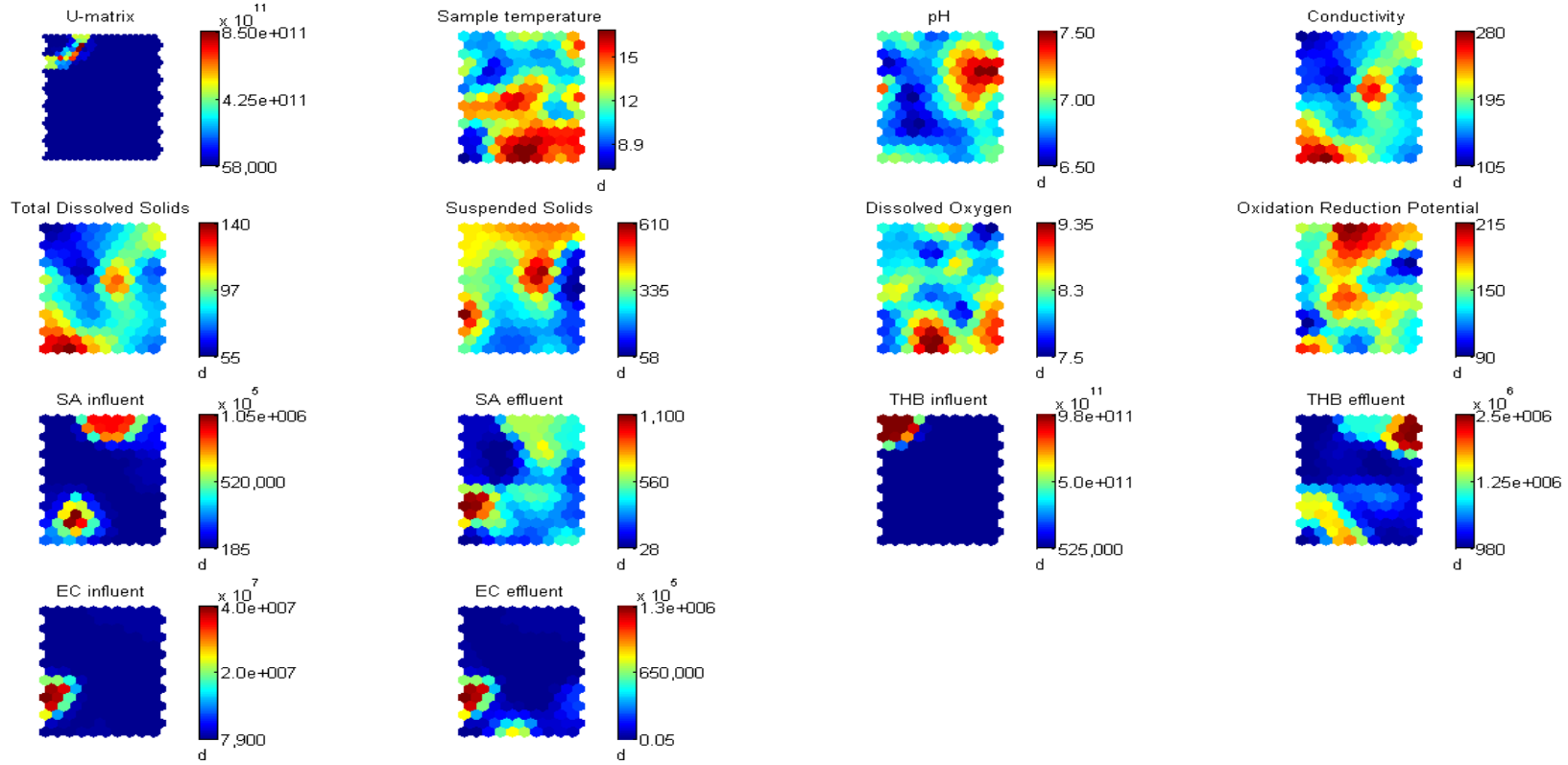
In bin 2o, high values of NH_4 effluent were correlated with low values of pH in the influent. High sample temperatures had slight impact on high NH_4 effluents, as well as on some NO_{2+3} effluent values, as in **Figure 8-22**. No further visible correlations were found.

Corresponding bin 2i correlations were found between sample temperature and NO_{2+3} effluent values. High ORP levels, together with high SS concentrations, had also influenced NO_{2+3} effluents, as on **Figure 8-23**.

The most visible relationship (bin 3o) is seen between inflow ORP, SS and sample temperature. This example shows the ease of misinterpretation when comparing maps visually. It also provides information on one of the weak points of SOM when working with large datasets.
The strong impact of ORP and SS influents on NO_{2+3} effluent samples is found with an additional impact from sample temperatures (**Figure 8-24**).

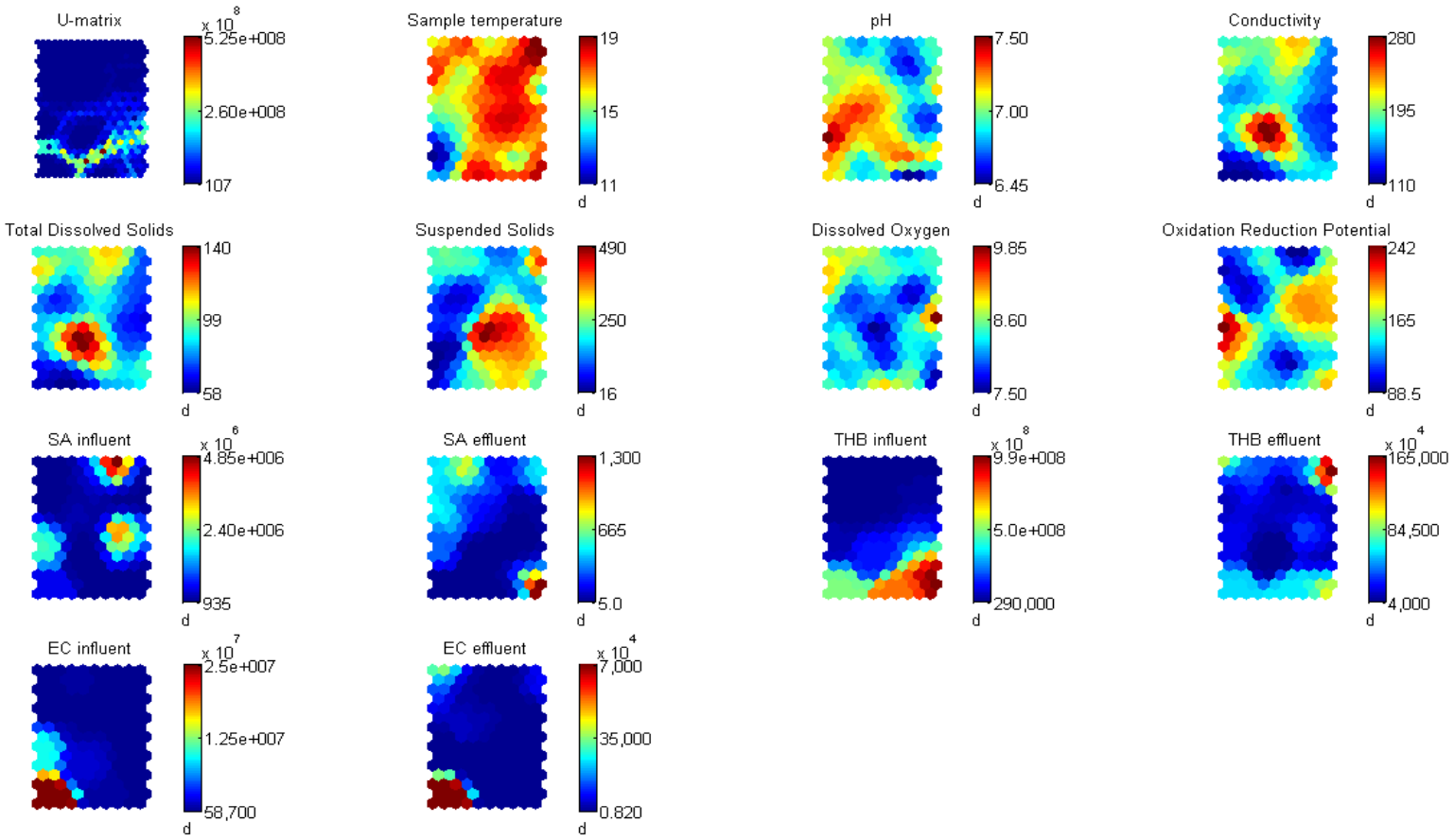
In bin 3i (**Figure 8-25**), PO_4 influent and effluent values provide information on strong connections between them. Effluent ortho-phosphate-phosphorus concentrations were strongly reduced compared to influent and mainly dependent on influent values. Similar conclusions could be made for NO_{2+3}, as its high influent levels were determining some high effluent levels, just as in the case of NH_4. Strong impact on NO_{2+3} effluent values was made by temperature.

8.2.2 SOM maps for chosen microbes



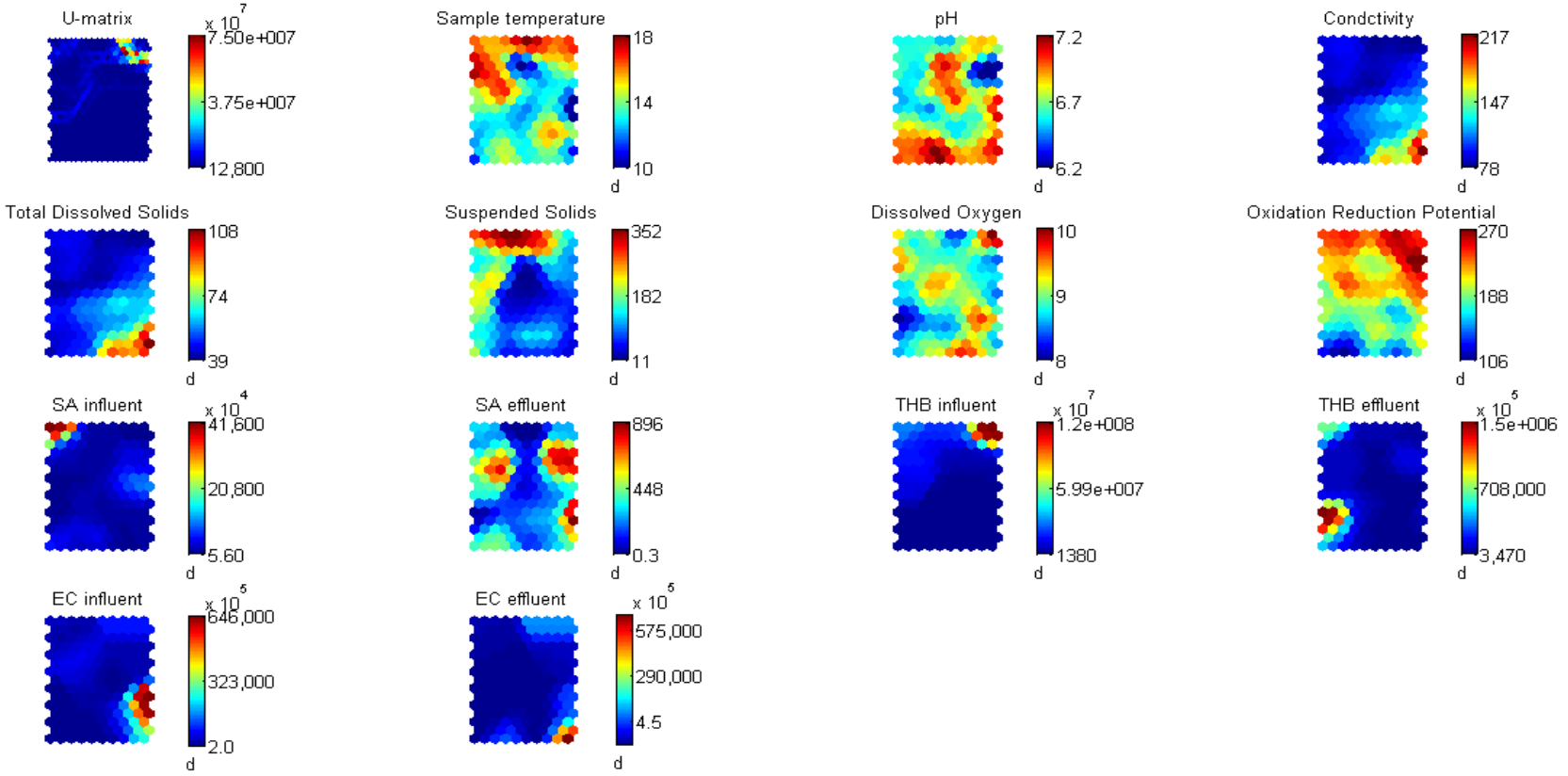
Units and abbreviation of displayed data: Temperature – ^{o}C; Conductivity - μS*cm^{-1}; TDS - ppm, SS, DO, ORP – mg/l; SA – *Salmonella sp*; THB – Total Heterotrophic Bacteria; EC – *Escherichia coli sp*; bacterial units in CFU/100ml

Figure 8-26 SOM maps relating influent physico-chemical parameters to bacterial influent and effluent levels. Bin1o, with H/C installation and receiving faeces.



Units and abbreviation of displayed data: Temperature – ^{o}C; Conductivity - µS*cm^{-1}; TDS - ppm, SS, DO, ORP – mg/l; SA – *Salmonella sp*; THB – Total Heterotrophic Bacteria; EC – *Escherichia coli sp*; bacterial units in CFU/100ml

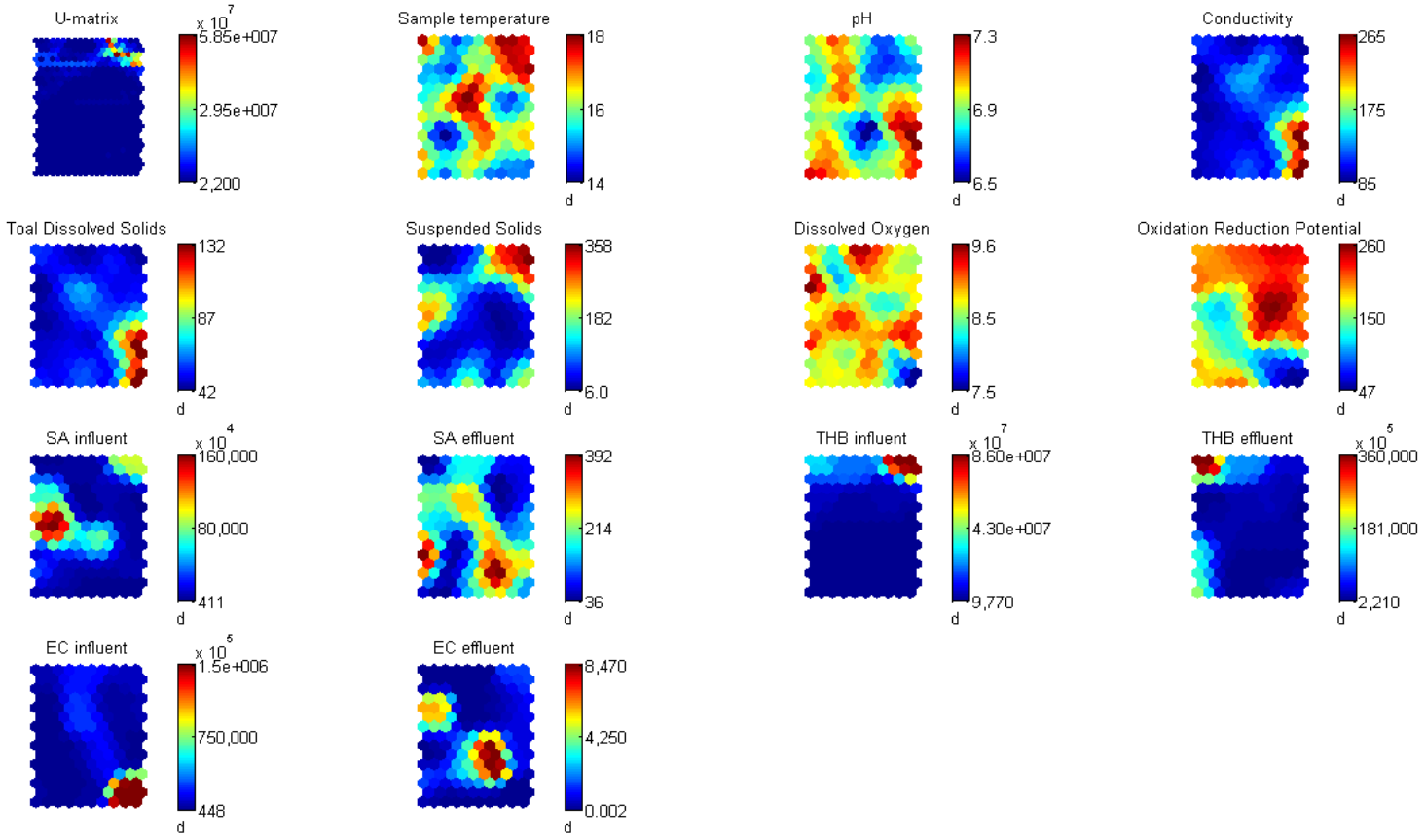
Figure 8-27 SOM maps relating influent physico-chemical parameters to bacterial influent and effluent levels. Bin1i, with H/C installation and receiving faeces.



Units and abbreviation of displayed data: Temperature – ^{o}C; Conductivity - µS*cm^{-1}; TDS - ppm, SS, DO, ORP – mg/l; SA – *Salmonella sp*; THB – Total Heterotrophic Bacteria; EC – *Escherichia coli sp*; bacterial units in CFU/100ml

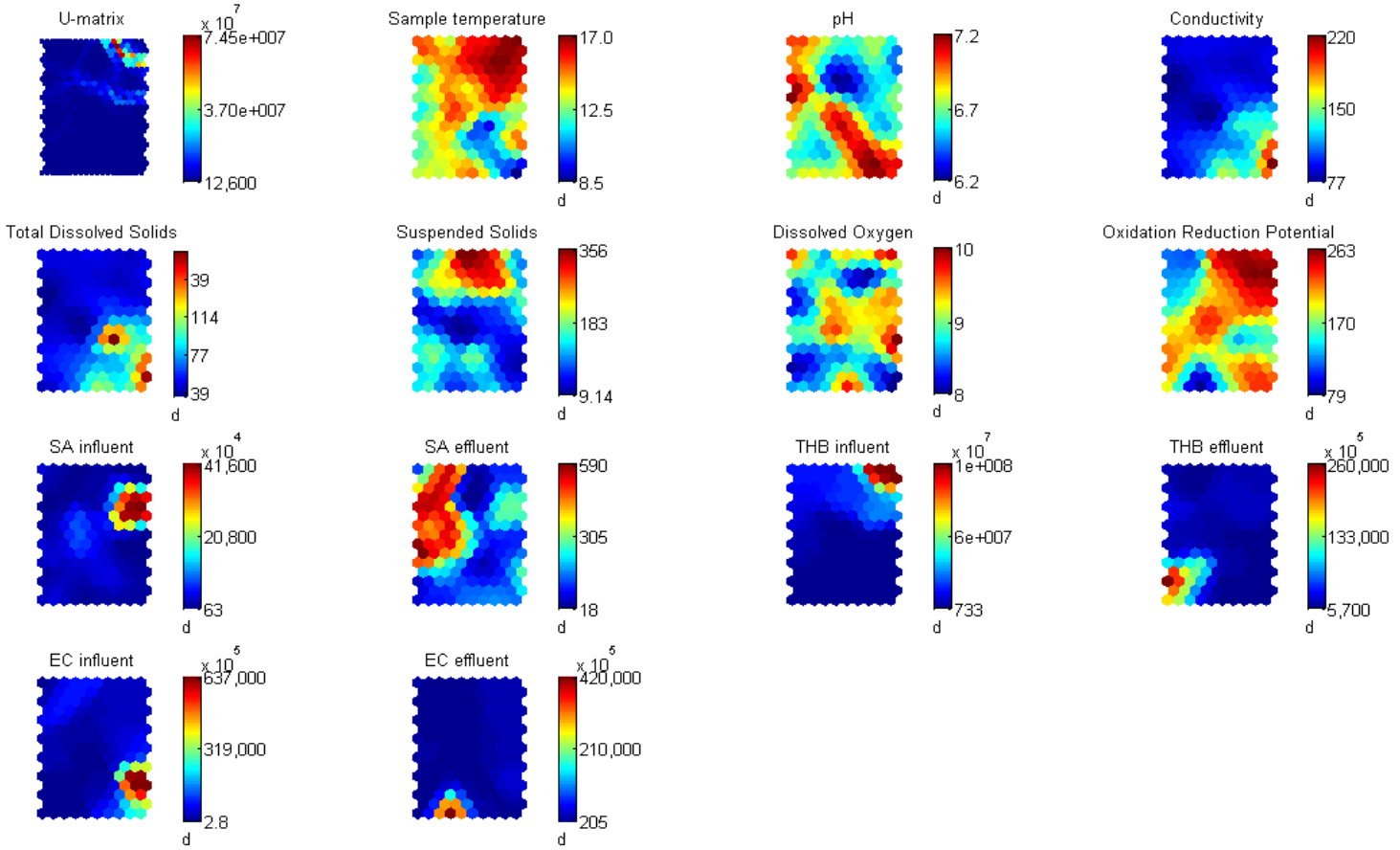
Figure 8-28 SOM maps relating influent physico-chemical parameters to bacterial influent and effluent levels.

. Bin2o, with H/C installation and not receiving faeces.



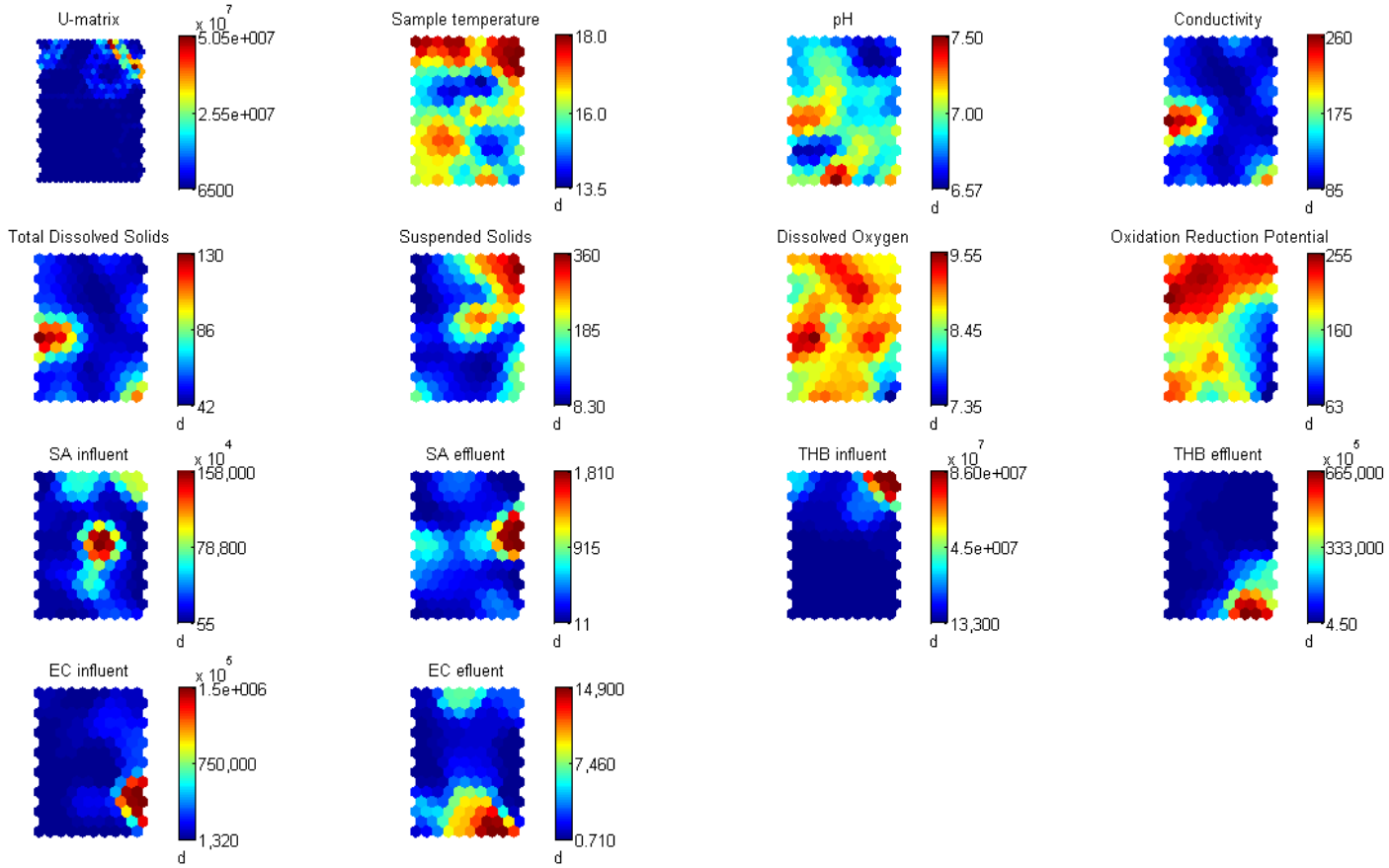
Units and abbreviation of displayed data: Temperature – ^{o}C; Conductivity - μS*cm^{-1}; TDS - ppm, SS, DO, ORP – mg/l; SA – *Salmonella sp*; THB – Total Heterotrophic Bacteria; EC – *Escherichia coli sp*; bacterial units in CFU/100ml

Figure 8-29SOM maps relating influent physico-chemical parameters to bacterial influent and effluent levels. Bin2i, with H/C installation and not receiving faeces.



Units and abbreviation of displayed data: Temperature – ^{o}C; Conductivity - μS*cm^{-1}; TDS - ppm, SS, DO, ORP – mg/l; SA – *Salmonella sp*; THB – Total Heterotrophic Bacteria; EC – *Escherichia coli sp*; bacterial units in CFU/100ml

Figure 8-30 SOM maps relating influent physico-chemical parameters to bacterial influent and effluent levels. Bin3o, with no H/C installation and not receiving faeces.



Units and abbreviation of displayed data: Temperature – ^{o}C; Conductivity - μS*cm^{-1}; TDS - ppm, SS, DO, ORP – mg/l; SA – *Salmonella sp*; THB – Total Heterotrophic Bacteria; EC – *Escherichia coli sp*; bacterial units in CFU/100ml

Figure 8-31 SOM maps relating influent physico-chemical parameters to bacterial influent and effluent levels. Bin3i, with no H/C installation and not receiving faeces.

Figure 8-26 (bin 1o) presents the situation where there is no impact on *Escherichia coli* effluents from any of the tested parameters. Inflow values distribution is similar, although the pathogen reduction was high, as discussed in chapter 7. Temperature impact on THB effluent is seen only at the values of approx. 1.3E+006 CFU/100 ml. Higher concentrations of the organisms do not show relationships between other parameters. *Salmonella sp* is determined by its influents. Some of the microbial effluents are correlated with high SS concentrations and low pH.

THB effluents in bin 1i (**Figure 8-27**) were influenced by the highest water temperatures, which means that there was an impact of changing temperature on THB numbers. This link is not clear when discussing *Escherichia coli* effluent concentrations. Firstly, the outflow mirrors the inflow values and, secondly, a negative correlation is found between EC concentrations and water sample temperatures – with higher temperatures and low bacteria numbers recorded, and vice versa. pH values of 7.2 might have a slight impact on the above organisms, but cannot be considered as a strong determinative parameter in the above example. As for the *Salmonella sp* effluent numbers, high temperature values had an impact on its levels and distribution over the grid. This outcome is as expected, because *Salmonella sp* values are just a small part of THB community and will usually follow heterotrophic bacteria population regimes.

Bin 2o (**Figure 8-28**) can be characterised by comparing pH influent concentrations with low THB effluent concentrations. It seems that because of a close to neutral pH, bacteria were removed with a high efficiency. *Salmonella sp* numbers were determined by high ORP values and low pH

levels. *Escherichia coli sp* relationship was found for TDS, in which high concentrations provided favourable conditions for the growth and development of pathogens.

Bin 2i (**Figure 8-29**) THB effluent concentrations were compared with other measured parameters. The links found are mainly with low values in suspended solids influents. Also, some of the high THB effluent concentrations were found to be under the influence of high sample temperatures, but the link is not strong in this instance. Stronger relationships were found between raised *Escherichia coli* effluent concentrations and low ORP and pH influents which had some impact on the sample values. There is no implication on *Salmonella sp* effluents being influenced by any other inflow parameters.

Figure 8-30 presents SOM maps for bin 3o. High THB effluent concentrations show a slight connection with low DO values in the sample influent. Some high *Salmonella sp* concentrations show the existence of a relationship between high pH values in the influent, but the link is not clear and should be considered weak. *Escherichia coli* effluents show the same correlations with low ORP influent concentrations.

THB and *Salmonella sp* effluent concentrations in bin 3i (**Figure 8-31**) were found not to be related strongly to any other analysed parameter. *Escherichia coli* effluents seem to be correlated with THB effluents (THB determination on the pathogen concentrations in the outflows).

A strong relationship is found between conductivity and TDS influents, where the latter would determine the former's levels.

Summarising the SOM findings, the response in the effluent is mainly found during nutrient parameters analysis. It was easier to find clear relationships between influents and nutrients in effluents than it is to find microbial organisms in the effluents.

Main correlations were found principally between NO_{2+3} and NH_4 effluents and water sample temperature which had a strong impact on the effluent concentrations. Other important parameters impacting effluents include: pH, SS and ORP (influents).

The microbial analysis is not very clear, as not many factors were found to determine the effluent concentrations. The most important parameters found were: ORP, DO and pH.

In bin 1i, a strong relationship between THB concentrations and temperature was found. This might be the result of high differences in sample numeric values, i.e., 58 parts per million (TDS) and 9.9E+008 x 10^8 CFU/100ml (THB influent). Other reasons for such occurrence might be different n values, i.e., indoor DO n=110 and indoor THB n=35.

In general, correlations found for nutrient concentrations outdoor were usually similar to the correlations found indoors. While discussing microbial values, there were not as many correlations between THB and analysed pathogens with other analysed influent levels. More total correlations were found to occur in the outdoor rig.

9 **Conclusions**

9.1 General findings

The conducted research provided varied information on PPS and GSHP simulations within the sub-base.

9.1.1 Findings regarding the systems' construction:

~ The constructed applications proved their workability both by removing nutrients and providing correct, comparable to industrial applications, GSHP EERs and COPs, allowing for trustworthy data collection.

~ All analysed bins provided adequate performance whether with or without H/C installations which was assessed by nutrient and microbiological removal efficiencies. The result provided evidence for correct PPS/GSHP design.

~ CO_2 levels higher than background air concentrations provided evident, increased microbial activity on the geotextile level, close to the values found in the upper part of the lower sub-base.

~ The collection pipe responsible for increased DO levels, as it was introducing atmospheric oxygen to the bottom of the tanked system

(ventilation). This was the cause of increased nitrification and inhibited denitrification, as proved by TIN mass balance calculations – nitrogen concentrations based mainly on the NO_{2+3} concentrations rather than NH_4 concentrations.

~ Collected data levels were a mixture of water and sediments, as explained in methods section. This was the result of the effluent being pumped out by a hand pump, creating strong suction (high pressure). As a result, both sediments were collected as a part of the sample. It is not appropriate to compare such a mixture with the data available in the industry and literature, as the industrial nutrient and bacterial effluents are much lower and do not contain such large amounts of sediments. The sediment also introduced additional pollution into the water sample, as tanked system's pollutants are kept mainly within the PPS filter structure, but some are incorporated into the sediment (flocculation).

~ As a result of the above, collected effluent data should be divided (i.e., 100 for dilution) in order to provide comparable values existing in current research.

~ SOM analysis was found to be an outstanding example for ANN modelling and good for assisting in data interpretation, but because of high numbers of variables and tested parameters, SO maps could introduce errors in data interpretations caused by visual

comparisons. These would also require an experienced SOM modeller assistance in data interpretation.

9.1.2 Findings regarding data analysis:

~ Both statistical and SOM analysis proved the existence of highly significant correlations ($p<0.01$) between nutrient influents and effluents – NO_{2+3}, NH_4, PO_4 with total correlation values of $r_s = 0.4925$, 0.1644 and 0.7757, respectively. NH_4 correlation was the weakest during the N_2 cycle, denitrification has been limited by the introduction of O_2, resulting in increased nitrification and low organic matter availability due to rapid microbial consumption.
The above allowed for the conclusion that it was mainly the influent concentrations determining nutrient effluents, rather than the temperature changes.

~ Ephemeral and rapidly changing temperatures of coils present in the sub-base determined NO_{2+3} and NH_4 removal efficiencies (Kurskal-Wallis $p<0.0001$), in addition to increased ventilation of bins with O_2, resulting in increased nitrification and inhibited denitrification.

~ Despite increased NO_{2+3} concentrations in the influent and negative removal efficiencies, effluent concentrations were still within EU wastewater discharge standards.

~ The research has proven that the possibility of the potential release of pathogenic organisms during simulated events was low, as pathogens accounted for a very small percentage of THB, between 0.1-2.5% (*Salmonella sp* and Enterococci).

~ Significant correlations were found between the microbial influent and effluent removal values for *E.coli* only with r_s = 0.10747. Because of negative removals in bins 1i and 4i (r_s = -0.2205 and -0.3791), it was proven that with more *Salmonella sp* organisms introduced into PPS, higher removal efficiencies were calculated. Therefore, it can then be concluded that the organisms' concentrations were mainly dependent on the type of influent, indicating that IN+P was a significant (p = 0.0019) determining parameter as assessed by u-tests.

~ Low coil temperatures correlations with bacterial removal numbers (which were insignificant) found for *E.coli* confirmed findings of the raw data analysis and removal efficiencies analysis during different seasons. It can be concluded that the organism is prone to cooler temperatures in PPS. No significant temperature-microbial removal efficiencies correlations were found for any of the microbial removals.

~ Because of a planned overloading of the systems and collection of sediments together with the water sample, high removal rates reassure that in standard, real-life applications, the risk of a transfer

of pathogenic organisms is extremely low and pollutant removal efficiencies can be expected to be even higher.

~ Raised bioactivity was shown by CO_2 levels, with the maximum values of 2000 ppm (air average approximately 400 ppm). Increased bioactivity on the geotextile level by measured CO_2 concentrations confirms the importance of a geotextile presence for enhancement of microbial activities.

~ Because of a lack of temperature correlations with pathogen removals, as well as increased conductivity for GSHP usage within PPS (proven by previous case studies), this type of application should be used wherever appropriate and designed for, without concerns of negative impacts on human health.

~ The above conclusions indicate that effluent waters should continue to be used as they are at present (garden watering, toilet flushing, aesthetic applications or direct discharge to soils and water streams), and do not pose a greater threat to the environment or humans than other SUDS techniques. From a public health protection perspective, their usage should be continued.

9.1.3 Summarising findings in the aspect of aims and objectives.

- Designed simulations of PPS-GSHP provided a reliable dataset for further analysis.
- Pollutant removal efficiencies were found to be very high with concentrations fulfilling European norms for wastewater discharges despite their over pollution in the influent
- Overall PPS performance in nutrient and bacterial removals was found to be very good, despite increased nitrification and inhibited denitrification resulting in negative NO_{2+3} removal efficiencies; GSHP performance was found as good, which was confirmed by COP and EER calculations
- No significant correlations were found between microbial (especially pathogenic) removal efficiencies and temperature fluctuations

9.2 Recommendations for future work

Future research could focus on organisms such as *Legionella pneumonia* and use much more accurate techniques such as molecular analysis (PCR, DGGE, DNA sequencing).

Despite the current findings, it is advisable to continue researching the subject. It may be found that data can be normalised after further collection, i.e., in another two years.

Further data collection might also be useful when considering mathematical modelling, such as ANN, Fuzzy Logic modelling or any other relevant modelling that may predict and describe the analysed data set. For example, ANN could be used as a 'black box' to model the performance of the PPS based on BOD, nutrients and microbiological parameters..

It is also desirable to conduct work on any other bacterial species of concern, such as *Legionella sp* organisms' possible presence or probability of occurrence in heating cycles.

Further possibilities for PPS assessments include surface clogging, or alternative sub-base waters usage. During various discussions with engineers and specialists, ideas of microbial fuel cells (MFC) usage arose, which might be an additional argument for continued research on PPS.

MFCs can be integrated into PPS for further water treatment and the production of bio energy, as a result of the high conductivity of stored PPS water. With redox potential present, it allows the possibility of electron transfer between the particles.

Other ideas raised during the research covered areas of:

- systems restoration after sterilisation (i.e., with chlorine);
- photocatalytic treatment (use of a catalyst and light) for oxidation type treatment;
- stored water treatment with UV light and water harvesting;
- GSHP temperature distribution modelling in the porous media specifically for granite sub-base in saturated and non-saturated areas;
- improved thermocouples distributions design including data loggers and conductivity measurements;
- usage of alternative sub-base components, e.g., permavoid boxes made of recycled tyres, and changes in structural properties or recycled material in block components, e.g., recycled ashes;
- introduction of genetically engineered microorganisms in order to remove specific pollutants, e.g., cancerogenic;
- PPS sub-base improvement in order to treat 'grey' water, e.g., provision of additional layers.

It is also recommended that future work be conducted on real-site applications or on designs close to the existing systems. Alternatively, it is proposed that the outflow collection points be set on the level of stored water within the sub-base. Misleading interpretation of the above data was recognised, especially when presented to the public. Nutrients and microbial concentrations do not present actual concentrations at the overflow outflows. The values collected at the real-site overflow valves or

chambers do not match collected data values as in the research, making it complicated for comparison and assessment with other findings in the literature.

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Appendix

Appendix 1 Hanson Formpave Industrial Risk Assessment proposal

Hanson Formpave Permeable Pavement Risk Assessment with Ground Source Heat Pumps installations for domestic usage (end client)

July 2008 v. 1.1

Permeable Pavement Systems is one of the techniques used in Sustainable Urban Drainages Systems for treating urban runoff and water recycling. Although the structure of the system is safe and designed to the highest engineering standards (British Standards, Highway Agency Code) there are certain recognized risks which need identification, description and explanation.

Permeable Pavement Components

Element	**Components**	**Risk to health** L / M / H
Paving surface	Sand, cement, clay, loam, various fine aggregates	L
Aggregates	Stone aggregates varying from 5 to 200 mm mainly composed of granite, sandstone, basalt	L
Inbitex geotextiles	Flexible membranes made of polyethylene – polyethylene fibres for microbiological development enhancement allowing water penetration	L
Inbitex composite	As above with the addition of reinforced mesh and impermeable foil to either prevent evaporation from tanked system or for tanked system construction	L
Ground Source Heating Pumps Coils	Reinforced polyethylene – polyethylene pipes for GSHP water transportation allowing heat exchange within the coil and PPS sub-base.	L

Possible Hazards in everyday usage

Hazards	Description and action	Risk to Health
Trips and falls	Caution should be taken while walking in 'high heels' on PPS surface	L
Icing	Should be treated as usual although de-icing salts or sand should not be used – possible clogging of PPS which will result in decreased infiltration	L
Oil contamination	Should be washed into the PPS sub-base, decomposition of oil will occur in the sub-base mostly on geotextile level	L
Fecal contamination	Should be picked up and disposed if possible; the remaining matter can be washed into the sub-base where biological decomposition will take place.	L

The importance of micro-organisms

World Heath Organization Water Quality Standards and Health Guidelines recognize three groups of indicator organisms:

- process indicators - represents the quality and efficiency of water disinfection
- faecal indicators – infers the presence of pathogens resulted in faecal contamination
- index and model indicators – infers the presence of groups of species indicating the presence of pathogen presence i.e. *E. coli* as indicator of *Salmonella sp* presence

As there is no universal indicator, only bacterial presence, their numbers and characteristics can be described.

Species pointed below occur naturally and may be found in waters such as lakes, rivers or ponds. As it is impossible to mention all the species occurrences, only the most important for human health prevention have been described.

Pathogenic micro-organisms that may be found in the sub-base

Stored water may contain intestinal bacteria of many different types, including *Bacteroides, Clostridium, Lactobacillus, Bifidobacterium*, family Enterobacteriaceae (including *Escherichia* and *Enterobacter*), *Streptococcus* and *Enterococcus*, among others. Organisms such as *Pseudomonas, Salmonella, Shigella* and *Proteus* or *Bacteroides* and *Bifidobacterium* may also be found within the system. The most important pathogenic organisms which might be found within the sub-base are listed below (hazard group according to Advisory Committee on Dangerous Pathogens (appointed by Health and Safety Commission) classification).

Bacterial Pathogen	**Possible Symptoms**	**Hazard Group according to ACDP***	**Possible occurrence (scale 1-5)****
Salmonella sp	Usually infection is bound with abdominal pain, fever, vomiting, nausea, fluid loss. In case of typhoid malaise, aches and pains, rose pink macular, papular spots can occurs in addition to the above. Should be treated with antibiotics. Untreated can lead to delirium and death.	3	3
Shigella sp	Disease varies depending on the strain. Usual symptoms include diarrhoea, vomiting, fever, abdominal pain, meningitis (very rare), headache, dehydration. In hard cases bleeding and mucus can occur. Severe disease usually associated with Shigella dysenteriae may cause gangrenous cholera-type form and lead to death. As a result post –infection may lead to hemorrhoids and Reiter's syndrome.	2	2
Escherichia coli	Depending on the strain *E.coli* can	2	2

	cause dehydrating diarrhoea in children, can cause fever and persisted diarrhoea up to 14 days in developing countries. Diarrhoea can cause bloody and abdominal pain in extreme cases leading to rising serum urea and creatinine, anemia and thrombocytopenia		
Enterococcus faecalis (group D Streptococcus)	This bacteria can cause symptoms such as diarrhea, dehydration and fever. Can cause bladder, prostate and epididymal infections. Very rarely causes CNS infections.	2	1

*Danger increases with hazard group number
**1-low occurrence; 5-high occurrence

It is of a high importance to indicate that some species (i.e., *Salmonella sp*) need to be introduced into the system, in order, first, to discuss possible development or general occurrence.

There is no evidence of a *Legionella pneumophila* presence in the system, but ongoing academic research is set to provide more evidence on this organism occurrence in PPS. This organism is therefore not included in this Risk Assessment.

Protozoan community

Four functional groups may found in PPS including flagellates, gymnamoebae, ciliates and testate amoebae including: Amoeba sp, Acanthamoeba sp, Clopoda sp, Euglypha rotunda, Heteromita globosa, Lembadion sp, Monosiga sp, Salpingocea sp, Vorticella sp

Protozoan Parasites	**Possible Symptoms**	**Hazard Group according to ACDP***	**Possible occurrence (scale 1-5)****
Giardia lamblia	Causes Giardiasis. Infects humans and wild animals.	2	3

	Cysts are found in water. The main source of pollution is human and animal faeces. Explosive diarrhea, abdominal cramps, bloating, flatulence. Malaise is common. Symptoms may last for several weeks. Can cause failure to thrive in children if not treated at the early stage.		
Acanthamoeba sp	Symptoms include eye pain, eye redness, blurred vision, sensivity to light. Can cause keratisis or brain and spinal cord disease Granulomatous Amebic Encephalitis in individuals with compromised immune disease.	2	3
Cryptosporidium sp	Causes Cryptosporidiosis. Typical symptoms: diarrhea, abdominal pain, malaise, fever. Severe diarrhea causes weight loss. Hepatitis, cholecystitis or respiratory disease may occur in individuals with chronic immune system disease such as HIV.	2	3
Naegleria fowleri	Causes amoebic meningoencephalitis. Typical symptoms: headache which can lead to coma., fever, vomiting, neck stiffness. If introduced into the human body can cause brain death within 3 days.	3	2
Toxocaria canis	Can develop in children while eating dirt, animal	2	4

	faeces or contaminated water. Can cause eye damage and total sight loss.		

*Danger increases with hazard group number
**1-low occurrence; 5-high occurrence

The presence of the above organisms does not determine that these will definitely be found in recycled waters. It indicates the biodiversity of the system. As protozoan organisms feed on bacteria, they establish a diverse community, allowing for better water quality and pollutant decomposition.

Public Health

PPS water is to be used as urban non-potable water. Although there is a potential risk while irrigating public spaces such as parks or lawns, there is no record of gastrointestinal diseases linked to recycled water distribution.

Special care needs to be taken when in contact with children.
Attention should be taken when contact with water occurs by swallowing.

It is a good practice to keep a record of faecal coliform levels measured by local authority licensed bodies especially during summer where a high temperature flush is introduced into the PPS sub base.

This Risk Assessment has been prepared according to The University of Edinburgh, DEFRA and Health and Safety Executive UK, regulations. It should offer the assistance and protection while PPS installation consideration, but is not a description of a definite occurrence of the above organisms.