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VILMAURORA CASTILLO TALENO

CO-DIRECTOR OF THESIS PMPCA

DRA. MA. CATALINA ALFARO DE LA TORRE

CO-DIRECTOR OF THESIS ITT:

PROF. DR.-ING. MICHAEL STURM

ASSESSOR:

DR. PETER KUSCHK

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Matri.-Nr. / *N° de matricula*: 0191545 **(UASLP),** 11081423 **(CUAS)**

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ABSTRACT

The aim of this research was to evaluate the influence of soil depth on the nitrogen removal efficiency of two different pilot-scale Horizontal Subsurface Flow Constructed Wetlands (HSSF CWs) treating domestic wastewater in the Langenreichenbach facility, located in the municipality of the city Mockrehna in North Saxony, Germany.

The design for the HSSF CWs was 5.5 m length, 1.2 m width and 1.2 m depth. The Standard and Shallow CWs had two systems each; one unplanted for control and the other was planted with common reed of the genera *Phragmites australis*. The Standard CWs had a gravel depth of 0.55 cm and the Shallow CWs had a depth of 0.30 cm; where all four CWs had a vadose (unsaturated) soil zone of 5 cm. The water samples were taken from the wetlands at 0.5, 1.1, 2.3, 3.4 and 4.7 m distance from the inflow. The depth of each sampling point varied between the type of CWs, where for the Standard CWs the depth were at 12.5 and 40 cm and for the Shallow was only at 12.5 cm. The inflow samples were taken from the feeding pipe of the CWs. The water samples were collected at intervals of about 15 days for 3 months, given in total 6 sampling dates. The results were calculated as areal water loadings for a better interpretation.

The nitrogen removal process in HSSF CWs is low due to the amount of oxygen and the reduce conditions present in the CWs. The nitrification process starts with the oxidation of ammonium, where only the Planted Shallow CW had 20 % removal. However, both CWs (Standard and Shallow CWs) presented a high increase of nitrite loads in relation to the inflow value. The Partial Nitrification or even complete Nitrification is helped by the low depth of the Shallow CWs. However, the Standard CWs have more removal decrease of nitrate than the Shallow CW; therefore it is more suitable for the denitrification process. Because Standard CWs had more depth, the anaerobic conditions are suitable for this process. Even though, the nitrate decrease is highly correlated to the organic matter degradation, this process competes with others. The sulfate reduction had very high percentage of reliance with the BOD_5 values; therefore it is the major influential parameter for the nitrogen removal. But also the methane loads could become an influential factor although they don't correlate as much as sulfate.

RESUMEN

El objetivo de esta investigación fue evaluar la influencia de la profundidad en la eficiencia de eliminación de nitrógeno de dos tipos de Humedales Artificiales Horizontales de flujo Subsuperficial (HSSF CWs) a escala piloto, tratando agua residual doméstica en la instalación de Langenreichenbach, situado en la ciudad Mockrehna, Sajonia del Norte, Alemania.

El diseño de los HSSF CWs fue 5.5 m de longitud, 1.2 m de anchura y 1.2 m de profundidad. Los humedales Estándar y Superficial tienen dos sistemas cada uno; uno solo con la cama de grava como sistema de control y el otro fue plantado con caña común *Phragmites australis*. El humedal Estándar tiene una profundidad de grava de 0.55 cm mientras que el humedal Superficial es de 0.30 cm. Las muestras de la agua fueron tomadas a los 0.5, 1.1, 2.3, 3.4 y 4.7 metros de distancia del afluente. La profundidad de cada punto de muestreo varió en dependencia del tipo de humedal, ya que el humedal Estándar tiene 2 profundidades de muestreo; 12.5 y 40 cm, y el Superficial fue sólo a 12.5 cm. Las muestras de la afluente fueron tomadas del tubo que alimenta los Humedales. Las muestras de agua fueron tomadas cada 15 días por 3 meses, obteniendo 6 muestreos en total. Los resultados de los distintos análisis fueron calculados como carga orgánica aplicada para una mejor interpretación de los datos.

El proceso de la eliminación del nitrógeno en HSSF CWs es bajo debido a la cantidad de oxígeno y las condiciones reductoras presentan en los humedales. El proceso de la nitrificación comienza con la oxidación de amonio, donde sólo el sistema Superficial con Plantas obtuvo 20 % de remoción. Sin embargo, ambos humedales (Estándar y Superficial) presentaron un aumento en las cargas de nitrito en relación con el valor del afluente. La Nitrificación Parcial o completa es ayudada por la baja profundidad del humedal Superficial. Sin embargo, el humedal Estándar tuvo mayor disminución en la eliminación de nitrato que el humedal Superficial; por lo que es más apropiado para el proceso de desnitrificación. Debido a que el humedal Estándar tiene más profundidad, las condiciones anaerobias propician este proceso. La disminución de nitrato como degradación de materia orgánica, compite fuertemente con otros procesos. La reducción del sulfato tuvo porcentaje muy alto de dependencia con los valores BOD_5; por lo tanto es uno de los parámetros influyente para la eliminación de nitrógeno. De igual manera, las cargas de metano podrían convertirse en un factor influyente aunque no fueron tan correlacionadas tanto como el sulfato.

ZUSAMMENFASSUNG

Ziel dieser Arbeit war die Untersuchung zweier verschiedener Subsurface Flow Pflanzenkläranlagen (HSSF PKAs) in Hinblick auf den Einfluss der Bodentiefen auf die Effizienz des Stickstoffabbaus in der Pilotanlage in Langenreichenbach. Das System wurde mit Kommunalabwasser bestückt und befindet sich im Norden von Sachsen, im Landkreis Mockrehna.

Die HSSF – PKAs waren 5.5 m lang, 1.2 m breit und 1.2 m tief. Die Standard und die Flachbett-Pflanzenkläranlage hatten jeweils 2 Systeme; ein unbepflanztes Kontrollsystem und ein mit Schilfrohr (*Phragmites australis*) bepflanztes System. Das Standardsystem wies eine Kiestiefe von 0.55 cm auf, während die des Flachbettsystems nur 0.30 cm betrug. Alle vier PKAs beinhalteten eine 5 cm dicke Oberflächenschicht aus ungesättigtem Kies. Die Wasserproben wurden in den PKAs in 0.5 m, 1.1 m, 2.3 m, 3.4 m und 4.7 m Entfernung vom Zulauf genommen. Die Tiefe des jeweiligen Probennahmepunktes variierte vom Typ der PKA. Im Flachbettsystem gab es nur eine Probennahmetiefe von 12.5 cm, während es im Standardsystem jeweils einen Probennahmepunkt in 12.5 cm und 40 cm Tiefe gab. Die Zulaufproben wurden direkt aus dem Schlauch entnommen. Die Wasserproben wurden in Intervallen von 15 Tagen über einen Zeitraum von 3 Monaten genommen (was insgesamt 6 Probennahmetage ergibt). Die Ergebnisse wurden zur besseren Interpretation als flächenspezifisch.

Der Prozess des Stickstoffabbaus in den HSSF PKAs ist aufgrund der geringen Menge an Sauerstoff und den vorherrschenden reduzierenden Bedingungen im System mäßig. Der Nitrifikationsprozess startet mit der Oxidation von Ammonuim, wobei lediglich die bepflanzte Flachbett-PKA eine 20%-ige Entfernung von Stickstoff aus dem System aufzeigte. Jedoch wiesen beide PKAs (Standard- und Flachbettsystem) einen starken Zuwachs an Nitritfrachten in Hinblick auf die Zulaufwerte auf. Die partielle oder sogar vollständige Nitrifikation ist durch die geringe Tiefe des Flachbettsystem begünstigt. Da das Standardsystem eine höhere Tiefe aufweist, dominieren anaerobe Bedingungen. Trotzdem korreliert die Verringerung von Nitrat stark mit dem Abbau organischer Materie. Der Prozess konkurriert mit anderen Prozessen. Die Sulfatreduktion wies einen hohen Anteil an BSB5-Werten auf. Daher ist sie der größte Einflussparameter des Stickstoffabbaus. Allerdings könnten auch die Frachtwerte von Methan ein Einflussfaktor werden, auch wenn sie nicht so stark korrelieren, wie die Sulfatwerte.

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CHAPTER ONE
INTRODUCTION

Natural wetlands have been used for wastewater treatment for centuries because they have been considered as "wastelands". The main reason was using the wetland as disposal rather than treatment, where the wetland served as a convenient recipient that was closer than a river or other waterway [*Vymazal,* (2011)].

Uncontrolled discharge of untreated or insufficiently treated wastewaters containing high concentrations of nitrogen effluents into receiving rivers are undesirable because it can be toxic to aquatic life by depleting dissolved oxygen (DO) levels, resulting in serious eutrophication of receiving water bodies like lakes and rivers [*Effler et al.,*(*1990*); *Paredes et al.,* (2007); *Vymazal and Kröpfelova,* (2008); *Lin and Kumar,* (2010)].

Because some conventional wastewater treatment techniques have several disadvantages, such as expensive cost, continuous addition of toxic chemicals, extensive space and side effects of secondary pollution, the development of new technologies focused on natural systems have emerged, especially constructed wetlands (CWs).

The CWs are engineered systems by applying various technological designs to treat domestic wastewater, using natural wetland processes, associated with wetland hydrology, soils, microbes and macrophytes [*Vymazal*, (2010)].

Further, it can be built with a much greater degree of control, thus allowing the establishment of experimental treatment facilities with a well-defined composition of substrate, type of vegetation, and flow pattern. In addition, constructed wetlands offer several additional advantages compared to natural wetlands, including site selection, flexibility in sizing and most importantly, control over the hydraulic pathways and retention time. The pollutants in such systems are removed through a combination of physical, chemical, and biological processes including sedimentation, precipitation, adsorption to soil particles, assimilation by the plant tissue, and microbial transformations [*Brix,* (1993); *Vymazal et al.,* (1998); *Masudi et al.,* (2001); *Vymazal and Kröpfelova,* (2008)].

CWs have two basic types: Free Water Surface (FWS) and Subsurface (SSF). However, the SSF CWs is the more preferred due to the simple technology in principle, reliable operating conditions and the potential to remove total nitrogen by simultaneous nitrification and denitrification [*Kuschk et al.,* (2003)].

Nitrogen compounds present in the wastewater can be removed by a variety of processes. The known and much studied processes of nitrogen transformation in CWs are ammonification, nitrification, denitrification and biological uptake among others like ANAMMOX and ammonia volatilization [*Mayo and Bigambo,* (2005); *Vymazal,* (2007); *Maranger et al.,* (2009)]. However, the amount of nitrogen removed or transformed from the water phase, the wetland in general and the main involved processes depend on water chemistry and other wetland conditions, such as climate, vegetation, water depth and water flow [*Bastviken*, (2006)].

It has been established the fact that CWs treatment performance and removal efficiency depends on operational and design parameters. In most cases, treatment efficiency is determined for the water compartment either by areal water loadings or observed decline of contaminant concentrations [*Seeger et al.,* (2011)].

To enhance nitrogen removal, it is essential that a more comprehensive understanding is obtained on the complex nitrogen transformation processes taking place inside the 'black box' of constructed wetlands [*Sun and Austin*, (2007)].

This investigation was conducted in two Horizontal SSF CWs with different depths to identify and evaluate the influence of this designed parameter on the nitrogen transformation processes for a better understanding and improvement on its removal efficiency. Also, the presence and absence of vegetation was evaluated in each type of wetland as well as other influential parameters.

OBJETIVES

1.1. General Aim

Evaluate the influence of soil depth on the nitrogen removal performance of HSSF CWs.

1.2. Specific Aims

- ☑ Determine the nitrogen compounds in two different types of HSSF CWs with and without plants.
- ☑ Analyze the dynamics of the nitrogen compounds with other present water contaminants/parameters.
- ☑ Propose improvements for the nitrogen removal process in Horizontal Subsurface Flow Constructed Wetlands.

CHAPTER TWO
CONSTRUCTED WETLANDS

Constructed wetlands (CWs) are engineered systems that have been designed and constructed to utilize the natural processes involving vegetation, soils and the associated microbial to assist in treating wastewaters. They are designed to take advantage of many processes that occur in natural wetlands but do so within a more controlled environment [*Vymazal,* (2010)].

Because CWs can be built with a much greater degree of control, it allows them to be established in experimental treatment facilities with a well-defined composition of substrate, type of vegetation and flow patterns. Other benefits of CWs compared to natural wetlands are the site selection, flexibility in sizing and most important, the control over the hydraulic pathways and retention time.

Also, they are constructed with local materials and local labor without excessive operation and maintenance costs, which is a great advantage for developing countries [*Kadlec and Wallace,* (2009); *Kong et al.,* (2009); *Marecos do Monte & Albuquerque*, (2010)].

CWs can be sturdy and effective systems to remove pollutants through a combination of physical, chemical, and biological processes including sedimentation, precipitation, adsorption to soil particles, assimilation by the plant tissue, and microbial transformations [*Brix,* (1993); *Vymazal and Kröpfelova,* (2008)].

Furthermore have CWs been used for the treatment of domestic or municipal sewage, industrial and agricultural wastewaters, landfill leachate or stormwater runoff but they have to be carefully designed, constructed, operated and maintained for each purpose [*United States Environmental Protection Agency, (*1995); *Vymazal,* (2005); *Mena Sanz, et al., (*2007*)*].

2.1. Historical Development of Constructed Wetlands

Since the development of sewage system, discharge of wastewater sites grew. In 1953, Dr. Käthe Seidel first discussed the possible use of wetlands “to lessen the over fertilization, pollution and silting up of inland waters through appropriate plants so allowing the contaminated waters to be capable of supporting life once more” [*Boyd,* (2006)]. The experimenting work with aquatic macrophytes for water quality improvement expanded in the 1950s and 1960s for various waste streams, including phenol wastewaters, dairy wastewaters and livestock wastewaters. The system evolved into a series of vertical and horizontal subsurface flow filter beds [*Brix,* (1994)]. These systems are the basis for the “hybrid” wetland systems that were reestablished at the end of the 20th century.

In the mid-1960s, Dr. Seidel began collaboration with Reinhold Kickuth from Göttingen University. This collaboration ended after a few years due to personal reasons. Kickuth went on to develop a horizontal subsurface flow (HSSF) wetland process commonly known as the root zone method (RZM). RZM wetlands were constructed with a soil media (typically clay loam to sandy clay) and planted with *Phragmites* in the belief that the root systems of this plant would improve the hydraulic conductivity of the media [*Kadlec and Wallace, (2009)*].

HSSF CWs predominated in Europe during the 1980s and 1990s instead of the Free Water Surface (FWS) CWs [*Vymazal,* (2005); *Vymazal and Kröpfelova*, (2008); *Vymazal,* (2010)].

At present, CWs are used to treat all kinds of wastewaters including those from industrial and agricultural operations, stormwater runoff or landfill leachates [*United States Environmental Protection Agency*, (1999)*; Vymazal and Kröpfelova,* (2008); *United Nations Human Settlements Programme,* (2008)] mainly due to factors like cost-effectiveness, environmental friendliness and technical feasibility.

2.1. Types of Constructed Wetlands

Because modern treatment wetlands are designed to emphasize specific characteristics of natural wetland ecosystems, they can be constructed in a variety of hydrologic modes [*Kadlec & Wallace,* (2009)].

According with water flow, CWs are classified in two types:

2.1.1. Free water surface (FWS) CWs

FWS wetlands have areas of open water and are similar in appearance to natural marshes. It consists of basins or channels, filled with soil or another suitable medium to support the rooted vegetation (if present) and water at a relatively shallow depth flowing through the unit (see Figure 2-1.).

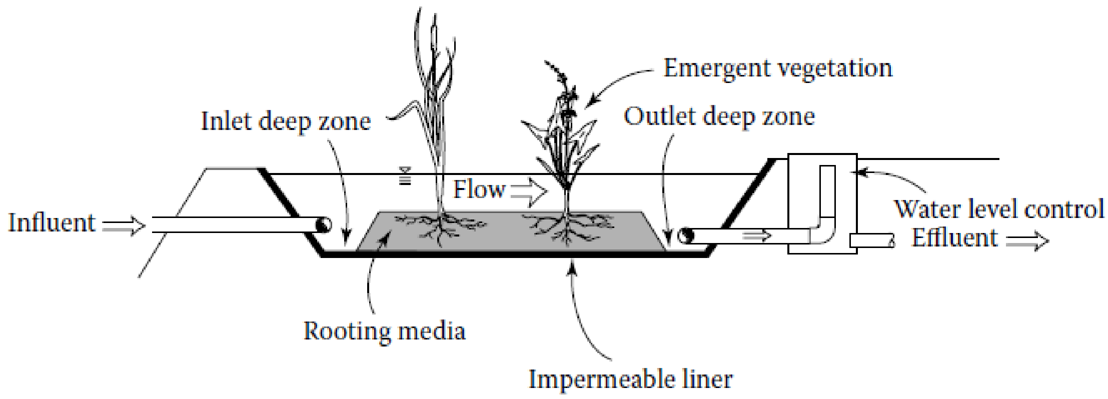

Figure 2-1. Basic elements of a FWS CWs
[*Kadlec & Wallace,* (2009)]

The shallow water depth, low flow velocity and presence of the plant stalks and litter regulate water flow and, especially in long, narrow channels, ensure plug-flow conditions [*United States Environmental Protection Agency,* (1988); *Vymazal and Kröpfelova,* (2008)].

In these types of wetlands, the water surface is exposed to the atmosphere. The plants root in generally in an impermeable soil layer, sand or gravel bed, to prevent infiltration into the groundwater [*Silva,* (2002)].

The main advantage of this wetlands is the low costs because their simple design and operation. Also they can be used for higher suspended solids wastewaters. On the other hand, they have the lowest rates of contaminant removal per unit of land, thus they require more land to achieve a particular level of treatment [*Halverson,* (2004)]. *D*ue to their size and buffer requirements, they are mostly used for stormwater treatment than a secondary treatment processes [*Kadlec and Wallace,* (2009)].

The most common application for FWS wetlands is for tertiary treatment of municipal wastewater and also for stormwater runoff and mine drainage waters [*Vymazal,* (2011)].

2.1.2. Subsurface flow (SSF) CWs

SSF wetlands are also known as reed beds, rock-reed filters, gravel beds or vegetated submerged beds.

These wetlands are constructed with a porous material (e.g. soil, sand or gravel) as a substrate for growth of wetland plants in addition to various microbes. They are designed to keep the water level totally below the surface of the filter bed, avoiding mosquito and odors problems.

The water flows horizontally or vertically through the soil body and below the ground surface, minimizing the exposure risk of pathogen. Also, these systems are capable of operating under colder conditions because of the ability to insulate the surface [*Vymazal,* (2010)].

Different aerobic and anaerobic treatment zones are established, which improves wastewater treatment. The emergent vegetation, mostly bulrush, reeds, and sometimes cattails, supplies oxygen to the soil body and allows biological growth to accumulate on its roots. Bacteria and beneficial fungi live there as biofilm attached to the surface of the gravel or sand. The flow is maintained by either a sloping bottom and/or an adjustable outlet structure producing the pressure head required to overcome flow resistance through the media of the soil body. An adjustable outlet provides greater flexibility and control and is the recommended method [*Halverson,* (2004)].

In contrast to the FWS wetlands, the soil contributes to the treatment processes by providing a surface area for microbial growth and supporting adsorption and filtration processes. This effect results in a lower area demand and generally higher treatment performance per area than free-water-surface wetlands [*Heers*, (2006)].

SSF wetlands can be classified into two basic flow systems: horizontal flow and vertical flow.

- Vertical Subsurface Flow Constructed Wetland (VSSF CWs)

The main characteristic of this type of CWs is the intermittent charging, where the wastewater comes from a large batch container and is pumped on the wetland surface, where wastewater percolates vertically through a soil layer that consists of sand, gravel or a mix of them. This principle corresponds to the vertical filter stage of the Krefeld Process according to Dr. Seidel [*Heers,* (2006)].

The key advantage of VSSF systems is an improved oxygen transfer into the soil layer. Therefore, it is capable of diffusing the oxygen from the air into the bed and enables them to have much higher oxygenation ability. Beside oxygen input by the plants and diffusion processes, vertical flow filter show a significant oxygen input into the soil through convection caused by the intermittent charging and drainage [*Gaboutloeloe, et al.,* (2009)].

Consequently, it increases the ability of BOD decomposition and nitrification process under aerobic conditions [*Vymazal,* (2010)].

The ability of VSSF CWs to oxidize ammonia has resulted in their application for treating wastewater with higher ammonium levels than municipal or domestic wastewater, like food processing wastewater and landfill leachates. In this type of CW, the ammonia level can be hundreds of milligrams per liter [*Lavrova and Koumanova,* (2010)].

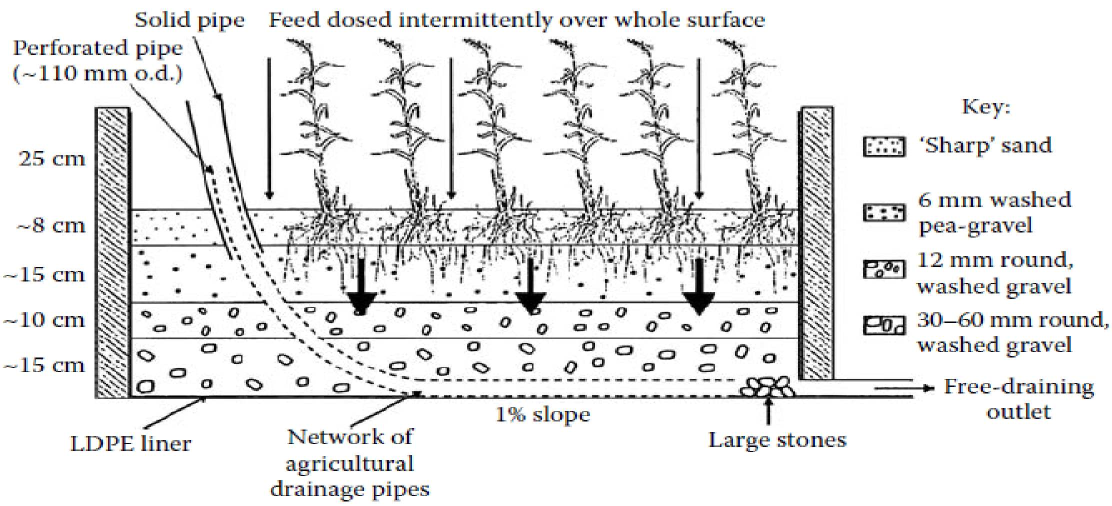

Figure 2-2. Typical arrangement of a VF CW
[*Kadlec & Wallace,* (2009)]

However, this new type did not spread as quickly as HSSF CWs probably because of the higher operation and maintenance requirements as well as operation costs due to the necessity to pump the wastewater intermittently on the wetland surface [*Vymazal,* (2010)].

- Horizontal Subsurface Flow Constructed Wetlands (HSSF CWs)

The most widely used concept of CWs in Europe is the HSSF CW (Fig. 2.3.). The design usually consisted of a rectangular bed planted with common reed (*P. australis*) and lined with an impermeable membrane. Mechanically pre-treated wastewater is fed in at the inlet and passes slowly through the filtration medium under the surface of the bed in a more or less horizontal path until it reached the outlet zone where it is collected before discharge via level control arrangement at the outlet. During the passage of wastewater through the reed bed the wastewater makes contact with a network of aerobic, anoxic and anaerobic zones [*Vymazal,* (2005)].

Typical arrangement of HSSF CWs has the depth of filtration bed usually 0.6–0.8 m in order to allow roots of wetland plants to penetrate the whole bed and ensure oxygenation of the whole bed through oxygen release from roots. Roots and rhizomes of reeds and all other wetland plants are hollow and contain air-filled channels that are connected to the atmosphere for the purpose of transporting oxygen to the root system. The majority of this oxygen is used by the roots and rhizomes themselves for respiration, but as the roots are not completely gastight, some oxygen is lost to the rhizosphere [*Vymazal,* (2005)].

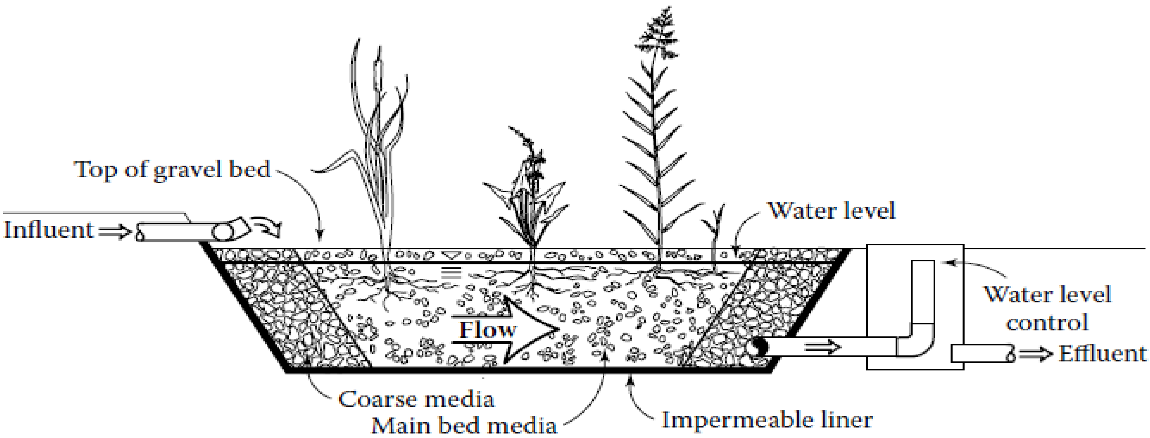

Figure 2-3. HSSF wetland schematic
[*Kadlec and Wallace,* (2009)]

In these wetlands, pollutants are removed by microbial degradation and physic-chemical processes in the different aerobic and anaerobic zones. However, the aerobic zone is limited as oxygen is supplied to the system mainly by oxygen leakage from the macrophytes roots and rhizomes in the rhizosphere [*Vymazal and Kröpfelova,* (2008)].

In general, a lot of reports have been done regarding the removal of organic carbon expressed as BOD_5, COD and TOC, heavy metals and nutrients, especially in the case of nitrogen [*Paredes et al.,* (2007)].

Also, it has been hypothesized that nitrification and denitrification are the main processes for nitrogen transformation and removal in constructed wetlands but they have two critical points for both processes: the availability of oxygen and organic carbon. Therefore, in nitrogen removal, HSSF CWs are more conducive for denitrification, but less effective at nitrifying ammonium due to the restriction of aerobic conditions [*Kadlec and Wallace,* (2009)].

A key operational consideration is the propensity for clogging of the media. To prevent soil-clogging it is recommended that subsurface flow systems receive at least primary treated wastewater [*Mena Sanz et al.,* (2007)].

The type of CW design for this study is the SSF specifically the HSSF, because it has higher rates of contaminant removal per unit of land than SF CWs and has minimal ecological risk. Also, have higher climatic tolerance ranges making their use in nearly all climate zones and regions worldwide possible. Even though this type of wetland has oxygen limitations, further transformation process can be investigated [*Heers,* 2006].

2.2. Main Components of Horizontal Subsurface Flow Constructed Wetlands

Constructed wetlands consist of a properly designed basin that contains water, a substrate, and, most commonly, vascular plants. These components can be manipulated in constructing a wetland. Other important components of wetlands, such as the communities of microbes and aquatic invertebrates, develop naturally [*United States Environmental Protection Agency,* (1999); *Mena Sanz et al.,* (2007)].

2.2.1. Soil body

For the soil body in constructed wetlands mineral soils (e.g. clay, silt, sand and gravel) and organic soils (e.g. compost and decomposed plant litter) are used. Its selection depends on the type of the wastewater and on the hydraulic regime chosen. The soil material strongly affects the movement of water through the wetland (hydraulic conductivity). The soil provides a huge surface area for attached microorganisms additionally to plant biomass and acts as filtration and adsorption medium for pollutants such as suspended solids [*Heers,* (2006)].

The physical and chemical characteristics of soils and other materials are altered when they are flooded. In a saturated soil body, water replaces the atmospheric gases in the pore spaces and microbial metabolism consumes the available oxygen. Since oxygen is consumed more rapidly than it can be replaced, the soil body becomes anoxic (without oxygen). This reducing environment is important in the removal of pollutants such as nitrogen and metals [*United States Environmental Protection Agency,* (1999)].

The media of HSSF beds normally present clogging problems, whose causes are related to both the variation of properties of the media and the characteristics of the wastewater. The gradual clogging of the bed media leads to resistance to flow, particularly near inlets, and, therefore, to the reduction of the volume available for treatment. In the last few years, alternative bed media (e.g. expanded clay aggregates or thermoplastics) have been developed in order to minimize the clogging problem or to increase the treatment capacity since they present both higher porosity and specific surface area, which allow a better biofilm adhesion [*Albuquerque et al.,* (2009)].

In general, the depth of the soil body in a SSF CW is restricted to approximately the rooting depth of plants so that the plants are in contact with the flowing water and have an effect on treatment [*United Nations Human Settlements Programme*, (2008)].

2.2.2. Microorganisms

A fundamental characteristic of CWs is that their functions are largely regulated by microorganisms (MOs) and their metabolism. MOs include bacteria, yeasts, fungi, protozoa and rind algae.

The microbial activity (1) transforms a great number of organic and inorganic substances into innocuous or insoluble substances; (2) alters the reduction/oxidation conditions of the soil body/filter material of the soil body and thus affects the processing capacity of the wetland and (3) is involved in the recycling of nutrients [*Kadlec and Wallace,* (2009)].

Some microbial transformations are aerobic while others are anaerobic. Many bacterial species are facultative anaerobes, that is, they are capable of functioning under both aerobic and anaerobic conditions in response to changing environmental conditions. The microbial community of a CW can be affected by toxic substances, such as pesticides and heavy metals, and care must be taken to prevent such chemicals from being introduced at damaging concentrations [*United States Environmental Protection Agency*, (1999)].

2.2.3. Vegetation

Wetland vegetation especially is essential to improve treatment efficiencies. Emergent macrophytes are herbaceous (soft tissue and non-woody) vascular plants (higher plants) and have a structure consisting of aerial stems, leaves and an extensive root and rhizome system, so that it can root in the soil and emerge right above the water surface. Depth penetration of the root system and exploitation of the soil layer differs from species to species [*Brix*, (1993)].

The plants used in CWs designed for wastewater treatment should also (1) be tolerant to high organic and nutrient loadings, (2) have rich belowground organs (i.e. roots and rhizomes) even under certain levels of anoxia and/or anaerobiosis in the rhizosphere in order to provide substrate for attached bacteria and oxygenation (even very limited) of areas adjacent to roots and rhizomes [*Vymazal and Kröpfelová*, (2005)].

It has been reported that the oxygen transported by the plant can reached 2.08 g O_2/m^2-d until 12 g O_2/m^2-d. Plants absorb nutrients and trace elements, which are incorporated into the plant structure. A study described the growth and nutrient uptake of eight emergent species and found that the mean removal of total nitrogen showed a significant positive linear correlation with plant biomass. Moreover, plants increase the support surface for biofilm growth, act as thermal insulation from the water surface and increase the elimination efficiency of pathogens [*Mena Sanz et al., 2007)*.

Other criteria for the choice of plant species are (3) the availability in different climate zone, (4) the plant productivity and biomass utilizations like use as forage plant, composting purposes and organic soil conditioner [*Heers,* (2006)].

Considering the mentioned criteria, there is a broad group of plants that could possibly be used in CWs. However, the field experience has proven that only few plants are commonly used. By far the most frequently used plant in CWs around the world is *Phragmites australis* (common reed) [*Vymazal and Kröpfelová,* (2005); *Vymazal,* (2011)].
Compared to the other used wetland species (*Typha latifolia*, *Glyceria maxima*, *Iris pseudacorus*), *Phragmites australis* have showed the highest oxygen releases from roots into the rhizosphere.

Some authors calculated a possible oxygen flux from roots of Phragmites, where the values are up to 4.3 g/m^2-day by Lawson, 0.02 g/m^2-day by Brix, 1 – 2 g/m^2-day by Gries and 5-12 g/m^2-day by Armstrong. The wide range in these values is caused partly by the different experimental techniques used in the studies and partly by the seasonal variation in oxygen release rates [*Heers,* (2006)].

2.3. Hydraulic for Subsurface Flow Constructed Wetlands

The hydraulics and the internal flow patterns can be of importance for the efficiently rate of the wetland area used for pollutants transformations. Different flow patterns can cause shortcuts in the system and result in much shorter nitrogen residence times, higher water velocities and less efficient wetland area [*Bastviken,* (2006)].

This affects the contact between the nutrients in the water and the bacteria and consequently the nitrogen removal. The hydraulics can depend on the morphology and vegetation of the wetland [*Bendoricchio et al.,* (2000)].

2.3.1. Hydraulic loading rate (HLR)

The HLR refers to the loading on a water volume per unit area over a specified time interval. It is defined as the volumetric averaged flow rate divided by the wetland surface area. The HLR depends on soil material (which is a critical parameter for SSF CWs), flow rate, area-size and the resulting hydraulic retention. The HLR is determined by the required and desired removal efficiency [*Heers,* (2006)].

2.3.2. Hydraulic residence time (HRT)

The HRT is defined as the average residence time during which the water remains within the wetland system. The HRT can be described as a function of the "reactive" volume of the wetland divided by the volumetric average flow rate. In subsurface flow systems, the "reactive" volume is defined as the volume of water in the soil [Shrestha, (2011)].

2.4. Removal of Nitrogen in HSSF CWs

Nitrogen is an important element in wetland biogeochemical cycles since it occurs in different oxidation states and is present in particulate and dissolved organic and inorganic forms (organic N, ammonia, nitrite and nitrate) [*Albuquerque et al.,* (2009)].

The transformation and removal of nitrogen involves a complex set of processes and relations that are interesting for many reason.

Particularly, ammonium can cause a significant oxygen demand through biological nitrification resulting in strong depletion of the dissolved oxygen (DO) concentration in the receiving water. Further, ammonia (NH_3) is potentially toxic to aquatic organisms. In combination with phosphorus nitrogen is responsible for eutrophication processes in receiving waters [*Heers,* (2006)].

In wetlands, decomposition and mineralization processes are believed to convert a significant part of organic nitrogen, which is associated with particulate matter such as organic wastewater solids and/or algae, to ammonia. Biological nitrification followed by denitrification is believed to be the major pathway for ammonia removal in CWs [*Mayo and Bigambo,* (2005)]. It has been reported other nitrogen removal process like ammonia volatilization, plant uptake and others (Fig. 2-4.).

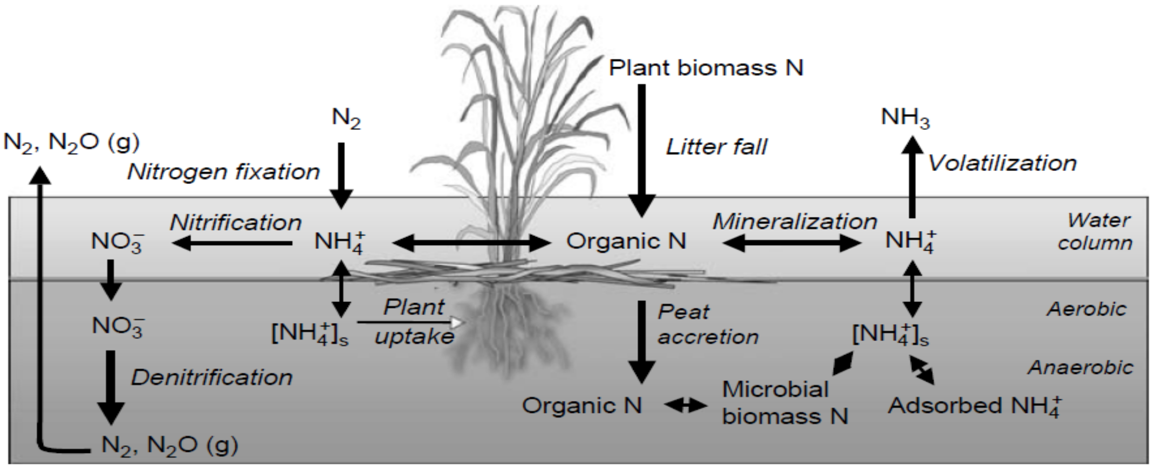

Figure 2-4. Schematic showing nitrogen transformation in wetlands [*Ramesh and DeLaune, (2008)]*

With the discovering of the Anaerobic Ammonium Oxidation (ANAMMOX) pathway, new possibilities and alternatives have opened up [*Joss et al.,* (2011)]. Recently, studies have shown that ANAMMOX could also be the removal route for ammonia in HSSF CWs. However, at present, the available evidence is limited and therefore it's difficult to draw conclusions on the role of ANAMMOX in ammonia removal [*Vymazal and Kröpfelova,* (2009)].

2.4.1. Nitrogen transformation process

The major nitrogen transformations in wetlands are presented in Table 2-1. The various forms of nitrogen are continually involved in chemical transformations from inorganic to organic compounds and back from organic to inorganic. Some of these processes require energy (typically derived from an organic carbon source) to proceed, and others release energy, which is used by organisms for growth and survival. All of these transformations are necessary for wetland ecosystems to function successfully, and most chemical changes are controlled through the production of enzymes and catalysts by the living organisms they benefit [*Vymazal,* (2007)].

Process	Transformation
Volatilization	ammonia-N (aq) → ammonia-N (g)
Ammonification	organic-N → ammonia-N
Nitrification	ammonia-N → nitrite-N → nitrate-N
Nitrate-ammonification	nitrate-N → ammonia-N
Denitrification	nitrate-N → nitrite-N → gaseous N_2, N_2O
N_2 Fixation	gaseous N_2 → ammonia-N (organic-N)
Plant/microbial uptake (assimilation)	ammonia-, nitrite-, nitrate-N → organic-N
Ammonia adsorption	
Organic nitrogen burial	
ANAMMOX (anaerobic ammonia oxidaton)	ammonia-N → gaseous N_2

Table 2-1. Nitrogen transformation in constructed wetlands [*Vymazal,* (2007)]

In the following paragraphs, the main nitrogen processes will be discussed.

- Ammonification

This is the first step in mineralization of organic nitrogen, where is essentially a catabolism of amino acids and presumably include several types of deamination reactions. Nitrogen mineralization refers to the biological transformation of organically combined nitrogen to ammonium nitrogen due to the degradation of organic matter. Ammonification is defined as the biological transformation of organic nitrogen to ammonium, which can occur in either aerobic or anaerobic conditions, but is slower under anaerobic conditions due to less efficient decomposition [*Kadlec and Wallace,* (2009); *Reddy and DeLaune,* (2008); *Vymazal and Kröpfelova,* (2008)].

Kinetically, ammonification proceeds more rapidly than nitrification. Mineralization rates are fastest in the oxygenated zone and decrease as mineralization switches from aerobic to facultative anaerobic and obligate anaerobic microflora. The rate of ammonification in wetlands is dependent on temperature, pH value (optimal range: 6.5 to 8.5), C/N ratio of the residue, available nutrients in the system, soil conditions such as texture and structure, extracellular enzyme, microbial biomass and soil redox conditions [*Vymazal and Kröpfelova,* (2008)].

The range of ammonification rates reported is 0.004 – 0.053 g N m^{-2} d^{-1} and depends on $r_a = \alpha T$ where α is the correlation coefficient ~ 0.0005 – 0.143 where T is the water temperature [*Kadlec and Wallace,* (2009)].

- Nitrification

Nitrification is defined as the biological oxidation of ammonium to nitrate under aerobic soil conditions. Three groups of MOs are capable of oxidizing ammonium under aerobic conditions: (1) chemoautotrophic bacteria; (2) methane-oxidizing bacteria and (3) heterotrophic bacteria and fungi [*Reddy and DeLaune,* (2008)].

This process is known to take place in two stages as a result of obligate chemoautotrophic bacteria.

The chemoautotrophic bacteria *Nitrosomonas* sp. converts

$$2\ NH_4^{\ +} + 3\ O_2 \rightarrow 2\ NO_2^{\ -} + 2H_2O + 4H^+ + \text{energy}$$

and then *Nitrobacter* sp. converts

$$2\ NO_2^{\ -} + O_2 \rightarrow 2\ NO_3^{\ -} + \text{energy.}$$

The autotrophic bacteria use ammonium ions as their primary source of energy. Nitrification is influenced by temperature, pH values, moisture, microbial population, concentrations of NH_4-N and dissolved oxygen [*Kong et al.,* (2009)].

Oxygen is essential for nitrification. It takes 2 mol of oxygen to oxidize 1 mol of ammonium to nitrate. Stoichiometrically, these organisms require 4.57 g of oxygen per gram of oxidized ammonium. Therefore these reactions potentially use large quantities of oxygen [*Reddy and DeLaune,* (2008)].

The methanotrophic bacteria are also capable of oxidizing ammonium to nitrate because the similarities with the autotrophic ammonium oxidizers. Ammonium N has been shown to be a competitive inhibitor of methane oxidation, suggesting that ammonia and ammonium are oxidized by the methane monooxygenase system. There are striking similarities between ammonium oxidation by *Nitrosomonas* and methane oxidation by methanotrophs [*Strous and Jetten,* (2004); *Reddy and DeLaune,* (2008)].

Furthermore, heterotrophic nitrifiers use organic substrates as energy source. They gain no energy from the oxidation of ammonium. Heterotrophic nitrifiers do not accumulate large amounts of end products compared to autotrophic nitrifiers. Under oxygen-limited conditions, some of these heterotrophic oxidizers can also reduce nitrite and nitrate to gaseous end products. It has been suggested that at low C:N ratios autotrophic nitrification dominates the oxidation of ammonia, whereas at high C:N ratios heterotrophic nitrification is higher than autotrophic nitrification. However, the relative importance of this group in the oxidation of ammonium is not clearly understood and the significance of this process in wetlands is not documented [*Vymazal and Kröpfelova,* (2008); *Reddy and DeLaune*, (2008)].

The primary limiting agent for nitrification in CWs is dissolved oxygen concentration, followed by temperature and retention time. Increased BOD levels have been shown to decrease nitrification rates in wetlands due to competition for available dissolved oxygen [*Lee et al., (2009*)].

Other parameters influencing nitrification are pH, alkalinity, the microbial population and concentrations of ammonium [*Vymazal,* (1995)]. It has been suggested that nitrifying communities can adapt to temperature changes and may maintain their activity at lower temperatures by metabolic adaptation. However, other investigations have shown that nitrification is inhibited by water temperatures lower than 10°C [*Xie et al.,* (2003)].

- Denitrification

This process is linked to microbial respiration where electrons are added to nitrate or nitrite, resulting in the production of nitrous oxide or nitrogen gas. The oxidation state of N decreases from +5 to 0 going from nitrate to nitrogen gas. It is microbial mediated, where facultative bacteria such as *Bacillus* and *Pseudomonas* possess the enzymes that allow them to use nitrate, nitrite, and nitrous oxide as the terminal electron acceptor during oxidation of organic C in anaerobic environments [*Reddy and DeLaune,* (2008)].

Denitrification is the process of converting nitrate to gaseous nitrogen by microorganisms under anaerobic conditions. This process depends on environmental conditions such as soil moisture, concentration of NO_3-N and temperature (limits to denitrification in two pasture soils in a temperate maritime climate) [*Vymazal,* (2005); *Kadlec and Wallace,* (2009); *Lee et al.,* (2009)].

Denitrifying bacteria degrade BOD_5 in the absence of free molecular oxygen to obtain energy for cellular activity and carbon for cellular synthesis under a redox potential range from +50 to -50 mV. Most denitrifiers reduce NO_3^- via NO_2^- to molecular nitrogen without accumulation of intermediates [*Vymazal and Kröpfelova,* (2008); *Lin and Mathava,* (2010)].

Environmental factors for the denitrification process:

1. Degree of aeration: Denitrification can be observed with relatively low measured DO, not above 0.3 – 1.5 mg/L.
2. Redox potential: In the range of +350 - +100 mV.
3. Temperature: High temperatures around 60 - 75 °C can lead N_2 to become the main product.
4. Soil Moisture
5. pH: Favored at slightly alkaline pH

[*Vymazal and Kröpfelova,* (2008); *Kadlec and Wallace,* (2009)]

The bacterium *Thiobacillus denitrificans* can reduce nitrate to nitrogen gas while oxidizing elemental sulfur or reduce sulfur compounds including sulphite (S^{2-}), thiosulfate ($S_2O_3^{2-}$) and sulphite (SO_3^{2-}). The reaction using elemental sulfur is:

$$NO_3^- + 1.1S + 0.4CO_2 + 0.76\,H_2O + 0.08NH_4^+ \rightarrow 0.5\,N_2 + 0.08C_5H_7O_2N + 1.1\,SO_4^{2-} + 1.2\,H^+$$

and when sulfide is used:

$$NO_3^- + 0.74S^{2-} + 0.1886CO_2 \rightarrow 0.48\,N_2 + 0.037C_5H_7O_2N + 0.74\,SO_4^{2-} + 0.1\,H^+ + 0.37\,H_2O$$

This means that 1.69 g of sulphite sulfur per gram nitrate nitrogen is needed [*Kadlec and Wallace, 2009)*.

In conventional anaerobic reactors treating high-strength wastewater containing high concentration of *Kjeldahl* Total Nitrogen (TKN) and sulfate, the “normal behavior” is high ammonification with negligible N_2 formation and almost complete reduction of sulfates to sulfides [*Fdz-Polanco et al.,* (2001)].

- Dissimilatory nitrate reduction to ammonia (DNRA) and Assimilatory nitrate reduction to ammonia (ANRA).

There are two contrasting pathways:
(1) DNRA occurs in anaerobic soil and involves the reduction of nitrate to ammonium rather than to nitrogen gas. It's carried out by obligate anaerobes under highly reduced conditions. The reaction is

$$NO_3^- + 10H^+ + 8e^- \rightarrow 3H_2O + NH_4^+$$

where the pH becomes alkaline.

(2) ANRA pathway occurs in both aerobic and anaerobic soil conditions and involves the reduction of nitrate to ammonia or amino nitrogen as a cell constituent. This process is common to many microorganisms and most plants [*Reddy and DeLaune,* (2008)].

- Ammonia Volatilization

Ammonia Volatilization is a physicochemical process controlled by the pH of the environment. This process has four major components in series: (1) partial conversion of ionized ammonia to free ammonia (dissociation), (2) diffusion of free ammonia to the air–water interface (water-side mass transfer), (3) release of free ammonia to the air at the interface (volatilization) and (4) diffusion of free ammonia from the air–water interface into the air above (air-side mass transfer) [*Kadlec and Wallace,* (2009)].

The process of ammonia volatilization involves proton transfer and a theoretical decrease in pH, that is why pH values: (1) below 7.5, NH_3 losses through volatilization is significant, (2) around 7.5 to 8.0 ammonia nitrogen is in NH_4^+ form and (3) and 9.3 or more, the ratio ammonia and ammonium is 1:1 and the losses via volatilization are significant [*Vymazal,* (2007); *Vymazal & Kröpfelova,* (2008); *Kadlec and Wallace,* (2009)].

- Immobilization

Immobilization is the ammonium is assimilated into the biomass of plants and microbes. The amount and type of plant residue or organic matter in the soil can influence amount of nitrogen immobilized in microbial and plant biomass. A high amount of organic matter in the soil will result in immobilization. Microbial immobilization of ammonium nitrogen depends on the carbon-to-nitrogen ratio of organic residues undergoing decomposition [*Reddy and DeLaune,* (2008)].

- Anaerobic Oxidation of Ammonia (ANAMMOX)

The ANAMMOX process shows that ammonia can be directly oxidized by nitrite as electron acceptor to nitrogen gas without carbon source and N_2O production. In natural environments, this process was first reported in oxygen-limited water columns and sediments. Presently, up to 67 % of N_2 production in marine oxygen-limited systems may be attributed to ANAMMOX [*Zhu et al.,* (2011)]. However, until now the contribution and effect of ANAMMOX in the nitrogen cycle in constructed wetlands remain uncertain [*Joss et al.,* (2011)].

To maintain a stable ANAMMOX process in a CWs, four different approaches should be considered from aspects of microbial stability and biodiversity: (1) Addition of nitrifying sludge, where the growth of ANAMMOX bacteria will be dependent on the availability of nitrite; (2) increase the ammonium loading (high ammonia concentration to stimulate ANAMMOX bacteria); (3) biomass retention and substrate mixing and (4) hydrodynamics [*Zhu et al.,* (2011)].

Development and retention of ANAMMOX bacteria in wastewater treatment systems are affected by several factors, including pH, alkalinity, dissolved oxygen concentration, NH_4^+ and NO_2^- concentrations, and specific surface area of biomass carrier [*Tao et al.,* (2011)].

2.4.2. Interference in the Nitrogen Removal Process

Due to the oxygen release by the helophytes into the rhizosphere, spatial and temporal micro-scale gradients of oxygen concentrations and redox states are established close to root surfaces. These conditions enable the development of microbial mats and layers of functionally different microorganisms which simultaneously realize processes like nitrification, denitrification, mineralization of organic carbon, methanogenesis, sulfate reduction, sulfide oxidation etc. [*Kuschk et al.,* (2005)].

Sulfate reduction, nitrate reduction and methanogenesis are governed by several factors, such as the nature of carbon source, COD:SO_4^{2-} and COD:NO_3^- ratio, pH, concentration of sulfate or nitrate (it is well known, that the sulfate and nitrate are indirect inhibitors of both process, methanogenesis and sulfate reduction), redox potential, temperature, microbial populations, kinetic and thermodynamic competitions [*Martínez Amador et al*., (2011)].

- Sulfate reduction

Sulfate is a normal constituent of domestic wastewater, and reduced sulphur compounds are known to be potent inhibitors of plant growth and certain microbial activities. Sulfate emissions may not be of any direct threat for the environment as sulfate is chemically inert, non volatile and non toxic. However, under anaerobic conditions, dissimilatory sulfate reducing bacteria use sulfate as a terminal electron acceptor in the degradation of organic matter, resulting in the production of sulfide, which is the most energetically stable form of sulfur under anaerobic conditions, is highly reactive, corrosive and toxic to microorganisms, plants and animals [*Ahmad,* (2007)].

Even though the allowed concentration of sulfate in tap water is up to 240 mg L^{-1}, under adequate reduction conditions this value can theoretically be up 80 mg L^{-1} of sulfide. On the other hand, the legal limits of sulfide concentration in wastewater are in a range of 1–2mg L^{-1} [*Kuschk et al.,* (2005)].

In model experiments with a laboratory scale CWs, it is showed that also the sulfate/sulfur of domestic sewage can play an important role as electron acceptor for the removal of organic carbon, for half or more of the total organic carbon mineralization, and influences the ammonia removal [*Kuschk et al., 2005).* Dissimilatory sulfate reduction can account in many environments. The competitive domination of sulfate reduction over methane production in sulfate-rich environments has been well established as a consequence of thermodynamic and kinetic differences between the two processes [*Westermann and Ahring,* (1987)].

- Iron reduction

Although some redox reactions such as Fe^{2+} oxidation with nitrite may happen chemically, redox reactions in anaerobic environments are largely microbially mediated with anaerobic electron acceptors being sequentially reduced in the order of NO_3^-, Mn^{4+}, Fe^{3+}, SO_4^{2-} and CO_2 (see Figure 2-4.) [*Reddy and DeLaune,* (2008)].

For example, NO_3^- and its intermediate products NO and N_2O are toxic to methanogens but SO_4^{2-} is much less toxic than NO_3^-. In addition, some microbes, including fermenting bacteria, some SO_4^{2-} reducers and CH_4 producers may reduce some metals such as Fe^{3+} but not couple energy yield to support growth [*Huang,* (2005)].

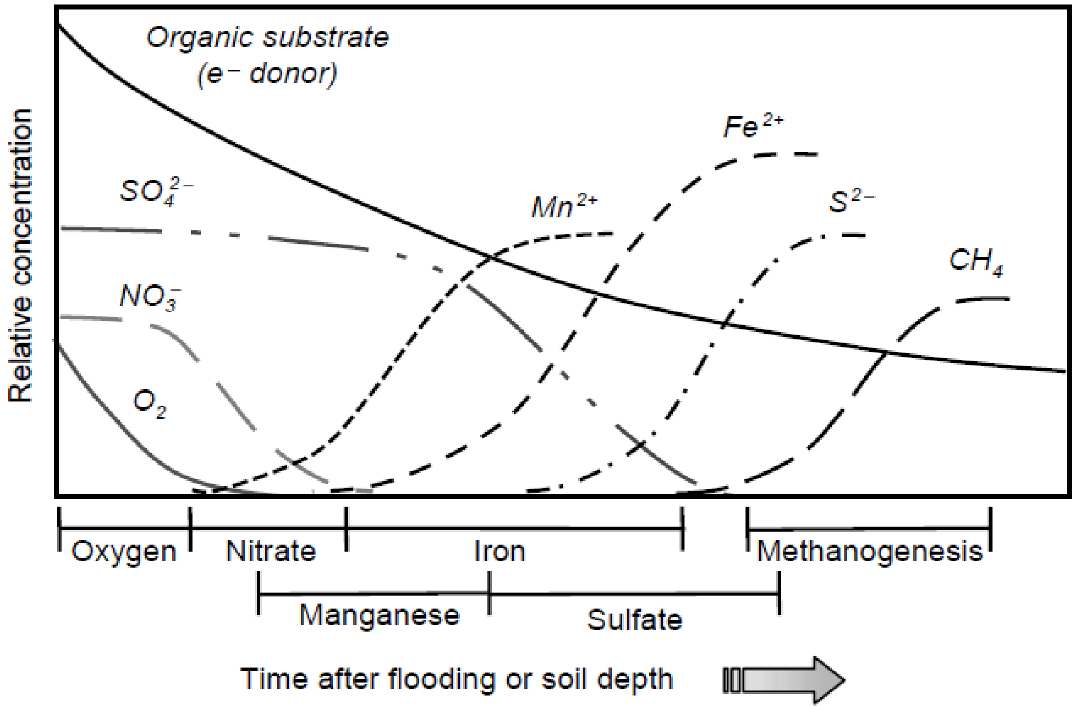

Figure 2-5. Relative reduction rates of electron acceptors as a time's function [*Reddy and DeLaune,* (2008)]

There is no clear distinction between NO_3^- reducers, Fe^{3+} reducers, SO_4^{2-} reducers, and CH_4 producers in that many species of microbes that reduce other AEAs are capable of Fe^{3+} reduction. Many NO_3^- reducers are Fe^{3+} reducers. Even some SO_4^{2-} reducers and methanogens can reduce Fe^{3+}. Also ferric iron can directly inhibit CH_4 production [*Huang,* (2005)].

- Methanogenesis

Wetlands are known to be a major source of methane. Recent interest has been on determining different anaerobic pathways that regulate the ratios of methane and carbon dioxide produced in wetlands. Regulation of methane production by electron acceptors (such as iron oxides and sulfates) with higher reduction potentials has been demonstrated. Although, this concept has been recognized about more than four decades ago, only recently its significance with respect to methane emissions has been quantified [*Reddy and DeLaune,* (2008)].

The reduction of oxygen is most favorable and the reduction of CO_2 to CH_4 is the least favorable. Sulfate reduction (SR) is only slightly more favorable than CO_2 reduction.

Organic matter degradation will, in general, only result in CH_4 production when inorganic electron accepters are depleted [*Meulepas,* (2009)].

Methanogenic degradation of organic matter proceeds via a number of microbial processes; during hydrolyses, acidogenesis and acetogenesis complex organic matter is degraded to hydrogen and CO_2, formate, acetate and ammonium [*Strous and Jetten,* (2004); *Martínez Amador et al.,* (2011)].

Methane production rates are inhibited in soils with intense cycling of iron and manganese. In soils with limited availability of Fe(III) and Mn(IV) oxides and other electron acceptors, methanogenesis is the dominant pathway in regulating organic matter decomposition, and ultimately a major methane source to the atmosphere [*Roden and Wetzel,* (2002)].

- Winter and Summer Operation

CWs continue to function during cold weather. Rates of microbial decomposition slow as temperatures drop and the wetland may need to be made larger to accommodate the slower reaction rates [*United States Environmental Protection Agency,* (1999)].

Because CWs relies on the microbial activity to break down organic wastes, it may be prudent to store the wastewater in the pretreatment unit during the cold months for treatment during the warm months. The high flows that are common in winter and spring because of snowmelt, spring rains, and high groundwater tables can move water so quickly through the wetland that there is not enough retention time for adequate treatment.

CWs lose large amounts of water in the summer through evapotranspiration. The adequacy of flow in the summer must be considered since it will affect water levels in the wetland. A supplemental source of water may be required to maintain adequate moisture in the wetland *[United States Environmental Protection Agency,* (1995)].

CHAPTER THREE
METHODOLOGY

3.1. Langenreichenbach Experimental Treatment Plant

Langenreichenbach belongs to the municipality of the city Mockrehna in North Saxony, Germany. The fed wastewater comes from the cities Torgau and Schildau as well as from the municipalities Mockrehna and Thallwitz. The sewage is treated in a central wastewater treatment plant (WWTP) for 16.000 population equivalents (p.e.), including a biological treatment stage. The WWTP is located in the direct neighborhood of the pilot-scale experimental facility.

From the central sewer leading to the WWTP, some wastewater is pumped to the pilot-scale experimental station through a small tube. From there, the sewage is fed to the experimental CWs after treatment in a septic tank (see Photo. 3.1).

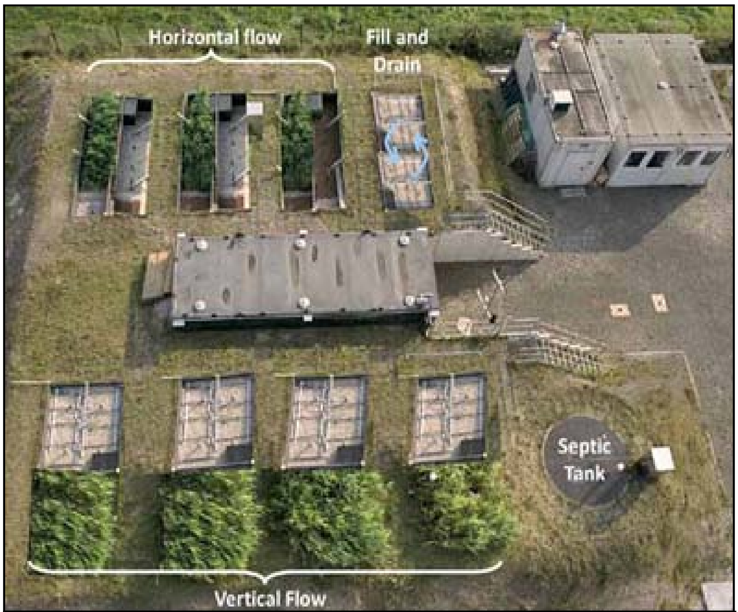

Photo 3-1. Upper view of the LRB facility.
[*CE - Business and Technology for civil engineer,* (2011)]

Subsurface flow constructed wetlands (SSF CWs) are primarily designed for secondary or tertiary treatment of wastewater, and use a septic tank pre-treatment stage similar to most home systems. This very critical first step removes most solids (measured as Total Suspended Solids, TSS), which settle to the bottom and are degraded by anaerobic bacteria. Maintenance of a septic tank is simple; a regular cycle of pumping is all that is necessary after proper initial installation.

3.2. Horizontal Subsurface Flow Constructed Wetlands (HSSF CWs)

The design for the HSSF CWs for this study was 5.5 m length, 1.2 m width and 1.2 depth. The Standard and Shallow CWs had two systems each; one unplanted for control and the other was planted with common reed of the genera *Phragmites australis*. The Standard CWs had a gravel depth of 0.55 cm and the Shallow CWs had a depth of 0.30 cm; where all four CWs had a vadose (unsaturated) soil zone of 5 cm.

The inflow and outflow zones were filled with coarse gravel with a diameter between 16 and 32 mm in order to provide good water distribution along the inflow zone and good even collection of water along the outflow zone.

Therefore in the Standard CWs, the inlet total surface area was 0.42 m^2 and for the outlet 0.3 m^2. The total volume was 0.5 and 0.36 m^3 respectively (See Figure 3-1.).

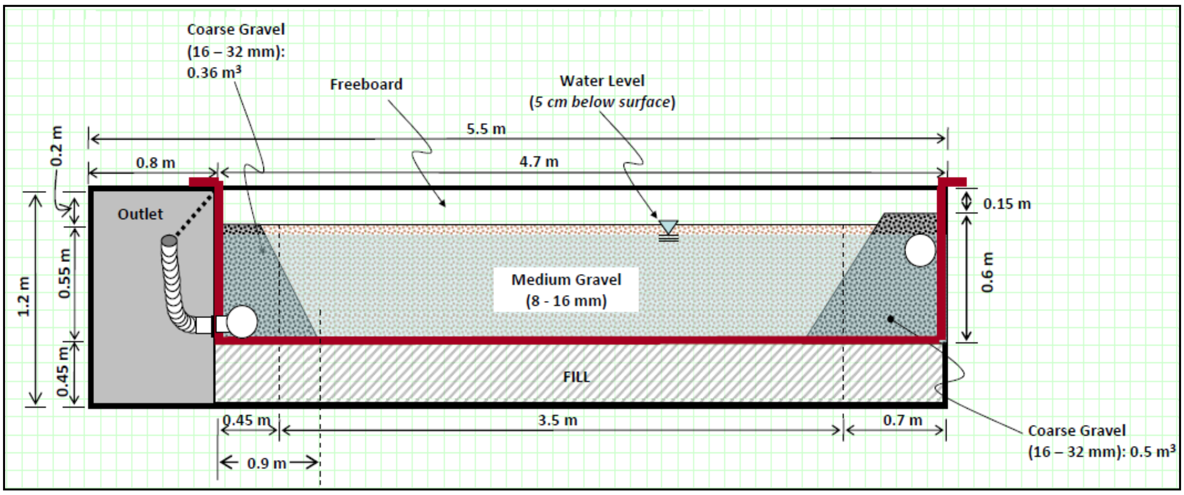

Figure 3-1. Standard HSSF Constructed Wetland – Gravel Quantities – Profile View. [*UFZ - Helmholtz Center for Environment Research,* (2009)]

For the Shallow CWs, the inlet total surface area was 0.24 m^2 and for the outlet 0.17 m^2. The total volume was 0.24 and 0.17 m^3 respectively (See Figure 3-2.). The rest of the wetlands were filled with medium gravel with a diameter around 8 – 16 mm.

Inflow water was supplied via a closed non-aerated septic tank, which has a theoretical hydraulic retention time of 1 day [*Berhard,* (2012)]. The mean flow for the Standard CWs was around 0.2 m^3/d and 0.1 m^3/d for the Shallow CWs.

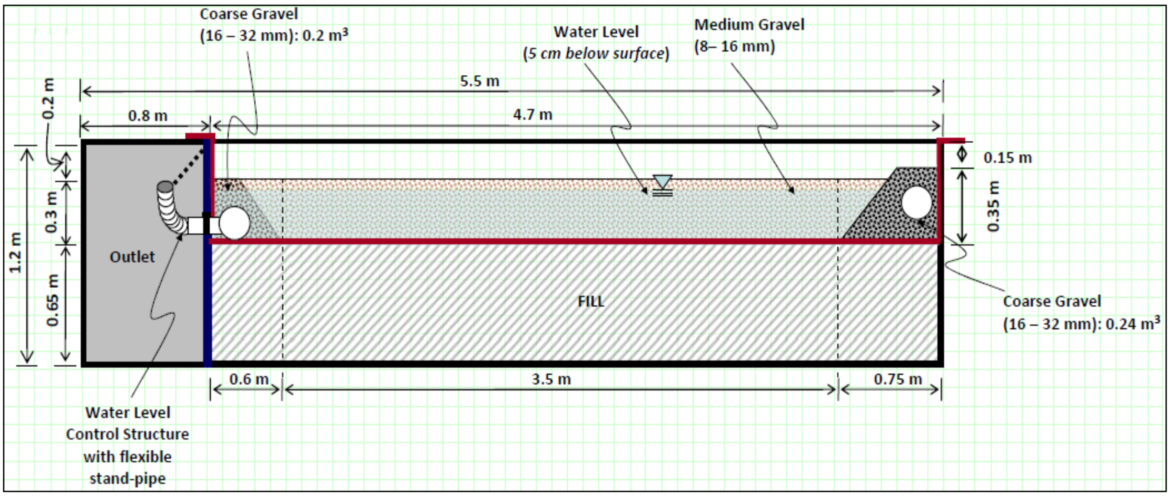

Figure 3-2. Shallow HSSF Constructed Wetland – Gravel Quantities – Profile View
[*UFZ - Helmholtz Center for Environment Research,* (2009)]

During March the plants were still in the resting phase. In April the plants started to spread out so that they were half a meter high in the beginning of May. In the End of May they already had a high of one to almost two meters.

3.2.1. Water Balance and Treatment Removal Efficiency in the wetland

To evaluate the performance of different horizontal subsurface flow CWs treating domestic wastewater under field conditions, it is needed to utilize a detailed balancing approach, especially for the nitrogen removal.

In this study, the calculation of treatment removal efficiency of the CWs is based upon system-specific influent and effluent loading rates of the contaminants, and thus accounts for the water loss due to evapotranspiration (ET). This methodology is also implemented in the article of Seeger *et al.*, 2011.

The contaminant mass balance in the constructed wetlands is maintained as follows:

$$\mathrm{ACL_{in}} = \mathrm{ACL_{out}} + \Delta m \qquad (1)$$

where ACL in/out (mg/m^2-d) is the areal contaminant load for the inflow or outflow, respectively, and Δm is the overall contaminant mass loss in the water phase. ACL in/out was obtained as follows:

$$\mathrm{ACL_{in/out}} = \mathrm{A}^{-1} \times \sum_{i=1}^{n} \left(c_{\mathrm{in/out}}(t_i) \times \bar{Q}_{\Delta t,\,\mathrm{in/out}} \right) \qquad (2)$$

where c is the contaminant concentration (mg/L) at the inflow (in) or outflow (out) at a sampling time t_i, $Q_{\Delta t,\ in/out}$ is the average inflow or outflow water volume (L/d) between two consecutive concentration samplings at time t_i, and t_{i+1}, and A is the surface area of the wetland. The treatment removal efficiency for the water phase R_w (%) was calculated using eq. 3:

$$(R_w) = \frac{ACL_{in} - ACL_{out}}{ACL_{in}} \times 100 \qquad (3)$$

3.3. Experimental Design

The water samples were collected at intervals of about 15 days for 3 months, given 6 sampling dates.

Pore water samples were taken from the wetlands at 0.5, 1.1, 2.3, 3.4 and 4.7 m distance from the inflow. The depth of each sampling point varied between the type of CWs, where for the Standard CWs the depth were at 12.5 and 40 cm and for the Shallow was only at 12.5 cm. Inflow samples were taken from the feeding pipe (See Figure 3-3.).

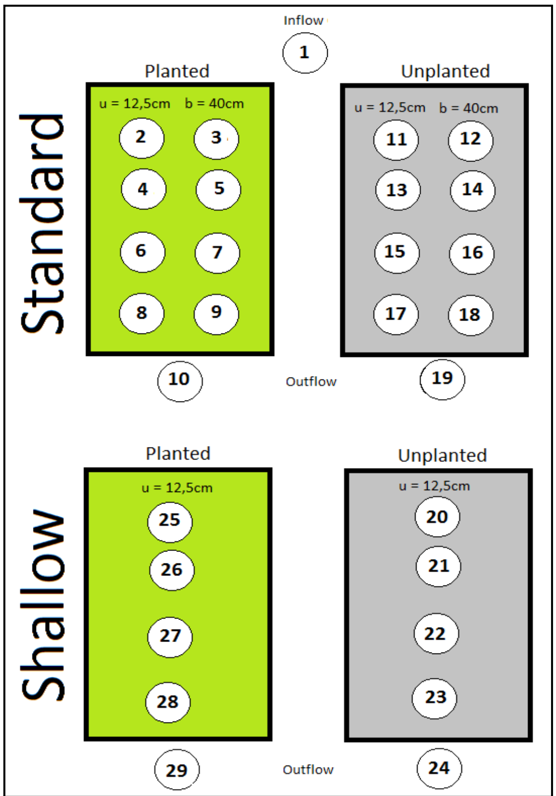

Figure 3-3. Distribution of the sampling points in the wetlands.
[*UFZ - Helmholtz Center for Environment Research*, (2009)]

The sampling of the water was carried out using specially-made stationary stainless steel lances with an internal diameter of 5 mm and a length of 0.7 m with eight boreholes each with a diameter of 2 mm at their ends. A peristaltic pump (Ismatec SA Reglo Analog MS/CA2-6C or Behr PLP 66) and various measuring devices (temperature sensor and redox electrode) - which were installed in a flow through cell - were used for the sampling.

The flow rate of the pumps was adjusted to the respective flow rate of each CW (See Figure 3-2). The pipe connections between the individual segments were all made of gastight and chemically inert Marprene tubing (Watson-Marlow).

For the filtration of the samples syringe filters with a pore size of 5 µm were used (5 µm, non-sterile, hydrophilic, No.: 17594, Minisart, Sartorius AG), so that the oxygen-sensitive sulfide, nitrite, nitrate and pH could be measured directly after the sampling at the on-side laboratory in Langenreichenbach. Oxygen, redox potential and temperature were measured at the CWs while taking the samples.

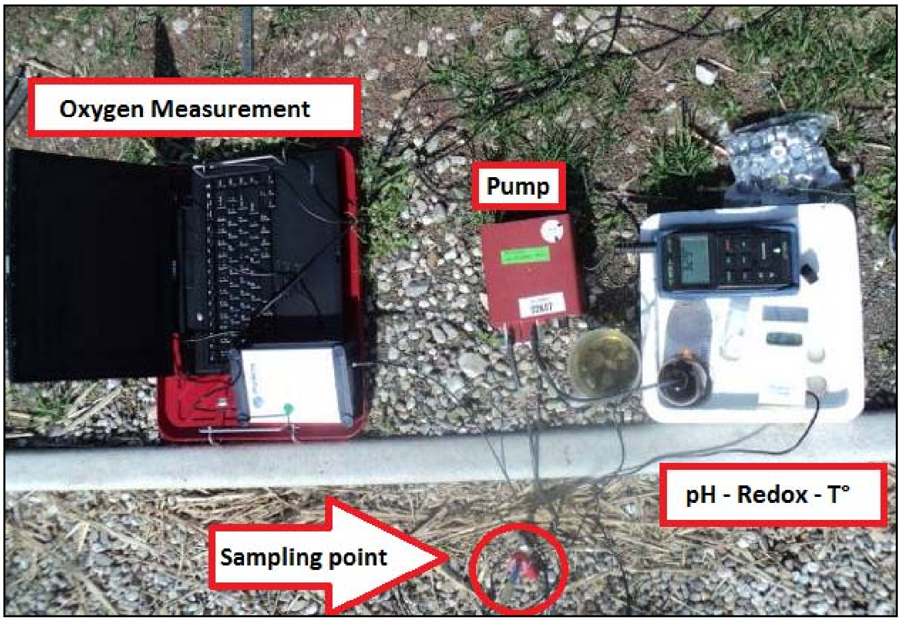

Photo 3-2. Measurement equipment in one sampling point [Own archive].

All samples were stored in a fridge at 8°C and measured the next days after sampling. The samples for measuring ammonia, phosphorous and sulfate were frozen at -20°C to be measured within a week.

Samples for Fe^{2+} determination were brought to a pH of 1 – 2 using 3 M HCl and afterwards filled in small glass vials with no headspace.

Elemental sulfur was extracted using a mixture 2 ml Chloroform and 10 ml sample volume in 20 ml gastight glass vials.

3.4. Analytical Methods

- pH-Meter

The pH measurement was carried out with the pH 197, a pH-meter from Wissenschaftlich Technische Werkstätten (WTW) that was equipped with a SenTix® 41 electrode (pH 0-14/0-80°C; storage in 3 M KCl solution) from the same manufacturer. The combination electrode has been calibrated with special buffer solutions (pH 4 and pH 7) according to manufacturer's specifications. The measurement principle is based on the pH dependence of the water’s potential of hydrogen ions (H^+ ion concentration).

- Oxygen

Oxygen has been measured using oxygen micro sensor Fibox-3-trace with optical oxygen sensor and the flow rate measuring cell FTC-TOS7 with integrated planar sensor from PreSens. The principle of this optical, sensory method is based on luminescence measurements respectively luminescence radiation of a fluorescent substance indicator (luminophore). The basis of this principle is shown in Figure 3-4.

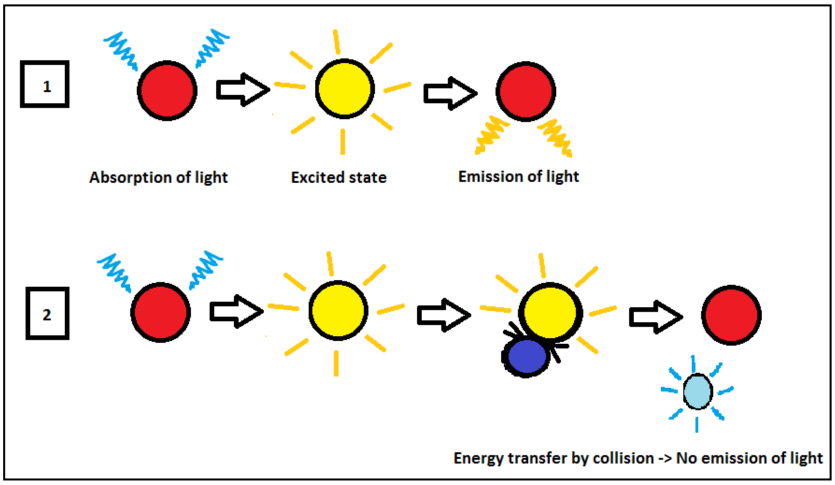

Figure 3-4. Principle of the dynamical decreasing of the luminescence: (1) Luminescence principle in the absence of O2; (2) Decreasing of luminescence through molecular O2 [*PreSens*, (2004)].

A direct correlation exists between the O_2 concentration in the sample and the luminescence intensity which is described as Stern-Volmer-Equation:

$$F_o/F = 1 + kc\,\tau \qquad (1)$$

where,

c = concentration of the quenching substance (O_2)

τ = fluorescence lifetime

F_o = fluorescence intensity when no quencher is present

F = fluorescence intensity in the presence of quencher

k = constant that depends on the system

- Redox potential

The redox potential (EH) of the pore water was measured with a specially designed flow cell in which the redox electrode was inducted through a Teflon-coated screw cap with omitted to fit septum. The used electrode was a Pt/Ag+/AgCl/Cl—electrode, type Sentix ORP by WTW and the measurement device was the handheld meter pH 340/Ion by WTW.

The redox potential depends on the temperature which is why charts for the temperature compensation of the manufacturer are available. Thereby the Standard redox potential the electrode deployed lies between 217 mV (20°C) and 196 mV (40°C).

In the context of this work a Standard potential of 210 mV of the Pt-Ag^{+}/AgCl/Cl^{-} electrode was used for the calculations that corresponds with the potential at a temperature of 25°C. A conversion between a normal hydrogen electrode and the silver/silver chloride system is possible without any further ado.

The corresponding potential of the normal hydrogen electrode (U_H) is calculated by the addition of the measured redox potential (U_G) and the Standard potential of the reference electrode (U_R) (see eq. 2).

$$U_H = U_G + U_R \qquad (2)$$

As temperature electrode a thermistor Checktemp1 by Hanna Instruments has been used.

- Nitrite

Nitrite is not commonly measured as a process control parameter because of difficulty with sample handling. Although some concentration of nitrite will be present in a process under steady state conditions, once a sample is extracted from the process, immediate analysis is required. If it is not possible, oxidation or reduction processes may continue in the sample container unless it is stored at 4°C. If analysis cannot be performed within 24 hours, acid preservation is usually recommended for biological process samples, but acidification of biological samples will convert any nitrite present into nitrate. This will not allow nitrate and nitrite to be determined in acidified samples as individual species [*ASA Analytics*, (2012)].

The Spectroquant® NOVA 60 (Merck KGaA, Darmstadt, Germany) is compact and mobile photometer. The device automatically recognizes the cell that has been inserted and uses the measured absorbance to calculate the concentration. It was used the Merck spectroquant nitrite cell Test no. 1.14776.0001, range 0.002-0.2 mg/L NO_2-N, where the photometer identifies the optical path length of the inserted cell and immediately calculates the correct concentration. Errors due to the incorrect choice of cells are thus excluded.

- Nitrate

Due to nitrite is an intermediate of the full oxidation of ammonium to nitrate, the procedure for the nitrate detection by the 2,6-dimethylphenol method is by far the more environmentally compatible alternative. It is used the Merck spectroquant nitrate cell Test No. 1.09713.0001, range 0.1-5.0 mg/L NO_3-N with a Merck Nova 60 Spectrophotometer.

- Ammonium

The samples were analyzed immediately after sampling with the Merckoquant® Ammonium Test. If it were necessary diluted with distilled water samples and adjust pH to the range 4 – 13. Also filter turbid samples.

Concentrations of ammonium were measured by the NOVA 60 Photometer with the Spectroquant Test No. 1.00683.001, where the range is 5 to 150 mg/L NH_4-N. This method is analogous to EPA 350.1, APHA 4500-NH3 D, ISO 7150/1, and DIN 38406 E5**.**

- Total Nitrogen

Total Nitrogen (TN) is the sum of nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen and organically bonded nitrogen. TN should not be confused with TKN (Total Kjeldahl Nitrogen) which is the sum of ammonia-nitrogen plus organically bound nitrogen but does not include nitrate-nitrogen or nitrite-nitrogen.

TN is sometimes regulated as an effluent parameter for municipal and industrial wastewater treatment plants, but it is more common for limits to be placed on an individual nitrogen form, such as ammonia. Treatment plants that have a TN limit will usually need to nitrify and denitrify in order to achieve the TN limit.

Concentrations of total nitrogen was measured in the NOVA 60 Photometer with the Spectroquant Test 1.14763.0001 in the range of 10 -150mg/L TN.

- Sulfide

For the determination of sulfide the Hach-Lange sulfide pipetting/cell test with an extra calibration (LCW 053) and a Lambda XLS+ spectrometer from PerkinElmer have been used. The test specific calibration series are already factory programmed. The measuring principle is based on the reaction of dimethyl-p-phenylendiamin with hydrogen sulfide to an intermediate which merges into leuco methylene blue. The leuco methylene blue is oxidized by iron(III) ions to methylene blue. Afterwards the photometric detection takes place at 665 nm whereas the effective range lies between 0.1 and 2.0 mg S^{2-}/l.

- Sulfate

Sulfate was measured by turbidity of the barium sulphate ($BaSO_4$) method at 880 nm after precipitation in acidic gelatin solution. This method based on the formation of poorly soluble $BaSO_4$ by sulphate and barium ions.

- BOD_5

The biochemical oxygen demand (BOD_5) indicates the amount of oxygen that is necessary for the biotic degradation of organic substances contained in the water und under special conditions (incubated by 20°C) and within a special time period (normally 5 days).

A respirometric OxiTop system by WTW has been used. The oxygen has been measured indirectly inside a brown glass bottle by the emerging carbon dioxide that is absorbed by sodium hydroxide to form sodium carbonate. Due to the resulting pressure difference inside the bottle the oxygen demand can be calculated with following formula:

$$BOD = \frac{M(O_2)}{R \cdot T_m} \cdot \left(\frac{V_{ges} - V_{fl}}{V_{fl}} + \alpha \frac{T_m}{T_O} \right) \cdot \Delta p(O_2) \qquad (3)$$

where,

$M(O_2)$	Molecular weight of oxygen (32000 mg/mol)
R	Gas constant (83.144 l•hPa/(mol•K))
T_0	Temperature (273.15 K)
T_m	Measuring temperature (293.15 K) for BSB_5
V_{ges}	Volume of the bottle [ml]
V_{fl}	Volume of the sample [ml]
α	Bunsen absorption coefficient (0.03103)
$\Delta p(O_2)$	Difference of the partial pressure of O_2 [hPa]

Nitrifiers consume also oxygen when transforming ammonia via nitrite to nitrate. This consumption does not count to the BOD_5 which is why three drops of the nitrification inhibitor N-allylthiourea (ATH) is added to the test solution.

- *COD*

The chemical oxygen demand (COD) is the volume-related mass of oxygen which is required for complete oxidation of organic (the main part) and inorganic matter. Also, is the volume-related mass of oxygen which is equivalent to the potassium dichromate that reacts with the oxidable substances in the water in this procedure (1 mol $K_2Cr_2O_7$ corresponds 1.5 mol O_2).

The COD determination was performed with a test kit from Hach-Lange (LCK 514, 100-2000 mg/L O_2 with Hach-Lange HT200S) and a high-temperature thermostat. Oxidizable substances react with sulphuric potassium dichromate solution in the presence of silver sulfate as catalyst. The oxidation of the ingredients reduces the yellow chrome (VI) compounds of the potassium dichromate to green chrome (III). As oxidant $K_2Cr_2O_7$ decomposes biologically easy and hard as well as the biologically not biodegradable ingredients to carbon dioxide. The reaction takes place in a LT 100 thermostat from Hach-Lange at 148°C over a period of two hours.

Subsequently, the spectrophotometrically analysis was conducted by a CADAS 100/LPG 210 photometer from Hach-Lange at a wavelength of 605 nm. The test specific calibration series of the CADAS 100 are already programmed by the manufacturer and the procedure conforms the requirements of DIN 38 409 – H 41 – 1.

- Methane

A gas chromatograph (Hewlett-Packard 6890) with a packed column (25 m length, 320 µm nominal diameter, 5 µm film thickness, CP-Sil 8CB) and a flame ionization detector (FID) (250°C) was used to determine methane.

The flame FID used in conjunction with a gas chromatography detects analytes by measuring an electrical current generated by electrons from burning carbon particles in the sample.

The FID works by directing the gas phase through the output of the column into a hydrogen flame. A voltage of 100-200 V is applied between the flame and an electrode located away from the flame. The increased current due to electrons emitted by burning carbon particles is then measured.

Except for a very few organic compounds (e.g. carbon monoxide, etc.) the FID detects all carbon containing compounds. The detector also has an extremely wide linear dynamic range that extends over, at least five orders of magnitude with a response index between 0.98-1.02 [*Library4science,* (2009)]

- Elemental sulfur

Elemental sulfur was determined following *Rethmeier et al.,* 1997, 10 ml samples were shaken with 2 ml chloroform. After the separation of both phases the prepared samples were further analyzed via High-Performance-Liquid-Chromatography (HPLC). Here the stationary phase of the column owns/possesses a lower polarity as the mobile phase. Used was a LiChrospher 60, RP 18 column (5 µm, Merck, Darmstadt) and for the detection a UV detector at 263 nm. The detection limit for elemental sulfur was approximately 0.064 mg/L.

In the following section the conditions of the analysis are summarized:

→ *Column: LiChrospher 60 RP, RP Select B (250-4) 5 µm; flow rate 2 ml/min*
→ *Temperature of the column: 35°C*
→ *Eluent: methanol*
→ *Elution: isocratic flow*
→ *Detection: UV detection at 263 nm (UV detector UV 6000 LP)*

- Total Organic Carbon (TOC)

The determination of the total organic carbon (TOC) took place with a TOC-5050 analysis device from Shimadzu. The device works with the combustion/non-dispersive-infrared gas analysis where the total carbon (TC) is measured first, then the inorganic carbon (IC), followed by the TOC which is determined by the difference of TC and IC (Shimadzu Corporation; 1991, Total Carbon Analyzer TOC-5000/5050).

$$TC - IC = TOC \quad (4)$$

3.5. Statistical Approach for Data

The statistical tool analysis was executed in the program SPSS version 17.0 released in September 2009. The following tests were performed in this program to have a better understanding of the values in relation to the mathematical models.

Simple Linear Regression and the Determination coefficient (R^2)

Regression analysis is a statistical technique that attempts to explore and model the relationship between two or more variables. Every experiment analyzed in the statistical program includes regression results for each of the responses. These results provide information that is useful to identify significant factors in an experiment and explore the nature of the relationship between these factors and the response.

R-squared, often called the coefficient of determination, is defined as the ratio of the sum of squares explained by a regression model and the "total" sum of squares around the mean. An R^2 of 1.0 indicates that the regression line perfectly fits the data and 0.0 indicates the no-correlation between the variables.

Important cases where the computational definition of R^2 can yield negative values, depending on the definition used, arise where the predictions which are being compared to the corresponding outcomes have not been derived from a model-fitting procedure using those data, and where linear regression is conducted without including an intercept. Additionally, negative values of R^2 may occur when fitting non-linear trends to data. In these instances, the mean of the data provides a fit to the data that is superior to that of the trend under this goodness of fit analysis.

CHAPTER FOUR
RESULTS AND DISCUSSION

This chapter presents the results of Standard and Shallow Horizontal Subsurface Flow Constructed Wetlands (HSSF CWs) in Langenreichenbach, where different analyses were performed in the facility as well as in the laboratory in the UFZ Center. The sampling dates were six from March to May. The results are presented by months mean with their corresponding Standard Deviation.

As explained in the Chapter 3, the Standard CWs had 2 sampling depths, 12.5 cm and 40 cm, whereas the Shallow CWs had just only one depth, at 12.5 cm. For the statistical analysis, 4 sampling points along the wetland and their respective outflow point were evaluated due to the inflow point had the same values for the two CWs.

4.1. Standard Wetlands

4.1.1. Nitrogen Parameters

Ammonium-Nitrogen

The average values of NH_4-N load from the six sampling dates at the two sampling depths (12.5 cm and 40 cm) along the two systems (planted and unplanted Standard HSSF CWs) are illustrated in the Figure 4-1.

During the sampling period, the wastewater entered the system with 2.07 g NH_4-N/m^2-d, where throughout the wetland an increase around 10 % was detected for both systems, the unplanted system stated 2.26 g NH_4-N/m^2-d and the planted system with 2.24 g NH_4-N/m^2-d. These values could be explained by the fact that ammonification of organic nitrogen took place, resulting in higher ammonia areal load values [*Tsihrintzis and Akratos*, (2007)]. Ammonification process is accelerated in aerobic conditions but it can also occur in anaerobic conditions and it optimal pH is between 6.5 and 8.5 [*Armstrong et al.,* (2000)], approximately the values observed in this research (range from 7.02 to 7.56).

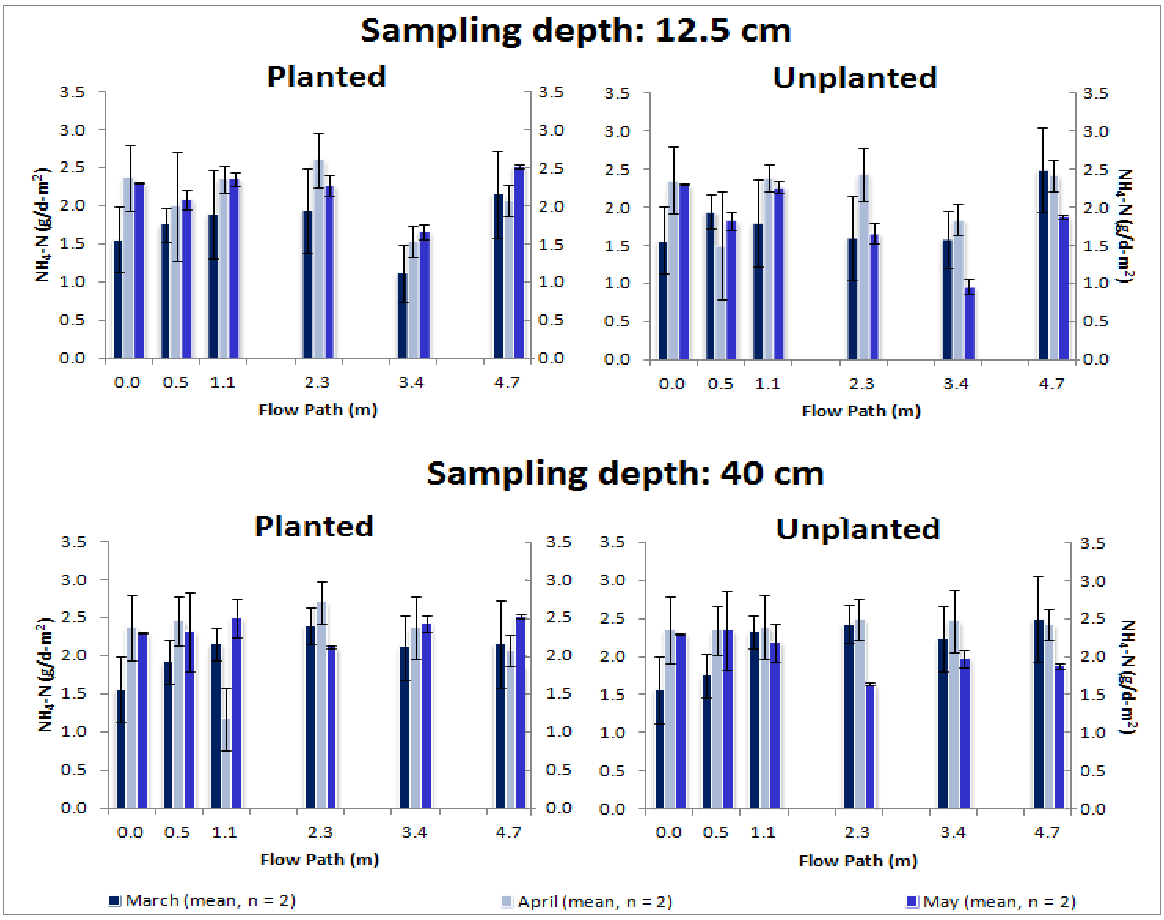

Figure 4-1. NH_4-N loads in the Planted and Unplanted Standard HSSF CWs with their different sampling depths.

It has been proved that ammonification is highly positively correlated with temperature, where the microbial activity and plant uptake are inhibit in low temperatures (under 10 °C), therefore the differences between summer and winter were detected [*Shamir,* (1998)]. Because the sampling times matched with the end of winter (March) and all spring season (April – May) this statement can be applicable.

Also, the temperature can corroborate this declaration. The first sampling date (15.03.12) the unplanted wetland oscillated between 6.8 and 15.5 °C. Compared to the last sampling date (24.05.2012), where the values were from 22.4 to 31.4 °C, these ranges represent the two different seasons of the year, the end of winter and the entire spring season. The same behavior was observed for the planted system.

In general, it can be observed that there was no significant difference between the two systems in each measured depth. Comparing the values by depths, the 40 cm deep has more stable values than the 12.5 cm deep, maybe due to the presence of oxygen in the upper layer of the wetlands.

In addition, the inhibition of beneficial microbial processes such as ammonium oxidation by sulfur compounds is known but insufficiently investigated [*Kuschk et al.,* (2010)].

Oxidized Nitrogen: Nitrate and Nitrite

In this research, the NO_3–N and NO_2–N had very low values (under 0.06 g NO_x/m^2-d).

For the nitrite values, the reported inflow load (0.0004 g NO_2-N/m^2-d) had an increased to 75 % in the planted system (0.0007 g NO_2-N/m^2-d) and the unplanted system was 100 % (0.0008 g NO_2-N/m^2-d), interpreted as some incomplete nitrification process in the wetlands. It is known that under low-oxygen conditions, the production of nitrite from ammonia is favored over the production of nitrate. Then, the nitrite can be denitrified to nitrous oxide and/or dinitrogen without being converted to nitrate. This process has been termed "partial nitrification–denitrification" [*Vymazal,* (2007)].

The inflow value of nitrate (0.0219 g NO_3-N/m^2-d) reported a decrease of 32 % for the unplanted system (0.0148 g NO_3-N/m^2-d) and 38 % for the planted system (0.0136 g NO_3-N/m^2-d). It can be hypothesized that the denitrification process was happening even a low values.

According to the theory, the amount of nitrate and nitrite depend on the oxygen present in the system.

In general, the oxygen values were low and did not exceed 0.009 g/d-m^2. It is important to take in account that the number of sampling dates is not the same due to technical difficulties, therefore March and April have only one value and May is the mean of the two measurements. Even though, some suppositions can be made for the behavior of the oxygen with other parameters.

Therefore, to understand better the behavior of NO_3-N and NO_2-N with the measured values of oxygen, correlations were made.

The correlation between Oxygen, NO_3-N and NO_2-N in the unplanted and planted system at 12.5 cm depth is found in the Table 4-1. The best correlation value was found in the planted system, with the nitrite-oxygen correlation of 92 % at a 0.05 significance level. The value indicates the direct relationship between nitrite and oxygen, assuming that nitrification is occurring, especially in the first step (ammonium to nitrite). Nitrate-oxygen correlation is also better in the unplanted system, could indicate the complete nitrification occurring at very low levels. The correlation values are understandable for nitrification process due to the supplied oxygen released from macrophytes roots as the low depth of the sampling.

Also, correlation was made for the association level of the nitrate-nitrite at 12.5 cm depth, where the best correlation value was found in the unplanted system in an inverse association (-37 %) indicating that when nitrate values are low, the nitrite values are higher and vice versa. The behavior of these compounds can be explained by the nitrification process. The absence of plant could help to determinate a better correlation of the oxidized nitrogen due the plants uptake by the roots [*Vymazal*, (2007)]. It has been reported that plant uptake and the dissimilatory reduction of nitrate to ammonium represent 1-34 % of the total N retention [*Arce et al.,* (2009)].

Table 4-2. Correlation between oxygen, NO_3-N and NO_2-N in Unplanted and Planted Standard CWs at 12.5cm depth.

Correlation: Nitrate, Nitrite and Oxygen_Standard_Unplanted_12.5cm_depth

		Nitrate_Unplanted_Standard_12.5cm_depth	Oxygen_Unplanted_Standard_12.5cm_depth	Nitrite_Unplanted_Standard_12.5cm_depth
Nitrate_Unplanted_Standard_12.5cm_depth	Correlación de Pearson	1	.081	-.372
	Sig. (bilateral)		.897	.538
	N	5	5	5
Oxygen_Unplanted_Standard_12.5cm_depth	Correlación de Pearson	.081	1	-.098
	Sig. (bilateral)	.897		.876
	N	5	5	5
Nitrite_Unplanted_Standard_12.5cm_depth	Correlación de Pearson	-.372	-.098	1
	Sig. (bilateral)	.538	.876	
	N	5	5	5

Correlation: Nitrate, Nitrite and Oxygen_Standard_Planted_12.5cm_depth

		Oxygen_Planted_Standard_12.5cm_depth	Nitrate_Planted_Standard_12.5cm_depth	Nitrite_Planted_Standard_12.5cm_depth
Oxygen_Planted_Standard_12.5cm_depth	Correlación de Pearson	1	.244	.923*
	Sig. (bilateral)		.693	.025
	N	5	5	5
Nitrate_Planted_Standard_12.5cm_depth	Correlación de Pearson	.244	1	.125
	Sig. (bilateral)	.693		.842
	N	5	5	5
Nitrite_Planted_Standard_12.5cm_depth	Correlación de Pearson	.923*	.125	1
	Sig. (bilateral)	.025	.842	
	N	5	5	5

*Correlation is significative at 0.05 (bilateral).

Note: The red underline marks the correlation between the NO_3-N and NO_2-N with oxygen values and the green square is the relation NO_3-N/NO_2-N.

Comparing the same wetland systems but at the sampling depth of 40 cm, the correlation values were a little different than the systems at 12.5 cm depth. Even though the oxygen at this depth is supposed to be low, the best correlation was found to be with the nitrite in the unplanted system. It can be assumed that the partial nitrification took place.

It is worth mentioning the fact that the nitrate values associated to the oxygen values has almost the same negative grade of association, around 48 %, in the planted and unplanted systems meaning that nitrification and denitrification can take place simultaneously [*Tsihrintzis and Akratos*, (2007)].

Table 4-3. Correlation between Oxygen and NO_3-N and NO_2-N in Unplanted and Planted Standard CWs at 40 cm depth.

Correlation_ Nitrate, Nitrite and Oxygen_Standard_Unplanted_40cm_depth

		Oxygen_ Unplanted_ Standard_ 40cm_depth	Nitrate_ Unplanted_ Standard_ 40cm_depth	Nitrite_ Unplanted_ Standard_ 40cm_depth
Oxygen_Unplanted_ Standard_40cm_depth	Correlación de Pearson	1	-.471	.597
	Sig. (bilateral)		.423	.288
	N	5	5	5
Nitrate_Unplanted_ Standard_40cm_depth	Correlación de Pearson	-.471	1	-.810
	Sig. (bilateral)	.423		.096
	N	5	5	5
Nitrite_Unplanted_ Standard_40cm_depth	Correlación de Pearson	.597	-.810	1
	Sig. (bilateral)	.288	.096	
	N	5	5	5

Correlation: Nitrate, Nitrite and Oxygen_Standard_Planted_40cm_depth

		Oxygen_ Planted_ Standard_ 40cm_depth	Nitrate_ Planted_ Standard_ 40cm_depth	Nitrite_ Planted_ Standard_ 40cm_depth
Oxygen_Planted_ Standard_40cm_depth	Correlación de Pearson	1	-.484	.168
	Sig. (bilateral)		.409	.787
	N	5	5	5
Nitrate_Planted_ Standard_40cm_depth	Correlación de Pearson	-.484	1	.152
	Sig. (bilateral)	.409		.807
	N	5	5	5
Nitrite_Planted_ Standard_40cm_depth	Correlación de Pearson	.168	.152	1
	Sig. (bilateral)	.787	.807	
	N	5	5	5

Note: The red underline marks the correlation between the NO_3-N and NO_2-N with oxygen values and the green square is the relation NO_3-N/NO_2-N.

In addition, nitrogen compounds correlations in the unplanted system were strongly inversed, where the conditions are mostly anaerobic and the denitrification process is most likely to be dominating.

Because nitrate serves as terminal electron acceptors in the denitrification process, where is converted into nitrogen gas and the denitrifying bacteria degrade BOD in the absence of free molecular oxygen to obtain energy, a linear regression was made between the BOD_5 and nitrate loads.

Comparing the variables at the 12.5 cm of depth, the best correlated condition was in the unplanted system (r^2 = 0.758). Even though the upper layer supposed to be more aerated (oxygen diffusion and release from the roots of the plants), the denitrification process is not been inhibited and the organic matter is oxidized to reduce the nitrate.

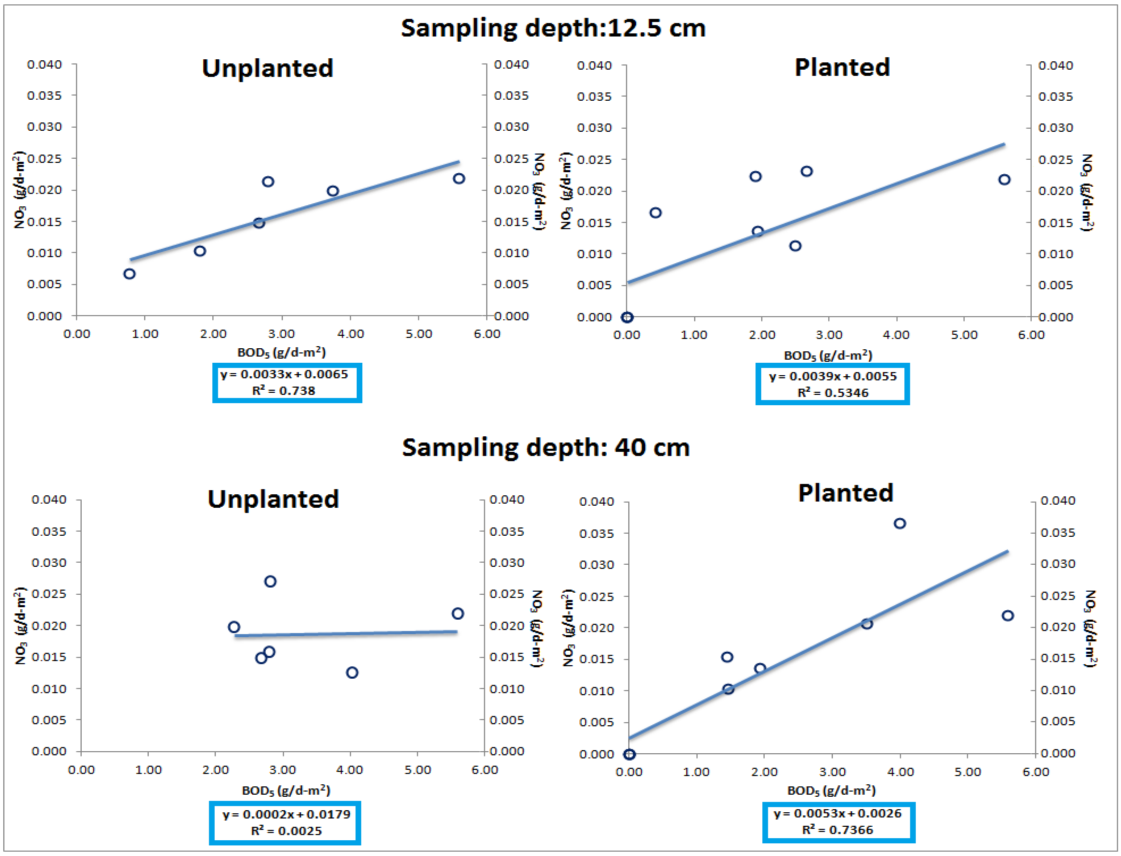

Figure 4-2. NO_3-N and BOD_5 ratio in the two Standard CWs (Unplanted and Planted) at different depths (12.5 cm and 40 cm).

In contrast of the values of the sampling depth at 12.5 cm, the best correlated situation at 40 cm depth was in the planted system (r^2 = 0.7366). Even thought the conditions in the unplanted systems are relative optimal for the denitrification process, more and more evidence is being provided from pure culture studies that nitrate reduction can occur in the presence of oxygen [*Vymazal*, 2007)]. Also, the redox potential confirmed the reductive conditions of the wetlands, where the values for the planted system oscillated around -89.17 to -131.33 mV, whereas the unplanted system is from -102.33 to -131.67 mV.

Total Nitrogen

The removal of total nitrogen by constructed wetlands occurs through different mechanisms: plant absorption, ammonification, aerobic nitrification, denitrification, assimilation by the biomass growth and volatilization in the NH_3 form [*Villaseñor Camacho et al.,* (2007)].

The average inflow TN loading was 2.67 g TN/m^2-d. The removal efficiency for the planted system presented 7 % where for the unplanted system was 11 %. Along the wetlands, the behavior was almost the same for the different systems and depths.

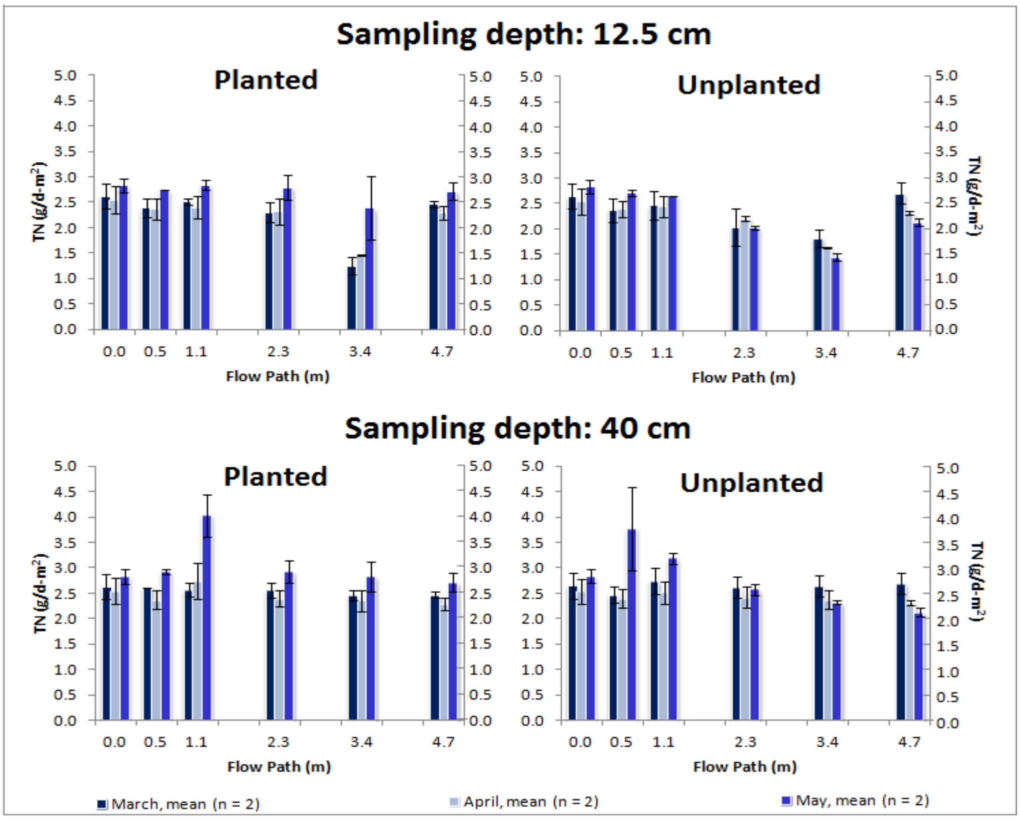

Figure 4-3. Total Nitrogen loads in the Planted and Unplanted Standard HSSF CWs with their different sampling depths (12.5 cm and 40 cm)

Because TN represent the different nitrogen forms (ammonium, nitrate, nitrite and organic nitrogen), a correlation between the TN and ammonium was carried out.

In general, the unplanted and planted systems at 12.5 cm depth have relatively high correlation among the variables. However, the planted system presented the higher value and therefore the Total Nitrogen depended in 92 % to the Ammonium value in a very good statistical significance α = 0.013. Nevertheless, the unplanted system presented 74 % of association.

Table 4-4. Correlation of NH_4-N and Total Nitrogen loads at the 12.5 cm and 40 cm sampling depth in the Unplanted and Planted Standard CWs.

Ammonium and TN_Planted_Standard_12.5cm depth

		Ammonium_ Planted_ Standard_12. 5cm_depth	TN_Planted_ Standard_12. 5cm_depth
Correlación de Pearson	Ammonium_Planted_ Standard_12.5cm_depth	1.000	.922
	TN_Planted_Standard_ 12.5cm_depth	.922	1.000
Sig. (unilateral)	Ammonium_Planted_ Standard_12.5cm_depth	.	.013
	TN_Planted_Standard_ 12.5cm_depth	.013	.

Ammonium and TN_Unplanted_Standard_40cm depth

		Ammonium_ Unplanted_ Standard_ 40cm_depth	TN_ Unplanted_ Standard_ 40cm_depth
Correlación de Pearson	Ammonium_Unplanted_ Standard_40cm_depth	1.000	-.196
	TN_Unplanted_ Standard_40cm_depth	-.196	1.000
Sig. (unilateral)	Ammonium_Unplanted_ Standard_40cm_depth	.	.376
	TN_Unplanted_ Standard_40cm_depth	.376	.

Note: The red underline marks the correlation between the NO_3-N and NO_2-N with oxygen values and the green square is the relation NO_3-N/NO_2-N

In the case of the unplanted and planted system at 40 cm depth, the correlations were negative; meaning inverse proportionality. Therefore, when the ammonium value increase the TN would decrease. This response could be explained due the dependency of TN removal in other nitrogen compounds rather than ammonium.

Table 4-5. Correlation of NH_4 and Total Nitrogen loads at the 12.5 cm and 40 cm sampling depth in the Unplanted and Planted Standard CWs.

Ammonium and TN_Unplanted_Standard_12.5cm depth

		Ammonium_ Unplanted_ Standard_12. 5cm_depth	TN_ Unplanted_ Standard_12. 5cm_depth
Correlación de Pearson	Ammonium_Unplanted_ Standard_12.5cm_depth	1.000	.740
	TN_Unplanted_ Standard_12.5cm_depth	.740	1.000
Sig. (unilateral)	Ammonium_Unplanted_ Standard_12.5cm_depth	.	.076
	TN_Unplanted_ Standard_12.5cm_depth	.076	.

Ammonium and TN_Planted_Standard_40cm depth

		Ammonium_ Planted_ Standard_ 40cm_depth	TN_Planted_ Standard_ 40cm_depth
Correlación de Pearson	Ammonium_Planted_ Standard_40cm_depth	1.000	-.858
	TN_Planted_Standard_ 40cm_depth	-.858	1.000
Sig. (unilateral)	Ammonium_Planted_ Standard_40cm_depth	.	.031
	TN_Planted_Standard_ 40cm_depth	.031	

Note: The red underline marks the correlation between the NO_3-N and NO_2-N with oxygen values.

4.1.2. Organic Compounds

Wastewaters contain complex mixtures of organic matter of different size (from dissolved to particulate) and types (from readily biodegradable to inert constituents). The size frequency distribution function of the organic matter is a key factor in determining the removal efficiency. Particulate organic biodegradable substrates (as well as high molecular weight dissolved and colloidal constituents) must undergo cell external hydrolysis before they are available for biodegradation and this process can be one of the most limiting steps during the removal of organic matter either under anaerobic, anoxic and aerobic conditions [*Caselles Osorio,* (2006)].

Chemical Oxygen Demand

COD can be removed by different mechanisms, but mainly by aerobic respiration (AE), denitrification (DN), reduction of sulfate (SR), and anaerobic methanogenesis (MET) [*Villaseñor Camacho et al.,* (2007)].

The mean COD inflow value was 15 g/m^2-d, where the range varied from 11 to 25 g COD/m^2-d, where these values are classified into moderate loading rates according to

Caselles Osorio (2006). The German guideline ATV-A 262 (2006) suggests a maximum allowable influent of Organic Load Range should not be greater than 16 g COD/m^2-d in order to minimize bed clogging.

The COD loads values throughout the unplanted and planted standard wetlands and their different sampling depths are presented in the Figure 4-4.

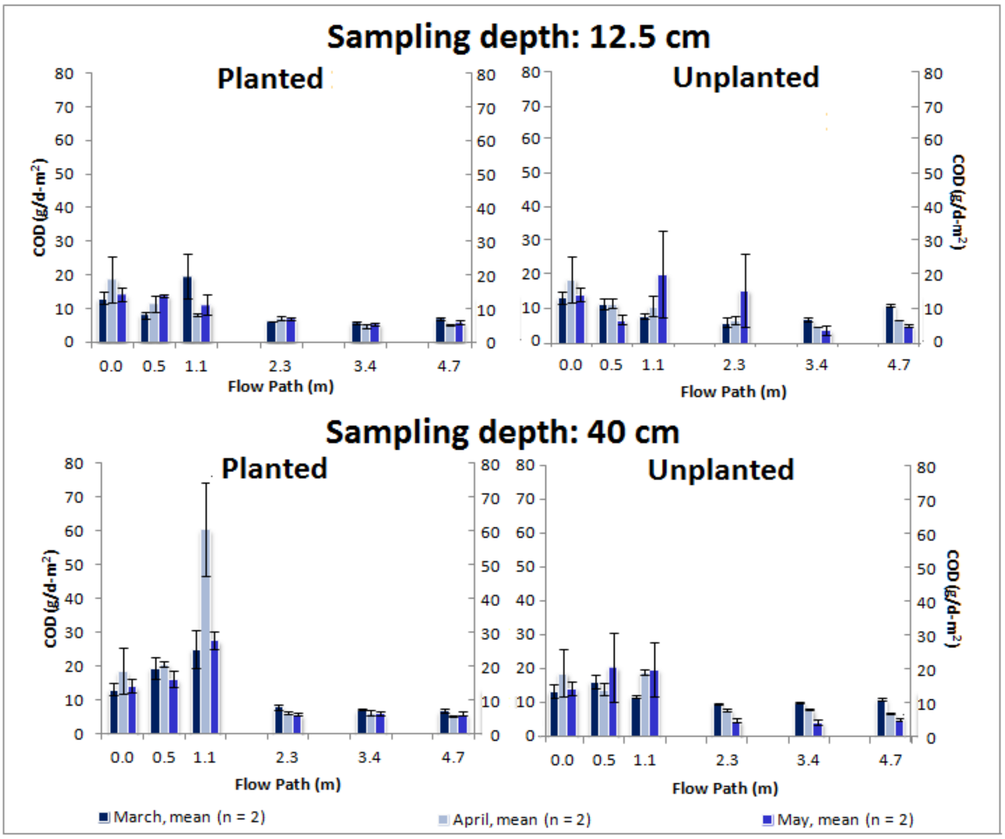

Figure 4-4. COD loads for the Planted and Unplanted Standard HSSF CWs with their different sampling depths (12.5 cm and 40 cm)**.**

The removal efficiency for the planted system marked a 61% of removal, where the unplanted system was about 50 %. Even though the difference between the two system is not much, it could be due to the root-system of the plants as support for the microorganism.

In general, it can be observed that the values in the sampling depth of 40 cm, the values became more “stable” after 1.1 m away from the inflow. In this sampling point, the change in the diameter of the gravel changed from coarse to medium. This area of transition acted like a filter, where the big particles cannot pass through and they settled down due to gravity.

Biochemical Oxygen Demand

The means values for BOD_5 for the planted and unplanted systems and their different depths are illustrated in the Figure 4-5. Some technical problems with the caps of the respirometric OxiTop system was given, maybe they were complete or incompletely closed, were the pressure's difference was measured. The values won't be as representative as the other parameters but they can be used to give an idea about the degradation of the organic matter.

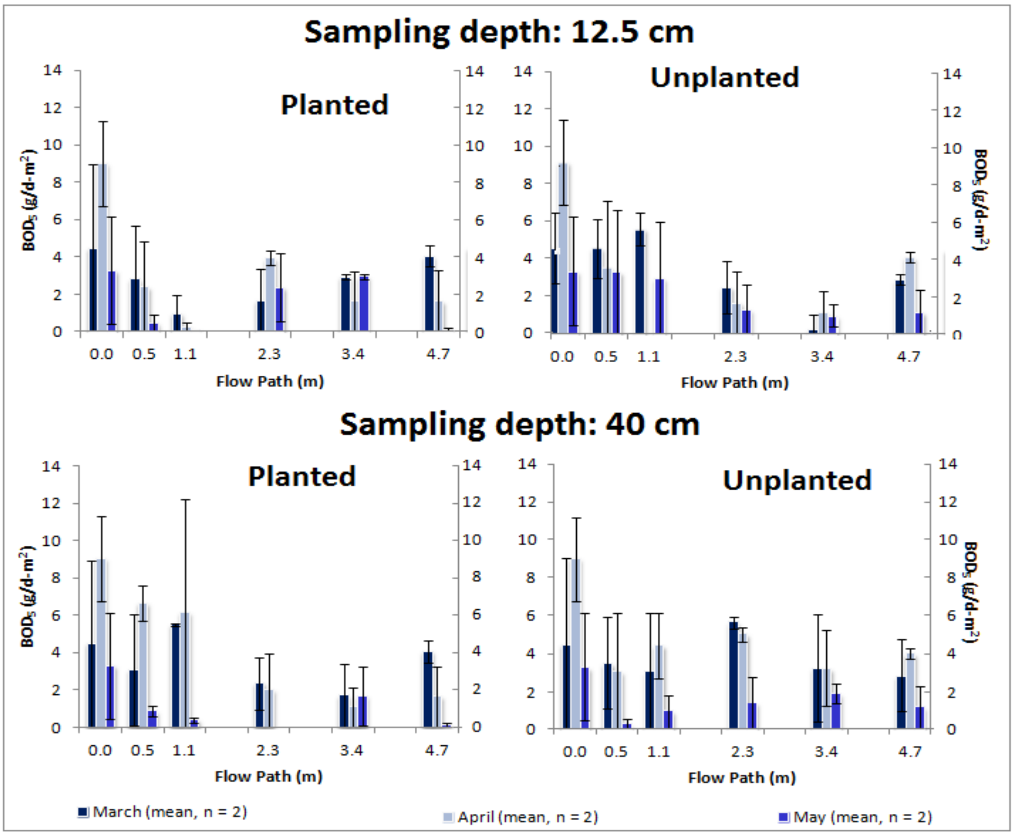

Figure 4-5. BOD_5 loads in the planted and unplanted Standard HSSF CWs with their different sampling depths.

As recommended by *Caselles Osorio*, (2006), the organic loading rates for HSSF CWs should not exceed the 6 g BOD_5/m^2-d to reduce problems related to excess deposition, where the inflow value was 5.6 g BOD_5/m^2-d.

In general, it can be observed that the BOD_5 removal occurred along the wetland. The planted system performed 65 % of removal and the unplanted system had 52 %. The small difference could be because dissolved organic matter can be absorbed by the plant roots and detritus easily and then oxidized by resident microbial populations [*Caselles Osorio*, (2006)].

4.1.3. Sulfur compounds

Sulfate

Most of wastewaters contain sulfate and depending on the availability of organic carbon and/or oxygen, the dissimilatory sulfate reduction can become prevalent inside the constructed wetland [*Kuschk et al.,* (2010); *Ahmad,* (2007)]. Figure 4-6. depict the sulfate loads for the two systems for their different soil depth measurement.

In general, the sulfate loads presented a decrease of their values in both systems, regardless the depth.

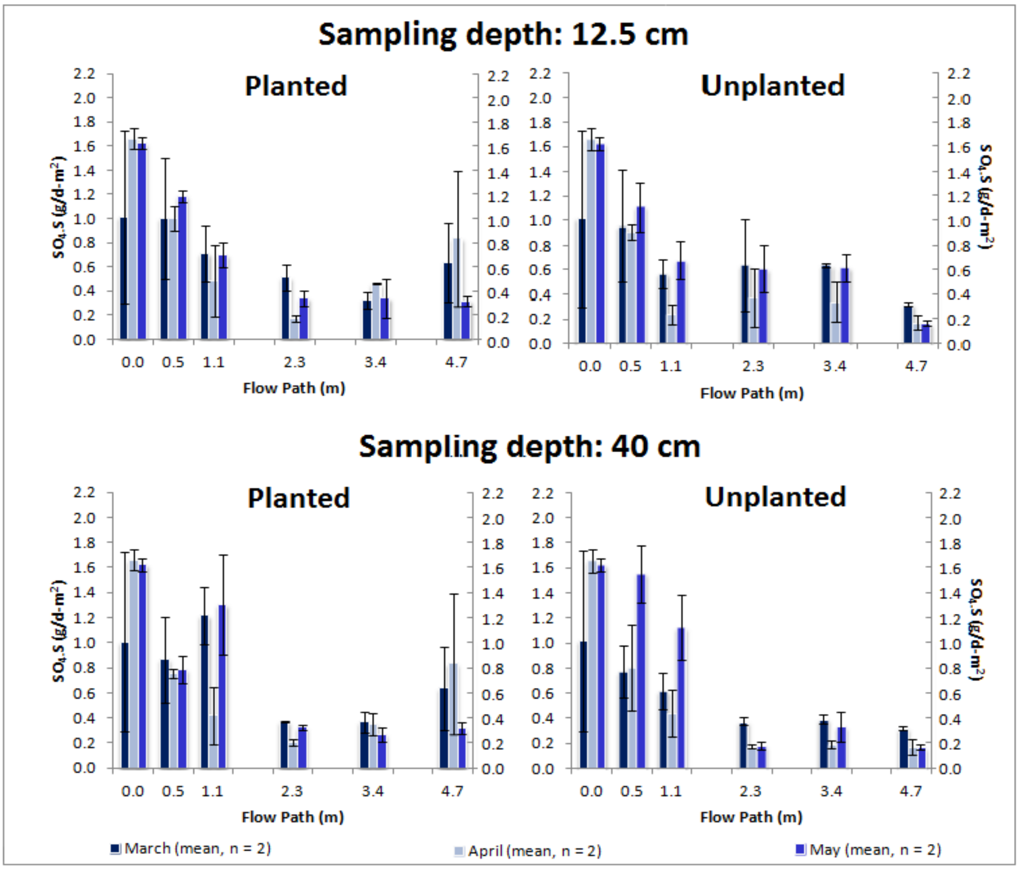

Figure 4-6. SO_4^{2-} loads in the Planted and Unplanted Standard HSSF CWs with their different sampling depths (12.5 cm and 40 cm)

Nevertheless, the removal percentages reported a big difference among the systems, where the planted wetland presented 58 % of removal and the unplanted system was more than 84 %. The reason could be due to the release of oxygen and/or organics by the plant roots, where the sulfate reduction can be influenced of these electron acceptors with higher redox potential *[Meulepas et al.,* (2010)]. Moreover, competition between sulfate reducing bacteria and methanogenic bacteria could exist, where the carbon and energy source is more suitable for sulfate reduction than for methanogenesis *[Villaseñor Camacho et al.,* (2007)].

To visualize better the use of organic matter for the sulfate reduction throw, a correlation was made between the sulfate and BOD_5 loads.

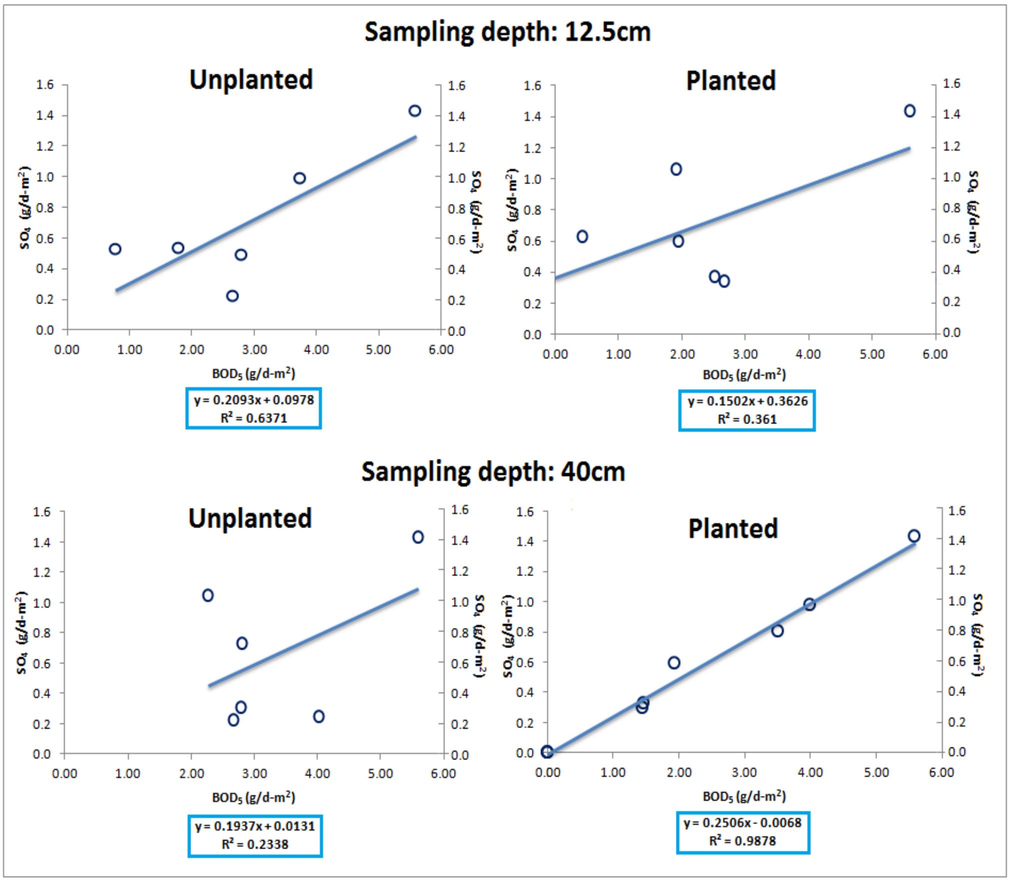

Figure 4-7. Sulfate and BOD_5 ratio in the Unplanted and Planted Standard HSSF CWs at different depths (12.5 cm and 40 cm).

As expected, the higher ratio at 12.5 cm depth was at the unplanted system due to sulfate reduction is an anaerobic process and therefore the dependency was around 65 %. Moreover, at sampling depth of 40 cm, the planted system had higher correlation with 98 % of reliance. Because the plants released oxygen into the rhizosphere, some spatial and temporal micro-scale gradient is established close to root surfaces enhancing the microbial processes to occur simultaneously, like sulfate reduction.

Sulfide

The Figure 4-8. depict the S^{2-} loads for the planted and unplanted system of the Standard HSSF CW at different depths. The wastewater entered the systems with a mean of 0.39 g S^{2-}/m^2-d, where an increase was reported in the outflow of the unplanted system around twice the initial (0.79 g S^{2-}/m^2-d) and for the planted system was more than the double of the inflow load (0.86 g S^{2-}/m^2-d).

It has been stated that the suitable potential redox for microbial dissimilatory sulfate reduction is in the range of -200 mV to -100 mV, meaning under reduced conditions [*Stottmeister et al.,* (2003); *Kuschk et al.,* (2010); *Szogi et al.,* (2004)]. The values reported in this research ranged from 89.17 to -131.33 mV in the planted system, whereas the unplanted system was from -102.33 to -131.67 mV, therefore the conditions of the wastewater could be accurate for the sulfate reduction process.

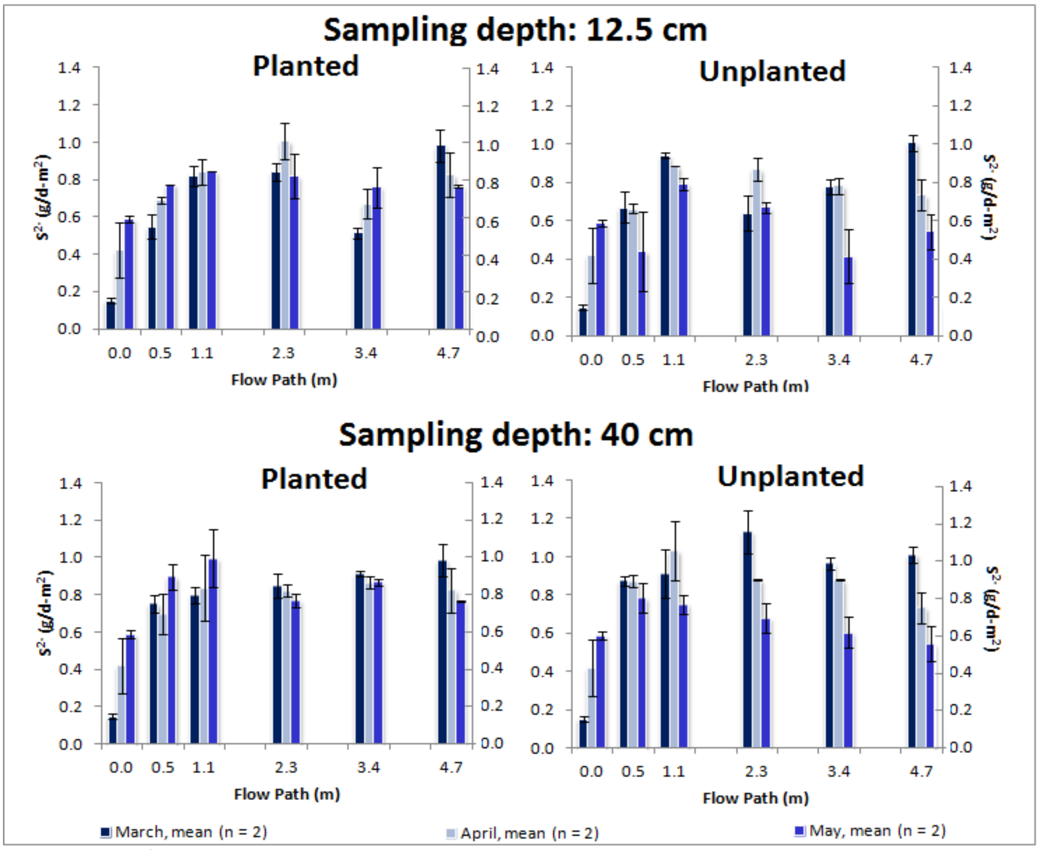

Figure 4-8. S^{2-} loads in the Planted and Unplanted Standard HSSF CWs with their different sampling depths (12.5 cm and 40 cm).

Different processes of sulfur cycling, depending on the availability of organic carbon and/or oxygen, are accordingly prevalent in constructed wetlands [*Dong et al.,* (2011)]. As a tool to discern the microbial activity of the reactant consumption (SO_4-S) to product formation (S^{2-}), the correlation analysis was performed.

The results of the correlation for both sampling depth (12.5 cm and 40 cm) have the best association in the unplanted systems, through the process of sulfate reduction in anaerobic conditions (reduce conditions according to the redox potential, organic matter available, low or none oxygen amount and relative high sulfate presence).

Table 4-6. Correlation of SO_4-S and S^{2-} loads in the unplanted and planted Standard CWs at 12.5 cm depth.

Correlation Sulphate and Sulphide: Unplanted_Standard_12.5cm_depth

		Sulphate_Unplanted_Standard_12.5cm_depth	Sulphide_Unplanted_Standard_12.5cm_depth
Sulphate_Unplanted_Standard_12.5cm_depth	Correlación de Pearson	1	-.658
	Sig. (bilateral)		.227
	N	5	5
Sulphide_Unplanted_Standard_12.5cm_depth	Correlación de Pearson	-.658	1
	Sig. (bilateral)	.227	
	N	5	5

Correlation Sulphate and Sulphide: Planted_Standard_12.5cm_depth

		Sulphate_Planted_Standard_12.5cm_depth	Sulphide_Planted_Standard_12.5cm_depth
Sulphate_Planted_Standard_12.5cm_depth	Correlación de Pearson	1	-.377
	Sig. (bilateral)		.532
	N	5	5
Sulphide_Planted_Standard_12.5cm_depth	Correlación de Pearson	-.377	1
	Sig. (bilateral)	.532	
	N	5	5

Note: The red underline marks the correlation between the NO_3-N and NO_2-N with oxygen values .

It can be observed the negative correlation between the planted and unplanted systems at the sampling depth of 12.5 cm (see Table 4-5), whereas at 40 cm depth wetlands have the opposite situation. In the upper layer, the possible process occurring is the sulfate reduction due to the inverse association and in the lower layer, could be processes like re-oxidation of reduced sulfur compounds and decomposition by the fungi or bacteria [*Kuschk et al.,* (2010)].

Table 4-7. Correlation of SO_4-S and S^{2-} loads in the unplanted and planted Standard CWs at 40 cm depth.

Correlation Sulphate and Sulphide: Unplanted_Standard_40cm_depth

		Sulphate_Unplanted_Standard_40cm_depth	Sulphide_Unplanted_Standard_40cm_depth
Sulphate_Unplanted_Standard_40cm_depth	Correlación de Pearson	1	.327
	Sig. (bilateral)		.591
	N	5	5
Sulphide_Unplanted_Standard_40cm_depth	Correlación de Pearson	.327	1
	Sig. (bilateral)	.591	
	N	5	5

Correlation Sulphate and Sulphide: Planted_Standard_40cm_depth

		Sulphate_Planted_Standard_40cm_depth	Sulphide_Planted_Standard_40cm_depth
Sulphate_Planted_Standard_40cm_depth	Correlación de Pearson	1	.023
	Sig. (bilateral)		.971
	N	5	5
Sulphide_Planted_Standard_40cm_depth	Correlación de Pearson	.023	1
	Sig. (bilateral)	.971	
	N	5	5

It has to be taken in consideration the fact that sulfide may be highly toxic to microorganisms and macrophytes and is a competitor for the consumption of oxygen and inhibitor of the methanogenic process [*Meulepas et al.,* (2010)].

Elemental Sulfur

Oxidized sulfur compounds can be converted to elemental sulfur by applying subsequently sulfate reduction and partial sulfide oxidation [*Meulepas et al.,* (2010)]. Elemental sulfur could be a product of the reduction biological oxidation with O_2 or NO_3^- or it can be anaerobic oxidation by phototrophic bacteria [*Ahmad,* (2007)]. The loads of elemental sulfur during the sampling period presented some technical problems and therefore they won’t have the same representativeness as other parameters.

The mean inflow value was 0.15 g S^0/m^2-d increasing the double in the outflow of the unplanted system (0.32 g S^0/m^2-d) and the planted system (0.34 g S^0/m^2-d).

At the sampling depth of 40 cm, the behavior is different as the 12.5 cm depth. This could be due to the change of diameter in the gravel material, as explained before. With more “empty” spaces, the reduce sulfur compounds can be oxidized into elemental sulphur. A similar behavior in both sampling depths and the different systems (unplanted and planted) is noted.

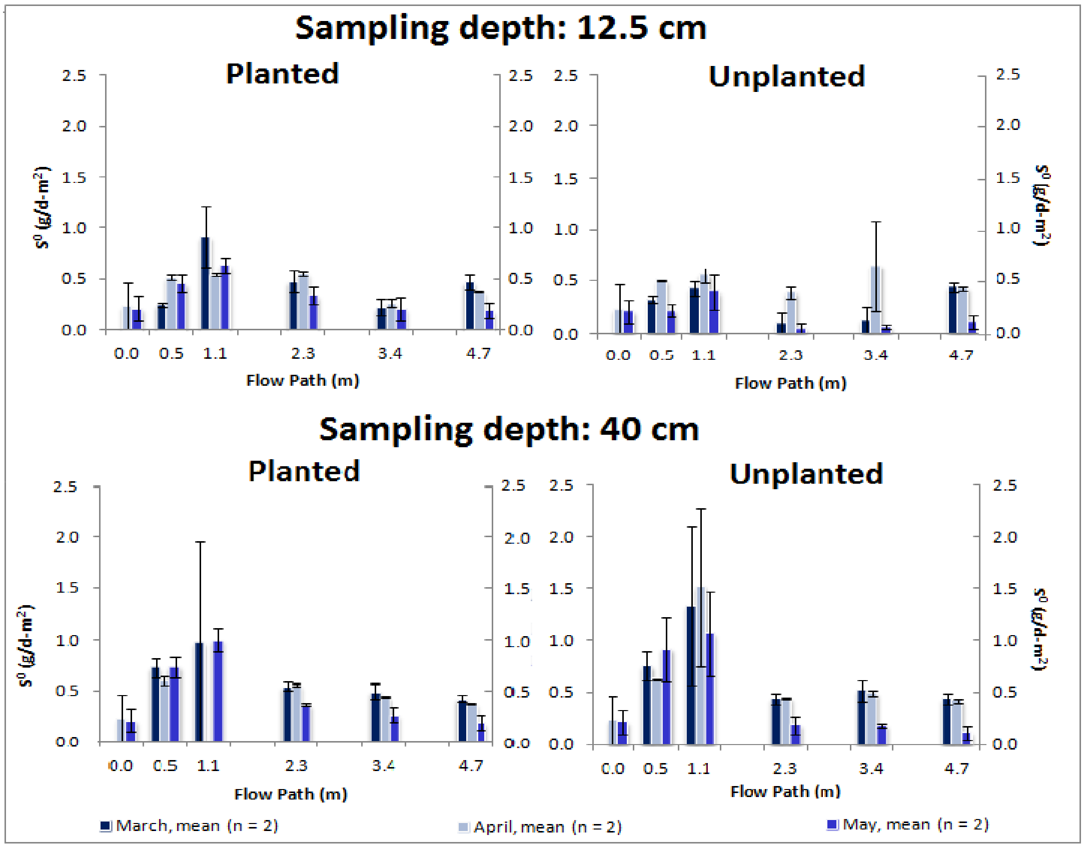

Figure 4-9. S^0 in the Planted and Unplanted Standard HSSF CWs with their different sampling depths (12.5 cm and 40 cm).

4.1.4. Methane

Anaerobic degradation of organic matter proceeds via a number of microbial processes, including hydrolysis, acidogenesis and acetogenesis, by which complex organic matter is degraded to hydrogen and CO_2, formate, acetate and ammonium. The final step is methanogenesis under strict anaerobic conditions. During anaerobic methane oxidation, methane is oxidized with sulfate as the terminal electron acceptor, mediated by a consortium of methane-oxidizing archaea and sulfate-reducing bacteria [*Treude*, (2003)].

As observed in Figure 4-10, the methane load increased in relation to their flow path in the wetland. The inflow value dated 0.02 g/d-m^2, where the outflow of the unplanted system increased to 0.84 g/d-m^2 and the planted system until 0.89 g/d-m^2.

The methane load production was higher in the deeper part of the wetland for both systems (planted and unplanted). In 12.5 cm depth, the release of oxygen from the macrophytes to the reed bed and also oxygen from the atmosphere is added to the upper part of the soil body, could affect methanogenesis.

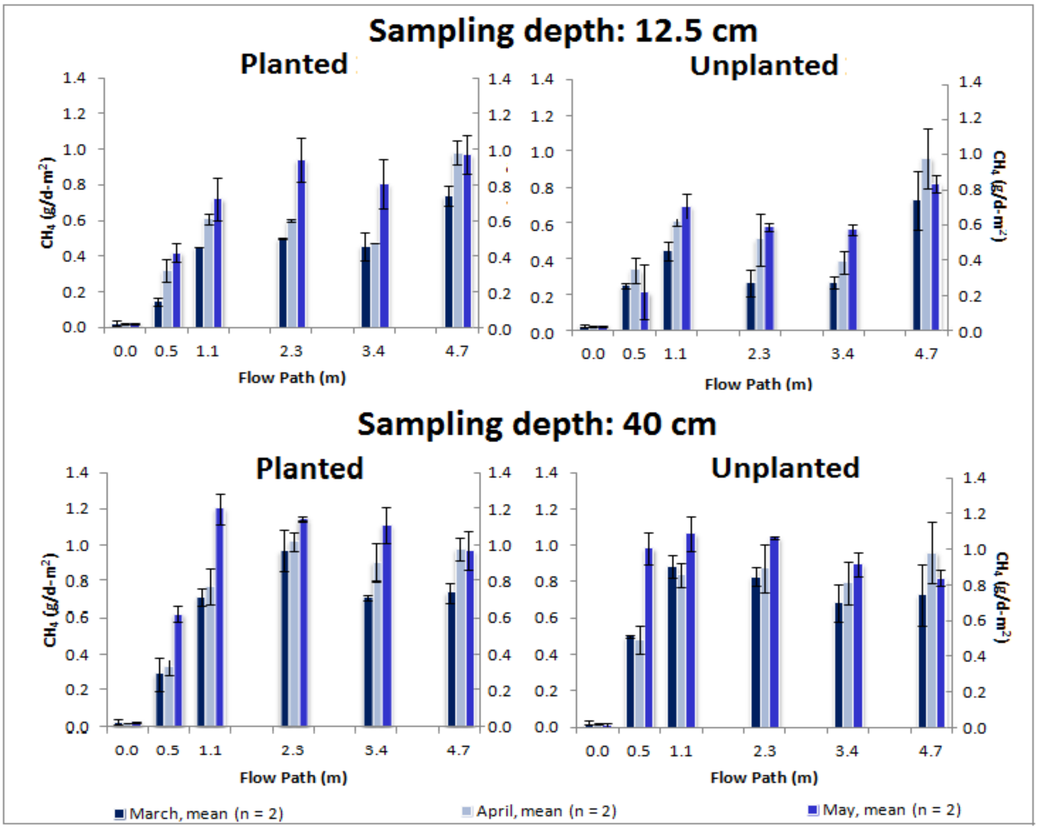

Figure 4-10. CH_4 loads in the Planted and Unplanted Standard HSSF CWs with their different depth (12.5 cm and 40 cm).

The Figure 4-11 represents the ratio between the methane and BOD_5 loads. The aim for this association is to relate the BOD_5 removal due to the methanogenesis process. Because this process occurred in anaerobic conditions, it was expected that they have more correlation in the unplanted systems. As it is observed, this hypothesis is accepted in this research because the higher percentages were found in the unplanted system with 33 % and 56 % for the 12.5 cm and 40 cm depth respectively.

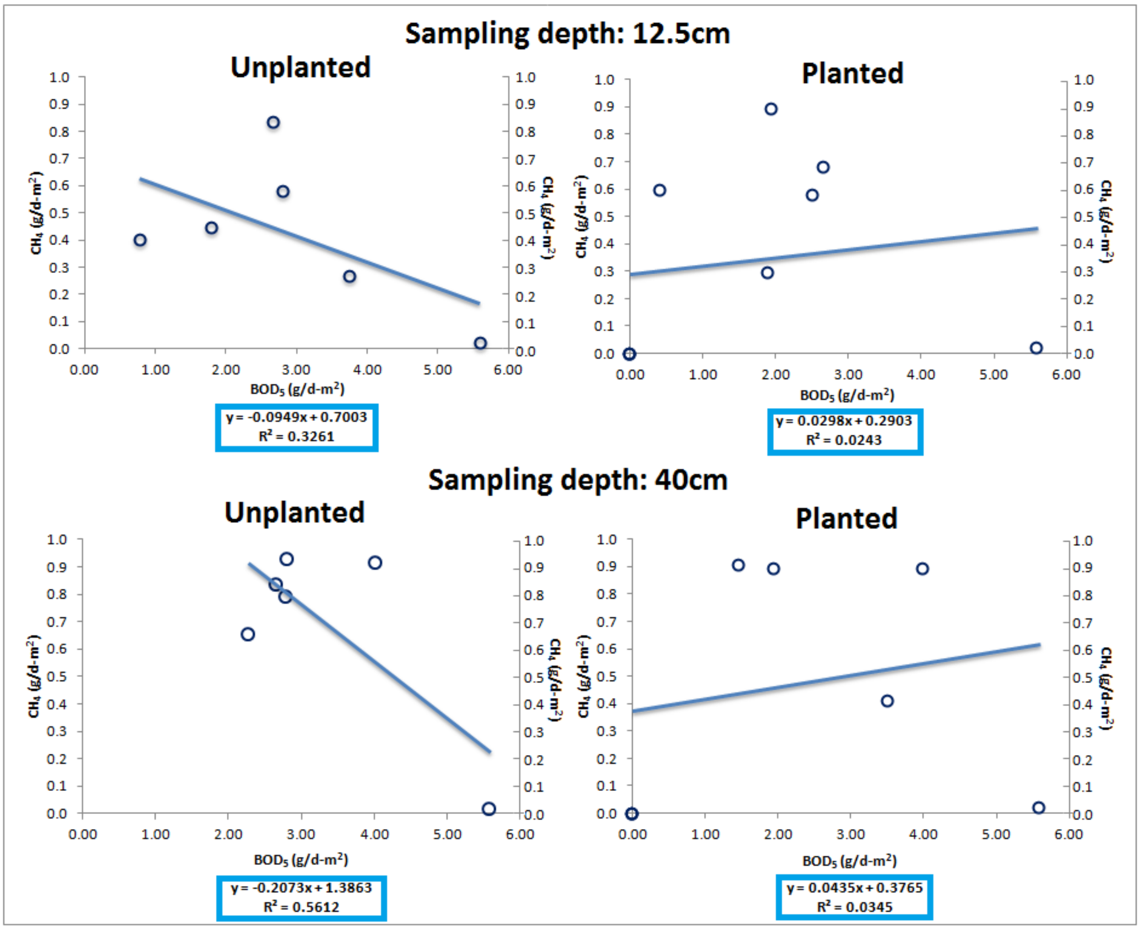

Figure 4-11. CH_4 and BOD_5 ratio in the different systems and depths.

4.2. Shallow Wetlands

4.2.1. Nitrogen Parameters

Ammonium-Nitrogen

Figure 4-12. depict the average values of NH_4-N load along the wetland from the six sampling dates measured at 12.5 cm depth in the planted and unplanted Shallow HSSF CWs.

The mean value of ammonium loads in the inflow was 1 g NH_4-N/m^2-d. Compared to the outflow value for the planted system presented a decrease about 20%. This value is similar to the reported removal range from 15 % to 90 % in experimental CWs fed with different types of wastewater [*Kadlec et al.,* (2005); *Lee et al.,* (2009)].

In the unplanted system, an increased was reported to be around 6%. This negative values of nitrogen removal efficiency could be explained by either the decomposition of litter and microbial biomass during winter time or the ammonification of organic nitrogen in the spring season [*Tsihrintzis and Akratos*, (2007)].

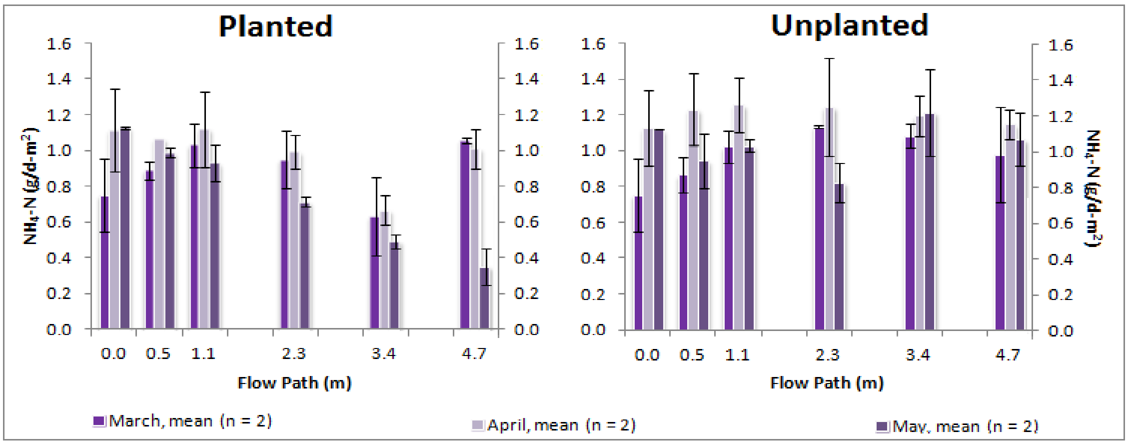

Figure 4-12. NH_4-N loads in the Planted and Unplanted Shallow HSSF CWs.

Oxidized Nitrogen: Nitrate and Nitrite

The NO_3–N and NO_2–N had very low values (under 0.011 g NO_x/m^2-d) in this research.

The inflow value of nitrate (0.0106 g NO_3-N/m^2-d) compared to the outflow value of the unplanted system (0.0105 g NO_3-N/m^2-d) had no removal, whereas the planted system reported a 35 % removal (0.0068 g NO_3-N/m^2-d). It can hypothesize that the nitrification process is happening where the presence of oxygen could be more notable (the planted system).

The formation of NO_3-N from the nitrification process is dependent with the variation of the depletion of NH_4 as well as the temperature season, where spring in summer the ability of nitrogen assimilation and oxygen transferred into the rhizosphere are highest and therefore the nitrification takes place intensively. The mean temperature value in the planted and unplanted CWs were above 15 °C, (16.53 to 19.75 °C and 16.50 to 20.08 °C respectively) and therefore the nitrification process could function properly.

For the nitrite values, the reported inflow load (0.0002 g NO_2-N/m^2-d) had an increase of 200 % in the planted system (0.0006 g NO_2-N/m^2-d) and the unplanted system was 100 % (0.0004 g NO_2-N/m^2-d). These values indicated that first step of the nitrification process is happening in the wetlands.

With the presence of plants, the increase was the double percentage as without plants, marking the presence of the nitrifier bacteria in the root system in major density than the unplanted system. The reported increase according to the respective inflow value was more noticed to be in the first step of the nitrification process, where it can be supposed the partial nitrification is predominating.

It is well-known that the nitrification process occurs under aerobic conditions, where the oxygen values in this research were low and did not exceed 0.004 g/d-m^2. As before mentioned, the number of sampling dates is not the same due to technical difficulties. However, some assumption can be made of the behavior of oxygen with other parameters, therefore a correlation among the oxidized nitrogen and oxygen was made.

Table 4-8. Correlation between oxygen, NO_3-N and NO_2-N in Unplanted and Planted Shallow CWs.

Correlation: Nitrate, Nitrite and Oxygen_Unplanted_Shallow

		Oxygen_Unplanted_Shallow	Nitrite_Unplanted_Shallow	Nitrate_Unplanted_Shallow
Nitrate_Unplanted_Shallow	Correlación de Pearson	-.271	-.029	1
	Sig. (bilateral)	.659	.963	
	N	5	5	5
Nitrite_Unplanted_Shallow	Correlación de Pearson	.668	1	-.029
	Sig. (bilateral)	.218		.963
	N	5	5	5
Oxygen_Unplanted_Shallow	Correlación de Pearson	1	.668	-.271
	Sig. (bilateral)		.218	.659
	N	5	5	5

Correlation: Nitrate, Nitrite and Oxygen_Planted_Shallow

		Oxygen_Planted_Shallow	Nitrate_Planted_Shallow	Nitrite_Planted_Shallow
Oxygen_Planted_Shallow	Correlación de Pearson	1	.017	.139
	Sig. (bilateral)		.978	.824
	N	5	5	5
Nitrate_Planted_Shallow	Correlación de Pearson	.017	1	.135
	Sig. (bilateral)	.978		.828
	N	5	5	5
Nitrite_Planted_Shallow	Correlación de Pearson	.139	.135	1
	Sig. (bilateral)	.824	.828	
	N	5	5	5

Note: The red underline marks the correlation between the NO_3-N and NO_2-N with oxygen values and the green square is the relation NO_3-N/NO_2-N

As observed, nitrite is better correlated to the oxygen compound values in both systems (Unplanted and Planted), 68 % and 14 % respectively, than nitrate because the first step of the nitrification process was dominating.

The correlation between the oxidized nitrogen was better in the planted system (13 %), even though is still a low value. It is consisted because it has been found that nitrification occurs more rapidly in rhizome biofilms than in gravel bed biofilms [*Shamir*, (1998)].

When nitrate is readily available, carbon availability can become the limiting factor for denitrification, therefore an analysis about the BOD_5 and NO_3 ratio was executed.

As observed in the Figure 4-13., the best correlation was in the planted system for the removal of BOD_5 with 56 % of dependency. As viewed in the Table 4-7., the nitrate correlation with oxygen was very low (2 %) in the planted system, therefore the nitrate is more related to the BOD_5 and therefore, the denitrification process.

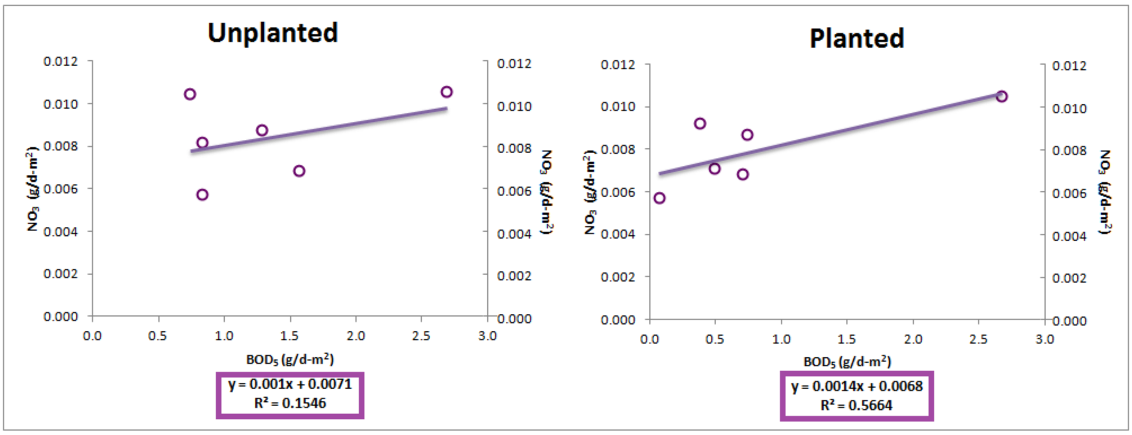

Figure 4-13. NO_3-N and BOD_5 ratio in the Unplanted and Planted Shallow CWs.

Total Nitrogen

The Figure 4-14 presents the values of Total Nitrogen for the planted and unplanted in the Shallow CWs. The average inflow TN loading was 1.28 g/m^2-d. The removal efficiency for the planted system presented 25 % where for the unplanted system almost 1 %.

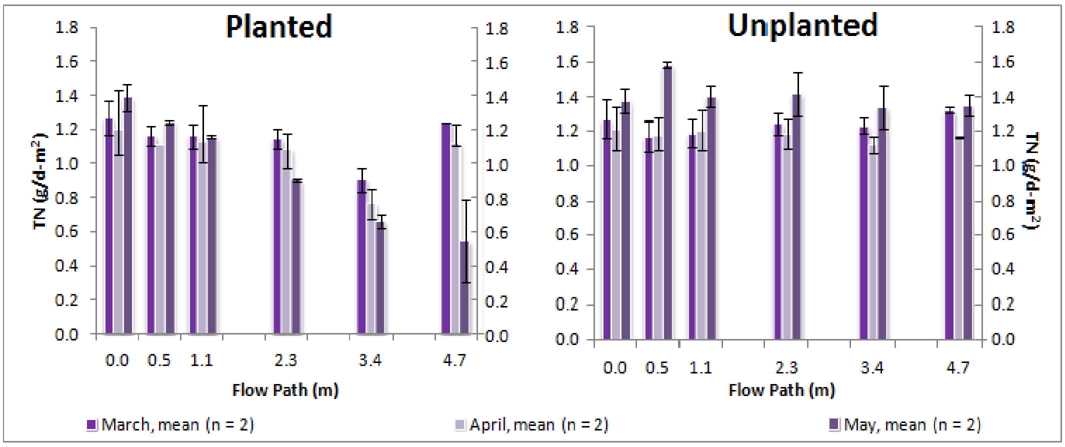

Figure 4-14. Total Nitrogen loads in the Planted and Unplanted Shallow HSSF CWs.

It can observed the influence of the plants for the N removal mechanisms can be partially determined by N-NH_4 and N-NO_3 balances [*Villaseñor Camacho et al.,* (2007)], where the planted system presented an ammonium decrease around 20 %, which can be linked to the total nitrogen removal.

One of the major nitrogen component in wastewater is ammonium, where its dynamic can reflect some part of the transformations occurring in the CWs. Due to Total Nitrogen represent the sum of NO_3-N, NO_2-N, NH_4-N and organically bonded nitrogen, a correlation to identify if there is an association between the behavior of ammonium and the removal efficiency of TN in the CWs was executed.

Table 4-9. Correlation between NH_4 and Total Nitrogen in Unplanted and Planted Shallow HSSF CWs.

Correlation: Ammonium and TN_Unplanted_Shallow

		TN_ Unplanted_ Shallow	Ammonium_ Unplanted_ Shallow
TN_Unplanted_Shallow	Correlación de Pearson	1	-.998**
	Sig. (bilateral)		.000
	N	5	5
Ammonium_Unplanted_ Shallow	Correlación de Pearson	-.998**	1
	Sig. (bilateral)	.000	
	N	5	5

Correlation: Ammonium and TN_Planted_Shallow

		TN_Planted_ Shallow	Ammonium_ Planted_ Shallow
TN_Planted_Shallow	Correlación de Pearson	1	.991**
	Sig. (bilateral)		.001
	N	5	5
Ammonium_Planted_ Shallow	Correlación de Pearson	.991**	1
	Sig. (bilateral)	.001	
	N	5	5

*Correlation is significative at 0.05 (bilateral)

It is astonished the grade of correlation of these compound in both system (99 %) at a significance level of 0.01 (α), where the only difference was the proportional relation. In the planted CWs, the variables were highly correlated in a direct proportion where the TN removal depended on the behavior of the ammonium and its transformation process (ammonification, partial nitrification, nitrification, plant uptake). However, the unplanted CWs had a completely different correlation due to the calculated inverse association, and therefore, TN removal depended on other nitrogen compounds.

4.2.2. Organic Compounds

It have been reported that HSSF gravel beds usually provide high removal of organic matter (BOD_5 and COD). Organic matter is normally removed through precipitation, filtration and both aerobic and anaerobic biological pathways carried out by heterotrophic bacteria [*Albuquerque et al.,* (2009)].

Chemical Oxygen Demand

COD test is used to indirectly measure the amount of organic compound in water. The mean COD inflow value is 7.36 g/m^2-d, classifying the wastewater into moderate loading rates according to *Caselles Osorio (2006)*. The removal efficiency for the planted system was 52 % whereas the unplanted system was 42 %. The difference could be based on the root-system of the plants acting as a support for the microorganism like denitrifiers, methanogenics and sulfate reduction bacteria. Additionally, the oxygen could diffuse through the water – air interface due to the shallow condition of the wetland and to the intermittent flow.

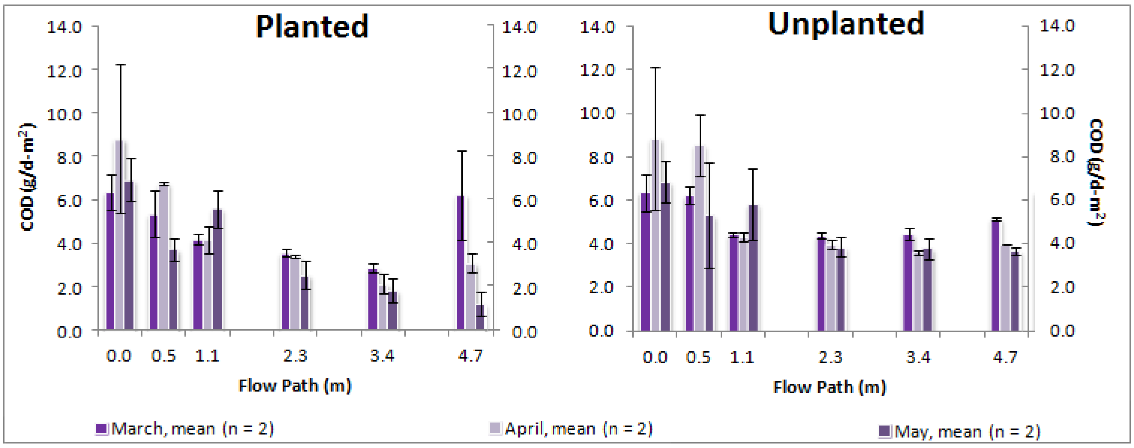

Figure 4-15. COD loads in the Planted and Unplanted Shallow HSSF CWs.

BOD_5

The BOD_5 average values for the planted and unplanted systems and their different depths are illustrate/displayed in the Figure 4-16. As mentioned in the Standard CWs, the data had some technical problems with caps of the BOD_5 bottles, so the representativeness won't be as good as other parameters but they can be used to give an idea about the degradation of the organic matter.

Due to the technicality problems, it is not clear if the organic matter removal is being affected by the presence of oxygen along the wetland. However, it can be observed that the BOD_5 removal occur in both systems. The inflow mean value was about 2.67 g BOD_5/m^2-d and the outflow load value for the planted wetland was 0.71 g BOD_5/m^2-d and the unplanted systems 0.74 g BOD_5/m^2-d, where the both systems performed about 73 % of removal.

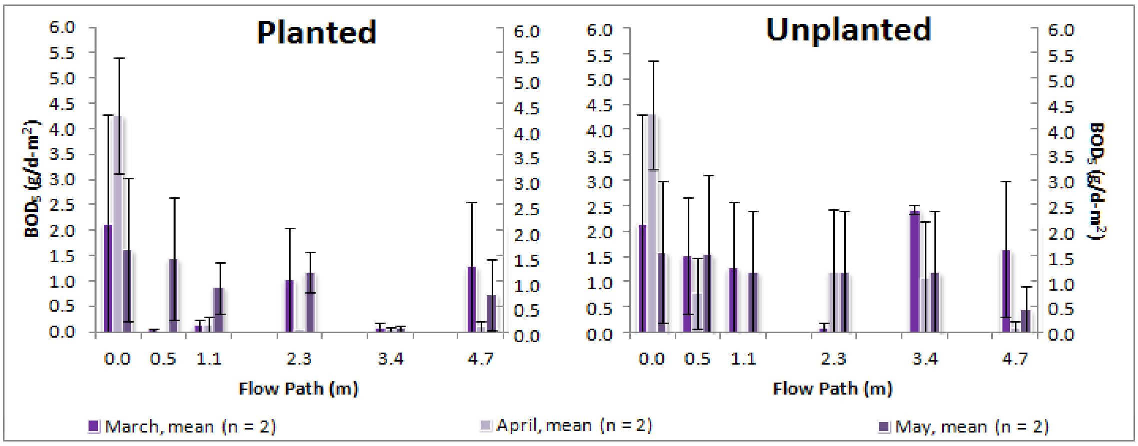

Figure 4-16. BOD_5 loads in the planted and unplanted Shallow HSSF CWs.

4.2.3. Sulfur compounds

Sulfate

Sulfate is a normal constituent of domestic wastewater, and reduced sulfur compounds are known to be potent inhibitors of plant growth and certain microbial activities. Therefore, sulfate reduction has to be considered as a factor that may control performance, particularly in wetland systems [*Kuschk et al.,* (2005)].

In the Figure 4-17. the mean values of the sulfate loads measured in the two systems along the wetland is presented.

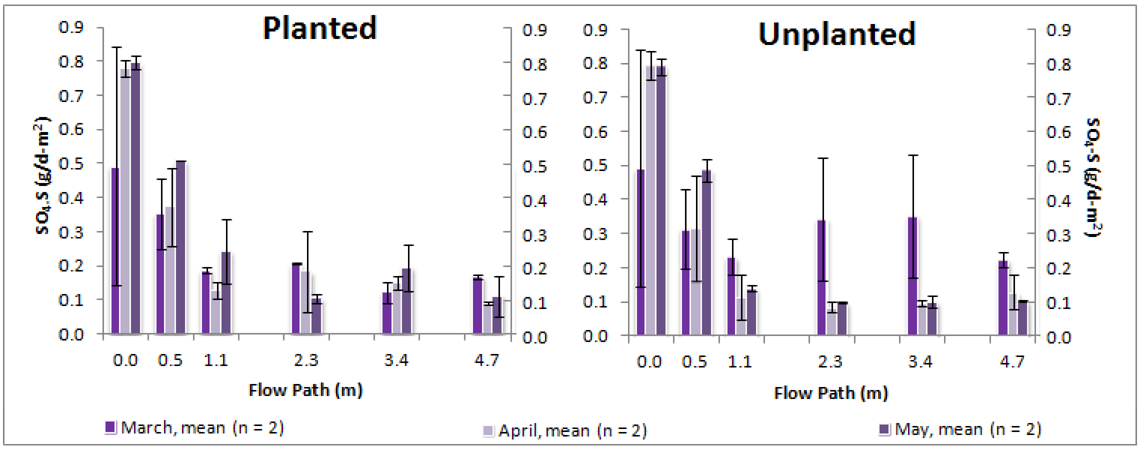

Figure 4-17. SO_4-S loads in the Planted and Unplanted Shallow HSSF CWs.

The inflow value dated 1.43 g SO_4-S/d-m^2 presented 80 % decrease in the outflow value of the unplanted system (0.22 g SO_4-S/d-m^2) and 59 % for the planted system (0.59 g SO_4-S/d-m^2), where it can be assumed is due to the sulfate reduction. Despite that sulfate reduction process occurs in anaerobic conditions, it is interesting to remark the potential of sulfur microorganisms for coexisting very close with other microorganisms involved in the removal processes [*Kuschk et al.,* (2005)].

As sulfate is a common constituent of wastewaters, different processes of sulfur cycling, depending on the availability of organic carbon and/or oxygen, are accordingly prevalent in constructed wetlands. Thus a lineal regression was produced.

The ratio between the sulfate and BOD_5 loads are presented in the Figure 4-18. Both systems have high determination coefficient which indicates the amount of dependency of the variables with each other. The 72 % of connection was found in the unplanted system and 82 % for the planted system, indicating the proportion of BOD_5 values influenced by the sulfur transformation process.

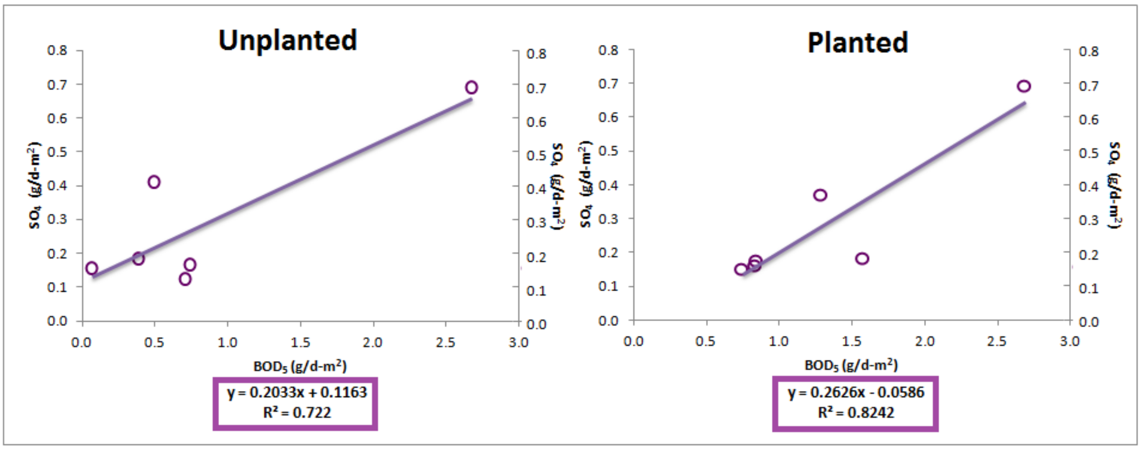

Figure 4-18. SO_4-S and BOD_5 ratio in the Shallow wetlands for the different systems

Sulfide

Sulfide is a product of bacterial dissimilatory sulfate reduction (BSR) by using organic compounds as electron donors.

In the Figure 4-19., the sulfide loads are showed for the planted and unplanted CWs. It can be observed the increase in the loads compared to the inflow load (0.19 g/d-m^2), where the planted had almost the double (0.35 g/d-m^2) and the unplanted had even more than the double (0.45 g/d-m^2). It is notable the variation along the wetland in the planted system rather than the unplanted wetland, corresponding to the microbial activities attached in the plants roots and S^{2-} was oxidized to further mechanisms.

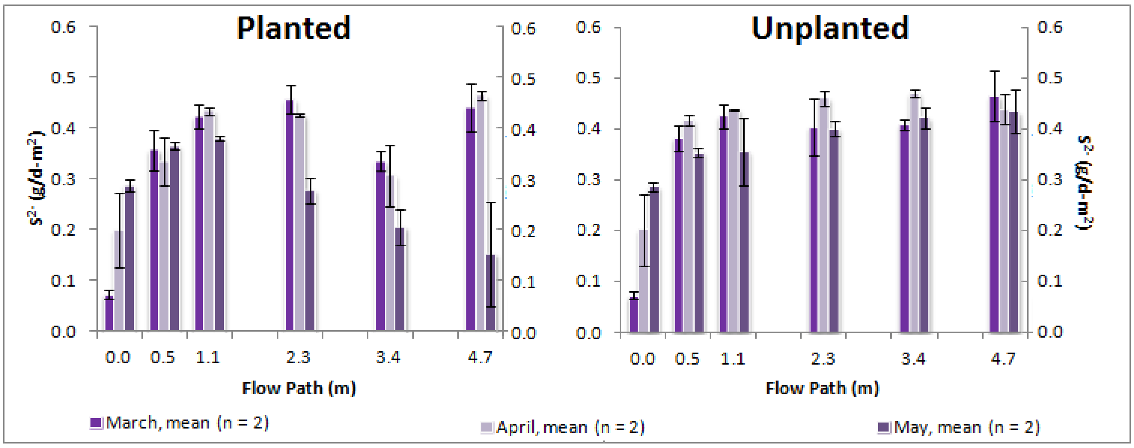

Figure 4-19. S^{2-} loads in the Planted and Unplanted Standard HSSF CWs with their different depth (12.5 cm and 40 cm)

It is well documented the process of sulfate reduction, where the final product is sulfide. The variability of the redox state in the root zone may also affect the fate of sulphate and lead to the formation of sulphide, which has not yet been sufficiently considered. The optimal sulfate reduction redox potential values are from -75 to -150 mV. In this research the planted system ranged from -80.5 to -121.17 mV and the unplanted system was from -80.5 to -120.33 mV, therefore the reduced conditions of the water could enhance the sulfate reduction and the production of sulfide.

To correlate that the main process of sulfide production is through the reduction of sulfate, these variables were analyzed.

Table 4-10. Correlation between the values of SO_4-S and S^{2-} in Unplanted and Planted Shallow HSSF CWs.

Correlation Sulphate and Sulphide: Unplanted_Shallow

		Sulphate_Unplanted_Shallow	Sulphide_Unplanted_Shallow
Sulphate_Unplanted_Shallow	Correlación de Pearson	1	-.841
	Sig. (bilateral)		.074
	N	5	5
Sulphide_Unplanted_Shallow	Correlación de Pearson	-.841	1
	Sig. (bilateral)	.074	
	N	5	5

Correlation Sulphate and Sulphide: Planted_Shallow

		Sulphate_Planted_Shallow	Sulphide_Planted_Shallow
Sulphate_Planted_Shallow	Correlación de Pearson	1	.025
	Sig. (bilateral)		.968
	N	5	5
Sulphide_Planted_Shallow	Correlación de Pearson	.025	1
	Sig. (bilateral)	.968	
	N	5	5

As predicted by the theory, the best correlation amount the two systems were in the unplanted wetland with a negative correlation of 84 %, as a result of the anaerobic conditions.

Elemental Sulfur

Elemental sulfur is a product of sulfide oxidation, which may be performed by abiotic oxidation and/or biological oxidation by using different electron acceptors, such as oxygen, nitrite and nitrate [*Wu et al.,* (2011); *Ahmad,* (2007)].

The loads of elemental sulfur during the sampling period are presented in the Figure 4-20. Some data is missing due to technical problems with the equipment but gives us an idea about the sulfur compound behaviour in wetlands.

The production of elemental sulphur can be observed along the wetland, achieving more than the double of the inflow value (0.07 g/d-m^2), where the unplanted system reached 0.18 g/d-m^2 and the planted system was 0.15 g/d-m^2, confirming the re-oxidation of sulfide.

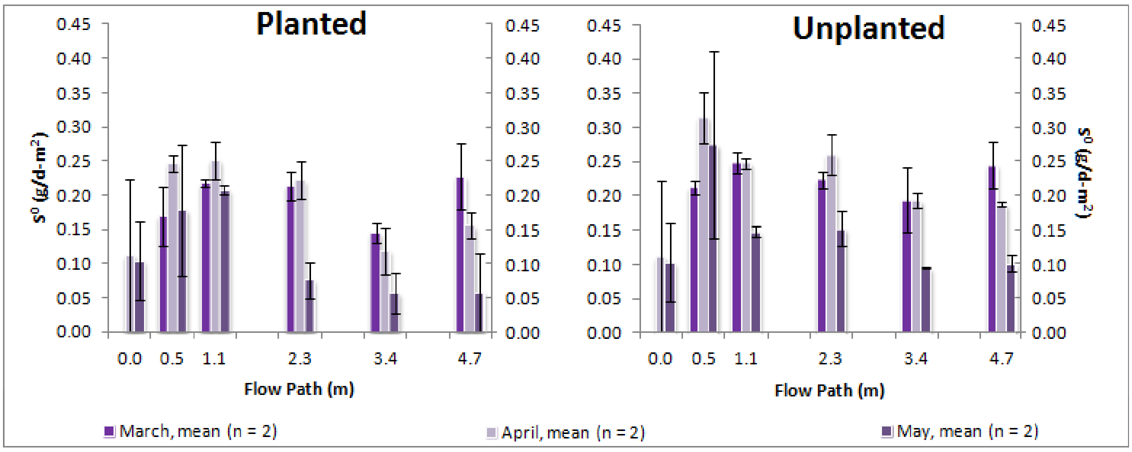

Figure 4-20. S^0 loads in the Planted and Unplanted Shallow HSSF CWs.

4.2.4. Methane

In Figure 4-21., the methane loads are presented for the planted and unplanted system in relation to the flow path in the wetland. Clearly, it can be noticed the methane production throughout the wetland in both systems.

Even though the depth was at 12.5 cm where the methanogenesis process can be affected by the presence of oxygen, the increase is remarkable. The inflow load entered the wetlands with a value of 0.011 g/d-m^2, where at the end of the planted wetland reached 0.219 g/d-m^2 and the unplanted value was 0.23 g/d-m^2. In addition, the CH_4 loads were more constant in the unplanted system than the planted, could be to the anaerobic conditions that the unplanted offered.

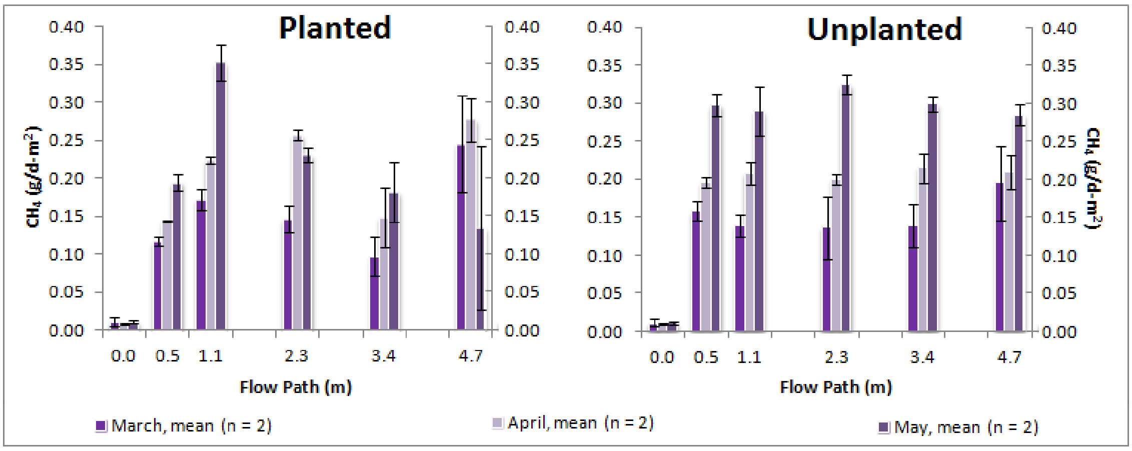

Figure 4-21. CH_4 loads in the planted and unplanted Shallow HSSF CWs.

The production of methane is clearly happening in the wetlands, but it does not mean that the removal of BOD_5 was due to just this process. To give an idea of the amount of association of these variables, a lineal regression test was executed.

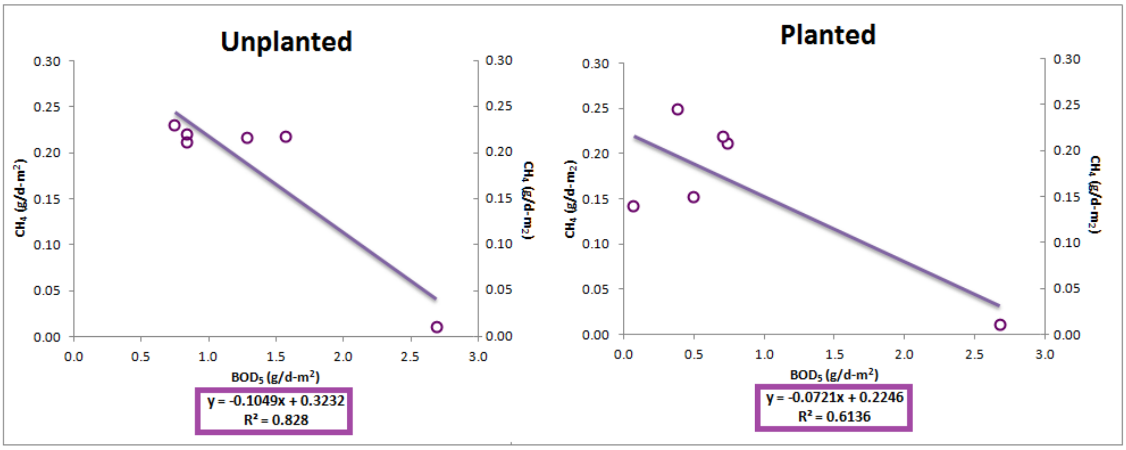

Figure 4-22. CH_4 and BOD_5 ratio in the Shallow wetlands for the different systems

The methane production had a strong relation with the BOD_5 where the unplanted system presented 83 % of dependence and the planted system 61 %. The unplanted relation value was expected due to the process nature of being anaerobic, however in the planted system the relation is more than half percentage indicating that the removal of organic matter was not being interfered by the presence of the plants.

4.3. Removal Evaluation of the Standard and Shallow Horizontal Subsurface Flow Constructed Wetlands.

4.3.1. Nitrogen Parameters

Ammonium

In the Standard CWs, an increased of the outflow values for the planted and unplanted systems was detected to be around 10%. For the Shallow CWs, this increased was just observed in the unplanted system with 6%. These negative values of nitrogen removal efficiency could be explained by either the decomposition of litter and microbial biomass or the ammonification of organic nitrogen [*Tsihrintzis and Akratos*, (2007)].

On the other side, the planted Shallow CWs was the only one with a removal percentage of 20 % where many mechanisms can contribute to this percentage, coinciding with the reported removal range from 15 % to 90 % in experimental CWs fed with different types of wastewater [*Kadlec et al.,* (2005); *Lee et al.,* (2009)]. The possibility of nitrification in this type of wetland was higher due to the low depth and the oxygen supply from the root system. Certainly, the amount of oxygen did not fulfill the requirements for complete nitrification, whereby plant uptake can be another explanation for the finding of small effects on ammonia removal rates by vegetated in this study.

The behavior of the ammonium along the Standard CWs in the different depths (12.5 cm and 40 cm) had no big difference. Nevertheless, the 40 cm depth measurement had more stable values than the 12.5 cm depth, maybe to the less amount of oxygen in the upper layer of the wetlands.

Oxidized Nitrogen: Nitrate and Nitrite

The oxidized nitrogen in this research had very low values, where the Standard CWs reported to be under 0.060 g NO_x/m^2-d and the Shallow CWs were under 0.011 g NO_x/m^2-d. Even under these low values, some transformations were noted.

For the nitrite values, the inflow load of the Standard CWs was 0.0004 g NO_2-N/m^2-d, where it had an increased to 75 % in the planted system (0.0007 g NO_2-N/m^2-d) and the unplanted system was 100 % (0.0008 g NO_2-N/m^2-d). For the Shallow CWs, the reported inflow load was 0.0002 g NO_2-N/m^2-d, had an increase of 200 % in the outflow of the planted system (0.0006 g NO_2-N/m^2-d) and 100 % for the unplanted system (0.0004 g NO_2-N/m^2-d).

These values can indicate that first step of the nitrification process is happening in the wetlands. It is more remarkable the first step of the nitrification where the ammonium is oxidized into nitrite. As observed, the Shallow wetlands (planted and unplanted) had the higher increase percentage. It could be due to the low depth of the wetland where the oxygen amount could be a little higher than the Standards.

For the nitrate values, the Standard CWs had a inflow value of 0.0219 g NO_3-N/m^2-d, which was reported to decrease at the outflow value of 32 % for the unplanted system (0.0148 g NO_3-N/m^2-d) and 38 % for the planted system (0.0136 g NO_3-N/m^2-d). In the case of the Shallow CWs, the inflow value of nitrate was 0.0106 g NO_3-N/m^2-d, where the outflow value of the unplanted system (0.0105 g NO_3-N/m^2-d) had no removal, whereas the planted system reported a 35 % removal (0.0068 g NO_3-N/m^2-d). The low loads of NO_3-N values and the removal percentage indicated that there is no nitrate accumulation in the wetlands and process like denitrification can occurred.

According to the theory, the production of nitrate and nitrite depend on the oxygen present in the system. In general, the oxygen values were low and did not exceed 0.090 g/d-m^2 for the Standard CWs and 0.040 g/d-m^2 for the Shallows CWs. It is known that under low-oxygen conditions, the production of nitrite from ammonia is favored over the production of nitrate [*Vymazal,* (2007)]. The results of the correlation of NO_3-N and NO_2-N with the measured values of oxygen in the Standard CWs confirmed that the nitrite has the best association with oxygen in both depths for both systems (planted and unplanted). Same association was found as well in the Shallow CWs.

Also, the correlation between the nitrate values and the BOD_5 in the Standard CWs and Shallow CWs confirmed the denitrification and nitrification process are occurring simultaneously due to the values obtained (76 % Unplanted Standard at 12.5 cm depth, 74 % Planted Standard at 40 cm and 54 % Planted Shallow) [*Vymazal*, (2007)].

Total Nitrogen

The removal of TN in the Standard CWs was 7 % and 11 % for the planted and unplanted systems respectively, whereas the Shallow CWs presented 25 % and 1 % respectively. Because NH_4-N is the major nitrogen compound in wastewater, the TN removal could be related to the ammonium behavior. The correlation percentages in the CWs were high, which could be to certain association between Total Nitrogen and NH_4-N.

The Planted Shallow CWs as well as both Standard CWs at 12.5 cm depth (Planted and Unplanted) had high and positive percentage correspondence, indicating that the behavior of the ammonium and its transformation process (ammonification, partial nitrification, nitrification, plant uptake) affect directly the TN removal. For the Unplanted Shallow and both Standard CWs at 40 cm depth CWs, the percentage was negative; meaning inverse proportionality. Therefore, when the ammonium value increase the TN would decrease. This response could be explained due to the different oxygen amount at 40 cm depth on the planted system in relation to the unplanted. Another explanation is the dependency of TN removal in other nitrogen compounds rather than ammonium.

4.3.2. Organic Compounds

Chemical Oxygen Demand

The inflow values of COD in the wetlands were classified as moderate loading rates according to *Caselles Osorio (2006)*, where the mean value in this research for the Standard CWs was 15 g/m^2-d and for the Shallow CWs was 7.36 g/m^2-d. The German guideline ATV-A 262 (2006) suggests a maximum allowable influent of Organic Load Range should not be greater than 16 g COD/m^2-d in order to minimize bed clogging.

The removal efficiency in the Standard CWs for the planted system marked a 61% of removal, where the control unplanted was around 50 %. In general, the load values decrease, but in the sampling depth of 40 cm, the values became more "stable" after 1.1 m away from the inflow, where the change in the diameter of the gravel changed from coarse to medium, and therefore this change acted like a filter, where the big particles cannot pass through and they settled down due to gravity.

In the Shallow CWs, the removal efficiency was also higher in the planted system with 52 % of removal, where the unplanted system was 42 %. One possibility could be due to the depth of the wetland is not too deep and it could help to the water-oxygen contact.
The fact that in both CWs the planted system presented higher removal percentage, confirmed that the root-system of the plants acted as a support for the microorganism like denitrifiers, methanogenics and sulfate reduction bacteria.

Biochemical Oxygen Demand

Even though there were some technical problems with the caps of the respirometric OxiTop system, the values can be used to give an idea about the degradation of the organic matter.

In general, it can be observed that the BOD_5 removal occurred along the wetland. The inflow mean value for the Standard CWs was about 5.6 g BOD_5/m^2-d, where the planted system performed 65 % of removal and the unplanted system had 52 % and had no big difference between the sampling depths. For Shallow CWs, the inflow mean value was about 2.67 g BOD_5/m^2-d and the outflow load value for the planted wetland was 0.71 g BOD_5/m^2-d and the unplanted systems 0.74 g BOD_5/m^2-d, where the both systems performed a 73 % of removal.

The small difference between the planted and unplanted system could be because dissolved organic matter can be absorbed by the plant roots and detritus easily and then oxidized by resident microbial populations [*Caselles Osorio*, (2006)].

4.3.3. Sulfur Parameters

Sulfate

In the Standard CWs, the sulfate loads presented a decrease of their values in both systems, regardless the depth, where the planted wetland presented 58 % of removal and the unplanted system is more than 84 %. It could be due to the release of oxygen and/or organics by the plant roots, where the dissimilatory sulfate reduction can be influenced by these electron acceptors *[Meulepas et al.,* (2010)].

For the Shallow CWs, the sulfate loads also presented a decrease around 80% for both systems, which can be assumed is due to the sulfate reduction. Despite that sulfate reduction process occurs in anaerobic conditions, it is interesting to remark the potential of sulfur microorganisms had to coexisting very close with other microorganisms involved in the removal processes [*Kuschk et al.,* (2005)].

The lineal regression made to visualize the dependency of sulfide production and the BOD_5 loads, where the Standard CWs at the sampling depth of 12.5 cm had high coefficient in the unplanted system with a 65 % of dependency. At the 40 cm depth, the best reliance was found in the planted system with 98 %. In the Shallow CWs, both systems presented high determination coefficient which indicates the amount of dependency of the variables with each other. The 72 % of connection was found in the unplanted system and 82 % for the planted system.

These values indicated the proportion of BOD_5 values influenced by the sulfur transformation process, regardless the released oxygen into the rhizosphere, where some micro-scale gradient are established close to root surfaces enhancing the microbial processes to occur simultaneously, like sulfate reduction.

Sulfide

In the Standards CWs, the wastewater entered the systems with a mean of 0.39 g S^{2-}/m^{2}-d, reporting an increase in the outflow of the unplanted system around twice the initial (0.79 g/m^2-d) and for the planted system was more than the double of the inflow load (0.86 g/m^2-d).

For the Shallow CWs, the sulfide loads had an increase in the loads compared to the inflow load (0.19 g/d-m^2), where the planted had almost the double (0.35 g/d-m^2) and the unplanted had even more than the double (0.45 g/d-m^2). It is notable the variation along the wetland in the planted system rather than the unplanted wetland, corresponding to the microbial activities attached in the plants roots and S^{2-} was oxidized to further mechanisms.

It has been reported that the suitable potential redox for microbial dissimilatory sulfate reduction is in the range of -200 mV to -100 mV, meaning under reduced conditions [*Stottmeister et al.,* (2003); *Kuschk et al.,* (2010); *Szogi et al.,* (2004)]. The values reported in this research ranged from 89.17 to -131.33 mV in the planted system, whereas the unplanted system was from -102.33 to -131.67 mV for the Standard CWS, whereas the Shallow CWs had -80.5 to -121.17 mV in the planted system and -80.5 to -120.33 mV for the unplanted system.

Therefore, both CWs had reduced conditions that enhanced the sulfate reduction and the production of sulfide.

As a tool to discern the microbial activity of SO_4-S to produce S^{2-}, the correlation analysis was performed.

The Standard CWs for both sampling depth (12.5 cm and 40 cm) have the best association in the unplanted systems, due to the process of sulfate reduction is an anaerobic process. Also, it can be observed the negative correlation in both wetlands in the sampling depth of 12.5 cm, whereas at 40 cm depth wetlands have the opposite situation. In the upper layer, the possible process occurring is the sulfate reduction due to the inverse association whereas in the lower layer could be happening processes like re-oxidation of reduced sulfur compounds and decomposition by the fungi or bacteria [*Kuschk et al.,* (2010)].

For the Shallow CWs, the best correlation amount the two systems were in the unplanted wetland with a negative correlation of 84 %, as a result of the anaerobic conditions.

Element Sulfur

Regardless of the technical issues presented in this research, the values of elemental sulfur could help to identify the dynamics of this parameter.

In the Standard CWs, the mean inflow value was 0.15 g S^0/m^2-d increasing the double in the outflow of the unplanted system (0.32 g S^0/m^2-d) and the planted system (0.34 g S^0/m^2-d).

As explained before, the coarse gravel diameter of the inflow zone (until the 1.1 m from the inlet) and the outlet point have 16 mm to 32 mm, therefore the porosity is bigger than the rest of the wetland. With more “empty” spaces, the reduce sulfur compounds can be oxidized into elemental sulphur. A similar behavior in both sampling depths and the different systems (unplanted and planted) is noted.

For the Shallow CWs, the production of elemental sulfur can be observed along the wetland, achieving more than the double of the inflow value (0.07 g/d-m^2), where the unplanted system reached 0.18 g/d-m^2 and the planted system was 0.15 g/d-m^2, confirming the re-oxidation of sulfide [*Ahmad,* (2007)].

4.3.4. Methane

It can be noticed the methane production along the Standard and Shallow CWs.

The Standard CWs had better values in the lower part of the wetland (40 cm depth) and/or in the unplanted system due to the anaerobic nature of the methanogenesis. The inflow value dated 0.02 g/d-m^2, where the outflow of the unplanted system increased to 0.84 g/d-m^2 and the planted system until 0.89 g/d-m^2. The Shallow CWs, even thought it has 12.5 cm depth and the methanogenesis process can be affected by the presence of oxygen, the increase is also remarkable, where the inflow value was 0.011 g/d-m^2 and reached 0.219 g/d-m^2 in the planted system and 0.23 g/d-m^2 for the unplanted system. Between the unplanted and planted system, it was expected that the unplanted CWs had optimal circumstances due to the anaerobic conditions prevailing.

The reliance of the BOD_5 removal associated with the CH_4 production due to the methanogenesis process was studied. In the Standard CWs, the unplanted system presented the higher association percentage where 56 % for the 40 cm depth and 33 % for the 12.5 cm depth. The Shallow CWs had a strong relation with the BOD_5 and the methane production, where the unplanted system presented 83 % of dependence and the planted system 61 %.

The methanogenesis process occurs in anaerobic conditions, where it is expected that they have more correlation in the unplanted systems, as they did in this research.

CHAPTER FIVE
CONCLUSSION

In the Standard HSSF CWs, the ammonium removal had negative values where processes like decomposition of litter and microbial biomass or the ammonification of organic nitrogen could happen. The influence of depth was minimal, where at 12.5 cm depth; the ammonium values presented some removal values in both systems (Unplanted and Planted) than the 40 cm depth CWs.

The presence of oxygen conditions in the upper layer could be the influential factor, even though the oxygen values were low and did not exceed 0.009 g/d-m^2. The increase of the nitrite loads is detected, where the Unplanted CW reached to the double of the inflow value. It was expected that the correlation values proved that nitrite had more association with oxygen at 12.5 cm depth than the 40 cm depth, due to the low vertically dispersion of the oxygen. The nitrate compound reported a decrease of 32 % for the Unplanted CW and 38 % for the Planted CW. Also, the correlations with the BOD_5 values had high percentage of dependency (73 %) in both depths, therefore the denitrification process was happening even a low values.

The reduced conditions found in the CWs and the relatively high removal of BOD_5 (around 55 %) lead to processes like sulfate reduction and methanogenesis to take place. As expected, the removal percentages of sulfate were higher in the Unplanted CWs (84 %). The increase of sulfide values, as a terminal product of the sulfate reduction, confirmed that the process was taking place. Because this process degrades organic matter, the correlation with the BOD_5 values was found in be higher in the Planted CWs at 40 cm depth with 98 % of reliance. In addition, the re-oxidation of sulfide to produce elemental sulfur could interfere with the available oxygen amount for nitrification. The increase of elemental sulfur was detected in this research. Methane production is also organic matter degradation process. The methane load production was detected along the CWs. The best association level of the methane production and the BOD_5 removal was found in the Unplanted CW at 40 cm depth with 56 % of dependency.

For the Shallow HSSF CWs, ammonium removal of 20 % was reported in the planted system, matching with the reported range when experimental CWs are fed with different types of wastewater. This percentage could be due to certain nitrification due to the little depth of this wetland, even though the oxygen amount did not fulfill the requirements for a complete nitrification. Plant uptake could be another explanation for the finding of small effects on ammonia removal rates by vegetated in this study.

The increase of the nitrite loads was observed, where the highest percentage was in the Planted Shallow CWs. It can be assumed that the depth parameter as well as the presence of vegetation plays an interesting role for the first part of the nitrification process. The main condition for this removal process is the amount of oxygen, where the values in the CWs were low and did not exceed 0.040 g/d-m^2. In addition, the correlation of NO_3-N and NO_2-N with the measured values of oxygen shown that nitrite had the best association with oxygen over nitrate.

For the nitrate values, the Planted CW presented 35 % removal. The low loads of NO_3-N values and the removal percentage indicated that there is no nitrate accumulation and process like denitrification can occurred. In addition, the correlation values between the NO_3-N and BOD_5 presented 56 % of dependency and low association with the oxygen values (2 %), confirming that denitrification and nitrification process occurred simultaneously.

As mentioned before, the redox potential values brought about reductive processes in the CWs. In addition, the BOD_5 removal performed by both CWs with 73 % of removal indicated that anaerobic processes were occurring. One process is the sulfate reduction, where high decrease of sulfate load was observed, 80 % for the Unplanted CW and 60 % for the Planted CW. The lineal regression made to visualize the sulfate reduction and the BOD_5 loads behavior reported a high coefficient, with more than 70 % of dependency. In addition, the values of elemental sulfur increased more than the double of the inflow value. This increase confirmed the process of re-oxidation of sulfide and could affect the amount of oxygen available for the nitrification process.

The increase of the methane values along the Shallow CWs is due to the methanogenesis process, where the organic matter is degraded microbiologically. The reliance of the BOD_5 removal associated with the CH_4 production due to the methanogenesis process was studied. The Shallow CWs 83 % of dependence. The methanogenesis process occurs in anaerobic conditions, where it is expected that they have more correlation in the unplanted systems, as they did in this research.

In general, the nitrogen removal process in HSSF CWs is low due to the amount of oxygen present in the CWs. The first part of this process is the oxidation of ammonium, where the Planted Shallow CW had 20 % removal. However, both CWs (Standard and Shallow CWs) presented a high increase of nitrite loads where the Shallow CWs have higher increase percentage and therefore Partial Nitrification or even complete Nitrification. However, the Standard CWs have more removal decrease of nitrate than the Shallow CW; therefore it is more suitable for the denitrification process. The denitrification process as a degradation of organic matter process competes with other processes found in this research. The sulfate reduction had very high percentage of reliance with the BOD_5 values. The methanogenesis did not have very high values of correlation between the increase of methane and the organic matter removal as sulfate did, but it can become an influential process.

Even though is difficult to evaluate the nitrogen removal performance of the HSSF CWs due to the short period of observation, it can be generally concluded that the Standard HSSF CWs seemingly had the same volume-specific turnover rates than the Shallow HSSF CWs. Also, the nitrification-denitrification connection is the main nitrogen removal process. However, the sulphate reduction as the main correlated process for the removal of organic matter interfered with the denitrification process.

Some seasonal variation that set the CWs conditions (like temperature, redox potential, evaporation, evapotranspiration, etc.) should be deeply investigated in a longer period.

The main process to improve the nitrogen removal is the oxidation of ammonium. Under these specific conditions, the influence of wetland depth was not as significant as the presence (or absence) of vegetation in the CWs. Further processes like Anaerobic Ammonium Oxidation (ANAMMOX) should be studied in more depth due to the low amount of oxygen. Recent studies promote the application of ANAMMOX process in CWs with high pollutant influent concentrations where the results demonstrated that the ANAMMOX process was successfully established and operated consistently in the Horizontal SSF CWs with a bio-contact oxidation reactor as a pretreatment. In addition, the vegetation positively affected the growth and enrichment of ANAMMOX bacteria [*Li and Wang,* (2011)]. However, it is unclear whether ANAMMOX process can be effective for low ammonium influent concentrations and how to establish steady operations of ANAMMOX process for decentralized domestic sewage.

CHAPTER SIX
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ANNEX I: Hydraulic Data

- Dilution Factor

The dilution factor was calculated using this formula: $F_i = \frac{V_{wetland\_x} + V_{outlet\_i}}{V_{wetland\_x} + V_{inlet\_i}}$

Shallow Planted CW

Sampling Date	Dilution Factor				
	0.5 m	1.1 m	2.3 m	3.4 m	4.7 m
15.03.2012	1.0069	1.0119	1.0173	1.0199	1.0213
29.03.2012	1.0014	1.0022	1.0026	1.0032	1.0035
12.04.2012	1.0035	1.0054	1.0079	1.0090	1.0097
26.04.2012	1.0049	1.0083	1.0118	1.0137	1.0146
10.05.2012	0.9776	0.9627	0.9465	0.9377	0.9330
24.05.2012	0.9526	0.9213	0.8870	0.8690	0.8592

Shallow Unplanted CW

Sampling Date	Dilution Factor				
	0.5 m	1.1 m	2.3 m	3.4 m	4.7 m
15.03.2012	1.0091	1.0135	1.0180	1.0203	1.0214
29.03.2012	1.0063	1.0093	1.0126	1.0139	1.0147
12.04.2012	1.0074	1.0110	1.0148	1.0166	1.0174
26.04.2012	1.0045	1.0067	1.0091	1.0101	1.0108
10.05.2012	1.0023	1.0038	1.0053	1.0058	1.0061
24.05.2012	0.9989	0.9987	0.9981	0.9979	0.9978

Standard Unplanted CW

Sampling Date	Dilution Factor				
	0.5 m	1.1 m	2.3 m	3.4 m	4.7 m
15.03.2012	1.0050	1.0083	1.0121	1.0141	1.0147
29.03.2012	1.0068	1.0111	1.0163	1.0188	1.0195
12.04.2012	1.0007	1.0014	1.0021	1.0025	1.0026
26.04.2012	0.9975	0.9956	0.9937	0.9927	0.9924
10.05.2012	0.9872	0.9790	0.9695	0.9646	0.9632
24.05.2012	0.9767	0.9618	0.9448	0.9357	0.9333

Standard Planted CW

Sampling Date	Dilution Factor				
	0.5 m	1.1 m	2.3 m	3.4 m	4.7 m
15.03.2012	1.0046	1.0070	1.0095	1.0107	1.0108
29.03.2012	1.0009	1.0015	1.0020	1.0023	1.0023
12.04.2012	1.0018	1.0026	1.0036	1.0039	1.0040
26.04.2012	0.9979	0.9967	0.9956	0.9950	0.9950
10.05.2012	0.9982	0.9974	0.9965	0.9959	0.9959
24.05.2012	1.0000	1.0002	1.0001	1.0002	1.0002

- Flow rate

Shallow Planted CW

Sampling Date	Flow Rate (m^3/d)					
	0 m	0.5 m	1.1 m	2.3 m	3.4 m	4.7 m
15.03.2012	0.0907	0.0917	0.0929	0.0953	0.0976	0.1
29.03.2012	0.0885	0.0887	0.0889	0.0892	0.0896	0.09
12.04.2012	0.0898	0.0903	0.0908	0.0919	0.0929	0.094
26.04.2012	0.0877	0.0884	0.0892	0.0908	0.0924	0.094
10.05.2012	0.0934	0.0901	0.0864	0.079	0.0717	0.064
24.05.2012	0.0915	0.0846	0.0769	0.0613	0.0461	0.03

Shallow Unplanted CW

Sampling Date	Flow Rate (m^3/d)					
	0 m	0.5 m	1.1 m	2.3 m	3.4 m	4.7 m
15.03.2012	0.0907	0.0923	0.0939	0.0972	0.1005	0.104
29.03.2012	0.0889	0.09	0.0911	0.0934	0.0956	0.098
12.04.2012	0.0892	0.0905	0.0918	0.0945	0.0972	0.1
26.04.2012	0.0913	0.0921	0.0929	0.0946	0.0962	0.098
10.05.2012	0.0922	0.0926	0.0931	0.0941	0.095	0.096
24.05.2012	0.0914	0.0912	0.0911	0.0907	0.0904	0.09

Standard Unplanted CW

Sampling Date	Flow Rate (m^3/d)					
	0 m	0.5 m	1.1 m	2.3 m	3.4 m	4.7 m
15.03.2012	0.1868	0.1882	0.1898	0.1931	0.1964	0.2
29.03.2012	0.1864	0.1883	0.1904	0.1949	0.1992	0.204
12.04.2012	0.1857	0.1859	0.1862	0.1868	0.1874	0.188
26.04.2012	0.1909	0.1902	0.1893	0.1876	0.1859	0.184
10.05.2012	0.1892	0.1856	0.1816	0.1732	0.165	0.156
24.05.2012	0.1882	0.1817	0.1744	0.1593	0.1443	0.128

Standard Planted CW

Sampling Date	Flow Rate (m^3/d)					
	0 m	0.5 m	1.1 m	2.3 m	3.4 m	4.7 m
15.03.2012	0.1861	0.1876	0.1893	0.1928	0.1963	0.2
29.03.2012	0.185	0.1853	0.1857	0.1864	0.1872	0.188
12.04.2012	0.1869	0.1875	0.1881	0.1894	0.1906	0.192
26.04.2012	0.1905	0.1898	0.189	0.1874	0.1857	0.184
10.05.2012	0.1893	0.1887	0.1881	0.1868	0.1854	0.184
24.05.2012	0.1877	0.1877	0.1878	0.1878	0.1879	0.188

- Active Volumen

Table 1. Water volumes corresponding to both types of **SHALLOW** horizontal flow constructed wetlands at different system and subsystem scale.

Active volumes of water[a] (m^3)					
Subsystem	0.5 m	1.1 m	2.3 m	3.4 m	4.7 m
Planted	0.0540	0.0941	0.1759	0.2552	0.3452
Unplanted	0.0854	0.1469	0.2694	0.3926	0.5311

[a] Active volume means the volume filled with water

Table 2. Water volumes corresponding to both types of **STANDARD** horizontal flow constructed wetlands at different system and subsystem scale.

Active volumes of water[a] (m^3)					
Subsystem	0.5 m	1.1 m	2.3 m	3.4 m	4.7 m
Planted	0.0913	0.1734	0.3352	0.4948	0.7141
Unplanted	0.1416	0.2700	0.5156	0.7634	1.0987

[a] Active volume means the volume filled with water

- Hidraulic Retention Time

Shallow Planted CW

Sampling Date	HRT (d)				
	0.5 m	1.1 m	2.3 m	3.4 m	4.7 m
15.03.2012	0.5889	1.013	1.8452	2.6144	3.4523
29.03.2012	0.6088	1.0586	1.9714	2.8479	3.8359
12.04.2012	0.598	1.0365	1.9135	2.7467	3.6727
26.04.2012	0.6109	1.0551	1.9367	2.7616	3.6727
10.05.2012	0.5994	1.0892	2.226	3.5588	5.3942
24.05.2012	0.6383	1.2238	2.8687	5.5351	11.5077

Shallow Unplanted CW

Sampling Date	HRT (d)				
	0.5 m	1.1 m	2.3 m	3.4 m	4.7 m
15.03.2012	0.9255	1.5643	2.7721	3.9061	5.107
29.03.2012	0.9491	1.6124	2.8849	4.1064	5.4196
12.04.2012	0.9439	1.6001	2.8513	4.0388	5.3112
26.04.2012	0.9275	1.5811	2.8483	4.0807	5.4196
10.05.2012	0.9225	1.5777	2.8634	4.1323	5.5325
24.05.2012	0.9366	1.6124	2.9708	4.3426	5.9014

Standard Unplanted CW

Sampling Date	HRT (d)				
	0.5 m	1.1 m	2.3 m	3.4 m	4.7 m
15.03.2012	0.485	0.9137	1.7357	2.5196	3.5706
29.03.2012	0.4847	0.9108	1.7196	2.4842	3.5006
12.04.2012	0.491	0.9314	1.7942	2.6406	3.7985
26.04.2012	0.4799	0.9161	1.7866	2.6619	3.8811
10.05.2012	0.4918	0.955	1.9351	2.9991	4.5777
24.05.2012	0.5023	0.9944	2.1039	3.4293	5.5791

Standard Planted CW

Sampling Date	HRT (d)				
	0.5 m	1.1 m	2.3 m	3.4 m	4.7 m
15.03.2012	0.7547	1.4261	2.6744	3.8889	5.4933
29.03.2012	0.7641	1.4537	2.7662	4.078	5.8439
12.04.2012	0.7551	1.4352	2.7224	4.0052	5.7222
26.04.2012	0.746	1.4283	2.7515	4.1109	5.9709
10.05.2012	0.7503	1.4352	2.7603	4.1176	5.9709
24.05.2012	0.7543	1.4374	2.7456	4.0628	5.8439

ANNEX II: Main Data table

1. Shallow Planted

HSSF Shallow Planted			Dist. from Inflow (meter)	15.03.2012	29.03.2012	March, mean (n = 2)	March SD	12.04.2012	26.04.2012	April, mean (n = 2)	April SD	10.05.2012	24.05.2012	May, mean (n = 2)	May SD	General Mean	General SD
Temp Lab [°C]	1	Inflow	0.0	11.50	11.20	11.35	0.15	16.30	16.50	16.40	0.10	21.90	21.8	21.85	0.05	16.53	4.29
	25	HSP1	0.5	10.50	10.90	10.70	0.20	13.30	21.20	17.25		22.80	25.7	24.25	1.45	17.40	6.04
	26	HSP2	1.1	12.20	11.30	11.75	0.45	12.90	21.50	17.20	4.30	22.90	26	24.45	1.55	17.80	5.84
	27	HSP3	2.3	11.90	10.80	11.35	0.55	13.00	19.90	16.45	3.45	23.40	27	25.20	1.80	17.67	6.15
	28	HSP4	3.4	13.70	10.80	12.25	1.45	15.10	19.40	17.25	2.15	24.20	26.7	25.45	1.25	18.32	5.69
	29	HSPOut	4.7	16.00	11.20	13.60	2.40	14.20	22.60	18.40	4.20	24.90	29.6	27.25	2.35	19.75	6.45
Temp out [°C]	1.00	Inflow	0.0	15.50	9.70	12.60	2.90	12.70	18.80	15.75	3.05	12.70	31.40	22.05	9.35	16.80	7.10
	25.00	HSP1	0.5	7.20	9.90	8.55	1.35	11.50	14.90	13.20		11.50	22.80	17.15	5.65	12.97	4.96
	26.00	HSP2	1.1	7.00	9.40	8.20	1.20	11.30	15.90	13.60	2.30	11.30	25.60	18.45	7.15	13.42	6.07
	27.00	HSP3	2.3	7.10	8.90	8.00	0.90	11.30	14.90	13.10	1.80	11.30	28.50	19.90	8.60	13.67	7.05
	28.00	HSP4	3.4	8.30	9.30	8.80	0.50	11.00	14.60	12.80	1.80	11.00	23.20	17.10	6.10	12.90	5.01
	29.00	HSPOut	4.7	10.40	9.20	9.80	0.60	11.40	20.50	15.95	4.55	11.40	27.10	19.25	7.85	15.00	6.55
EH [mV]	1.00	Inflow	0.0	-77.00	-100.00	-88.50	11.50	-60.00	-57.00	-58.50	1.50	-60.00	-129.00	-94.50	34.50	-80.50	26.26
	25.00	HSP1	0.5	-111.00	-112.00	-111.50	0.50	-119.00	-111.00	-115.00		-119.00	-155.00	-137.00	18.00	-121.17	15.52
	26.00	HSP2	1.1	-107.00	-78.00	-92.50	14.50	-125.00	-108.00	-116.50	8.50	-125.00	-154.00	-139.50	14.50	-116.17	23.08
	27.00	HSP3	2.3	-124.00	-115.00	-119.50	4.50	-122.00	-89.00	-105.50	16.50	-122.00	-147.00	-134.50	12.50	-119.83	17.02
	28.00	HSP4	3.4	-122.00	-111.00	-116.50	5.50	-110.00	-85.00	-97.50	12.50	-110.00	-132.00	-121.00	11.00	-111.67	14.36
	29.00	HSPOut	4.7	-135.00	-120.00	-127.50	7.50	-114.00	-102.00	-108.00	6.00	-114.00	-128.00	-121.00	7.00	-118.83	10.62
pH	1.00	Inflow	0.0	7.47	7.67	7.57	0.10	7.52	7.50	7.51	0.01	7.51	7.66	7.59	0.08	7.56	0.08
	25.00	HSP1	0.5	7.39	7.58	7.49	0.10	7.53	7.51	7.52	0.01	7.39	7.66	7.53	0.13	7.51	0.10
	26.00	HSP2	1.1	7.34	7.42	7.38	0.04	7.44	7.33	7.39	0.06	7.26	7.46	7.36	0.10	7.38	0.07
	27.00	HSP3	2.3	7.30	7.46	7.38	0.08	7.35	7.27	7.31	0.04	7.27	7.36	7.32	0.05	7.34	0.07
	28.00	HSP4	3.4	7.23	7.19	7.21	0.02	7.25	7.12	7.19	0.06	7.03	7.20	7.12	0.08	7.17	0.07
	29.00	HSPOut	4.7	7.69	7.31	7.50	0.19	7.25	7.20	7.23	0.02	7.17	7.00	7.09	0.08	7.27	0.21
O_2	1.00	Inflow	0.0	0.0037					0.0062			0.0017	0.0011	0.0014	0.00	0.0032	0.0020
	25.00	HSP1	0.5	0.0010					0.0002			0.0009	0.0019	0.0014	0.00	0.0010	0.0006
	26.00	HSP2	1.1	0.0005					0.0007			0.0000	0.0014	0.0007	0.00	0.0006	0.0005
	27.00	HSP3	2.3	0.0009					0.0120			0.0012	0.0006	0.0009	0.00	0.0037	0.0048
	28.00	HSP4	3.4	0.0007					0.0069			0.0000	0.0011	0.0005	0.00	0.0022	0.0028
	29.00	HSPOut	4.7	0.0002					0.0037			0.0012	0.0007	0.0009	0.00	0.0014	0.0014

NH_4-N	1.00	Inflow	0.0	0.55	0.95	0.75	0.20	1.35	0.88	1.11	0.23	1.13	1.12	1.13	0.01	1.00	0.25
	25.00	HSP1	0.5	0.84	0.94	0.89	0.05	1.16	0.97	1.06	0.10	0.96	1.01	0.99	0.03	0.98	0.10
	26.00	HSP2	1.1	0.91	1.15	1.03	0.12	1.33	0.90	1.12	0.21	0.82	1.03	0.93	0.10	1.02	0.17
	27.00	HSP3	2.3	0.79	1.11	0.95	0.16	1.08	0.90	0.99	0.09	0.74	0.68	0.71	0.03	0.88	0.16
	28.00	HSP4	3.4	0.41	0.85	0.63	0.22	0.58	0.75	0.67	0.08	0.45	0.53	0.49	0.04	0.60	0.16
	29.00	Outlow	4.7	1.04	1.07	1.05	0.01	0.90	1.12	1.01	0.11	0.45	0.25	0.35	0.10	0.81	0.33
NO_3-N	1.00	Inflow	0.0	0.0131	0.0156	0.0143	0.0013	0.0083	0.0109	0.0096	0.0013	0.0086	0.0066	0.0076	0.0010	0.0105	0.0031
	25.00	HSP1	0.5	0.0037	0.0103	0.0070	0.0033	0.0080	0.0089	0.0084	0.0005	0.0074	0.0042	0.0058	0.0016	0.0071	0.0024
	26.00	HSP2	1.1	0.0068	0.0164	0.0116	0.0048	0.0051	0.0094	0.0072	0.0021	0.0083	0.0094	0.0088	0.0005	0.0092	0.0035
	27.00	HSP3	2.3	0.0074	0.0122	0.0098	0.0024	0.0100	0.0081	0.0091	0.0010	0.0054	0.0091	0.0073	0.0019	0.0087	0.0021
	28.00	HSP4	3.4	0.0064	0.0090	0.0077	0.0013	0.0046	0.0034	0.0040	0.0006	0.0070	0.0040	0.0055	0.0015	0.0057	0.0019
	29.00	Outflow	4.7	0.0131	0.0101	0.0116	0.0015	0.0061	0.0061	0.0061	0.0000	0.0014	0.0040	0.0027	0.0013	0.0068	0.0038
NO_2-N	1.00	Inflow	0.0	0.0002	0.0002	0.0002	0.0000	0.0001	0.0002	0.0002	0.0001	0.0000	0.0002	0.0001	0.0001	0.0002	0.0001
	25.00	HSP1	0.5	0.0003	0.0001	0.0002	0.0001	0.0002	0.0001	0.0001	0.0001	0.0000	0.0006	0.0003	0.0003	0.0002	0.0002
	26.00	HSP2	1.1	0.0004	0.0004	0.0004	0.0000	0.0004	0.0005	0.0004	0.0000	0.0003	0.0000	0.0001	0.0001	0.0003	0.0002
	27.00	HSP3	2.3	0.0004	0.0004	0.0004	0.0000	0.0004	0.0006	0.0005	0.0001	0.0003	0.0003	0.0003	0.0000	0.0004	0.0001
	28.00	HSP4	3.4	0.0000	0.0004	0.0002	0.0002	0.0002	0.0003	0.0003	0.0001	0.0002	0.0001	0.0002	0.0001	0.0002	0.0001
	29.00	Outflow	4.7	0.0004	0.0005	0.0005	0.0000	0.0021	0.0005	0.0013	0.0008	0.0002	0.0001	0.0001	0.0001	0.0006	0.0007
NO_x-N	1.00	Inflow	0.0	0.0133	0.0158	0.0146	0.0013	0.0084	0.0111	0.0098	0.0014	0.0086	0.0068	0.0077	0.0009	0.0107	0.0031
	25.00	HSP1	0.5	0.0040	0.0104	0.0072	0.0032	0.0082	0.0090	0.0086	0.0004	0.0074	0.0048	0.0061	0.0013	0.0073	0.0023
	26.00	HSP2	1.1	0.0072	0.0168	0.0120	0.0048	0.0055	0.0098	0.0077	0.0022	0.0086	0.0094	0.0090	0.0004	0.0096	0.0035
	27.00	HSP3	2.3	0.0078	0.0126	0.0102	0.0024	0.0104	0.0087	0.0095	0.0009	0.0057	0.0095	0.0076	0.0019	0.0091	0.0022
	28.00	HSP4	3.4	0.0064	0.0094	0.0079	0.0015	0.0048	0.0037	0.0042	0.0005	0.0072	0.0041	0.0057	0.0016	0.0059	0.0020
	29.00	Outflow	4.7	0.0135	0.0106	0.0121	0.0015	0.0081	0.0066	0.0074	0.0008	0.0016	0.0041	0.0029	0.0012	0.0074	0.0040
TN	1.00	Inflow	0.0	1.16	1.37	1.27	0.10	1.35	1.05	1.20	0.15	1.46	1.31	1.39	0.08	1.28	0.14
	25.00	HSP1	0.5	1.11	1.22	1.16	0.06	1.22	1.00	1.11	0.11	1.26	1.22	1.24	0.02	1.17	0.09
	26.00	HSP2	1.1	1.09	1.23	1.16	0.07	1.24	1.01	1.12	0.11	1.16	1.15	1.16	0.01	1.15	0.08
	27.00	HSP3	2.3	1.08	1.20	1.14	0.06	1.19	0.98	1.09	0.11	0.91	0.90	0.90	0.01	1.04	0.12
	28.00	HSP4	3.4	0.83	0.98	0.90	0.07	0.68	0.85	0.76	0.09	0.70	0.62	0.66	0.04	0.78	0.12
	29.00	Outflow	4.7	1.24	1.24	1.24	0.00	1.11	1.13	1.12	0.01	0.79	0.30	0.54	0.24	0.97	0.33
TOC	1.00	Inflow	0.0	0.22	2.4683	1.35	1.12	2.8453	1.18	2.01	0.83	2.3367	2.3621	2.35	0.01	1.90	0.91
	25.00	HSP1	0.5	1.23	1.3632	1.29	0.07	1.0500	0.38	0.72	0.33	1.2901	1.2376	1.26	0.03	1.09	0.33
	26.00	HSP2	1.1	0.97	1.0331	1.00	0.03	0.7523	0.26	0.50	0.25	0.8629	0.8094	0.84	0.03	0.78	0.25
	27.00	HSP3	2.3	0.84	0.8206	0.83	0.01	0.4764	0.23	0.35	0.12	0.5489	0.4673	0.51	0.04	0.56	0.21
	28.00	HSP4	3.4	0.65	0.6920	0.67	0.02	0.2041	0.12	0.16	0.04	0.4609	0.3186	0.39	0.07	0.41	0.21
	29.00	Outflow	4.7	1.17	1.0122	1.09	0.08	0.4093	0.35	0.38	0.03	0.4469	0.1974	0.32	0.12	0.60	0.36

COD	1.00	Inflow	0.0	5.52	7.1553	6.34	0.82	12.2122	5.36	8.79	3.42	7.9158	5.9053	6.91	1.01	7.34	2.36
	25.00	HSP1	0.5	6.38	4.3152	5.35	1.03	6.8605	6.69	6.78	0.08	3.2172	4.2581	3.74	0.52	5.29	1.41
	26.00	HSP2	1.1	3.95	4.4548	4.20	0.25	4.7588	3.57	4.17	0.59	4.7340	6.4442	5.59	0.86	4.65	0.91
	27.00	HSP3	2.3	3.40	3.7580	3.58	0.18	3.4488	3.36	3.40	0.05	3.1951	1.8896	2.54	0.65	3.18	0.60
	28.00	HSP4	3.4	2.63	3.0600	2.84	0.22	1.7047	2.57	2.14	0.43	2.4080	1.2714	1.84	0.57	2.27	0.60
	29.00	Outflow	4.7	8.29	4.1795	6.24	2.06	2.6420	3.55	3.10	0.45	1.7469	0.6718	1.21	0.54	3.51	2.42
BOD_5	1.00	Inflow	0.0	0.00	4.2838	2.14	2.14	5.4135	3.11	4.26	1.15	3.0305	0.2060	1.62	1.41	2.67	1.99
	25.00	HSP1	0.5	0.00	0.0630	0.03	0.03	0.0000	0.00	0.00	0.00	0.2343	2.6435	1.44	1.20	0.49	0.97
	26.00	HSP2	1.1	0.00	0.2528	0.13	0.13	0.2914	0.00	0.15	0.15	0.3687	1.3818	0.88	0.51	0.38	0.47
	27.00	HSP3	2.3	0.00	2.0614	1.03	1.03	0.0000	0.0033	0.00	0.00	1.5909	0.7712	1.18	0.41	0.74	0.83
	28.00	HSP4	3.4	0.00	0.1753	0.09	0.09	0.1073	0.00	0.05	0.05	0.1192	0.00	0.06	0.06	0.07	0.07
	29.00	Outflow	4.7	0.00	2.5621	1.28	1.28	0.2019	0.00	0.10	0.10	1.4293	0.0457	0.74	0.69	0.71	0.97
SO_4-S	1.00	Inflow	0.0	0.84	0.1427	0.49	0.35	0.7569	0.80	0.78	0.02	0.7758	0.8160	0.80	0.02	0.69	0.25
	25.00	HSP1	0.5	0.45	0.2483	0.35	0.10	0.4845	0.26	0.37	0.11	0.5087	0.5082	0.51	0.00	0.41	0.11
	26.00	HSP2	1.1	0.19	0.1764	0.19	0.01	0.1509	0.10	0.13	0.02	0.1477	0.3354	0.24	0.09	0.18	0.07
	27.00	HSP3	2.3	0.21	0.2026	0.21	0.00	0.3006	0.06	0.18	0.12	0.1160	0.0921	0.10	0.01	0.16	0.08
	28.00	HSP4	3.4	0.09	0.1504	0.12	0.03	0.1290	0.17	0.15	0.02	0.2607	0.1275	0.19	0.07	0.15	0.05
	29.00	Outflow	4.7	0.16	0.1733	0.17	0.01	0.0930	0.09	0.09	0.00	0.0512	0.1704	0.11	0.06	0.12	0.05
S^{2-}	1.00	Inflow	0.0	0.08	0.0647	0.07	0.01	0.2728	0.13	0.20	0.07	0.2996	0.2764	0.29	0.01	0.19	0.10
	25.00	HSP1	0.5	0.40	0.3163	0.36	0.04	0.3805	0.29	0.33	0.05	0.3714	0.3576	0.36	0.01	0.35	0.04
	26.00	HSP2	1.1	0.44	0.3991	0.42	0.02	0.4404	0.43	0.43	0.01	0.3762	0.3828	0.38	0.00	0.41	0.03
	27.00	HSP3	2.3	0.48	0.4273	0.46	0.03	0.4225	0.43	0.43	0.00	0.3022	0.2531	0.28	0.02	0.39	0.08
	28.00	HSP4	3.4	0.32	0.3541	0.34	0.02	0.2466	0.37	0.31	0.06	0.2394	0.1711	0.21	0.03	0.28	0.07
	29.00	Outflow	4.7	0.49	0.3935	0.44	0.05	0.4543	0.47	0.46	0.01	0.2553	0.0505	0.15	0.10	0.35	0.16
S^0	1.00	Inflow	0.0	0.000	0.0000	0.00	0.00	0.2233	0.00	0.11	0.11	0.1613	0.0461	0.10	0.06	0.07	0.09
	25.00	HSP1	0.5	0.21	0.1257	0.17	0.04	0.2346	0.26	0.25	0.01	0.2736	0.0830	0.18	0.10	0.20	0.07
	26.00	HSP2	1.1	0.21	0.2234	0.22	0.01	0.2775	0.22	0.25	0.03	0.2014	0.2134	0.21	0.01	0.23	0.02
	27.00	HSP3	2.3	0.19	0.2350	0.21	0.02	0.1938	0.25	0.22	0.03	0.1023	0.0499	0.08	0.03	0.17	0.07
	28.00	HSP4	3.4	0.13	0.1599	0.15	0.01	0.0849	0.15	0.12	0.03	0.0861	0.0273	0.06	0.03	0.11	0.05
	29.00	Outflow	4.7	0.28	0.1786	0.23	0.05	0.1364	0.17	0.16	0.02	0.1158	0.0000	0.06	0.06	0.15	0.08
CH_4	1.00	Inflow	0.0	0.02	0.0063	0.01	0.0051	0.0099	0.01	0.01	0.0010	0.0132	0.0094	0.011	0.002	0.011	0.003
	25.00	HSP1	0.5	0.12	0.1102	0.12	0.0062	0.1430	0.14	0.14	0.0010	0.2046	0.1843	0.194	0.010	0.152	0.033
	26.00	HSP2	1.1	0.16	0.1848	0.17	0.0131	0.2185	0.23	0.22	0.0048	0.3746	0.3279	0.351	0.023	0.249	0.077
	27.00	HSP3	2.3	0.13	0.1633	0.15	0.0176	0.2496	0.26	0.26	0.0071	0.2400	0.2208	0.230	0.010	0.211	0.049
	28.00	HSP4	3.4	0.07	0.1227	0.10	0.0254	0.1097	0.19	0.15	0.0390	0.2205	0.1421	0.181	0.039	0.142	0.049
	24.00	Outflow	4.7	0.18	0.3091	0.25	0.0640	0.2491	0.30	0.28	0.0277	0.2424	0.0265	0.134	0.108	0.219	0.096

2. Shallow Unplanted

HSSF Shallow Unplanted			Dist. from Inflow (meter)	15.03.2012	29.03.2012	March, mean (n = 2)	March SD	12.04.2012	26.04.2012	April, mean (n = 2)	April SD	10.05.2012	24.05.2012	May, mean (n = 2)	May SD	General Mean	General SD
Temp Lab [°C]	1.00	Inflow	0.0	11.50	11.20	11.35	0.15	16.30	16.50	16.40	0.10	21.90	21.80	21.85	0.05	16.53	4.29
	20.00	HSP1	0.5	17.50	10.80	14.15	3.35	13.30	25.80	19.55	6.25	25.70	27.40	26.55	0.85	20.08	6.54
	21.00	HSP2	1.1	18.00	10.80	14.40	3.60	13.30	20.90	17.10	3.80	24.30	28.30	26.30	2.00	19.27	6.03
	22.00	HSP3	2.3	15.80	11.80	13.80	2.00	12.30	19.40	15.85	3.55	23.70	25.30	24.50	0.80	18.05	5.22
	23.00	HSP4	3.4	15.50	10.40	12.95	2.55	11.10	16.70	13.90	2.80	22.40	24.90	23.65	1.25	16.83	5.36
	24.00	Outflow	4.7	11.90	11.70	11.80	0.10	12.20	17.40	14.80	2.60	20.70	25.10	22.90	2.20	16.50	5.08
Temp out [°C]	1.00	Inflow	0.0	15.50	9.70	12.60	2.90	12.70	18.80	15.75	3.05	12.70	31.40	22.05	9.35	16.80	7.10
	20.00	HSP1	0.5	11.10	10.10	10.60	0.50	14.40	25.30	19.85	5.45	14.40	26.30	20.35	5.95	16.93	6.47
	21.00	HSP2	1.1	16.00	10.00	13.00	3.00	13.70	21.90	17.80	4.10	13.70	26.80	20.25	6.55	17.02	5.65
	22.00	HSP3	2.3	13.10	9.70	11.40	1.70	10.60	18.90	14.75	4.15	10.60	24.30	17.45	6.85	14.53	5.34
	23.00	HSP4	3.4	13.60	8.90	11.25	2.35	9.20	16.50	12.85	3.65	9.20	23.30	16.25	7.05	13.45	5.21
	24.00	Outflow	4.7	11.40	9.90	10.65	0.75	8.80	17.60	13.20	4.40	8.80	21.10	14.95	6.15	12.93	4.73
EH [mV]	1.00	Inflow	0.0	-77.00	-100.00	-88.50	11.50	-60.00	-57.00	-58.50	1.50	-60.00	-129.00	-94.50	34.50	-80.50	26.26
	20.00	HSP1	0.5	-130.00	-103.00	-116.50	13.50	-121.00	-101.00	-111.00	10.00	-121.00	-146.00	-133.50	12.50	-120.33	15.42
	21.00	HSP2	1.1	-90.00	-120.00	-105.00	15.00	-111.00	-93.00	-102.00	9.00	-111.00	-133.00	-122.00	11.00	-109.67	14.83
	22.00	HSP3	2.3	-125.00	-119.00	-122.00	3.00	-106.00	-69.00	-87.50	18.50	-106.00	-142.00	-124.00	18.00	-111.17	22.49
	23.00	HSP4	3.4	-103.00	-107.00	-105.00	2.00	-98.00	-89.00	-93.50	4.50	-98.00	-118.00	-108.00	10.00	-102.17	8.97
	24.00	Outflow	4.7	-128.00	-97.00	-112.50	15.50	-88.00	-85.00	-86.50	1.50	-88.00	-121.00	-104.50	16.50	-101.17	17.02
pH	1.00	Inflow	0.0	7.47	7.67	7.57	0.10	7.52	7.50	7.51	0.01	7.51	7.66	7.59	0.08	7.56	0.08
	20.00	HSP1	0.5	7.29	7.48	7.39	0.10	7.48	7.38	7.43	0.05	7.42	7.29	7.36	0.06	7.39	0.08
	21.00	HSP2	1.1	7.23	7.40	7.32	0.09	7.45	7.36	7.41	0.04	7.34	7.52	7.43	0.09	7.38	0.09
	22.00	HSP3	2.3	7.27	7.38	7.33	0.06	7.36	7.31	7.34	0.03	7.37	7.36	7.37	0.00	7.34	0.04
	23.00	HSP4	3.4	7.24	7.30	7.27	0.03	7.39	7.34	7.37	0.02	7.35	7.43	7.39	0.04	7.34	0.06
	24.00	Outflow	4.7	7.23	7.23	7.23	0.00	7.29	7.39	7.34	0.05	7.33	7.37	7.35	0.02	7.31	0.06
O_2	1.00	Inflow	0.0	0.0037					0.0065			0.0016	0.0011	0.0014	0.0003	0.0032	0.0021
	20.00	HSP1	0.5	0.0000					0.0013			0.0015	0.0018	0.0016	0.0001	0.0011	0.0007
	21.00	HSP2	1.1	0.0022					0.0032			0.0018	0.0018	0.0018	0.0000	0.0022	0.0006
	22.00	HSP3	2.3	0.0039					0.0074			0.0015	0.0019	0.0017	0.0002	0.0037	0.0023
	23.00	HSP4	3.4	0.0009					0.0050			0.0029	0.0021	0.0025	0.0004	0.0027	0.0015
	24.00	Outflow	4.7	0.0004					0.0039			0.0022	0.0013	0.0018	0.0005	0.0019	0.0013

NH_4-N	1.00	Inflow	0.0	0.5495	0.9547	0.75	0.20	1.339	0.9176	1.13	0.21	1.1171	1.1182	1.12	0.00	1.00	0.24
	20.00	HSP1	0.5	0.7694	0.9601	0.86	0.10	1.431	1.0317	1.23	0.20	0.7922	1.0984	0.95	0.15	1.01	0.22
	21.00	HSP2	1.1	0.9302	1.1140	1.02	0.09	1.406	1.1073	1.26	0.15	0.9907	1.0647	1.03	0.04	1.10	0.15
	22.00	HSP3	2.3	1.1307	1.1459	1.14	0.01	1.518	0.9726	1.25	0.27	0.7163	0.9310	0.82	0.11	1.07	0.25
	23.00	HSP4	3.4	1.0165	1.1477	1.08	0.07	1.306	1.0844	1.20	0.11	0.9735	1.4555	1.21	0.24	1.16	0.17
	24.00	Outflow	4.7	0.7166	1.2459	0.98	0.26	1.233	1.0638	1.15	0.08	0.9175	1.2101	1.06	0.15	1.06	0.19
NO_3-N	1.00	Inflow	0.0	0.0131	0.0157	0.0144	0.0013	0.008	0.0113	0.0098	0.0016	0.0085	0.0066	0.0075	0.0010	0.0106	0.0031
	20.00	HSP1	0.5	0.0186	0.0080	0.0133	0.0053	0.006	0.0107	0.0083	0.0025	0.0067	0.0026	0.0046	0.0021	0.0087	0.0051
	21.00	HSP2	1.1	0.0107	0.0044	0.0076	0.0031	0.007	0.0034	0.0054	0.0020	0.0060	0.0026	0.0043	0.0017	0.0057	0.0027
	22.00	HSP3	2.3	0.0103	0.0049	0.0076	0.0027	0.006	0.0080	0.0071	0.0009	0.0152	0.0044	0.0098	0.0054	0.0081	0.0037
	23.00	HSP4	3.4	0.0045	0.0182	0.0114	0.0069	0.002	0.0062	0.0039	0.0023	0.0084	0.0022	0.0053	0.0031	0.0069	0.0056
	24.00	Outflow	4.7	0.0064	0.0167	0.0116	0.0052	0.011	0.0127	0.0118	0.0008	0.0112	0.0047	0.0079	0.0033	0.0105	0.0040
NO_2-N	1.00	Inflow	0.0	0.0002	0.0002	0.0002	0.0000	0.000	0.0002	0.0002	0.0001	0.0000	0.0002	0.0001	0.0001	0.0002	0.0001
	20.00	HSP1	0.5	0.0005	0.0006	0.0005	0.0000	0.000	0.0004	0.0002	0.0002	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002
	21.00	HSP2	1.1	0.0005	0.0003	0.0004	0.0001	0.000	0.0005	0.0002	0.0002	0.0002	0.0004	0.0003	0.0001	0.0003	0.0002
	22.00	HSP3	2.3	0.0000	0.0004	0.0002	0.0002	0.001	0.0005	0.0006	0.0001	0.0003	0.0003	0.0003	0.0000	0.0004	0.0002
	23.00	HSP4	3.4	0.0005	0.0005	0.0005	0.0000	0.001	0.0004	0.0005	0.0001	0.0003	0.0005	0.0004	0.0001	0.0005	0.0001
	24.00	Outflow	4.7	0.0007	0.0002	0.0004	0.0002	0.000	0.0004	0.0005	0.0000	0.0004	0.0005	0.0004	0.0001	0.0004	0.0001
NOx-N	1.00	Inflow	0.0	0.0133	0.0159	0.0146	0.0013	0.008	0.0116	0.0100	0.0016	0.0085	0.0068	0.0077	0.0009	0.0107	0.0032
	20.00	HSP1	0.5	0.0191	0.0085	0.0138	0.0053	0.006	0.0111	0.0085	0.0026	0.0067	0.0026	0.0046	0.0021	0.0090	0.0052
	21.00	HSP2	1.1	0.0112	0.0047	0.0080	0.0032	0.007	0.0039	0.0056	0.0018	0.0062	0.0030	0.0046	0.0016	0.0061	0.0027
	22.00	HSP3	2.3	0.0103	0.0054	0.0078	0.0025	0.007	0.0085	0.0077	0.0008	0.0154	0.0046	0.0100	0.0054	0.0085	0.0036
	23.00	HSP4	3.4	0.0051	0.0187	0.0119	0.0068	0.002	0.0066	0.0044	0.0022	0.0087	0.0027	0.0057	0.0030	0.0074	0.0056
	24.00	Outflow	4.7	0.0071	0.0169	0.0120	0.0049	0.011	0.0131	0.0123	0.0008	0.0116	0.0052	0.0084	0.0032	0.0109	0.0039
TN	1.00	Inflow	0.0	1.1643	1.3791	1.27	0.11	1.339	1.0933	1.22	0.12	1.4448	1.3083	1.38	0.07	1.29	0.12
	20.00	HSP1	0.5	1.0856	1.2559	1.17	0.09	1.277	1.0890	1.18	0.09	1.6074	1.5686	1.59	0.02	1.31	0.21
	21.00	HSP2	1.1	1.1066	1.2684	1.19	0.08	1.320	1.0957	1.21	0.11	1.3364	1.4620	1.40	0.06	1.26	0.13
	22.00	HSP3	2.3	1.1841	1.3071	1.25	0.06	1.270	1.0973	1.18	0.09	1.2885	1.5427	1.42	0.13	1.28	0.14
	23.00	HSP4	3.4	1.1896	1.2747	1.23	0.04	1.176	1.0745	1.13	0.05	1.2127	1.4624	1.34	0.12	1.23	0.12
	24.00	Outflow	4.7	1.3080	1.3350	1.32	0.01	1.174	1.1664	1.17	0.00	1.2897	1.4088	1.35	0.06	1.28	0.09
TOC	1.00	Inflow	0.0	2.2369	2.4794	2.36	0.12	2.826	1.2332	2.03	0.80	2.3066	2.3595	2.33	0.03	2.24	0.49
	20.00	HSP1	0.5	1.0809	1.3147	1.20	0.12	1.252	0.4483	0.85	0.40	3.2929	2.0804	2.69	0.61	1.58	0.90
	21.00	HSP2	1.1	0.9626	1.1311	1.05	0.08	0.891	0.2670	0.58	0.31	0.9518	1.2447	1.10	0.15	0.91	0.31
	22.00	HSP3	2.3	0.9512	1.1527	1.05	0.10	0.690	0.2810	0.49	0.20	1.1073	1.2189	1.16	0.06	0.90	0.33
	23.00	HSP4	3.4	1.0481	1.1396	1.09	0.05	0.490	0.1912	0.34	0.15	0.8566	1.1494	1.00	0.15	0.81	0.36
	24.00	Outflow	4.7	1.3199	1.3060	1.31	0.01	0.514	0.5111	0.51	0.00	0.8920	1.0625	0.98	0.09	0.93	0.33

COD	1.00	Inflow	0.0	5.5160	7.1877	6.35	0.84	12.131	5.5848	8.86	3.27	7.8141	5.8989	6.86	0.96	7.36	2.30
	20.00	HSP1	0.5	5.8295	6.6319	6.23	0.40	9.941	7.1682	8.55	1.39	2.8798	7.7209	5.30	2.42	6.70	2.13
	21.00	HSP2	1.1	4.3028	4.5648	4.43	0.13	4.542	4.0958	4.32	0.22	7.4564	4.1781	5.82	1.64	4.86	1.18
	22.00	HSP3	2.3	4.2633	4.5276	4.40	0.13	4.200	3.7914	4.00	0.20	4.3106	3.4028	3.86	0.45	4.08	0.37
	23.00	HSP4	3.4	4.7452	4.1762	4.46	0.28	3.504	3.6896	3.60	0.09	3.3206	4.2706	3.80	0.48	3.95	0.49
	24.00	HSPOut	4.7	5.2359	5.0778	5.16	0.08	3.969	3.9869	3.98	0.01	3.5278	3.8373	3.68	0.15	4.27	0.64
BOD_5	1.00	Inflow	0.0	0.00	4.30	2.15	2.15	5.38	3.24	4.31	1.07	2.99	0.21	1.60	1.39	2.69	1.98
	20.00	HSP1	0.5	0.37	2.67	1.52	1.15	0.09	1.48	0.78	0.69	0.00	3.10	1.55	1.55	1.28	1.24
	21.00	HSP2	1.1	0.00	2.58	1.29	1.29	0.00	0.00	0.00	0.00	0.00	2.40	1.20	1.20	0.83	1.17
	22.00	HSP3	2.3	0.00	0.19	0.09	0.09	2.43	0.00	1.22	1.22	0.00	2.39	1.20	1.20	0.84	1.12
	23.00	HSP4	3.4	2.35	2.51	2.43	0.08	2.17	0.00	1.09	1.09	0.00	2.38	1.19	1.19	1.57	1.11
	24.00	Outflow	4.7	0.32	2.98	1.65	1.33	0.23	0.00	0.12	0.12	0.00	0.92	0.46	0.46	0.74	1.05
SO_4-S	1.00	Inflow	0.0	0.8422	0.1433	0.49	0.35	0.752	0.8366	0.79	0.04	0.7658	0.8151	0.79	0.02	0.69	0.25
	20.00	HSP1	0.5	0.4295	0.1978	0.31	0.12	0.469	0.1605	0.31	0.15	0.5190	0.4536	0.49	0.03	0.37	0.14
	21.00	HSP2	1.1	0.2836	0.1801	0.23	0.05	0.180	0.0496	0.11	0.07	0.1488	0.1318	0.14	0.01	0.16	0.07
	22.00	HSP3	2.3	0.5251	0.1602	0.34	0.18	0.100	0.0682	0.08	0.02	0.1023	0.0942	0.10	0.00	0.17	0.16
	23.00	HSP4	3.4	0.5316	0.1721	0.35	0.18	0.105	0.0873	0.10	0.01	0.1190	0.0810	0.10	0.02	0.18	0.16
	24.00	Outflow	4.7	0.2450	0.2009	0.22	0.02	0.179	0.0768	0.13	0.05	0.1025	0.1026	0.10	0.00	0.15	0.06
S^{2-}	1.00	HSPIn	0.0	0.0806	0.0650	0.07	0.01	0.271	0.1309	0.20	0.07	0.2958	0.2761	0.29	0.01	0.19	0.10
	20.00	HSP1	0.5	0.4061	0.3572	0.38	0.02	0.427	0.4070	0.42	0.01	0.3435	0.3620	0.35	0.01	0.38	0.03
	21.00	HSP2	1.1	0.4487	0.4010	0.42	0.02	0.436	0.4397	0.44	0.00	0.4207	0.2899	0.36	0.07	0.41	0.05
	22.00	HSP3	2.3	0.3486	0.4579	0.40	0.05	0.444	0.4752	0.46	0.02	0.3864	0.4140	0.40	0.01	0.42	0.04
	23.00	HSP4	3.4	0.4193	0.3984	0.41	0.01	0.463	0.4762	0.47	0.01	0.4415	0.4011	0.42	0.02	0.43	0.03
	24.00	Outflow	4.7	0.5138	0.4146	0.46	0.05	0.408	0.4678	0.44	0.03	0.4758	0.3905	0.43	0.04	0.45	0.04
S^0	1.00	Inflow	0.0	0.0000	0.0000	0.00	0.00	0.222	0.0000	0.11	0.11	0.1593	0.0461	0.10	0.06	0.07	0.09
	20.00	HSP1	0.5	0.2025	0.2220	0.21	0.01	0.278	0.3526	0.32	0.04	0.4111	0.1374	0.27	0.14	0.27	0.09
	21.00	HSP2	1.1	0.2330	0.2632	0.25	0.02	0.256	0.2391	0.25	0.01	0.1555	0.1398	0.15	0.01	0.21	0.05
	22.00	HSP3	2.3	0.2117	0.2354	0.22	0.01	0.232	0.2893	0.26	0.03	0.1777	0.1263	0.15	0.03	0.21	0.05
	23.00	HSP4	3.4	0.1481	0.2409	0.19	0.05	0.182	0.2032	0.19	0.01	0.0958	0.0940	0.09	0.00	0.16	0.05
	24.00	Outflow	4.7	0.2118	0.2782	0.24	0.03	0.191	0.1834	0.19	0.00	0.1144	0.0888	0.10	0.01	0.18	0.06
CH_4	1.00	HSPIn	0.0	0.0164	0.0063	0.01	0.01	0.010	0.0083	0.01	0.00	0.0131	0.0094	0.01	0.001839	0.011	0.00
	20.00	HSP1	0.5	0.1448	0.1702	0.16	0.01	0.189	0.2018	0.20	0.01	0.3127	0.2819	0.30	0.015404	0.217	0.06
	21.00	HSP2	1.1	0.1237	0.1532	0.14	0.01	0.193	0.2222	0.21	0.01	0.3215	0.2565	0.29	0.032482	0.212	0.07
	22.00	HSP3	2.3	0.0946	0.1778	0.14	0.04	0.192	0.2065	0.20	0.01	0.3120	0.3371	0.32	0.012548	0.220	0.08
	23.00	HSP4	3.4	0.1102	0.1667	0.14	0.03	0.194	0.2345	0.21	0.02	0.2880	0.3087	0.30	0.010345	0.217	0.07
	24.00	Outflow	4.7	0.1460	0.2433	0.19	0.05	0.188	0.2318	0.21	0.02	0.2980	0.2707	0.28	0.013649	0.230	0.05

3. Standard Planted CW

HSSF Standard Planted			Dist. from Inflow (meter)	15.03.2012	29.03.2012	March (mean, n = 2)	March SD	12.04.2012	26.04.2012	April (mean, n = 2)	April SD	10.05.2012	24.05.2012	May (mean, n = 2)	May SD	General Mean	General SD
Temp Lab [°C]	1	Inflow	0	11.50	11.20	11.35	0.15	16.30	16.50	16.40	0.10	21.90	21.80	21.85	0.05	16.53	4.70
	2	Up (12.5 cm)	0.5	15.20	11.80	13.50	1.70	14.50	20.00	17.25	2.75	24.50	28.20	26.35	1.85	19.03	6.36
	4		1.1	15.50	10.90	13.20	2.30	16.10	23.90	20.00	3.90	24.70	28.10	26.40	1.70	19.87	6.65
	6		2.3	14.00	10.80	12.40	1.60	16.00	26.20	21.10	5.10	22.70	27.30	25.00	2.30	19.50	6.84
	8		3.4	12.90	11.00	11.95	0.95	12.50	17.00	14.75	2.25	22.20	24.30	23.25	1.05	16.65	5.53
	10	Outflow	4.7	11.90	10.20	11.05	0.85	12.00	20.30	16.15	4.15	21.90	26.40	24.15	2.25	17.12	6.64
	1	Inflow	0	11.50	11.20	11.35	0.15	16.30	16.50	16.40	0.10	21.90	21.80	21.85	0.05	16.53	4.70
	3	Below (40 cm)	0.5	13.80	11.80	12.80	1.00	13.70	19.00	16.35	2.65	22.30	27.00	24.65	2.35	17.93	5.92
	5		1.1	15.10	12.50	13.80	1.30	15.40	23.60	19.50	4.10	22.30	28.30	25.30	3.00	19.53	6.12
	7		2.3	12.30	10.60	11.45	0.85	13.30	21.50	17.40	4.10	21.80	27.90	24.85	3.05	17.90	6.84
	9		3.4	11.20	11.00	11.10	0.10	14.00	19.40	16.70	2.70	22.10	23.30	22.70	0.60	16.83	5.48
	10	Outflow	4.7	11.90	10.20	11.05	0.85	12.00	20.30	16.15	4.15	21.90	26.40	24.15	2.25	17.12	6.64
Temp out [°C]	1	Inflow	0	15.50	9.70	12.60	2.90	12.70	18.80	15.75	3.05	12.70	31.40	22.05	9.35	16.80	7.78
	2	Up (12.5 cm)	0.5	9.20	9.60	9.40	0.20	12.60	16.70	14.65	2.05	12.60	24.40	18.50	5.90	14.18	5.68
	4		1.1	10.60	9.90	10.25	0.35	12.30	19.00	15.65	3.35	12.30	22.70	17.50	5.20	14.47	5.17
	6		2.3	10.40	9.40	9.90	0.50	11.10	21.00	16.05	4.95	11.10	21.90	16.50	5.40	14.15	5.70
	8		3.4	8.90	8.50	8.70	0.20	12.80	15.20	14.00	1.20	12.80	20.90	16.85	4.05	13.18	4.56
	10	Outflow	4.7	8.50	9.50	9.00	0.50	11.00	17.10	14.05	3.05	11.00	22.00	16.50	5.50	13.18	5.26
	1	Inflow	0	15.50	9.70	12.60	2.90	12.70	18.80	15.75	3.05	12.70	31.40	22.05	9.35	16.80	7.78
	3	Below (40 cm)	0.5	8.80	9.60	9.20	0.40	12.10	16.10	14.10	2.00	12.10	24.40	18.25	6.15	13.85	5.76
	5		1.1	9.20	9.70	9.45	0.25	11.50	22.00	16.75	5.25	11.50	26.30	18.90	7.40	15.03	7.25
	7		2.3	8.60	9.30	8.95	0.35	11.30	25.60	18.45	7.15	11.30	22.60	16.95	5.65	14.78	7.36
	9		3.4	8.60	8.40	8.50	0.10	12.30	17.30	14.80	2.50	12.30	21.40	16.85	4.55	13.38	5.09
	10	Outflow	4.7	8.50	9.50	9.00	0.50	11.00	17.10	14.05	3.05	11.00	22.00	16.50	5.50	13.18	5.26
EH [mV]	1	Inflow	0	-77.00	-100.00	-88.50	11.50	-60.00	-57.00	-58.50	1.50	-60.00	-129.00	-94.50	34.50	-80.50	28.77
	2	Up (12.5 cm)	0.5	-118.00	-133.00	-125.50	7.50	-138.00	-116.00	-127.00	11.00	-138.00	-135.00	-136.50	1.50	-129.67	10.01
	4		1.1	-138.00	-121.00	-129.50	8.50	-146.00	-121.00	-133.50	12.50	-146.00	-132.00	-139.00	7.00	-134.00	11.37
	6		2.3	-128.00	-128.00	-128.00	0.00	-124.00	-109.00	-116.50	7.50	-124.00	-119.00	-121.50	2.50	-122.00	7.18
	8		3.4	-101.00	-50.00	-75.50	25.50	-119.00	-55.00	-87.00	32.00	-119.00	-91.00	-105.00	14.00	-89.17	30.41
	10	Outflow	4.7	-123.00	-121.00	-122.00	1.00	-133.00	-82.00	-107.50	25.50	-133.00	-111.00	-122.00	11.00	-117.17	19.10

EH [mV]	1	Inflow	0	-77.00	-100.00	-88.50	11.50	-60.00	-57.00	-58.50	1.50	-60.00	-129.00	-94.50	34.50	-80.50	28.77
	3	Below (40 cm)	0.5	-133.00	-128.00	-130.50	2.50	-134.00	-117.00	-125.50	8.50	-134.00	-139.00	-136.50	2.50	-130.83	7.63
	5		1.1	-130.00	-134.00	-132.00	2.00	-137.00	-121.00	-129.00	8.00	-137.00	-129.00	-133.00	4.00	-131.33	6.09
	7		2.3	-120.00	-117.00	-118.50	1.50	-124.00	-109.00	-116.50	7.50	-124.00	-123.00	-123.50	0.50	-119.50	5.82
	9		3.4	-95.00	-53.00	-74.00	21.00	-116.00	-86.00	-101.00	15.00	-116.00	-105.00	-110.50	5.50	-95.17	23.78
	10	Outflow	4.7	-123.00	-121.00	-122.00	1.00	-133.00	-82.00	-107.50	25.50	-133.00	-111.00	-122.00	11.00	-117.17	19.10
pH	1	Inflow	0	7.47	7.67	7.57	0.10	7.52	7.50	7.51	0.01	7.51	7.66	7.59	0.08	7.56	0.09
	2	Up (12.5 cm)	0.5	7.39	7.62	7.51	0.12	7.55	7.46	7.51	0.04	7.44	7.54	7.49	0.05	7.50	0.08
	4		1.1	7.35	7.50	7.43	0.08	7.45	7.26	7.36	0.10	7.32	7.33	7.33	0.00	7.37	0.09
	6		2.3	7.46	7.49	7.48	0.02	7.42	7.31	7.37	0.06	7.29	7.40	7.35	0.06	7.40	0.08
	8		3.4	6.94	6.91	6.93	0.02	6.97	7.02	7.00	0.02	7.02	7.27	7.15	0.13	7.02	0.13
	10	Outflow	4.7	7.15	7.31	7.23	0.08	7.14	7.20	7.17	0.03	7.20	7.19	7.20	0.00	7.20	0.06
	1	Inflow	0	7.47	7.67	7.57	0.10	7.52	7.50	7.51	0.01	7.51	7.66	7.59	0.08	7.56	0.09
	3	Below (40 cm)	0.5	7.35	7.47	7.41	0.06	7.46	7.40	7.43	0.03	7.36	7.41	7.39	0.02	7.41	0.05
	5		1.1	7.26	7.21	7.24	0.02	7.29	7.16	7.23	0.06	7.11	7.34	7.23	0.12	7.23	0.09
	7		2.3	7.11	7.21	7.16	0.05	7.22	7.38	7.30	0.08	7.16	7.25	7.21	0.04	7.22	0.09
	9		3.4	7.20	7.32	7.26	0.06	7.31	7.29	7.30	0.01	7.21	7.32	7.27	0.06	7.28	0.06
	10	Outflow	4.7	7.15	7.31	7.23	0.08	7.14	7.20	7.17	0.03	7.20	7.19	7.20	0.00	7.20	0.06
O_2	1	Inflow	0	0.0076					0.0135			0.0034	0.0023	0.00	0.00	0.007	0.15
	2	Up (12.5 cm)	0.5	0.0050					0.0017			0.0017	0.0087	0.01	0.00	0.004	0.10
	4		1.1	0.0064					0.0027			0.0017	0.0087	0.01	0.00	0.005	0.10
	6		2.3	0.0190					0.0040			0.0013	0.0080	0.00	0.00	0.008	0.20
	8		3.4	0.0091					0.0026			0.0013	0.0083	0.00	0.00	0.005	0.11
	10	Outflow	4.7	0.0111					0.0039			0.0013	0.0083	0.00	0.00	0.006	0.13
	1	Inflow	0	0.0076					0.0135			0.0034	0.0023	0.00	0.00	0.007	0.15
	3	Below (40 cm)	0.5	0.0057					0.0017			0.0017	0.0087	0.01	0.00	0.004	0.10
	5		1.1	0.0054					0.0027			0.0013	0.0093	0.01	0.00	0.005	0.10
	7		2.3	0.0059					0.0033			0.0007	0.0087	0.00	0.00	0.005	0.10
	9		3.4	0.0081					0.0029			0.0020	0.0087	0.01	0.00	0.005	0.11
	10	Outflow	4.7	0.0111					0.0039			0.0013	0.0083	0.00	0.00	0.006	0.13
NH_4-N	1	Inflow	0	1.1275	1.99	1.56	0.43	2.80	1.91	2.36	0.45	2.2935	2.2963	2.29	0.00	2.07	32.32
	2	Up (12.5 cm)	0.5	1.5308	1.97	1.75	0.22	2.07	1.90	1.99	0.08	1.7634	2.3962	2.08	0.32	1.94	29.26
	4		1.1	1.6798	2.10	1.89	0.21	2.60	2.10	2.35	0.25	2.5313	2.1648	2.35	0.18	2.20	33.07
	6		2.3	1.7151	2.16	1.94	0.22	3.11	2.08	2.60	0.52	2.2553	2.2645	2.26	0.00	2.26	34.45
	8		3.4	0.9012	1.32	1.11	0.21	1.77	1.30	1.53	0.23	0.9151	2.3992	1.66	0.74	1.43	23.54
	10	Outflow	4.7	2.0876	2.21	2.15	0.06	2.49	1.64	2.07	0.43	2.4220	2.6005	2.51	0.09	2.24	33.56

NH_4-N	1	Inflow	0	1.1275	1.99	1.56	0.43	2.80	1.91	2.36	0.45	2.2935	2.2963	2.29	0.00	2.07	32.32
	3	Below (40 cm)	0.5	1.7904	2.04	1.92	0.13	2.95	1.96	2.45	0.50	2.2562	2.3629	2.31	0.05	2.23	33.81
	5		1.1	1.9684	2.33	2.15	0.18	2.28	0.05	1.17	1.12	2.0664	2.8975	2.48	0.42	1.93	33.61
	7		2.3	2.2510	2.52	2.39	0.13	3.11	2.29	2.70	0.41	1.9477	2.2645	2.11	0.16	2.40	36.01
	9		3.4	1.9939	2.22	2.11	0.11	2.82	1.91	2.36	0.46	2.5675	2.2659	2.42	0.15	2.30	34.41
	10	Outflow	4.7	2.0876	2.21	2.15	0.06	2.49	1.64	2.07	0.43	2.4220	2.6005	2.51	0.09	2.24	33.56
NO_3-N	1	Inflow	0	0.0268	0.0326	0.0297	0.0029	0.0172	0.0237	0.0204	0.0032	0.0174	0.0135	0.0155	0.0020	0.0219	0.3498
	2	Up (12.5 cm)	0.5	0.0279	0.0260	0.0270	0.0010	0.0218	0.0152	0.0185	0.0033	0.0264	0.0165	0.0215	0.0049	0.0223	0.3447
	4		1.1	0.0298	0.0037	0.0168	0.0130	0.0174	0.0241	0.0208	0.0034	0.0180	0.0060	0.0120	0.0060	0.0165	0.3010
	6		2.3	0.0226	0.0105	0.0165	0.0061	0.0221	0.0306	0.0264	0.0043	0.0336	0.0196	0.0266	0.0070	0.0231	0.3731
	8		3.4	0.0095	0.0045	0.0070	0.0025	0.0184	0.0044	0.0114	0.0070	0.0170	0.0143	0.0157	0.0014	0.0114	0.2002
	10	Outflow	4.7	0.0049	0.0083	0.0066	0.0017	0.0116	0.0198	0.0157	0.0041	0.0161	0.0211	0.0186	0.0025	0.0136	0.2362
	1	Inflow	0	0.0268	0.0326	0.0297	0.0029	0.0172	0.0237	0.0204	0.0032	0.0174	0.0135	0.0155	0.0020	0.0219	0.3498
	3	Below (40 cm)	0.5	0.0309	0.0215	0.0262	0.0047	0.0113	0.0212	0.0163	0.0050	0.0226	0.0158	0.0192	0.0034	0.0206	0.3267
	5		1.1	0.0145	0.0365	0.0255	0.0110	0.0166	0.0506	0.0336	0.0170	0.0451	0.0564	0.0508	0.0057	0.0366	0.6290
	7		2.3	0.0226	0.0180	0.0203	0.0023	0.0190	0.0149	0.0170	0.0020	0.0067	0.0113	0.0090	0.0023	0.0154	0.2467
	9		3.4	0.0064	0.0173	0.0118	0.0055	0.0161	0.0141	0.0151	0.0010	0.0074	0.0008	0.0041	0.0033	0.0103	0.1912
	10	Outflow	4.7	0.0049	0.0083	0.0066	0.0017	0.0116	0.0198	0.0157	0.0041	0.0161	0.0211	0.0186	0.0025	0.0136	0.2362
NO_2-N	1	Inflow	0	0.0005	0.0005	0.0005	0.0000	0.0003	0.0005	0.0004	0.0001	0.0001	0.0004	0.0003	0.0002	0.0004	0.0063
	2	Up (12.5 cm)	0.5	0.0002	0.0013	0.0007	0.0005	0.0006	0.0004	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000	0.0004	0.0105
	4		1.1	0.0000	0.0011	0.0005	0.0005	0.0007	0.0002	0.0005	0.0003	0.0000	0.0000	0.0000	0.0000	0.0003	0.0096
	6		2.3	0.0007	0.0010	0.0008	0.0001	0.0015	0.0011	0.0013	0.0002	0.0005	0.0009	0.0007	0.0002	0.0009	0.0150
	8		3.4	0.0007	0.0002	0.0004	0.0003	0.0007	0.0008	0.0007	0.0000	0.0007	0.0004	0.0005	0.0001	0.0006	0.0093
	10	Outflow	4.7	0.0002	0.0011	0.0006	0.0005	0.0006	0.0006	0.0006	0.0000	0.0005	0.0014	0.0010	0.0004	0.0007	0.0135
	1	Inflow	0	0.0005	0.0005	0.0005	0.0000	0.0003	0.0005	0.0004	0.0001	0.0001	0.0004	0.0003	0.0002	0.0004	0.0063
	3	Below (40 cm)	0.5	0.0000	0.0004	0.0002	0.0002	0.0002	0.0003	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0036
	5		1.1	0.0000	0.0053	0.0027	0.0027	0.0000	0.0000	0.0000	0.0000	0.0000	0.0009	0.0004	0.0004	0.0010	0.0415
	7		2.3	0.0010	0.0013	0.0011	0.0002	0.0011	0.0011	0.0011	0.0000	0.0005	0.0009	0.0007	0.0002	0.0010	0.0154
	9		3.4	0.0008	0.0010	0.0009	0.0001	0.0010	0.0011	0.0010	0.0001	0.0004	0.0005	0.0005	0.0001	0.0008	0.0125
	10	Outflow	4.7	0.0002	0.0011	0.0006	0.0005	0.0006	0.0006	0.0006	0.0000	0.0005	0.0014	0.0010	0.0004	0.0007	0.0135
NO_X-N	1	Inflow	0	0.0273	0.0331	0.0302	0.0029	0.0175	0.0242	0.0208	0.0033	0.0175	0.0140	0.0157	0.0018	0.0223	0.3556
	2	Up (12.5 cm)	0.5	0.0282	0.0273	0.0277	0.0004	0.0224	0.0156	0.0190	0.0034	0.0264	0.0165	0.0215	0.0049	0.0227	0.3512
	4		1.1	0.0298	0.0048	0.0173	0.0125	0.0181	0.0243	0.0212	0.0031	0.0180	0.0060	0.0120	0.0060	0.0168	0.3026
	6		2.3	0.0233	0.0114	0.0174	0.0059	0.0235	0.0317	0.0276	0.0041	0.0340	0.0204	0.0272	0.0068	0.0241	0.3851
	8		3.4	0.0102	0.0047	0.0074	0.0028	0.0191	0.0052	0.0121	0.0070	0.0177	0.0147	0.0162	0.0015	0.0119	0.2079
	10	Outflow	4.7	0.0050	0.0094	0.0072	0.0022	0.0122	0.0204	0.0163	0.0041	0.0167	0.0225	0.0196	0.0029	0.0144	0.2477

NO_x-N	1	Inflow	0	0.0273	0.0331	0.0302	0.0029	0.0175	0.0242	0.0208	0.0033	0.0175	0.0140	0.0157	0.0018	0.0223	0.3556
	3	Below (40 cm)	0.5	0.0309	0.0219	0.0264	0.0045	0.0115	0.0215	0.0165	0.0050	0.0227	0.0158	0.0192	0.0034	0.0207	0.3285
	5		1.1	0.0145	0.0418	0.0282	0.0137	0.0166	0.0506	0.0336	0.0170	0.0451	0.0573	0.0512	0.0061	0.0376	0.6453
	7		2.3	0.0236	0.0193	0.0214	0.0022	0.0202	0.0161	0.0181	0.0020	0.0072	0.0122	0.0097	0.0025	0.0164	0.2616
	9		3.4	0.0071	0.0182	0.0127	0.0055	0.0170	0.0151	0.0161	0.0009	0.0078	0.0013	0.0045	0.0032	0.0111	0.2027
	10	Outflow	4.7	0.0050	0.0094	0.0072	0.0022	0.0122	0.0204	0.0163	0.0041	0.0167	0.0225	0.0196	0.0029	0.0144	0.2477
TN	1	Inflow	0	2.3889	2.87	2.63	0.24	2.81	2.28	2.54	0.26	2.9664	2.6867	2.83	0.14	2.67	39.93
	2	Up (12.5 cm)	0.5	2.1954	2.58	2.39	0.19	2.57	2.17	2.37	0.20	2.7513	2.7370	2.74	0.01	2.50	37.40
	4		1.1	2.4457	2.58	2.51	0.07	2.61	2.18	2.40	0.21	2.7446	2.9481	2.85	0.10	2.59	38.61
	6		2.3	2.1023	2.50	2.30	0.20	2.57	2.06	2.32	0.26	2.5589	3.0261	2.79	0.23	2.47	37.13
	8		3.4	1.0687	1.42	1.24	0.18	1.48	1.46	1.47	0.01	1.7560	3.0190	2.39	0.63	1.70	28.14
	10	Outflow	4.7	2.4026	2.52	2.46	0.06	2.42	2.17	2.29	0.13	2.5404	2.8896	2.71	0.17	2.49	36.94
	1	Inflow	0	2.3889	2.87	2.63	0.24	2.81	2.28	2.54	0.26	2.9664	2.6867	2.83	0.14	2.67	39.93
	3	Below (40 cm)	0.5	2.6074	2.61	2.61	0.00	2.57	2.18	2.37	0.19	2.8815	2.9732	2.93	0.05	2.64	39.48
	5		1.1	2.4359	2.71	2.57	0.13	3.09	2.39	2.74	0.35	4.4541	3.6036	4.03	0.43	3.11	48.38
	7		2.3	2.4084	2.71	2.56	0.15	2.57	2.24	2.40	0.16	2.7014	3.1470	2.92	0.22	2.63	39.30
	9		3.4	2.3636	2.55	2.46	0.09	2.56	2.15	2.36	0.21	2.5267	3.1293	2.83	0.30	2.55	38.07
	10	Outflow	4.7	2.4026	2.52	2.46	0.06	2.42	2.17	2.29	0.13	2.5404	2.8896	2.71	0.17	2.49	36.94
TOC	1	Inflow	0	4.5898	5.16	4.87	0.28	5.92	2.57	4.25	1.67	4.7359	4.8456	4.79	0.05	4.64	71.91
	2	Up (12.5 cm)	0.5	2.6194	3.20	2.91	0.29	2.79	1.02	1.91	0.89	3.3067	3.1030	3.20	0.10	2.67	42.57
	4		1.1	4.3600	2.35	3.36	1.00	1.83	0.75	1.29	0.54	2.4233	2.5888	2.51	0.08	2.38	40.85
	6		2.3	1.5698	1.77	1.67	0.10	1.36	0.39	0.88	0.48	1.7149	1.9328	1.82	0.11	1.46	23.71
	8		3.4	1.2294	1.66	1.45	0.22	0.80	0.22	0.51	0.29	1.2647	1.5835	1.42	0.16	1.13	19.21
	10	Outflow	4.7	1.6567	1.66	1.66	0.00	0.58	0.18	0.38	0.20	1.2791	1.3326	1.31	0.03	1.11	19.41
	1	Inflow	0	4.5898	5.16	4.87	0.28	5.92	2.57	4.25	1.67	4.7359	4.8456	4.79	0.05	4.64	71.91
	3	Below (40 cm)	0.5	5.8510	3.23	4.54	1.31	2.60	0.98	1.79	0.81	4.1413	4.3597	4.25	0.11	3.53	60.22
	5		1.1	3.4509	2.96	3.21	0.24	6.34	2.22	4.28	2.06	17.7665	5.4087	11.59	6.18	6.36	140.65
	7		2.3	1.8262	2.18	2.00	0.18	1.08	0.25	0.66	0.41	1.6766	1.4419	1.56	0.12	1.41	24.03
	9		3.4	2.3358	1.71	2.02	0.31	1.11	0.26	0.69	0.43	1.4575	1.4529	1.46	0.00	1.39	23.44
	10	Outflow	4.7	1.6567	1.66	1.66	0.00	0.58	0.18	0.38	0.20	1.2791	1.3326	1.31	0.03	1.11	19.41
COD	1	Inflow	0	11.3178	14.96	13.14	1.82	25.42	11.65	18.54	6.88	16.0435	12.1140	14.08	1.96	15.25	245.77
	2	Up (12.5 cm)	0.5	7.0841	9.14	8.11	1.03	8.99	13.87	11.43	2.44	13.2253	14.3437	13.78	0.56	11.11	173.60
	4		1.1	26.1941	12.79	19.49	6.70	8.53	7.58	8.05	0.47	14.1373	8.0264	11.08	3.06	12.88	226.67
	6		2.3	6.2807	6.23	6.25	0.03	7.79	6.48	7.13	0.65	7.4921	6.5936	7.04	0.45	6.81	101.32
	8		3.4	5.1711	6.12	5.65	0.48	5.33	4.32	4.83	0.50	5.1398	5.5648	5.35	0.21	5.27	78.40
	10	Outflow	4.7	7.2405	6.41	6.83	0.41	5.37	4.84	5.10	0.26	6.4981	5.2344	5.87	0.63	5.93	88.14

COD	1	Inflow	0	11.3178	14.96	13.14	1.82	25.42	11.65	18.54	6.88	16.0435	12.1140	14.08	1.96	15.25	245.77
	3	Below (40 cm)	0.5	16.2399	22.66	19.45	3.21	21.25	19.98	20.61	0.63	18.7024	13.7447	16.22	2.48	18.76	284.25
	5		1.1	19.4005	30.73	25.07	5.67	74.23	46.59	60.41	13.82	30.2706	24.9118	27.59	2.68	37.69	661.59
	7		2.3	8.7308	7.09	7.91	0.82	6.61	5.79	6.20	0.41	6.0729	5.5613	5.82	0.26	6.64	99.52
	9		3.4	7.2465	6.85	7.05	0.20	6.99	5.34	6.16	0.82	6.5475	5.2982	5.92	0.62	6.38	94.68
	10	Outflow	4.7	7.2405	6.41	6.83	0.41	5.37	4.84	5.10	0.26	6.4981	5.2344	5.87	0.63	5.93	88.14
BOD_5	1	Inflow	0	0.0000	8.95	4.48	4.48	11.27	6.76	9.01	2.26	6.1422	0.4227	3.28	2.86	5.59	116.19
	2	Up (12.5 cm)	0.5	0.0000	5.66	2.83	2.83	0.00	4.80	2.40	2.40	0.9385	0.0000	0.47	0.47	1.90	54.79
	4		1.1	0.0000	1.95	0.97	0.97	0.00	0.47	0.24	0.24	0.0931	0.0000	0.05	0.05	0.42	15.28
	6		2.3	0.0000	3.34	1.67	1.67	4.35	3.54	3.94	0.40	4.1916	0.5628	2.38	1.81	2.66	52.00
	8		3.4	2.7720	3.09	2.93	0.16	3.25	0.00	1.62	1.62	2.8154	3.0990	2.96	0.14	2.50	42.83
	10	Outflow	4.7	4.6239	3.47	4.05	0.57	3.27	0.00	1.64	1.64	0.0000	0.2334	0.12	0.12	1.93	44.98
	1	Inflow	0	0.0000	8.95	4.48	4.48	11.27	6.76	9.01	2.26	6.1422	0.4227	3.28	2.86	5.59	116.19
	3	Below (40 cm)	0.5	0.0936	6.02	3.06	2.96	7.59	5.68	6.63	0.96	1.1288	0.5624	0.85	0.28	3.51	78.35
	5		1.1	5.4078	5.57	5.49	0.08	12.24	0.00	6.12	6.12	0.2329	0.5162	0.37	0.14	3.99	103.63
	7		2.3	0.9697	3.74	2.36	1.39	3.98	0.00	1.99	1.99	0.0000	0.0000	0.00	0.00	1.45	40.06
	9		3.4	0.0000	3.36	1.68	1.68	2.10	0.00	1.05	1.05	0.0917	3.2389	1.67	1.57	1.47	36.36
	10	Outflow	4.7	4.6239	3.47	4.05	0.57	3.27	0.00	1.64	1.64	0.0000	0.2334	0.12	0.12	1.93	44.98
SO_4^{2-}-S	1	Inflow	0	1.7280	0.30	1.01	0.71	1.58	1.75	1.66	0.09	1.5724	1.6740	1.62	0.05	1.43	23.45
	2	Up (12.5 cm)	0.5	1.5000	0.50	1.00	0.50	1.10	0.89	1.00	0.10	1.1379	1.2373	1.19	0.05	1.06	16.83
	4		1.1	0.9376	0.48	0.71	0.23	0.78	0.18	0.48	0.30	0.8002	0.5942	0.70	0.10	0.63	10.46
	6		2.3	0.6198	0.40	0.51	0.11	0.19	0.14	0.17	0.02	0.2697	0.4063	0.34	0.07	0.34	5.81
	8		3.4	0.3929	0.25	0.32	0.07	0.45	0.46	0.46	0.01	0.1809	0.4948	0.34	0.16	0.37	5.94
	10	Outflow	4.7	0.9653	0.30	0.63	0.33	1.39	0.27	0.83	0.56	0.2693	0.3607	0.31	0.05	0.59	11.73
	1	Inflow	0	1.7280	0.30	1.01	0.71	1.58	1.75	1.66	0.09	1.5724	1.6740	1.62	0.05	1.43	23.45
	3	Below (40 cm)	0.5	1.2076	0.53	0.87	0.34	0.79	0.72	0.76	0.04	0.8918	0.6780	0.78	0.11	0.80	12.56
	5		1.1	1.4432	0.99	1.22	0.23	0.19	0.65	0.42	0.23	1.7000	0.9047	1.30	0.40	0.98	17.44
	7		2.3	0.3613	0.38	0.37	0.01	0.23	0.18	0.21	0.03	0.3457	0.3028	0.32	0.02	0.30	4.64
	9		3.4	0.2874	0.45	0.37	0.08	0.44	0.26	0.35	0.09	0.2073	0.3260	0.27	0.06	0.33	5.11
	10	Outflow	4.7	0.9653	0.30	0.63	0.33	1.39	0.27	0.83	0.56	0.2693	0.3607	0.31	0.05	0.59	11.73
S^{2-}	1	Inflow	0	0.1653	0.14	0.15	0.01	0.57	0.27	0.42	0.15	0.6072	0.5670	0.59	0.02	0.39	6.94
	2	Up (12.5 cm)	0.5	0.4825	0.61	0.55	0.06	0.67	0.71	0.69	0.02	0.7733	0.7738	0.77	0.00	0.67	10.15
	4		1.1	0.7679	0.88	0.82	0.05	0.77	0.91	0.84	0.07	0.8437	0.8407	0.84	0.00	0.83	12.41
	6		2.3	0.8886	0.79	0.84	0.05	1.10	0.91	1.00	0.10	0.9400	0.6984	0.82	0.12	0.89	13.31
	8		3.4	0.4844	0.54	0.51	0.03	0.59	0.75	0.67	0.08	0.8688	0.6516	0.76	0.11	0.65	9.98
	10	Outflow	4.7	0.8961	1.07	0.98	0.09	0.71	0.94	0.83	0.12	0.7687	0.7600	0.76	0.00	0.86	12.85

S^{2-}	1	Inflow	0	0.1653	0.14	0.15	0.01	0.57	0.27	0.42	0.15	0.6072	0.5670	0.59	0.02	0.39	6.94
	3	Below (40 cm)	0.5	0.8010	0.70	0.75	0.05	0.59	0.81	0.70	0.11	0.8294	0.9623	0.90	0.07	0.78	11.82
	5		1.1	0.8385	0.75	0.80	0.04	0.66	1.01	0.84	0.18	0.8389	1.1476	0.99	0.15	0.88	13.36
	7		2.3	0.9166	0.78	0.85	0.07	0.79	0.85	0.82	0.03	0.8086	0.7359	0.77	0.04	0.81	12.05
	9		3.4	0.8974	0.93	0.91	0.01	0.83	0.90	0.86	0.03	0.8861	0.8507	0.87	0.02	0.88	13.01
	10	Outflow	4.7	0.8961	1.07	0.98	0.09	0.71	0.94	0.83	0.12	0.7687	0.7600	0.76	0.00	0.86	12.85
S^0	1	Inflow	0	0.0000	0.00	0.00	0.00	0.46	0.00	0.23	0.23	0.3270	0.0946	0.21	0.12	0.15	4.21
	2	Up (12.5 cm)	0.5	0.2610	0.23	0.25	0.02	0.54	0.49	0.52	0.03	0.5457	0.3659	0.46	0.09	0.41	6.52
	4		1.1	1.2122	0.61	0.91	0.30	0.53	0.55	0.54	0.01	0.7094	0.5516	0.63	0.08	0.70	11.22
	6		2.3	0.3741	0.58	0.48	0.10	0.53	0.58	0.55	0.02	0.4240	0.2470	0.34	0.09	0.45	7.11
	8		3.4	0.1392	0.30	0.22	0.08	0.22	0.30	0.26	0.04	0.0953	0.3152	0.21	0.11	0.23	3.77
	10	Outflow	4.7	0.5459	0.39	0.47	0.08	0.37	0.38	0.37	0.00	0.2584	0.1184	0.19	0.07	0.34	5.53
	1	Inflow	0	0.0000	0.00	0.00	0.00	0.46	0.00	0.23	0.23	0.3270	0.0946	0.21	0.12	0.15	4.21
	3	Below (40 cm)	0.5	0.8272	0.62	0.72	0.10	0.56	0.64	0.60	0.04	0.8383	0.6251	0.73	0.11	0.68	10.35
	5		1.1	0.0000	1.96	0.98	0.98					1.1160	0.8830	1.00	0.12	0.99	23.97
	7		2.3	0.5807	0.50	0.54	0.04	0.54	0.57	0.56	0.02	0.3789	0.3551	0.37	0.01	0.49	7.38
	9		3.4	0.4256	0.56	0.49	0.07	0.44	0.45	0.44	0.01	0.3365	0.1906	0.26	0.07	0.40	6.29
	10	Outflow	4.7	0.4611	0.39	0.43	0.03	0.37	0.38	0.37	0.00	0.2584	0.1184	0.19	0.07	0.33	5.23
CH_4	1.00	Inflow	0	0.0337	0.01	0.02	0.01	0.02	0.02	0.02	0.00	0.0269	0.0193	0.02	0.004	0.02	0.35
	2.00	Up (12.5 cm)	0.5	0.1604	0.13	0.14	0.02	0.25	0.38	0.32	0.06	0.3674	0.4716	0.42	0.052	0.29	4.99
	4.00		1.1	0.4529	0.45	0.45	0.00	0.58	0.64	0.61	0.03	0.8416	0.6025	0.72	0.120	0.59	9.18
	6.00		2.3	0.4969	0.50	0.50	0.00	0.59	0.61	0.60	0.01	0.8185	1.0610	0.94	0.121	0.68	10.86
	8.00		3.4	0.4010	0.51	0.46	0.08	0.47	0.47	0.47	0.00	0.6646	0.9410	0.80	0.138	0.58	9.31
	10.00	Outflow	4.7	0.6954	0.78	0.74	0.06	1.05	0.91	0.98	0.07	1.0787	0.8615	0.97	0.109	0.89	13.53
	1.00	Inflow	0	0.0337	0.01	0.02	0.01	0.02	0.02	0.02	0.00	0.0269	0.0193	0.02	0.004	0.02	0.35
	3.00	Below (40 cm)	0.5	0.3542	0.22	0.29	0.10	0.28	0.37	0.32	0.04	0.6646	0.5774	0.62	0.044	0.41	6.84
	5.00		1.1	0.6760	0.74	0.71	0.05	0.67	0.87	0.77	0.10	1.1144	1.2822	1.20	0.084	0.89	14.01
	7.00		2.3	1.0525	0.88	0.97	0.12	0.97	1.07	1.02	0.05	1.1354	1.1556	1.15	0.010	1.05	15.56
	9.00		3.4	0.6930	0.72	0.70	0.02	0.80	1.01	0.90	0.11	1.0149	1.2063	1.11	0.096	0.91	13.98
	10.00	Outflow	4.7	0.6954	0.78	0.74	0.06	1.05	0.91	0.98	0.07	1.0787	0.8615	0.97	0.109	0.89	13.53

4. Standard Unplanted CW

HSSF Standard Unplanted			Dist. from Inflow (meter)	15.03.2012	29.03.2012	March, mean (n = 2)	March SD	12.04.2012	26.04.2012	April, mean (n = 2)	April SD	10.05.2012	24.05.2012	May, mean (n = 2)	May SD	General Mean	General SD
Temp Lab [°C]	1	Inflow	0	11.50	11.20	11.35	0.15	16.30	16.50	16.40	0.10	21.90	21.80	21.85	0.05	16.53	4.29
	11	Up (12.5 cm)	0.5	18.70	11.70	15.20	3.50	16.00	21.60	18.80	2.80	28.50	28.90	28.70	0.20	20.90	6.27
	13		1.1	13.20	11.20	12.20	1.00	14.00	22.90	18.45	4.45	25.20	28.90	27.05	1.85	19.23	6.72
	15		2.3	10.70	11.10	10.90	0.20	15.00	19.90	17.45	2.45	25.30	26.40	25.85	0.55	18.07	6.29
	17		3.4	11.80	11.00	11.40	0.40	11.40	16.50	13.95	2.55	23.10	23.70	23.40	0.30	16.25	5.38
	19	Outflow	4.7	11.20	10.50	10.85	0.35	14.40	17.40	15.90	1.50	23.30	26.50	24.90	1.60	17.22	5.95
	1	Inflow	0	11.50	11.20	11.35	0.15	16.30	16.50	16.40	0.10	21.90	21.80	21.85	0.05	16.53	4.29
	12	Below (40 cm)	0.5	14.10	11.30	12.70	1.40	15.30	20.20	17.75	2.45	25.60	30.20	27.90	2.30	19.45	6.66
	14		1.1	15.30	11.20	13.25	2.05	15.60	22.20	18.90	3.30	25.50	28.70	27.10	1.60	19.75	6.18
	16		2.3	10.90	11.80	11.35	0.45	14.90	20.80	17.85	2.95	25.50	28.60	27.05	1.55	18.75	6.73
	18		3.4	10.90	10.80	10.85	0.05	12.80	18.60	15.70	2.90	23.00	24.50	23.75	0.75	16.77	5.59
	19	Outflow	4.7	11.20	10.50	10.85	0.35	14.40	17.40	15.90	1.50	23.30	26.50	24.90	1.60	17.22	5.95
Temp out [°C]	1	Inflow	0	15.50	9.70	12.60	2.90	12.70	18.80	15.75	3.05	12.70	31.40	22.05	9.35	16.80	7.10
	11	Up (12.5 cm)	0.5	10.60	9.70	10.15	0.45	13.90	19.00	16.45	2.55	13.90	30.60	22.25	8.35	16.28	7.06
	13		1.1	9.50	9.40	9.45	0.05	12.30	18.90	15.60	3.30	12.30	29.80	21.05	8.75	15.37	7.18
	15		2.3	8.10	9.50	8.80	0.70	12.80	17.10	14.95	2.15	12.80	25.10	18.95	6.15	14.23	5.63
	17		3.4	6.80	9.00	7.90	1.10	9.90	15.00	12.45	2.55	9.90	22.40	16.15	6.25	12.17	5.19
	19	Outflow	4.7	7.10	9.00	8.05	0.95	11.80	14.40	13.10	1.30	11.80	24.70	18.25	6.45	13.13	5.66
	1	Inflow	0	15.50	9.70	12.60	2.90	12.70	18.80	15.75	3.05	12.70	31.40	22.05	9.35	16.80	7.10
	12	Below (40 cm)	0.5	14.00	9.60	11.80	2.20	13.10	19.30	16.20	3.10	13.10	30.60	21.85	8.75	16.62	6.87
	14		1.1	9.40	9.80	9.60	0.20	13.90	18.30	16.10	2.20	13.90	31.10	22.50	8.60	16.07	7.35
	16		2.3	8.30	9.70	9.00	0.70	11.70	18.40	15.05	3.35	11.70	27.20	19.45	7.75	14.50	6.50
	18		3.4	7.60	9.60	8.60	1.00	10.80	15.30	13.05	2.25	10.80	22.90	16.85	6.05	12.83	5.06
	19	Outflow	4.7	7.10	9.00	8.05	0.95	11.80	14.40	13.10	1.30	11.80	24.70	18.25	6.45	13.13	5.66
EH [mV]	1	Inflow	0	-77.00	-100.00	-88.50	11.50	-60.00	-57.00	-58.50	1.50	-60.00	-129.00	-94.50	34.50	-80.50	26.26
	11	Up (12.5 cm)	0.5	-135.00	-122.00	-128.50	6.50	-131.00	-150.00	-140.50	9.50	-131.00	-121.00	-126.00	5.00	-131.67	9.62
	13		1.1	-105.00	-107.00	-106.00	1.00	-141.00	-140.00	-140.50	0.50	-141.00	-135.00	-138.00	3.00	-128.17	15.82
	15		2.3	-75.00	-113.00	-94.00	19.00	-124.00	-124.00	-124.00	0.00	-124.00	-123.00	-123.50	0.50	-113.83	17.81
	17		3.4	-92.00	-97.00	-94.50	2.50	-111.00	-96.00	-103.50	7.50	-111.00	-107.00	-109.00	2.00	-102.33	7.61
	19	Outflow	4.7	-113.00	-117.00	-115.00	2.00	-133.00	-125.00	-129.00	4.00	-133.00	-125.00	-129.00	4.00	-124.33	7.45

EH [mV]	1	Inflow	0	-77.00	-100.00	-88.50	11.50	-60.00	-57.00	-58.50	1.50	-60.00	-129.00	-94.50	34.50	-80.50	26.26
	12	Below (40 cm)	0.5	-108.00	-123.00	-115.50	7.50	-138.00	-137.00	-137.50	0.50	-138.00	-111.00	-124.50	13.50	-125.83	12.69
	14		1.1	-133.00	-106.00	-119.50	13.50	-132.00	-158.00	-145.00	13.00	-132.00	-116.00	-124.00	8.00	-129.50	16.18
	16		2.3	-94.00	-88.00	-91.00	3.00	-128.00	-124.00	-126.00	2.00	-128.00	-118.00	-123.00	5.00	-113.33	16.23
	18		3.4	-125.00	-106.00	-115.50	9.50	-122.00	-120.00	-121.00	1.00	-122.00	-116.00	-119.00	3.00	-118.50	6.21
	19	Outflow	4.7	-113.00	-117.00	-115.00	2.00	-133.00	-125.00	-129.00	4.00	-133.00	-125.00	-129.00	4.00	-124.33	7.45
pH	1	Inflow	0	7.47	7.67	7.57	0.10	7.52	7.50	7.51	0.01	7.51	7.66	7.59	0.08	7.56	0.08
	11	Up (12.5 cm)	0.5	7.32	7.60	7.46	0.14	7.69	7.40	7.55	0.15	7.85	7.65	7.75	0.10	7.59	0.18
	13		1.1	7.33	7.45	7.39	0.06	7.45	7.24	7.35	0.10	7.33	7.41	7.37	0.04	7.37	0.08
	15		2.3	7.21	7.46	7.34	0.13	7.50	7.32	7.41	0.09	7.37	7.53	7.45	0.08	7.40	0.11
	17		3.4	7.25	7.28	7.27	0.02	7.42	7.31	7.37	0.06	7.33	7.33	7.33	0.00	7.32	0.05
	19	Outflow	4.7	7.16	7.22	7.19	0.03	7.22	7.18	7.20	0.02	7.14	7.25	7.20	0.06	7.20	0.04
	1	Inflow	0	7.47	7.67	7.57	0.10	7.52	7.50	7.51	0.01	7.51	7.66	7.59	0.08	7.56	0.08
	12	Below (40 cm)	0.5	7.22	7.61	7.42	0.20	7.48	7.29	7.39	0.10	7.27	7.35	7.31	0.04	7.37	0.13
	14		1.1	7.03	7.11	7.07	0.04	7.15	7.14	7.15	0.01	7.11	7.15	7.13	0.02	7.12	0.04
	16		2.3	7.13	7.20	7.17	0.04	7.30	7.12	7.21	0.09	7.20	7.19	7.20	0.00	7.19	0.06
	18		3.4	7.20	7.30	7.25	0.05	7.34	7.22	7.28	0.06	7.21	7.29	7.25	0.04	7.26	0.05
	19	Outflow	4.7	7.16	7.22	7.19	0.03	7.22	7.18	7.20	0.02	7.14	7.25	7.20	0.06	7.20	0.04
O_2	1	Inflow	0	0.0076					0.0135			0.0034	0.0023	0.0028	0.00	0.007	0.00
	11	Up (12.5 cm)	0.5	0.0104					0.0061			0.0065	0.0017	0.0041	0.00	0.006	0.00
	13		1.1	0.0200					0.0063			0.0085	0.0030	0.0057	0.00	0.009	0.01
	15		2.3	0.0090					0.0063			0.0068	0.0045	0.0057	0.00	0.007	0.00
	17		3.4	0.0138					0.0065			0.0062	0.0057	0.0060	0.00	0.008	0.00
	19	Outflow	4.7	0.0295					0.0068			0.0061	0.0118	0.0090	0.00	0.014	0.01
	1	Inflow	0	0.0076					0.0135			0.0034	0.0023	0.0028	0.00	0.007	0.00
	12	Below (40 cm)	0.5	0.0114					0.0064			0.0065	0.0021	0.0043	0.00	0.007	0.00
	14		1.1	0.0102					0.0063			0.0085	0.0035	0.0060	0.00	0.007	0.00
	16		2.3	0.0107					0.0066			0.0071	0.0079	0.0075	0.00	0.008	0.00
	18		3.4	0.0109					0.0075			0.0073	0.0082	0.0078	0.00	0.009	0.00
	19	Outflow	4.7	0.0295					0.0068			0.0061	0.0118	0.0090	0.00	0.014	0.01
NH_4-N	1	Inflow	0	1.1317	2.0017	1.57	0.43	2.7868	1.9186	2.35	0.43	2.2923	2.3024	2.30	0.01	2.072	0.50
	11	Up (12.5 cm)	0.5	1.7187	2.1664	1.94	0.22	2.2026	0.7836	1.49	0.71	1.9424	1.6991	1.82	0.12	1.752	0.47
	13		1.1	1.2120	2.3725	1.79	0.58	2.5671	2.2055	2.39	0.18	2.1785	2.3495	2.26	0.09	2.148	0.44
	15		2.3	1.0493	2.1544	1.60	0.55	2.7834	2.0789	2.43	0.35	1.5258	1.7879	1.66	0.13	1.897	0.54
	17		3.4	1.2067	1.9559	1.58	0.37	2.0433	1.6261	1.83	0.21	0.8546	1.0534	0.95	0.10	1.457	0.45
	19	Outflow	4.7	1.9279	3.0638	2.50	0.57	2.6210	2.2123	2.42	0.20	1.9032	1.8428	1.87	0.03	2.262	0.45

NH_4-N	1	Inflow	0	1.1317	2.0017	1.57	0.43	2.7868	1.9186	2.35	0.43	2.2923	2.3024	2.30	0.01	2.072	0.50
	12	Below (40 cm)	0.5	1.4581	2.0359	1.75	0.29	2.6637	2.0113	2.34	0.33	1.8163	2.8634	2.34	0.52	2.141	0.48
	14		1.1	2.1078	2.5362	2.32	0.21	2.7982	1.9720	2.39	0.41	1.9337	2.4387	2.19	0.25	2.298	0.32
	16		2.3	2.1796	2.6725	2.43	0.25	2.7576	2.2072	2.48	0.28	1.6183	1.6545	1.64	0.02	2.182	0.44
	18		3.4	1.8098	2.6544	2.23	0.42	2.8710	2.0580	2.46	0.41	1.8626	2.0828	1.97	0.11	2.223	0.40
	19	Outflow	4.7	1.9279	3.0638	2.50	0.57	2.6210	2.2123	2.42	0.20	1.9032	1.8428	1.87	0.03	2.262	0.45
NO_3-N	1	Inflow	0	0.0269	0.0328	0.0299	0.0030	0.0171	0.0237	0.0204	0.0033	0.0174	0.0136	0.0155	0.0019	0.0219	0.0066
	11	Up (12.5 cm)	0.5	0.0152	0.0273	0.0212	0.0061	0.0186	0.0327	0.0257	0.0070	0.0147	0.0114	0.0130	0.0017	0.0200	0.0076
	13		1.1	0.0169	0.0325	0.0247	0.0078	0.0351	0.0219	0.0285	0.0066	0.0114	0.0107	0.0111	0.0003	0.0214	0.0095
	15		2.3	0.0047	0.0143	0.0095	0.0048	0.0142	0.0090	0.0116	0.0026	0.0087	0.0115	0.0101	0.0014	0.0104	0.0034
	17		3.4	0.0088	0.0065	0.0076	0.0011	0.0105	0.0081	0.0093	0.0012	0.0064	0.0005	0.0035	0.0029	0.0068	0.0031
	19	Outflow	4.7	0.0130	0.0150	0.0140	0.0010	0.0181	0.0314	0.0248	0.0067	0.0048	0.0067	0.0058	0.0009	0.0148	0.0087
	1	Inflow	0	0.0269	0.0328	0.0299	0.0030	0.0171	0.0237	0.0204	0.0033	0.0174	0.0136	0.0155	0.0019	0.0219	0.0066
	12	Below (40 cm)	0.5	0.0008	0.0228	0.0118	0.0110	0.0328	0.0091	0.0210	0.0118	0.0257	0.0277	0.0267	0.0010	0.0198	0.0112
	14		1.1	0.0337	0.0119	0.0228	0.0109	0.0299	0.0423	0.0361	0.0062	0.0320	0.0121	0.0221	0.0100	0.0270	0.0113
	16		2.3	0.0164	0.0182	0.0173	0.0009	0.0113	0.0052	0.0082	0.0030	0.0195	0.0042	0.0119	0.0076	0.0125	0.0061
	18		3.4	0.0136	0.0073	0.0104	0.0031	0.0391	0.0067	0.0229	0.0162	0.0185	0.0092	0.0138	0.0046	0.0157	0.0112
	19	Outflow	4.7	0.0130	0.0150	0.0140	0.0010	0.0181	0.0314	0.0248	0.0067	0.0048	0.0067	0.0058	0.0009	0.0148	0.0087
NO_2-N	1	Inflow	0	0.0005	0.0005	0.0005	0.0000	0.0003	0.0005	0.0004	0.0001	0.0001	0.0004	0.0003	0.0002	0.0004	0.0002
	11	Up (12.5 cm)	0.5	0.0003	0.0000	0.0002	0.0002	0.0000	0.0009	0.0004	0.0004	0.0013	0.0005	0.0009	0.0004	0.0005	0.0005
	13		1.1	0.0010	0.0012	0.0011	0.0001	0.0009	0.0011	0.0010	0.0001	0.0000	0.0000	0.0000	0.0000	0.0007	0.0005
	15		2.3	0.0007	0.0010	0.0009	0.0001	0.0041	0.0007	0.0024	0.0017	0.0007	0.0010	0.0009	0.0002	0.0014	0.0012
	17		3.4	0.0008	0.0007	0.0007	0.0001	0.0010	0.0004	0.0007	0.0003	0.0003	0.0002	0.0003	0.0000	0.0006	0.0003
	19	Outflow	4.7	0.0010	0.0011	0.0010	0.0001	0.0008	0.0008	0.0008	0.0000	0.0005	0.0007	0.0006	0.0001	0.0008	0.0002
	1	Inflow	0	0.0005	0.0005	0.0005	0.0000	0.0003	0.0005	0.0004	0.0001	0.0001	0.0004	0.0003	0.0002	0.0004	0.0002
	12	Below (40 cm)	0.5	0.0002	0.0001	0.0001	0.0000	0.0004	0.0011	0.0007	0.0003	0.0010	0.0015	0.0013	0.0003	0.0007	0.0005
	14		1.1	0.0003	0.0010	0.0006	0.0003	0.0004	0.0003	0.0003	0.0000	0.0004	0.0000	0.0002	0.0002	0.0004	0.0003
	16		2.3	0.0009	0.0011	0.0010	0.0001	0.0000	0.0007	0.0004	0.0003	0.0004	0.0009	0.0006	0.0002	0.0007	0.0004
	18		3.4	0.0013	0.0000	0.0006	0.0006	0.0000	0.0004	0.0002	0.0002	0.0009	0.0006	0.0008	0.0002	0.0006	0.0005
	19	Outflow	4.7	0.0010	0.0011	0.0010	0.0001	0.0008	0.0008	0.0008	0.0000	0.0005	0.0007	0.0006	0.0001	0.0008	0.0002
NO_X-N	1	Inflow	0	0.0274	0.0333	0.0304	0.0030	0.0174	0.0242	0.0208	0.0034	0.0175	0.0140	0.0158	0.0017	0.0223	0.0067
	11	Up (12.5 cm)	0.5	0.0155	0.0273	0.0214	0.0059	0.0186	0.0335	0.0261	0.0074	0.0160	0.0119	0.0140	0.0021	0.0205	0.0075
	13		1.1	0.0179	0.0337	0.0258	0.0079	0.0360	0.0230	0.0295	0.0065	0.0114	0.0107	0.0111	0.0003	0.0221	0.0099
	15		2.3	0.0055	0.0153	0.0104	0.0049	0.0184	0.0096	0.0140	0.0044	0.0094	0.0125	0.0110	0.0015	0.0118	0.0042
	17		3.4	0.0095	0.0072	0.0084	0.0012	0.0115	0.0085	0.0100	0.0015	0.0067	0.0008	0.0037	0.0030	0.0074	0.0034
	19	Outflow	4.7	0.0140	0.0161	0.0150	0.0011	0.0189	0.0323	0.0256	0.0067	0.0053	0.0074	0.0063	0.0010	0.0157	0.0088

NO_x-N	1	Inflow	0	0.0274	0.0333	0.0304	0.0030	0.0174	0.0242	0.0208	0.0034	0.0175	0.0140	0.0158	0.0017	0.0223	0.0067
	12	Below (40 cm)	0.5	0.0009	0.0229	0.0119	0.0110	0.0331	0.0102	0.0217	0.0115	0.0267	0.0292	0.0280	0.0013	0.0205	0.0113
	14		1.1	0.0340	0.0129	0.0234	0.0106	0.0303	0.0425	0.0364	0.0061	0.0325	0.0121	0.0223	0.0102	0.0274	0.0112
	16		2.3	0.0174	0.0194	0.0184	0.0010	0.0113	0.0059	0.0086	0.0027	0.0199	0.0051	0.0125	0.0074	0.0132	0.0061
	18		3.4	0.0149	0.0073	0.0111	0.0038	0.0391	0.0071	0.0231	0.0160	0.0194	0.0098	0.0146	0.0048	0.0163	0.0111
	19	Outflow	4.7	0.0140	0.0161	0.0150	0.0011	0.0189	0.0323	0.0256	0.0067	0.0053	0.0074	0.0063	0.0010	0.0157	0.0088
TN	1	Inflow	0	2.3979	2.8915	2.64	0.25	2.7885	2.2861	2.54	0.25	2.9648	2.6939	2.83	0.14	2.67	0.25
	11	Up (12.5 cm)	0.5	2.1285	2.6064	2.37	0.24	2.5507	2.2209	2.39	0.16	2.7656	2.6544	2.71	0.06	2.49	0.23
	13		1.1	2.1913	2.7478	2.47	0.28	2.6339	2.2402	2.44	0.20	2.6435	2.6344	2.64	0.00	2.52	0.22
	15		2.3	1.6751	2.4022	2.04	0.36	2.2446	2.1666	2.21	0.04	1.9733	2.0641	2.02	0.05	2.09	0.23
	17		3.4	1.6364	1.9949	1.82	0.18	1.6129	1.6396	1.63	0.01	1.5309	1.3684	1.45	0.08	1.63	0.19
	19	Outflow	4.7	2.4889	2.9102	2.70	0.21	2.3631	2.2712	2.32	0.05	2.2097	2.0493	2.13	0.08	2.38	0.27
	1	Inflow	0	2.3979	2.8915	2.64	0.25	2.7885	2.2861	2.54	0.25	2.9648	2.6939	2.83	0.14	2.67	0.25
	12	Below (40 cm)	0.5	2.3166	2.6373	2.48	0.16	2.5777	2.2131	2.40	0.18	2.9569	4.5940	3.78	0.82	2.88	0.80
	14		1.1	2.4950	2.9985	2.75	0.25	2.7278	2.2987	2.51	0.21	3.0797	3.3012	3.19	0.11	2.82	0.35
	16		2.3	2.4062	2.8282	2.62	0.21	2.6360	2.2248	2.43	0.21	2.4714	2.6846	2.58	0.11	2.54	0.20
	18		3.4	2.4487	2.8412	2.64	0.20	2.5612	2.1841	2.37	0.19	2.2779	2.3543	2.32	0.04	2.44	0.21
	19	Outflow	4.7	2.4889	2.9102	2.70	0.21	2.3631	2.2712	2.32	0.05	2.2097	2.0493	2.13	0.08	2.38	0.27
TOC	1	Inflow	0	4.6071	5.1987	4.90	0.30	5.8838	2.5785	4.23	1.65	4.7334	4.8585	4.80	0.06	4.64	1.01
	11	Up (12.5 cm)	0.5	2.0269	2.9395	2.48	0.46	2.5104	1.2763	1.89	0.62	3.4696	2.8023	3.14	0.33	2.50	0.70
	13		1.1	1.9002	2.5876	2.24	0.34	1.9049	0.8661	1.39	0.52	2.5177	2.2166	2.37	0.15	2.00	0.57
	15		2.3	1.1841	1.7339	1.46	0.27	0.7820	0.5976	0.69	0.09	1.1620	1.2315	1.20	0.03	1.12	0.36
	17		3.4	1.3931	2.0694	1.73	0.34	0.5463	0.1105	0.33	0.22	0.7978	0.6272	0.71	0.09	0.92	0.64
	19	Outflow	4.7	2.2849	2.9862	2.64	0.35	1.0140	0.1878	0.60	0.41	1.0667	1.1448	1.11	0.04	1.45	0.92
	1	Inflow	0	4.6071	5.1987	4.90	0.30	5.8838	2.5785	4.23	1.65	4.7334	4.8585	4.80	0.06	4.64	1.01
	12	Below (40 cm)	0.5	2.8546	2.7294	2.79	0.06	2.5477	1.0721	1.81	0.74	4.1258	14.5340	9.33	5.20	4.64	4.51
	14		1.1	2.9259	3.6455	3.29	0.36	2.8650	1.0596	1.96	0.90	5.2044	3.7444	4.47	0.73	3.24	1.24
	16		2.3	1.9533	2.5536	2.25	0.30	1.6101	0.3669	0.99	0.62	1.4880	1.2446	1.37	0.12	1.54	0.67
	18		3.4	2.1333	2.5037	2.32	0.19	1.3800	0.4155	0.90	0.48	1.3390	1.2372	1.29	0.05	1.50	0.67
	19	Outflow	4.7	2.2849	2.9862	2.64	0.35	1.0140	0.1878	0.60	0.41	1.0667	1.1448	1.11	0.04	1.45	0.92
COD	1	Inflow	0	11.3604	15.0706	13.22	1.86	25.2539	11.6774	18.47	6.79	16.0350	12.1462	14.09	1.94	15.26	4.80
	11	Up (12.5 cm)	0.5	12.9448	9.8824	11.41	1.53	12.7978	10.1590	11.48	1.32	5.4902	8.0867	6.79	1.30	9.89	2.60
	13		1.1	6.9221	8.6746	7.80	0.88	13.5878	7.7860	10.69	2.90	32.4996	7.4649	19.98	12.52	12.82	9.07
	15		2.3	4.5740	7.3050	5.94	1.37	5.5428	7.7013	6.62	1.08	25.9915	4.6700	15.33	10.66	9.30	7.56
	17		3.4	6.1093	7.6284	6.87	0.76	4.5635	4.6790	4.62	0.06	4.9384	2.4419	3.69	1.25	5.06	1.58
	19	Outflow	4.7	10.6508	11.2102	10.93	0.28	6.6840	6.7990	6.74	0.06	5.4882	4.5752	5.03	0.46	7.57	2.50

COD	1	Inflow	0	11.3604	15.0706	13.22	1.86	25.2539	11.6774	18.47	6.79	16.0350	12.1462	14.09	1.94	15.26	4.80
	12	Below (40 cm)	0.5	17.9416	14.0169	15.98	1.96	15.4365	11.9419	13.69	1.75	10.2333	30.0497	20.14	9.91	16.60	6.49
	14		1.1	12.2154	11.4140	11.81	0.40	19.3403	18.1116	18.73	0.61	11.4742	27.3020	19.39	7.91	16.64	5.73
	16		2.3	9.4946	9.8336	9.66	0.17	8.3307	7.5030	7.92	0.41	5.2102	4.0829	4.65	0.56	7.41	2.12
	18		3.4	10.0291	9.7874	9.91	0.12	8.1610	7.7547	7.96	0.20	3.4428	4.8359	4.14	0.70	7.34	2.43
	19	Outflow	4.7	10.6508	11.2102	10.93	0.28	6.6840	6.7990	6.74	0.06	5.4882	4.5752	5.03	0.46	7.57	2.50
BOD_5	1	Inflow	0	0.0000	9.0226	4.51	4.51	11.1947	6.7695	8.98	2.21	6.1389	0.4238	3.28	2.86	5.59	4.14
	11	Up (12.5 cm)	0.5	5.3657	3.5967	4.48	0.88	6.9596	0.0000	3.48	3.48	6.4973	0.0000	3.25	3.25	3.74	2.85
	13		1.1	5.4291	5.5490	5.49	0.06	0.0000	0.0000	0.00	0.00	5.8316	0.0000	2.92	2.92	2.80	2.80
	15		2.3	1.5593	3.3610	2.46	0.90	3.2692	0.0000	1.63	1.63	0.0000	2.5565	1.28	1.28	1.79	1.40
	17		3.4	0.0000	0.5074	0.25	0.25	2.2484	0.0000	1.12	1.12	0.3584	1.5178	0.94	0.58	0.77	0.83
	19	Outflow	4.7	0.9104	4.7569	2.83	1.92	4.3112	3.7233	4.02	0.29	0.0000	2.2876	1.14	1.14	2.66	1.76
	1	Inflow	0	0.0000	9.0226	4.51	4.51	11.1947	6.7695	8.98	2.21	6.1389	0.4238	3.28	2.86	5.59	4.14
	12	Below (40 cm)	0.5	1.0363	5.9496	3.49	2.46	6.1350	0.0000	3.07	3.07	0.0000	0.4877	0.24	0.24	2.27	2.69
	14		1.1	0.0000	6.1109	3.06	3.06	6.1492	2.7268	4.44	1.71	1.8220	0.0416	0.93	0.89	2.81	2.54
	16		2.3	5.9601	5.3382	5.65	0.31	5.4100	4.6605	5.04	0.37	0.0000	2.7753	1.39	1.39	4.02	2.06
	18		3.4	6.0740	0.4066	3.24	2.83	5.2630	1.1976	3.23	2.03	1.3517	2.4658	1.91	0.56	2.79	2.13
	19	Outflow	4.7	0.9104	4.7569	2.83	1.92	4.3112	3.7233	4.02	0.29	0.0000	2.2876	1.14	1.14	2.66	1.76
SO_4-S	1	Inflow	0	1.7345	0.3005	1.02	0.72	1.5652	1.7493	1.66	0.09	1.5715	1.6785	1.62	0.05	1.43	0.51
	11	Up (12.5 cm)	0.5	1.4129	0.5030	0.96	0.45	0.9681	0.8480	0.91	0.06	1.3125	0.9163	1.11	0.20	0.99	0.30
	13		1.1	0.6875	0.4528	0.57	0.12	0.3235	0.1577	0.24	0.08	0.5225	0.8319	0.68	0.15	0.50	0.22
	15		2.3	1.0091	0.2708	0.64	0.37	0.6151	0.1408	0.38	0.24	0.8019	0.4116	0.61	0.20	0.54	0.30
	17		3.4	0.6582	0.6204	0.64	0.02	0.1840	0.5009	0.34	0.16	0.7308	0.5070	0.62	0.11	0.53	0.18
	19	Outflow	4.7	0.3066	0.3396	0.32	0.02	0.2347	0.1118	0.17	0.06	0.1932	0.1463	0.17	0.02	0.22	0.08
	1	Inflow	0	1.7345	0.3005	1.02	0.72	1.5652	1.7493	1.66	0.09	1.5715	1.6785	1.62	0.05	1.43	0.51
	12	Below (40 cm)	0.5	0.9806	0.5649	0.77	0.21	1.1504	0.4646	0.81	0.34	1.3275	1.7819	1.55	0.23	1.04	0.45
	14		1.1	0.7655	0.4730	0.62	0.15	0.6279	0.2577	0.44	0.19	0.8672	1.3796	1.12	0.26	0.73	0.35
	16		2.3	0.4068	0.3436	0.38	0.03	0.1910	0.1598	0.18	0.02	0.2125	0.1536	0.18	0.03	0.24	0.10
	18		3.4	0.4269	0.3603	0.39	0.03	0.2262	0.1657	0.20	0.03	0.2144	0.4547	0.33	0.12	0.31	0.11
	19	Outflow	4.7	0.3066	0.3396	0.32	0.02	0.2347	0.1118	0.17	0.06	0.1932	0.1463	0.17	0.02	0.22	0.08
S^{2-}	1	Inflow	0	0.1659	0.1364	0.15	0.01	0.5641	0.2737	0.42	0.15	0.6069	0.5685	0.59	0.02	0.39	0.20
	11	Up (12.5 cm)	0.5	0.5875	0.7493	0.67	0.08	0.6878	0.6368	0.66	0.03	0.2338	0.6448	0.44	0.21	0.59	0.17
	13		1.1	0.9257	0.9531	0.94	0.01	0.8853	0.8884	0.89	0.00	0.8237	0.7629	0.79	0.03	0.87	0.06
	15		2.3	0.5461	0.7331	0.64	0.09	0.8099	0.9271	0.87	0.06	0.6980	0.6422	0.67	0.03	0.73	0.12
	17		3.4	0.7388	0.8125	0.78	0.04	0.8249	0.7396	0.78	0.04	0.5552	0.2717	0.41	0.14	0.66	0.19
	19	Outflow	4.7	1.0507	0.9653	1.01	0.04	0.6543	0.8134	0.73	0.08	0.6361	0.4528	0.54	0.09	0.76	0.20

S^{2-}	1	Inflow	0	0.1659	0.1364	0.15	0.01	0.5641	0.2737	0.42	0.15	0.6069	0.5685	0.59	0.02	0.39	0.20
	12	Below (40 cm)	0.5	0.8498	0.8977	0.87	0.02	0.8413	0.9040	0.87	0.03	0.8606	0.7082	0.78	0.08	0.84	0.06
	14		1.1	0.7825	1.0407	0.91	0.13	0.8750	1.1843	1.03	0.15	0.8018	0.7015	0.75	0.05	0.90	0.17
	16		2.3	1.0170	1.2380	1.13	0.11	0.8761	0.8803	0.88	0.00	0.7573	0.6013	0.68	0.08	0.89	0.20
	18		3.4	0.9941	0.9351	0.96	0.03	0.8752	0.8817	0.88	0.00	0.6853	0.5262	0.61	0.08	0.82	0.16
	19	Outflow	4.7	1.0507	0.9653	1.01	0.04	0.6543	0.8134	0.73	0.08	0.6361	0.4528	0.54	0.09	0.76	0.20
S^0	1	Inflow	0	0.0000	0.0000	0.00	0.00	0.4618	0.0000	0.23	0.23	0.3268	0.0948	0.21	0.12	0.15	0.18
	11	Up (12.5 cm)	0.5	0.3594	0.2877	0.32	0.04	0.4906	0.5020	0.50	0.01	0.2770	0.1624	0.22	0.06	0.35	0.12
	13		1.1	0.3577	0.4844	0.42	0.06	0.6215	0.4820	0.55	0.07	0.5551	0.2269	0.39	0.16	0.45	0.13
	15		2.3	0.0000	0.2052	0.10	0.10	0.3342	0.4409	0.39	0.05	0.0000	0.0934	0.05	0.05	0.18	0.17
	17		3.4	0.0000	0.2494	0.12	0.12	1.0760	0.2147	0.65	0.43	0.0814	0.0443	0.06	0.02	0.28	0.37
	19	Outflow	4.7	0.3814	0.4836	0.43	0.05	0.4383	0.4034	0.42	0.02	0.1744	0.0454	0.11	0.06	0.32	0.16
	1	Inflow	0	0.0000	0.0000	0.00	0.00	0.4618	0.0000	0.23	0.23	0.3268	0.0948	0.21	0.12	0.15	0.18
	12	Below (40 cm)	0.5	0.8918	0.6149	0.75	0.14	0.6359	0.6220	0.63	0.01	1.2240	0.6048	0.91	0.31	0.77	0.23
	14		1.1	2.1017	0.5656	1.33	0.77	0.7563	2.2729	1.51	0.76	1.4739	0.6536	1.06	0.41	1.30	0.69
	16		2.3	0.3853	0.4913	0.44	0.05	0.4359	0.4439	0.44	0.00	0.2681	0.0969	0.18	0.09	0.35	0.13
	18		3.4	0.4106	0.6170	0.51	0.10	0.5175	0.4613	0.49	0.03	0.2005	0.1585	0.18	0.02	0.39	0.16
	19	Outflow	4.7	0.3814	0.4836	0.43	0.05	0.4383	0.4034	0.42	0.02	0.1744	0.0454	0.11	0.06	0.32	0.16
CH_4	1	Inflow	0	0.0338	0.0132	0.02	0.01	0.0204	0.0173	0.02	0.00	0.0268	0.0194	0.02	0.00	0.02	0.01
	11.00	Up (12.5 cm)	0.5	0.2381	0.2655	0.25	0.01	0.2672	0.4070	0.34	0.07	0.0585	0.3678	0.21	0.15	0.27	0.11
	13.00		1.1	0.3902	0.4917	0.44	0.05	0.5819	0.6249	0.60	0.02	0.7628	0.6231	0.69	0.07	0.58	0.12
	15.00		2.3	0.1913	0.3407	0.27	0.07	0.3585	0.6544	0.51	0.15	0.5925	0.5516	0.57	0.02	0.45	0.16
	17.00		3.4	0.2331	0.3023	0.27	0.03	0.3201	0.4417	0.38	0.06	0.5870	0.5317	0.56	0.03	0.40	0.13
	19	Outflow	4.7	0.5613	0.8924	0.73	0.17	0.7921	1.1267	0.96	0.17	0.8632	0.7746	0.82	0.04	0.84	0.17
	1	Inflow	0	0.0338	0.0132	0.02	0.01	0.0204	0.0173	0.02	0.00	0.0027	0.0194	0.01	0.01	0.02	0.01
	12.00	Below (40 cm)	0.5	0.5030	0.4941	0.50	0.00	0.4024	0.5550	0.48	0.08	0.8966	1.0727	0.98	0.09	0.65	0.24
	14.00		1.1	0.8211	0.9482	0.88	0.06	0.7703	0.9022	0.84	0.07	0.9677	1.1611	1.06	0.10	0.93	0.12
	16.00		2.3	0.7762	0.8780	0.83	0.05	0.7435	1.0048	0.87	0.13	1.0480	1.0359	1.04	0.01	0.91	0.12
	18.00		3.4	0.5827	0.7844	0.68	0.10	0.6762	0.9064	0.79	0.12	0.9595	0.8326	0.90	0.06	0.79	0.13
	19	Outflow	4.7	0.5613	0.8924	0.73	0.17	0.7921	1.1267	0.96	0.17	0.8632	0.7746	0.82	0.04	0.84	0.17