018530 - SWITCH

Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

D5.3.5: Initial Research Plan of Workpackage 5.3, including (pre)proposals of PhD research

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Revision [FINAL]

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	X
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

SWITCH WP 5.3. Use of natural systems in the urban water cycle
Task 1: Inventory of natural systems and processes for urban water management

RESEARCH PLAN

1. Task description based on DoW

Task 1a
To implement a literature review on the use of natural systems in urban water management. Some examples of existing natural systems and processes are: (river)bank filtration, rainwater harvesting, wetlands for effluent treatment, stabilization ponds for effluent treatment and reuse, phyto-remediation, or eco-hydrology concepts for improved self purification in municipal river and lake systems. Case studies of the use of natural systems in various components of the urban water cycle will be described.

Task 1b
To develop a workshop to discuss and analyse the use of natural systems in the urban water cycle and produce a preliminary plan on how to maximise their use in demo-cities.

2. Workplan

The literature review is intended to be a joint effort of all partners involved in WP 5.3 and will consist of staff input and student input through MSc and PhD studies. It will consist of a comprehensive compilation of the specific literature reviews carried out in the subsequent tasks. When the individual literature studies are finished, a decision will be taken whether or not the compilation can be published as a book.

This literature will also be translated into training material for LA members and city researchers. The training material will be tested during two workshops, the first one in Accra in April 2007, the second one in Lodz in July 2007. With this input and based on subsequent discussions, a preliminary plan on how to maximise their use in demo-cities will be developed.

3. Deliverables

M10	Nov 2006	• **M** Decide about dissemination/publication of review (T1)
M13	Feb 2007	• **D5.3-1a R** LitRev Inventory of natural systems and processes for UWM (T1)
M17	Jun 2007	• **D5.3-2a T** Organise a workshop on use of natural systems, and produce a draft plan to maximise their use in Demo-cities (T1)
M18	Jul 2007	• **D5.3-2b T** Final plan to use natural systems in Demo-cities (T1)

SWITCH WP 5.3. Use of natural systems in the urban water cycle
Task 2: Natural systems for drinking water treatment

RESEARCH PLAN

1. Task description based on DoW

Task 2a
To perform a literature survey and collect operational data from existing Bank Filtration (BF) and Artificial Recharge and Recovery (ARR) water treatment systems. The work will include the analysis of factors influencing the feasibility of BF and ARR for drinking water treatment for centralised (for urban water supply) and decentralised applications (for small towns and rural water supply). Furthermore the potential of BF and ARR as a 'Total Water Treatment System' (i.e. avoiding disinfection) under different conditions will be explored.

Task 2b
To perform soil column studies. Laboratory scale soil column studies will be conducted to evaluate the effect of redox conditions (aerobic and anoxic), and biotic and abiotic conditions on removal of different contaminants (particulate, dissolved, microorganisms), by BF and ARR. Based on the experimental results, residence time-distance relationships will be developed for each category of contaminants.

Task 2c
To perform field studies in BF and ARR sites. This phase will include the collection of raw water and treated water quality data from existing BF and ARR sites in South-Korea and/or The Netherlands (Study area), and to validate the residence time-distance relationship developed for removal of microorganisms, nitrogen and organic matter (DOC and trace organic compounds) based on laboratory-scale soil column experiments.

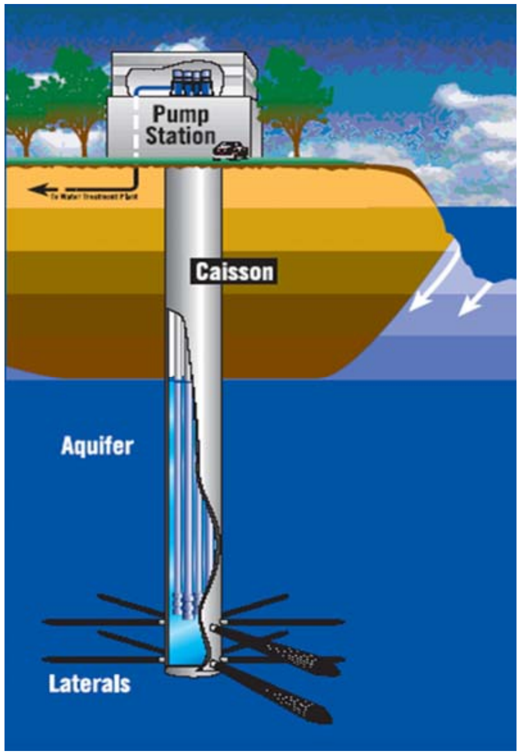
Task 2d
To develop and apply models describing BF and ARR processes. Based on the literature review, experimental results and field data collected, models will be developed to estimate the removal of selected contaminants by BF and ARR under given conditions. This will help in the effective design, operation and optimisation of BF and ARR schemes in conjunction with subsequent treatment processes (if any).

2. Staff and student involvement

UNESCO-IHE	
Staff input	• Research coordination • Contribution to literature survey • Distill design criteria from research results
PhD Maeng	Multiple objective treatment aspects of bank filtration (proposal below)
MSc research	• Topic 1: Feasibility of riverbank filtration (RBF) for water treatment in selected cities of Malawi (2005-2006) • Topic 2: NOM characterization, EDCs removal and role of Schmutzdecke during river bank filtration (2006-2007) • Topic 3: soil column studies: experimental and model-based approach

3. Deliverables

M10	Nov 2006	• **D5.3-1b R** LitRev Inventory of use of BF and ARR water treatment systems (T2)
M12	Jan 2007	• **D5.3-4a R** Implement field studies in BF and ARR sites, apply models (T2) • **D5.3-3a R** Progress report MSc and staff research on soil column tests (T2)
M16	May 2007	• **D5.3-8a R** MSc theses, Report describing conceptual TecSel model (T3)



Multiple Objective Treatment Aspects of

Riverbank Filtration System

Ph.D. research proposal

By

Sung Kyu Maeng

Promoter

Prof. Gary Amy, PhD (UNSCO-IHE)

Supervisor

Saroj Kumar Sharma, PhD (UNESCO-IHE)

UNESCO - IHE
INSTITUTE FOR WATER EDUCATION

PhD Research Proposal

Multiple Objective Treatment Aspects of Riverbank Filtration System

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Delft

February 2007

Abstract

Many countries worldwide are faced with the challenge of providing safe drinking water to an ever-increasing population. However, increasing pollution of surface waters, often by wastewater effluent, has made water treatment much more difficult and expensive. Riverbank filtration (RBF) is natural water treatment process by inducing surface water to flow downward through sediment and into a vertical or horizontal well. It is a relatively low-cost and efficient technology. In historical perspective of RBF, it is first mentioned in the bible. In chapter 7 phrase 24 in Exodos, "all the Egyptians had to dig in the neighbourhood of the river for drinking water, since they could not drink the river water." RBF has been recognized as a proven method for drinking water treatment process in Europe. But these facilities have all been based on local experiences and so far, there are no tools or a methodology that would help to transfer the experiences or design of this system from one place to another. For water supply companies, currently there are no tools or guidelines for the design of RBF systems and to predict the water quality as a function of operational conditions.

The main objective of this study is to understand and to develop tools to utilize the multi-objectives water treatment potential of RBF, especially under extreme environmental conditions. This study will mainly focus on the removal of bulk organic matter, endocrine disrupting compounds (EDCs) and pharmaceutical active compounds (PhACs). This study aims to the following specific objectives: a evaluation of the changes in the character of bulk organic matter upon soil column passage to simulate the impact of wastewater effluent during RBF, a understanding the fundamental of endocrine disrupting compounds interactions occurring during RBF, a investigation of the fate and transport of selected PhACs during RBF

A framework or guidelines for the assessment or prediction of water quality (bulk organic matter, EDCs and PhACs) from a RBF system will be a very important tool for quick screening of candidate RBF project sites and to compare its costs with other conventional treatment systems. The use of this framework will facilitate the increased application of RBF technology for water treatment. This study consists of soil column and batch experiments in the laboratory (UNESCO-IHE) and field study in Korea.

Keywords: riverbank filtration, pharmaceutical active compounds, endocrine disrupting compounds, redox conditions, PH3TD

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1. Introduction

1.1 Background

1.1.1 Riverbank filtration

Riverbank filtration (RBF) is natural water treatment process by inducing surface water to flow downward through sediment and into a vertical or horizontal well by lowering hydraulic head. It is a relatively low-cost and efficient technology. In historical perspective of RBF, it is first mentioned in the bible. In chapter 7 phrase 24 in Exodos, “all the Egyptians had to dig in the neighbourhood of the river for drinking water, since they could not drink the river water.” RBF has been recognized as a proven method for drinking water treatment process in Europe. The inhabitants of Düsseldolf (approximately 600,000 people) have been supplied with drinking water through RBF in the Rhine River for 130 years (Eckert and Irmscher, 2006). Also, more than 100 filtration sites in Europe have been using RBF as drinking water treatment process and several wells have been operated more than 100 years (Irmscher and Teermann, 2002). In the United States, RBF is considered as a pre-treatment process of removing microbial pathogens and did not receive much credit as in European countries. However, numbers of RBF systems have been increased by water utilities because of its effectiveness and sustainability. For example, water utilities located in the cold region are suffering in supplying drinking water from the freezing river during winter however this would not be a problem with RBF.

It is a sustainable technology if the system is run with proper guideline in appropriate hydrogeological location because the sediment layer of subsurface and the travel time play an important role in the performance of RBF system. Thus, the feasibility assessment test including preliminary pumping test is necessary to determine the location of well. However, it is cost and time consuming work (72-hour pumping test). Currently, several ground water modeling software are available to predict the yield of RBF at user selected location in the model boundary. However, a decision tool which is able to predict the optimum location of well with respective of water quality is not available. Water utility engineers and researchers must be able to predict the removal performance of contaminants before its construction.

1.1.2 RBF under extreme environmental conditions

As the world population is increasing, provision of clean drinking water is become the most important global environmental problem around the world, especially in developing countries. Many water utilities in developed countries have been employing advanced water treatment methods like membrane filtration after pretreatment or followed by advanced oxidation. But in developing countries, most of water utilities have conventional treatment process or less and there is lack of financial resources and manpower for advanced treatment technologies. Many developing countries discharge their sewage into receiving aquatic environment without any treatment or after primary treatment. Therefore, the amount of contaminants loading is higher than that of developed countries so advanced methods (e.q. membrane filtration and advanced oxidation) may not remove all the contaminants as designed.

Natural filtration system such as RBF is attractive for drinking water production not only for developing countries but also for developed countries because it can cope with extreme variation in water quality and can efficiently deal with chemical shock load or temperature changes. However, only a few studies have done on infiltration of polluted surface water into sediment layer and were carried out in case studies (Ćosović et al., 1996; Reemtsma et al., 2000). Thus, the impact of secondary effluent on RBF was not fully understood in an operational RBF scheme and the fate of effluent organic matter derived from wastewater effluent during RBF was not considered in these studies.

1.1.3 Effluent organic matter (EfOM) in secondary effluent

Effluent organic matter (EfOM) in secondary effluent is a mixture of organic molecules of different molecular weight, structure and biodegradability however most of which have not been identified (Drewes et al., 2006). EfOM was not extensively studied compared to the natural organic matter (NOM). Therefore, several studies have tried to show the behaviour of this complex mixture by chemical characterization to isolate organic fraction in secondary effluent (Drewes and Fox, 1999; Drewes et al., 2006; Rauch and Drewes, 2004). Rauch and Drewes (2004) investigated the fate of transport behaviour of four bulk fractions in EfOM during ground water recharge: hydrophilic organic matter, hydrophobic acids, colloidal organic matter and soluble microbial product. This study revealed that the four organic fractions of EfOM showed a significantly different behaviour with respect to biodegradation. NOM derived from

the drinking water sources and soluble microbial products (SMPs) derived from conventional biological treatment plant dominate fraction of EfOM in secondary effluent. Drewes et al (2006) indicated that EfOM and NOM after soil infiltration overlap extensively in molecular weight distribution, amount and distribution of hydrophobic and hydrophilic carbon fraction, and organic carbon characterization using state-of-art analytical techniques including excitation-emission matrix fluorescence spectroscopy, size exclusion chromatograph and carbon-13 nuclear magnetic resonance spectroscopy. Thus, organic carbon characterization of EfOM is gradually transformed into organic characteristics close to NOM. EfOM has more biodegradable fraction of organic compared to NOM before soil infiltration and the degradation of biodegradable fraction during infiltration might plays role in transformation of organic carbon characteristics between EfOM and NOM. The biodegradation of bulk organic matter during aerobic soil passage indicated that aliphatic carbon sources are preferentially used, whereas during anaerobic infiltration more aromatic and double-bond are degraded according to specific UV absorbance (SUVA) in the study of RBF (Grünheid et al., 2005).

There are several reasons to reduce the concentration of bulk organic matter during water treatment even if it does not pose direct health effect to human. However, bulk organic matter (dissolved organic carbon (DOC), EfOM and NOM) gives many surface waters a distinct colour and odors, and is well known to be major precursors for the formation of disinfection by-products (Weiss et al., 2004). As mentioned above, EfOM has more biodegradable organic fraction compared to that of NOM. This fraction of the DOC is used as a substrate for the regrowth of microorganisms during distribution by providing energy and carbon (Rittmann, 1984). Also, the accumulation of polysaccharides and other biopolymers (e.q. protein) with membrane surfaces can result in serious productivity loss in water utilities. Membrane fouling is one of the impediments to use of membrane processes in drinking water treatment. Therefore, many water utilities are aimed to investigate the fate of organic carbon characterization in their water and reduce its concentration during pretreatment to prevent membrane fouling.

1.1.3 EDCs and PhACs in the receiving aquatic environment

(i) Pharmaceutical Active Compounds (PhACs)

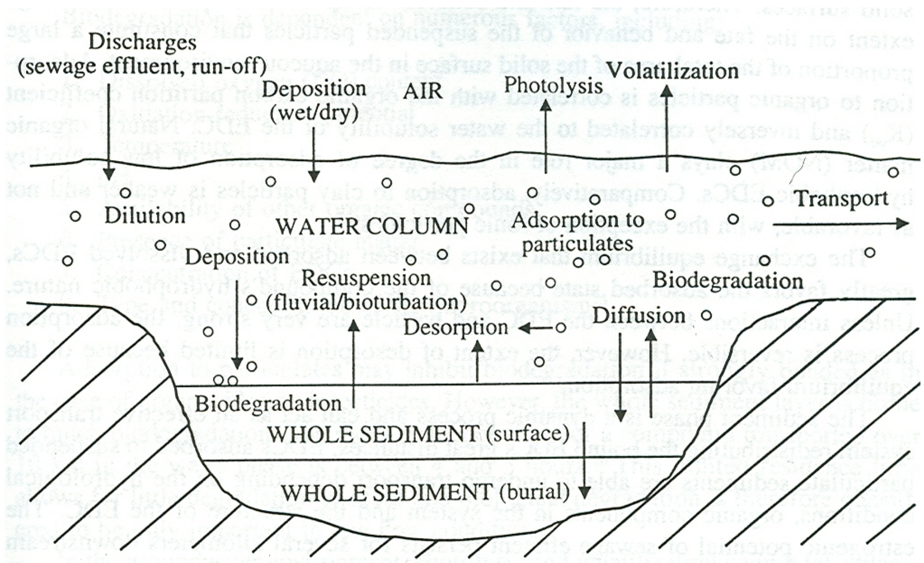
Recently, the occurrence and fate of endocrine disrupting compounds (EDCs) in receiving aquatic environment was gained much interest from scientists and public. U.S. Geological Survey conducted nationwide occurrence study on streams and rivers under the influence of secondary effluent and agricultural, and the study showed that a large number of trace organic pollutants which can give an adverse impact on human can be present in surface water and ground water (Kolpin et al., 2002). A study done by Heberer revealed more than 80 compounds of PhACs and several drug metabolites were detected in the aquatic environment of following countries: Austria, Brazil, Canada, Croatia, England, Germany, Greece, Italy, Spain and Switzerland (Heberer, 2002a). Most of PhACs are not completely taken up by the human body and some are excreted into municipal wastewater in original form or in slightly changed form (Heberer, 2002b).

Analgesics and anti-inflammatory compounds are often detected in secondary effluent. The study done by Heberer showed that PhACs such as clofibric acid, diclofenac, ibuprofen, propyphenazone, primidone, gemfibrozil, naproxen, ketoprofen and carbamazepine were detected at individual concentrations up to the μg/L-level in the effluents from sewage treatment plants (STPs) in Berlin, Germany (Heberer, 2002b). PhACs in secondary effluent subsequently reaches the surface waters and subsequently to the ground water by soil aquifer treatment or naturally occurring infiltration into aquifer. The drinking water treatment plant located downstream of sewage treatment plant provided water that contained 8 ng/L of ibuprofen and ketoprofen during winter time (Vieno et al., 2005). Even though PhACs and their metabolites are present in aquatic environments, scientists believes at the low levels of PhACs in the aquatic environment do not pose an appreciable risk to human health (Schwab, 2005). However, the possible detrimental effects of PhACs on aquatic environment and lifelong exposure are currently not well known and especially for those PhACs recently developed (Cunningham et al., 2006).

(ii) Endocrine Disrupting Compounds (EDCs)

The use of organic chemicals has been increasing for the last four decade and consequently it brings abnormalities in the aquatic environment (Blaber, 1970; Gomes and Lester, 2003; Smith, 1971). EDCs in aquatic environments interferes with endocrine glands and their hormones or where the hormones act – the target tissues. Many EDCs have nonpolar and hydrophobic characteristics and are favourably absorbed onto particulates. Therefore, most of EDCs are often concentrated in

suspended solids or sediment than in the aqueous phase and the intrusion of EDCs into ground water is minimized by its characteristics so the ground water is less influenced by the EDCs compared to surface waters. However, the sediment could be dynamic under seasonal variation and enable to carry bound EDCs for long distance or into aquifer (Figure 1). Therefore, the degradation kinetic of bound EDCs is important to investigate and it is dependent on numerous factors: redox conditions, temperature, dissolved organic matter and pH. Figure 1 shows sources and behaviour of EDCs in the receiving aquatic environment.



Source: Gomes et al. (2003)

Figure 1: Sources and behaviour of EDCs in the receiving aquatic environment.

Among many EDCs, estrogens such as estrone (E1), 17β-estradiol (E2), 17α-ethinylestradiol (EE2) showed the most estrogenic activity, and alkylphenols (APs) and their ethoxylates (APEOs) showed lesser than that of estrogens (Gomes and Lester, 2003). With advances in technology and instrumentation, estrogens could now be measured more accurately in the range of parts per trillion (ppt) and there is an increasing concern about the presence of those EDCs in aquatic environment (Shappell, 2006). Ternes et al (1999) showed the frequent presence of E1, E2 and 16α-hydroxyestrone in effluent of German and Canadian STPs within range of ng/L and a maximum concentration was 70 ng/L for estrone. Recently, several studies showed the presence of estrogens in surface waters, wastewater and treated wastewater in different

parts of the world (Carballa et al., 2004; Cargouët et al., 2004; Hintemann et al., 2006; Lishman et al., 2006; Ma et al., 2006; Nakada et al., 2005; Sarmah et al., 2006). A number of studies have reported the feminization of male aquatic species in receiving waters mainly originated from the effluents from wastewater treatment plants, and surface runoff from agricultural activities and municipal biosolids (Khanal et al., 2006). It is plausible that EDCs exposure could be harmful to humans and may be reason for some of the increases in human disorders. Therefore, more study is required to investigate the fate of most estrogenic compounds such E1, E2 and EE2 in source of drinking water.

1.2 Problem Identification

Most RBF systems located in U.S. and Europe have been successfully implemented as natural filtration systems to produce high drinking water quality (Eckert and Irmscher, 2006). In Düsseldorf (Germany), RBF wells have been used to supply the source of the drinking water along the Rhine River for 130 years (Irmscher and Teermann, 2002). In Berlin, after abstraction, aeration and rapid sand filtration are only treatments before the distribution. The environment conditions in which the RBF systems operate in North America and European countries have favourable conditions such as high quality source water with many experiences in designing RBF systems. However, such is not always true for many industrialized Asian countries and developing countries where the river carry tremendous amounts of sewage load, the hydrogeographic information is unknown, the flows vary widely among the seasons and the ground water is often polluted. Several studies were carried out to determine the performance of ground passage on polluted surface water in both field and laboratory studies (Ćosović et al., 1996; Jekel and Gruenheid, 2005; Reemtsma et al., 2000). However, the potential implications in running RBF system under extreme environmental conditions with respect to the fate and biodegradation of bulk organic matter and dissolved organic nitrogen are not well known.

With rapid development in technology and instrumentation, researchers are able to measure emerging trace contaminants more accurately and EDCs have been recognized as new category of environmental contaminants that interrupt with the function of the endocrine system (Colborn and Clement, 1992). Among these compounds, the natural (estrone and 17β-estradiol) and synthetic estrogens (ethinylestradiol) have been received most of scientific attention and classified as

inevitable endocrine disrupting compounds (Birkett., 2003). These compounds listed in the most estrogenic compounds (endogenous EDCs) observed in aquatic environments and possessed estrogenic potency 10,000 to 100,000 times higher than exogenous EDCs such as organochlorine aromatic compounds (Cargouët et al., 2004; Gomes and Lester, 2003; Hanselman et al., 2003). Wastewater treatment plants receive a large variety of EDCs but could not promise removing those compounds with current wastewater treatment technologies before discharging into the rivers. This could be vital for water utilities where their raw water is strongly influenced by wastewater effluent. Therefore, there is a possibility for remaining of EDCs in drinking water sources and could pose critical effect on human health. There is a need to understand the biodegradability, sorption and transport of estrogen compounds (E1, E2 and EE3) during RBF. Therefore, understanding the removal of those estrogens during RBF may help to provide a provision against the estrogens contamination and the development of its model will help to predict estrogen compounds removal.

Many studies have shown that RBF is a promising technology for pre-treatment of raw water prior to conventional water treatment by removing bulk organic matter and trace organic contaminants including PhACs and EDCs and reducing the cost of chemicals. However, the performance of RBF in removing those contaminants is depend on several factors including hydraulic conductivity, temperature and travel time and there is a lack of fundamental understanding of degradation of bulk organic matter and trace organic compounds under different redox conditions during the RBF. Also, one of major concerns in RBF system is the prediction of RBF performance before its construction. The model should be able to provide a decision tool in designing RBF system to help users to perceive its performance based on the model results. However, very little is known with respect to a decision tool in designing RBF system.

Currently, there is a model called NASRI bank filtration simulator and it able to predict the ratio of river water and local ground water in riverbank filtrate during RBF. The model is based on only hydraulic aspect and so far there are no tools or simulators that help to transfer the experiences or design of RBF system from one place to another. RBF has been successfully applied for water treatment in Europe and United States, and many water utilities companies have a great concern about RBF as a new source of water supply. However, these facilities have all been based on local experiences and so far, there are no tools or a methodology that would help to transfer the experiences or

design of this system from one place to another. For water supply companies, currently there are no tools or guidelines for the design of RBF systems and to predict the water quality as a function of operational conditions. Therefore, a framework or guidelines is necessary to serve as a quick screening tool to estimate the yields and treated water quality before conducting costly pilot experiments and site investigations. Therefore, this research is an innovative effort to better understand and utilize the multi-objectives water treatment potential of natural and sustainable systems like RBF.

1.3 Research hypotheses and objectives

1.3.1 Hypotheses

Four hypotheses were developed based on literature survey. Each hypothesis is elaborated below along with brief statement supporting its development.

(i) Effluent organic matter (EfOM) found in wastewater effluent will have minimum impact on RBF and will enhance its degradation rate. Its performance can be verified using laboratory-scale soil column study. Both EfOM and NOM show heterogeneity with respect to organic fractions and they can be characterized by molecular weight distribution, size exclusion chromatography, specific ultraviolet absorbance, fluorescence and carbon-13 nuclear magnetic resonance spectroscopy (Drewes et al., 2006). EfOM has more biodegradable organic carbon fraction than that of naturally derived organic matter according to the preliminary experiment (result is not shown). Therefore, more viable biomass and variety of microorganisms' distribution may attached in soil can enhance the degradation of bulk organic matter. Biodegradable organic carbon (BOC) limits soil biomass growth during soil infiltration of conventionally treated effluents (Rauch-Williams and Drewes, 2006). The removal of different organic fractions (NOM, EfOM, glucose and glutamic acid) showed a positive correlation with respect to total viable biomass in the column study (Rauch and Drewes, 2005).

(ii) The variation in the bulk organic matter and the redox conditions affects biomass activity to remove estrogen compounds during riverbank infiltration. The degradation of free estrogen compounds is mainly involved biodegradation and showed in biotic column study and estrogen concentrations high enough to cause the detrimental effect on endocrine system in aquatic environments were still remained under abiotic conditions (DEPA, 2004). Biodegradation fraction of bulk organic matter

will be limiting factor on the biomass, and total viable biomass will play an important role in degrading estrogen compounds. More estrogen compounds were degraded in higher concentration of biosolids (Ternes et al., 1999). Therefore, total viable biomass in soil may vary the degradation rate of estrogens. Also, the changes in redox conditions during RBF may significantly influence the degradation kinetic organic compounds including estrogens. In many cases 17β-estradiol (E2) could be readily transformed to estrone (E1) however the complete degradation of estrogen compounds under anoxic conditions was minimal (Czajka and Londry, 2006). During RBF, if dissolved oxygen is rapidly depleted, estrogens may accumulate in the aquifer because of its potential to be recalcitrant under anoxic conditions. The redox conditions may drive the fate of estrogen compounds in the environment and impact on both the rates and mechanisms of estrogen compounds transformation.

(iii) The removal of PhACs during RBF can be optimized by controlling redox conditions. A recent study shows that the effect of variable redox conditions on the behaviour of a number of PhACs including cabamazepine, phenazone, and several phenazone-type PhACs (Massmann et al., 2006). In this study, oxygen concentration changes in infiltrate through out the season reflect on the removal of PhACs, and the role of oxygen presence during RBF was more decisive than the temperature dependency. During the winter, when oxygen concentrations were high in infiltrate, the removal of Phenazone-type pharmaceuticals was more efficient than summer. Phenazone-type pharmaceuticals known as redox sensitive PhACs and able to fully degrade during in winter when oxygen concentration is high even phenazone-degrading bacteria (aerobic) may prefer for high temperature. Therefore, the redox conditions play an important role in removing phenazone-type pharmaceuticals. Conversely, Vieno et al. (2005) showed that cold season can severely increase the environmental risk of pharmaceuticals (ibuprofen, naproxen, ketoprofen, diclofenac, and bezafibrate) and the risk for contamination of drinking water because the elimination of the PhACs decreased significantly in a sewage treatment plant (STP) (an average of 25% compared to spring and summer) in wintertime leading to increased concentrations of PhACs in the effluent water. A drinking water treatment plant (DWTP) located downstream from the STP has a high risk of PhACs in their produced water. In this case, employing RBF system may prevent the introducing PhACs into DWTP. Further investigation is required to conduct on other PhACs in order to conclude the role of oxygen presence is more decisive than the temperature in removing PhACs during RBF. The experiment on biodegradability of emerging PhACs

under different redox conditions should be used to advance the prediction of RBF system and able to manage the risk of PhACs in riverbank infiltrate. However, there have been very limited studies done in the prediction of PhACs from RBF.

(iv) A modeling framework provides a means of assessing the operational variables in order to obtain an optimal configuration of RBF systems with respect to required bulk organic matter, EDCs and PhACs removal efficiency. The reported removals of dissolved organic carbon - DOC (organic matter), selected trace organic compounds, nitrogen-species (ammonia and nitrate) as well as microbes during RBF will be analyzed using statistical techniques such as multiple regression and principal component analysis in order to delineate removal trends as a function of site characteristics and operating conditions. In this study, hydraulic models and chemical models (e.g., performance algorithms for DOC, nitrogen, selected trace organics, and microbes) will be combined to develop a framework or guidelines for prediction of water quality.

1.3.2 Objectives

Based on the literature survey and the hypothesis prepared above, the following are the specific objectives of this study.

1) To evaluate changes in the character of bulk organic matter upon soil column passage to simulate the impact of wastewater effluent during RBF
2) To understand the fundamental of endocrine disrupting compounds (estrogen compounds) interactions occurring during RBF
3) To investigate the fate and transport of selected pharmaceutical active compounds (PhACs) during RBF
4) To develop a modeling framework or decision support tool for the assessment and prediction of the treated water quality (bulk organic matter, EDCs and PhACs) from a RBF system

2. Literature Review

2.1 Riverbank filtration performance

2.1.1 Fundamental removal mechanisms in riverbank filtration

Riverbank filtration (RBF) systems have shown potential to remove (1) both natural organic matter and effluent organic matter that served as a precursor to the disinfection by-product (Ray et al., 2002; Vogt, 2003; Wang et al., 2002); (2) pathogenic microorganisms including *Cryptosporidium*, *Giardia* and viruses (Berger, 2002; Schijven et al., 2002); (3) EDCs such as estrogens; (4) PhACs. There are different mechanisms involved in contaminants removal during RBF.

Physical process: Surface water contains variety size of solids from small particle (colloids) to suspended solids and those can be removed by the pore size of aquifer materials by preventing solids transport along the pathway to recovery well. In same time, microorganisms attached to the solids are also removed as well (Ray et al., 2002).
Geochemical process: The travel time of RBF is usually more than a month before the time that reaches the recovery well, therefore surface water containing bulk dissolved organic matter will easily adsorbed into the soil.
Biological process: Surface water contains dissolved organic mater which is substrate of microorganisms. Unless the level of river is higher than the level of ground water, surface water infilter into the aquifer region and degradable organic matter will be used as electron donor when electron acceptors are not limited. The degradation rate of organic matter is different due to the different electron acceptors available along the aquifer depth. If the availability of dissolved oxygen is limited for electron acceptors, the redox potential drops and proceeds in a sequential order from the highest yield downward (Table 1). Degradable organic pollutants are therefore subject to a wide range of redox conditions that should remove most of them from the infiltrating river water.

Table 1. Sequence of microbially mediated redox processes

Aerobic respiration
$CH_2O + O_{2(g)} \rightarrow CO_{2(g)} + H_2O$
Denitrification
$CH_2O + 0.8\ NO_3^- + 0.8\ H_2O \rightarrow CO_{2(g)} + 0.4N_{2(g)} + 1.4\ H_2O$
Mn(IV) – reduction
$CH_2O + 2MnO_{2(s)} \rightarrow 2Mn^{2+} + 3H_2O + CO_{2(g)}$
Fe(III) – reduction
$CH_2O + 8H^+ + 4Fe(OH)_{3(s)} \rightarrow 4Fe^{2+} + 11\ H_2O + CO_{2(g)}$
Sulfate-reduction
$CH_2O + 0.5SO_4^{2-} + 0.5H^+ \rightarrow CO_{2(g)} + 0.5HS^- + H_2O$

Source: (Lensing et al., 1994)

2.1.2 General factors affecting riverbank filtration systems

Different factors affect the performance of RBF system. They include (i) raw water quality, (ii) well types, (iii) location and alignment of the wells, (iv) travel time, (v) Clogging and (vi) Schmutzdecke

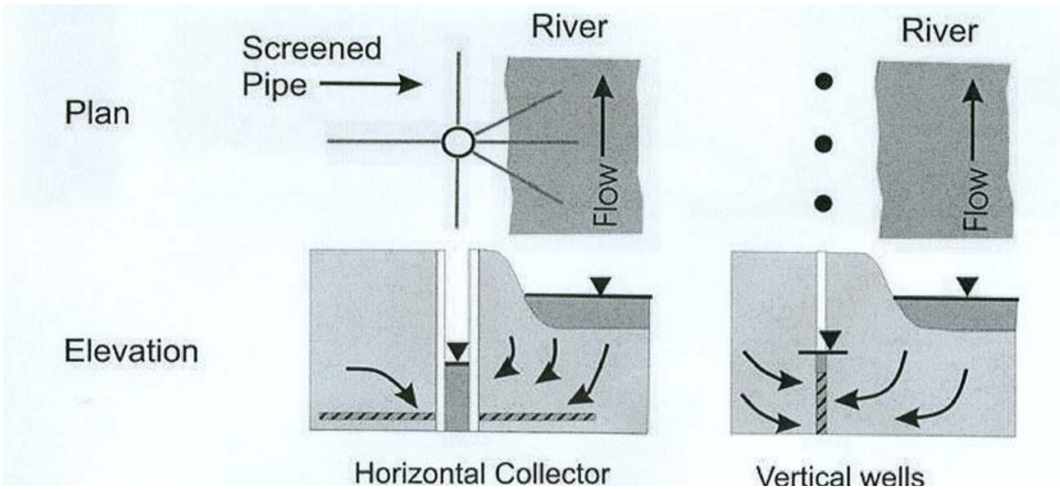
(i) Raw water quality

Raw water quality is one of the main factors affecting the performance of RBF systems. Rivers carrying less polluted water in terms of suspended matter, turbidity, NOM, industrial discharge, wastewater discharge, pesticides etc. will be easier to treat than heavily polluted rivers. Heavily polluted river water requires more travel length or detention time. In addition, RBF systems with heavily polluted river water are more susceptible to riverbed clogging.

(ii) Well types

RBF wells can either be horizontal or vertical depending on the hydrogeologic setting, the required production rate, and the utilities preference. Shallow alluvial deposits and a higher rate of pumping from a given location are often favour for horizontal wells, sometimes called collector well. The laterals of the horizontal well can all be directed towards the river or distributed in all directions. The horizontal wells yield higher production rates than the vertical wells however it costs more than that of the vertical wells. Despite the horizontal wells being in use for more than 10 years, there are no specific design requirements in regulation and little is known about the horizontal

wells modelling. Figure 2 below provides a schematic diagram of the representation of two types of RBF wells.



Source: Ray et al., 2002a

Figure 2. A schematic diagram of the representation of types RBF systems

(iii) Location and alignment of the wells

Though biologically mediated degradation processes mainly occur at the first meter of the flow path from the top of the riverbed (schmutzdecke) to the well from the river to the well, distance of the production well from the river also plays an important role in the water quality improvement of riverbank filtrate through the process of adsorption and biogeochemical reaction. In general, if the travel time in subsurface increases, the quality of the riverbank filtrate improves however redox sensitive organic compounds such as phenazone may not significantly affected by the travel time (Greskowiak et al., 2006).

(vi) Clogging

Clogging reduces aquifer recharge rates and may therefore be perceived as a problem in water supply systems. Recent investigations have indicated that riverbed conductance is likely the limiting factor in high-capacity RBF systems (NWRI, 2003). However, the impact of riverbed conductance and its change with time has not been thoroughly evaluated. It has been observed that riverbed conductance varies as a function of time, which is likely the result of riverbed clogging. This clogging can be caused by mechanical particle impingement, biological growth, or geochemical

reactions within the aquifer/riverbed interface. However, the impact of these factors on the long-term specific capacity of a well field is poorly understood.

(vii) Schmutzdecke

The schmutzdecke in RBF is a biofilm formed at the river bed/bank - water interface. In general, it consists of numerous forms of life including algae, plankton, diatoms, protozoa, and bacteria. The schmutzdecke is a layer where inert suspended particles can be mechanically strained, organic matter and nitrogenous compounds broken down, and microorganisms entrapped (Huisman, 1989). This biological active layer is a key element in the attenuation of contaminants at RBF sites. If this surface layer is removed during floods due to the high shear stress, the chance of contaminants penetrating through riverbed to the recovery well is increased. To assess the risk of such events and to have proper monitoring tools, it is crucial to understand how this protective layer is re-established following flood events in the rivers. However, the mechanism of restoration in the schmutzdecke is still not known.

2.1.3 Removal of effluent organic matter during RBF

The fate and removal bulk organic matter derived from wastewater effluent (EfOM) has become quite a concern for indirect potable reuse system (Cha et al., 2004; Drewes et al., 2006; Grünheid et al., 2005; Rauch-Williams and Drewes, 2006; Rauch and Drewes, 2004; Rauch and Drewes, 2005). EfOM contains natural organic matter (NOM) originated from drinking water, anthropogenic organic compounds remaining in secondary effluent and soluble microbial product (SMP) excreted during the biological wastewater treatment process (Drewes et al., 2006). NOM dominated by humic substances in EfOM serve as a precursor to disinfection-by-products (DBPs) and also cause colour. Anthropogenic organic compounds include endocrine disrupting compounds (EDCs) and pharmaceutically actives compounds (PhACs) known as persistent compounds during conventional wastewater treatment process (Grünheid et al., 2005). Soluble microbial product (SMP) is also refractory organic compound in EfOM that is very poor absorbable to activated carbon and difficult to remove with current post-treatment process (Rauch and Drewes, 2004).

Commonly, XAD-8 and XAD-4 are used to characterize EfOM matter and separate into hydrophilic fraction and hydrophobic fraction based on affinity of organics in a water sample (Drewes et al., 2006; Weiss et al., 2004). Acidified samples (pH 2) pass

through XAD-8 resin and organics in effluent defined as hydrophilic fraction. EfOM adsorbed on XAD-8 resin was eluted by NaOH and defined as hydrophobic fraction. During the soil passage of secondary effluent in short term period, hydrophilic organic matter was preferentially removed as compared to hydrophobic organic matter (Drewes et al., 2006). However, Weiss et al (2004) showed that no significant, consistent, preferential removal of either fraction upon ground passage. The fraction of both hydrophilic and hydrophobic organic matter did not show any significant change during RBF. The long travel time of riverbank filtrate in this study may have reduced slowly degradable hydrophobic organic fraction.

SUVA (specific UV-absorbance) is an indicator to determine the aromatic content of NOM and it is defined as the ratio of UV-absorbance at 254 nm to the DOC concentration (L/mg-m). Commonly, the hydrophobic organic matter showed a higher value of SUVA than that of hydrophilic organic matter (Weiss et al., 2004). This was shown to reflect a preferential removal of non-humic over humic substances. Grünheid et al. (2005) showed that SUVA values were increased during aerobic soil passage and most of aliphatic carbon sources were preferentially removed by biodegradation under aerobic condition whereas more UV absorbing compounds such as aromatic and double-bond structures were degraded during anaerobic infiltration. The LC-OCD measurements confirm part of this assumption that the fraction of humic substances, humic building block and low molecular weight acids (LMA) were partially removed in well water which had longer travel time under anoxic/anaerobic conditions (Grünheid et al., 2005).

The removal of bulk organic matter derived from secondary effluent undergo through variety of mechanisms during ground passage of RBF or soil aquifer treatment. Sorption and biotransformation have been commonly known as the dominant mechanism in removing bulk organic matter however only few studies have attempted to investigate the factors contributing in each process and their relative contributions in removing bulk organic matter. The majority of organic carbon is removed by the biodegradation during infiltration and total viable soil biomass was used as an indicator for the biological removal of EfOM during soil infiltration (Rauch and Drewes, 2005; Rauch and Drewes, 2006). A strong positive correlation between total viable soil biomass and organic carbon removal was showed and it reflects that biodegradation is a key mechanism in removing EfOM during soil infiltration. Although other environment factors including total viable soil biomass, travel time, temperature and

redox conditions are needed to be considered, only few studies have attempted to investigate the contribution of each factor during soil infiltration (Grünheid et al., 2005; Massmann et al., 2006; Ray, 2006). Understanding the effect of these factors during infiltration from surface water into the aquifer system (organic matter, microbes, trace organics and nitrogen) the quality of riverbank filtrated water can be predicted.

2.2 EDCs and PhACs removal during RBF

2.2.1 Role of physicochemical properties of PhACs and EDCS

In order to achieve understanding the removal of PhACs and EDCs mechanisms during RBF, the role of physicochemical properties in their fate and behaviour in water. The important physicochemical properties in removing EDCs and PhACs for riverbank filtrate drinking water are solubility, octanol/water partition coefficient (K_{ow}) and Henry's Law constant (H_c). Most of EDCs and some PhACs are favour to adsorb to surface of biota or solids because of their nature (Nonpolar and hydrophobic). The degree of partitioning of a given compound is determined by their solubility and partition coefficient. The solubility of a given compound in water reflects its affinity for water. For those compounds have high solubility in water commonly shows greater mobility during soil infiltration and often detected in riverbank filtrate water. The affinity of a given compound is expressed by its log K_{ow} value and often used to describe hydrophobicity. Therefore, to enhance association with the solids surface and biota, a compound with low solubility in water and a high K_{ow} is preferred. H_c is indicator of volatilization potential of a given compound that might evaporate during post-treatment of riverbank filtrate water. Commonly, aeration or ozone is often used in riverbank filtrate water followed by rapid sand filtration for iron or manganese removal. A detail description of physicochemical properties for selected EDCs and PhACs is mentioned in Chapter 3.

2.2.2 Adsorption

RBF could be complex process with respect to adsorption of organic compounds. The heterogeneous environment and site specific conditions reflect different results of removal organic compounds. EDCs and PhACs with hydrophobic properties tend to preferentially adsorb onto suspended solids and sediment during infiltration. The K_{ow} values often used to determine the degree of association between the organic

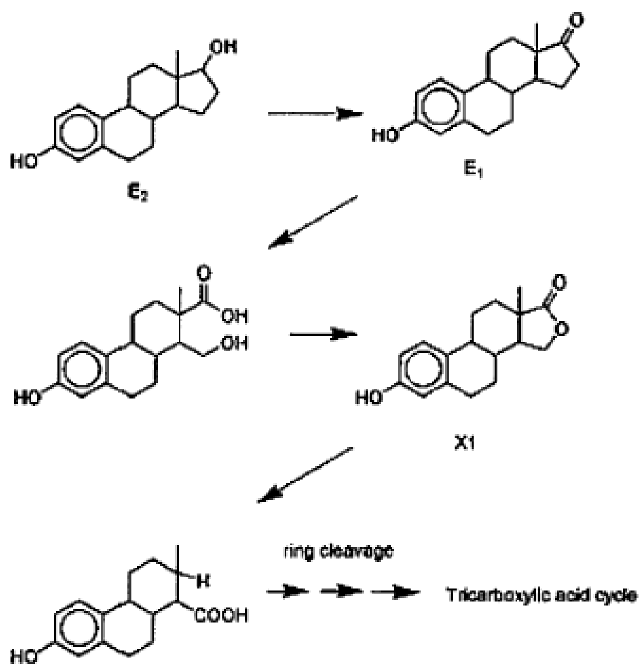
compounds and the solid phase. K_{ow} is defined by the concentration ratio at equilibrium of organic compounds partitioned between octanol and water. Among other quantitative physical properties, K_{ow} shows a good correlation with biological activities and gives a better indication of the degree of adsorption by microorganisms with biological activity. The K_{oc} is also important when considering adsorption because it is organic-carbon/water partition coefficient. A compound with a high value of K_{oc} will tend to adsorb on organic content such as biomass, whereas a low value remains in liquid phase. Adsorption of organic compounds on biomass and inorganic is important in removing PhACs and EDCs because this is the first step in biological degradation of these compounds.

2.2.3 Biodegradation and transformations

Biodegradation by aquatic microorganisms can play an important role in fate of EDCs and PhACs, especially for those PhACs compounds that have highly water-soluble with low K_{ow}. If PhACs have low K_{ow} values, those compounds will be high mobile and probably migrate into the ground water easily, and sorption is not significant in this case therefore biodegradation is major part of reduction (Holm et al., 1995). Several studies showed a high potential of biodegradation of lipid regulator and ani-inflammatory drugs during soil filtration but some antiepileptic drugs such as carbamazepin and primidone were not removed during wastewater treatment and soil infiltration and are known to be very persistent in terms of the biodegradation and the adsorption. (Drewes et al., 2002; Heberer, 2002b; Scheytt et al., 2006).

The biodegradation of EDCs from water, sediments, and soils is expected to be occurred as a result of a combination of physical sorption and binding to biota. Published studies showed that natural estrogens estrone (E1) and 17β-estradiol (E2) in sewage treatment plants or batch experiment using municipal sludge were largely degraded biologically (Andersen et al., 2003; Khanal et al., 2006; Shappell, 2006; Suzuki and Maruyama, 2006). The removal mechanism of the estrogens during soil infiltration is adsorption to the soil and subsequent additional attenuation by biodegradation (Mansell et al., 2004; Ying et al., 2003). Danish Environment Protection Agency (DEPA) reported that the degradation of free estrogens was achieved mainly through biodegradation because the level of estrogens still remained constant at an initial estrogen level of 500 ng/L as E2 equivalent in an abiotic column during a soil column study (DEPA, 2004). The removal of E2 should be considered

more than just degradation of its compound because E1 which is intermediate compound from E2 oxidation still posses estrogenic activity at 0.1-0.2 of E2 equivalent. Thus, ^{14}C-labeled E2 compound was used to demonstrate its fate during mineralization, and bacteria presented in the activated sludge from wastewater treatment plant were capable to mineralize 70 to 80% of E2 to carbon dioxide in 24h (Layton et al., 2000). The biodegradation pathway of E2 by sewage bacteria is shown in Figure 3. The oxidation of the cyclopentane ring D at C17 of E2 into E1 in enzymatic degradation and then E1 is further degraded into X1 metabolite and finally removed through a tricarboxylic acid (TCA) cycle to carbon dioxide.



Source: (Khanal et al., 2006)

Figure 3. Pathway of estrogen (E2 and E1) degradation

Generally, biodegradation of EDCs and PhACs is associated with numerous chemical factors including structure characteristics and environmental factors such as redox conditions. First, in regard to structure characteristics, molecules with highly branched hydrocarbon chain are less favourable to biodegradation than unbranched chains and the long chains are more quickly biodegrade compared to the short chain. Second, the extent of biodegradation of EDCs and PhACs during RBF may be

different under oxic and anoxic/anaerobic conditions. Sulfonamides (antibiotic for urinary infections) was degraded strongly under anaerobic condition and most of its derivatives are attenuated in the zone characterized as methanogenic/sulphate-reducing and iron-reducing conditions (Holm et al., 1995). Phenazone-type pharmaceuticals, is antipyretic pharmaceuticals that have been detected during routine analysis for ground water in north-west Berlin (Massmann et al., 2006). It is redox sensitive PhACs and was generally degraded under oxic condition however when temperature increases during summer which promotes anoxic/anaerobic conditions in the region of aquifer then the phenzone was not fully eliminated.

2.2.4 Quantitative structure activity relationships (QSARs)

Biodegradation plays an important role in removing mechanisms of organic chemicals in the environment and also it is a key parameter for determining the risk of long term adverse effects on aquatic environment. Information on the degradability of chemicals may be used for hazard and persistency assessments. For example, USEPA assesses thousands of chemicals in each year to determine toxicological effects of the chemicals. The premanufacture notices (PMN) submitted to the USEPA are required for new chemicals for approval, but PMN reports often do not contain information regarding the biodegradability of the compounds. Biodegradability of chemicals is a crucial piece of information in determining their potential risk. (Boethling et al., 2003). This suggests the need of predictive model to estimate the biodegradability of chemicals in both reliable and conveniently ascertain way with little or no dependence on measured input (Raymond et al., 2001). A number of models have been developed to predict biodegradation. These models include structure biodegradability relationships (SBRs) activity and quantitative structure biodegradability relationships (QSBRs). SBRs estimate qualitative endpoints such as passing or failing a ready biodegradation test. QSBR provide an estimation of rate or half life.

Table 2 summarize the developed QSBR models (heterologous biodegradability correlation) for predictive used in determining the biodegradability of various chemical compounds (Raymond et al., 2001). Each model was ranked according to its complexity, accuracy, effective range of chemical structures, reliability of data set, and size of data used to develop in the model. The scale of ranking model is from 1 to 10. The evaluation and comparison of these models are carried for initial comparison purposes only and this assessment was based on very subjective and judicious

interpretation by Raymond et al (2001). Each model in the table indicates its benefits and limitation. The group contribution method by Howard et al.(1992), also known as BIOWIN, shows the most appropriate for use in predictive screening of biodegradability of various chemicals. The model includes a great extent of chemicals from BIODEG and the ministry of international trade and industry (MITI, Japan), and these two databases are recognized as the most reliable source of biodegradation. Among many other methods developed in QSBR, BIOWIN is appeared to be the most advantageous for use in broad screening for tendency to biodegrade.

BIOWIN is a predictive model based on group contribution method that assesses aerobic biodegradability of a wide variety of chemical structures (Jaworska et al., 2003). The original model of BIOWIN (BIOWIN1 and BIOWIN2) had 35 structural fragments, and coefficients of those fragments were developed by linear and nonlinear regression using 264 chemicals in the BIODEG database that has two or more biodegradation studies. Two years after BIOWIN1 and BIOWIN2 were developed, a revised version of BIOWIN was introduced with redefined substructures and molecular weight as independent variable. New coefficients were developed by linear and nonlinear regression using 250 chemicals from the BIODEG database. Two new models were introduced using semiquantitative estimation of rates of primary (BIOWIN3) and ultimate (BIOWIN4) biodegradation. BIOWIN model of linear equation is defined as:

$$Y_j = a_0 + a_1 \cdot f_1 + a_2 \cdot f_2 + \cdots a_{36} \cdot f_{36} + a_m \cdot Mw_j + e_j \qquad (1)$$

where *fn*: number of nth substructure in *j*th chemical; a_0: the equation intercept; an: the regression coefficient for *j*th substructure; Mw_j: molecular weight; a_m: regression coefficient for *Mw*; e_j: error term

The variable Y is the probability of *j*th chemical biodegradation as a binary indicator. A value of 1 represents the threshold for fast degradation, and zero for slow biodegradation. In addition, nonlinear model was determined the probability of aerobic biodegradation to compare to the linear correlation. It is represented as follows:

$$Y_j = \frac{\exp(a_0 + a_1 \cdot f_1 + a_2 \cdot f_2 + \cdots a_{36} \cdot f_{36} + a_m \cdot Mw)}{1 + \exp(a_0 + a_1 \cdot f_1 + a_2 \cdot f_2 + \cdots a_{36} \cdot f_{36} + a_m \cdot Mw)} \qquad (2)$$

Table 2. Comparison of QSAR models

Author	Method	Complexity	Accuracy	Range	Reliability of data	Size of data set
Dearden et al (1987)	Atomic charge	④	⑧	⑥	⑥	⑦
Geating (1981)	DA[a]/GC[b]	⑨	⑦	⑦	⑤ − ⑥	⑧
Gombar et al (1990)	DA	③	⑧	⑧	⑦	⑧
Howard et al (1992)	AERUD	⑦	⑦	⑤	③	②
Howard et al (1992)	GC[c] (BIOWIN)	⑩	⑧	⑦	⑦	⑧
Klopman et al (1994)	PR[d] (CASE)	①	⑤	⑦	⑦	⑧
Klopman et al (1994)	PR (META)	①	⑦	⑦	⑦	⑩
Niemi et al (1987)	DA	②	⑨	⑥	⑥	⑧
Tabak et al (1993)	GC	⑩	⑥	④	⑦	①
Tabak et al (1993)	Neural net/ GC	⑦	⑦	④	⑦	①

DA[a]: discriminant analysis; GC[b]: group contribution; PR[d]: pattern recognition

Source: (Raymond et al., 2001)

Most updated version of BIOWIN consist a total of six models including the linear and nonlinear BIOWIN probability that reparameterized for the MITI data (BIONWIN5 and BIOWIN6). Two new models were developed based on the results (pass/no pass) from the MITI test for 884 discrete organic substances. New fragments were added into the model (hydrazine, organotin, quaternary ammonium and fluorine and some of old fragments were changed. Among the changes made in this model, the modification made to better account for molecular size and branching in alkyl-containing molecules and aromatics (Jaworska et al., 2003).

2.3 Modeling filtrate quality in RBF system

2.3.1 Flow simulation

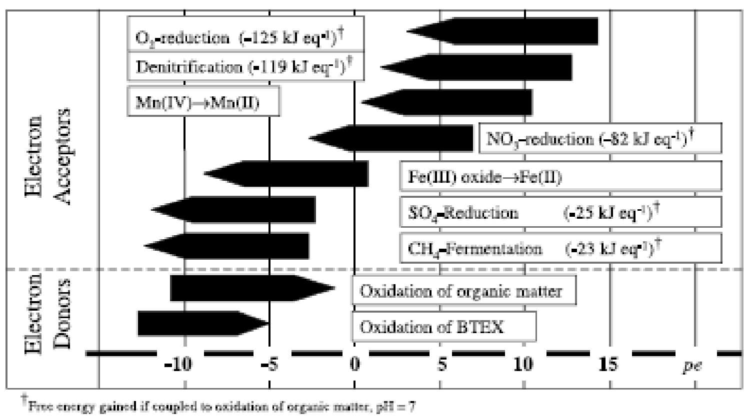
Predicting the extent of natural attenuation of contaminants in surface water along the pathway of ground passage during RBF is important for both existing and projected facilities. A major concern in RBF systems is the fate and transport of organic compounds during the infiltration of surface water to the pumping well. The development of RBF models is required to use the flow model and the reactive transport model to estimate the yield and the water quality of the riverbank filtrate water, respectively. A flow simulation model needs to be defined prior to considering reactive transport modeling of contaminants (Ray, 2003). Most of flow models used for RBF system is divided into analytical and numerical methods. Flow simulation model begins with a conceptual understanding of the physical problems and translate the physical systems into the mathematical terms.

Currently, numerical models are widespread in simulating stream-aquifer interaction. MODFLOW is the mostly widely used of ground water computer model developed by USGS and has become the worldwide standard ground water flow model which simulates three-dimensional (3D) ground water flow using the finite-difference method and commonly used for estimating stream-aquifer interaction modeling (Barlow and Harbaugh, 2006). In MODFLOW, many built-in packages (river, drain, well, etc…) are available and represents as grid in model boundary. The flow direction between the river and the aquifer is depended on their hydraulic heads. If the hydraulic head in the aquifer is lower than the river stage, then the flow is from the river to the aquifer and vice versa. MODPATH is 3D particle tracking program for MODFLOW and used to conduct to advective tracking of neutrally buoyant particles in the flow field using forward or reverse particle tracking techniques. Tracking particles from the pumping well to the riverbed would be able to determine the influence of RBF system on the hydraulic head of the region and the travel time between any two points in the model boundary.

2.3.2 Modeling of multi-species transport and biogeochemical process

For a dissolved chemical that has strong dependency on the concentration of one or more other dissolved species, reactive multi-species models can typically provide a better simulated description (Ray, 2003). A reactive multi-component transport model

needs to be applied when sediment-water interaction changes the water quality by mineral dissolution/precipitation, ion-exchange reactions, redox conditions and biodegradation. Therefore, a multi-component transport model typically requires an extensive reaction database. In the reaction database of multi-component transport models, the degradability of DOC and the redox conditions are key elements to simulate the reactions in the surface water along the soil passage. During the induced infiltration process, river water penetrates the aquifer, as does DOC under oxic condition (dissolved oxygen 6-8 mg/L). During its travel path, DOC from river water is degraded or mineralized completely, or transformed to intermediates through bacterial catalysis. DOC is strongly dependent on the redox conditions during microbially medicated degradation and aerobic degradation is most favourable followed by anoxic degradation under the sequence of following electron acceptors: nitrate, manganese, sulfate, iron and methane (Figure 4).



Source: (Barry et al., 2002)

Figure 4. Redox sequence that donate electrons and species that accept electrons

Oxygen is used as an electron acceptor in the process however oxygen can become depletion short after introducing to travel path of riverbed.

$$CH_2O(NH_3)_{0.15} + 1.3O_2 \rightarrow HCO_3^- + 0.15NO_3^- + 1.15H^+ + 0.15H_2O \qquad (3)$$

Once microbes consume the oxygen, an anoxic zone develops where the nitrate of the infiltrating river water and ground water is used as a substitute electron acceptor.

$$CH_2O(NH_3)_{0.15} + 0.90NO_3^- \rightarrow HCO_3^- + 0.52N_2 + 0.11H^+ + 0.67H_2O \qquad (4)$$

Once nitrate is also depleted, thermodynamically less favourable oxidized manganese might act as alternative electron acceptors.

$$CH_2O(NH_3)_{0.15} + 2.225MnO_2(s) + 3.45H^+ \rightarrow HCO_3^- + 0.075N_2 + 2.225Mn^{2+}O_2 + 2.45H_2O \qquad (5)$$

where $CH_2O(NH_3)_{0.15}$ was used to represent simplified version of generalized organic matter composition $(CH_2O)_{106}(NH_3)_{16}(H_3PO_4)$ (Greskowiak et al., 2006). Mineralization of organic matter is described by standard Monod-type rate expression:

$$r_{OM} = f_t[r_{OX}(\frac{C_{OX}}{K_{OX}+C_{OX}}) + r_{nitr}(\frac{C_{nitr}}{K_{nitr}+C_{nitr}})(\frac{K_{OX\,inh}}{K_{OX\,inh}+C_{OX}}) + r_{mn} \qquad (6)$$

r_{om} : Overall degradation rate of organic matter

$r_{ox},\ r_{nitr},\ r_{mn}$: Maximum rate constants under aerobic, denitrifying and manganese-reducing conditions

C_{ox}, C_{nitr} : Concentration of DO and nitrate

K_{ox}, K_{nitr} : Half-saturation concentration

$K_{ox\,inh},$: Inhibition constant

Transport model

The development of MT3D and its multi-species transport simulator MT3DMS provided the starting point for a number of models that simulate hydrological reactive transport model for multiple chemical species and the chemical reaction in these species (Prommer et al., 2003). MT3D is the probably the most common single species transport simulator that is used conjunction with MODFLOW. MT3D and MT3DMS is used same grid of MODFLOW and solves advection-dispersion equation, along with sorption and degradation reactions, to estimate the concentration of a contaminant at a given location in the model domain. A detailed description of structures and properties for MT3DMS model is described elsewhere (Prommer et al., 2003).

Biogeochemical model

Biogeochemical modeling code PHREEQC-2 is able to calculate all concentration changes of aqueous components as result of the computation of reactive processes. In contrast to previous models PHREEQE and PHREEQC, PHREEQC-2 has capability

of simultaneously solving arbitrary, kinetically controlled reaction in addition to geochemical equilibrium problems. A full set of biogeochemical reaction data by PHREEQC-2 with ion exchange, aqueous complexation and mineral precipitation/dissolution is able to solve most of subsurface interaction/transport problem (Prommer et al., 2003). A detailed description of structures and properties for PHREEQC-2 model is described elsewhere (Parkhurst and Appelo, 1999)

A novel approach called PHT3D for solving problems associated with modelling the multicomponent reactive transport has been developed (Prommer et al., 2003). PHT3D is a three-dimensional reactive component model for saturated model which combines the previously mentioned model MT3DMS (Release 4.0) with a geochemical model for the quantification of reactive processes, PHREEQC-2 (Release 2.4). PHT3D can handle a broad range of equilibrium and kinetically controlled reactive processes including aqueous complexation, mineral precipitation/dissolution, and ion exchange (Prommer et al., 2003). Also, PHT3D can include process/reactions such as microbial growth and decay via the extensible PREEQC-2 database file. In PHT3D redox reactions can be connected by applying the so-called partial equilibrium approach (PEA). McNab and Narasimhan (1994) proposed the use of a PEA to model biogeochemical processes and showed redox zonations in a number of field studies (McNab.Jr. and Narasimhan, 1994). The entire degradation of an organic compound is expressed in two steps instead of the single step process. The first reaction is consumption of substrate and production of biomass and electrons. The second reaction balances the production of electrons by PEA method under following assumptions: i) the electron donors (oxidation of organic matter or oxidation of EDCs or PhACs) is the rate limiting step that control overall reaction kinetics and ii) the electron acceptors are instantaneous reaction. Therefore, the terminal electron acceptors are used in order of their thermodynamic favourability.

Greskowiak et al recently applied PHT3D model to simulate the transport and reactive processes on the fate of pharmaceutical residue phenazone near a artificial recharge scheme at an infiltration site in Berlin, Germany (Greskowiak et al., 2006). The degradation of phenazone is varied during infiltration because it is sensitive to redox conditions. The result provided by PHT3D model showed an excellent agreement between simulated and measured phenazone concentrations. PHT3D is comprehensive and ideal to study both steady and transient effects. However, the model requires extensive data and the field data may not be available to support the

simulation. As the model gets more complex, input parameters are rarely found in the literature and are very site specific. Laboratory-scale experiment can be carried out to determine input data however the simulation of field site using those data may not be warranted due to scale-issues. Therefore, field monitoring must be incorporated to verify model predictions.

3. Research Approach and Methodology

3.1 Introduction

The main objective in this research includes (i) laboratory soil column and batch studies, (ii) field study in Korea and (iii) modelling for water quality predictions. Figure 5 shows the approach that will be used in this study. To accomplish the goal of the study, following four studies are required to carry out.

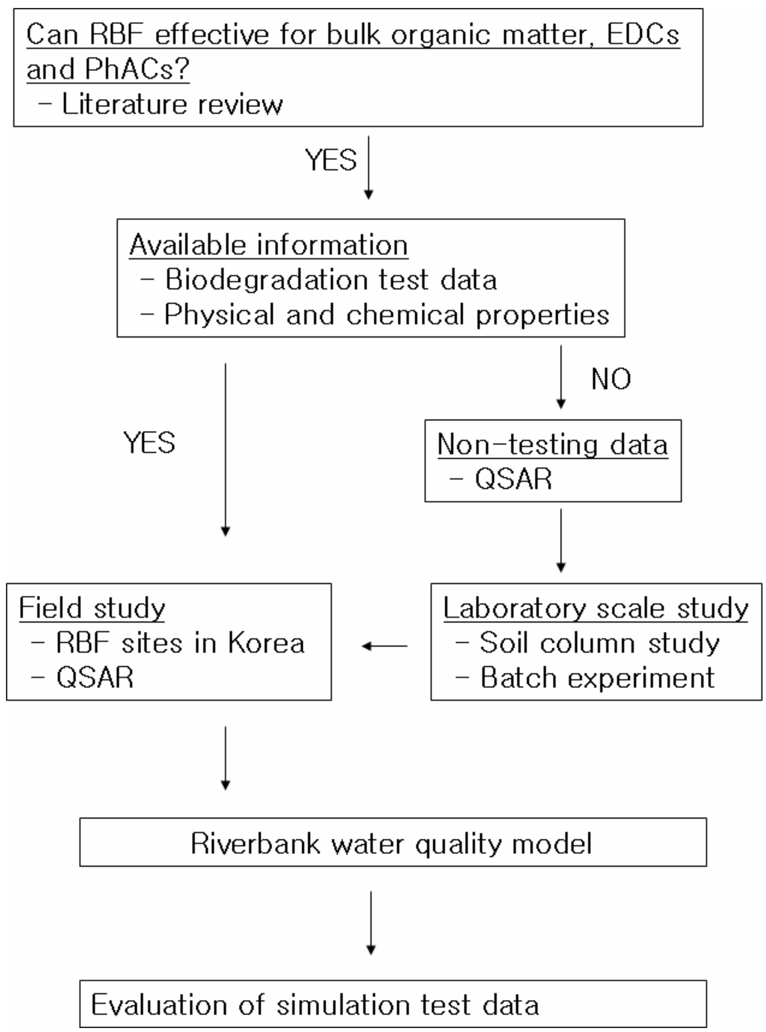


Figure 5. Schematic diagram of the research approval

3.2 Evaluation of the changes in the character of bulk organic matter upon soil column passage to simulate the impact of wastewater effluent during RBF

3.2.1 Introduction

RBF system is a sustainable technology if the system locates in a well-connected region between the river and the aquifer, and it is a low cost and highly efficient treatment technology for drinking water treatment. When a pumping well along the river is in operation, it lowers hydraulic head then surface water is induced to flow to the well and the contaminants in surface water will be naturally attenuated by physico/chemical and microbial reactions. The fate and transport of many toxic substances during the passage of the surface water from the riverbed to the pumping well are largely governed by the interactions with redox conditions and biodegradable dissolved organic carbon. Therefore, the change of organic character matter accompanied with hydrogeochemical reaction under different redox conditions during RBF is important to assess.

In Europe, RBF systems have been operated for a century to supply clean drinking water to the city of Zuirch, Düsseldorf and Berlin (Grünheid et al., 2005). However, the hydrogeological situation and environment conditions vary from country to country, and surface water qualities in developed countries appear to be different from those encountered in developing countries. A vast majority of water utilities in developing countries do not have protected watershed around their intake locations. The rivers are extremely impacted by organic contaminants, pathogens, and nutrients from agricultural and industries activities. Sometime, such problems are not only associated in developing countries but also in developed countries. For example, the city of Cedar Rapids in USA is having difficulties in supplying the Cedar River water during spring and summer because of high concentration nitrate in the River and the cost of removing nitrate using ion exchange or reverse osmosis is expensive.

The objective of this study is to assess the performance of natural attenuation in the RBF system located along wastewater effluent-dominated river. The study also provides a better understanding the fate of bulk organic matter in the role of hydrogeochemical condition (e.q., redox conditions). The results obtained from the laboratory scale experiment in UNSCO-IHE will be compared to the field study in Korea because the implementing laboratory scale study data to model may not be

warranted due to scale-issues. Therefore, field monitoring will be incorporated to verify the results of laboratory scale study. The site in Korea will examine the changes of organic character matter in a highly polluted stream during RBF and the role of redox conditions in degradation of bulk organic matter is also going to be considered.

3.1.2 Materials and Methods

Laboratory studies

Laboratory based soil columns, constructed and instrumented according to the schematic diagram shown in Figure 6 will be used for evaluating the removal of bulk organic matter from the Delft canal water and the wastewater secondary effluent. The columns are constructed with PVC pipe with internal diameter of 100 mm. The set up is made in such a way that there will be two columns of each 2.5 m height connected in series. The bottom of each column will be packed with filter media support of 15 cm thick graded gravel and then filled with silica sand sized between 0.8 and 1.25 mm. The two columns will be connected with teflon tubes and 13 sampling points will be provided as shown in the schematic diagram (Figure 6). The first five sampling points will be placed closely to each other (SP1-SP2=50 mm, SP2-SP3=100 mm, SP3-SP4=10 mm, SP4-SP5=200 mm) because most of organic matter will be degraded in the first few meters. The rest sampling points will be placed every 50 cm interval. In addition, valves to control the hydraulic loading rate under gravity flow and manometers to control the head losses through the soil column will be provided. A backwashing system will be provided in order to clean the filter media with tap water when the effluent flow rate is reduced significantly from its initial value as a result of clogging.

The Delft canal water and the wastewater secondary effluent from Hoek van Holland wastewater treatment plant will be used as influent. Experiments will be carried out by varying process conditions (loading rates and redox conditions) to evaluate RBF system performance. Table 3 summarizes the experimental process conditions of the soil columns.

The performance will be tested by applying the influent water in the following ways:

- 100% The Delft canal water
- 50% The Delft canal water and 50% wastewater secondary effluent

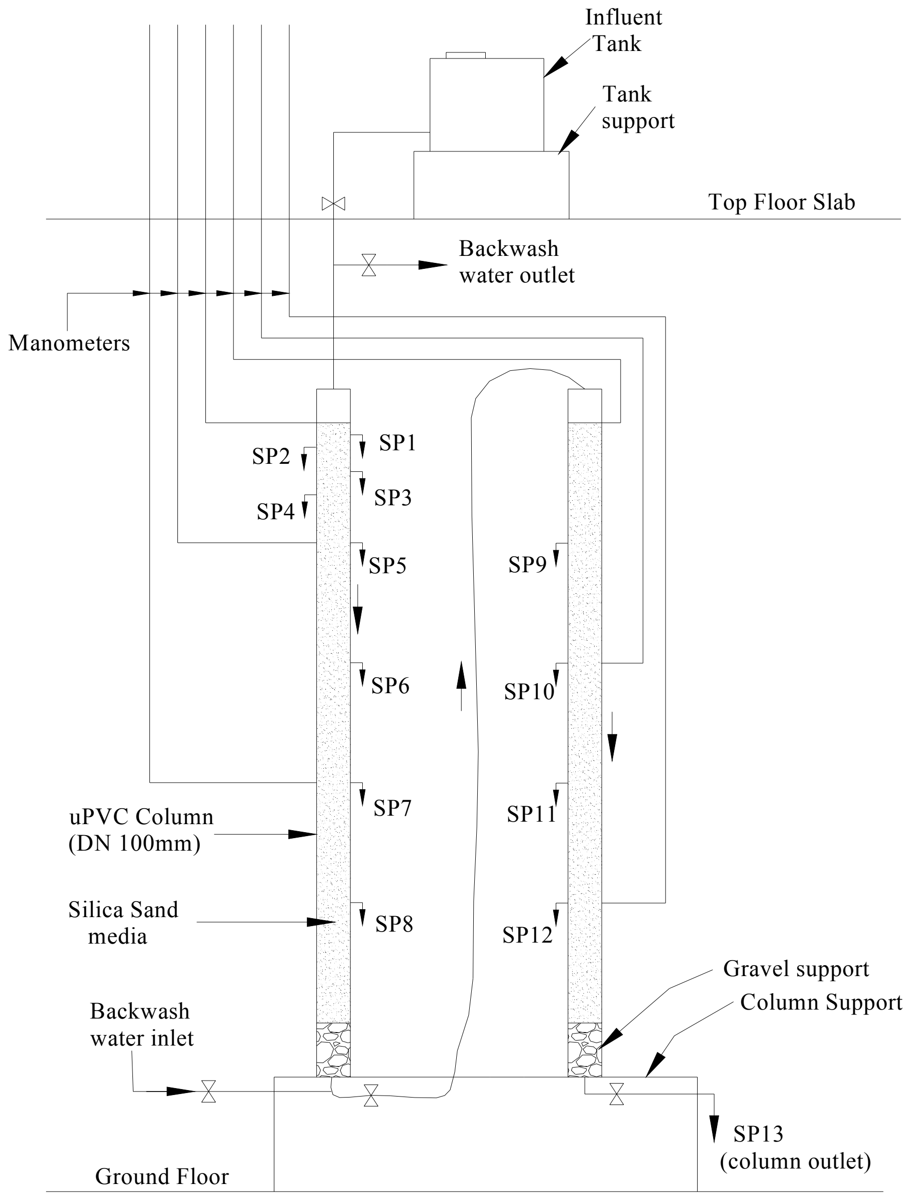


Figure 6. The schematic diagram of soil column

All influents will be characterized within 3 days after the sample collection and store at 4 ^{O}C to minimize the degradation of organic matter. The secondary effluent will be percolated through the fixed bed for about one month for acclimination. After the columns show the steady performance of organic matters, the influent tank will be

filled with the predetermined influents which will be passed through the soil column with a predetermined flow rate. Analysis of extensive characterization of organic matter will then be carried out by taking samples from various sampling points.

Table 3. Process conditions for soil-column experiments

Expt. no.	Influent	Hydraulic loading rate	Redox condition
1	Delft canal water	1.2 m/d	Aerobic
2	Delft canal water	0.6 m/d	Aerobic
3	Delft canal water + wastewater secondary effluent (1:1 ratio)	1.2 m/d	Aerobic
4	Delft canal water + wastewater secondary effluent (1:1 ratio)	0.6 m/d	Aerobic

Degradation experiment under different redox conditions

Batch experimental setup will be used to investigate the fate of bulk organic matter under different redox conditions. Each batch reactor will run in triplicate under oxic or anoxic condition: 1)oxic condition, 2-3)changes in redox conditions in every 5 days and 4)anoxic condition. About 3 kg of pre-washed silica sand (0.8-1.25 mm) will be placed in a 10-litre container with Delft canal water during a month of acclimation period. Batch experiments will then be conducted under various conditions as shown in Table 4 by transferring 100 g of the bio-sand to each of the duplicate 1 litre glass bottles.

Table 4. Process conditions for batch experiments

Expt. no.	Influent	Redox condition	Remark
1	Delft canal water + wastewater secondary effluent (1:1 ratio)	Aerobic	
2 and 3	Delft canal water + wastewater secondary effluent (1:1 ratio)	Aerobic ↔ Anoxic	
4	Delft canal water + wastewater secondary effluent (1:1 ratio)	Anoxic	

Analytical Methods

The characteristics of EfOM composition were carried out in various analytical methods including fluorescence excitation-emission matrix (EEM), size exclusion chromatography with on-line DOC detection (SEC-DOC), specific UV absorbance (SUVA), dissolved organic nitrogen (DON) and LC-OCD/OND. In EEM analysis, all samples were fixed to a pH 2 by diluting samples to 1 mg/L of DOC with 0.01 N KCL due to the fluorophores interferences by metals. A Shimadzu high performance liquid chromatograph (HPLC) with UVA Shimadzu detector and a modified Sievers 800 Turbo portable total organic carbon analyzer were sequentially connected. SUVA was calculated from the ratio between DOC and UVA. Dissolved organic nitrogen (DON) was calculated the different concentration in nitrogen between total dissolved nitrogen (TDN) and total inorganic nitrogen (TIN) in samples. LC-OCD/OND uses a liquid chromatography method that similar to SEC-DOC and has more enhanced sensitivity (DOC-Labour Dr. Huber, Germany). Also, built-in software in LC-OCD has a great feature in distinguishing between different fractions of bulk organic matter in more efficiently.

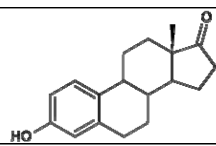
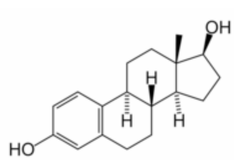
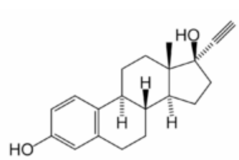
3.2 Understanding the endocrine disrupting compounds interactions in RBF

3.2.1 Introduction

Many studies have investigated that wastewater and sewage treatment plants are efficient in the removal of 17β-estradiol (E2) and estrone (E1) (Andersen et al., 2003; Khanal et al., 2006; Shappell, 2006; Suzuki and Maruyama, 2006). The removal efficiencies of natural estrogens (E2 and E1) exceeded 98% and ethinylestradiol (EE2) was reduced by more than 90% (Andersen et al., 2003). The fate of steroid hormones in biosolids through partitioning and mineralization to CO_2 by using ^{14}C-labeled compounds was demonstrated, whereas other studies only showed their disappearance of parent compounds (Layton et al., 2000). 84% of E2 in influent wastewater was mineralized by batch experiment using biosolids taken from municipal wastewater treatment plant. Generally, a conventional wastewater treatment process is feasible to remove natural estrogen compounds (E2 and E1). Little information is available on the fate of natural estrogens during RBF but understanding the results obtained from previous studies in wastewater treatment processes may provides insight about their fate and behaviour during RBF.

During RBF, redox conditions significantly influence the degradation kinetic of organic compounds and trace compounds (Grünheid et al., 2005). In addition, the degradation experiment using cultures prepared using lake water and sediment was conducted to assess anaerobic biotransformation of estrogens (Czajka and Londry, 2006). E2 was transformed to E1 under anaerobic conditions but the transformation rate is varied in each electron acceptor and the final steady state concentration of E2 is depended on the redox conditions. Table 5 shows the physical-chemical properties of selected steroidal estrogen hormones.

Table 5. Phsico-chemical properties of E1, E2 and EE2

Estrogens	Structure	Formula	Molar Mass (g/mol)	Water solubility (mg/L)	pK_a	$Log(K_{ow})$
Estrone(E1)		$C_{18}H_{22}O_2$	270.37	0.8-13	10.3-10.8	2.45-3.43
17-beta-Estradiol (E2)		$C_{18}H_{24}O_2$	272.38	3.9-13.3	10.5-10.7	3.10-4.01
17-alpha-Ethinylestradiol		$C_{20}H_{24}O_2$	296.41	4.8	10.4	3.67-4.15

Sources: Auriol et al, 2006

3.2.2 Materials and Methods

Laboratory studies

Two series of batch experiment will be performed using acclimated sand used in the study of 3.1 and will run in triplicate. In addition to the previous batch reactor set-up, a vial containing 0.5 N NaOH is going to be connected to each batch reactor for trapping ^{14}C-CO_2 release. The ^{14}C-CO_2 measurement after 96-h incubation will indicates the mineralization of parent compound (E2). A batch reactor with addition of sodium azide will represent abiotic control and other control reactor will have no bio-sand. The amount of ^{14}C-labeled E2 in biomass will be determined followed by acid digestion.

The percentage of each fraction of ^{14}C-labeled E2 in aqueous, biomass and CO_2 is going to be measured by liquid scintillation counter and its intermediate E1 will be measured in aqueous by ELSIA kit (Japan Environment Chemical, Japan). The first series of batch experiment will determine the impact of E2 spiking concentration and its fate during incubation of 96-h. The spiking concentration was selected to be approximately ten times higher than the concentration found in Delft canal water. The second series will examine the degradation of E2 under different redox conditions. As mentioned previously, all runs will include the abiotic control to determine the primary removal mechanism of E2 during surface water infiltration via RBF. All batch reactors will place in a shaker table for 24 hours in fixed temperature chamber (25 °C) with no light.

Two set of biotic soil column tests (i.d. 100mm, length 5000 mm) are going to be used in this study and each soil column will receive different source of influent (Delft canal water or secondary effluent). A detail description of operation procedure is explained in the previous section 3.1. Each biotic column should have acclimated least a month prior to introducing E2. In this study, the fate of E2 in different characteristics of bulk organic matter during infiltration under saturated aerobic conditions. In addition, a soil column test will be conducted under anoxic conditions by sparging nitrogen gas (dissolved oxygen less than 1 mg/L) to assess the influence of the redox conditions on the removal of E2.

ATP will be measured in different interval depth along the length of the soil column to determine the concentration of the active biomass as well as DHA to assess their microbial activity. ATP measurement is selected because of speed and accuracy of the analysis and its general use in aquatic microbiology. ATP was extracted as described by Magic-Knezev et al (2004) and the measurement is based on the production of light in the luciferine-luciferase assay. The intensity of the emitted light was measured in a luminometer (Celsis Advance™). Phospholipids measurement is also going to be measured in parallel and the discrepancy between ATP and phospholipids measurements along the length of soil column will be compared. The total viable active biomass is expected to vary along the depth of soil column.

<u>Analytical method</u>

The characteristics of bulk organic matter composition were carried out in various methods described in section 3.1. ELISA kit will be used to measure the concentration

of estrogens in samples. Specific ELISA kit for each estrogen compound (E1, E2 and EE2) was used for water samples. The analysis is based on a competitive reaction where enzyme-labelled standard estrogens competes with free estrogens in the sample for binding to a specific monoclonal antibody immobilised to the surface of the microplate. The amount of labelled estrogens bound to the antibody is determined by addition of a non-coloured substrate which is converted into a coloured product. The colour intensity is measured at 450 nm and is inversely proportional to the amount of estrogens in the sample. The assay is calibrated using a standard solution of estrogens supplied with the kit.

^{14}C-labeled E2 from NEN LifeScience Products (BOSTON, USA) with a purity greater than 97% will be used and E2 (specific activity 1.96-2.00 GBq/mmol) is labelled on the C-14 carbon of the steroid backbone. For mineralization experiment, CO_2 will be trapped by suspending in 0.5 N NaOH with 10 mL of ready-safe scintillation fluid for mineralization experiment. A liquid scintillation counter in TU-DELFT will be used to determine radioactivity in water samples.

3.3 Investigation of the fate and transport of selected pharmaceutical active compounds (PhACs) during RBF

3.3.1 Introduction

PhACs are made with intention of performing a role in the biological function in nature and designed to cure and treat disease (Cunningham et al., 2006; Halling-Sørensen et al., 1998). Some of these pharmaceuticals are lipophilic which enable to pass membrane and persistent to prevent to be inactive before having a curing effect. Polar structures in some persistent PhACs are not significantly removed by wastewater treatment plants and subsequently can enter the surface waters and may even percolate into the ground water (Ternes, 1998). For example, the city of Berlin (Germany) is strongly dependent on RBF and ground water recharge nearly 70% of the total water supply (BWB, 2003). A few of the PhACs were detected at the ng/L range in Berlin tap water as result of large contribution of sewage discharge on the surface water (Heberer, 2002b).

Recently, many drug companies are spending a lot of money on the development of innovative drug delivery systems because it is prominent way to controls the delivery of drug so that an optimum amount of the drug reaches the target site. Conversely, more drugs could be more persistent to biodegradation in the environment. When the

condition does not satisfy the way of drug to be metabolized, some of these persistent drugs developed by drug delivery system may not ever be degraded in the environment. Scientists need to understand impact of these new drugs to aquatic life however there are some limitations on its investigation because there are so many chemicals need to be assessed to determine their impacts in the environment. Thus, non-testing methods such as QSARs could be used to predict their fate in the environment. However, the development and validation QSARs are still under investigation.

The aim of this study is to determine the degradation and mobility behaviour of the PhACs under saturated porous media conditions in laboratory biotic sand column and field study. Only few studies showed the impact of redox conditions on removing PhACs under saturated porous media. (Greskowiak et al., 2006; Scheytt et al., 2006). Therefore, the role of redox conditions in the elimination of the selected PhACs will be investigated under laboratory and field study. Also, the biodegradation of selected PhACs calculated by quantitative structure activity relationship (QSAR) will be compared to batch study measurement.

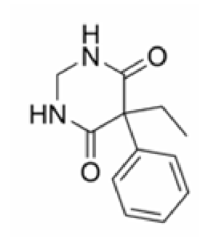
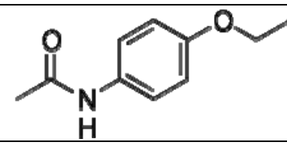
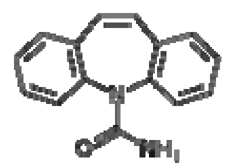
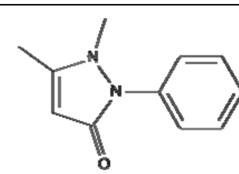
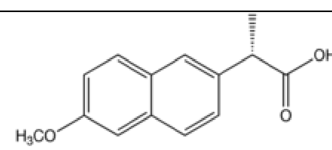
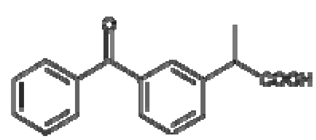
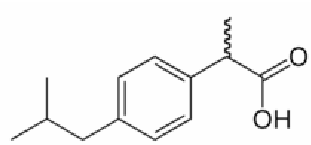
3.3.2 Materials and Methods

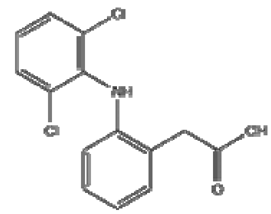
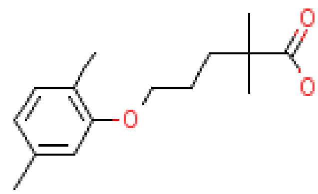
<u>Selected PhACs</u>

In this study, target emerging PhACs shown in Table 5 pollutants will be used to study their fate during different infiltration conditions. The compounds were selected based on the presence of their compounds in aquatic environment and the physicochemical properties reported in literature. The reference for determining between hydrophobic and hydrophilic compounds was based on a log K_{ow} of 2 at the pH of 7. The biodegradability of selected PhACs was predicted using QSAR (Quantitative Structure-Activity Relationships) based model (BIOWIN) in Table 7. The prediction value cut off points between ready biodegradable and not ready degradability is varied with each particular BIOWIN model. The cut off point is 0.5 in the BIOWIN (1,2,5, and 6) tested in this study (Table 7).

Table 6. Structure and properties of selected PhACs

Compound & CAS #	Molecular weight (g/mole)	pKa	log K_{ow}	Structure
Hydrophilic neutrals				

Primidone (antiepileptic) 125-33-7	218.5	12.26	0.91	
Phenacetine (antipyretic) 62-44-2	179.22	N/A	1.94	
Hydrophobic neutrals				
Carbamazepine (antiepileptic) 298-46-4	236.28	13.94	2.45	
Phenazone (analgesic) 60-80-0	180.226	1.4	0.38	
Hydrophilic anionsx				
Naproxen (analgesic/anti inflammatory) 22204-53-1	230.26	4.15	0.41 (pH 7)	
Ketoprofen (analgesic/anti inflammatory) 22071-15-4	254.28	4.45	0.07 (pH 7)	
Ibuprofen (analgesic/anti inflammatory) 15687-27-1	206.28	4.91	1.15 (pH 7)	

Diclofenac (analgesic/anti inflammatory) 15307-86-5	296.16	4.15	0.48 (pH 7)	
Hydrophobic anions				
Gemfibrozil (lipid regulator) 25812-30-0	250.34	4.77	2.14 (pH 7)	

Source: (Drewes et al., 2004)

Table 7. Biodegradability of selected PhACs by QSAR

NAME	BIODEG linear model	BIODEG non-linear model	MITI Linear model prediction	MITI Non-linear model prediction
Primidone	1.0081	0.9954	0.4943	0.4211
Phenacetine	1.0043	0.9955	0.5839	0.6246
Carbamazepine	0.6351	0.4143	0.0873	0.0364
Phenazone	0.7860	0.8943	0.2003	0.0962
Naproxen	0.8972	0.9611	0.4439	0.3477
Ketoprofen	0.8888	0.8770	0.3192	0.1848
Ibuprofen	0.8314	0.8672	0.1976	0.1521
Diclofenac	0.1353	0.0027	-0.1313	0.0029
Gemfibrozil	0.7584	0.8522	0.6680	0.6123

(A probability greater than or equal to 0.5 indicates readily degradable and a substance less than 0.5 indicates not readily degradable)

<u>Biodegradation experiment</u>

The biodegradability of selected PhACs will be measured by batch experiment and the detail description of batch reactor set-up and operation is described in section 3.2. A decrease in concentration of biotic batch reactor relative to abiotic control experiment

is evidence for biodegradation. The PhACs concentration decrease over time in oxic or anoxic conditions will provides the impact of redox conditions on their biodegradation. The kinetic data from the biodegradation experiments will be used for input data of reactive transport model in section 3.4.

Predicting biodegradability by BIOWIN

The biodegradation probability program for windows (BIOWIN) calculates the probability that a chemical under aerobic conditions with mixed cultures of microorganisms will biodegrade rapidly or slowly (http:// www.syyre.com/esc/biowin.htm). BIOWIN break down the selected compound into fragments based on its structure and uses several methods including multiple linear and non-linear regressions in a given database to determine each fragment value of biodegradability and sums the fragment values to determine an over biodegradability to the selected compound (Yu et al., 2006). Selected PhACs will be tested in BIOWIN and compare with batch measurements of relative biodegradability.

Analytical methods

Two highly sensitive analytical methods (method 1 and method 2) developed by Reddersen and Heberer will be used in this study to measure selected PhACs in water samples (Reddersen and Heberer, 2003). All sample measurements of PhACs concentration are based on a solid-phase extraction (SPE) followed by gas chromatography (GC) coupled with a mass spectrum (MS) detector (Shimazdu Corporation, GCMS-QP2010). SPE will be performed using an Oasis® MCX 3cc cartridge. These methods are only different in using PFBBR or MTBSTEF as reagents for derivatization. A method 1 is only for acidic PhACs including naproxen, ketoprofen, ibuprofen, diclofenac and gemfibrozil, whereas a method 2 is for neutral PhACs including primidone, phenacetine, carbamazepine and propyphenazone.

500 ml of water sample will be filtered with GFC (Whatman, USA) into 1000 mL Erlenmeyer flask. The samples will have 100 ng of 4-chlorophenoxy-butyric acid as a surrogate standard and an additional 10,11-dihydrocarbamazepine is going to be use as a second surrogate standard to compensate for matrix effect observed during the analysis. Before sample extraction the cartridges will be installed in the vacuum manifold and conditioned using 1 mL of methanol and 1 mL of MilliQ water (<pH 2) and this pH adjustment is not required for method 2. After conditioning, a vacuum will be applied and the samples should be passed through the cartridges at a flow rate less

than 10 mL/min. The cartridges then dry for 20-min under a gentle flow of nitrogen gas. The samples will be eluted from cartridges into 7 ml stopped test tube with 4 mL of acetone by applying vacuum and dry the elute completely under nitrogen gas at 40 °C. Internal standards for each method 1 and method 2 will be added and dry it again. The dried samples need to be dissolved in derivatization reagents prepared for method 1 and 2 and dry for one hour at 100 °C. Finally, the dried samples will be dissolved with 100 μL of toluene and will transfer to 200 μL glass inserts.

3.4 Development of a modeling framework or decision support tool for the assessment and prediction of the treated water quality from a RBF

3.4.1 Introduction

Many countries worldwide are faced with the challenge of providing safe drinking water to an ever-increasing population. However, increasing pollution of surface waters, often by wastewater effluent, has made water treatment much more difficult and expensive. RBF is a reliable and proven natural water treatment technology, in which surface water contaminants are removed or degraded as water moves through the soil to a recovery well. Because of its ability to remove even the most persistent contaminants and microbes, RBF can support or even replace other treatment processes in a water treatment scheme. RBF, however, is site specific and requires site investigations and pilot studies to assess its feasibility under local conditions.

This study will involve collection and analysis of data on hydrology, hydraulics and water quality from the published literature on laboratory and field-based studies on RBF throughout the world. The reported removals of dissolved organic carbon - DOC (organic matter), selected trace organic compounds, nitrogen-species (ammonia and nitrate) as well as microbes during RBF will be analyzed using statistical techniques such as multiple regression and principal component analysis in order to delineate removal trends as a function of site characteristics and operating conditions. In this study, hydraulic model (MODFLOW/MT3DMS) and chemical model (PHREEQC-2) (e.g., performance algorithms for DOC, nitrogen, selected trace organics, and microbes) will be combined to develop a framework or guidelines for prediction of water quality. While specific site characteristics (e.g., permeability) may affect RBF water quality performance, design and operational conditions such as well placement and pumping rate affect travel distance and travel (residence) time. Thus, a modeling

framework provides a means of assessing the importance of individual design and operational variables in order to reveal an optimal configuration.

3.4.2 Materials and Methods

<u>Flow model</u>

Visual Modflow 4.1.2 (Waterloo Hydrogeologic Inc.) is going to be used to develop for flow model. Flow simulation is the first step prior to undertaking transport simulation. In this study, the flow model for vertical wells and horizontal wells will be developed and simulated data will be compared with the actual data obtained from the field site in Korea to determine its accuracy. Figure 7 and 8 shows the typical layout of grid designed for the vertical wells and the horizontal wells, respectively. Figure 9 and 10 shows the direction of flow into pumping wells and the water table for the vertical wells and the horizontal wells, respectively.

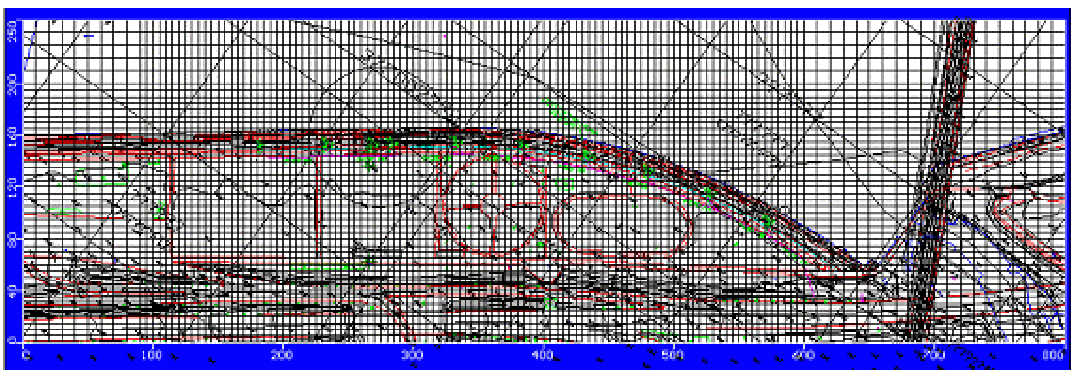


Figure 7. Typical layout of grid designed for vertical wells

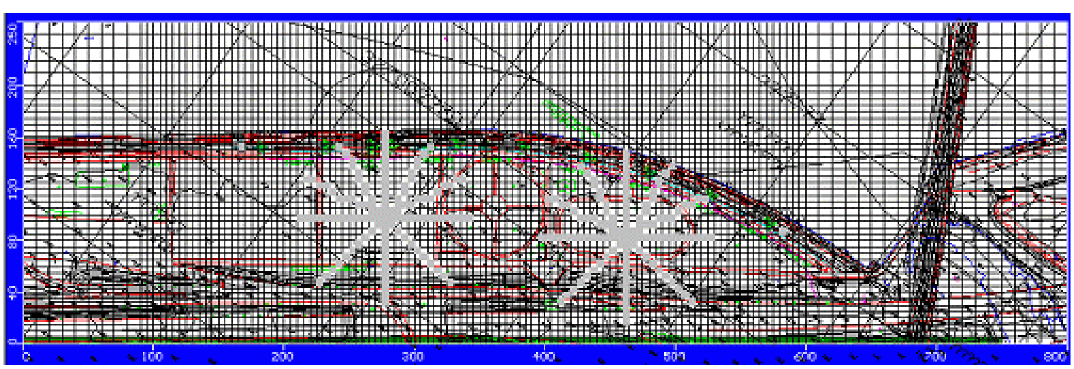


Figure 8. Typical layout of grid designed for horizontal wells

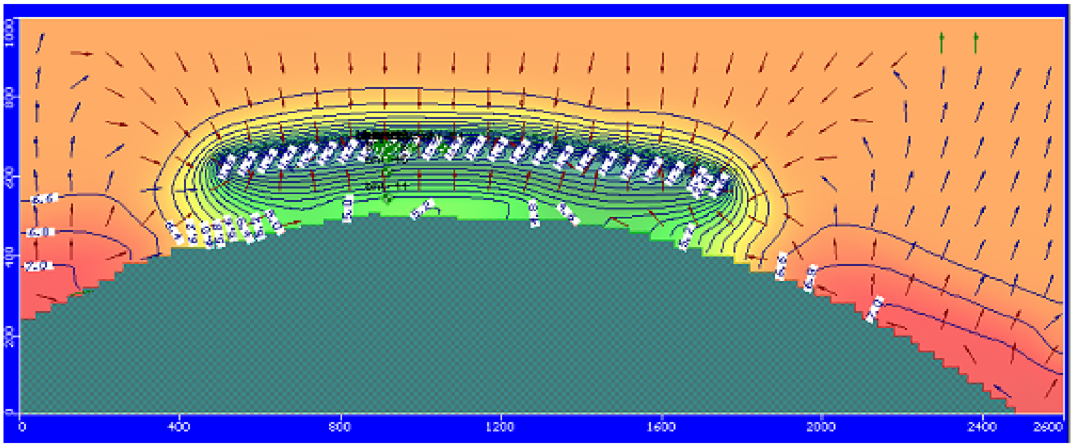


Figure 9. Profile of water table changes and flow direction for typical vertical wells operation

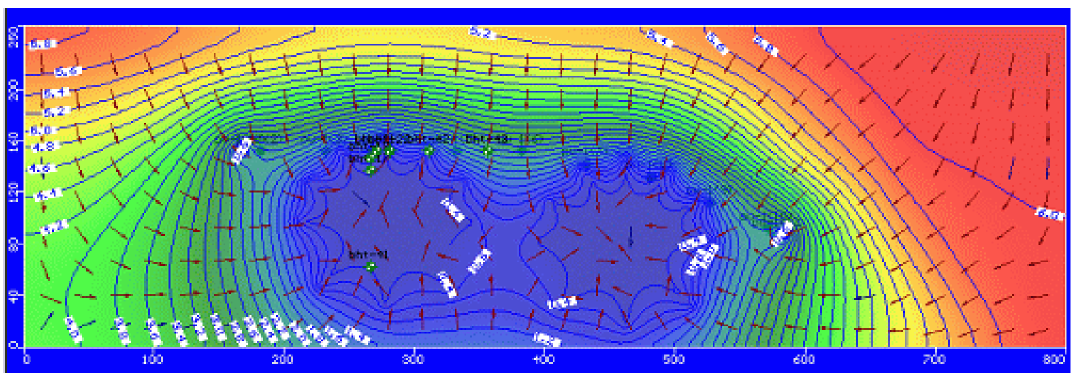


Figure 10. Profile of water table changes and flow direction for typical horizontal wells operation

<u>Reactive multicomponent biogeochemical transport model PHT3D</u>

For the biogeochemical transport model, a biodegradation reaction module incorporated to geochemical model, PHT3D, will be used to carry out to assess the influence of redox conditions, transient flow field and seasonal variation on transport and natural attenuation during RBF. PHT3D combines MODFLOW/MT3DMS flow/transport simulator family with PHREEQC-2 geochemical model. The reaction kinetics in PHREEQC-2 can be modified by changing user-defined rate expressions within the database. Given user-defined rate expression in PHT3D will be determined through the experiments conducted in section 3.1, 3.2 and 3.3.

PHT3D model will be implemented in graphic user interface to become more user friendly tool (Visual basic, Microsoft). It will provide users to help to design RBF system by providing its yield estimation and the fate of selected contaminants at user selected location of pumping well. Based on this model, a framework or guidelines for the assessment or prediction of water quality from a RBF system will be established and it is very important tool for quick screening of candidate RBF project sites and to compare its costs with other conventional treatment systems.

3.5 Evaluation of results and proposed research

A continuous processing and evaluation of results will be done after different sets of experiments are completed. There are three major parts in this study that need to be evaluated:

3.5.1 Laboratory experiment and field validation

Some limited soil column experiments will be conducted to fill the existing knowledge gaps however it is necessary to validate these results. The use of laboratory scale studies in the model remains challenging because of the scale up issues. Thus, the field study in Korea will be used to validate the laboratory-scale experiments or the previous field data.

3.5.2 Biodegradation kinetic of PhACs and EDCs in RBF

In general, the assessment of biodegradation process is based on the experimental data obtained from standard methods or OECD tests. Alternatively, non-testing biodegradation data from QSAR model (e.g. BIOWIN) will be compared with biodegradability test conducted in the laboratory. The validation of using BIOWIN data for estimating biodegradability for selected PhACs and EDCs should be carried in order to use non-testing data in the model.

3.5.3 Model development

A prediction model will be developed based on an existing hydraulic model and a water quality model supplemented by laboratory and literature study. The model output will be validated or calibrated with experimental data obtained from field study or previous field study data in Korea.

3.6 Preparation of thesis

The preparation of thesis is referred mainly to the writing process. However it will involve a continuous update and improvement of information according to the evaluation and interpretation of results. Attempts will be made to publish different chapter of the thesis in the form of papers in journals or conference proceedings.

4. Research Organization

The tentative schedule of this study is presented below. It is subjected to changes depending on times required for the configuration of the experimental setup and availability of equipment and materials.

Table 8. Time schedule

Activities	Year 1				Year 2				Year 3				Year 4			
	Jul 06	Oct 06	Jan 07	Apr 07	Jul 07	Oct 07	Jan 08	Apr 08	Jul 08	Oct 08	Jan 09	Apr 09	Jul 09	Oct 09	Jan 10	Apr 10
1. Literature review	■	■														
2. Research proposal		■	■													
3. Experimental setup		■														
4. Analysis methods			■													
5. First group experiment				■	■	■										
- Analysis of results						■										
6. Second group experiment							■	■								
- Analysis of results								■								
7. Third group experiment									■	■	■					
- Analysis of results											■					
8. Models development & validation					■	■	■	■	■	■	■	■	■	■		
9. Writing of thesis								■	■	■	■	■	■	■	■	
10. Thesis defense																■

4.2 Organizational and financial aspects

4.2.1 Supervision

The research will be supervised by UNESCO-IHE, Institute for Water Education, in close coordination with the Delft University of Technology (TU Delft). The supervision team is conformed by a group of staff members of both institutions, as follows:

Table 9. Supervision team

Promoter	Prof. G. Amy, PhD	UNESCO-IHE	Department of Urban Water and Sanitation
		Delft University of Technology	Department of Sanitary Engineering
Co-Promoters			
Supervisor	Saroj Kumar Sharma, PhD	UNESCO-IHE	Department of Urban Water and Sanitation

The meeting frequency with promoter and supervisor will be once every two weeks. Progress reports will be submitted to the Supervision Team every month. Regular communications will be established to discuss experimental progress of the research or issues/questions that may evolve. Results and detailed research plan for the coming year will be submitted every year to the Academic Board of UNESCO-IHE. At the end of the research period, a dissertation, based on published/prepared papers, will be submitted and defended.

4.2.2 Budget and financial support

The research will be conducted in The Netherlands, at facilities of UNESCO-IHE, Delft University of Technology and Korea Institute of Science and Technology. This research is partly initially sponsored by SWITCH project under WP 5.3 natural systems for drinking water treatment (tuition fee and accommodation). Additional

funds are being obtained from AWWARF and Korea Institute of Science and Technology. Table 10 shows the overview of the estimated budget.

Table 10. Overview of the scheduled budget

Component	Rate (per year)	Year	Total amount (EUR)
1. Tuition fee	8,400	4	33,600
			33,600
2. Handling fee	455	4	1,820
Insurance	456	4	1,824
Thesis cost			4,538
Public defense			2,723
Registration Alien Police			188
Extension of residence permit	52	3	156
Application MVV			250
			11,499
3. Salary allowance	1,075	4	51,600
Book allowance	300	4	1,200
Travel cost in Netherlands	500	4	2,000
Conferences	750	4	3,000
Miscellaneous	500	4	2,000
			59,800
Total PhD programme Budget (EUR)			**104,899**

5. References

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SWITCH WP 5.3. Use of natural systems in the urban water cycle
Task 3: Natural systems & processes for waste- and stormwater treatment and reuse

RESEARCH PLAN

1. Task description based on DoW

Task 3a

To perform a literature survey and collect operational data from existing wetland systems (constructed and natural), stabilisation pond systems (algal and macrophyte systems) and anaerobic treatment systems. An analysis of factors influencing the feasibility of each of these natural treatment systems in centralised (urban) or decentralised (small towns and rural) situations, will be made.
Contributions for this task will mainly come from staff members of the various partners, as they have the expert knowledge necessary for the completion of this task. Two MSc studies at UNESCO-IHE (of which one non-SWITCH funded) are dealing with natural systems for wastewater and stormwater treatment and are studying specific cases in The Netherlands.

Task 3b

To implement an applied research programme on selected natural systems to study their possible use, function and optimization in the treatment and reuse of wastewater and stormwater. Research will be undertaken at laboratory scale, pilot-scale and full scale. Part of the research will be executed in the wastewater research station of Acuavalle in Ginebra, Colombia, and in Kampala, Uganda (Study areas). Research projects will include:

a) Comparison of selected anaerobic wastewater treatment systems for the removal of selected contaminants (organic matter, (trace)metals, pathogens) and for energy recovery (biogas).
This topic will mainly be covered through an in-depth literature review. A parallel (non-SWITCH funded) PhD study by Mr. Christian Sekomo at UNESCO-IHE on metal removal in natural systems will provide more insights into the mechanisms of metal removal under anaerobic conditions.
b) Comparison of conventional and high performance facultative and maturation ponds for removal or possible recovery of selected contaminants (same as under a, plus N and P). High performance ponds are modified waste stabilisation ponds (optimization of hydraulic performance, introduction of aerobic/anoxic zones, adding media for algal-bacterial biofilms, introduction of macrophytes).
This topic is covered in the PhD research of Mr. Mohammed Babu. His research plan is given further in this research plan. Two MSc studies will contribute to the PhD research.
c) Comparison of constructed and natural wetlands for wastewater and stormwater treatment.
This topic will be covered by staff (literature) research and one MSc study.
d) Evaluation of the removal of selected contaminants by integrated systems (combinations of systems mentioned above).
This topic will be covered by staff (literature) research and will also benefit from the activities of a postdoc at UNESCO-IHE, Mr. Shi Wenxin, who is studying the removal of endocrine disruptors in natural wastewater treatment

systems (algae ponds and duckweed ponds). Results from this study will be compared with the outcomes of WP 5.3 task 2 on artificial recharge and bank filtration, where the problem of micropollutants is also intensively studied. Also the earlier mentioned PhD research of Mr. Sekomo on heavy metal removal will give inputs to this topic.

e) Evaluation of the resource recovery potential (N, P, energy) and reuse potential of effluents in above eco-technologies.
This topic will be covered by staff (literature) research and one MSc study.

f) Evaluation of greenhouse gas emissions from above eco-technologies.
This topic is covered in the PhD research of Mr. Juan Pablo Silva. His research plan is given further in this research plan. Specific topics within this study will be done through MSc research.

g) Development of a master plan for the city of Cali, Colombia (Study area), which maximises the use of natural systems for wastewater treatment and reuse.
Staff time from UNESCO-IHE and UNIVALLE will be used for the elaboration of the master plan, which will be devised in collaboration with local stakeholders such as EMCALI. Results from the PhD study of Mr. Alberto Galvis on technology selection will contribute to this study.

Task 3c

To develop design criteria for optimum treatment efficiency and resource recovery in treatment systems studied under 6.4.9, based on an increased understanding of the natural processes taking place, their effect on the performance and the effect of operational variables.

One MSc study will deal with modelling the results of the PhD study of Mr Mohammed Babu. This model can than serve as a design tool. Staff time will be used to compile design guidelines from all the studies carried out in tasks 3a, 3b and 3c.

Task 3d

To develop a conceptual and a computer based model for technology selection, which will provide a useful tool for decision makers, town engineers, consultants and R&D staff for the selection of optimal eco-technologies for wastewater treatment for reuse. The approach will not be limited to the usual interventions ‘at the end of pipe’, but will take into account the entire municipal water cycle, pollution prevention and pollution control. This work will be developed by Univalle in Colombia, and UNESCO-IHE, with inputs from other partners.

This topic is covered by the PhD of Mr Alberto Galvis and will be assisted by targeted MSc resarch. The PhD proposal of Mr Galvis can be found below.

2. Staff and student involvement

UNESCO-IHE	
Staff time	• Coordination research activities • General literature survey giving overview of natural systems and the feasibility of implementing them in urban areas • Specific literature review on contaminant removal and resource recovery in anaerobic wastewater treatment systems • Specific literature review on constructed and natural wetlands for wastewater and stormwater treatment. • Specific literature review on contaminant removal by integrated natural systems • Specific literature review on resource recovery potential (N, P, energy) and reuse potential of effluents in ecotechnologies • Master plan for wastewater treatment in Cali • To develop design criteria for optimum treatment efficiency and resource recovery in natural treatment systems
Postdoc Shi Wenxin	• Removal of endocrine disrupting chemicals in algae ponds and duckweed ponds (lab-scale study)
PhD Mohamed Babu	Optimizing nitrogen removal in algae and duckweed wastewater stabilization ponds (proposal below)
MSc studies	• Topic 1: Wastewater treatment by means of natural systems in urban areas (Ms. R. Shrestha, 2006-2007, non-SWITCH funded). This study consists of a literature review and the follow-up of a houseboat with a completely closed water cycle. • Topic 2: Water quality enhancement in Sloterbinnen-polder (Amsterdam, The Netherlands) by adopting ecological engineering approaches (Mr. Ahmed Ali, 2006-2007). Focuses on stormwater treatment and in-stream remediation. • Topic 3: Removal of nitrogen in high-performance algal ponds (2007-2008) • Topic 4: Model study of high-performance algal ponds (2007-2008). • Topic 5: Greenhouse gas emissions from natural treatment systems under temperate climatic conditions (2007-2008) • Topic 6: Removal of nitrogen in high-performance algal ponds (2008-2009) • Topic 7: Evaluation of the resource recovery potential (N, P, energy) and reuse potential of effluents in above eco-technologies (2008-2009)
PhD Chris Sekomo (non-SWITCH)	• Removal of heavy metals in natural treatment systems (lab-scale and pilot-scale study)

ULODZ	
Staff time	• Contribution to various literature reviews • Planning and follow-up of the willow plantation with specific attention for biomass production, sludge degradation and metal uptake.
PhD Katarzyna Drzewiecka	Development and evaluation of the Ner River system quality indicators and their application for regional assessment and management of watershed. Work on willow plantation and AS management. This work will start in Sept 2007 and a workplan will therefore be included in the updated research proposal of M24.
UNIVALLE	
Staff time	• Contribution to various literature reviews • Development of master plan for city of Cali
PhD Alberto Galvis	Technology selection model for pollution prevention and control from domestic wastewater in small and medium towns (proposal below)
PhD Juan Pablo Silva:	Greenhouse gas emissions from open waters and natural treatment systems (proposal below)
MSc research	• Topic 8: Optimisation of measurement method for greenhouse gases and emission measurements of selected technologies at the research station Ginebra (2007-2008) • Topic 9: Greenhouse gas emissions from sugarcane fields irrigated with (treated) wastewater (2008-2009). • Topic 10: Technical, social, environmental and economical factors to be included in the technology selection tool (2007-2008) • Topic 11: Transfer of the technology selection tool to Belo Horizonte, one of SWITCH' demo cities (2008-2009) • Topic 12: Scenario development and scenario analysis within the master plan for wastewater treatment in Cali (2008-2009).
WUR	
Staff time	• Contribution to various literature reviews, especially with regard to anaerobic technologies
TUHH	
Staff time	• Feasibility analysis for the implementation of natural systems in the city of Hamburg
DCE-KNUST	
Staff time	• Feasibility analysis for the implementation of natural systems in the city of Accra • Contributing to natural systems workshop to be held in Accra in April 2007.

3. Deliverables

M4	May 2006	• **D5.3-5 R** Draft research plan for NatSystems (T3)
M5	Jun 2006	• Progress report existing willow plantation (T7)
M6	Jul 2006	• **D5.3-13a D** Demo Plan Lodz • **M** Detailed research plan NatSystems (including PhD studies Babu, Silva, Ansa, Galvis) defines work/approach (T3)
M9	Oct 2006	• Construction of new willow plantation (T7) • **M** Update research plan WWT based on knowledge from LitRev (T3)
M10	Nov 2006	• **D5.3-1c R** LitRev Inventory of natural systems and processes for wastewater (T3)
M12	Jan 2007	• **D5.3-12a R** PhD research plans and progress reports Galvis/Silva/Babu/Ansa (T3) • **M** Evaluation of PhD progress and decision on continuation
M13	Feb 2007	• **D5.3-1a R** LitRev Inventory of natural systems and processes for UWM (T1)
M14	Mar 2007	• **M** Use information gained to develop TecSel computer model (T3)
M16	May 2007	• **D5.3-8a R** MSc theses, Report describing conceptual TecSel model (T3)
M17	Jun 2007	• **D5.3-2a T** Organise a workshop on use of natural systems, and produce a draft plan to maximise their use in Demo-cities (T1)
M18	Jul 2007	• **D5.3-2b T** Final plan to use natural systems in Demo-cities (T1) • **D5.3-13a D** Progress report Demo site Lodz (T4) • **D5.3-12b R** 4 MSc theses on WWT (T3) • **D5.3-13b R** Progress reports per study site
M23	Dec 2007	• **D5.3-12a R** PhD progress reports

PHD PRE-PROPOSAL BY JUAN PABLO SILVA
GREENHOUSE GAS EMISSIONS FROM ECO-TECHNOLOGIES FOR SUSTAINABLE DOMESTIC WASTEWATER MANAGEMENT IN TROPICAL REGIONS

1. Introduction

1.1 Eco-technologies sustainable alternatives for domestic wastewater in developing countries

Water is a renewable resource, which is naturally recycled in the hydrological cycle. This recycle renews water resources and potentially provides a continuous supply. Water resources provide valuable food trough aquatic life and irrigation for agricultural production. With the advent of industrialization, intensification of agriculture and increasing populations, the demands for water has increased generating a rapid deterioration of surface and ground water quality emerging a problem worldwide.

Wastewater has been identified as the main land based point source pollutant causing contamination of the resource water in the world (UNEP/ GPA, 2000). Approximately 95% of the generated wastewater in the world is released to environment without treatment (Niemczynowics, 1997 in Zimmo, 2003). About half of the world's population lacks adequate sanitation and this has resulted in rivers downstream from large cities in developing country being barely cleaner than open sewers. This situation causes an estimated 80 percent of all diseases in developing world with annual death quote of 5 million lives (UN 2000). This implicitly suggest that we have to rely on the natural self-purification capacity of the receiving water bodies, however has been demonstrated with sufficiency that given the great volume of residual waters spilled to the receiving bodies this alternative is not a viable solution.

Millennium Development Goals, specifically number 7 (Environmental Sustainability) target 10 aims at improvement of the coverage for water supply and sanitation services. This goal in fact presents two conflicting ambitions: Increasing water supply delivery will lead to increasing volumes of wastewater, which, without being properly managed will exacerbate the ongoing water resources destruction (Gijzen, 2004).

Waste water management should be considered within the wider context of sustainable development. This means that a holistic approach must be followed where the management of wastewater is linked to that of water resources and of nutrients. It also means that interventions should not be focussed exclusively at the "end of pipe" (Gijzen, 2001).

A solution of this problematic can be achieved by adopting the concept of the Urban Cycle of the Water that considers three aspects: the rational use of the water, the waste water treatment based on the recovery of resources (nutrients, energy and water) and the stimulation of the self purification capacity of natural water bodies (Gijzen, 2004).

Unfortunately the traditional solution has been limited to the application of "end of pipe" treatment technologies characterized by high energy consumption and minimum reuse and nutrients recovery. These technologies have been developed in the high GNP countries and generally are expensive for implementation in developing countries in e.g. tropical, sub-tropical and arid climate regions (van Lier and Lettinga, 2001).

Conventional systems like (advanced) primary treatment and activated sludge, are characterized by their low sustainability, related to the high costs of investment, operation and maintenance, the great consumption of external energy and use of chemicals, as well as to the by-product generation of difficult handling and disposition that are not reuse or recovery to attenuate their environmental impact fixing the objective of the treatment in obtaining a cleaner effluent (Gijzen, 2001).
The search of new effective technologies that provide low costs O&M (less dependency of external energy and chemicals), a minimum infrastructure level, flexibility in the operation and that allows recovering energy, nutrients and water is required to address the increasing wastewater problems in developing regions. The technologies that seem most suitable to achieve these goals are so called Eco-technologies, which are based on natural systems (anaerobic treatment, wetlands, algal ponds, macrophyte stabilization ponds and aquaculture). The Eco-technologies have been projected in such a way that they contribute with the second aspect of the Urban Cycle of the Water, by its simple operation, the no dependency of source external energy different from the sun light, the low costs of O&M and perhaps most important it is than they specially allow to the recovery of valuable resources like energy, nutrients and waters, making possible its application in medium and small municipalities of the tropical region.

Eco-technologies will influence the future of wastewater, environmental restoration and remediation, food production, fuel generation architecture and the design of human settlements (Todd and Josephson, 1996). During last years much research has proven that Eco-technologies appear like appropriate alternatives, friendly and sustainable for the context of small and medium municipalities (Reed et al, 1995).

However, even a natural treatment system may generate environmental impacts due to the different transformations and processes biochemistry, non biotic factors and operation condition in different stages of wastewater treatment. Whereas natural systems have an advantage over electro-chemical systems in that they use less hardware and less energy, it is not yet know whether secondary environmental effects in the form of greenhouse gas emissions are lower for these systems (van der Steen et al., 2002).

1.2 Greenhouse Effect: Impacts and Policy

The world is faced with an intrinsic environmental responsibility, i.e. the minimisation of greenhouse gas emission to acceptable levels. The major greenhouse gases in order of contribution are Methane (CH_4), Carbon Dioxide (CO_2), Chlorofluorocarbons (CFCs) and Nitrous Oxide (N_2O). These gases have the effect of acting like a thermal blanket around the globe, trapping energy radiated by surface earth (greenhouse effect), generating changes in the distribution of energy that contributed to increase the temperature in the atmosphere (Global Warming). Such situation can modify levels of precipitation, atmospheric circulation and the

hydrologic cycle worldwide. In addition increase of the average temperature will bring defrosting of glaciers and thermal expansion of the oceans, increasing sea level affecting low coastal zones and small islands.

Carbon Dioxide (CO_2) is the gas most commonly thought of as greenhouse gas; it is responsible for about half of the atmospheric heat retained by trace gases; CO_2 is produced primarily by burning of fossil fuels and deforestation, accompanied by burning and biodegradation of biomass. The quantities of CO_2 have increased from 315 ppm in 1960 to 350 ppm in 1990 (Manahan S., 1994).

Methane (CH_4) is a naturally occurring gas that is produced under anaerobic conditions. One molecule of CH_4 methane is 20-30 times more effective in trapping heat than CO_2 and its atmospheric concentration is going up at a rate of almost 0.02 ppm/year. The comparatively rapid increase in methane levels is attributed to a number of factors resulting from human activities: leakage of natural gas, by-product emissions from coal mining and petroleum recovery, and release from the burning of savannas and tropical forest.

Nitrous oxide (N_2O) absorbs thermal radiation at the same wavelength as methane (7.6 µm). It is produced in the nitrogen cycle via nitrification. It has a residence time of about 150 years and is about 200 times as potent a greenhouse gas as CO_2. The quantities of N_2O produced are insignificant in comparison with CO_2. Emissions arise from wastewater treatment systems, industrial sources and gas combustion.

Levels of these greenhouses gases have increased at a rapid rate during recent decades and are continuing to do so, therefore should adopt measures to limit emissions of these gases. Intergovernmental Panel on Climate Change (IPCC) was created to provide policy makers the state of scientific knowledge concerned climate change. The IPCC published its first reported in 1990 concluding that the growing accumulation of human-made greenhouse in the atmosphere would “enhance the greenhouse effect, resulting on average in an additional warming of the Earth’s”. The report confirmed that climate change was a threat and called for an international treaty to address the problem.

The United Nations General Assembly responded by formally launching negotiations on a framework convention on climate change and establishing an “Intergovernmental Negotiating Committee” to develop the treaty. Negotiations to formulate an international treaty on global climate protection began in 1991 and resulted in the completion, by May 1992, of the United Nations Framework Convention on Climate Change (UNFCCC). The Convention sets an ultimate objective of stabilizing atmospheric concentrations of greenhouse gases at safe levels. To achieve this objective, all countries have a general commitment to address climate change, adapt to its effects, and report their actions to implement the convention.

During the Conference of Parties in Kyoto (1997), Japan, a legally binding set of obligations for 38 industrialized countries and 11 countries in Central and Eastern Europe was created, to return their emissions of greenhouses gases to an average of approximately 5.2% below their 1990 levels over the commitment period 2008-2012. This is called the Kyoto Protocol. The targets cover six main greenhouse gases: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydro fluorocarbons

(HFC`s); per fluorocarbons (PFC`s); and sulphur hexafluoride (SF6). The Protocol also allows these countries the option of deciding which of the six gases will form part of their national emissions reduction strategy. Some activities in the land-use change and forestry sector, such as forestation and reforestation that absorb carbon dioxide from the atmosphere, are also covered (Contraloria General de la República, 1998).

The Kyoto protocol too defined Clean Development Mechanism(CDM), that allows emission reduction projects that assist developing countries in achieving sustainable development and that generate 'certified emission reductions' for use by the investing countries or companies.

"The funding channelled through the CDM should assist developing countries in reaching some of their economic, social, environmental and sustainable development objectives, such as cleaner air and water, improved land-use, accompanied by social benefits such as rural development, employment, and poverty alleviation and in many cases, reduced dependence on imported fossil fuels. In addition to catalysing green investment priorities in developing countries, the CDM offers an opportunity to make progress simultaneously on climate, development, and local environmental issues. For developing countries that might otherwise be preoccupied with immediate economic and social needs, the prospect of such benefits should provide a strong incentive to participate in the CDM" (UNEP 2004).

Specifically, the CDM can contribute to a developing country's sustainable development objectives through transfer of technology and financial resources, sustainable ways of energy production and increasing energy efficiency & conservation. Protocol states that projects must result in "reductions in emissions that are additional to any that would occur in the absence of the project activity". A difficulty of developing countries to submit projects to CDM is that data about greenhouse gas emission are scarce. Therefore it is difficult to achieve benefits of CDM. Projects that recover energy (Biogas) trough of treatment of wastewater based in Eco-Technologies (UASB reactor and Anaerobic Ponds) are limited because few data about quantity of CH_4, CO_2, and N_2O are available especially in countries in tropical regions. Therefore there is a need to develop a low-cost and feasible methodology to estimate greenhouse gas emissions and so set up contributions of these projects to CDM.

1.3 Greenhouse gas emissions in Eco-technologies systems

Treatment of wastewater in Eco-technologies prevents or reduces the negative environmental impact of uncontrolled disposal of sewage. At the same time, eco-technologies might present possible sources for the emission of gaseous compounds like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). As described above, these gases are of environmental concern due to their rapid current accumulation in the atmosphere and their potential global warming (PGW). Some estimated that wastewater treatments account for about 5 % of global emissions of methane, but a sound basis for this estimate is lacking (Czepiel et al., 1993. quoted by van der Steen, 2002). In Australia the committee of GGI (Greenhouse Gas Inventory) estimates that about 4% of greenhouse gas emissions are generated by the management of societal wastes, of which 90% correspond to sanitary landfills and 10% to wastewater treatment (Environment Protection Authority, 2000).

Most of the greenhouse gases in Eco-technologies systems are formed from anaerobic and anoxic biodegradation process of carbon and nitrogen compounds by predominant methanogenesis, nitrification and denitrification.

Picot and co-workers (2003) reported that in Anaerobic Ponds located in the Mediterranean 74% of removed organic matter (or carbon) was converted into CH4, 13% into dissolved inorganic carbon and 15% was stored in sludge. An estimated 2067 - 5039 kg CH4/day in anaerobic lagoons loaded 48000 kg BOD/day, equal to 0.8- 1.6 * 10^6 population equivalents was realized by DeGarie and co-workers (Veenstra et al., 1997). Extrapolating this data for the world population would estimate the CH_4 contribution from this natural treatment system to be 1-4% of the total anthropogenic methane emissions (310 * 10^{12} gram/year; Clausen, 2001) (van der Steen et al., 2000).

In Algae Based Ponds (ABP) aerobic conditions are maintained in the upper layer by natural process and most of the methane from the lower layer is oxidised to carbon dioxide as it passes through the aerobic surface areas, so that methane and odours emission are generally low. Diurnal differences in pH, oxygen dissolved (DO), solar radiation are important parameters in both chemical and biological nitrogen transformation processes such as ammonia volatilization, nitrification, denitrification. Process as photosynthesis by algae uptake CO_2 and limited methane formation due a DO highest which reduce anaerobic activity. The increase of pH values (8-10), as a result of intense photosynthetic activity (CO_2 uptake) in ABP will stimulate volatilization (Zimmo, 2003). The nitrous oxide (N_2O) is formed by denitrifying bacteria in two steps under anoxic conditions if enough organic matter is available. The firs step consists of nitrate reduction to nitrite. This step is followed by production of nitric oxide, nitrous oxide and nitrogen gas. The mechanism is as follows:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

Duckweed Based Ponds (DBP) might have several advantages over ABP systems respect to greenhouse gas emissions. Duckweed cover can be a physical barrier for volatilization, since it can trap such gasses. In addition the duckweed barrier can be a favourable environment for bacteria that have an effect on any compounds that influence greenhouse gas emissions. Van der Steen et al. (2002) concluded preliminary that duckweed covers on DBP may reduce the emission of odours associated to H_2S, while results on methane emissions were not conclusive so far, but the same mechanism that prevent H_2S volatilisation may prevent methane volatilisation. In some studies in macrophyte systems, denitrification was referred to as unaccounted and found to contribute for 10 to 20% to the nitrogen loss (Alaerts et al., 1996).

Constructed wetlands for wastewater treatment have many advantages. They can be used for several purposes, for example, to reduce levels of organic matter and nutrients and to retain toxic metals. However, most wetlands are inherently net sources of gaseous compounds like methane and nitrous oxide. In a study on a pilot scale constructed wetland to reduce nutrients levels in secondary treated wastewater conducted over two growth seasons was encountered that the emissions for the spring

to autumn period average 141 mg CH_4/ m^2 d , ranging from 375 mg CH_4/ m^2 d to emissions of 1739 mg CH_4/ m^2 d. The spatial and temporal variations were large and due sediment and water temperatures (Johansson, A.E., et al., 2004).

2. Scope and objectives of this proposal

As shown earlier, Eco-Technologies may prevents the negative environmental impact of uncontrolled disposal of sewage, but also may generate secondary negative environmental impacts in terms of greenhouse gas emissions that may be important to contribute to Global Warming. Unfortunately few studies have been undertaken to estimate greenhouse gas emissions data and much less to compare different Eco-technologies with a view to explain the greenhouses gasses formation and reduction.

The present proposal of investigation is framed in the project "Eco-Technologies for Sustainable Waste Water Treatment and Reuse in Small and Medium Size Municipalities in Colombia". The aims of this investigation are to evaluate and quantify the greenhouse gas emission rates in Eco-technologies for sustainable domestic wastewater management in tropical regions. The specific objectives of this research are:

1. To develop a low-cost and feasible methodology to estimate greenhouse-gas emissions in Eco-Technologies.
2. To compare the rates of greenhouse gas emissions from two different anaerobic systems, treating domestic wastewater in tropical regions at pilot and full scale (UASB and anaerobic ponds). COD (pre-treatment)
3. To compare the rates of greenhouse gas emissions from facultative and duckweed based ponds treating domestic wastewater at pilot and full scales. Tertiary treatment (N, P, COD)
4. To evaluate the influence of environmental and operation conditions of the experimental units on their greenhouse gas emission rates.
5. To develop mass balance models based on carbon and nitrogen to predict greenhouse emission rates in the experimental units.

Hypotheses

1. The green-house gas emissions from WWT Eco-technologies maybe estimated on the basis of appropriate experimental methods.
2. There might be significant differences in the greenhouse gas emission rates within and among the two anaerobic systems tested. UASB < AP
3. There might be significant differences in the greenhouse gas emission rates within and among the facultative and duckweed based ponds tested
4. The Environmental and operational conditions of experimental units may influence significantly their greenhouse gas emission rates.
5. The prediction of greenhouse gas emission rates will be possible on the grounds of both theoretical and experimental approaches.

3. Methods

The aims of this investigation are to evaluate and quantify the greenhouse gas emissions rates in Eco-technologies for sustainable domestic wastewater management in tropical regions.

3.1 Location of research

The experimental site for this work is principally the Research Station on Wastewater Treatment and Reuse located in Ginebra town (9800 population and average temperature 26^{o}C), Valle del Cauca region in southwest Colombia. The research station consist of several Eco-Technologies based in anaerobic process (UASB reactor, Anaerobic Ponds and anaerobic filter) and Algal and Duckweed waste stabilization ponds both at pilot and full scale.

3.2 Estimation greenhouse gas emissions in Eco-Technologies

The first stage of research will be focused to establish an analytical method to estimate greenhouse gas emissions in Eco-Technologies for wastewater treatment system. A review literature over methods of quantification and analytical techniques so as studies about topic investigated will be do. Preliminary collectors made in materials as Plexiglas transparent of shape circular or box supported at the surface of wastewater treatment system can be used to measure quantity of gas emitted at pilot and full scale. Zimmo et al. (2003) reference this method like accurate, convenient and feasibility for analysis of a wide range of gasses emitted from stabilization ponds and possibly another aquatic system. Composite sample will be collected taking account hourly and daily variations. Concentration of greenhouse gas will be measured with a gas chromatograph or volumetric technique.

3.3 Compare the rates of greenhouse gas emission in UASB reactor, Anaerobic Ponds Algal and Duckweed waste stabilization ponds both at pilot and full scale.

Several experiments at pilot and full scale reactors will be conducted to estimate and compare greenhouse gas emissions in UASB reactor, Anaerobic Ponds Algal and Duckweed waste stabilization.

3.4 Influence of environmental and operation conditions of the Eco-Technologies in their greenhouse gas emission

Parameters like pH, temperature, equilibrium conditions, hydraulic flow patterns, load organic, physical barrier, microbiology and process biodegradation anaerobic, aerobic, nitrification and denitrification, will be studied to explain greenhouse gas emissions in Eco-Technologies selected in the research.

3.5 Models based in mass balance

Through mass balance the various compounds related with greenhouse gas in Eco-Technologies selected will be estimated to enable the modelling of emissions. Monitoring of BDO, SS, COD, COT, kjeldahl nitrogen, ammonium, bicarbonate, and

gas accumulation in sludge, duckweed density and quantity of gases dissolved at liquid phase can help to calculate rate volatilization, mass transfer and kinetics of process associated formation greenhouse gas.

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PHD PRE-PROPOSAL BY ALBERTO GALVIS
TECHNOLOGY SELECTION MODEL TO POLLUTION PREVENTION AND CONTROL FROM DOMESTIC WASTEWATER IN SMALL AND MEDIUM TOWNS

1. INTRODUCTION

The constantly increasing pressure on water resources is a consequence of fast growth over the past few years not just of the population, but also of the agricultural and industrial sectors, all of which demand great quantities of water for their activities. In most cases, the used water is returned to water sources as untreated wastewater, generating pollution and affecting the quality of life of communities, with the subsequent economic, social and environmental impacts.

Wastewater is the cause of 80% of morbidity in developing countries. This is closely related to low sewerage coverage, and also to inadequate treatment and final disposal of wastewater (PAHO/WHO, 2001). In Colombia, the present infrastructure for treating domestic wastewater has effective coverage of 8% of the population (Ministerio del Ambiente, 2002). Most wastewater is dumped without treatment and raw sewage is used in agriculture.

In response to this situation, different strategies have been designed, which include the revision and updating of the sector's regulations and policies. This aims to prioritise investment in the drinking water and sanitation sector, through decentralisation of service provider companies, subsidy reduction and setting up self-funding systems.

However, these strategies have had a limited impact. The assessment of wastewater treatment made by the PMAR (National Plan for Municipal Wastewater Management) estimated that $3,400 million US dollars would be needed to set up wastewater treatment systems in 300 Colombian municipalities (URL – 1).

In a sector analysis undertaken as part of the PMAR (URL – 1), it was calculated that it has resources of $708 million US dollars from: the National Royalty Fund (10%), charging for discharge (8%), territorial entities (4%) external credit (1%), public service provider investment (42%), and other sources from the Regional Environmental Authorities (35%). Therefore, only 12% of the treatment systems could be financed with the available resources, leaving a deficit of $2,700 million US dollars (URL -1).

For investment in water and sanitation to produce the expected outcomes in quality of life improvement in communities, a systemic vision of the problem is necessary. Water should be administrated as a limited resource with multiple uses and any solutions should be formulated with appropriate assignation and protection criteria, considering the basin as a planning unit.

In addition, although the new policies and regulations formulated by the government have begun to consider these issues, more work is necessary to develop more specific regulations, to strengthen capacity in the responsible institutions as well as to train consultants and other people who work on sanitation and water pollution control.

The analyses carried out have shown that one of the mechanisms with the greatest impact on water resource protection is the correct choice of technological solutions in

municipal wastewater treatment. This integrates technical, environmental, social, cultural, economic, policy and regulatory aspects, allowing for a transition from a traditional approach to another of closed and efficient processes. The former views the environment as an inexhaustible source of resources and a recipient of waste generated by production and consumption processes whereas with the latter, environmental impact is lessened and water reuse is guaranteed.

As a contribution to the efforts of the responsible institutions for pollution control and the water supply and sanitation sector in Colombia will be developing a model (conceptual model and software) for technology selection to pollution control from domestic wastewater. This model is part of a process to create a planning tool to select and prioritise sustainable technologies. It takes into account technology characteristics, dumped water quality, treatment aims, receiving water body uses, the cleaner production approach, costs of initial investment, operation and maintenance, as well as the socioeconomic and cultural features of the communities where the systems will be set up. On the basic of cleaner production concept, the model involve the so called 3- step strategic approach for sewage management three steps include (Gijzen, 2004): 1) pollution prevention and minimization, 2) treatment for reuse, and 3) stimulation of the self-purification capacity of the receiving environment.

This Project will be developed in the context of SWITCH Project: Sustainable Water Management Improves Tomorrow's Cities´ Health, leads by UNESCO – IHE. SWITCH involves 32 institutions from 13 different countries from Europe, Asia, Africa and Latin America.

2. BACKGROUND

Decision making for technology is generally accompanied by methodological tools that facilitate the process of selection, considering multiple aspects or criteria, from the technical, environmental, social and economic points of view, in order to guarantee the sustainability of the technology implemented.

Horan and Parr (1994) classify technology selection methods into five categories: descriptive documents, checklists, selection matrices, algorithms and methods that include computer programmes (software).

The common selection criteria for most authors can be classified into the following factors: treatment objectives, technological aspects, costs, operation and maintenance, wastewater characteristics, demographical and socio-cultural factors, site characteristics, climate factors, environmental impact, capacity and willingness to pay and construction aspects. In general, a total of 93 selection variables were identified in the authors consulted, which were distributed among the 11 factors mentioned above. The number of variables proposed by each author depended on how seriously the issue of technology selection was taken within the work, which in turn depended on the objectives for which each methodology or selection model was developed.

Authors such as Metcalf & Eddy (1995), von Sperling (1996) Yang & Kao (1996) and WEF & ASCE (1998) discuss descriptive and general technology selection variables, including terms as wide-ranging as environmental impact and treatment objectives.

While other methodologies such as those applied to select wastewater treatment technologies for the Piracicaba River and Capivari basins in Brazil, for the Tajo River in Spain, as well as those studied by Ruiz in Tucumán province, Argentina (URL – 2),

and by Horan and Parr in Mauritius (1994) are specific case studies, they consider some important selection criteria that cannot be excluded from the process. They also provide conceptual support for developing new technology selection models. In addition, Horan and Parr (1994) present a list of technological, environmental, social, institutional and economic factors for technology selection. However, their work does not have a clear structure with systematised information flow to facilitate application.

A more elaborate method, with a medium level of complexity, are decision trees, which have been used by Helmer & Hespanhol (1999), Reid (1982), UNEP (2002, URL–5). Even though decision trees have a very simple structure, a fast and efficient decision can be taken, based on precise information about the case in question. In these models, technological options are recommended according to the evaluation of different aspects involved in technology selection. These methods include new variables that other authors do not consider, and may be viewed as much more elaborate decision tools that aim to generate more precise solutions, with much wider possibilities for application.

The Colombian Environment Ministry (2002) and Morgan et al (1998, URL–3), use the method of weightings for their selection. By giving a score to each of the parameters evaluated, they are differentiated in terms of the aspects which are considered important in the technology selection. The methodology used by the Colombian Environment Ministry (2002), has some limitations in terms of the technological offer and also in that the selection criteria weightings do not vary according to the individual conditions of each community.

Sobalvarro and Batista (1997, URL – 4) have developed a decision matrix in which the characteristics of 12 technologies are correlated. These characteristics include the area required for the treatment system, soil movement, odour production, operational features including factors like climate, soil characteristics and topography. The limitation of the matrix is that it does not allow for other treatment alternatives to be evaluated and it also assigns weightings that could vary according to the case study.

The selection models that incorporate multi-criteria analysis are PROSAB, SANEX (Loetscher, 1997), WAWTTAR and PROSEL. These models have a higher degree of complexity and involve a larger number of factors and variables, as well as allowing for selection from a greater number of alternatives.

On revising the criteria adopted by each author to carry out the technology selection process, it was found that many do not contemplate re-use of wastewater as a treatment objective. This is an important variable within the framework of integrated water resource management, environmental conservation and resource recovery.

As well as the factors identified in the revision of selection tools, the basis for the conceptual model was the models developed by Bernal and Cardona (2003) and Castro (2003) and Guerrero (2003).

3. RESEARCH QUESTIONS AND HYPOTHESIS

The research questions related to this PhD research are:

i) What is the role of technology selection for the sustainability of a system for prevention and pollution control of water resources by domestic wastewater in Colombia?

ii) Which are the main factors in technology selection for the prevention and pollution control of water resources by domestic wastewater in the framework of IWRM for small and mid -size towns in Colombia?

iii) Keeping in mind (i) and (ii), how it could be defined a methodology to support the decision makers, consultants, and professionals involved in pollution prevention and control of domestic wastewater in small and mid-size towns in Colombia

In the context of this research the following hypotheses are defined:

i) Technology Selection is one of most important factors for sustainability in pollution prevention and control from domestic waste water in small and mid size towns in Colombia

ii) Pollution prevention and control of domestic wastewater in small and mid-size Colombian towns should consider the basin as the basic unit of analysis. It should include, besides the treatment technology, the water uses, particular conditions of the communities and the regional and local context of the impact of the wastewater pollution.

The most important factors in a process of technology selection in small and medium communities are: socio-cultural conditions and local infrastructure; climate conditions; site characteristics; technological aspects; wastewater characteristics; treatment objectives; policies, regulations; economic and financial aspects; and ability and willingness to pay.

iii) Considering the factors indicated in (ii) it is possible to develop and to validate a model for technology selection which will contribute to the decision making process to define control and prevention strategies to avoid or to minimize the impact from domestic waste water pollution, in small and medium Colombian towns. This model will be useful for non experts professionals involved in decision making.

The development of a computer model (software) will allow to optimize the use of the developed conceptual model and it will make more efficient its validation, training, applications and updates.

4. OBJECTIVES

General objective

To develop a conceptual and a computer based model for technology selection, this will provide a useful tool for decision makers, town engineers, consultants and R&D staff for the selection of optimal technologies for wastewater treatment for reuse. The approach will not exclusively consider interventions ‘at the end of pipe’, but will take into account the entire urban water cycle, pollution prevention and pollution control.

Specific objectives

i) To characterize the technologies for prevention and pollution control by domestic waste water that have been implemented or with good possibilities of being used in the future in small and mid-size towns in Colombia.

Main activities:

- The basin like analysis unit
- Characterization of pollution prevention strategies
- Self-purification capacity of the body water
- Characterization of sewer system
- Used treatment technologies or technologies with potential of being used in Colombia.
- Efficiency of the technologies.
- Operation and maintenance
- Applicability of the technologies according to the geographical, socioeconomic and cultural context

ii) To develop a conceptual model of technology selection to pollution prevention and control from domestic waste water in small and medium Colombian towns.

Main activities:

- Basic concepts (system theory, sustainability, IWRM, cleaner production, etc)
- Legislation and policies.
- Identification of factors (treatment objectives and discharge criteria; experiences in Colombia; geographical, socioeconomic and cultural aspects, environmental aspects, economic and financial aspects).
- Cost models
- Identification of variables and indicators
- Development of conceptual model
- Regional seminars
- Validation of the conceptual model
- Web site

iii) To develop a computer program (software) to technology selection for prevention and pollution control by domestic waste water in small and mid size towns in Colombia

- Review conceptual model
- Approach
- Analysis
- Design
- Implementation of the software
- Regional seminars
- Validation
- Website update

5. RELEVANCE

The relevance of the research is:

a) Contributes to the sustainability of the water supply and sanitation systems in medium and small communities in Colombia.
b) Contributes to the paradigm shift in connection with the water supply and sanitation
c) Contributes to the optimization of the investments in pollution prevention and control for domestic waste water domestic.
d) Contributes to performance Millennium Development Goals MDG, in particular to the Objectives 4 (Goal 5) and 7 (Goal 9). MDG 4 refers to the reduction of child mortality and MDG 7 refers to ensuring environmental sustainability.

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PHD PROPOSAL BY MOHAMMED BABU

OPTIMIZING NITROGEN REMOVAL IN ALGAE AND DUCKWEED WASTEWATER STABILIZATION PONDS

1. Introduction

1.1 Background

The primary objective of this proposal is to review ways by which nitrogen removal in algae and duckweed ponds can be improved. This requires a full understanding of nitrogen transformation processes in wastewater stabilization ponds and of the current problems associated with algae and duckweed systems in terms of nitrogen removal. Possibilities of improving these systems will be suggested and investigated. The major aim of this study is related to reduction of nitrogen in wastewater to the low levels recommended for discharge.

Prior to improving this system, rationale for nitrogen removal requires to be understood. The question of why nitrogen is an important water quality and environmental parameter needs to be addressed.

Nitrogen gas is inert in nature but the active forms such as ammonia, ammonium, nitrite, nitrate, nitrous oxide etc are known to have detrimental effects on public health and environment (Gijzen and Mulder, 2001). Here, active forms refer to nitrogen forms that are chemical reactive and have a greater potential of being incorporated in biological systems. These are for an important part produced through anthropogenic sources. Nitrogen forms like Ammonia can cause eutrophication and massive fish kills due to oxygen depletion in water while nitrates cause underground water pollution, poor drinking water quality and high levels result into blue – baby symptoms in infants. Nitrous oxide particularly, has been found to have a 200 –300 fold stronger greenhouse effect as compared to carbon dioxide, which has raised lots of concern of recent (Takaya et al, 2003).

There is growing concern about the amount of nitrogen fixed artificially. Gijzen and Mulder (2001) estimate that the current production of fertilizer nitrogen is about 37% of the total terrestrial and marine biological nitrogen fixation. Bernhard and Schwarzaenbach (1997) also estimate that anthropogenic fixation of nitrogen has reached *ca.* 145 Mt N yr^{-1} and is approaching values close to natural fixation by bacteria. This implies that the total amount fixed is doubling and the capacity for the denitrifiers to cope up with this is still unknown. The effects on the world water bodies are bound to increase. And in fact, these effects have become increasingly visible since the 1960’s when increasingly reports are given of eutrophication of water bodies.

Many undesired long term effects linked to nitrogen pollution have been identified thus high environmental standards and stringent regulations are being adopted by many developed nations. This is exerting pressure on existing treatment systems and a paradigm shift towards treatment plants for nitrogen removal is taking shape. This is true for EU and USA but elsewhere; there is laxity in setting up high effluent standards and in enforcing these standards. This is attributed to prohibitive costs of advanced wastewater treatment.

Various advanced systems for treating nitrogen have been developed such as activated sludge with biological nitrogen removal (BNR), but these require high capital investments, maintenance costs and skilled manpower (Veenstra and Alaerts, 1996). Developing nations cannot afford these, yet urbanization and population is on the rise (Gijzen and Khonker, 1997; Yu et al, 1997). This leaves a big technical gap between developed and developing nations, which needs to be closed.

Many developing nations have adopted wastewater stabilization ponds (WSP) as the major wastewater treatment technology. This is due to its cost-effectiveness in construction and maintenance. Indeed these have been found to be performing similar to advanced systems (Mara and Pearson, 1998). The major shortcoming here is the long hydraulic retention time, low bacterial biomass, high total suspended solids (TSS) in effluent and large space required for construction. As population pressure increases, more space for effective treatment will be required yet the cost of land in urban areas is rising. This technology can only be cost effective if the cost of land is < US$ 15/m^2 (Yu et al, 1997).

Due to these limitations, many other systems have been combined with WSP with the purpose of increasing treatment efficiency, re-use of nutrients and reduction of space requirements. An example of such a new system is the algal-duckweed technology. Algae-duckweed stabilization ponds have been shown to be effective in wastewater treatment and in reducing TSS. However they suffer from limited surface area for microbial attachment thus various studies have recommended that increasing microbial attachment surface and improved hydraulic flow can further improve their performance (Caicedo, 2005, Zimmo, et al, 2000). It is the aim of this study to adopt such measures with the anticipation of improving performance. This can be achieved by the introduction of vertical baffles, which will increase attachment surface and at the same time modify hydraulic flow patterns.

Scope

This study will be limited to algae-duckweed wastewater treatment. It will address the issue of introducing more surface area for microbial attachment and improving hydraulic flow patterns for effective treatment. It will also investigate the effects of introduced changes and consequent changing environmental conditions on other important treatment parameters.

1.2 Research Objectives

Aim of the Study

The major aim of this study is to contribute to the development of effective technologies to prevent eutrophication by optimizing nitrogen removal from sewage in algae, duckweed or a combination of the two (hybrid) wastewater stabilization ponds. Environmental quality standards are becoming more strict, which demands more stringent regulations in wastewater disposal.

In most conventional wastewater treatment plants, there is no pathogen removal and focus is usually on removal of Suspended Solids (SS) and Biochemical Oxygen Demand (BOD)/ Chemical Oxygen Demand (COD). Wide-spread technologies such as activated sludge with biological nitrogen/ phosphorous removal (BNR/BPR) have been developed for nitrogen and phosphorous removal but these are too costly for many developing nations to afford. Wastewater stabilizations ponds (WSP) are the

most common in developing countries and do remove some nitrogen and phosphorous. However, the removal mechanisms are poorly understood and no design criteria for these parameters seem to exist.

It is the prime objective of this study to improve nitrogen removal from wastewater in already existing treatment systems like algae and duckweed wastewater stabilization ponds or the combination of the two (hybrid) without compromising other important parameters such as BOD, COD, coliforms etc. Literature shows that nitrogen transformation and removal in wastewater stabilization ponds is influenced by important variables such as dissolved oxygen, pH etc as well as other factors like hydraulic performance and biofilms.

Investigating the effect of introducing vertical baffles in wastewater stabilization ponds will be fundamental in understanding how to improve their treatment performance. It is expected that the baffles will minimize the problems of short-circuiting and stratification as usually observed in these ponds. The vertical baffles will also force wastewater to move from the upper aerobic zones to the deeper anaerobic zones hence improving on the process of nitrification/ denitrification. Besides this, the baffles will provide support for attachment surface for nitrifiers and denitrifiers and the overall effect of improved nitrogen removal is expected.

Key Research Questions

In order to be able to achieve the above aim, the following questions will be required to be answered:

1. Can the performance of baffled algae and duckweed wastewater stabilization ponds in nitrogen removal at pilot scale be described and predicted using a model? Can the rate constants for the model be based on activity tests performed in the laboratory?

2. Can nitrogen removal in duckweed wastewater stabilization ponds be improved by introduction of vertical baffles due to?
(a) Improved hydraulic flow patterns by vertical baffles?
(b) Provision of support for biofilm attachment surfaces on the baffles?

3. Can nitrogen removal in algae-duckweed wastewater stabilization ponds be improved in relation to?
(a) Oxygen levels influenced by algae in different pond configurations?
(b) Taking wastewater from upper aerobic zone to the deeper anaerobic zones in relation to 1(a) above?

4. Removing limitations of denitrification by a lack of COD in the last duckweed wastewater ponds can be achieved by:
(a) Re-circulation of the last duckweed pond effluent to the first anaerobic pond having high COD?
(b) Addition of COD to the last duckweed pond?

5. What will be the effects of changing environmental conditions in baffled algae and duckweed wastewater stabilization ponds on:
(a) Nitrification potential?
(b) Denitrification potential?
(c) Methanogenic potential?

6. In relation to 1-4 above, will the overall performance of the wastewater stabilization ponds in terms of BOD, COD, SS, Phosphorous and coliforms improve, decline or remain the same?

Hypotheses

1. The performance of baffled algae and duckweed wastewater stabilization ponds in nitrogen removal can be described and predicted by a model and laboratory experiments. Laboratory experiments (activity tests) are suitable to generate rate constants that can be used in the model to predict the performance of the pilot scale experiments.

2 (a) Nitrogen removal can be improved in duckweed wastewater stabilization ponds by improving hydraulic performance of these ponds. This can be through introduction of vertical baffles that will prevent short circuiting, stratification and induce a plug flow pattern. High hydraulic performance of the system will be achieved and sufficient treatment will be provided.

(b) Provision of attachment surfaces on the baffles will increase biofilm formation hence improved nitrogen removal. All nitrifiers and denitrifiers are slow growers and prefer attached growth hence their biomass will increase resulting in improved nitrogen removal.

3 (a) Changing oxygen levels (due to algae production) by introducing aerobic zones in baffled duckweed wastewater stabilization ponds will improve nitrogen removal.

(b) Taking wastewater from the top aerobic zones to the deeper anaerobic zones (and vice versa) by down and up flow patterns induced by vertical baffles in both algae and duckweed wastewater stabilization ponds will improve nitrogen removal in these zones.

4. Limitation of denitrification in the last baffled duckweed wastewater stabilization pond due to low COD can be overcome by either:
(a) Re-circulating the effluents to the first anaerobic pond with higher COD or
(b) By addition of COD to the last pond.

5. Modification of hydraulic flow patterns by the baffles will change environmental conditions such as DO and pH. These changes will affect nitrification, denitrification and methanogenic potentials.

6. The overall performance of the baffled duckweed wastewater stabilization ponds will remain the same or improve in terms of BOD, COD, SS, Phosphorous and coliforms in relation to modifications proposed under 1-4 above.

Objectives

General Objective: The major objective of this study is to improve nitrogen removal from domestic wastewater in algae and duckweed wastewater stabilization pond or a combination of the two systems. This will be achieved by introduction of vertical baffles for improved hydraulic flow and increased surface area for microbial attachment.

Specific Objectives: *The following specific objectives will be addressed in the course of the study:*

1. To determine rate constants using laboratory experiments (activity tests) that can be used in a model as rate constants to predict nitrogen removal in the pilot scale system. This will involve developing an appropriate methodology for determining nitrification and denitrification activity in the bulk and biofilms.

2. To introduce vertical baffles in the pond design with view to:
(a) Improve hydraulic performance of the ponds by creating plug flow patterns and minimizing problems associated with short-circuiting and stratification. Moreover, to create an upflow/downflow pattern that is expected to increase oxygen input and nitrification.
(b) Increase nitrogen removal in the duckweed wastewater stabilization ponds as a result of mounting artificial biofilm support on baffles to create enough surface area for biofilm attachment.

3 To study the effect of induced changes in oxygen balance in the pond system by:
(a) Increasing oxygen levels and consequently nitrification by introduction of aerobic zones or anaerobic zones for denitrification in the different pond configurations in duckweed wastewater stabilization ponds
(b) Taking wastewater from upper aerobic layers to the deeper anaerobic water layers by the vertical baffles (Appendix II). This is important because the nitrates formed in the aerobic zones can be reduced in the anaerobic zones.

4 To study conditions that stimulates the denitrification process in the outlet-zone of the pond system by:
(a) Recycling the effluents from the last duckweed ponds to the first anaerobic ponds with higher BOD levels. This is because the anaerobic ponds will provide anoxic conditions and the high BOD required for denitrification of the nitrate in the final pond effluent.
(b) Addition of COD in the last pond will provide a carbon source to the denitrifiers hence improving denitrification.

5. To study how changes in environmental conditions brought about by baffles affect nitrification, denitrification and methanogenic potential. This is because increased oxygen levels in the system will increase oxidation of ammonia thus producing more nitrates. The nitrates are expected to provide more substrates for denitrification.

6. To improve the overall performance of the baffled duckweed wastewater stabilization ponds in terms of all parameters with respect to 1- 4 above.

2. Research Methodology

The research will be carried out in Uganda at Kampala (Bugolobi sewage treatment plant) at pilot scale under realistic tropical conditions of temperature of 25^0C. Specific laboratory studies will be carried out at IHE laboratories using synthetic wastewater of medium strength, since the primary objective is pollution control. This research is facilitated by cooperation between UNESCO-IHE Institute for Water Education, Makerere University and National Water & Sewerage Corporation, Kampala - Uganda.

2.1 Pilot scale experimental set up

Four channels of 4mx0.8mx0.8m in length, width and depth will be constructed at Bugolobi sewage treatment plant. Channel one will be a long open channel. Channel two will have seven baffles suspended parallel to the flow direction and channel three will also have seven baffles but placed perpendicular to the influent flow direction. Channel four will have seven horizontal baffles (Figure 3). In terms of flow patterns, channel 1 and 2 will have direct horizontal flow, channel 3 up and down flow while channel 4 will have horizontal flow but directed around the baffles. Wastewater of medium strength (Appendix 1) will be fed to the systems, duckweed introduced and water quality parameters monitored.

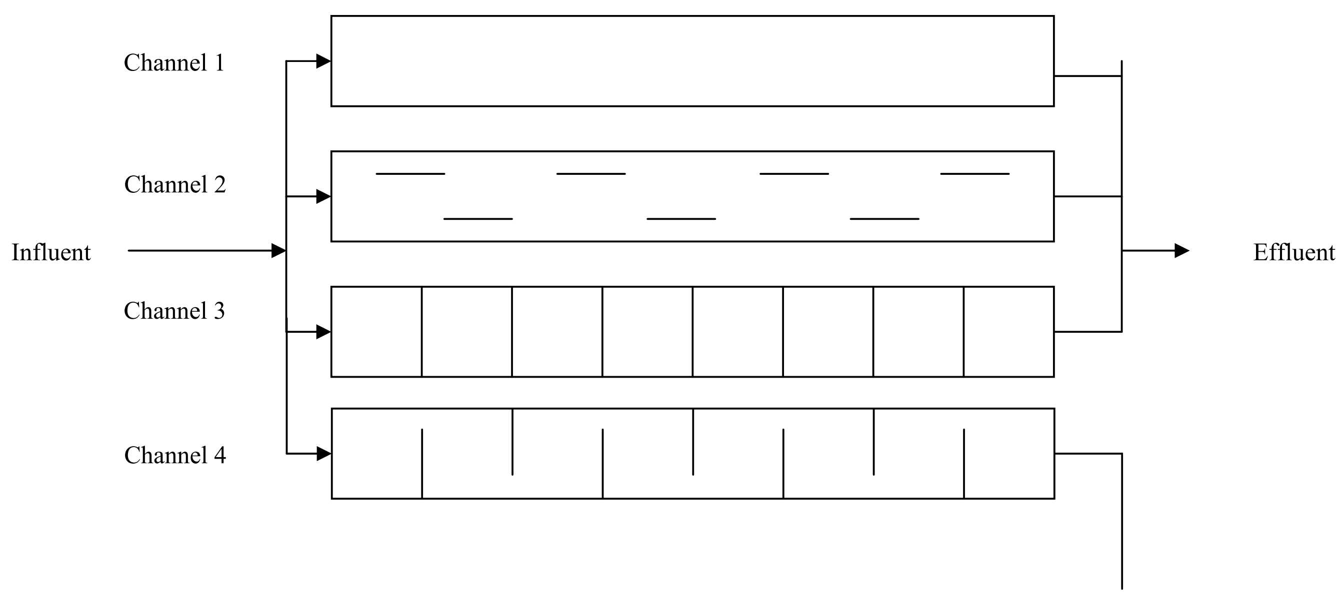

Figure 3. Plan view of the proposed pilot plant set up

The major aim of this research is to investigate ways by which nitrogen and pathogen removal can be improved in constructed algae and duckweed wastewater stabilization ponds treating sewage. This study proposes introduction of vertical baffles into these systems to enhance treatment performance. When the baffles are placed perpendicular to the flow, up and down flow patterns will be induced. It is expected that the down flow pattern will take wastewater from upper aerobic zones, where nitrification will be predominant, to lower anaerobic zones for denitrification. Moreover, the downflow

pattern will transport oxygen deeper into the pond and in this way nitrification is expected to occur in a larger part of the pond volume. Likewise, the up flow will take the remaining un-oxidized ammonia in the anaerobic zones to the upper aerobic zones for oxidation in the next pond (Appendix II). In this way, the process of nitrogen removal through nitrification and denitrification is expected to improve. Besides modification of flow patterns, baffles will also provide extra surface area for biofilm development and prevent short-circuiting as commonly observed in wastewater stabilization ponds.

Prior to the pilot plant experiments, there is need of thorough study and understanding of the fundamental processes that occur in these ponds. This study is also aimed at providing rate constants for the model that will be developed on the basis of currently available information in the literature and on laboratory activity tests (nitrification and denitrification rates). The model seeks to differentiate between the process of nitrification and denitrification in the bulk and in the biofilms. Laboratory studies will be carried out to measure nitrification and denitrification rates in bulk and in the biofilms. This will involve incubating biofilm plates in a laboratory scale system of duckweed and algae pond-reactors (Figure 4) simulating the pilot scale studies. The results obtained will be used for predicting the treatment characteristics of the pilot scale system. Pilot scale studies will then be conducted and this will involve monitoring influent and effluent composition, as well as measuring nitrification and denitrification rates. Results can then be compared with the prediction from the model (model validation).

It is also known that introduction of vertical baffles in wastewater stabilization ponds change their hydraulic properties. There is need of deeper understanding of how these changes affect the hydraulic performance of the ponds. Detailed tracer studies will be conducted at pilot scale to compare performance of the different types of baffles. Other important variables that will be investigated in this research will include the effect of introduction of artificial substrata on the baffles and of creation of aerobic zones in baffled duckweed ponds.

The methodology of this research will take the following approach: First, process modeling and preliminary laboratory experiments that seek to address research question (1) will be performed. This will be followed by pilot scale studies, which will answer research questions (2) – (6). The details of these will be discussed in the sections that follow.

2.2 Process modeling

(1) In order to address research question (1), computer modeling will be performed. The International Water Association (IWA) has developed and evaluated biofilm modeling using analytical, pseudo-analytical and numerical solutions. They have developed models for substrates conversion in the bulk and in biofilms in wastewater treatment systems (Noguera and Morgenroth, 2004). These models have been incorporated in computer software Aquasim (Rittman, et al., 2004; Reichert, 1994) and are able to predict biofilm thickness, substrate concentration and microbial species numbers in the biofilm and in the bulk over time. It can also simulate biofilm-sloughing events (Warner and Morgenroth, 2004). Several researchers (Moussa et al., 2003; Janning, et al, 1995; Reichert et al, 1995; Warner and Morgenroth, 2004; Eberi et al, 2004; Rittmann et al, 2004; Koch et al, 2000; Noguera and Picioreanu, 2004)

used this program and have found results that are comparable to experimental measurements. It is proposed that Aquasim will be used in this study to model substrates and biofilms in pilot scale experiments. Experimental measurements will be used to calibrate and valide the model. Since computer modeling requires to be fed with rate constants there is need to establish these constants under conditions which are similar to the pilot scale system. Preliminary laboratory experiments then become a pre- requisite.

2.3 Preliminary laboratory experiments

These experiments will be performed in order to understand processes and establish nitrification and denitrification rate constants of modified wastewater stabilization ponds. Materials that will be used at pilot scale i.e. wood for vertical baffles and polyurethane for the artificial attachment surface will be tested in the laboratory. These materials will be incubated in 1-meter length & 23cm diameter algae and duckweed columns at 5cm, 45cm and 85cm depth. The columns will be run using synthetic wastewater (Appendix 1) seeded with activated sludge in a continuous flow system with up and down flow patterns simulating hydraulic flow of the vertical baffled wastewater stabilization ponds (Figure 4). Nitrification and denitrification rates of biofilms and in the bulk liquid will be determined. This information will be used in Aquasim to predict the behavior of the pilot scale system.

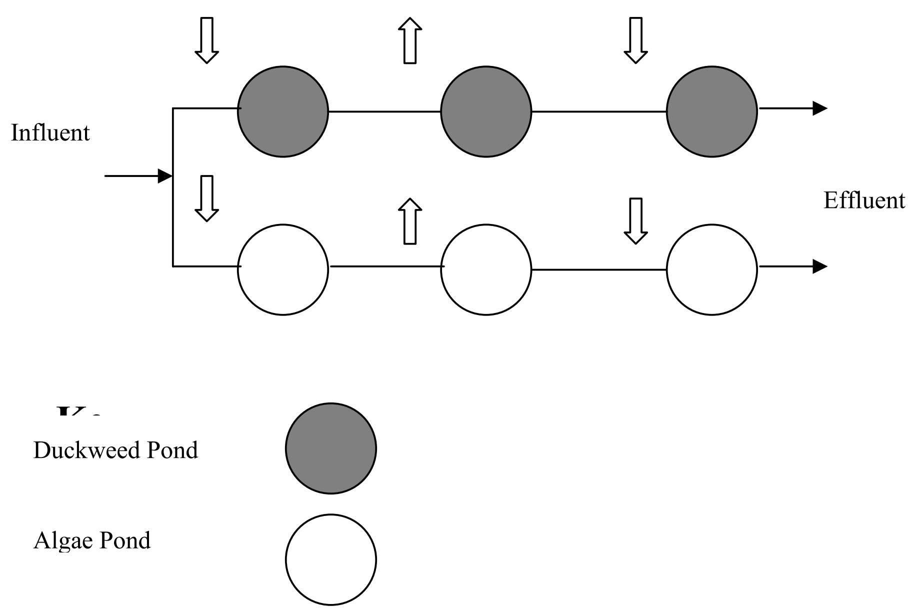

Figure 4. Plan view of Duckweed and Algae columns simulating the up and down flow patterns of the planned pilot scale experiments with vertical baffles. The block arrows represent up and down flow patterns.

Before the biofilms plates from the columns are used in the tests, there is need to develop an appropriate method to measure nitrification and denitrification rates of biofilms. This process requires many biofilm plates for different trial experiments. However, the volume of the columns is limited and may not permit insertion of many

biofilm plates. Therefore, for trail experiments, another set-up will be used to incubate the biofilm plates. In this case, two PVC trays of dimensions 5.5cmX3.7cmX9.0cm (Length, width & depth) will be used. The experimental set up will be a continuous flow system similar to that of Gunatilike (2005) except that the acrylate glass biofilm plates will be replaced by thin pieces of wood. Each tray will hold at least 60 pieces of wood and this is sufficient biofilm material for trial tests required for developing the methodology. Synthetic wastewater seeded with activated sludge and of the same composition as that of the columns will be used. The set up will be exposed to light and when the biofilm reaches a steady state, the plates will be transferred to batch reactors for determining nitrification and denitrification potential as described in sections 3.3 (i) – (ii).

(i) Nitrification Potential: Biofilm plates will be washed using suspension media (Moussa et al, 2003) and re-incubated in conical flasks containing fresh synthetic wastewater which is deficient of ammonia and not seeded with nitrifiers. Each flask will have only one plate and the tests will be done in duplicates. Ammonia and nitrite oxidation activities will be determined using the method developed by Moussa et al, (2003). A known amount of $NaN0_2$ will be added to the flasks, mixed to obtain a homogenous solution and the plates placed back in the flasks. Water samples will be drawn from the reactor on hourly basis, filtered and measured for $N0_2^-$ to determine the rate of nitrite uptake. When all the $N0_2^-$ has been consumed, the plates will be removed, NH_4Cl added to the flask, mixed and immediately the plates replaced. The concentration of ammonia will be monitored every hour. This will give tan indication of ammonia uptake rate. Other experiments will include leaving the biofilm plates in the flasks but pumping and recycling of the synthetic water or using a magnetic stirrer to slowly stir the contents of the flask without disturbing the biofilm plates while adding nitrite and ammonia.

A separate experiment using a portion of the wastewater in which the biofilm plates were previously incubated will be carried out simultaneously with the above experiment. The synthetic wastewater will be aerated for 1 hour to ensure that all the ammonia has been depleted and nitrite and ammonia added as described above. This is to determine the process of nitrification in the bulk. In this way, nitrification in the biofilm and the bulk can be differentiated. This is important in determining the significance of attached nitrifiers in the system.

If the above tests give reproducible results, the appropriate methodology will be adapted and used to investigate nitrification and denitrification potentials of the biofilms in the columns and later in the pilot scale.

(ii) Denitrification Potential: This will be determined based on the principle of NO_3^- - N consumption, with the amount of nitrates consumed in a given period indicating the rate of denitrification. Biofilm plates will be placed in conical flasks containing synthetic wastewater in which ammonia is replaced with known amount KNO_3. To ensure anaerobic conditions, oxygen from the wastewater will be flushed out using nitrogen and the flasks immediately sealed. The disappearance of nitrates with time will be monitored.

For bulk liquid experiments, the bulk liquid will be aerated for about 1 hour to be sure that all the ammonia has been consumed (Moussa et al, 2003). A water sample will be taken in order to determine the initial nitrate concentration before a known amount of nitrate is added. Flushing with nitrogen gas to ensure that all the oxygen is lost to establish anaerobic conditions required by the denitrifiers will follow this. The reactor will then be immediately sealed and concentration of nitrates monitored with time. Methods of cultivation of microorganisms and of ensuring a homogeneous mixture in the flasks will be as described in 3.3 (i) above.

(iii) Methanogenic potential: Methanogenic activity will be determined using the dark glass bottle method developed by Soto et al (1993). This is a simple method that has high measurement precision and requires very small quantities of inoculums (sludge). This method can accurately determine methanogenic activities up to 0.05 g $COD.g^{-1}VSS.d^{-1.}$

NB: It is important to note that the preliminary experiments (i) & (ii) will be carried out on two types of biofilms, one type will consist of an algal-bacteria biofilm while the other will be bacterial biofilm without algae. This implies that incubation of biofilm plates will take place under light and dark conditions.

2 (a) In order to answer research question 2 (a), duckweed will be introduced in channel 1,2, 3 & 4 (Figure 3). To assess the hydrodynamic behavior of the four channels, stepwise tracer studies will be performed. Dead space fraction, volumetric efficiency and mean retention time will be calculated as described in section 2.8.1 - 2.8.1.3 of this proposal and compared between the four channels. It is also noted that channel 2, 3 & 4 have equal number of baffles though differently arranged (Figure 3). The reason for having an equal number of baffles in these channels is to keep attachment surface constant such that any differences in treatment performance are only attributed to change in flow pattern. Treatment performance will be evaluated using the right model as described in section 2.8.1.4 of this proposal and compared within and between the treatments.

2 (b) The design of the ponds in terms of placement of baffles will be flexible. Vertical baffles similar to those in channel 3 will be used to replace the horizontal baffles in channel four. Extra biofilm support polyurethane will be mounted on baffles of channel 3 while channel 4 will be run without biofilm support. Since both channels have a similar up and down flow pattern, any differences in treatment performance between the two systems will be attributed to the presence of biofilm support.

3 (a) Biofilm support polyurethane will be mounted on baffles of both channel 3 and 4 of experiment 2(b) above. One set will have full duckweed cover while the second one will have aerobic zones created by removing partially duckweed cover (Figure 5). The effect of creating aerobic zones in baffled duckweed ponds having artificial biofilm support will then be evaluated. Since both channels have biofilm support and same flow patterns, any differences in treatment performance can then be attributed to aerobic zones in channel 4.

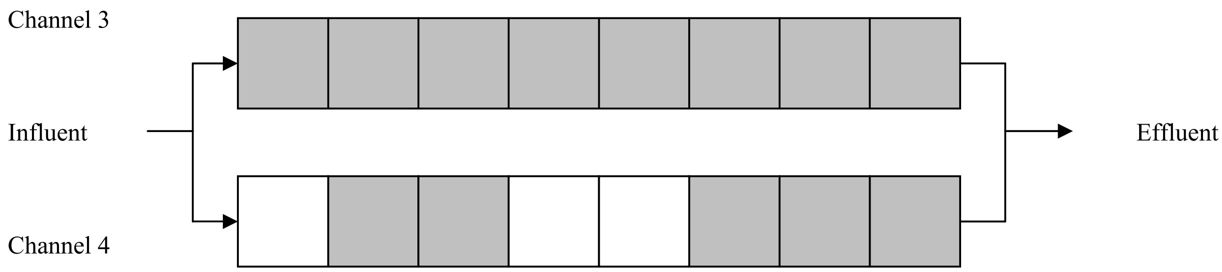

Figure 5. Experimental set up for 3 (a). Two duckweed systems, channel 3 with full duckweed cover while 4 with aerobic zones in compartments 1,4 & 5. The white areas indicate aerobic zones while gray show duckweed cover

3 (b). This is to study the effect of taking wastewater from aerobic to anaerobic zones and vice versa by vertical baffles. Channel 2 and 3 will be used in this experiment. In both cases, the baffles will be mounted with artificial biofilm support and aerobic zones created by removing partially duckweed cover (Figure 6). The reason for having aerobic zones in both systems is to keep oxygen level constant such that any differences observed in treatment performance are attributed to the difference in flow pattern i.e. horizontal flow in channel 2 and up and down flow in channel 3.

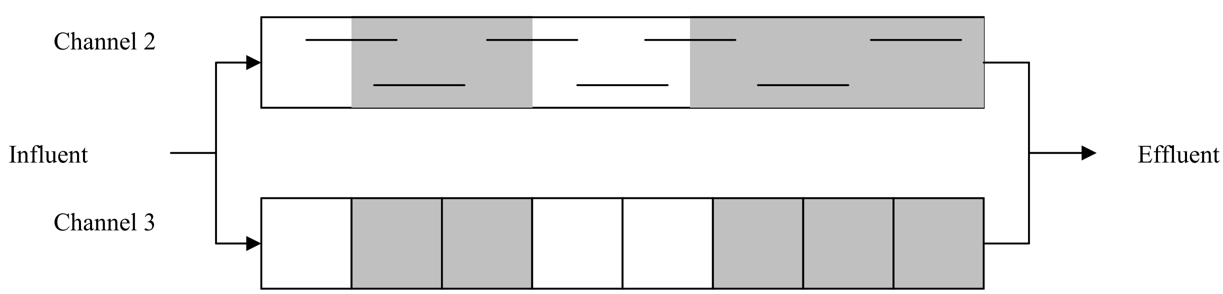

Figure 6. Experimental set up for 3 (b). Two duckweed systems, channel 1with baffles parallel to flow and channel 2 with baffles perpendicular to flow. Both channels have aerobic zones

4 (a) After running experiment 3 (b) for three months, effluent from the last pond will be recycled to the first pond (Figure 7). Various fractions of total effluent will be tested and special attention will be given to possible removal of nitrate via denitrification.

5. At the end of experiment 3 (b), biofilm will be sampled at depths of 5cm, 35cm and 65cm on the attachment surface. Nitrification, denitrification and methanogenic potentials of microorganisms (activity tests) will be determined as described in section 3.2 (i), (ii) & (iii). This is to check on the effect of change in oxygen levels and pH created by partially removing duckweed cover to create aerobic zones.

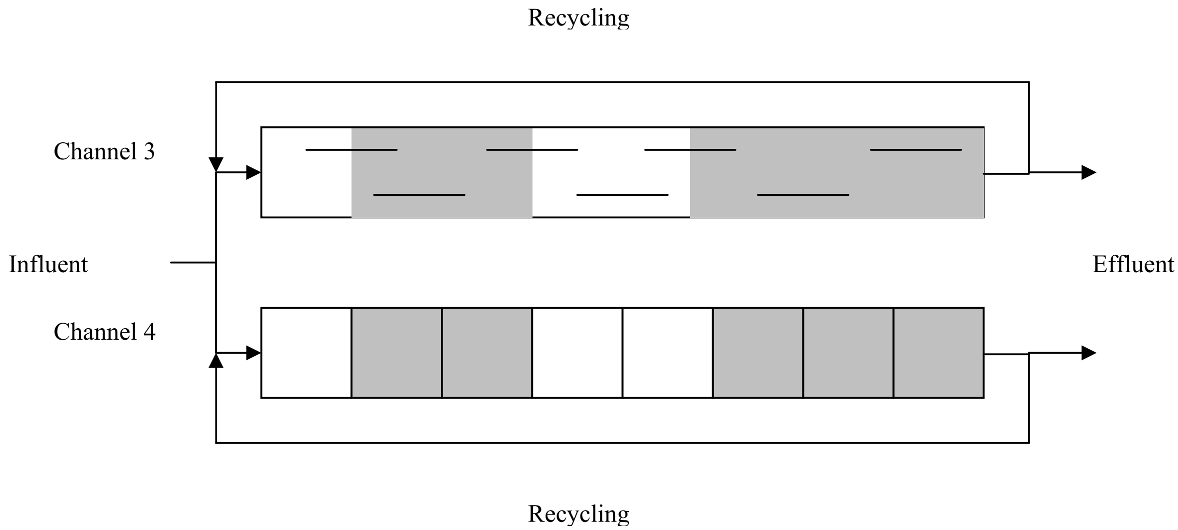

Figure 7. Experimental set up for objective 4 (a), various fractions of total effluents of 3 (a) will be recycled to the respective first ponds

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SWITCH WP 5.3. Use of natural systems in the urban water cycle
Task 4: Natural systems for the stimulation of water retention and self purification capacity of water resources

RESEARCH PLAN

1. Task description based on DoW

The approach proposed here is to consider options to boost the water retention and the natural purification capacity of receiving water bodies. The aim is to diminish flood threats, allowing higher waste adsorption capacity, and stimulate restoration of water quality in municipal water systems. This could for instance be achieved by allowing rivers to flow outside their often times artificial embankments, employing natural wetlands, applying phyto-technologies, applying eco-hydrology concepts, cause rapids or turbulence for re-aeration, or allow controlled growth of algae for oxygen supply.

Task 4a
To perform a literature survey and collect operational data from existing natural systems and processes aimed at improvement of the self-purification capacity of water resources.

Task 4b
To study the capacity for improvement of self-purification for selected options in pilot and field studies. Research will be done in selected study areas and will be applied in demo-cities. Research projects will include:

a) Hyporheic zone assessment. The hyporheic zone provides a buffer zone between ground and surface waters in which the mixing of waters and the environmental conditions provide potentially important chemical and biological attenuation reactions that can be used to sustain or improve water quality and reduce harmful chemicals entering the adjacent environments. The requirement is to quantify the attenuation capacity of this zone for a range of contaminants. Work will be undertaken on the Tame river that runs through the heart of Birmingham, and has recently been subject (on some sections) to rehabilitation strategies based on developing principles of sustainable management. Groundwater (contaminated with metals, fluorides, TCE, PCE) and river water (mainly treated wastewater) are distinctly different in chemical composition. Experimental data obtained from field trials, laboratory based, and 'in situ' microcosm experiments should support the formulation of guidelines for 'exploitation' of the hyporheic zone, and provide information on options for engineering the behaviour of the hyporheic zone.

b) In-stream remediation by using 'eco-hydrology principles'. Under this research project two main variables will be studied for their effect on boosting the self-purification capacity of water systems: 1) the effect of introducing (wetland) plant species along river beds and canals, and 2) the effect of changing the hydraulic behaviour (by introduction of plants or by engineering interventions). The choice of plant species, their optimal location in river and canal systems, the improved use of floodplanes, the use of (natural) wetlands in/along river systems, the hydraulic and ecological impacts of introduction

and harvesting of plant biomass must all be worked out. Projects will include: 1) pilot plant trials on the use of wetlands in river systems), 2) Restoration of municipal rivers, including Ner and Sokolowka, Lodz, Poland (Demo-city).

Task 4c

To develop design criteria, and to develop, adjust and apply appropriate computer models, which describe the impact of proposed interventions in water systems, with a view to optimise the natural self-purification capacity of targeted water bodies.

2. Staff and student involvement

UNESCO-IHE	
Staff input	• Research coordination • Contribution to literature survey • Distill design criteria from research results
MSc research	• Topic 1: Water quality enhancement in Sloterbinnen-polder (Amsterdam, The Netherlands) by adopting ecological engineering approaches (Mr. Ahmed Ali, 2006-2007). Focuses on stormwater treatment and in-stream remediation. • Topics 2 and 3: Effect of hydraulic dynamics on urban stream selfpurification – aerial photographs analyses and hydraulic modelling (2007-2008). This study will be carried out in the demo-city Lodz • Topic 4: Research on effects of plants on self-purification capacity (2008-2009)
ULODZ	
Staff time	• Literature study on ecohydrological techniques with special attention for urban river restoration • Design and follow-up of reservoirs • Design and follow-up of river restoration project
PhD Fratczak	Application of ecohydrology for urban river restoration with special consideration of harmonization of hydro-technical infrastructure with ecosystems (proposal below)
UNIVALLE	
Staff time	• Contribution to literature survey • Research on effects of plants on self-purification capacity
MSc research	Topic 3: Purification effect of planted buffer strips
TUHH	
Staff time	Feasibility analysis of the implementation of ecohydrological techniques for restoring urban rivers in the demo city Hamburg
UNI BIRMINGHAM	
Staff time	• Contribution to literature survey • Test site planning and follow-up • Hyporheic zone hydraulic testing and chemical investigations • Extraction of design guidelines
MSc research	• Topics 1 and 2: Hyporheic zone test site characterisation (2006-2007) • Topics 2 and 4: Hyporheic zone hydraulic testing and chemical investigations

3. Deliverables

M5	Jun 2006	• **D5.3-9c R** Research plan for Dai Yu, N.N. (Lag de Sonzo) (T4)
M6	Jul 2006	• **D5.3-13a D** Demo Plan Lodz / Plan for study site Birmingham
M9	Oct 2006	• Restoration plan "Zgierska" reservoir, "Teresa" reservoir (T6)
M11	Dec 2006	• **M** Decision on development of Demo Project Birmingham (T4) • Construction of "Wycieczkowa" reservoir (T6)
M12	Jan 2007	• **D5.3-9a R** Hyporheic Zone report detailing field and lab testing design, programme and protocols (T4) • **M** Completion of hyporheic programme design and preliminary tests (T4)
M17	Jun 2007	• **D5.3-2a T** Organise a workshop on use of natural systems, and produce a draft plan to maximise their use in Demo-cities (T1) • Implementation vegetation belt "Zgierska" reservoir, "Teresa" reservoir (T6) • Plan for restoration of river section (T6)
M18	Jul 2007	• **D5.3-2b T** Final plan to use natural systems in Demo-cities (T1) • **D5.3-9b** Hyporheic Zone field test site constructed, instrumented and preliminary testing completed and report prepared (T4) • **M** Completion of hyporheic field site (T4) • **D5.3-9c R** Progress report Dai Yu and N.N. (Lag de Sonzo) (T4) • **D5.3-13a D** Progress report Demo site Lodz and Study site Birmingham (T4) • **D5.3-12c R** 2 MSc theses on EH (T4) • **D5.3-13b R** Final report Cartagena study, progress reports per study site
M19	Aug 2007	• Hydrological monitoring of the Sokolowka River: Final installation of the online monitoring system for research, education and demonstration
M23	Dec 2007	• **D5.3-13a D** Overall progress report • **D5.3-13b R** PhD progress reports, progress reports per project
M29	June 2008	• First stage of the construction of the Zabieniec reservoir –project documentary
M30	July 2008	• Restoration of the natural river bed between reservoirs (600 m section, meander M8) – project documentary • Development of the mathematical model of stormwater runoff in the Sokolowka River catchment

PHD PRE-PROPOSAL BY WOJCIECH FRĄTCZAK
APPLICATION OF ECOHYDROLOGY FOR URBAN RIVER RESTORATION WITH SPECIAL CONSIDERATION OF HARMONIZATION OF HYDRO-TECHNICAL INFRASTRUCTURE WITH ECOSYSTEMS

1. Introduction

According to hydrological practice, majority of water constructions and river regulations were primarily concerned with the elimination of threats related to quantitative, economic aspects of managing water resources. They usually did not take into account ecological processes within the river basin.

These investments often permanently change the environmental conditions on adjacent landscape. Processes and events appear that have previously not existed and that caused large-scale, permanent changes. These processes include eutrophication, secondary succession, and rotting of peat bogs, thus worsening the ecological state of water ecosystems.

The greatest intensification of these processes can be observed in reservoirs, impoundments, and on grounds of effluent drainage. A single solution at a local scale, without analysis of processes at a macro-scale and without taking into account the consequences for the functioning of the ecosystems does not improve or can even cause a negative effect on fresh water resources.

Modern technologies applied for the sustainable environment should be leaning for the system- approach, integrating knowledge from different disciplines of science. An example of such an approach is ecohydrology, integrative engineering hydrology with ecology. Such an approach makes possible the harmonious coexistence of the nature and civilization enhancement of the ecosystem capacity for anthropogenic stress and the achievement of sustainable development success. It is also concordant with strategies of the environment protection formulated by UNESCO and UNEP which consider that to reach of the sustainable development, insufficient is a factor preservation of nature, but it is necessary to reverse biosphere degradation and moreover restitution of key ecological processes in which water is a major regulative factor.

Through regulation of the water dynamics in the various parts of a river basin, we can influence its hydrokinetic processes, physical-chemical properties, and in consequences biota dynamics. The effective tool whereby we can regulate the structure and dynamics of ecosystem seems to be utilization of existing water-engineering devices.

The hydro technical infrastructure harmonized with proprieties of adjacent ecosystems, based on modern ecohydrological knowledge, becomes an important tool for achieving good ecological status and meeting the requirements of the Frame Water Directive 2000 /60/EC.

2. Study area

1. Sokołówka River characteristics
   - River length – 13,4 km
   - Catchments area – 44,5 km^2
   - River channel regulation – 100%

2. Existing reservoirs
   - Upper Pond
   - Lower Pond
   - Zgierska Reservoir
   - Teresy Reservoir
   - Pabianka Reservoir

3. Monitoring system

Water samples for chemical analysis will be collected three to four times per month from 15 sites (10 located on the river bed, 5 located on the reservoirs).

Water samples for chemical analyses will be filtered on Whatman GF/F filters and analysed in the ICE PAS Chemical Laboratory for assessment:

- Phosphate phosphorus (P-PO4)
- Ammonium nitrogen (N-NH4)
- Nitrate nitrogen (N-NO3) concentration.

Non-filtered water samples will be analysed for TP,TN. Additionally will be collected samples for assessment total suspended mater contents (mineral and organic).
In the same times water samples will be analyzed for biological parameters:

- Zooplankton
- Phytoplankton
- Chlorophyll-*a*

4. Goals

1. **Hydrological cycle analysis in the city catchment:**
   - River flow characteristics,
   - Identification of threats,
   - Analysis of the frequency flooding,
   - Patterns of contaminants transport in relation to discharge characteristic.

2. **Restoration of the municipal river for storm water management and improve water quality:**
   - Enhancing carrying capacity of existing reservoirs for reduction eutrophication symptoms,
   - Construction of Żabieniec Reservoir by using ecohydrology principles,
   - Construction of wetlands at storm water outlets (sedimentation area for organic matter and pollutants),
   - Renaturisation of the river channel,
   - Harmonization of hydro-technical infrastructure with ecosystems.

3. Expected results

- Reduction of the storm water flow peaks,
- Reduction of nutrient and pollutants in reservoirs,
- Improvement of water quality and ecological status of Sokołówka River,
- Increase retention of water in landscape,
- Increase green space in the city,
- Improvement of quality of life and human health.